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**Federal Highway
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Highway Safety Evaluation

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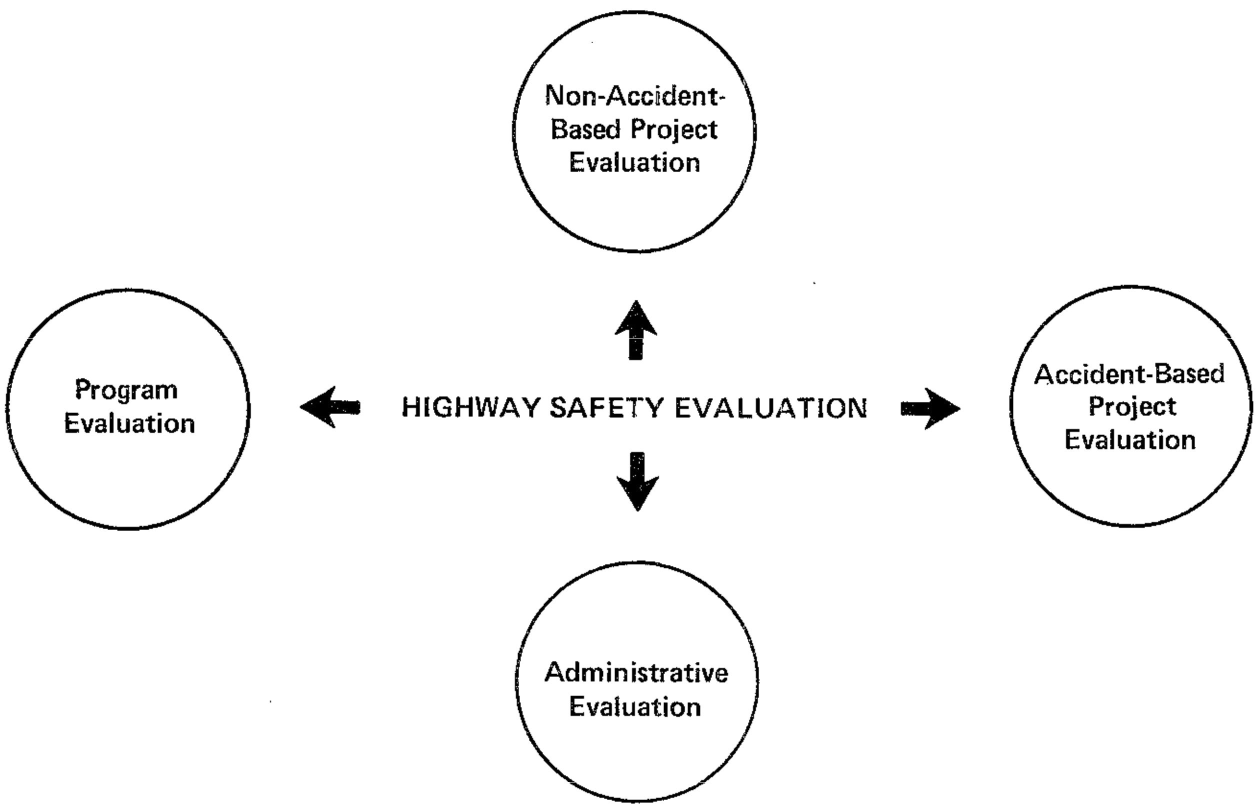
Procedural Guide



FOREWORD

This Procedural Guide describes procedures for evaluating highway safety programs and projects. It should be beneficial to State and local engineers and other professionals involved in evaluation.

The objectives of this Guide are to describe how to:

1. Select appropriate measures of effectiveness and efficiency to perform evaluations by using either accident data or alternate measures of hazard reduction.

2. Perform an evaluation of implemented safety improvements to gauge their effectiveness and efficiency and to use the results in recommending improvements for other safety or operational problems.

3. Describe and guide the organization and management of evaluation process(es) for providing feedback on the effectiveness of safety programs to the planning and implementation components of the Highway Safety Improvement Program.

4. Perform program effectiveness and administrative evaluations.

The Guide was prepared by Goodell-Grivas, Inc. Mr. David Perkins was the Principal Investigator. Mr. Rudolph Umbs is the Implementation Manager.

Additional copies of the Guide can be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

for R G Betsold
Director, Office of Development
Federal Highway Administration

NOTICE

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INTRODUCTION

The "Highway Safety Evaluation" Procedural Guide contains guidelines for evaluating ongoing and completed highway safety improvements (projects and programs). It is intended for use by those who are responsible for planning, implementing and evaluating highway safety improvements on streets and highways.

The Guide contains procedures and guidelines for performing the evaluation processes and subprocesses within the Highway Safety Improvement Program described in the Federal-Aid Highway Program Manual (FHPM) 8-2-3.

HISTORY OF THE HIGHWAY SAFETY IMPROVEMENT PROGRAM

Highway safety professionals have long recognized the need for an organized approach to the correction of highway safety problems. In the late 1960's and early 1970's the importance of a highway safety program was emphasized through legislation and research. More recently, the private sector has expressed a desire for a systemmatic approach to improving highway safety, and similar concerns have been expressed by State and local highway agencies.

As a result of the demonstrated need for improved highway safety methods and the continual increase in annual traffic accident losses in the 1960's and early 1970's, several important Federal programs were initiated. In the mid 1960's, the Federal Highway Administration (FHWA) initiated the Spot Improvement Program. This program attempted to identify "hazardous" locations and provided funds for their correction. Two years later, Congress passed the 1966 Highway Safety Act (23 U.S.C. 402), which set requirements for States to develop and maintain a safety program. To assist in maintaining a safety program, the "Yellow Book" developed by the American Association of State Highway and Transportation Officials (AASHTO) and the U.S. DOT Highway Safety Program Standards were published in 1967 (first edition) and 1974 (second edition). These sources defined safety design practices and policies. In 1973, categorical funding was made available for specific program areas, such as: pavement marking demonstration programs, rail/highway crossings, high hazard locations, and elimination of roadside obstacles. These actions, in conjunction with other concurrent safety efforts such as vehicle design improvements and highway safety programs and policies of public and private agencies, resulted in a decline in the number and rate of highway fatalities in the late 1960's and early 1970's.

The recent emphasis on highway safety has led to the availability of additional funding for the application of new procedures to enhance highway safety efforts at the State and local levels. Among the objectives of these procedures were the efficient use and allocation of available resources and the improvement of techniques for data collection, analysis and evaluation.

With these objectives in mind, the Federal-Aid Highway Program Manual (FHPM) 6-8-2-1, "Highway Safety Improvement Program" was developed and issued. Under this FHPM, a systematic process for organizing a highway safety improvement program was prescribed. This was refined in FHPM 8-2-3 "Highway Safety Improvement Program" which superceded FHPM 6-8-2-1.

FHPM 8-2-3 recommends that processes for planning, implementing, and evaluating highway safety projects be instituted on a Statewide basis. Its' stated objective is that each State "develop and implement, on a continuing basis, a highway safety improvement program which has the overall objective of reducing the number and severity of accidents and decreasing the potential for accidents on all highways."

FRAMEWORK OF THE HIGHWAY SAFETY IMPROVEMENT PROGRAM

The structure of the Highway Safety Improvement Program (HSIP) is described in FHPM 8-2-3. It consists of three components: Planning, Implementation and Evaluation. Each component is comprised of processes and subprocesses which produce specified outputs which in turn serve as input to subsequent HSIP activities.

The HSIP process level, consisting of six processes, is illustrated in Figure 1. Four processes are defined in the Planning Component, and the Implementation Component and Evaluation Component each contain one process. The arrows indicate the flow of data and information in the HSIP.

The subprocess level of the HSIP is shown in Figure 2, where 14 specific subprocesses are defined.

This Procedural Guide contains detailed descriptions of each evaluation subprocess.

HIGHWAY SAFETY IMPROVEMENT TERMINOLOGY

Any improvement made to the roadway or roadside environment to reduce the number and severity of accidents or the potential for accidents may warrant evaluation with one or more of the subprocesses contained in this Procedural Guide.

Safety improvements may range from the installation of a single advance warning sign; to the implementation of several safety improvements at a single location; to the correction of several high accident locations throughout a State with different types of improvements at each location. The complexity and level of aggregation of an improvement are deciding factors in selecting the best method to evaluate the improvement. Therefore, three categories of highway safety improvements (countermeasures, projects, and programs) are defined to assist in the selection of the appropriate evaluation subprocess.

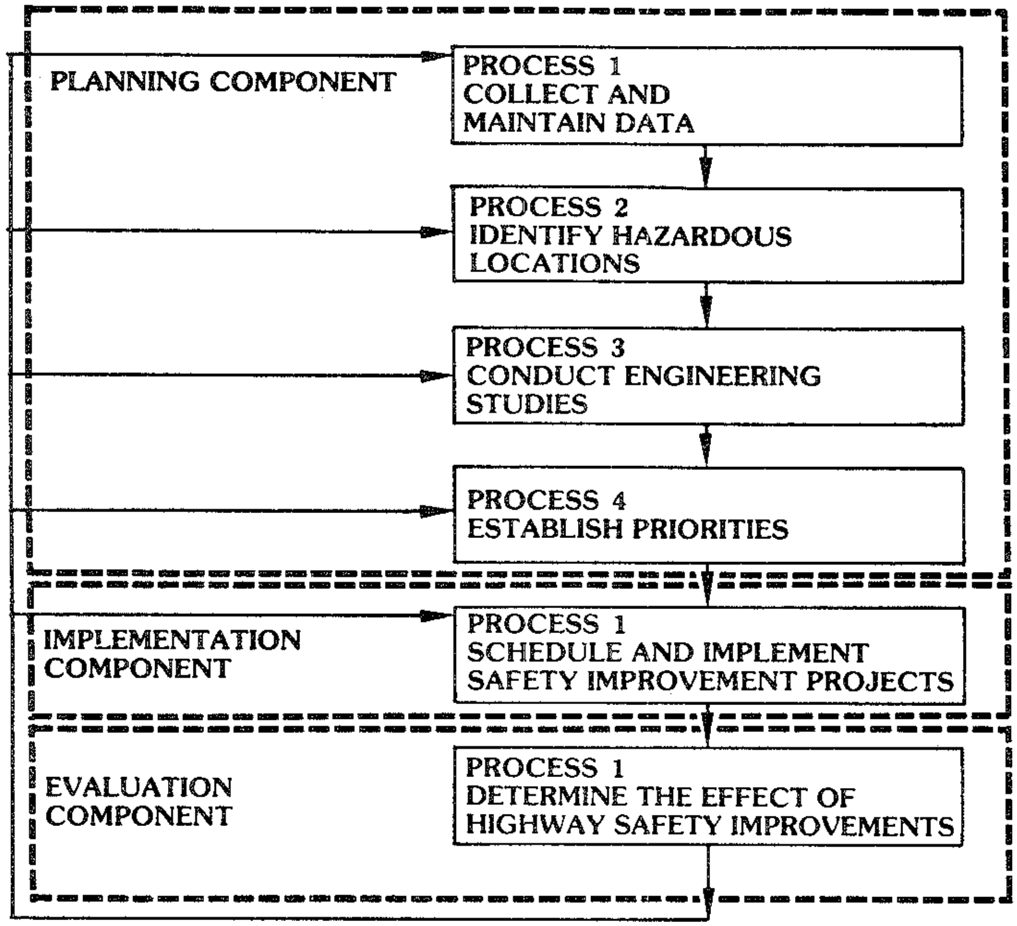


Figure 1. Highway Safety Improvement Program at the process level.

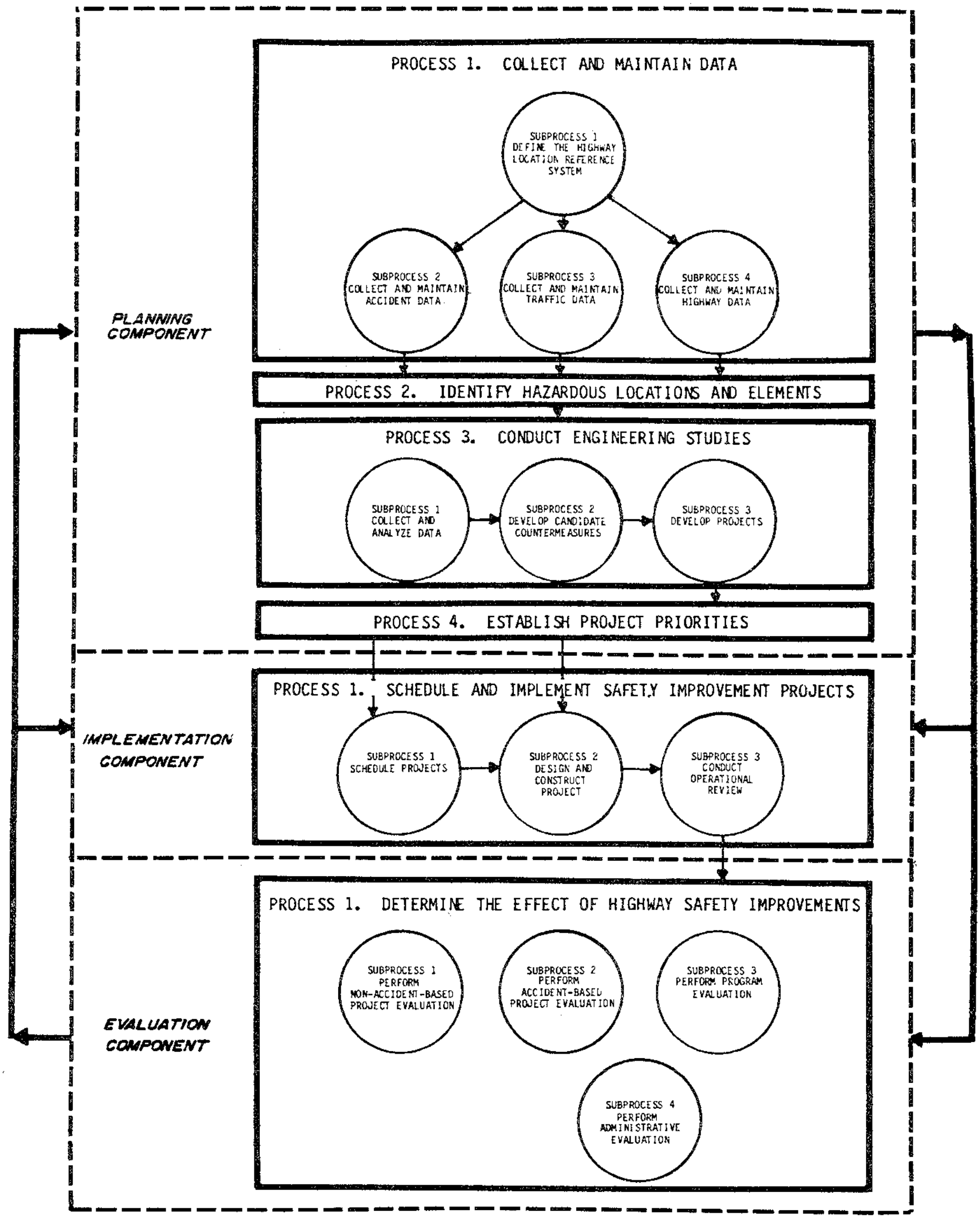


Figure 2. Highway Safety Improvement Program subprocesses.

Countermeasure

A single highway safety treatment or corrective activity designed to alleviate a safety problem or a potentially hazardous situation. Examples: 1) an advance warning sign; 2) a crash cushion; 3) left-turn prohibition during peak traffic periods at a signalized intersection; and 4) edgeline striping.

Project

The implementation of one or more countermeasures to reduce identified or potential safety deficiencies at a location (spot or section) on the highway or its environs. A project may also consist of the implementation of identical countermeasures implemented at several similar locations, which have been grouped to increase the evaluation sample size. Examples: 1) installation of an open grade friction course on a section of highway which is experiencing a disproportionately high number of wet-weather accidents; 2) adding separate left-turn phases at three adjacent urban intersections which are experiencing high numbers of left-turn accidents; and 3) implementing shoulder stabilization, edgelining, and fixed-object removal along a section of rural highway which is experiencing abnormally high run-off-road accidents and severity.

Program

A group of projects, (not necessarily similar in type or location) implemented to achieve a common highway safety goal. Examples: 1) a skid treatment program designed to reduce wet-weather-related accidents at different locations, consisting of the following projects; improved signing, longitudinal grooving, and overlay; and 2) all projects resulting from the HSIP Planning Component.

WHAT IS EVALUATION?

Evaluation is an assessment of the value of an activity as measured by its success or failure in achieving a predetermined set of goals or objectives. By this definition, a wide-range of analysis procedures may be labeled as evaluation. In this Procedural Guide, however, evaluation deals specifically with assessing the value of ongoing and completed highway safety projects and programs which result from the Highway Safety Improvement Program.

Two types of evaluation are addressed in this Procedural Guide: Effectiveness Evaluation, and Administrative Evaluation. Effectiveness Evaluation is the statistical and economic assessment of the extent to which a project or program achieves its ultimate safety goal of reducing the number and severity of accidents. This type of evaluation is referred to as Accident-Based Evaluation. This definition of Effectiveness Evaluation has been expanded in the Procedural Guide to include a determination of the intermediate effect of a highway safety project based on changes in non-accident safety measures. This type of evaluation is referred to as Non-Accident-Based Evaluation. This evaluation provides an indication of project effectiveness based on observed changes in traffic operations and driver behavior resulting from the project. Non-Accident-Based Evaluation is an intermediate evaluation procedure which may be conducted prior to Accident-Based Evaluation. When conditions permit, Accident-Based Evaluation should follow Non-Accident-Based Evaluation.

Administrative Evaluation is the assessment of 1) scheduling, 2) design, 3) construction, and 4) operational review activities undertaken during the implementation of a highway safety project or program. It evaluates these activities in terms of the issues of actual resource expenditures, planned versus actual resource expenditures, and productivity.

Administrative Evaluation supplements Effectiveness Evaluation by providing detailed information on project costs, manpower involvement, and material and time expenditures. Administrative Evaluation does not address the effectiveness of the project or program on improving highway safety.

WHY EVALUATE?

The ultimate goal of evaluation is to improve the agency's ability to make future decisions in all components of the HSIP. These decisions can be aided by conducting formal effectiveness and administrative evaluations of ongoing and completed highway safety projects and programs. Evaluation involves obtaining and analyzing quantitative information on the benefits and costs of implemented highway safety improvements. Estimates of benefits and costs reduces the dependence on engineering judgment and increases the ability of the agency to plan and implement future highway safety improvements which have the highest probability for success. Thus, scarse safety funds can be properly allocated to high pay-off improvements and diverted from those which are marginal or ineffective.

Evaluation provides input to every component of the HSIP. In the Planning Component, projects are selected to reduce accident experience or hazard potential. Effectiveness Evaluation provides information on whether and to what extent past improvements reduced accidents, accident severity, and/ or hazard (potential). These evaluation outputs can be used to increase the evaluator's ability to recognize countermeasures with a proven track record of effectiveness under similar conditions. The Planning Component also involves decisions relating to establishing project and program priorities. The decisions are generally based on the results of economic procedures which compares estimated benefits to estimated costs for competing projects or programs. Administrative Evaluation provides information on implementation cost, manpower, and material expenditures. Effectiveness Evaluation quantifies change in accident number, rate and severity. Together, these evaluation outputs can be used as inputs to priority techniques, such as the benefit-cost and cost-effectiveness. The use of evaluation results reduces subjective engineering in the planning decisions.

In the Implementation Component, scheduling decisions must be based on manpower and time estimates for implementation activities. Information on the appropriateness of scheduling decisions and the productivity of previous implementation activities, can significantly improve future scheduling for similar projects and programs, resulting in a more optimal use of available time and manpower resources.

In the Evaluation Component, Administrative Evaluation, provides cost information for economic analyses which accompany Effectiveness Evaluations. Administrative Evaluation also ensures that the Effectiveness Evaluation is being performed on the implemented project and not the planned project. Planned projects do not always correspond to the project implemented in the field. The knowledge of any discrepancy between the planned and actual project may be the deciding factor in the effectiveness of the improvement. The Evaluation Component also benefits from the experience and confidence gained by performing formal evaluations as a routine highway safety activity. As experience is gained, better decisions can be made in planning the evaluation, selecting measures of effectiveness (MOE's), and assessing the quality and reliability of evaluation data for similar projects and programs.

Evaluation benefits also extend beyond the limits of the HSIP and impact other highway-related activities within the agency. Highway design, operation and maintenance policy-makers can emphasize procedures and techniques which have been shown through evaluation to maximize safety. In this sense, other highway-related areas can enhance highway safety.

MANAGEMENT ISSUES

The ability of the Highway Safety Improvement Program to achieve its intended goal depends on the policies and management philosophy of the agency. Management must ensure that each component of the HSIP receives equitable emphasis and attention so that the cyclic structuring of the HSIP can be maintained. Among the three components, evaluation has historically received a disproportionately low level of attention as evidenced by numerous cases in which formal, scientific evaluation has been replaced by subjective or ill-defined evaluation or no evaluation at all. Management can significantly improve this situation by adopting a set of guidelines that benefit the entire HSIP by increasing the frequency and quality of evaluation.

The agency should be aware of the following basic issues when establishing their safety evaluation policies:

Agency-Wide Understanding of Evaluation Benefits

The first and, possibly, the most important step toward increasing evaluation is to ensure that the benefits of evaluation are understood at all agency levels (administrative, management, and technical levels). It is important to recognize that evaluation allows the agency to improve its own ability to make future safety-related decisions. It should also be recognized that the cost to the agency for not evaluating may be greater than the cost of conducting a formal evaluation. Decisions involving selection and implementation of corrective measures is a continuing challenge to the highway safety engineer in addition to decisions regarding the continuation, addition or deletion of ongoing highway safety improvements. The appropriateness of these decisions has a direct effect on the cost-effectiveness of the highway safety program. Well-designed evaluations provide necessary input to the selection of future improvements by providing quantitative answers as to whether the intended purposes of past improvements were accomplished, how efficiently the purposes were accomplished, and whether unexpected or contrary results were produced. Without formal evaluation, the answers to these questions may not be known and thus limited safety funds may not be allocated to projects and programs which are most effective in saving lives and reducing injuries and property damage.

Technical Level Training

The agency can significantly improve the quality of evaluation by ensuring that technical personnel who are responsible for conducting evaluation have the necessary background and training to properly plan and perform a sound evaluation study.

Facility and Resource Availability

The efficiency with which evaluation can be conducted depends on the type and availability of computerized accident data bases, digital computers for performing statistical tests, and computer facilities for storing project and program effectiveness data bases. Although such facilities are not required for evaluation, their availabilty can significantly reduce time and manpower involvement in collecting accidents and performing standard analytical procedures. Resources in the form of experienced data collectors and the availability of traffic engineering equipment such as radar meters, volume counters, and tally boards also reduce time requirements and increase field data accuracy and reliability.

Accident Data Reliability

Accident-Based Evaluation utilizes changes in accident experience as the primary measure of effectiveness. Thus, the reliability of evaluation results are impacted directly by the reliability of reported accidents. Problems associated with accident reporting procedures are well-known in the traffic engineering and safety profession. Positive steps are needed to improve accident reporting procedures within and between States to increase the usefulness of accident data in highway safety activities.

Adoption of a Standard Evaluation Methodology

The adoption of a comprehensive evaluation procedure for the agency is also important. The selected procedure should be based on proven, state-of-the-art techniques which are useable by engineers or technicians at all governmental levels including State and local levels. It should also be sufficiently flexible to allow any agency to perform an evaluation, regardless of the level of manpower, resources, and facilities available. The procedure should also be capable of evaluating the effectiveness and administrative aspects of the full range of possible highway safety countermeasures, projects and programs which may warrant evaluation. This includes improvements implemented to reduce observed accident problems as well as improvements to reduce accident or hazard potential.

PROCEDURAL GUIDE ORGANIZATION AND USE

Four evaluation subprocesses are provided in this Procedural Guide:

- Accident-Based Project Evaluation
- Non-Accident-Based Project Evaluation
- Program Evaluation
- Administrative Evaluation

These subprocesses provide step-by-step procedural guidelines for performing effectiveness and administrative evaluations for the full range of highway safety projects and programs which may be encountered by the evaluator.

Accident-Based Project Evaluation

The objective of this subprocess is to provide guidelines for assessing the value of a completed highway safety project. The measures of project effectiveness are observed changes in the number, rate, and severity of traffic accidents resulting from the implementation of project countermeasures. Project effectiveness is also examined with respect to the relationships between the costs and benefits of the project.

Non-Accident-Based Project Evaluation

The objective of this subprocess is to provide guidelines for assessing the intermediate effectiveness of a completed highway safety project prior to conducting Accident-Based Evaluation. The measures of intermediate effectiveness are observed changes in non-accident safety measures. This subprocess may be used when accident data are (1) not available, (2) insufficient for Accident-Based Evaluation, or (3) when an indication of project effectiveness is desired sooner than the time necessary for Accident-Based Evaluation. Non-accident measures are not intended to be a substitute for the ultimate safety measure (accident and severity reduction), since definitive quantitative relationships between accident experience and many non-accident measures have not been developed. Rather, they are measures which are logically related to accident experience and thus provide a measure of short-term project effectiveness. The ultimate effectiveness however, must be determined through an Effectiveness Evaluation based on observed changes in accident experience which should be conducted if and when possible.

Program Evaluation

The objective of this subprocess is to provide guidelines for assessing the value of an ongoing or completed highway safety program. The measures of program effectiveness are observed changes in the number, rate, and severity of traffic accidents resulting from the implementation of the program. Program effectivenss is also examined with respect to the relationships between costs and benefits for the program.

Administrative Evaluation

The objective of this subprocess is to provide guidelines for determining the amounts of manpower, time, money, and material used, the differences between planned and actual resource expenditures, and the implementation outputs obtained per unit of input associated with implementating highway safety projects and programs. Implementation in this subprocess refers to scheduling, designing, construction and operational review activities. This subprocess should be performed to supplement Effectiveness Evaluation or as a minimum evaluation effort when Effectiveness Evaluation is not warranted or feasible.

To achieve full utility of the evaluation subprocess contained in this Guide, a thorough understanding is required of the subprocess interrelationships within the Evaluation Component. As shown in Figure 3, input to the Evaluation Component is highway safety projects and programs which have been planned and implemented in previous HSIP components. The first decision to be made in the Evaluation Component is whether or not an Effectiveness Evaluation of the improvement is warranted. This is generally a management decision based on the evaluation policy of the agency, Federal evaluation requirements, cost of the project or program, anticipated future highway safety priorities, and the cost of evaluation. A technical decision must be made on the feasibility of conducting an Effectiveness Evaluation based on the availability of data and resources. If Effectiveness Evaluation is either not warranted from a management viewpoint or not technically feasible, an Administrative Evaluation should be performed and the results used as feedback to both the Planning and Implementation Components. If Effectiveness Evaluation is both warranted and feasible, the nature of the highway safety improvement (project and program) dictates the subprocess to be performed.

Two subprocesses are available for project evaluation. Non-Accident-Based (N-A-B) Project Evaluation may be performed prior to Accident-Based (A-B) Project Evaluation when time and/or accident history do not allow for Accident-Based Evaluation. Accident-Based Project Evaluation should be conducted when circumstances permit, regardless of whether Non-Accident-Based Evaluation is performed.

If a highway safety program is to be evaluated, Program Evaluation should be performed.

Following, or in conjunction with, the Effectiveness Evaluation, an Administrative Evaluation may be performed as a supplement.

It is important to note that the Effectiveness Evaluation subprocesses shown in Figure 3 represent the point in time when the evaluation is actually performed. Evaluation plans may and should be developed in the Planning Component, prior to project or program implementation. Administrative Evaluation should be conducted during or following implementation for all projects and programs.

Table 1 summarizes how the appropriate Effectiveness Evaluation subprocesses may be selected for a set of circumstances which may exist for an agency and a given highway safety improvement. For example, suppose an agency is considering whether to evaluate an improvement and the conditions 1,2,5 and 7 exist (other conditions are either not possible or nonexistent). That is, the improvement warrants Effectiveness Evaluation, it is a project to reduce accidents, reliable accident data are available and pre-implementation planning is possible. Each condition indicates that Accident-Based and Non-Accident-Based Evaluations may be performed, (Program Evaluation is not indicated for condition 2). The evaluator should refer to these sections of the Guide for details on performing the desired evaluations.

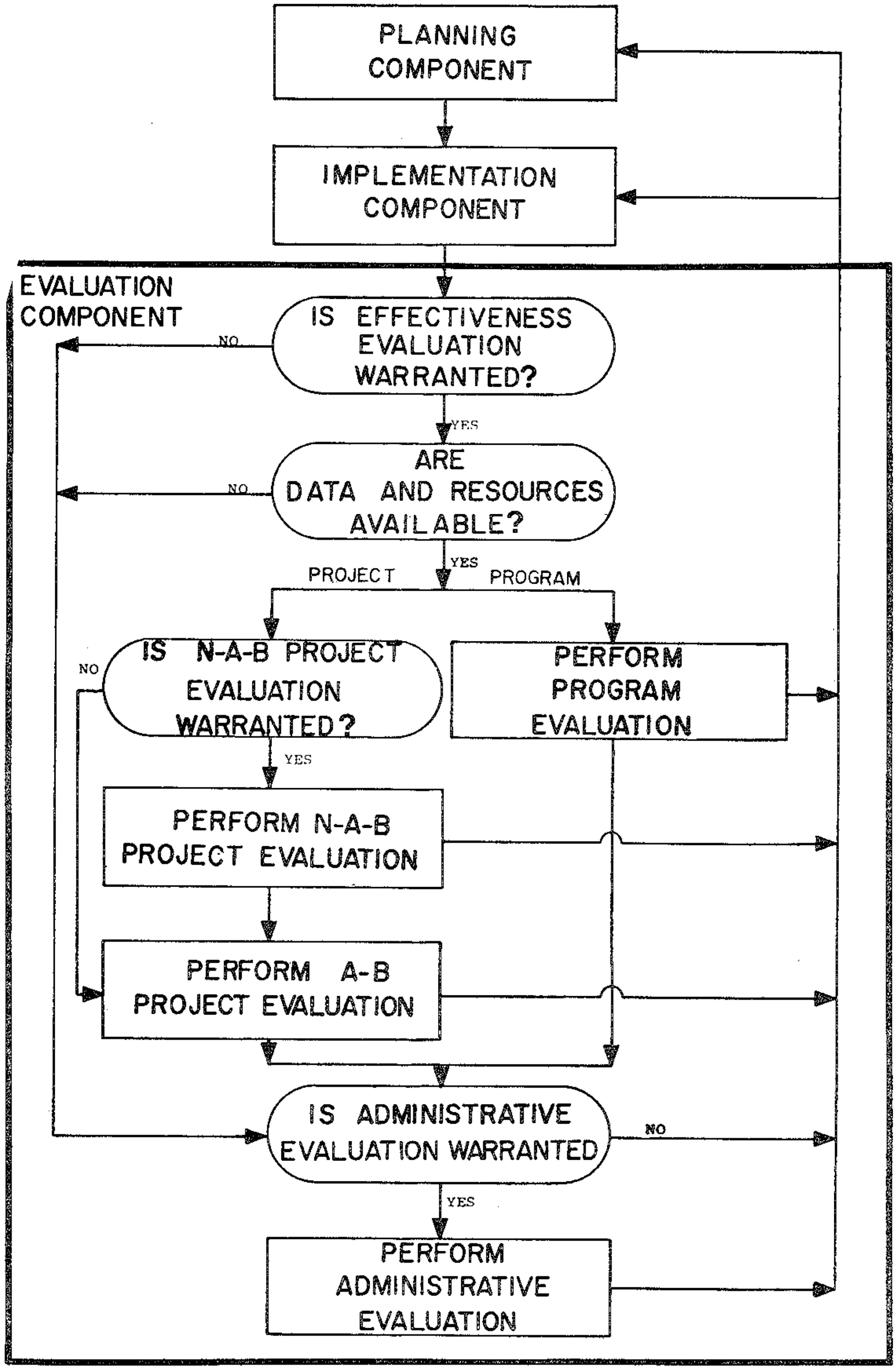
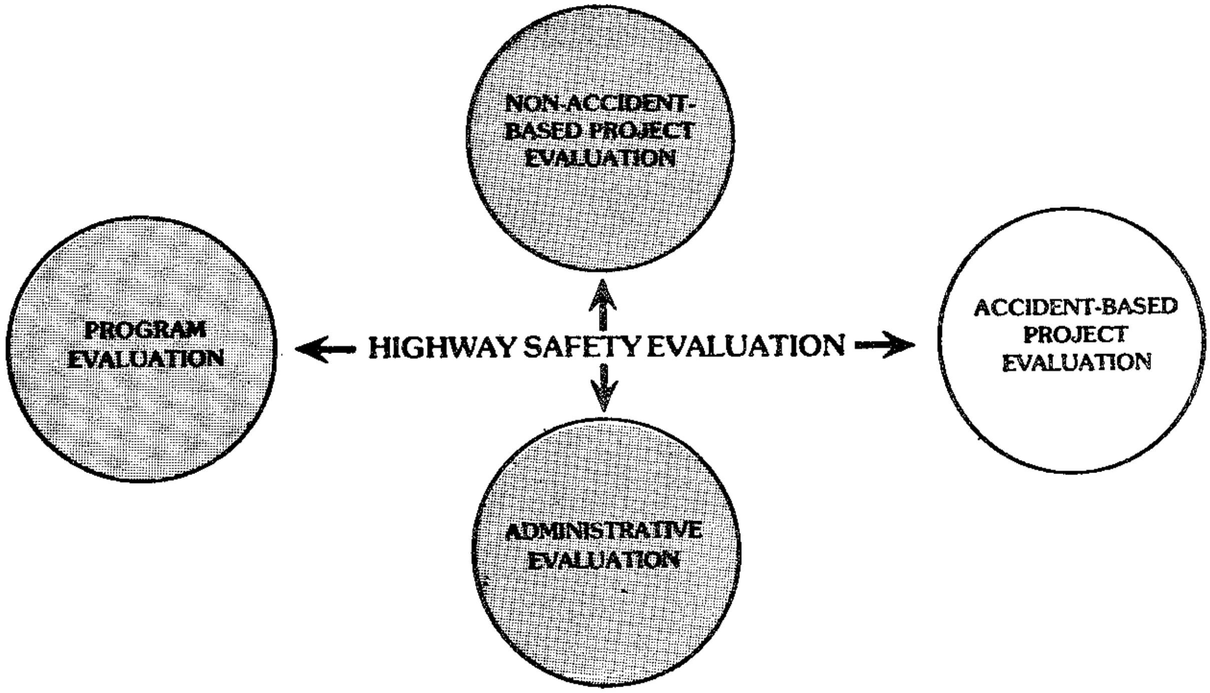


Figure 3. Evaluation Component in the HSIP

Table 1. Selection criterion for effectiveness evaluation subprocesses.

CONDITIONS	A-B Project Evaluation	N-A-B Project Evaluation	Program Evaluation
1. Effectiveness Evaluation is warranted	●	●	●
2. Project is to reduce accident number and/or severity	●	●	
3. Project is to reduce hazard potential		●	
4. Program is to reduce accident related goals			●
5. Accident data are (will be) available	●	●	●
6. Accident data are not (will not be) available		●	
7. Pre-implementation planning is employed	●	●	●
8. Post-implementation planning is employed	●		●

ACCIDENT-BASED PROJECT EVALUATION



A highway safety project is the process of applying one or more countermeasures to reduce identified or potential safety deficiencies at a location (spot or section) on the highway or its environs. A project may also consist of identical countermeasures implemented at several similar locations, which have been grouped to increase the evaluation sample size.

Countermeasures are highway safety treatments or corrective activities designed to alleviate a safety problem or a potentially hazardous situation.

The objective of Accident-Based Project Evaluation is to provide guidelines for assessing the value of a completed highway safety project. The measures of project effectiveness are observed changes in the number, rate, and severity of traffic accidents resulting from the implementation of the project. Project effectiveness is also examined with respect to the relationships between the costs and benefits of the project.

Accident-Based Project Evaluation consists of seven functions. Each function contains a series of systematic steps which lead the evaluator through the activities and decisionmaking processes of a properly designed evaluation study.

The seven functions which comprise Accident-Based Project Evaluation are:

FUNCTION A - Develop Evaluation Plan

FUNCTION B - Collect and Reduce Data

FUNCTION C - Compare Measures of Effectiveness (MOE's)

FUNCTION D - Perform Statistical Tests

FUNCTION E - Perform Economic Analysis

FUNCTION F - Prepare Evaluation Documentation

FUNCTION G - Develop and Update Effectiveness Data Base

FUNCTION A addresses the necessary planning activities which must be considered prior to performing an evaluation of a completed highway safety project. The evaluation objectives and MOE's, the analytical framework for the evaluation (experimental plan) and data requirements are established in this function. FUNCTION B provides guidelines for collecting, reducing and presenting evaluation data. FUNCTION C presents various methods for comparing MOE's according to the experimental plan selected for the evaluation. FUNCTION D provides a framework for testing the statistical significance of the changes in the MOE's. FUNCTION E presents economic analysis techniques for conducting a fiscal evaluation of ultimate project effectiveness. Guidelines for documenting the observed effectiveness of the project is presented in FUNCTION F. FUNCTION G provides a format for maintaining information on project effectiveness to be used as feedback to the Planning and Implementation Components of the HSIP.

These functions are common to all Effectiveness Evaluation subprocesses contained in this Procedural Guide. It is strongly recommended that the evaluator become familiar with the functional details of each subprocess prior to performing an evaluation using any single subprocess, since some of the information contained in program evaluation may be helpful in performing a project evaluation and vice versa.

FUNCTION A: Develop Evaluation Plan

This function enables the evaluator to:

1. Select highway safety projects to be evaluated.

2. Determine the purposes of the project.

3. Stratify and sample the projects.

4. Select the evaluation objectives and measures of effectiveness (MOE's).

5. List the assumptions, advantages and disadvantages of experimental plans and select the most appropriate experimental plan.

6. List evaluation data needs and sample size requirements.

7. Document the evaluation plan.

<u>Overview</u>

The first step in the evaluation of a highway safety project is the development of an evaluation plan. The plan provides overall guidance and direction to the evaluation study. Regardless of when the plan is developed, before project implementation or after, it offers the opportunity to think-through the entire evaluation process and establish the anticipated evaluation procedure for future reference.

To be effective, however, the plan should be developed and completed to the extent possible in the Planning Component of the HSIP. When developed before implementation, the plan may not be referred to for several years, at which time the evaluation is actually performed. The plan therefore communicates to the evaluator, the original intent of the project and the evaluation. If developed after implementation, the plan is still a valuable evaluation tool which provides a description of the evaluation activities to be performed.

The plan addresses such issues as the selection of: 1) projects for evaluation, 2) project purposes, 3) evaluation objectives and measures of effectiveness (MOE's), 4) experimental plans, and 5) data requirements.

Evaluation may be warranted for many reasons. These include the evaluation policy of the agency, requirements of Federal or State funding agencies, or special requests from policy-makers of a community. However, for many agencies, it may not be feasible to evaluate all highway safety projects due to manpower and fiscal constraints. When all projects cannot be evaluated, the selection of specific projects which warrant evaluation may be an effective way of obtaining evaluation results which are most useful to the agency.

The purposes of the project and the evaluation objectives are fundamental to the plan development process. The purpose of a project is the reason for which the countermeasure(s) was implemented. For safety projects, the purpose must relate to the reduction of accidents, severity or hazard potential. To the experienced evaluator/engineer, the project purpose may be obvious from the nature of the project and the safety problem for which the project was developed in the HSIP Planning Component. For example, the installation of a traffic signal for safety reasons indicates a purpose of reducing angle accidents and accident severity at the intersection. If the purpose is not evident, project justification statements often cite specific accident problems which are expected to be impacted by a particular project. Historical accident data used in identifying and analyzing the safety problem and develop countemeasures may also reveal predominant accident types which may indicate the purpose of the project.

Objectives of the evaluation are statements which reflect the specific accident, severity, or hazard potential measures to be evaluated. Objectives may correspond to specific project purposes or any other measure of interest to the evaluator. Measures of effectiveness (MOE's) are next selected for each evaluation objective. Once these items have been established, the experimental plan and data requirements of the evaluation study may be determined.

The evaluation plan helps to insure that no major evaluation step is overlooked. However, seldom are the steps of the Guide conducted in the given order. There is no mechanical or routine way to operate the step-by-step order given in this Guide. Questions, practical limitations, and the like, may require the evaluator to perform some steps several times and others not at all.

STEP A1 - SELECT PROJECTS FOR EVALUATION

It is desirable to perform Effectiveness Evaluation for all highway safety projects. However, most agencies have more projects which either require or warrant evaluation than manpower and fiscal capabilities permit. It is possible to maximize the evaluation efforts under these constraints through the careful selection and evaluation of projects for which evaluation results are most beneficial.

The selection of projects is generally a management decision. However, State and Federal funding agencies often require Effectiveness Evaluation in fulfillment of program responsibilities. When selecting projects for evaluation, the following factors should be considered:

1. Current and future highway safety project efforts. The implementation of highway safety projects is an on-going process which requires careful planning. To facilitate future planning and implementation decisions, evaluations should be performed for those types of projects which have the highest probability of being implemented in the

future. Evaluation results may be used to justify increases or reductions in expenditures for specific projects.

2. Project implementation date. Accident-Based Evaluation requires accident data for a two to three-year period (ideally) following implementation. This time frame provides a tradeoff between the need to collect sufficient accident data to perform the evaluation and the realistic need to keep data collection activities to a manageable scale. While quantity and quality of data are of primary importance, care should be taken when using less than one year of data. Monthly and seasonal variations do exist which can bias the traffic and accident characteristics of a given project site. In a similar way, environmental conditions may vary from year to year making one or two year time periods tentative as a basis for evaluation. On the other hand, it is important to avoid projects which are extremely old (i.e., greater than 6 years old) since the introduction of factors other than the project may influence accident experience.

3. Data availability. The availability, completeness and accuracy of accident and traffic exposure data are essential for any Accident-Based Evaluation. The potential weakness of any accident record system should be kept in mind. Inaccurate or incomplete accident information, unreported accidents, and variances in reporting thresholds lend uncertainty to the result of the evaluation study. Any project for which data are suspect in terms of these characteristics should be eliminated from consideration as a project for evaluation.

4. Sufficiency of accident data. Statistical tests of significance require data on the number of expected accidents and the percent reduction when compared with after accidents. The smaller the number of before accidents, the larger the required percent reduction in accidents must be to be statistically significant. Therefore, an analysis should be made during the project selection process to evaluate projects with a sufficiently large number of accidents to allow statistical analysis. An evaluation study of a project site with few accidents may not produce good supporting documentation of the effectiveness of the project.

   For example, consider a location where the total number of expected accidents was 15 for a 3 year period. An inspection of the Poisson curves indicates that it requires at least a 23% reduction in accidents to be significant even at the 80% level of confidence. If the type of improvement is expected to yield a 10% reduction in accidents, then even under favorable conditions, if a 10% reduction were achieved, the results would not be statistically significant. Therefore, the evaluation should not be performed unless grouping of countermeasures or some other technique could be employed.

5. Project purpose. The purpose of the project should also be considered. For example, suppose a policy decision has been made that all high accident curves on two-lane rural highways are to be delineated with edgelining and delineator countermeasures. Evaluations of past delineation projects with a purpose of reducing run-off-road (ROR) accidents may provide the agency with information on the probable outcome of the upcoming project.

The specific purposes of the project must be identified after the decision is made on which projects are to be evaluated.

Determination of Project Purpose

The purpose of a project is the reason(s) for which the project is implemented. Safety projects are usually implemented for a variety of purposes. The most common are:

- To reduce traffic accidents (in general or specific types)
- To reduce the severity of traffic accidents
- To reduce hazard potential

The improvement of traffic performance characteristics may also be a secondary purpose of the project.

Project purposes should include specific accident types, accident severity classifications, and measures of hazard potential which could possibly be altered by the project.

Traffic Accidents

The selection of accident-related project purposes should include specific accident types that are expected to be impacted by the safety project. Accident categories which are not expected to be significantly changed, should not be selected. Also, if the number of before accidents does not permit statistical testing in an accident category or a category is not predominant in relation to total accident experience, that accident category should be rejected as a project purpose.

Possible accident-related project purposes may include the reduction of any one or a combination of accident categories (when in sufficient number) such as those included in the following partial list:

1. Run-Off-The-Road Accidents
2. Skidding Accidents
3. Fixed Object Accidents
4. Right Angle Accidents
5. Rear-End Accidents
6. Head-On Accidents
7. Sideswipe Accidents
8. Night Accidents

The project purpose depends on the specific safety deficiencies identified at the project site. Collision diagrams may assist in identifying specific safety problems at a site.

Accident Severity

Some highway safety projects are not expected to reduce the frequency of accidents but rather to reduce accident severity. In such cases, the purpose of the project may be identified as reducing injury accidents (or injuries) or fatal accidents (or fatalities). The type of severity classifications (fatal, injury or property damage) which the project is expected to alter should be selected when the before accident frequency permits statistical evaluation.

Hazard Potential

Projects may be implemented to conform to safety standards or to reduce specific driver violations or hazardous maneuvers where relatively few accidents have occurred. When the number of before accidents is small, a highway safety project must result in a very high percent reduction in accidents for the improvement to be statistically significant. In such cases, it may be appropriate to select the improvement of non-accident measures as a project purpose. If the purpose is to improve non-accident measures, the evaluator is directed to the Non-Accident-Based Evaluation Subprocess.

Traffic Performance

Although the primary purpose of safety projects is to reduce accidents, severity and hazard potential, safety projects may also improve traffic performance. An evaluation of these measures can be helpful in explaining changes in accidents which is useful information for selecting countermeasures for future projects. Also, evaluations which include non-accident measures are helpful in determining the intermediate effects of the project prior to the time of conducting Accident-Based Project Evaluation. Evaluation based on traffic performance measures which are logically related to safety may be conducted using Non-Accident-Based Evaluation.

The selection of the purpose is primarily based on a review of both the before accident data and the nature of the countermeasures. Some guidance also may be obtained from project justification statements. A comparison of the project purpose as stated in the justification statement, and the purposes determined in this step is desirable to ensure that all project purposes have been identified.

Project purposes should be recorded with a statement justifying the selection of each. Figure 4 illustrates a format for listing project purposes.

STEP A2 - STRATIFY PROJECTS

When before accident experience is too small to allow a project to be selected for Accident-Based Evaluation, the project may be combined with other similar projects to increase the size of before accident frequency. In this approach, the combined group of projects is evaluated as a single project. In order to aggregate projects, the countermeasures for each must be identical, they must be implemented at similar types of locations, and they must have similar project purposes. When these conditions are met, the projects may be aggregated. This approach is applicable for projects with low accident experience such as rail/highway grade crossing projects, where several projects may be grouped to provide an aggregate accident experience of sufficient size to allow statistical evaluation.

To facilitate the process, it may be possible to stratify highway projects into groups of projects which exhibit similar characteristics. Project grouping should consider both the type of improvement and project site characteristics.

The process of aggregating projects to increase the accident sample may be a difficult and time consuming activity, especially when the agency implements several projects each year and several years must be reviewed to identify individual projects to be grouped. To minimize the time and effort involved in the process, it may be helpful to develop a card-file

Page ______ of ______

PROJECT PURPOSE LISTING

Evaluation No. A-1

Date/Evaluator 2/23/77/DDP **Checked by** 2/28/77/HES

Project No. P-1

Project Description and Location(s) Replace two-way stop sign with two-phase fixed time controller at Broadway and 7th Streets

Countermeasure(s)/Codes Traffic Signal Installation (FHWA Code 11)

Project Purpose	Justification
1. To Reduce Right Angle Accidents.	1. High incidence (32 for 3 years) of right angle type accidents during pre-project period.
2. To Reduce Accident Severity.	2. Severity of accidents was great (F and I = 50%) due to high approach speeds.
3. To Minimize Intersection Delay.	3. Studies conducted on 5/76 and 9/76 showed high congestion and significant delay on minor streets.

Figure 4. Sample project purpose listing.

of completed highway safety projects. The file should be organized to provide the basic information needed to determine whether a project is appropriate for evaluation either as a single project, within an aggregated project or as part of a highway safety program. The card-file should be organized by project type. The Federal-Aid Highway Program Manual (FHPM) 6-8-2-1 provides a comprehensive list of project types and countermeasures, (refer to the Appendix for codes) which may be used as the basis for the card system.

Highway safety project files for projects implemented within the last 5 years should be reviewed. For each project, the following information should be recorded and inserted in the card-file under the appropriate project type:

1. Project identification number
2. Classification code(s) shown in FHPM 6-8-2-1.
3. Project location and type of location
4. Construction start and end dates
5. Total accident frequency for each of the three years preceeding project implementation.
6. Whether formal evaluation has been conducted and if so, reference to evaluation report location.
7. Reference to project file location.

Figure 5 illustrates a sample card file system which should be updated as new safety projects are constructed.

After grouping all highway safety projects, the evaluator has three options:

1. Individual Project Evaluation - Evaluate a project of particular interest or randomly select a single project. If this is the case, the evaluator should continue with STEP A3 (page 27).

2. Aggregate Project Evaluation - When the accident sample size is too small for a single project, select all projects from a project grouping and evaluate the entire group as a single project. The evaluator should continue with STEP A3 (page 27). If the group consists of a large number of projects for which evaluation of each project would be impractical or unnecessary, select a statistically representative sample from the group and evaluate the sample as a single project.

3. Program Development for Evaluation - If a program is to be evaluated which requires the evaluator to select completed projects to form a highway safety program, the card file

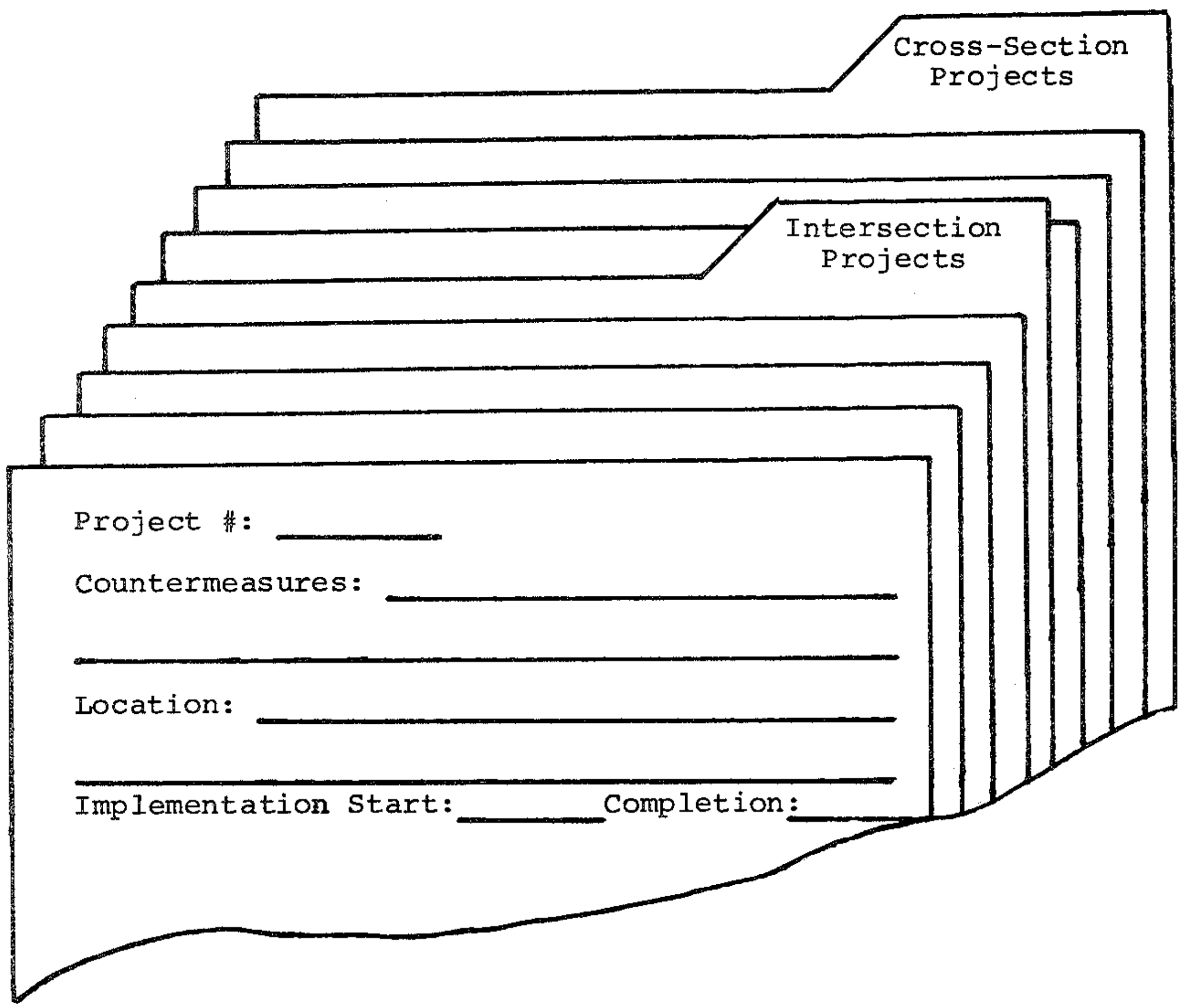


Figure 5. Sample project card file.

system provides easy reference to candidate projects for the program. If the file is to be used to develop a program, the Program Evaluation Subprocess should be used as an evaluation guide.

Sampling From Project Groupings

If the evaluation is to be conducted on a randomly selected sample of similar projects (item 2 above), the following procedure (illustrated in Figure 6) may be used to determine the minimum sample size and to select projects from a group.

1. Obtain and record the total number of accidents for each project for a three year period immediately prior to project implementation. Having a time period longer than 1 year is desirable. A time period of more than three years may be too long and may introduce unknown variables to the analysis.

2. Select the value of the allowable error in the sample (E). "E" is the amount by which the evaluator is willing to tolerate a departure from the population mean.

3. Calculate the mean number of accidents for all sites (μ).

4. Calculate the standard deviation of the accident frequency for all sites (σ).

5. Calculate the minimum sample size (n_s) for the group.

   Since $\overline{X} \pm 1.96\sigma/\sqrt{n_s}$ is a 95% confidence index for the population mean, to find an "n_s" which would satisfy this criteria set:

   $$E = 1.96\,\sigma / \sqrt{n_s} = 2\,\sigma / \sqrt{n_s}$$

   This equation may be rewritten as:

   $$n_s = 4\sigma^2/E^2$$

   For example, if the mean number of accidents is 20 accidents per site per year and it is desired to estimate this within $\pm$ 3 accidents then E = 3. If the standard deviation of yearly accidents is 7.3, then the sample size (n_s) is calculated as follows:

   $$n_s = 4\sigma^2/E^2$$

   $$n_s = 4(7.3)^2/3^2$$

   $$n_s = 23.7 \quad \text{use 24 sites}$$

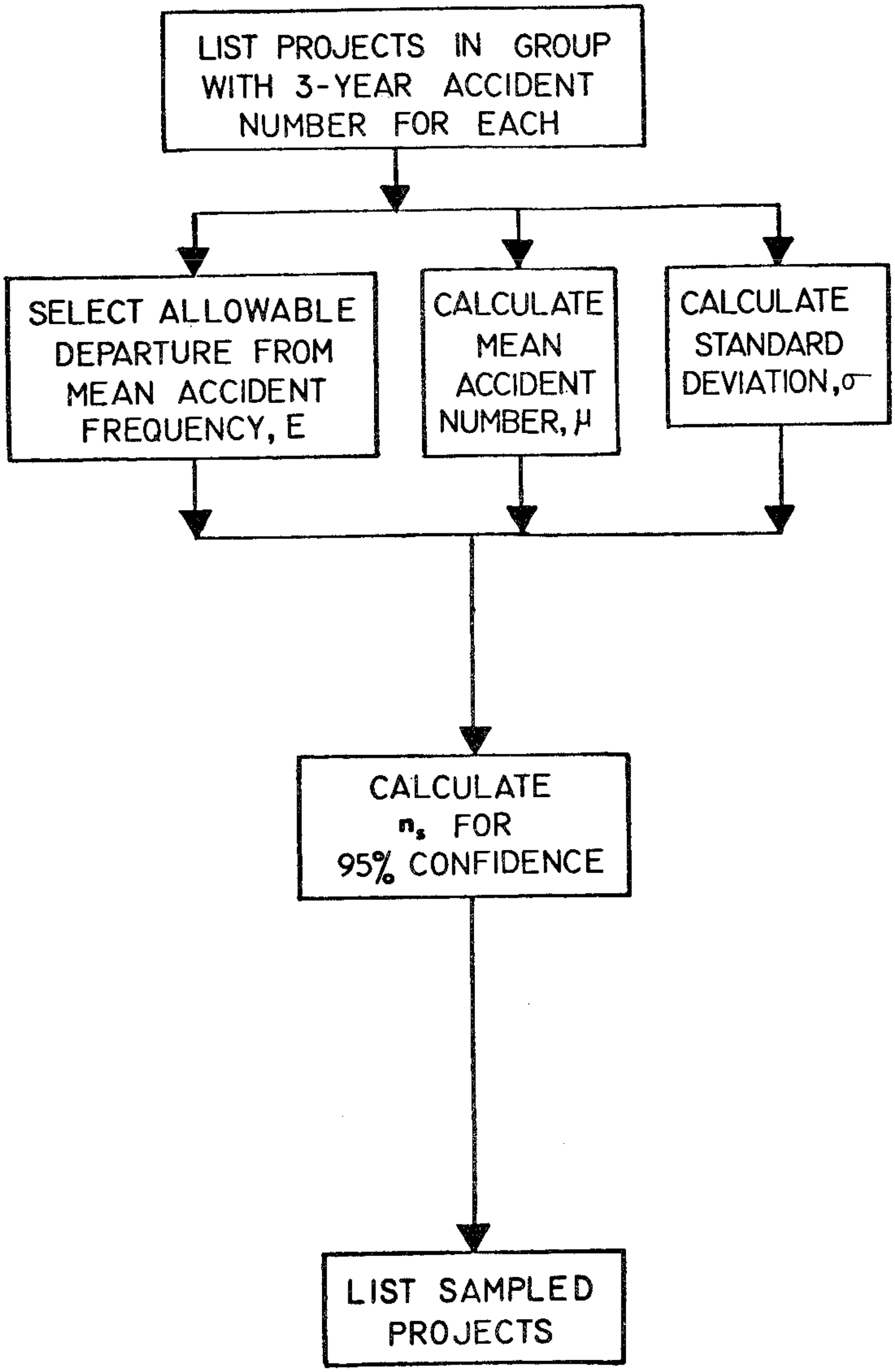


Figure 6. Project sampling strategy.

6. Randomly select the minimum sample size from the group and list the sampled projects.

STEP A3 - SELECT EVALUATION OBJECTIVES AND MOE

Evaluation objectives are statements of the safety measures to be evaluated. The evaluation objectives should be stated in terms of the expected effect of the project on an accident characteristic (type or severity).

Four fundamental evaluation objectives should always be selected for every evaluation study. They are to determine the effect of the project on:

1. Total Accidents

2. Fatal Accidents.

3. Personal Injury Accidents.

4. Property Damage Accidents.

Additional objectives should be selected which are specific to the project being evaluated and its purposes.

Although the highway safety project may have several purposes, only those purposes of critical interest should be translated into evaluation objectives. The number of objectives should be kept to a minimum to simplify the evaluation.

As a part of the objective statement, the evaluator should also specify that an economic evaluation be performed. However, the performance of an economic analysis is subject to statistically significant reductions in at least one accident measure associated with the evaluation objectives. However, an economic analysis is not recommended for projects which result in a non-significant reduction or in an increase in the MOE's.

Measures of Effectiveness

Measures of Effectiveness (MOE's) must be stated for each objective to provide quantifiable units of measurement.

The evaluator may select the MOE as being frequency-related, rate-related or both. When the project site is located in an area where no appreciable increase or decrease in traffic volume has occurred or is expected (i.e., fully developed areas or where no development is planned for the immediate future), it is appropriate to select frequency MOE's. Frequency-related MOE's are generally recorded on a yearly basis. When time periods other than a full year are encountered, they should be reduced or expanded to a full year.

The use of time periods less than one year should not be used except for performing preliminary evaluation studies and when the full year's data are not available. The expansion to a yearly accident level may result in estimating errors and thus lead to erroneous conclusions.

When traffic volumes are expected to vary, rate-related MOE's should be selected. When the MOE's are rate-related, the frequency of each MOE value is factored by the exposure at the project site. Rate-related MOE's are generally recommended for an evaluation study.

Rate MOE's are expressed as the number of accidents or severity of occurrences per unit exposure. Exposure units are expressed as either the number of vehicles or the number of vehicle-miles of travel (or a multiple thereof), depending on the type of project site. For intersection or spot improvements, numbers of vehicles should be used as the exposure unit. For extended roadway sections, vehicle-miles of travel should be used. Table 2 shows the highway safety project codes used by Federal Highway Administration (FHPM 6-8-2-1) with corresponding exposure units.

When vehicle-miles of travel are unavailable or are suspect in terms of accuracy, the evaluator may substitute the exposure factor with a coverage factor such as miles of roadway, yielding a MOE such as run-off-the-road accidents per mile of roadway. Objectives related to testing the effect of the project on pedestrian, motorcycle or bicycle accidents should use frequency-related MOE's. Ratio of a severity category to total accidents may also be used as MOE's. In such cases, the evaluator should also use rate-related MOE's wherever possible.

The objectives with the MOE's of the evaluation should to be recorded as shown in Figure 7 and included in an evaluation study file.

STEP A4 - SELECT EXPERIMENTAL PLAN

An experimental plan is an analytical framework used to measure the impact of a highway safety project on the selected MOE's. The experimental plan should be consistent with the nature of the project, and the completeness and availability of data. There are several different experimental plans for evaluating safety projects. Four plans have been selected for use in evaluating highway safety projects:

A. Before and after study with control sites
B. Before and after study
C. Comparative parallel study
D. Before, during and after study

Table 2. Recommended exposure factors.

Project Type	Recommended Exposure Factor*
1. Intersection Projects	
10-Channelization, including left turn bays	V
11-Traffic Signals, installed or improved	V
12-Combination of 10 and 11	V
13-Sight distances improved	V
19-Other intersection work (except structures)	V
2. Cross Section Projects	
20-Pavement widening, no lanes added	VM
21-Lanes added, without new median	V or VM
22-Highway divided, new median added	V or VM
23-Shoulder widening or improvement	VM
24-Combination of 20,21,22 and 23	V or VM
25-Skid Treatment/Grooving	VM
26-Skid Treatment/Overlay	VM
27-Flattening and/or clearing of side slopes	V or VM
29-Other cross section work or combinations of above categories	V or VM
3. Structures	
30-Widening existing bridge or other major structure	V
31-Replacing of bridge or other major structure	V
32-Construction of new bridge or major structure (except to eliminate a railroad grade crossing or one for pedestrians only)	V
33-Construction or improvement of minor structure	V
34-Construction of pedestrian over- or under-crossing	V
39-Other Structure work	V

*V = number of vehicles
VM= vehicle-miles of travel

Table 2. Recommended exposure factors (Continued).

Project Type	Recommended Exposure Factor
4. Alignment Projects	
40-Horizontal alignment changes (except to eliminate highway grade crossing, Code 52)	V or VM
41-Vertical alignment changes	V or VM
42-Combination of 40 and 41	V or VM
49-Other alignment work	V or VM
5. Railroad Grade Crossing Projects	
50-Flashing lights replacing signs only	V
51-Elimination by new or reconstructed grade separation	V
52-Elimination by relocation of highway or railroad	V
53-Illumination	V
54-Flashing lights replacing active devices	V
55-Automatic gates replacing signs only	V
56-Automatic gates replacing active devices	V
57-Signing and/or marking	V
58-Crossing surface improvement	V
59-Other railroad grade crossing improvement	V
6. Roadside Appurtenances	
60-Installation or upgrading of traffic signs	V or VM
61-Breakaway sign or lighting supports	V or VM
62-Installation or improvement of road edge guardrail	V or VM
63-Installation or improvement of median barrier	V or VM
64-Installation of striping and/or delineators	V or VM
65-Roadway lighting installation	V or VM
66-Improvement of drainage structures	V or VM
67-Installation of fencing	V or VM
68-Impact attenuators	V
69-Other roadside appurtenances	V or VM

Page ____ of ____

OBJECTIVE AND MOE LISTING

Evaluation No. A-1

Date/Evaluator 2/23/77/DDP Checked by 2/28/77/HES

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on: (fundamental)	Percent change in: (check one) Rate X or Frequency ____ (fundamental)
1. Total Accidents	1. Total Accidents/ MV
2. Fatal Accidents	2. Fatal Accidents/ MV
3. Injury Accidents	3. Injury Accidents/ MV
4. PDO Accidents	4. PDO Accidents/ MV
(project purpose)	(project purpose)
5. *Sideswipe Accident*	5. *Sideswipe Accident/MV*

Figure 7. Sample objective and MOE listing.

Each plan attempts to accomplish the same objective. That is, to compare the MOE after project implementation (A_{PF} or A_{PR}) with the expected MOE had no improvement been implemented (E_F or E_R). The expected MOE value for each plan is based on different underlying assumptions.

When using any experimental plan, the evaluator should not use accident or other MOE data for the period of time during and after project construction takes place. A time period of sufficient length to allow traffic to adjust to the new conditions should be allowed following completion of the project. This time period is referred to as "Construction and Adjustment Period" in the illustrations which accompany each experimental plan.

Experimental Plan A - The Before and After Study With Control Sites (Figures 8 and 9): This plan compares the percent change in the MOE at the project site (test site) with the percent change in the MOE at similar site(s) without the improvement (control sites) for the same time period. An assumption is made that the test site, in the absence of the improvement, exhibits accident experience similar to the control sites. Any difference between the accident experience at the project and control sites is attributable to the project (see Figure 8).

When plotted values of the before MOE's at the control and project sites indicate an increasing or decreasing trend over time, and regression analyses result in a significant trend, the expected value of the MOE should be based on an extension of the trend into the period following project implementation (see Figure 9). If a trend is not observed, an average MOE for the project and control sites may be used (see Figure 8).

For evaluation studies of projects implemented at an earlier point in time, control sites can be identified by searching and analyzing historic accident and locational data at sites similar to the project site. However, if the evaluation study is being planned prior to project implementation, caution must be exercised in the selection of control sites. Since the control site should be similar to the project site without the improvement, a question may arise regarding potential danger of improving one site based on an identified deficiency and not improving a second site or sites with a similar deficiency. This problem does not exist for completed project evaluations and therefore does not detract from the use of the experimental plan.

The Before and After Study with Control Sites is considered the most desirable plan for highway safety project evaluation, since evaluations are based on the assumption of a cause and effect relationship between project countermeasures and a change in the MOE's. The use of control sites allows the evaluator to reduce the influence of other variables on study results. Also, it may be desirable to control for specific independent variables such as climatic conditions, law enforcement, speed or pavement conditons.

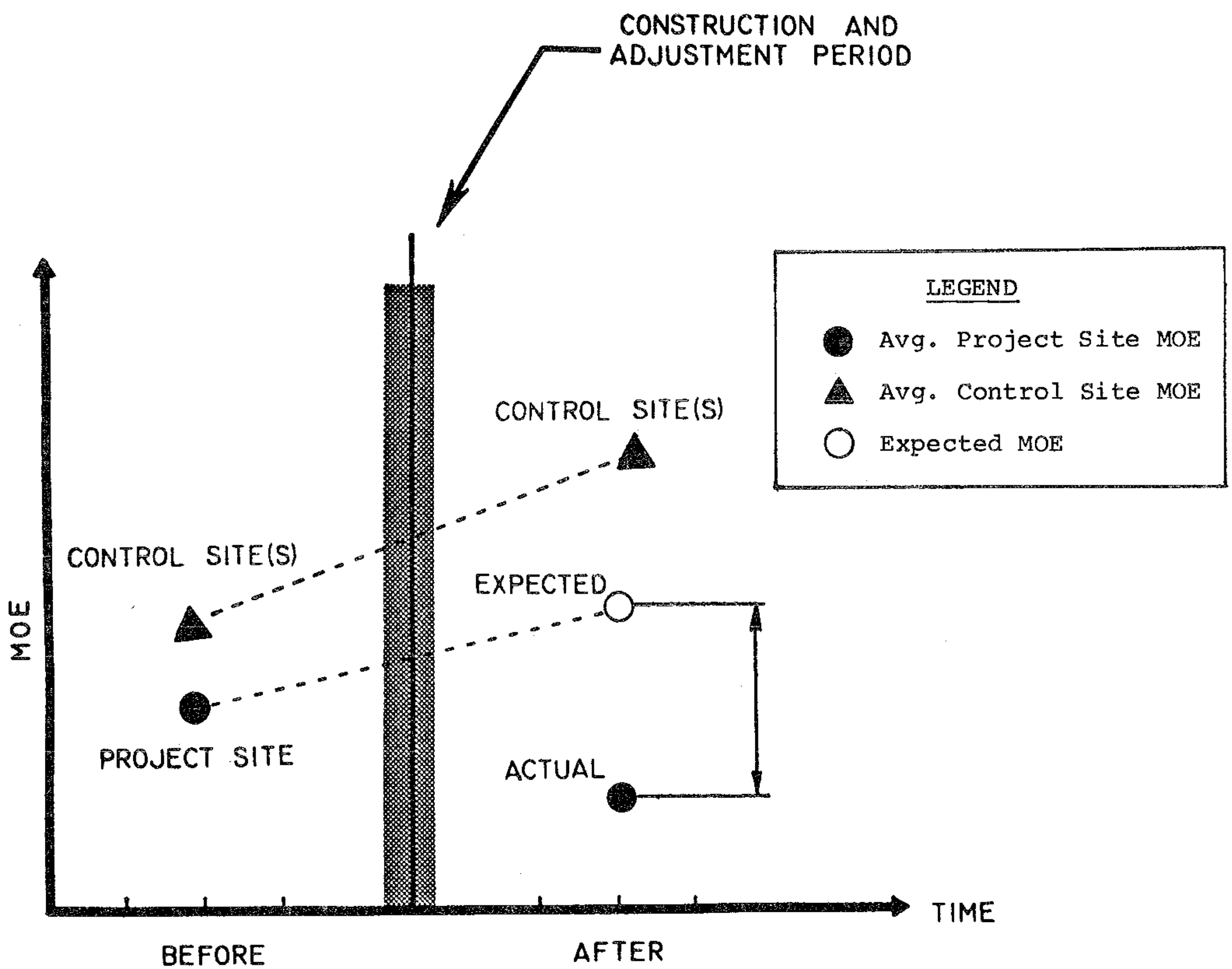


Figure 8. Before and after study with control sites.

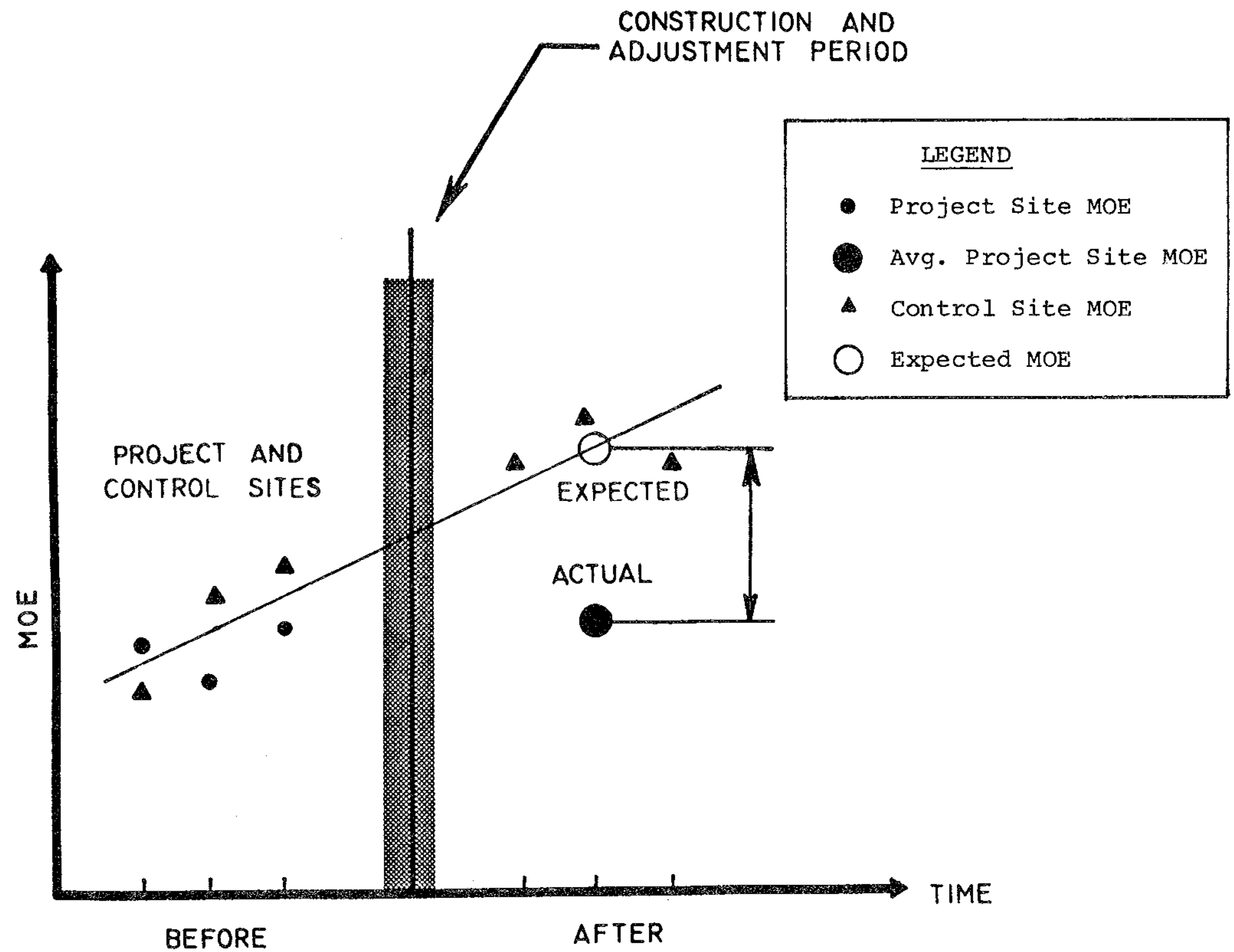


Figure 9. Before and after study with control sites (trend analysis).

The selection of control sites is the most difficult aspect of this plan. The number of control sites selected should be based on the sampling plan given in Figure 6.

Experimental Plan B - The Before and After Study (Figures 10 and 11): This plan is commonly used in the evaluation of highway safety projects, if control sites are not available or the control of specific independent variables is not critical. This approach is based on data collected at two points in time; before and after project implementation (refer to Figure 10). There are two basic assumptions involved in this plan: 1) without the introduction of the highway safety improvement, the MOE value will continue at the same level and 2) the MOE value measured after project implementation is attributable to the improvement. If either or both assumptions are erroneous, the plan may lead to inaccurate conclusions.

If the data for the before period exhibits a definable trend, it may be possible to modify the first of these two assumptions. This can be accomplished through the use of linear regression. If this technique is used, the first assumption is modified to: without the introduction of the highway safety improvement, the MOE will continue to increase (or decrease) at the same rate that it has been increasing (or decreasing) in the before period (see Figure 11). The second assumption however, still must be made. A discussion of the linear regression technique is provided in FUNCTION C.

When before traffic volume data are not available this plan requires an exposure estimate to be made. A growth factor may be used to estimate the before traffic volume thereby making the use of rate-related MOE's possible. Regression analysis can also be used in this regard.

Experimental Plan C - Comparative Parallel Study (Figure 12): This plan is similar to Experimental Plan A with the exception that no MOE's are required prior to project implementation. The assumption made in this plan is that the test site and the control site (or average of the control sites) will exhibit similar behavior in the absence of the improvement. The control sites should exhibit similar deficiencies to those at the project site prior to improvement. The observed difference in the MOE at the project site when compared to the average MOE for the control sites is attributed to the improvement (see Figure 12). The average value for these MOE's are compared to the project site MOE's.

The Comparative Parallel Study also has the advantages of utilizing control sites. However, in this experimental plan, an assumption is made (but not verified) that the test site and control sites had identical MOE prior to project implementation. While this reduces the data requirements, it is less desirable than experimental Plan A and in some cases less desirable than Plan B.

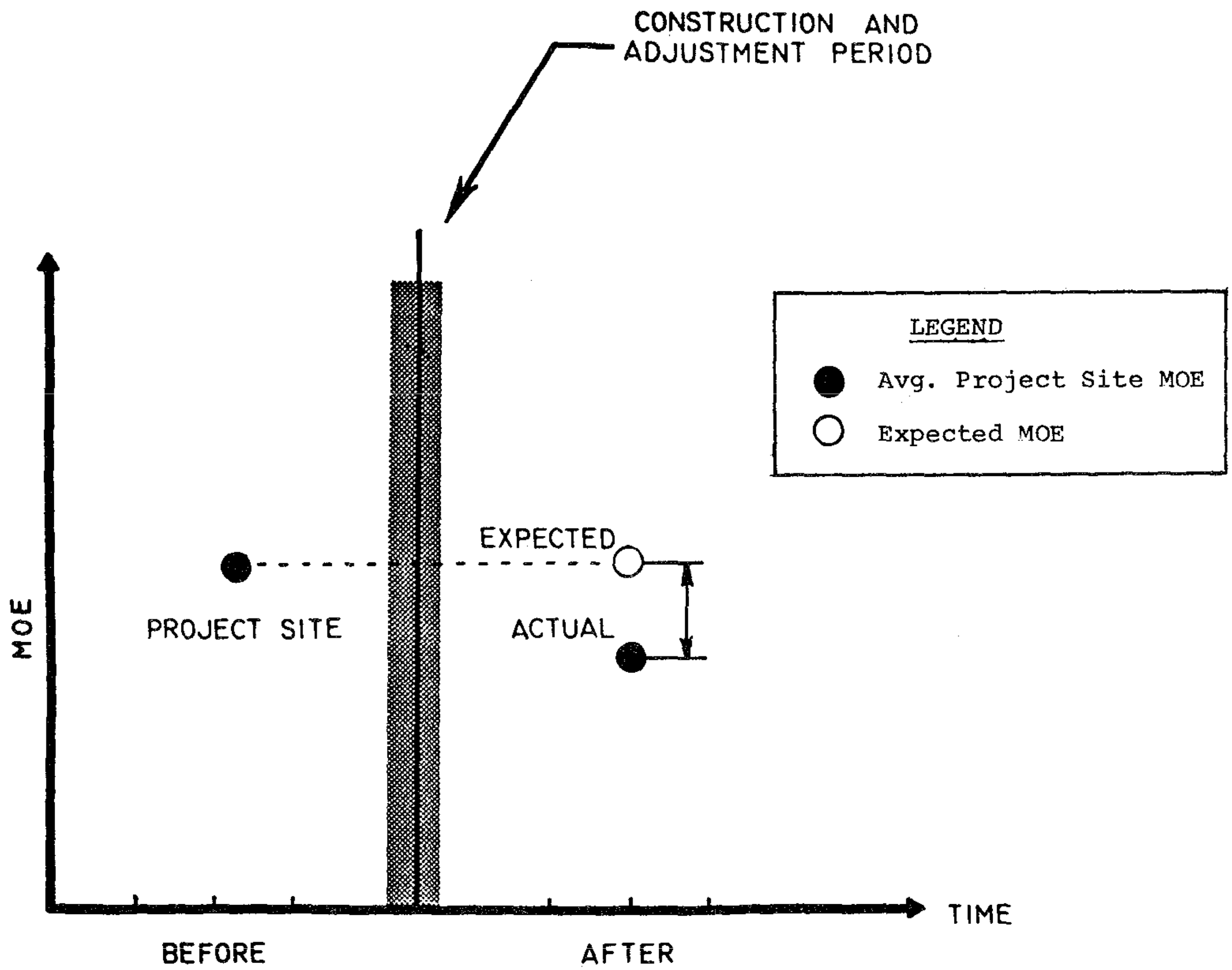


Figure 10. Before and after study.

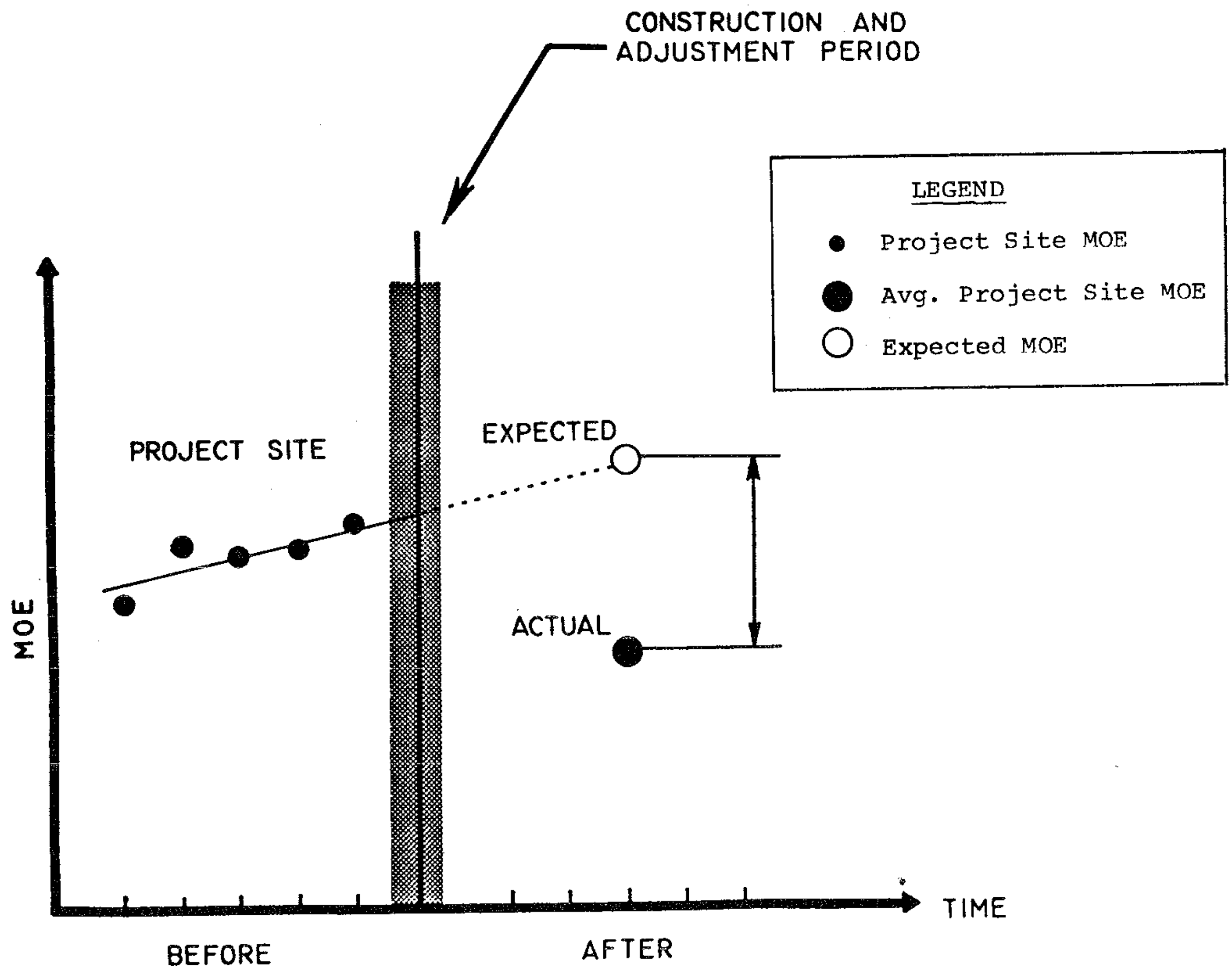


Figure 11. Before and after study (trend analysis).

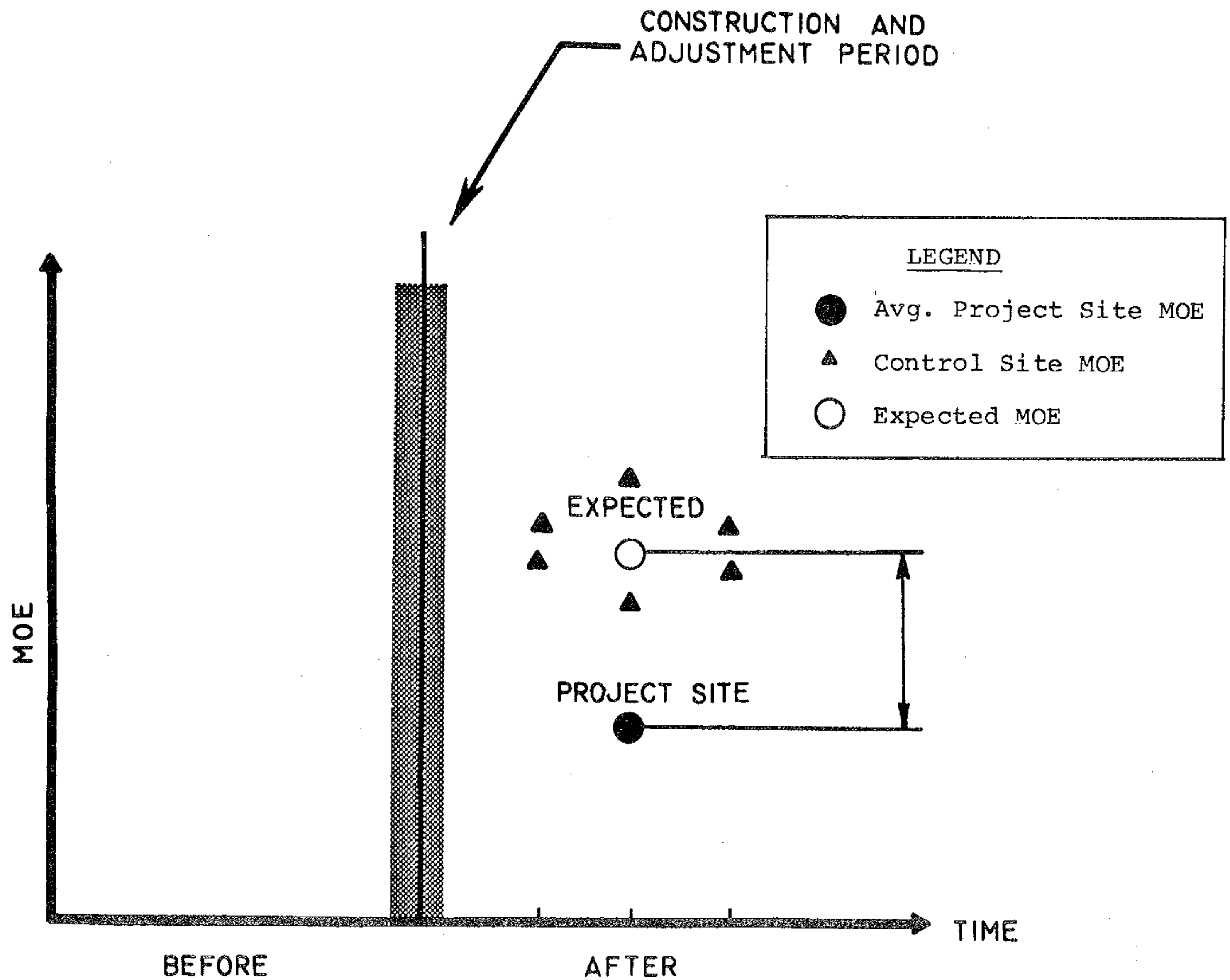


Figure 12. Comparative parallel study.

The greatest difficulty in using control site experimental plans is the selection of control sites. In many cases where projects are implemented at sites with atypical geometry or traffic performance characteristics, the selection of a comparable control site is not possible.

Experimental Plan D - Before, During and After Study (Figure 13): This is similar to the Before and After Study with the modification that measurements are taken at three points in time. This plan is applicable for temporary projects (i.e., temporary signing for construction zone traffic control) which is to be discontinued or removed after a period of time.

In this plan, the first comparison of MOE's is between the during and the expected during conditions (based on before experience) as shown in Figure 13. After the project is discontinued, a comparison is performed between the observed after experience and the expected after (based on the during experience). This comparison provides a measure of the change in accident experience which resulted from the removal of the project. A third comparison is made between the observed after experience and the expected after (based on the before experience) as shown in Figure 13. This comparison provides a measure of the residual effect of the temporary project.

Selecting Experimental Plans

The experimental plans described in this Guide provide the evaluator with the necessary experimental techniques to evaluate most highway safety projects. The evaluator must identify which experimental plan is most suitable for the evaluation study. If there are several evaluation objectives, more than one experimental plan may be appropriate.

The selection of the experimental plan aids in the identification and collection of data and guides the evaluator to the appropriate data analysis and comparison activities.

There are several experimental plans which are appropriate for use in evaluating highway safety programs. Thus, the evaluator must be able to select a plan which is appropriate for the evaluation and to assess the feasibility of applying the plan under prevailing resource limitations. This requires the evaluator to possess an understanding of each plan, its strengths, weaknesses, limitations, and assumptions.

Theoretical Considerations

Experimental plan selection should be based on maximizing the validity of the evaluation study. Validity is defined as the assurance that observed changes in the MOE's result entirely from the implementation of the program (and its component projects) and for no other reasons. The

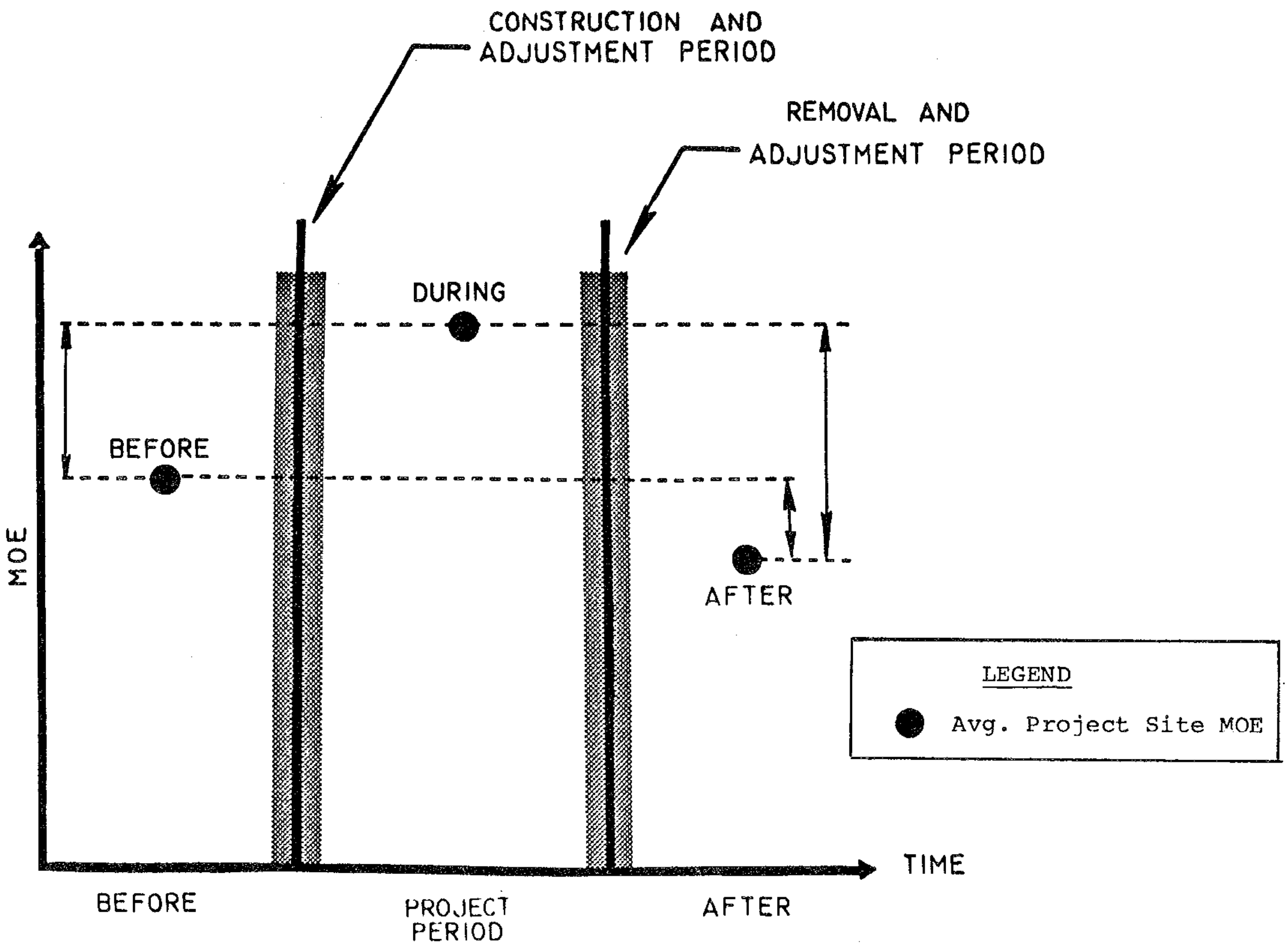


Figure 13. Before, during and after study.

type of experimental plan selected for the evaluation directly affects the ability of the investigator to achieve high levels of validity.

There are several factors (often referred to as threats to validity) which must be recognized and overcome in the evaluation of highway safety programs (and projects). They include:

a) Changes in the values of the MOE's caused by factors other than the program (referred to in the literature as a "history" threat). As an example, the initiation of a selective law enforcement program at one or more high accident intersections during the after evaluation period may affect the accident experience and mask the effectiveness of the program.

b) Trends in the values of the MOE's over time (referred to in the literature as "maturation"). As an example, a comparison of total accident rates before and after program implementation may show a large decrease in the total accident rate (Figure 14). This may be a result of the program or it may be that the decrease is an extension of a long-term decreasing trend in total accident rates at the program sites (Figure 15).

c) Regression to the mean. Regression-to-the-mean is a phenomenon which may result when sites are selected on the basis of extreme values (i.e., high accident experience). Regression is the tendency of a response variable such as accidents to fluctuate about the true mean value. As an example, the decrease in accident rates shown in Figure 14 may be a result of the program or it may be the regression (natural fluctuation) of the accident rate about the mean accident rate (Figure 16).

d) Random data fluctuations (instability). Accident data are particularly subject to random variations when measured over time or at a small number of locations.

The evaluator must recognize and attempt to overcome the validity threats. Threats (a), (b), and (c) may be minimized through appropriate experimental plan selection and use. Threat (d) may be overcome using statistical techniques.

Practical Considerations

The selection of an experimental plan should also consider the feasibility of using a plan under the resource constraints of the evaluating agency. The flow diagram shown in Figure 17 illustrates the experimental plan selection process. The evaluator should address five decision points (indicated as boxes in Figure 17). The first criteria is whether before accident data are available. If before data are not available, the Comparative Parallel Study (Plan C) should be selected. If data are

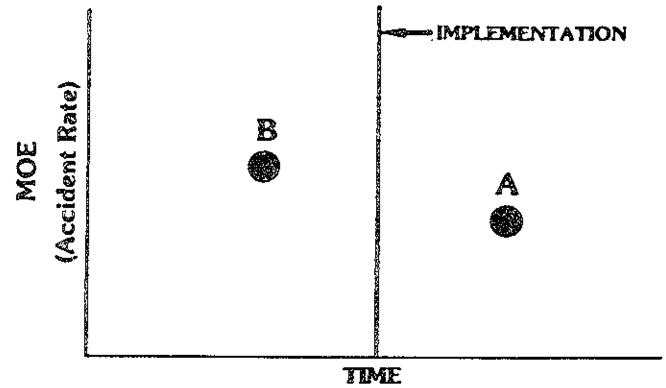


Figure 14. Assumed change in MOE's Before and After Project Implementation.

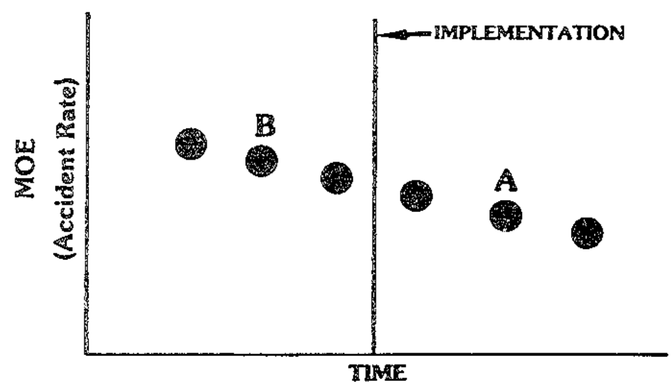


Figure 15. Trends in MOE's overtime.

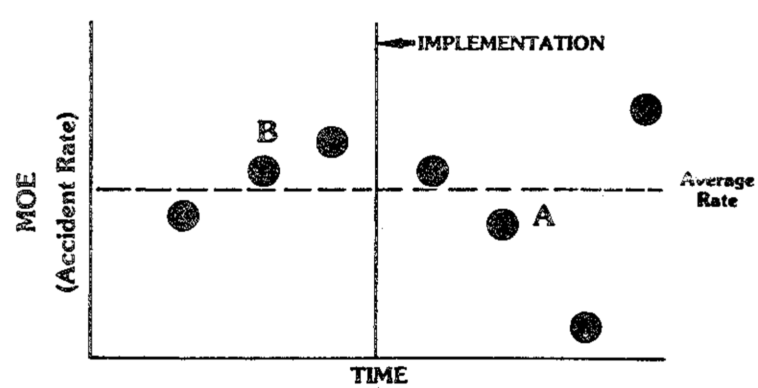


Figure 16. Regression-to-the-mean influences on MOE's

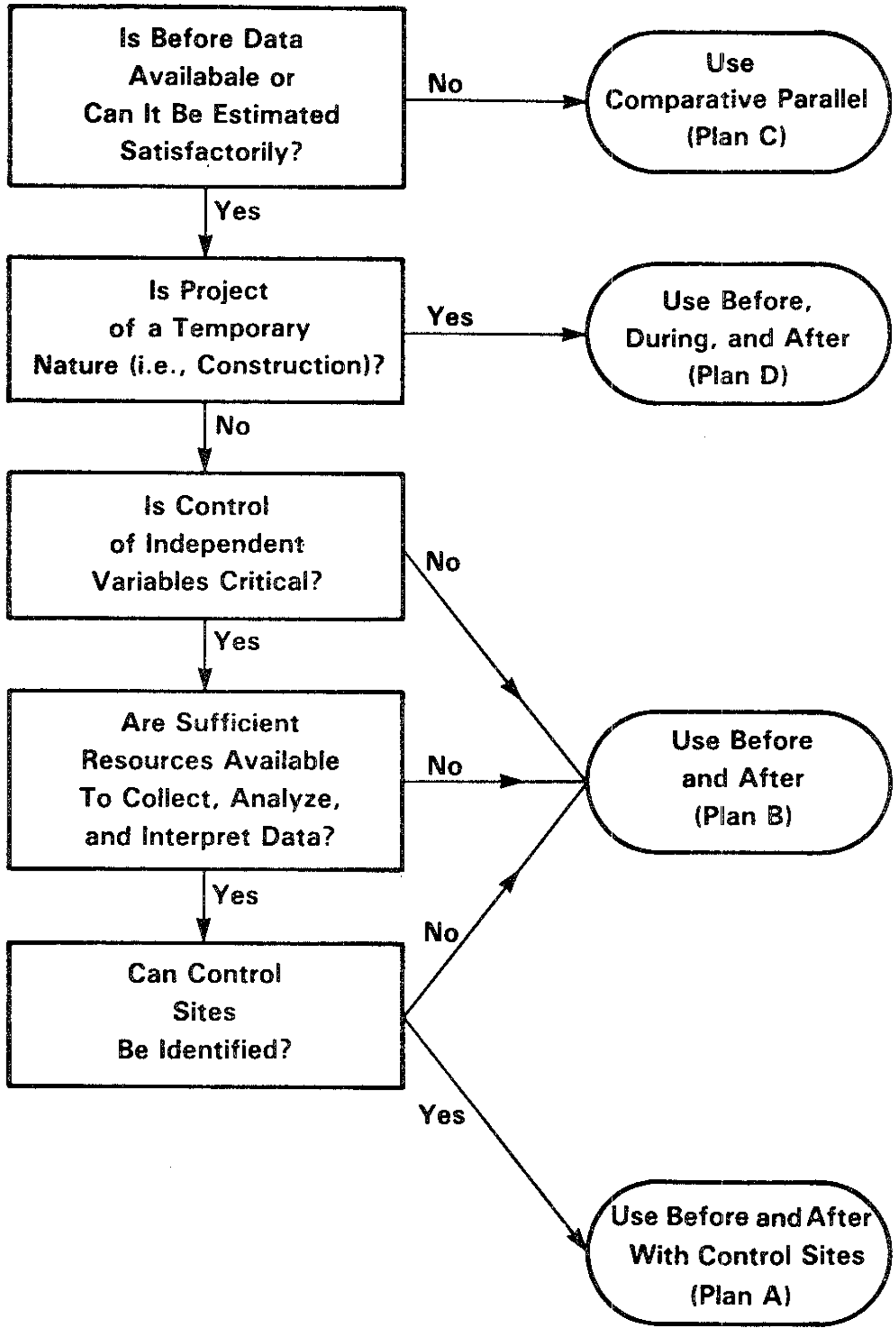


Figure 17. Experimental plan selection.

available, the remaining criteria should be addressed until a plan is selected. These criteria include the need for controlling independent variables, the adequacy of existing manpower resources for data collection and analysis, the availability of control sites and whether the project is temporary or experimental in nature. When a plan is selected which involves control sites, the actual use of that plan in the evaluation is subject to the availability and appropriateness of control sites which are selected in FUNCTION B.

STEP A5 - DETERMINE DATA VARIABLES TO BE COLLECTED

This step involves determining the type of data to be collected, data reduction activities, data stratifications and other information needed to develop an evaluation plan. It is important that the data needs be established and recorded before data collection activities are undertaken to avoid duplication of effort or failure to collect critical data. For future projects, it may be impossible to obtain certain before data following project implementation.

The evaluation of highway safety projects requires data for 1) comparison of MOE's, 2) interpretation of project effectiveness, and 3) economic analysis. The nature and extent of these data are dependent on the previous decisions made in this function, as well as on the ability of the evaluator to identify other safety aspects which may be impacted (negatively or positively) as a result of the project.

Evaluation data needs depend on the following criteria:

1. Objectives and MOE's of the evaluation.
2. Anticipated impacts from the environment surrounding the project site.
3. Anticipated impacts (other than the objectives) on the environment resulting from the project.
4. Project cost including implementation, and operating and maintenance costs.

Items 2 and 3 require the evaluator to exercise judgement based on experience. In these two items, impacts which may affect the project's effectiveness as well as impacts which may result from the project (other than those being evaluated as a purpose or objective) must be anticipated. The evaluator may include such impact in the evaluation objective statement as well.

The determination of the effect of a project requires an assessment of the evaluation objectives and degree to which the improvement has accomplished the objectives of the evaluation. Therefore, each accident type, or severity classification referred to in the evaluation objective and MOE listing must be considered in preparing the list of data to be collected for an evaluation study.

As a minimum, the following information should be specified for each project.

- Total cost, including construction, labor, equipment rental, overhead, etc. (Administrative Evaluation may be conducted to determine these evaluation data needs)

- For the analysis periods:
  - Number of years of accident data
  - Total number of accidents
  - Number of fatal accidents and fatalities
  - Number of injury accidents and injuries
  - Number of PDO accidents and involvements
  - Number of vehicles for spot or intersection locations, and vehicle-miles of travel for roadway section locations.

If a control site experimental plan is selected, data needs for control site selection must also be determined to the extent possible. Based on the type of countermeasures and the characteristics of the project site, the evaluator must attempt to identify key variables which may affect the MOE values (other than the countermeasures) and must therefore be controlled. Key variables may be geometric, operational and/or environmental in nature. The procedure for control site selection provided in the next function of this subprocess (FUNCTION B, STEP B1) should be consulted for additional information.

STEP A6 - DETERMINE MAGNITUDE OF DATA REQUIREMENTS

The experimental plan selected in STEP A4 partially determines the magnitude of data to be collected. Depending on the plan to be used, data sets must be collected at various locations and points in time. For instance, the Before and After Study with Control Sites requires each data variable to be collected at the project site and at all control sites for both the before and after periods. The number of data sets required for the selected experimental plan should be estimated for the purpose of developing a detailed data collection scheme. The exact number and location of control sites to be used are identified as a result of FUNCTION B activities.

Another consideration in establishing the magnitude of data needs is related to sample size requirements. This information along with the number of required data sets allows the evaluator to organize the necessary manpower for the data collection activities.

Analysis Period Length

The experimental plans outlined in STEP A4 are based on the assumption that the number of accidents used in the analysis accurately reflects the number of accidents for the entire before or after analysis period. Because there are random variations in the number of accidents occurring at a site, this assumption becomes more accurate as the analysis period is lengthened. Previous studies have indicated that a three year accident history is a sufficient approximation to the long term average for safety analysis. It is recommended that a three year before and a three year after period be selected for a final Accident-Based Evaluation. In addition, it is recommended that preliminary Accident-Based Evaluation be performed at the conclusion of the first and second years following the project implementation. This helps the evaluator to identify unexpected impacts prior to the final evaluation.

There are two factors to consider when selecting the length of the analysis periods. First, periods should be selected for which there is no significant changes in geometric, traffic or traffic control at the site except for the countermeasures during the entire before and after study period. The second is that it is desirable to evaluate the effectiveness of a project as soon as possible to determine whether additional (or different) countermeasures are warranted at the site.

The following conditions may dictate the analysis period length:

1. If there was a change in either the geometric features or traffic control devices at the site within the three year period prior to or following project implementation, the study period should be adjusted to eliminate the effect of the changes on the MOE.

2. If the evaluator suspects that the countermeasure has increased accidents, an intermediate study period should be selected to determine that effect and develop additional countermeasures to alleviate the safety deficiencies (See Non-Accident-Based Project Evaluation).

3. If data are not available and cannot be reliably estimated for the project site for a three year period prior to improvement, the study period should be adjusted to obtain a reliable accident experience.

When the first condition applies, the before study period should be limited to the time between the change and the countermeasure implementation date. The after study period should be of equal length and conducted during the same months as the before study period. That is, if the before period covers 18 months beginning in January, the after period should also extend for 18 months starting with the month of January. The criteria suggested on page 18, Sufficiency of Accident Data, can be used in this case to determine if the expected after experience is adequate to support subsequent statistical analysis.

When the second condition applies, an analysis using the full three year before period and whatever after period has expired before the after MOE's became suspect should be conducted. If the results are not conclusive, the project should be continued and a subsequent evaluation be made prior to the end of the three year after study period.

When the third condition applies, all available before data should be used with an after study period containing the same number of months.

Traffic volumes (expressed as average annual daily traffic, AADT) may be collected on a sampling basis. The ITE "Manual of Traffic Engineering Studies" states that in urban areas (population of over 2,000) 24 hour counts on a typical day taken during favorable weather conditions usually approximate the AADT within 10%. In rural areas, 24 hour counts must usually be adjusted for daily and seasonal factors. A detailed explanation of these factors is provided in the ITE "Manual of Traffic Engineering Studies" (pages 29 - 35).

All data requirements and the magnitude of data required for each data variable should be recorded in the Data Requirements form shown in Figure 18.

Output of Function A - Completed Evaluation Plan

Whether developed as part of pre-implementation engineering studies or after implementation, a report to document the Evaluation Plan should be developed.

The Evaluation Plan should include:

1) A statement of objective

   Include project purpose(s) and justification(s), evaluation objectives and MOE's.

2) A description of the overall plan

   Include a description of the selected project(s), available accident history and appropriate traffic performance or other variables to be compared.

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DATA REQUIREMENTS LISTING

Evaluation No. A-1

Date/Evaluator 2/23/77/DDP Checked by 2/28/77/HES

Experimental Plan Before and After

Data Needs	Magnitude (Number of Sites, Time Period, Dates)
1. Total Accidents Stratified by Severity	1. 3 years before (5/73 to 5/76) and after (5/77 to 5/80) project implementation for five sites.
2. Run-off-Road accidents stratified by lighting condition (night vs. day)	2. 3 years before (5/73 to 5/76) and after (5/77 to 5/80) project implementation for five sites.
3. Average annual daily traffic	3. For each year (5/73 thru 5/80) of the analysis for five sites.

Figure 18. Sample data requirements form.

3) An outline of the method of analysis

Clearly specify the experimental plan to be used, measures of effectiveness, types of comparison to be employed and other details concerning data collection needs. The desirability and type of economic analysis and statistical testing should be addressed including values and assumptions to be employed.

Appended to this report should be the listings, forms and work sheets shown in the Appendix. These should be completed to the extent possible. All available data should be listed at the time the evaluation plan is developed to facilitate later retrieval for subsequent evaluation activities.

Summary of FUNCTION A

STEP A1 - SELECT PROJECTS

- Obtain before documentation including accident histories and project justification statements if available.
- Review before accident data and identify the relationship between the project and safety deficiencies.
- Select projects to be evaluated which provide needed input to future HSIP decisions.
- Determine the project purposes.
- List the project purposes and justification for and build an evaluation study file.

STEP A2 - STRATIFY PROJECTS

- Group projects with similar types of countermeasures which are to be (or were) implemented at locations with similar site characteristics using a card indexing system.
- Determine which evaluation plan is appropriate.
- Sample projects for evaluation if desired.

STEP A3 - SELECT EVALUATION OBJECTIVES AND MOE'S

- State the fundamental evaluation objectives and identify the objectives by determining the probable effect of the project on one or more project purposes.

- If traffic volumes or exposure data are available for the project site, select a rate-related MOE for each objective. Select an exposure factor consistent with the project type and location from Table 2.

- If volume data are not available, estimate exposure and use rate MOE's or select frequency-related MOE's. Use the value of MOE over the entire analysis period or an average per unit time (i.e., year).

- Select objectives related to economic evaluation.

- Finalize selection of MOE's for all objectives.

- List objectives and MOE's and incorporate into the evaluation plan document.

STEP A4 - SELECT EXPERIMENTAL PLAN

- Select the experimental plan based on its applicability to the evaluation objectives and its overall desirability.

- Determine if the selected plan is feasible using Figure 18.

- Plot MOE's over time to determine whether or not regression analysis is appropriate.

STEP A5 - DETERMINE DATA VARIABLES TO BE COLLECTED

- List all data variables associated with the objectives (and MOE's) of the evaluation.

- List data needs for control site selection if necessary.

- List variables expected to be impacted either negatively or positively by the highway safety project.

STEP A6 - DETERMINE MAGNITUDE OF DATA NEEDS

- Estimate the number of data sets to be collected for each data variable identified in STEP A5 for the evaluation study. (The specific number and location of control sites will be determined in FUNCTION B).

- Estimate sample size requirements to the extent possible for each data set. List all data needs and magnitudes for inclusion in the evaluation plan document and develop the complete evaluation plan.

Example of FUNCTION A

The State Highway Agency is implementing projects to improve non-freeway locations where single vehicle run-off-the-road (ROR) accidents typically occur. The countermeasure for this project type is to be pavement edgelining at hazardous locations where edgelining did not previously exist. Therefore, the State is interested in evaluating past edgelining project experiences to determine the effectiveness of painted edgelines on ROR accidents.

The following illustrates the step-by-step procedure described in FUNCTION A:

STEP A1 - SELECT PROJECTS

Edgelining projects implemented in 1974, and continually maintained to date, were compiled from agency records. Since the evaluation is being conducted in 1978, projects implemented during 1974 were selected to ensure at least three years of accident data following initial edgelining. The project selection process considered only pavement edgelining which was specifically implemented as part of a "high hazard location" safety improvement project. Also, the edgelining portion of a project had to be the only countermeasure in the project which was designed to impact ROR accidents. That is, if guardrail or curve reconstruction were implemented along with edgelining, the projects would not be considered as a candidate because both guardrails and reconstruction could impact ROR accident experience.

A large number of projects was selected because of the small number of ROR accidents which constitute a ROR accident problem.

A review of the accident history and project justification statement for the projects resulted in the project purposes shown in Figure 19.

STEP A2 - STRATIFY PROJECTS

Following the initial project selection process (STEP A1), the resulting edgelining projects were stratified according to roadway type. The two stratifications utilized were: 1) two-lane, bi-directional non-freeways, and 2) multilane, bi-directional non-freeways.

It was determined that projects would be sampled from both the multilane and two-lane non-freeway stratifications. Sampling was performed because the large number of sites in

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PROJECT PURPOSE LISTING

Evaluation No. A-1A

Date/Evaluator 2/23/77/DDP **Checked by** 2/28/77/HES

Project No. P-1A

Project Description and Location(s) Pavement marking on non-freeway multilane and two-lane highways throughout Polk County.

Countermeasure(s)/Codes Edgelining (FHWA Code 64)

Project Purpose	Justification
1. Reduce Total Accidents	1. All sites are high accident locations by States 1976 criteria
2. Reduce ROR Accidents	2. High proportion of ROR accidents during pre-project period. (60% versus 30% Statewide).
3. Reduce Night ROR Accidents	3. High numbers of night ROR accidents during pre-project period. 50% of the ROR accidents occurring occurred at night. Only 15% of the travel occurred at night.

Figure 19. FUNCTION A example data - project purpose listing.

either group made the development of detailed accident summaries impractical for the manpower resources of the agency. Further, the sampled projects would allow sufficiently large numbers of ROR's for statistical testing. The number of sites in each group were 18 and 21, respectively.

Accident printouts were obtained for a three year period prior to project implementation for each project site. Figures 20 and 21 show a listing of the combined three year accident data for project sites in both groups. (The proportions of ROR accidents were approximately equal for all sites). For each group, the population mean, μ ,the population standard deviation, σ , were calculated. Mean accident values were calculated as 24.67 and 23.38 accidents while standard deviations were 11.51 and 7.29 accidents for the multi and two-lane roadways, respectively.

The required sample size (n_s) was calculated for both groups using an allowable accident tolerance of ± 7 accidents about the mean for the three year period. The procedure for calculating n_s was as follows:

For multilane group (group 1):

$$n_s = 4\sigma^2/E^2$$

$$= 4(11.51)^2/7^2$$

$$= 10.8, \text{ use 11 sites}$$

For two-lane group (group 2):

$$n_s = 4\ (7.29)^2/7^2$$

$$= 4.3, \text{ use 5 sites}$$

Eleven and five sites were randomly selected from the multi- and two-lane project groups respectively as shown in the last column of Figures 20 and 21. The average accident experience based on these sampled sites was then calculated for subsequent use in the evaluation study.

STEP A3 - SELECT EVALUATION OBJECTIVES AND MOE.

The list of objectives and MOE's of the evaluation is shown in Figure 22. In addition to the fundamental objectives selected for all evaluations, two additional objectives were selected.

PROJECT SAMPLING WORKSHEET

Evaluation No. A-1A (Multi-lane, Non-Freeway Projects)
Date/Evaluator 2/23/77/DDP Checked by 2/28/77/HES
Departure From Mean, Error: ± 7 Accidents
Sample Size: 11 Sites (Note Astericks)

Site No.	Location	Total Accidents Xi	$(X_i-\mu)^2$
1	A1	22	7.13
2 *	A2	18	44.49
3	A3	11	186.87
4 *	A4	11	186.87
5 *	A5	26	1.77
6 *	A6	42	300.33
7	A7	31	40.07
8	A8	12	160.53
9 *	A9	14	113.85
10	A10	19	32.15
11 *	A11	25	0.11
12 *	A12	22	7.13
13 *	A13	50	641.61
14	A14	40	235.01
15 *	A15	38	177.69
16 *	A16	28	11.09
17	A17	16	75.17
18 *	A18	19	32.15
*	Selected for Sample by Table of Random Numbers.		
$n_g = 18$		$\Sigma X_i = 444$ $\mu = 24.67$ $\sigma = 11.51$	$\Sigma (X_i-\mu)^2 = 2254.02$

$$\mu = \frac{\Sigma X_i}{n_g} = 24.67 \qquad \sigma = \sqrt{\frac{\Sigma (X_i-\mu)^2}{n_g-1}} = 11.51 \qquad n_s = \frac{4\,\sigma^2}{\text{Error}^2} = 10.8 \text{ Use } 11$$

Figure 20. Project sampling worksheet for FUNCTION A example (multi-lane, non-freeway projects).

PROJECT SAMPLING WORKSHEET

Evaluation No. A-1A (Two-lane, Non-Freeway Projects)
Date/Evaluator 2/23/77/DDD Checked by 2/28/77/HES
Departure From Mean, Error: ± 7 Accidents
Sample Size: 5 Sites (Note Astericks)

Site No.	Location	Total Accidents Xi	$(X_i-\mu)^2$
1	B1	22	1.90
2	B2	31	58.06
3 *	B3	12	129.50
4	B4	15	70.22
5	B5	14	87.98
6	B6	20	11.42
7 *	B7	26	6.86
8	B8	29	31.58
9	B9	16	54.46
10	B10	21	5.66
11	B11	20	11.42
12	B12	32	74.30
13 *	B13	40	276.22
14	B14	31	58.06
15 *	B15	18	28.94
16	B16	26	6.86
17	B17	24	.38
18	B18	16	54.46
19	B19	19	19.18
20 *	B20	29	31.58
21	B21	30	43.82
* Selected for Sample by Table of Random Numbers n_g = 21		ΣX_i = 491 μ = 23.38 σ = 7.29	$\Sigma(X_i-\mu)^2$ = 1062.86

$$\mu = \frac{\Sigma X_i}{n_g} = 23.38 \qquad \sigma = \sqrt{\frac{\Sigma(X_i-\mu)^2}{n_g-1}} = 7.29 \qquad n_s = \frac{4\,\sigma^2}{\text{Error}^2} = 4.3 \quad \text{Use } 5$$

Figure 21. Project sampling worksheet for FUNCTION A example (two-lane, non-freeway projects).

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OBJECTIVE AND MOE LISTING

Evaluation No. A-1A

Date/Evaluator 2/23/77/DDP Checked by 7/28/77/HES

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on: (fundamental)	Percent change in: (check one) Rate X or Frequency ____ (fundamental)
1. Total Accidents	1. Total Accidents/ MVM
2. Fatal Accidents	2. Fatal Accidents/ MVM
3. Injury Accidents	3. Injury Accidents/ MVM
4. PDO Accidents	4. PDO Accidents/ MVM
(project purpose)	(project purpose)
5. ROR Accidents	5. ROR Accidents/MVM
6. Night ROR Accidents	6. Night ROR Accidents/MVM

Figure 22. FUNCTION A example objective and MOE listing.

Since all projects are located on extended roadway sections and volume data are available for the selected sites, an exposure factor of vehicle-miles of travel (or a multiple thereof) was selected as the rate-related MOE.

STEP A4 - SELECT EXPERIMENTAL PLAN

Two projects consisting of eleven (multilane) and five (two-lane) individual project sites are to be evaluated independently.

A search for unimproved sites to serve as control sites for each project group was unsuccessful. Therefore, the before and after study was considered appropriate for the evaluation study.

A four year plot of annual total and ROR accident rates for the sampled projects in each group did not indicate either an increasing or decreasing trend. Therefore, the single point (average) estimate for each group was selected.

STEP A5 - DETERMINE DATA VARIABLES TO BE COLLECTED

The list of variables necessary to evaluate these two projects were developed and presented in Figure 23.

The data variables addressed the objectives and MOE of the evaluation as well as other data which are relevant to the evaluation study.

STEP A6 - DETERMINE MAGNITUDE OF DATA NEEDS

Since control sites are not involved in the evaluation, data need only be collected at the project sites.

The before and after periods were selected as three years. Thus, accident data are required for the project sites covering a three year period before and after the implementation. The magnitude of all data requirements including accident and volume data are also shown in Figure 23.

Output of FUNCTION A - COMPLETED EVALUATION PLAN

The completed evaluation plan for the project is shown on the following pages.

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DATA REQUIREMENTS LISTING

Evaluation No. A-7A

Date/Evaluator 2/23/77/DDP   Checked by 2/28/77/HES

Experimental Plan Before and After

Data Needs	Magnitude (Number of Sites, Time Period, Dates)
1. Total Accidents Stratified by Severity, fatalities & injuries	1. 3 years before (1970 to 1973 as appropriate) and after (1975 to 1977 as appropriate) project implementation for 39 sites.
2. ROR accidents stratified by lighting condition (night vs. day)	2. 3 years before (1970 to 1973 as appropriate) and after (1975 to 1978 as appropriate) project implementation for 39 sites.
3. Average annual daily traffic	3. For each year (1970 to 1978) of the analysis for all 39 sites.

Figure 23. FUNCTION A example data requirements listing.

Example Evaluation Plan

Title: Effectiveness of Pavement Edgelining

Date/Evaluator 9/8/78/RMU Checked by 9/14/78/HES

Evaluation Number A-3A

DESCRIPTION OF PROBLEM IDENTIFIED: A disproportionately high incidence of run-off-road (ROR) and night ROR accidents (greater than 5 and 2.5 accidents/mile respectively) have been identified on 39 highway sections. The statewide averages are 2.5 and 1.5 respectively. The locations of these highway sections are A1 through A18 and B1 through B21.

COUNTERMEASURE SELECTED: Edgelining has been selected as the proposed countermeasure to reduce the ROR and night ROR accidents.

STUDY EVALUATION OBJECTIVE: The objective of this evaluation is to determine the effectiveness of edgelining on ROR and night ROR accidents.

FUNCTION A - Develop Evaluation Plan

Step A1 - Select Projects to be Evaluated

CRITERIA FOR PROJECT SELECTION: Selection criteria include:

1. Projects completed in the same general time period. (Between 5-1-74 to 10-31-74).

2. Countermeasure properly maintained during evaluation period. Field reviews by maintenance superintendants will be made during routine travel. Locations will be marked as deemed necessary.

3. Data is or will be available from the State's accident files.

4. All sections of highway experienced high incidence of ROR and night ROR accidents.

5. Edgelining was the only countermeasure applied. Construction and maintenance records will be reviewed to identify any significant changes in environmental and highway features during the after analysis period.

IDENTIFY PROJECT PURPOSE AND JUSTIFICATION FOR SELECTION: The purpose sites selected have a disproportionately high incidence of ROR accidents and night ROR. (Project Purpose Listing, shown in the Appendix to Evaluation Plan).

Step A2 - Stratify Projects:

Thirty-nine highway sections with high incidence of ROR and night ROR accidents were grouped into multilane nonfreeway (A1-A18) and two lane nonfreeway highways (B1-B21).

DETERMINE EXTENT TO WHICH EACH GROUP WILL BE EVALUATED, i.e., ALL PROJECTS, SAMPLE, NONE: The multilane nonfreeways and two lane nonfreeways was studied to determine the reasonableness of selecting a sample of sites for evaluation. The projects were stratified into two groups - multilane nonfreeway and two lane nonfreeway - because of the similar site characteristics of the highway sections found in each group.

Because of the large number of sites in each group, individual project evaluations were determined to be impractical based on existing manpower restrictions. Therefore, sampling from the project grouping was conducted. (See Project Sampling Work Sheets in the Appendix to the Evaluation Plan).

Step A3 - Select Evaluation Objectives and MOE:

All fundamental objectives will be included in this evaluation. These are to determine the effect of the project on total accidents, fatal accidents, injury accidents, and PDO accidents. In addition, project related objectives are the effect on ROR accidents and night ROR accidents.

Rate related MOE's have been selected for this evaluation. All accident types will be measured in accidents per MVM. (Objective and MOE Listing as shown in the Appendix of the Evaluation Plan).

Step A4 - Select Experimental Plan:

Before and After Study with Control Sites appears to be the most desirable. However, because of limited manpower and resources, the use of control sites was determined to be impractical at this time.

No accident trends were identified or are anticipated. Therefore the before and after experimental plan was selected.

Step A5 - Determine Data Variable to be Collected:

All accident data is required during the entire evaluation period. In addition to the fundamental objectives of total accidents, fatal accidents, injury accidents and PDO accidents, it will be necessary to identify both day and night ROR accidents. Since rate related MOE's have been selected, traffic volumes for the before and after periods will be required. The Accident Summary Table (Appendix), MOE Data Comparison Worksheet (Appendix), and Exposure Worksheet are to be completed as data becomes available.

Step A6 - Determine the Magnitude of Date Requirements:

All data variables will be required for the entire 3 year before (5-1-70 to 5-1-73) and 3 year after (5-1-75 to 5-1-78) period. (See Data Requirements Listing in the Appendix).

FUNCTION B: Collect and Reduce Data

This function enables the evaluator to:

1. Collect data for the selection of control sites.

2. Select control sites.

3. Collect and reduce accident, severity, exposure, and project cost data.

Overview

Accident, exposure and cost data are the basic input to Accident-Based Evaluation. The type and magnitude of these data are dependent on the objectives of evaluation, the MOE's, and the experimental plan established in FUNCTION A.

FUNCTION B provides guidelines for collecting all data necessary for an evaluation study including:

1. Data necessary for selection of control sites.

2. Before accident and other data collection.

3. Data collection during implementation period.

4. After accident and other data collection.

Standard data collection procedures and equipment are discussed in this function to aid the evaluator in data collection and reduction.

Accident and volume data are the primary inputs to the evaluation measures of effectiveness. The following section is provided to enable the evaluator to recognize and minimize problems associated with the use of accident and volume data in Effectiveness Evaluations.

Accident Data Issues

Several accident data issues which may reduce the reliability of the evaluation must be considered by the evaluator.

Accident reporting inconsistencies present a significant problem to the evaluator in the form of differential reporting thresholds between and within States, changes in accident report forms, and reporting procedure differences between jurisdictions.

Other problems associated with accident data include biased, erroneous or incomplete accident report information. These problems exist in the form of incorrectly located accidents, biases created by officers' judgment on probable accident cause, the absence of appropriate reporting variables on the accident report forms, and unreported accidents.

The evaluator, with the knowledge of possible problems with accident data, must assess the impact of such problems on the outcome of the evaluation. Critical questions which must be considered include:

a. Do known problems or biases affect some MOE's differently than others?

b. Do known problems or biases affect the before period differently than the after period?

c. Do known problems or biases affect the project site differently than the control site?

If the answers to these questions suggest that the evaluation results may be affected, modifications to the experimental plan may solve or minimize the problem. If the problems cannot be overcome, the evaluator must note in the final report that these deficiencies may have affected the results of the evaluation.

Possible solutions to these problems lie in the ability of the evaluator and other professionals in the area of highway safety to inform administrators of the existence of these issues and suggest possible remedial measures such as improving accident report forms and procedures, and adopting reliable accident location systems.

<u>Exposure Data Issues</u>

Problems associated with exposure data must also be recognized by the evaluator since rate-related MOE's are often used. Because exposure data must be taken during the same period that the accident data are acquired, the use of existing volume data creates a problem in defining accident rates for such MOE's as wet weather accident rates and night or day accident rates. Another problem with using exposure data is that it is often derived from historic traffic count surveys or statewide statistics. The use of these data sources may grossly under- or over-estimate the exposure at a specific site. Bias associated with data collection techniques may also result from obtaining non-random samples which do not represent the "true" volume situation.

Again, if these problems and biases are suspected, the critical questions listed for the accident data must be addressed for the exposure data. Possible solutions to these problems consist of controlled traffic volume collection and exposure estimating procedures at all program and control sites.

STEP B1 - SELECT CONTROL SITES

The selection of control sites is necessary when the selected experimental plan is either The Before and After Study with Control Sites or The Comparative Parallel Study. For these plans, the evaluator must select one or more locations to serve as control sites.

Control sites should exhibit characteristics similar to those of the project site in the absence of the countermeasures.

Generally, it is not too difficult to identify sites which have similar geometrics. However, the accident experience at any site reflects the interaction of the driver, the roadway and the environment. An attempt should be made to select sites in which all three of these factors are similar to those of the project site. Recognizing that it may be difficult to find sites which are absolutely identical for these three factors, the evaluator must make a trade-off between the statistical desirability of using a control site experimental plan and the possible inaccuracies introduced by dissimilarities between the project and control sites. This loss of accuracy can be minimized by careful selection of those variables which differ between the project and control sites and by using an adequate number of control sites.

The control sites should exhibit accident patterns similar to those of the project site. Since the accident and severity can be similar at two or more different sites due to chance, variables such as horizontal and vertical alignment, number of lanes, pavement width, type of traffic control devices, land use, access control, and traffic volume should be similar. In addition to these considerations (similarities between MOE's accident patterns, geometry, traffic control, etc.), the evaluator should identify key variables which must be controlled in the evaluation. The key variables are those independent variables which are expected to influence the effectiveness of a specific project. For instance, suppose a skid proofing project is to be evaluated using a control site experimental plan. Both speed and the pavement surface conditions before the improvement may influence accidents. The control site selection process should, therefore, consider speed and type of pavement surface as key variables. Thus, the control sites must be similar to the project site for these two key variables in addition to geometric, traffic control and MOE similarities.

As another example, a pavement edgelining project which was implemented to reduce night run-off-the-road accidents should ensure that roadway lighting conditions in the before period are similar at the project and control sites. Differences in this key variable (level of roadway lighting) would affect the validity of evaluation results.

Operational data such as speed data, turning movements, or travel time and delay or other non-accident data may also be required for control site selection. The evaluator should use only standard data collection procedures for the collection of these data. Also, appropriate data collection equipment should be utilized. The "Manual of Traffic Engineering Studies" published by the Institute of Transportation Engineers (ITE) is recommended for further discussion on data collection procedure, equipment and data collection forms.

The matching of other independent variables adds to the desirability and validity of the control sites. The evaluator should use judgment when specifying key variables. As a guide, it is recommended that up to a 10% variation in any key variable between the project and control sites be considered acceptable. The use of a 10% variation is not based on a quantitative analysis of the control site selection process but is provided as a guide. The value for the allowable variation can be modified by the evaluator as he gains experience in selecting control sites.

The relationship between sample size (number of control sites) and accuracy exists for control sites as for other variables. That is, the greater the number of control sites, the greater the confidence that the accident experience at these sites typifies the expected accident experience at the project site without improvement. However, the number of control sites to be used in the study may be limited by the number of sites with similar key variables (which the evaluator wishes to control) and/or by the manpower requirements for data collection and reduction. It is recommended that the maximum possible number of sites be used, consistent with these two constraints.

The following procedure should be used in selecting control sites:

1. Identify and list candidate control sites. Candidates must have roadway geometry and traffic control features which are identical or nearly identical to the project site. Variables to be considered include the horizontal and vertical alignment, number of lanes, lane width, access control, land use, traffic volumes and traffic control devices. Geometric and traffic control data may need to be collected to make this comparison. These data can be collected from existing files, plans, photologs, or field surveys.

2. Select from the candidate sites, those which exhibit similar before accident experience in the units of the selected MOE's. For rate-related MOE's a candidate site may be selected, if the before MOE rate is within 10% of the project site MOE rate. Accident printouts or manual accident tabulations from police

reports are necessary for this activity. The sites which do not indicate similar accident-related MOE's should be rejected.

3. Collect other key variables which are to be controlled in the evaluation (i.e., climatic conditions, vehicular speed).

4. From the list of candidate sites, select control sites which exhibit similarity (within 10%) in the key variables.

STEP B2 - COLLECT DATA FOR THE BEFORE PERIOD

A critical factor to consider in the data collection process is the delineation of boundaries for the project site (and control sites if used in the evaluation). The boundary of the project site should include only that area influenced by the countermeasures. Evaluation data collected outside the area of influence may seriously effect the outcome of the evaluation. Control site boundaries should closely match those established for the project site.

Since the objectives of the evaluation are related to testing accidents by type or severity, before accident data should be available from evaluation plan development activities conducted in FUNCTION A. In this step, all before data must be collected and reduced to a usable form for subsequent analysis. Accident tabulations and collision diagrams may help to organize accident data. This is of special importance when accident data must be extracted from accident report files or from site-specific computer printouts. The evaluator should be certain, however, that all reported accidents are being considered in the study by checking with State, County and local law enforcement agencies and traffic engineering accident files.

The entire accident data base for a project site should be tabulated annually, by accident type, severity, time of day, surface and weather conditions, driver action, etc. A computerized accident system is extremely efficient for this process. However, manual tabulation of data from accident reports is acceptable, although it requires considerably more time. From these accident tabulations, the evaluator should identify those accident and severity categories which relate specifically to the data needs list prepared in STEP A4 of FUNCTION A. An Accident Data Summary (Figure 24) may be used to tabulate accident data.

Since the effectiveness of a safety improvement is often dependent on changes in accident or severity rates between the before and after periods, there is a need for reliable volume data. Volume data may be collected in the field or obtained from existing sources and used to obtain accident rates. An Exposure Worksheet as shown in Figure 25 may be used

ACCIDENT SUMMARY TABLE

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by ____________

Data Source ____________________

Location ______________ Check one: [Project Site(s): Before ________ or After ______]

Time Period ____ to _____ [Control Site(s): Before ________ or After ______]

Accident Category	Total Accidents	Fatal Acc.	Fatalities	Injury Acc.	Injuries	PDO Acc.	Invol.
Surface Condition							
Dry							
Wet							
Snowy/Icy							
Other							
Total							

Figure 24. Sample accident summary table.

EXPOSURE WORKSHEET

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by: ____________

Data Source ____________________

Location ____________________

Time Period ______________ to ______________

Check one: Project Site(s) Before ________ or After ________

Control Site(s) Before ________ or After ________

Site	Project* Length	Length of Time Period	AADT	Exposure Veh. ___ or Veh. Mi. ___
1.		1.	1.	
Total				

*For vehicle-mile units of exposure (only)

Figure 25. Sample exposure worksheet.

to tabulate volume data and compute exposure factors. Exposure, expressed in vehicles (V) for intersection or spot project sites and vehicle-miles of travel (VM) for extended roadway section project sites may be computed by expanding average annual daily traffic (AADT) counts. AADT for major roadways are often available from annual traffic count programs. However, supplemental volume studies taken on a sampling basis may be conducted by the evaluator to check the reliability or update traffic volumes. Exposure factors may be computed from AADT counts with the following equations.

For intersection or spot location exposure factors, (expressed as vehicles, V):

$$V = AADT \times T$$

For extended roadway sections exposure factors (expressed as vehicle miles of travel, VM):

$$VM = AADT \times T \times L$$

Where:

AADT = Average annual daily traffic volume

T = Number of days in the analysis period

L = Section length.

The analysis periods in the above equations represent the time over which the accidents have been collected (length of before or after period). Exposure is generally factored to reduce the magnitude of the number; this factor must always accompany any reference to accident rates (such as million vehicle-miles of travel).

It is also recommended that an inventory of existing roadway and environmental features be conducted for the before period and again for the after period. This may be accomplished by field reconnaisance or by checking historic project and maintenance files or photologs. The inventory of environmental and highway features should include but not be limited to:

- type of land use
- distances to nearest intersections
- type of traffic control devices
- project site geometrics
- intersection approach type
- pavement type
- channelization

- width and number of lanes
- number of driveways

This information for the before period provides a base condition which, when compared to a similar inventory taken of the after condition, can be used to identify any changes at the project (or control) site other than the countermeasures.

STEP B3 - COLLECT DATA FOR THE AFTER PERIOD

After the project countermeasures have been implemented, the evaluator must establish a database of the impacted conditions following implementation. These data are compared in FUNCTION C with expected MOE's.

Prior to the evaluation of after data, traffic operations must be allowed to establish a steady-state pattern. A waiting period from 4 to 6 weeks is generally recommended. Following this adjustment period, a similar data collection effort as performed in STEP B2 should be undertaken. The summary tables for accident and volume data (Figures 24 and 25) may be used for tabulating after data as well as before data. In cases where the evaluation of a project is ongoing, preliminary Accident-Based Evaluation should be conducted following both the first and second year after project implementation. These evaluations necessitate the collection of intermediate accident data for comparison with the average annual before MOE's. This approach also identifies improvements which have an initial effect that may diminish with time.

The Before, During and After Study is used if the highway safety project is temporary and is to be discontinued at a later date. Data collection during the time period when the project is in place should also allow for a waiting period following project implementation and project removal to allow traffic to adjust to the new conditions. The during analysis period should span only the time for which the project is operational (following the waiting period). Before and after data should be collected for time periods which are identical to the during period in length and season. Similar data collection and reduction efforts, as in STEP B2, should be undertaken.

Summary of FUNCTION B

STEP B1 - SELECT CONTROL SITES

- Select control sites if required by the experimental plan selected in FUNCTION A, and if sites are available.

STEPS B2 and B3 - COLLECT AND REDUCE BEFORE AND AFTER DATA

- Stratify and tabulate accidents at the project and/or control site(s) by time of day, weather and surface conditions, severity, accident type, etc. for the analysis periods.

- Identify those stratifications which relate to the MOE's and data listed in FUNCTION A.

- Compute both the total and average number of accidents per year for the before and after period at all sites as may be appropriate.

- Obtain before and after traffic performance data for the project site if available.

- If exposure data are not available, perform volume studies and estimate volumes. The data collection techniques and analysis procedures in the ITE "Manual of Traffic Engineering Studies" are recommended.

- Perform inventory of locational features including roadside features, traffic control features, etc. which may effect accident experience if varied over time. This inventory may be performed concurrently with other before project data collection activities.

Example of FUNCTION B

Control Site Selection

The intersection of two, multilane, high volume arterials was identified as one of the top 15 high accident locations in the state. An engineering study of the location recommended the implementation of an 8-phase, fully actuated traffic signal. The implementing agency is conducting an evaluation of the project to determine its effectiveness in reducing total accidents. Based on the results of the evaluation, recommendations for 8-phase signals at other locations which exhibit similar safety deficiencies may result.

The purpose of the project was to reduce total accidents at the project site. The evaluation objectives were to test the effect of the project on the fundamental objectives (total, fatal, injury and property damage accidents). Traffic volume data was available so the MOE's were specified as rate-related and expressed as accidents per 10 million approach vehicles at the intersection. The before and after study with control sites (plan A) was selected as the experimental plan.

Before project implementation, the subject site was controlled by a 2-phase, fixed time controller. The major approaches consisted of three through lanes in each direction with exclusive left and right turn lanes.

The volume for the two major approaches averaged 59,800 vehicles per day for the three years before implementation. The two minor approaches averaged 31,000 vehicles per day for the same period. Land use on all quadrants of the intersection was commercial and followed local access control requirements.

The first step in the control site selection process involved the identification of candidate sites which exhibited similarities in terms of geometry, alignment, number of lanes, traffic volumes and access control. The initial search for candidate sites considered the four adjacent intersections located on the major arterial of the project site; two on either side of the project site. These were considered reasonable candidates because 1) they were located on the same arterial as the project site, thus traffic volumes and vehicular composition would be similar on the major approaches, 2) All candidates had similar commerical land uses (gas stations, small retail shops, etc.), 3) All candidates had the same number of lanes on both the major and minor approaches and were controlled by 2-phase, fixed time signals and 4) The minor approaches were also relatively high volume arterials and had traffic volumes similar to the minor approaches at the project site.

Next, 3-year before total accident rates were calculated for the project site and the four candidates (called A,B,C and D). The 3-year total accident number, total approach volume (all approaches) and total accident rates are shown in Table 3.

Table 3. Project and control site comparison table

Site	3-Year Accidents	Average Annual Approach AADT	3 Yr. Rate (Acc. per 10 MV)
Project	325	90,800	3.27
A	267	79,130	3.08
B	229	73,400	2.85
C	205	65,450	2.86
D	240	67,200	3.26

The rates (expressed in accidents per 10MV) shown in Table 3 were calculated as follows:

3 Year Acc. Rate = Acc. Number x 10^6/Average AADT x 365 x 3

For the project site, the rate was calculated as follows:

3 Year Acc. Rate = 325 x 10^7/90,800 x 365 x 3

= 3.27 accidents/10 MV

Control site candidates A and D showed a total accident MOE rate within 10% of the project site and were determined to be appropriate control sites.

The evaluator identified another key variable to be law enforcement characteristics at the sites. The local authorities were contacted and it was found that there were no differences between the law enforcement treatments for the project site and control sites A and D.

Control sites A and D were selected.

FUNCTION C: Compare MOE's

This function enables the evaluator to:

1. Develop MOE data summary tables.

2. Calculate the expected value and percentage change in the MOE's.

Overview

This function involves determining the effect of the project on the selected MOE's. This requires that computations be made to determine the expected value of the MOE if the project had not been implemented and the percent difference between the expected MOE and the actual observed value of the MOE. The MOE's derived from the accident and volume data collected in FUNCTION B should be tabulated in a format which is unique for the selected experimental plan. The percentage change in the MOE's for the treated and untreated condition can then be easily determined using the equations provided in this function.

The percentage change and the expected accident frequency in each MOE is directly used in the statistical testing procedure, Poisson Test, in FUNCTION D.

STEP C1 - PREPARE MOE SUMMARY TABLES

MOE data summary tables are developed in this step using the data compiled in FUNCTION B. The MOE Data Comparison Worksheet shown in Figure 26 may be used to tabulate both accident and exposure data used in developing the MOE's. The column headings in Figure 26 can be modified for the experimental plan selected for the evaluation as shown in Figures 27 through 30.

Figure 27 illustrates the sample format to be used for tabulating MOE's for the Before and After with Control Sites experimental plan. Entries to the summary table should be the average annual or total value of the MOE's for all sites for both the before and after periods.

Figure 28 illustrates the recommended format used for tabulating MOE's for the Before and After experimental plan. Entries to the summary table should be the average annual or total MOE's for the project for each project evaluation period.

Figure 29 illustrates the format to be used for tabulating MOE's for the Comparative Parallel experimental plan.

Figure 30 illustrates the format to be used for tabulating MOE's for the Before, During and After experimental plan.

MOE DATA COMPARISON WORKSHEET

Evaluation No. ______________________

Date/Evaluator ______________________ Checked by ____________

Experimental Plan ______________________________________

	Control		Project		Expected After Rate ___ or Freq.___	Percent Reduction (%)
	Before	After	Before	After		
MOE Data Summary	(B_{CF})	(A_{CF})	(B_{PF})	(A_{PF})		
Accidents:						
(Fundamental)						
Total Accidents						
Fatal Accidents						
Injury Accidents						
PDO Accidents						
(Project Purpose)						
Exposure						
units:___V, or___VM						
MOE Comparison Rate ____ or Frequency ____	B_C_	A_C_	B_P_	A_P_	E_	(%)
Total Accidents/						
Fatal Accidents/						
Injury Accidents/						
PDO Accidents/						

Figure 26. MOE data comparison worksheet.

MOE DATA COMPARISON WORKSHEET

Evaluation No. ____________________

Date/Evaluator ____________________ **Checked by** __________

Experimental Plan ____

	Control		Project		Expected After Rate ___ or Freq. ___	Percent Reduction (%)
	Before	After	Before	After		
MOE Data Summary	(B_{CF})	(A_{CF})	(B_{PF})	(A_{PF})		
Accidents:						

Figure 27. Illustration of MOE data comparison worksheet for before and after with control sites study plan.

MOE DATA COMPARISON WORKSHEET

Evaluation No. ____________________

Date/Evaluator ____________________ **Checked by** __________

Experimental Plan ____

	~~Control~~		Project		Expected After Rate ___ or Freq. ___	Percent Reduction (%)
	~~Before~~	~~After~~	Before	After		
MOE Data Summary	~~(B_{CF})~~	~~(A_{CF})~~	(B_{PF})	(A_{PF})		
Accidents:						

Figure 28. Illustration of MOE data comparison worksheet for before and after study plan.

MOE DATA COMPARISON WORKSHEET

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by __________

Experimental Plan ______________________________

	Control		Project		Expected After Rate __ or Freq. __	Percent Reduction (%)
	Before	After	Before	After		
MOE Data Summary	(B_{CF})	(A_{CF})	(B_{PF})	(A_{PF})		
Accidents:						

Figure 29. Illustration of MOE data comparison worksheet for comparative parallel study plan.

MOE DATA COMPARISON WORKSHEET

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by __________

Experimental Plan ______________________________

	Control		Project		Expected After Rate __ or Freq. __	Percent Reduction (%)
	Before	After	Before	After		
MOE Data Summary	(B_{CF})	(A_{CF})	(B_{PF})	(A_{PF})		
Accidents:						

Figure 30. Illustration of MOE data comparison worksheet for before, during and after study plan.

The data recorded in the MOE Data Comparison Worksheet should include only those variables identified in the evaluation objective and MOE selection process. Units should be included with each data entry.

STEP C2 - CALCULATE THE PERCENT CHANGE IN THE MOE

In Accident-Based Project Evaluation, statistical tests of significance (FUNCTION D) assume that the project did not affect the MOE's at the project site, and thus the MOE observed after project implementation is similar to what it would have been if the project had not been implemented. The MOE's that would have occurred without project implementation cannot be measured (as this condition does not exist) and must be estimated. This estimate is called the expected value and is derived differently for each experimental plan. A description of the procedure used to obtain these estimates and the resulting percent change in the MOE's are described in this step.

Expected MOE values are based on the assumptions associated with each experimental plan. For example, the expected MOE for the control site experimental plans is based on the accident experience at the control sites. For experimental plans which do not involve control sites, the expected value of the MOE is based on the accident experience prior to project implementation.

The expected value of the MOE can be estimated in two ways, depending on the characteristics of a particular MOE over time. If the yearly mean values of the MOE follows an increasing or decreasing trend when plotted over several years, the expected MOE should be estimated by using linear regression techniques. If the MOE values follow a horizontal trend or are widely dispersed, the mean value of the MOE over the entire analysis period should be used for expected MOE estimation. The linear regression approach is statistically more attractive, however, its use is subject to: 1) correlation between the dependent (MOE value) and the independent (time) variables and 2) the assurance that the slope of the trend line is significantly different from zero (horizontal). Procedures for testing these aspects of the MOE's are described in this step.

Experimental Plan A - The Before and After Study With Control Sites

Frequency-Related MOE's:

When the MOE's are frequency-related, and the traffic volumes at the project and/or at the control site is not available, the following equations should be used to compute the expected value of the MOE.

$$E_F = B_{PF}(A_{CF}/B_{CF})$$

Where:

E_F = Expected frequency-related MOE at the project site if the improvement had not been implemented.

B_{PF} = Before period MOE frequency at the project site.

A_{CF} = After period MOE frequency at the control site(s).

B_{CF} = Before period MOE frequency at the control site(s).

When the MOE's are frequency-related and before volume data are available or can be estimated (see Volume Estimating Procedure in this function), the before frequency of accidents, B_{PF} and B_{CF}, must be adjusted for volume changes between the before and after period. This is accomplished by multiplying the before accident frequency (B_{PF}) by the ratio of the after to before period AADT's at the project site. Similarly, for the control sites, the before accident frequency (B_{CF}), is multiplied by the ratio of the after to before period AADT's at the control sites.

When volume data are available, the equation for the expected value of the MOE becomes:

$$\frac{(\text{After Project AADT})(A_{CF})(\text{Before Control AADT})}{(\text{Before Project AADT})(B_{CF})(\text{After Control AADT})}$$

It is not necessary to adjust the expected MOE for dissimilar section lengths between the project site and the control sites since the length of the section is canceled in the equations.

Percent change in the frequency-related MOE is then computed by the following equation:

$$\text{Percent Change} = [(E_F - A_{PF})/E_F]100$$

Where:

E_F = Expected frequency-related MOE at the project site if the improvement had not been implemented.

A_{PF} = After period MOE frequency at the project site.

The value for the expected frequency-related MOE, E_F, and its percent change describes the effectiveness of the project and are used as direct input to the statistical testing procedure in FUNCTION D.

Rate-Related MOE's:

When the MOE's are rate-related and traffic volumes are available or can be estimated (see Volume Estimating Procedure), the following equations should be used to compute the expected value and percent change in the MOE's.

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

Where:

E_R = Expected rate-related MOE at the project site if the project had not been implemented.

B_{PR} = Before period MOE rate at the project site

A_{CR} = After period MOE rate at the control site(s)

B_{CR} = Before period MOE rate at the control site(s)

Because the MOE's are expressed in terms of accident rates (as opposed to frequencies), no volume related adjustment is necessary.

Percent change in the rate-related MOE is computed by the following equation.

$$\text{Percent Change} = [(E_R - A_{PR})/E_R]100$$

Where:

E_R = Expected rate-related MOE at the project site if the project had not been implemented.

A_{PR} = After period MOE rate at the project site.

To determine the expected accident frequency, the expected value of the rate-related MOE must be transformed from an accident rate to an expected accident frequency. The expected accident frequency is calculated by:

$$E_F = E_R \times \text{After Project Exposure}/10^6$$

Where:

E_F = Expected before accident frequency to be used in the statistical testing procedure.

E_R = Expected rate-related MOE at the project site if the project had not been made (expressed in accidents/MV or MVM).

Exposure (MV) = Number of vehicles passing an intersection or spot location during the after period, expressed in MV.

Exposure (MVM) = Number of vehicles travelling over a section of roadway during the period multiplied by the length of the section, expressed in MVM.

The calculation for the expected value of the MOE as described above is based on the assumption that the value of the MOE is constant over the entire after period. If the control site MOE's indicate either an increasing or decreasing trend over time, a regression technique should be used to determine the expected value (E_F or E_R) of the MOE's.

Linear regression is a technique for expressing a linear (straight-line) functional relationship between related variables. Correlation is used to express the precision with which the value of one variable can be predicted if the value of an associated variable is known. The user should be cautioned that just because a functional relationship exists this does not necessarily mean that a causal relationship exists.

The least square regression technique is recommended for a trend analysis of the MOE's. In this technique, the value of the MOE for each year (Y_i) is plotted against time (X_i), where the i represents the number of years from the beginning of the evaluation period. The equation of the line which "best fits" the trend in the MOE is then given by:

$$Y_i = \overline{Y} + b(X_i - \overline{X})$$

Where:

Y_i = the estimated value of the MOE in year i

$\overline{Y}$ = the average value of the MOE over the entire evaluation period

X_i = the year for which the estimate is desired

$\overline{X}$ = the mid-point of the evaluation period

b = the regression coefficient (i.e., slope of the regression line)

The regression coefficient (i.e., slope of the regression line) is obtained by:

$$b = \sum_{i=1}^{n} (X_i - \overline{X})\ (Y_i - \overline{Y}) / \sum_{i=1}^{n} (X_i - \overline{X})^2 = S_{xy}/S_{xx}$$

Where:

$(X_i - \overline{X})$ = the value of the difference between each year and the mid-point of the evaluation period (i.e., mid-point of the before plus after period).

$(Y_i - \overline{Y})$ = the value of the difference between the MOE for each year and the average value of the MOE over the entire analysis period.

n = the number of years used in the analysis period.

Since the regression technique is designed to test the strength of the relationship between the MOE and time, longer time periods yield more reliable results. Therefore, the maximum number of years for which MOE data are available should be used. Further, the maximum number of data points should be used in the analysis. Therefore, it is recommended that the control site MOE for all years (before and after) and the MOE values for the project site for the before period be used to develop the linear regression model. This increases the number of data points and ensures that the regression model is representative of the before project site MOE's.

Two tests should be performed to determine whether the indicated trend is significant or is due to random variations in the data. The first test should be an evaluation of the correlation coefficient (r). The square of this coefficient is a measure of the ability of the independent variable (time) to explain the variation in the dependent variable (MOE). As a general rule, if the value of r^2 is greater than 0.8, then use of the regression results should be considered. If r^2 is less than 0.8, then the average value of the control and project site MOE should be used as described previously.

The correlation coefficient can be calculated as:

$$r = S_{xy}/\sqrt{S_{xx}S_{yy}}$$

Where:

$$S_{xx} = \frac{1}{n}\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2 = \sum (X_i - \overline{X})^2$$

$$S_{yy} = \frac{1}{n}\sum_{i=1}^{n} Y_i^2 - \left(\sum_{i=1}^{n} Y_i\right)^2 = \sum (Y_i - \overline{Y})^2$$

$$S_{xy} = \frac{1}{n}\sum_{i=1}^{n} X_i Y_i - \left(\sum_{i=1}^{n} X_i\right)\left(\sum_{i=1}^{n} Y_i\right) = \sum (X_i - \overline{X})(Y_i - \overline{Y})$$

Where the variables n, X_i and Y_i are as previously defined.

The second test is a determination of the significance of the regression coefficient (b). This test is used to determine whether the slope of the line is significantly different than zero. The equation for this test is:

$$t = (b/S_e)\sqrt{S_{xx}/n}$$

Where:

$$S_e^2 = (S_{xx}S_{yy} - S_{xy}^2)/(n(n-2)S_{xx})$$

If the value of "t" from this equation exceeds the values in the t-distribution tables (Table 4), then the regression coefficient (b) is significant, and the regresion equation should be used to obtain E_R or E_F, the expected value of the MOE.

Table 4. 't' statistic for various levels of confidence.

Years	't' Values at Level of Confidence		
n	0.8	0.9	0.95
4	0.941	1.533	2.132
6	0.906	1.440	1.943
8	0.899	1.397	1.860
10	0.879	1.372	1.812
12	0.873	1.356	1.782
14	0.866	1.345	1.761

If the accident trend before project implementation was increasing with time, the use of regression analysis results in an estimated value higher than that based on the recorded MOE values. It is important that the trend be well established to avoid overestimating project effectiveness. For this reason, it is recommended that the column for a 0.9 level of confidence be used to enter Table 4. This requires that we are at least 90% sure that the slope of the trend is different than zero, and thus can be used to estimate expected values of the MOE's.

The expected value and the percent reduction in the MOE can be calculated by:

$$E_i = \overline{Y} + b\ (X_i - \overline{X})$$

Where:

E_i = Expected MOE at the project site for time period i, if no improvement had been made.

X_i = years since the beginning of the analysis period.

If the MOE's are frequency-related, the equation should be solved for each year of the after period and the average of these MOE's are used as the expected MOE frequency for the after period.

The percent change is then calculated as follows:

$$\text{Percent Change} = [(E_F - A_{PF})/E_F]/100$$

Where:

E_F = Expected frequency-related MOE at the project site if no improvement had been made.

A_{PF} = The sum of the after period MOE frequency at the project site.

If the MOE's are rate-related, the equation for E_i should be solved for the midpoint of the after period. This value is the expected MOE rate for the after period.

The percent change is then calculated as follows:

$$\text{Percent Change} = [(E_R - A_{PR})/E_R]100$$

Where:

E_R = Expected rate-related MOE if the improvement had not been made.

A_{PR} = After MOE rate at the project site.

The development of the linear regression analysis should use the Linear Regression Summary Table shown in Figure 31.

The expected accident frequency for statistical testing purposes is calculated as described earlier in this section.

Experimental Plan B - The Before and After Study

Frequency-Related MOE:

When the MOE's are frequency-related, and before volume data are available, or can be estimated (see Volume Estimating Procedure), the before accident frequency at the project site must be adjusted for volume changes between the before and after period. This is accomplished by multiplying the before accident frequency by the ratio of after to before period AADT's.

$$E_F = B_{PF}\,(\text{After AADT}/\text{Before AADT})\,(T_A/T_B)$$

Where:

E_F = Expected frequency-related MOE at the project site if no improvement had been made.

B_F = The before accident frequency at the project site

T_A = Length of time of the after period

T_B = Length of time of the before period

In the absence of before volume data, the volume adjustment cannot be made. However, the time period adjustment should be made whenever unequal time periods exist. Thus,

$$E_F = B_F(T_A/T_B)$$

The percent change is then calculated as follows:

Page _____ of _____

LINEAR REGRESSION WORKSHEET

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by ____________________

Check one: Frequency MOE _____ or Rate MOE _____

X_i Eval. Period (Yrs.) (1)	Y_i Meas. of MOE (2)	$X_i-\bar{X}$ Col. (1)-$\bar{X}$ (3)	$(X_i-\bar{X})^2$ (Col. (3))^2 (4)	$Y_i-\bar{Y}$ Col. (2)-$\bar{Y}$ (5)	$(X_i-\bar{X})(Y_i-\bar{Y})$ Col. Col. (3) X (5) (6)	X_i^2 $\left(\text{Col. (1)}\right)^2$ (7)	Y_i^2 $\left(\text{Col. (2)}\right)^2$ (8)	$X_i Y_i$ Col. Col. (1) X (2) (9)
$\Sigma =$ $\bar{X} =$	$\Sigma =$ $\bar{Y} =$		$\Sigma =$		$\Sigma =$	$\Sigma =$	$\Sigma =$	$\Sigma =$

Figure 31. Sample linear regression summary table.

Percent Change = $[(E_F - A_{PF})/E_F]100$

Where:

E_F = Expected frequency-related MOE at the project site if no improvement had been made.

A_{PF} = After period MOE frequency at the project site.

The value for the expected frequency-related MOE, E_F is used directly in the statistical testing procedure as the expected accident frequency.

Rate-Related MOE:

When the MOE's are rate-related, the expected MOE's and percent changes are calculated by:

$E_R = B_{PR}$

Where:

E_R = Expected rate-related MOE at the project site if the improvement had not been made.

B_{PR} = Before period MOE rate at the project site

No volume related adjustments are necessary when the MOE's are rate-related.

The percent change is then calculated as follows:

Percent Change = $[(E_R - A_{PR})/E_R]100$

Where:

E_R = Expected rate-related MOE at the project site if the improvement had not been made.

A_{PR} = After period MOE rate or frequency at the project site.

To determine the expected accident frequency, the expected rate-related MOE (E_R) must be transformed from an accident rate to an accident frequency. This is accomplished as follows:

$E_F = E_R$ x After Project Exposure/10^6

Where:

E_F = Expected before accident frequency to be used in the statistical testing procedure.

E_R = Expected rate-related MOE at the project site if the improvement had not been made (expressed in accidents/MV or MVM).

Exposure (MV) = Number of vehicles passing an intersection or spot location during the period.

Exposure (MVM) = Number of vehicles travelling over a section of roadway during the period multiplied by the length of the section.

If the linear regression technique is used with this experimental plan, the equations for b, r^2 and t are identical to those in the previous experimental plan. However, only the data points for the before project period are used in the regression equations.

Volume Estimating Procedure

There may be times when a project is designated for evaluation after the project has been implemented. When this occurs, accident data are assumed to be available for both the before and after period. However traffic volumes or exposure data may not have been collected, thereby creating difficulties when rate-related MOE's are to be used. This problem may be handled by making an estimate of the before exposure.

The exposure index (MVM or MV) for the period prior to project implementation should be estimated for a point in time equidistant from project implementation to the mid-point to the after period. If it is reasonable to assume that the traffic has been increasing or decreasing at a constant rate, then this estimate can be made using:

$$E_b = E_a\ [1/(1+i)^n]$$

Where:

E_b = Estimated before period volume (AADT)

E_a = Average volume (AADT) of the after period

i = Average annual traffic growth rate (%)

n = Number of years between the midpoint of the after period and the mid-point of the before period.

The average annual traffic growth rate, i, can either be obtained from a knowledge of the growth rate for the city or county in which the project site is located, or it can be estimated using traffic volume data from the after period. If data are available from a permanent counter located in the vicinity of the project, the annual growth rate at that station can be used. If no station is located near the site, an estimate of growth rate can be obtained by the following equation:

$$i = (E_2 - E_1)/E_1 \times T_A$$

Where:

E_2 = Traffic volume (AADT) at the end of the after study period

E_1 = Traffic volume (AADT) at the beginning of the after study period

T_A = Length of the after study period (in years)

Experimental Plan C - Comparative Parallel Study

Frequency-Related MOE:

When the MOE is frequency-related, the expected MOE at the project site, (E_F), equals the after period frequency at control site(s) (A_{CF}), adjusted for volume differences between the project and control sites. The equation is:

$$E_F = A_{CF} \text{ (After Project AADT/After Control AADT)}$$

Where:

E_F = Expected frequency-related MOE at the project site if the improvement had not been made.

A_{CF} = After period frequency at the control site

Since the before period is not considered in this analysis, no other adjustments are required.

The percent change is calculated as follows:

$$\text{Percent Change} = [(E_F - A_{PF})/E_F]100$$

Where:

E_F = Expected MOE frequency at the project site if the improvement had not been implemented.

A_{PF} = After period MOE frequency at the project site

The value for the expected frequency-related MOE is used directly in the statistical testing procedure as the expected accident frequency.

Rate-Related MOE:

If the MOE is rate-related, the following equations should be used to calculate the expected MOE and percent change.

$$E_R = A_{CR}$$

Where:

E_R = Expected MOE rate at the project site if the improvement had not been made.

A_{CR} = After period MOE rate at the control sites

The percent change is then calculated as follows:

$$\text{Percent Change} = [(E_R - A_{PR})/E_R]100$$

Where:

E_R = Expected MOE rate at the project site if the improvement had not been made.

A_{PR} = After period MOE rate at the project sites

To determine the expected before accident frequency, the expected rate-related MOE (E_R), must be transformed from a rate to a frequency. The following equation should be used:

$$E_F = E_R \times \text{After Project Exposure}/10^6$$

Where:

E_F = Expected accident frequency to be used in the statistical testing procedure

E_R = Expected rate-related MOE at the project site if the improvement had not been made (expressed in accidents/MV or MVM).

Experimental Plan D - Before, During and After Study

There are three possible conditions that may be encountered in this experimental plan:

A. The MOE value after the project is completed and removed is lower than the MOE value before project implementation.

B. The MOE value after the project is completed and removed is higher than the MOE value before project implementation.

C. The MOE value after the project is completed and removed is the same or nearly the same as the MOE value before project implementation.

If either condition A or B exist, there is an implied residual effect from the temporary project. If condition C exists, it implies that there is no residual effect from the temporary project. The impact of the temporary project on the MOE's is assessed using three separate computations similar to the before-after study computations. The first measures the effect of the project by comparing the before MOE to the during MOE. The second measures the effect of the project by comparing the after MOE condition to the during MOE. The third measures the residual effect of the project using before and after MOE's only, neglecting MOE's during project implementation.

Rate-Related MOE:

When the MOE's are rate-related, the following procedure should be used to calculate the expected value and the percent change in the three possible conditions for this experimental plan.

To compare the during and before period MOE rates,

$$E_R = B_{PR}$$

Where:

E_R = Expected rate-related MOE if the improvement had not been made

B_{PR} = Before period MOE rate at the project site

and

$$\text{Percentage Change} = [(E_R - D_{PR})/E_R]100$$

Where:

E_R = Expected rate-related MOE rate if the improvement had not been made.

D_{PR} = During period MOE rate at the project site

The expected accident frequency for the during-before case is calculated as follows:

$$E_F = E_R \times \text{During Exposure}/10^6$$

Where:

E_F = Expected before accident frequency to be used in the statistical testing procedure

E_R = Expected rate-related MOE if the improvement had not been made (expressed in accidents/MV or MVM).

To compare the after and during period MOE rates,

$$E_R = D_{PR}$$

Where:

E_R = Expected rate-related MOE if the improvement had not been removed

D_{PR} = During period MOE rate at the project site

and

$$\text{Percentage Change} = [(E_R - A_{PR})/E_R]100$$

Where:

E_R = Expected rate-related MOE if the improvement had not been removed

A_{PR} = After period MOE rate at the project site

The expected during accident frequency for the during-after case is calculated as follows:

$$E_F = E_R \times \text{After Exposure}/10^6$$

Where:

E_F = Expected during accident frequency for statistical testing purposes

E_R = Expected rate-related MOE if the improvement had not been removed.

To compare the before and after period (residual effect) MOE rates,

$$E_R = B_{PR}$$

Where:

E_R = Expected rate-related MOE if no improvement had been made

B_{PR} = Before period MOE rate at the project site

and

Percent Change = $[(E_R - A_{PR})/E_R]100$

Where:

E_R = Expected rate-related MOE if no improvement had been made

A_{PR} = After period MOE rate at the project site

The expected accident frequency for the before-after case (residual effect) is calculated as follows:

$E_F = E_R \times \text{After Exposure}/10^6$

Where:

E_F = Expected accident frequency for statistical testing purposes

E_R = Expected rate-related MOE if the improvement had not been removed

<u>Frequency-Related MOE:</u>

When the MOE's are frequency-related, the expected and percent change for the MOE's are calculated as follows.

To compare the during and before period MOE frequencies

$E_F = B_{PF}$ (During AADT/Before AADT) (T_D/T_B)

Where:

E_F = Expected frequency-related MOE if no improvement had been made

B_{PF} = Before accident frequency at the project site

T_D = Length of time in during period

T_B = Length of time in before period

and

$$\text{Percent Change} = [(E_F - D_{PF})/E_F]100$$

Where:

D_{PF} = During period MOE frequency at the project site

To compare the after and during period MOE frequencies,

$$E_F = D_F \text{ (After AADT/During AADT) } (T_A/T_D)$$

Where:

E_F = Expected frequency-related MOE if the improvement had not been removed

D_F = During accident frequency at the project site

T_A = Length of time in the after period

T_D = Length of time in the during period

and

$$\text{Percent Change} = [(E_F - A_{PF})/E_F]/100$$

Where:

A_{PF} = After period MOE frequency at the project site

To compare the before and after period (residual effect) MOE frequencies,

$$E_F = B_{PF} \text{ (After AADT/Before AADT) } (T_A/T_B)$$

Where:

E_F = Expected frequency-related MOE if the improvement had not been made

B_{PF} = Before accident frequency at the project site

T_A = Length of time in the after period

T_B = Length of time in the before period

and

$$\text{Percent Change} = [(E_F - A_{PF})/E_F]100$$

Where:

A_{PF} = After period MOE frequency at the project site

The MOE Data Comparison Worksheet shown in Figure 32, should be used to tabulate the MOE's, the expected MOE's and the percent change in the MOE's for all experimental plans. The values for the expected accident frequencies should be recorded for each MOE on the statistical test summary table provided in the Appendix.

Summary for FUNCTION C

STEP C1 - PREPARE SUMMARY TABLES

- Modify the MOE Data Comparison Worksheet to the format which corresponds to the experimental plan used in the evaluation.
- Tabulate accident and exposure data collected in FUNCTION B on the worksheet.

STEP C2 - CALCULATE PERCENT CHANGE

- Calculate the expected value of the MOE's and record them on the Worksheet.
- Calculate percent change of the MOE's and record them on the Worksheet.
- Calculate the expected accident frequency each MOE to be used in FUNCTION D.

Examples of FUNCTION C

Comparison of MOE's Using the Before and After with Control Site Study

A highway safety project site consists of a two-lane, two-mile long highly traveled roadway section with a number of sharp curves. A majority of accidents at this site during the before period were of the "run-off-the-road" type. The safety project implemented at this site included curve straightening through major reconstruction. The entire section was then edgelined.

A single control site was identified by the evaluator prior to project implementation and the Before and After with Control Site experimental plan was used. The objectives of the evaluation were to determine the

Page ____ of ____

MOE DATA COMPARISON WORKSHEET

Evaluation No. ______________________

Date/Evaluator ______________________ Checked by ____________

Experimental Plan ______________________________________

	Control		Project		Expected After Rate ___ or Freq. ___	Percent Reduction (%)
	Before	After	Before	After		
MOE Data Summary	(B_{CF})	(A_{CF})	(B_{PF})	(A_{PF})		
Accidents:						
(Fundamental)						
Total Accidents						
Fatal Accidents						
Injury Accidents						
PDO Accidents						
(Project Purpose)						
Exposure						
units:___V, or___VM						
MOE Comparison Rate ____ or Frequency ____	B_C ___	A_C ___	B_P ___	A_P ___	E ___	(%)
Total Accidents/						
Fatal Accidents/						
Injury Accidents/						
PDO Accidents/						

Figure 32. Sample MOE data data comparison worksheet.

effect of the project on total accidents, fatal and personal injury, property damage and run-off-the-road (ROR) accidents. Rate-related MOE's were chosen. The modified worksheet for this study is shown in Figure 33.

The data for each MOE were plotted and no trend was observed in the MOE's over time. Therefore, the regression analysis technique was not used.

For illustrative purposes, sample calculations for only total ROR accidents are considered. The expected value and the percentage change in the total ROR accident rate are calculated below:

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

Where:

E_R = Expected rate-related MOE

B_{PR} = Before period MOE rate at the project site

A_{CR} = After period MOE rate at the control site

B_{CR} = Before period MOE rate at the control site

Substituting into the above equation:

$$E_R = 3.05\ (2.23/2.99)$$

$$= 2.27 \text{ ROR accidents/million vehicle-miles}$$

and

A_{PR} = After period total ROR accident rate at the project site

= 1.90 accidents/million vehicle-miles

$$\text{Percent Change} = [(E_R - A_{PR})/E_R]100$$

$$= [(2.27 - 1.90)/2.27]100$$

= 16.3% decrease in ROR accidents/million vehicle-miles of travel

Expected before accident frequencies were calculated using the following equation:

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MOE DATA COMPARISON WORKSHEET

Evaluation No. C-1

Date/Evaluator 8/22/77 /MUL **Checked by** 8/29/77 /HES

Experimental Plan Before - After with Control

	Control		Project		Expected After Rate X or Freq.__	Percent Reduction (%)
	Before	After	Before	After		
MOE Data Summary	(B_{CF})	(A_{CF})	(B_{PF})	(A_{PF})		
Accidents:						
(Fundamental)						
(3 Years)						
Total Accidents	30	21	24	18		
Fatal Accidents	9	6	12	3		
Injury Accidents	12	6	12	6		
PDO Accidents	9	9	0	9		
(Project Purpose)						
Total ROR Accidents	15	12	12	9		
Exposure (3 Years)						
units: __V, or M VM	5.01	5.37	3.93	4.74		
MOE Comparison Rate X or Frequency __	B_{CR}	A_{CR}	B_{PR}	A_{PR}	E_R	(%)
Total Accidents/ MVM	5.99	3.91	6.11	3.80	3.99	4.8
Fatal Accidents/ MVM	1.80	1.12	3.05	0.63	1.90	66.8
Injury Accidents/ MVM	2.40	1.12	3.05	1.27	1.42	10.6
PDO Accidents/ MVM	1.80	1.68	0	2.53	0	
Total ROR/MVM	2.99	2.23	3.05	1.90	2.27	16.3

Figure 33. FUNCTION C example #1 worksheet.

$E_F = E_R \times$ (After Project Exposure)/10^6

Where:

E_F = Expected accident frequency

E_R = Expected rate-related MOE if the improvement had not been made.

The expected 3-year accident frequency for ROR accidents was calculated using the appropriate values from the above sample calculations and Figure 33.

E_F = (2.27 x 4.74 MVM)

= 10.8 ROR accidents for 3 years

Similar calculations should be performed for the remaining data contained in Figure 33 to determine the percent change and the expected accident frequency for each MOE.

Examples of FUNCTION C (cont'd)

Comparison of MOE's Using the Before and After Study

On the northbound approach of a high volume signalized intersection near a steep downgrade, a large number of rear-end accidents were observed during the before period. The safety project implemented at this site consisted of increasing the amber time by two seconds and installing advance warning signs. It was not possible to identify control sites for this project and the Before and After Study was selected. The purpose of the project was to reduce rear-end accidents and severity of accidents at the intersection. The evaluation objectives were to determine the effect of the project on total fatal, personal injury, property damage, and rear-end accidents. The modified worksheet for this example is shown in Figure 34.

For illustrative purposes, sample calculations for only personal injury accidents are considered. The expected value and the percent change calculations in the personal injury accident rate using the rates shown in Figure 34 are:

$E_R = B_{PR} =$ 3.80 personal injury accidents/MV

Where:

E_R = Expected rate-related MOE if the improvement had not been made.

B_{PR} = Before period MOE rate at the project site

Page ____ of ____

MOE DATA COMPARISON WORKSHEET

Evaluation No. C-2
Date/Evaluator 8/22/77 /RUR **Checked by** 8/27/77 / HES
Experimental Plan Before - After

	~~Control~~		Project		Expected After Rate X or Freq.__	Percent Reduction (%)
MOE Data Summary	~~Before (B_{CF})~~	~~After (A_{CF})~~	Before (B_{PF})	After (A_{PF})		
Accidents: (3 Years)						
(Fundamental)						
Total Accidents			55	21		
Fatal Accidents			4	1		
Injury Accidents			38	14		
PDO Accidents			13	6		
(Project Purpose)						
Rear-End Accidents			40	10		
Exposure (3 Years)						
units: M V, or __VM			10.00	11.50		
MOE Comparison Rate X or Frequency ____	~~B_C~~	~~A_C~~	B_{P_R}	A_{P_R}	E_R	(%)
Total Accidents/ MVM			5.50	1.83	5.50	66.7
Fatal Accidents/ MVM			0.40	0.09	0.40	77.5
Injury Accidents/ MVM			3.80	1.22	3.80	67.9
PDO Accidents/ MVM			1.30	0.52	1.30	60.0
Rear-End Accidents/MV			4.00	0.87	4.00	78.2

Figure 34. FUNCTION C example #2 worksheet.

and

$$\text{Percent Change} = [(E_R - A_{PR})/E_R]100$$

Where:

A_{PR} = After period MOE rate at the project site = 1.22 personal injury accidents/MV

$= [(3.80 - 1.22)/(3.80)](100)$

= 68% decrease on personal injury accidents/MV

Expected before accident frequencies were calculated as:

$$E_F = E_R \times \text{After Project Exposure}/10^6$$

Where:

E_F = Expected accident frequency

E_R = Expected rate-related MOE if the improvement had not been made.

Substituting for the injury accident MOE, the expected 3-year injury accident frequency was calculated as follows:

$E_F = 3.8 \times 11.5$ MV

= 43.7 injury accidents for 3 years

The percent changes and expected before frequencies were similarly calculated for the remaining accident types.

Examples of FUNCTION C (cont'd)

Comparison of MOE's Using the Before and After Study with Exposure Estimation

A traffic signal was installed at a rural intersection in 1972. Accident data are available for the before and after condition and volume data were available for the after period. No before traffic volume data are available. The non-availability of similar sites in the area prevented the use of the Comparative Parallel Studies.

The purpose of the project was to reduce total accidents and accident severity. The evaluation objectives were to determine the effect of the project on total, fatal, personal injury, and property damage accidents. The MOE's were rate-related. The data shown in Figure 35, were obtained for 5 years before and after project implementation.

Exposure values for the project site were estimated using the available after period volumes. The growth factor was calculated as:

MOE DATA COMPARISON WORKSHEET

Evaluation No. C-3
Date/Evaluator 8/22/77 /DML **Checked by** 8/29/77 /HES
Experimental Plan Before - After (Estimate before exposure)

MOE Data Summary	Control Before (B_{CF})	Control After (A_{CF})	Project Before (B_{PF})	Project After (A_{PF})	Expected After Rate X or Freq. __	Percent Reduction (%)
Accidents: (5 Years)						
(Fundamental)						
Total Accidents			80	40		
Fatal Accidents			10	5		
Injury Accidents			60	15		
PDO Accidents			10	10		
(Project Purpose)						
Exposure (5 Years)			(Est)			
units: M V, or __ VM			26.57	31.94		
MOE Comparison Rate X or Frequency __	B_C	A_C	B_{P_R}	A_{P_R}	E_R	(%)
Total Accidents/ MV			3.01	1.25	3.01	58.5
Fatal Accidents/ MV			0.38	0.16	0.38	57.9
Injury Accidents/ MV			2.26	0.47	2.26	79.2
PDO Accidents/ MV			0.38	0.31	0.38	18.4

Figure 35. FUNCTION C example #3 worksheet.

$$i = (E_2 - E_1)/E_1 \times T_A$$

Where:

i = Average annual traffic growth rate

E_2 = AADT at the end of the after period

E_1 = AADT at the beginning of the after period

T_A = Number of years in the after period

Substituting in the above equation

$$i = (19{,}000 - 16{,}000)/(16{,}000)(5)$$

$$= 0.0375$$

The estimated before period volume is then calculated as follows:

$$E_b = E_a\,[1/(1+i)^n]$$

Where:

E_b = Estimated before period volume (AADT)

E_a = Average volume (AADT) of the after period

i = Average annual traffic growth rate

n = Number of years between the mid-points of the before and after periods

$$E_b = 17{,}500\,[1/(1 + 0.0375)^5]$$

= 14,558 approach vehicles/day(for one year)

For illustrative purposes, sample calculations for only the total accident rate is considered. The expected accident rate is:

$$E_R = B_{PR} = (80 \times 10^6)/(72{,}790)(365)$$

= 3.01 accidents/million approach vehicles

Percent Change = $[(3.01 - 1.25)/3.01]100$

= 58% decrease in total accident rate

The expected accident frequency was calculated as follows:

$$E_F = E_R \times \text{After Project Exposure}/10^6$$

Where:

E_F = Expected before accident frequency

E_R = Expected rate-related MOE if the improvement had not been made

Substituting for total accidents:

$$E_F = 3.01 \times 31.9 \text{ MV}$$

$$= 96.1 \text{ accidents for 5 years.}$$

Percent changes and expected accident frequencies were calculated for the remaining MOE's using the above equations.

Examples of FUNCTION C (cont'd)

Comparison of MOE's Using the Comparative Parallel Study

On a rural two-lane roadway with severe passing restrictions, a roadway reconstruction project was undertaken to increase the passing sight distance on a 0.3 mile roadway section. The purpose of the project was to reduce total and head-on accidents.

Evaluation objectives were to test the effect of the project on total fatal, injury, property damage, and head-on accidents. MOE's were rate-related.

Reliable data on the number of head-on accidents were not available for the before period. Six similar sites were identified as control sites and the Comparative Parallel Study was selected. Accident data were collected for the project site and each of the control sites for 3 years. The data collected are shown in Figure 36.

For illustrative purposes, sample calculations for only total head-on accidents are considered. The expected value and the percent change in the total head-on accident rate is shown below:

$$E_R = A_{CR}$$

Where:

E_R = Expected rate-related MOE if the improvement had not been made.

A_{CR} = After period MOE rate at the control site

From data contained in Figure 36, the expected MOE for head-on accidents was determined.

MOE DATA COMPARISON WORKSHEET

Evaluation No. C-4
Date/Evaluator 8/22/77 /RAC **Checked by** 8/29/77 /HES
Experimental Plan *Comparative Parallel*

	Control		Project		Expected After Rate X or Freq.__	Percent Reduction (%)
MOE Data Summary	~~Before (B_C)~~	After (A_{CF})	~~Before (B_P)~~	After (A_{PF})		
Accidents: (3 *Years*)						
(Fundamental)						
Total Accidents		24		28		
Fatal Accidents		8		4		
Injury Accidents		12		8		
PDO Accidents		4		16		
(Project Purpose)						
Head-On Accidents		18		14		
Exposure (3 *Years*)						
units:___V, or M VM		5.74		4.53		
MOE Comparison Rate ✓ or Frequency ___	~~B~~	A_{C_R}	~~B~~	A_{P_R}	E_R	(%)
Total Accidents/ *MVM*		4.18		6.18	4.18	-47.8
Fatal Accidents/ *MVM*		1.39		0.88	1.39	36.7
Injury Accidents/ *MVM*		2.09		1.77	2.09	15.3
PDO Accidents/ *MVM*		0.70		3.53	0.70	-404.3
Head-On Accidents/MVM		3.14		3.09	3.14	1.6

Figure 36. FUNCTION C example #4 worksheet.

E_R = 3.14 head-on accidents/MVM

The percent change was calculated by the following equation:

$$\text{Percent Change} = [(E_R - A_{PR})/E_R]100$$

Where:

E_R = Expected rate-related MOE if the improvement had not been made

A_{PR} = After period MOE rate at the project site

Substituting for the head-on accident rate MOE;

$$\text{Percent Change} = [(3.14 - 3.09)/3.14]100$$

= 1.6% decrease in head-on accident rate

The expected accident frequencies were calculated as follows:

$$E_F = E_R \times \text{Project AADT} \times 365 \times T_A \times L_P/10^6$$

Where:

E_F = Expected accident frequency

E_R = Expected rate-related MOE if the improvement had not been made

L_P = Length of the project site

Substituting in the equation for the 3-year head-on accident frequency:

$$E_F = 3.14 \times 4.53 \text{ MVM}$$

= 14.2 head-on accidents for 3 years

Expected frequencies and percent changes were determined for the remaining MOE's using the same procedure.

Examples of FUNCTION C (cont'd)

Comparison of MOE's Using Before, During and After Study

A highway safety project was undertaken to investigate the effectiveness of an experimental advance warning sign in advance of an intersection with restricted sight distance. The purpose of the improvement was to reduce total accidents at the intersection. The objective was to test the effect of the sign on total, fatal, injury, and property damage accidents at the intersection. The MOE's were selected as accident rates.

The countermeasure was implemented for a one year period and then removed. The data for this example are shown on Figure 37. The first data column includes all accidents in the before period at the project site. The next column includes all accidents which occurred during the project life. The third column includes all accidents occurring in the after period.

For illustrative purposes, sample calculations for only the total accident rate are considered. The expected value of the MOE and percent changes are:

For the first test:

$E_R = B_{PR} = 9.84$ Total Accidents/MV

Where:

E_R = Expected rate-related MOE if the improvement had not been made

B_{PR} = Before period MOE rate at the project site

Percent Change = $[(E_R - D_{PR})/E_R]100$

Where:

E_R = Expected rate-related MOE if the improvement had not been made

D_{PR} = During period MOE rate at the project site

Percent Change = $[(9.84 - 6.85)/9.84]100$

= 30.4% decrease in total accidents/MV during project implementation compared to the before period.

For the second test;

$E_R = D_{PR} = 6.85$ total accidents/MV

Where:

E_R = Expected rate-related MOE if the improvement had not been made

D_{PR} = During period MOE rate at the project site

Percent Change = $[E_R - A_{PR})/E_R]100$

MOE DATA COMPARISON WORKSHEET

Evaluation No. C-5

Date/Evaluator 8/22/77 /FEG **Checked by** 8/29/77 /HES

Experimental Plan Before, During, and After

MOE Data Summary	Control Before (B_{CF})	Control After (A_{CF})	Project Before (B_{PF})	Project After (A_{PF})	Expected After Rate X or Freq. __	Percent Reduction (%)
Accidents: (1 Year)	Project During					
(Fundamental)	(DPF)					
Total Accidents	10		18	12		
Fatal Accidents	1		1	0		
Injury Accidents	5		11	9		
PDO Accidents	4		6	3		
(Project Purpose)						
Exposure (1 Year)						
units: M V, or __ VM	1.46		1.83	1.46		
MOE Comparison Rate X or Frequency __	B_C	A_C	B_{PR}	A_{PR}	E_R (See Narative)	(%)
Total Accidents/ MV	6.85		9.84	8.22		
Fatal Accidents/ MV	0.68		0.55			
Injury Accidents/ MV	3.42		6.01	5.48		
PDO Accidents/ MV	2.74		3.28	2.05		

Figure 37. FUNCTION C example #5 worksheet.

Where:

E_R = Expected rate-related MOE if the improvement had not been made

A_{PR} = After period MOE rate at the project site

Percent Change = [(6.85 - 8.22)/6.85]100

= 20.0% increase in total accidents/MV after the project was removed compared to the during period

For the third test:

E_R = B_{PR} = 9.84 total accidents/MV

Where:

E_R = Expected rate-related MOE if the improvement had not been made

B_{PR} = Before period MOE rate at the project site

Percent Change = $[(E_R - A_{PR})/E_R]100$

Where:

E_R = Expected rate-related MOE if the improvement had not been made

A_{PR} = After period MOE rate at the project site

Percent Change = [(9.84 - 8.22)/9.84]100

= 16.5% decrease in total accidents/MV as a residual effect compared to the before period.

The expected accident frequencies to be used in the statistical testing procedure were calculated for each of the above sample cases as:

For the before-during case:

E_F = (E_R x During Exposure)/10^6

= (9.84 x 1.46 MV)

= 14.4 total accidents for one year

For the during-after case:

E_F = (E_R x After Exposure)/10^6

= (6.85 x 1.46 MV)

$$= 10.0 \text{ accidents for one year}$$

For the before-after case:

$$E_F = (E_R \times \text{After Exposure})/10^6$$

$$= (9.84 \times 1.46 \text{ MV})$$

$$= 14.4 \text{ total accidents for one year}$$

Percent changes and expected accident frequencies were calculated for all MOE's using the above procedures.

FUNCTION D: Perform Statistical Tests

This function enables the evaluator to:

1. List the underlying concepts, advantages and disadvantages of the Poisson technique.

2. Perform the statistical tests and interpret the results.

Overview

At this point in the evaluation process, the evaluator has collected, reduced, and performed comparisons of MOE's according to the selected experimental plan. The evaluator must now test the statistical significance of the effectiveness of the safety project to better understand whether the changes observed in the MOE, if any, are attributed to the safety project or due to some other factors unrelated to the project.

One of the key steps in performing the statistical test is the definition of a level of confidence by which statistical fluctuations will be tested. In other words, what is the level of risk a decision maker is willing to accept in rejecting a hypothesis when it is true (Type I error). If the results are to be combined with other study results to develop a Statewide database, it may be desirable to use a constant confidence level to determine whether the MOE changes are significant. On the other hand, confidence testing is a tool to be used in interpretation of study results. Results which are significant at the 95 percent level indicate a larger difference exists in the MOE being tested than those at the 80 percent level. Results at both levels may offer valuable insight into project effectiveness but one (95%) can be used with greater assurance that a large difference exists in the MOE.

The Poisson Distribution Test is recommended as the test to be used to determine whether the change in the MOE's is statistically significant. This technique is an accepted method of testing the effectiveness of accident-related MOE's for safety projects.

Inputs required for this function come from the data collected and reduced in FUNCTION B, as well as from the results of the MOE comparison performed in FUNCTION C.

STEP D1 - PERFORM STATISTICAL SIGNIFICANCE TESTING OF ACCIDENT RELATED MOE's

Historically, two techniques have been used to determine the significance of the reduction in the value of accident MOE's; the Chi-Square (χ^2) test, and the Poisson test.

One application of the Chi-square test utilizes a contingency table to determine whether accident frequencies at a site differ significantly from the frequencies of all the data sets considered in the analysis. This is particularly useful when the evaluator is interested in determining whether the proportion of the accidents falling in a specific category of severity (fatal, injury, property damage) has been altered by the implementation of a project. A commonly used form of the χ^2 test is used together with several simplified assumptions to generate curves similar to the Poisson curves. One of the assumptions is that the expected accident frequency is the average of the before and after data. This assumption is different from the assumptions used in FUNCTION C. In FUNCTION C, the expected value of the MOE was calculated based on the hypothesis that the performance of the site would remain constant (or consistent with trend) if the safety improvement were not implemented. We then compared the actual accident experience with that which was projected from the before period. Therefore in order to use the Chi-square test, it is necessary to calculate the expected value which is the average of the before and after values. Further use of the Chi-square test will not be discussed in this section, however, guidelines for using the procedure are included in FUNCTION D of non-accident-based evaluations.

Because the Poisson technique can be used directly with the results of FUNCTION C, this technique is used in Accident-Based Evaluation rather than the Chi-square technique. The Poisson technique is the more liberal (i.e., the easier of the two tests to show significance) for the same levels of confidence. However, more conservative results can be achieved by increasing the confidence level used in the Poisson technique.

The Poisson technique is used to determine whether an observed reduction in accident frequency constitutes a significant reduction within a specified degree of confidence. This technique is based on the fact that differences between the mean value of two samples randomly selected from a common distribution have known characteristics. If, by using the Poisson technique, it is concluded that the two samples are from different distributions, then it can be said that the implemented project effected a change in the tested MOE. If, on the other hand, the conclusion is that the samples are from the same distribution then it can be stated that the project had no effect on the tested MOE.

To illustrate the basis for reaching such conclusions, assume that there are a large number of data points representing accident frequencies at highway locations with a common set of characteristics. Those data points are randomly mixed in a single box and withdrawn two at a time. As they are withdrawn, the difference between the two samples is recorded. If this procedure is repeated over a large number of trials, the frequency with which each value of the difference occurs will form a distribution of known characteristics (see Figure 38).

The shaded area in Figure 38, as a percentage of the total area under the curve, represents the probability that the difference in the mean

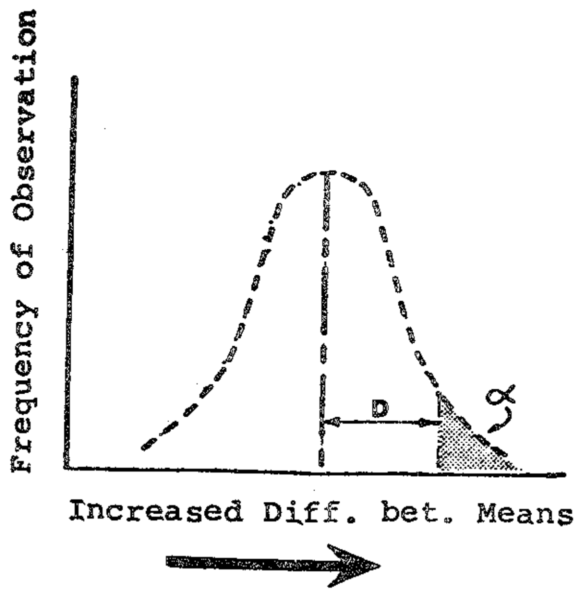


Figure 38.
The Distribution of Differences Between the Mean Values of Random Samples

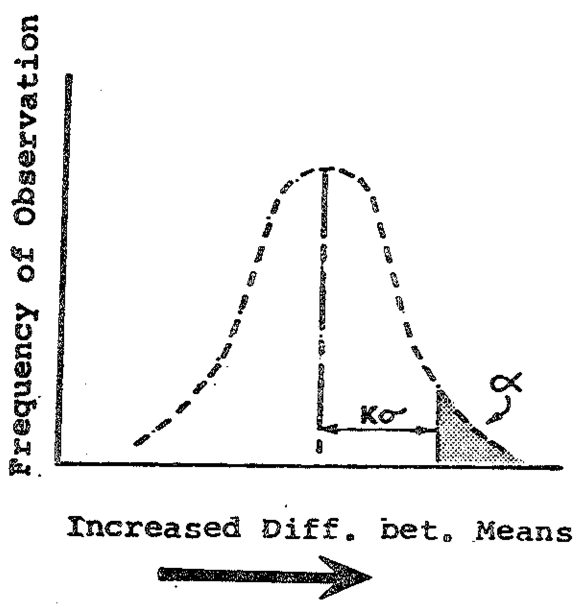


Figure 39.
Probability of A Type I Error

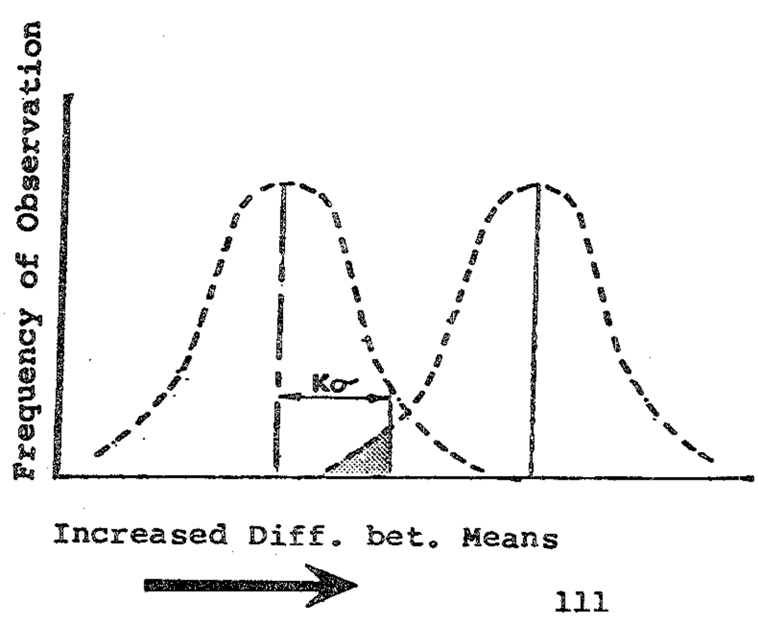


Figure 40.
Probability of a Type II Error

value of two samples will exceed D. As D is increased, the probability of the difference exceeding this value decreases. This characteristic property of distributions is used to select confidence levels for statistical testing.

If we designate the percent represented by the shaded area as α, and D as $K\sigma$, we have Figure 39. One should remember that statistical tests are based on the null hypothesis. That is, if the difference between two data points is larger than $K\sigma$, we conclude with confidence $1-\alpha$ that the two samples are not representative of the same distribution. In safety project evaluation studies, this would represent those times when the difference between the expected value of the MOE and the actual value of the MOE exceed $K\sigma$. This conclusion will be wrong α percent of the time, and this is called a Type I error.

On the other hand, if we conclude that the difference was the result of randomly selecting two samples from the same distribution, when in fact they represent samples from two different distributions, we will also be wrong. This is called a Type II error, and is represented by the shaded area in Figure 40.

It should be clear that for a given sample size as the value of $K\sigma$ is increased, the probability of a Type I error decreases, and the probability of a Type II error increases. The only way to decrease both Type I and II errors is to increase the sample size, i.e., collect additional data. For a more thorough discussion of errors, the reader should consult any standard statistics text.

The evaluator will be required to specify the risk (called level of confidence) of a Type I error to be used in the analysis. In specifying the level of confidence, the evaluator should consider the type of project (or improvement) and the overall cost of implementing and maintaining the project.

Since one of the uses of the evaluation of highway safety project effectiveness is to provide guidance for the selection of future projects, it is essential that the conclusions reached in each study specify the probability of a Type I error. The level of confidence associated with the conclusion is equal to one minus this probability, i.e., $1-\alpha$.

It is appropriate to use a greater degree of confidence in high cost projects than on low cost projects because the cost of a Type I error is greater. High confidence levels are justified for major construction projects because the probability of these projects being effective must be high to justify their cost. A confidence level of 95 or 99% is commonly used for these projects.

If the project consists of low cost safety treatments involving only minor construction or modification to traffic control devices the evaluator can use a comparatively low confidence level since the cost of a Type I error would be small.

The probability of making a Type I error has been calculated for various values of before accident frequency. The probabilities appear both in tabular form and in graphical form. A set of Poisson curves are shown in Figure 41. These curves are based on the assumption that the distribution of sample differences is drawn from the Poisson Distribution. This technique is called the Poisson test.

The Poisson distribution is described by the equation:

$$P(x, \mu) = \frac{e^{-\mu} \mu^{x}}{x!}$$

Where:

e is the base of natural logarithms
μ is the mean value of the MOE
x is any selected value of the MOE

Values for the sum of the probabilities from 0 to x for any value of μ have been tabulated and can be found in standard statistical texts. The curves shown in Figure 41 represent the table values of 80%, 90%, 95% and 99% confidence levels, respectively.

If the calculated difference between the "expected" and the "actual" MOE exceeds the difference which could be anticipated from the random selection of two samples, we conclude that some factor caused the difference. In conducting a highway safety evaluation, it is assumed that the difference is due to the implemented highway project. If there is reason to believe that factors other than those accounted for in the analysis have contributed to the change in the MOE, the results of the statistical analyses are questionable.

It can be observed from the Poisson curves that the percent change required to achieve statistical significance increases with a decreasing number of accidents. This limits the practical use of this technique to locations with accident frequencies greater than 5 accidents. If the observed frequency at the site is low, the percentage change in accidents must be very large to be significant. The use of this statistical technique does not require that the frequency be calculated on an annual basis. However, an assumption of the test is that the frequency used is the "true" mean of the accident experience at the project site. The frequency can be stated in terms of accidents per day, per month, per year, or per multi-year study period. The primary limitation on the accumulation of data over time is that the longer the time period, the higher the risk that factors other than the treatment being evaluated, contributed to the change in the MOE's.

The Poisson chart (Figure 41) can be used either for the expected annual average or expected total accidents. However, any conclusions drawn from the Poisson test will indicate the significance of the change for the time period used in expressing the expected accident frequency.

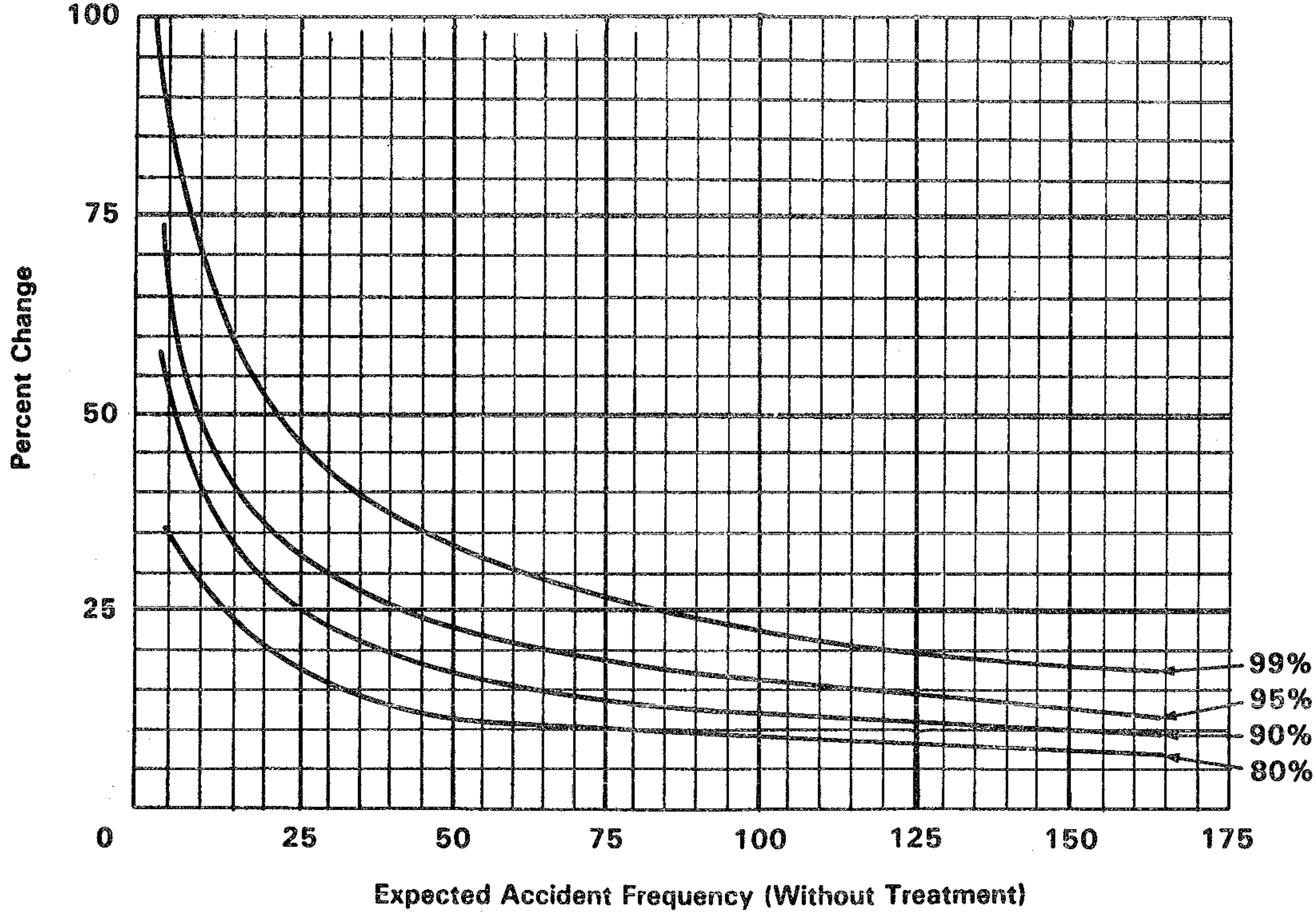


Figure 41. Poisson curves.

The interpretation of the results is directly dependent on the before accident frequency. If the difference in the expected and actual MOE exceeds $K\sigma$, then it can be concluded (with confidence $1-\alpha$) that there was a reduction in accident frequency per study period as a result of the safety project.

Although the Poisson curves shown in Figure 41 are used to determine if an accident reduction is significant, the curves can also be used to determine if accident increases are significant. It should be noted that a small error in the curves exist for accident frequencies less than 10 accidents, however, the error is small enough to be neglected.

The statistical testing procedure is as follows:

1. Obtain the value of the expected accident frequency associated with each MOE and the percent change in the MOE from FUNCTION C, STEP C2.

2. Locate the point of intersection of the expected frequency and the percent change on Figure 41. If the project is a high cost project (such as major reconstruction) compare this point to the curves for a level of confidence of 95% or 99%. If the project is a low cost project, compare the point of intersection to the curves for the 80% or 90% level of confidence.

3. If the point of intersection is below the curve, the change was not significant at the selected confidence level. It may also be of interest to compare the point with lower confidence limits to determine at which level the project becomes effective.

4. If the point of intersection is above the curve, the change was significant at the selected confidence level and we conclude that the project was effective for the particular MOE being tested. Again, it may be desirable to identify the confidence level at the point of intersection and note this level in the project report.

<u>Summary of FUNCTION D</u>

<u>STEP D1 - PERFORM STATISTICAL TESTING OF ACCIDENT-RELATED MOE'S</u>

- Select the level of confidence

- Obtain expected accident frequency without treatment(s) and percent changes for each MOE.

- Test the significance of MOE changes with the Poisson curves.

Example of FUNCTION D

Statistical Testing Example Using the Poisson Technique

An urban intersection with six approach legs and a three-phase signal was identified as a high-accident location based on a large number of accidents involving through and left-turning vehicles on two approaches, as well as a number of rear-end accidents on the right-turning lane of a third approach. A safety project consisting of adding separate left turn lanes and protected left turn phases and widening the right turn lanes was implemented at the intersection. The total cost of the project was $500,000 due to the requirements of a substantial right-of-way acquisition, new signal hardware, reconstruction, etc. It was not possible to identify any control site as the roadway and geometric characteristics were somewhat unique. Accident and traffic volume data for three-year before and three-year after periods were collected.

For illustrative purposes, only total accidents are considered for this example.

Because of the relatively expensive nature of the project, future decisions on utilizing this treatment at similar sites should be made with only a minimal probability of Type 1 error occuring, and thus a confidence level of 95% is specified.

The expected 3-year accident frequency without improvement for total accidents was 51 accidents and the percent reduction in the MOE total accident frequency was calculated as 35.3% using the appropriate equations in FUNCTION C.

Using 35.3% as the percent reduction in accident frequency and 51 accidents as the expected accident frequency, check the Poisson Curve for the 95% confidence level. The required percent reduction is 23%. Since 35.3% is greater than 23.0%, it can be concluded (at a 95% confidence level) that the number of accidents in the after period (3 year) are significantly reduced. The accident reduction is also significant at the 99% confidence level.

FUNCTION E: Perform Economic Analysis

This function enables the evaluator to:

1. Select an economic analysis technique for the evaluation study.

2. Perform an economic analysis.

Overview

An important objective of effectiveness evaluation is to obtain a complete picture of how well the completed project is operating from a safety standpoint. Economic analysis provides an additional perspective of the effectiveness of the completed safety project. From the analysis, an assessment of the combined effects of cost and accident reduction of the project may be made. This aspect of the evaluation is particularly valuable since it is possible to have an extremely effective project in terms of reducing accident MOE's but which is cost-prohibitive to the agency for future use under similar circumstances.

Engineering economic literature contains several economic analysis techniques which historically have been used in the evaluation of public works projects. Each method gives acceptable results when properly applied and all constraints are taken into account. There is generally no concensus among the authors of economic analysis, engineering economy and capital budgeting literature as to the relative merit of various analysis methods, how to handle certain factors, and the limitations of the methods. Thus, for the purpose of evaluating completed safety projects two methods have been included in the Guide which are most often used by evaluators at the State level (as determined from a 1979 current practices survey). They are the benefit/cost and cost/effectiveness methods. Further, the economic data can be derived using numerous economic approaches. However, for the purpose of this Guide, present worth of benefits and costs and equivalent uniform annual benefits and costs are the only approaches considered.

It is important that the results of the economic analysis are representative of the effect of the project. Thus, it is recommended to conduct the analysis for only those projects for which MOE's were found to be statistically significant at the selected level of confidence. The cost-effectiveness of a project based on a chance reduction in an accident category does not provide usable information on the effectiveness of the project.

STEP E1 - SELECT ECONOMIC ANALYSIS TECHNIQUE

In 1979, a current practices survey was conducted to determine the state-ofthe-practice in highway safety evaluation. The survey revealed that a majority of agencies use either the benefit/cost ratio or cost/effectiveness methods. The evaluator must recognize the pro and con aspects of each method in order to select a single method in this step.

The benefit/cost ratio is the ratio of the benefits accrued from observed accident and/or severity reduction to costs of implementing, operating and maintaining the project. The ratio of either present worth of benefits to costs or equivalent uniform annual benefits to cost can be used to determine the benefit/cost ratio. Any project that has a benefit/cost ratio greater than 1.0 yielded more dollar-value benefits than the cost of the project.

The use of this method requires that a dollar value be placed on all cost and benefit elements related to the project. The most controversial of these elements is the dollar value of benefits derived from saving a human life and reducing human suffering as a result of a safety improvement.

The selection of a dollar value for these benefits must be made in order to use the technique. The values used should be documented in the final report. If the agency conducting the evaluation has adopted a set of cost figures for highway fatalities, injuries and property damage accidents, the benefit/cost analysis technique is recommended. Also, if the MOE's of major interest are related to accident severity, (as opposed to specific accident types) the benefit/cost method may provide a good measure of economic effectiveness.

An alternative to the benefit/cost technique is to determine the cost to the agency of preventing a single accident and then deciding whether the project cost was justified. This is the cost/effectiveness technique. All project costs are valued on a dollar basis as in the previous technique. Benefits are not assigned a cost. Rather, they are used to determine the cost of reducing a type of accident. This can only be performed for one type of accident at a time. For example, the outcome of a cost/effectiveness analysis may indicate that the cost for each accident reduced was $750. In the same evaluation study, it can also be concluded that the cost for each injury accident reduced was $2500. If a project consists of more than one countermeasure and the accident analysis could not relate the reduction of a specific type of accident to a specific improvement, then it may be difficult to attach individual dollar costs to specific types of accidents and in turn to specific types of countermeasures.

If the agency conducting the study has neither adopted a set of cost figures for highway fatalities, injuries and property damage accidents, nor is willing to select established figures or undertake a study to determine accident cost data for the agency, it is recommended that the cost/effectiveness technique be selected. Also, if the MOE of major interest is related to a specific accident type (as opposed to severity) this method may provide a good measure of economic effectiveness.

STEP E2 - PERFORM THE ECONOMIC ANALYSIS USING THE B/C RATIO TECHNIQUE

The benefit/cost ratio (B/C) of a project may be determined in two ways.

$$B/C = EUAB/EUAC$$

or

$$B/C = PWOB/PWOC$$

where:

EUAB = Equivalent Uniform Annual Benefit
EUAC = Equivalent Uniform Annual Cost
PWOB = Present Worth of Benefits
PWOC = Present Worth of Costs

The benefit/cost method requires the following procedure be performed:

1. Determine the initial cost of implementation of the safety improvement being studied. This includes all costs associated with right-of-way acquisition, construction, site preparation, labor, equipment design, traffic maintenance, and other costs that may be associated with the implementation of the project. Typically, such cost data are available from ROW, design and construction files and reports. An Administrative Evaluation is recommended to determine these economic data.

2. Determine the net annual operating and maintenance costs. These data should be accumulated for each year of operation of the project facility. Such information is usually available from maintenance files. The net annual operating and maintenance cost should reflect the annual difference between the costs incurred before project implementation and those incurred following the implementation of the project. Therefore, if the project results in a lower combined annual operating and maintenance cost following the implementation, a negative cost results. On the other hand, if the after operating and maintenance costs are greater, the difference is positive.

3. Determine the average annual safety benefits derived from the project. Safety benefits are the annual reduction in the accident frequency associated with each severity MOE. This is the difference between the annualized expected

frequency and the after frequency for each severity MOE. These values were determined in FUNCTION C. The annual safety benefit determined in FUNCTION C, is assumed in this analysis to continue throughout the service life of the project.

Many economic evaluations consider the difference in road user costs as a highway safety benefit. Since, the basic purpose of this analysis is to evaluate completed highway safety projects, the road user costs are not considered.

4. Assign a dollar value to each safety benefit unit. Currently, various states follow different severity classification schemes and thus assign a dollar value to accidents saved that are unique to the particular agency. If a set of cost figures has been adopted by the agency, they should be used in the analysis and documented in the evaluation report.

   In the interest of a uniform data base of project effectiveness, it is desirable to use uniform cost figures for all Accident-Based Evaluation. However, there is disagreement on the appropriateness of including certain elements in the accident cost figures. As an example, the justification for including future production/consumption elements in cost estimates for fatalities (stemming from the loss of ability to produce goods and services) has been questioned. Similarly, certain researchers feel that the societal costs of long-term or permanent disability due to a non-fatal but severe injury is higher than a fatal accident because of the long term medical costs associated with such injuries.

   There are various papers and reports available dealing with the issue of accident costs. Some of these have recommended specific dollar values for accidents. As an example, the NHTSA document, "1975 Societal Costs for Motor Vehicle Accidents," provides a set of average costs per fatality and injury, and for property damage only involvements (PDO) per vehicle (Table 5). The third row of Table 5 shows the total cost figures. These costs include medical costs, funeral expenses (in the case of fatalities) legal and court fees, insurance and administration costs. The first row of Table 5 is the average cost excluding the vehicle damage and traffic delay costs which are shown in the second row of the table.

   The NHTSA procedure provides cost data for injury severities scaled from 1 to 6. This scaling is referred to as the Abbreviated Injury Scale (AIS) and is stratified as:

Table 5. Average and total accident costs for 1975.

	Fatality	Non-Fatal Injury					Average Injury	PDO Involvement
		5	4	3	2	1		
Average cost excluding vehicle damage and traffic delay, in dollars	283,105	188,190	82,935	5,005	2,325	435	1,360	45
Total	287,175	192,240	86,955	8,085	4,350	2,190	3,185	520
Number of occurrences in thousands	46.8	4	20	80	492	3,400	4,000	21,900
Total cost in billions of dollars	13.44	.77	1.74	.65	2.14	7.45	12.75	11.40

Source: 1975 Societal Costs of Motor Vehicle Accidents, NHTSA, December, 1976.

AIS Code	Category
1	Minor
2	Moderate
3	Severe (not life threatening)
4	Severe (life threatening, survival probable)
5	Critical (survival uncertain)
6	Maximum severity (fatal)

If the evaluator is using EPDO instead of various severity classifications, the average cost for PDO accidents may be used.

If the evaluator is using a different severity scale and wishes to use the NHTSA cost figures, he must transform his severity categories to AIS codes.

Other established accident cost figures include the cost data recommended by the National Safety Council (NSC)[1]. These are $160,000 per fatality, $6,200 per injury, and $870 per PDO accident. These figures are also used widely by various agencies. The NSC cost figures are updated annually.

The evaluator may use cost figures developed specifically for the agency, NHTSA, NSC or other cost data. Whichever is selected, the evaluator should use only the latest cost figures in economic evaluation.

5. Estimate the service life of the project based on patterns of historic depreciation of similar types of projects or facilities. For highway safety projects the service life is that period of time which the project can be reasonably expected to impact accident experience. Generally, major construction or geometric improvements should have a maximum service life of 20 years. The prediction of service life for specific highway improvements can be made reasonably accurately if the agency maintains service life data and survivor curves for various types of improvements and projects.

   It is desirable for each highway agency accumulate service life experiences and to develop service life estimation criteria. The procedure for the development of survivor

1 1979 Accident Costs Published by NSC.

curves for the service life estimations are available in most engineering economy texts. In the absence of service life data, past experience and engineering judgement should be applied for estimating service lives. The evaluator may also wish to utilize service life characteristics generated by other agencies.

However, it is important to consider geographic location and climatic condition of the areas for which service life data have been generated. It is unreasonable to expect that similar service life characteristics will exist for a project or facility implemented in Michigan and one implemented in Arizona.

Several States including California and Iowa have developed survivor curves. Existing survivor curves may provide a starting point for an agency in determining expected service life of safety improvements. The service lives of safety improvements such as traffic signs and pavement markings can be estimated from the life expectancy data of the manufacturers and modified by actual field experiences. The evaluator is recommended to start such service life data files. Selected service life criteria used by the Federal Highway Administration is provided in the Appendix.

While the economic evaluation of completed projects does not involve comparison of alternatives, the determination of present worth of costs for improvements with unequal service lives becomes a problem similar to the issue of comparison of alternative projects. Wohl and Martin[1] provides various approaches for handling the issue:

"Alternative investments can only be properly compared by examining the circumstances of cost and benefit over the same time period or time span. Briefly, if short- and long-life investments are being compared, the economic analysis is not complete unless one also considers the investment and income possibilities once the shorter-life project is terminated (since the longer-life project still continues and therefore may continue to produce gains or income). This problem of differing terminal dates or service lives may be handled in a number of ways.

1 Wohl, M. and Martin, B.V., "Traffic Systems Analysis for Engineers and Planners", McGraw-Hill, 1967.

1) It may be assumed that the projects will be perpetual and thus that the facility will be renewed and replaced periodically (according to the assumed service lives). While this assumption may be a convenient one, it hardly appears to be entirely valid. In any case, if this assumption is made, it should be stated explicitly.

2) The analysis may also be handled by analyzing the costs and benefits over a time period equal to the least common multiple of the lives of the projects being analyzed. During the time period, all items of capital and service lives shorter than the time period are renewed according to their respective services lives. The advantage of this method of handling the problem is simply that it eliminates the necessity of dealing with salvage values; that is, the end of the analysis or terminal date corresponds to a date where the capital of all projects is fully depreciated and (presumably) has no salvage value.

3) One may select as the time period of analysis (that is, the planning horizon) the service life of the project of longest life and may use this time period for analyzing all projects. However, in this case it may be necessary to account for the salvage value of some capital items, and it will be necessary to take account of the reinvestment possibilities for capital recovered from nonrenewable projects of shorter life than the terminal date."

6. Estimate the salvage value of the project or improvement after its primary service life has ended. This consists of the monetary value of the residual elements of the project.

   Agency maintained histories of safety improvements, service life data, and subsequent usage should provide the basis for estimating the salvage value of a project or an improvement. In the absence of organized data files, past experience and literature should be used to estimate the salvage value. Although salvage value is generally considered as a positive cost item, some projects may require an expenditure to remove the residual elements themselves. In these instances, the difference between the cost of removal should be deducted from the value of the scrap or residual elements in estimating the final salvage value. At times, salvage value can be zero or negative.

7. Determine the interest rate by taking into account the time value of money. Realistic estimates of interest rates are extremely important. The results of fiscal evaluations are very sensitive to small variations in in-

terest rates and thus may influence the outcome of economic analysis. Therefore, it may be advisable to vary the interest rate to determine the economic effectiveness of the project at different interest rates. If a project is found to change from a fiscally effective project to a marginally effective project with small changes in interest rates, the evaluator may obtain additional insight as to the true effectiveness of the project and draw appropriate conclusions in the final analysis of total project effectiveness.

It is recommended that a uniform rate of interest be used for all projects within an agency. The assumption of interest rate should consider:

- The market
- Interest rates for government bonds and securities
- Past practice of the agency
- Current practice and policy of the agency

Many agencies adopt interest rates as a matter of policy. However, in some instances the evaluator may be required to assume an interest rate for the evaluation study.

In recent economic studies various criteria have been used to estimate interest rates for highway safety evaluations. One approach is to utilize an interest rate which is reflected by the current marginal borrowing rate of the evaluating (or funding) agency. A common assumption is made that this rate is reasonably reflected in current rates on state and municipal bonds. Caution should be taken not to confuse this rate with the average borrowing rate of the agency. This rate generally does not reflect the current marginal borrowing rate since the average borrowing rate includes outstanding debts which were issued at interest rates which do not reflect the current market. This approach generally yields a conservative (low) rate of interest. Another approach uses an interest rate which is reflected in the marginal rate of return in marginal long-term investments in the private sector. This rate has been assumed to approximate the current net rate of interest on private savings invested in real estate. This approach yields a liberal (higher) interest rate. It may be helpful to the evaluator to utilize these two approaches to determine upper and lower bounds for the interest rate determination. However, agency policy should be used whenever available to promote uniformity between evaluations.

8. Calculate the B/C ratio using equivalent uniform annual costs and benefits. The use of these economic parameters provides the evaluator with the first of two alternatives for obtaining a B/C ratio for the completed highway safety projects. This formulation of the B/C ratio can be used when the service life of individual countermeasures within a single project are equal or unequal. This is because the approach makes the simplifying assumption of replacement of the short-lived countermeasures until the service life of the project is reached.

   Using the information described in items 1,2,5,6 and 7 above, equivalent uniform annual costs (EUAC) may be determined from the following equation.

   $$EUAC = I\ (CR_n^i) + K - T(SF_n^i)$$

   Where:

   EUAC = Equivalent uniform annual cost ($)

   I = Initial cost of the project ($)

   i = Interest rate (%)

   n = Estimated service life of the project or improvement (years)

   T = Net salvage value ($)

   K = Net uniform annual cost of operating and maintaining the improvement or project ($/year)

   CR_n^i = Capital recovery factor for n years at interest rate, i.

   The capital recovery factor may be found in the compound interest tables provided in the Appendix, or may be calculated as follows.

   $$CR_n^i = (i(1+i)^n)/(i+1)^n - 1$$

   SF_n^i = Sinking fund factor for n years at interest rate i

This factor may be found in the compound interest tables provided in the Appendix or may be calculated as follows:

$$SF_n^i = CR_n^i - i$$

Equivalent annual uniform benefits (EUAB) may be determined using the information described in items 3,4,5 and 7 above and the following equation:

$$EUAB = \bar{B}$$

Where:

EUAB = Equivalent uniform annual benefit ($)

$\bar{B}$ = Anticipated uniform annual benefit derived from the project throughout its service life. This estimate is based on the annualized savings in various severity categories, derived since implementation, times the appropriate accident cost values ($/year)

The B/C ratio for a project can be calculated using:

$$B/C = EUAB/EUAC$$

9. Calculate the B/C ratio using the present worth of costs and benefits. The use of these parameters provides an alternative for obtaining the B/C ratio for completed highway safety projects. However, this approach of calculating B/C based on present worth of benefits and costs should not be used for projects having multiple countermeasures with unequal service life unless the evaluator is thoroughly familiar with the required assumptions and adjustments which must be made under unequal service life conditions.

   Using the information described in items 1,2,5,6 and 7 above, the present worth of costs (PWOC) may be determined from the following equation:

$$PWOC = I + K\,(SPW_n^i) - T\,(PW_n^i)$$

   Where:

   PWOC = Present worth of costs ($)

I = Initial cost of the project ($)

i = Interest rate (%)

n = Estimated service life of the project or improvement. (years)

T = Net salvage value ($)

K = Net uniform annual cost of operating and maintaining the improvement or project. ($/year)

PW_n^i = Present worth factor for n years at interest rate i.

SPW_n^i = Present worth factor of a uniform series payment for n years at interest rate i.

The present worth of benefits (PWOB) may be determined using the information described in items 2,3,5 and 7 above and the following equation:

$$PWOB = \bar{B}\ (SPW_n^i)$$

Where:

PWOB = Present worth of benefits ($).

$\bar{B}$ = Anticipated uniform annual benefit derived from the project or improvement throughout its service life ($/year)

n = Service life of the project or improvement (years).

SPW_n^i = Present worth factor for an uniform series payment for n years at interest rate i.

The B/C ratio for a project or improvement can be calculated using:

$$B/C = PWOB/PWOC$$

The B/C worksheet (Figure 42) may be used in the analysis.

The results of the analysis should be viewed as a third piece of information (the change in the MOE's and the statistical significance of the changes were previously determined) on the effectiveness of the project. The evaluator must determine whether the resulting B/C ratio lies within the range of an effective project. It is important to recognize

B/C ANALYSIS WORKSHEET

Evaluation No:

Project No;

Date/Evaluator:

1. Initial Implementation Cost, I: $__________

2. Annual Operating and Maintenance Costs Before Project Implementation: $__________

3. Annual Operating and Maintenance Cost After Project Implementation: $__________

4. Net Annual Operating and Maintenance Costs, K (3-2): $__________

5. Annual Safety Benefits in Number of Accidents Prevented:

Severity	Expected - Actual = Annual Benefit
a) Fatal Accidents (Fatalities)	
b) Injury Accidents (Injuries)	
c) PDO Accidents (Involvement)	

6. Accident Cost Values (Source__________):

Severity	Cost
a) Fatal Accident (Fatality)	$
b) Injury Accident (Injury)	$
c) PDO Accident (Involvement)	$

7. Annual Safety Benefits in Dollars Saved, $\overline{B}$:

5a) x 6a) =

5b) x 6b) =

5c) x 6c) =

Total = $

Figure 42. Sample B/C analysis worksheet.

8. Services life, n: ____________________ yrs

9. Salvage Value, T: $____________________

10. Interest Rate, i: ____________ % = 0.____________

11. EUAC Calculation:

CR_n^i = ________________

SF_n^i = ________________

EUAC = $I\ (CR_n^i) + K - T\ (SF_n^i)$

12. EUAB Calculation:

EUAB = $\overline{B}$

=

13. B/C = EUAB/EUAC =

14. PWOC Calculation:

PW_n^i =

SPW_n^i =

PWOC = $I + K\ (SPW_n^i) - T\ (PW_n^i)$

15. PWOB Calculation:

PWOB = $\overline{B}(SPW_n^i)$

16. B/C = PWOB/PWOC =

Figure 42. Sample B/C analysis worksheet (continued).

that there is no universal criteria and each project must be individually analyzed on its own merit based on cost and effectiveness.

STEP E3 - PERFORM ECONOMIC ANALYSIS USING COST-EFFECTIVENESS METHOD

If the cost/effectiveness method of economic evaluation has been specified, the following steps should be performed.

1. Determine the initial cost of design, construction, right-of-way cost, and other costs associated with project implementation (same as Activity 1 in STEP E2).

2. Determine the annual operating and maintenance cost for the project (same as Activity 2 in STEP E2).

3. Select the units of effectiveness to be used in the analysis. The desired units of effectiveness may be:

   a) Number of total accidents prevented.

   b) Number of accidents by type prevented.

   c) Number of fatalities or fatal accidents prevented.

   d) Number of personal injuries or personal injury accidents prevented.

   e) Number of EPDO accidents prevented.

   As an alternative to considering benefits accrued from reduction of specific accident severity MOE's, a severity measure referred to as equivalent property damage only (EPDO) accidents may be utilized. This measure is based on weighting accident severity categories as multiples of property damage type accidents. Past studies have assigned a weighting factor of six to fatal and injury accidents as compared to a property damage accident. However, each agency must decide upon its own weighting scheme. The weighted number of accidents is called the EPDO number. Thus, the safety benefits can be estimated as yearly EPDO saved. If the EPDO approach is used, the evaluator should document the assumptions in the study report.

4. Determine the annual benefit for the project. Essentially this step is the same as Activity 3 in STEP E2 with the

exception that the savings in accidents is expressed in units of effectiveness (i.e., number of total accidents prevented) and not in dollar terms.

5. Estimate the service life as in STEP E2 Activity 5.

6. Estimate the net salvage value as in STEP E2 Activity 6.

7. Assume an interest rate as in STEP E2 Activity 7.

8. Calculate the EUAC or PWOC as described in Activities 8 and 9 of STEP E2.

9. Calculate the average annual benefit, $\overline{B}$, in the desired units of effectiveness using the following equation:

$$\overline{B} = \sum_{y=1}^{m} B_y/m$$

Where:

B_y = benefits for year y since project implementation in the desired unit of effectiveness.

m = number of years since project implementation.

10. Calculate the C/E value using one of the following equations.

$$C/E = EUAC/\overline{B}$$

or,

$$C/E = PWOC\ (CR_n^i)/\overline{B}$$

Where:

CR_n^i = Capital recovery factor for n years at interest rate i.

(This changes the PWOC to an annualized cost for compatibility with $\overline{B}$.)

Caution should be exercised when applying present worth to multiple countermeasure projects with unequal service lives. The C/E worksheet (Figure 43) may be used in the analysis.

C/E ANALYSIS WORKSHEET

Evaluation No:

Project No:

Date/Evaluator:

1. Initial Implementation Cost, I: $__________

2. Annual Operating and Maintenance Costs Before Project Implementation: $__________

3. Annual Operating and Maintenance Costs After Project Implementation: $__________

4. Net Annual Operating and Maintenance Costs, K (3-2): $__________

5. Annual Safety Benefits in Number of Accidents Prevented, $\overline{B}$: __________

Accident Type	Expected	- Actual	= Annual Benefit
Total	______	______	__________
			= __________

6. Service Life, N: ________ yrs

7. Salvage Value, T: $__________

8. Interest Rate: ________ % = 0. ________

9. EUAC Calculation:

CR_n^i = __________

SF_n^i = __________

$$EUAC = I\ (CR_n^i) + K - T\ (SF_n^i)$$

=

Figure 43. Sample C/E analysis worksheet.

10. Annual Benefits:

$\bar{B}$ (from 5) =

11. C/E = EUAC/$\bar{B}$ =

---

12. PWOC Calculation:

PW_n^i = ________________

SPW_n^i = ________________

$PWOC = I + K\ (SPW_n^i) - T\ (PW_n^i)$

13. Annual Benefit

n (from 6) = yrs.

$\bar{B}$ (from 5) = accidents prevented per year

14. $C/E = PWOC\ (CR_n^i)/B$

Figure 43. Sample C/E analysis worksheet (continued).

Summary of FUNCTION E

STEP E1 - SELECT ECONOMIC ANALYSIS TECHNIQUE

- Determine the need for economic analysis by assessing whether a statistically significant change had taken place in the MOE's of the evaluation.

- Select an economic analysis technique to be used in the evaluation.

STEP E2 AND E3 - PERFORM THE ECONOMIC ANALYSIS USING THE B/C RATIO TECHNIQUE, AND PERFORM ECONOMIC ANALYSIS USING THE COST EFFECTIVENESS METHOD

- Finalize necessary inputs to the selected economic techniques.

- Perform economic analysis.

Examples of FUNCTION E

Example of Economic Analysis Using Cost/Effectiveness Technique

A highway safety project to provide increased lighting levels at an urban intersection with a high level of night accident occurrence resulted in a statistically significant reduction in the injury accident rate. The following summary shows initial construction costs, operating and maintenance costs and annual benefits. The annual benefits were obtained by subtracting actual 3 year accident frequency for the after period from the adjusted 3 year before accident frequency and annualizing the difference. The service life of the project was estimated as 15 years, with a salvage value of 10% of the initial cost. The benefits are expressed as annual savings in injury accidents.

Initial Construction Costs	Operating and Maintenance Costs			Benefit (Injury Accidents Prevented)		
	1974	1975	1976	1974	1975	1976
$40,000	$1,000	$1,000	$1,000	8	7	6

An interest rate of 10% was used in the analysis. The EUAC was calculated as follows:

$$EUAC = I\ CR^{i}_{n} + K\text{-}T\ (SF^{i}_{n})$$

From standard interest tables for n = 15, and i = 10%,

CR_n^i and SF_n^i were found to be 0.1315 and 0.0315 respectively.

$$EUAC = (\$40{,}000 \times 0.1315) + \$1{,}000 - (0.10 \times 40{,}000 \times 0.0315)$$

$$= \$5{,}260 + \$1{,}000 - \$126$$

$$= \$6{,}134$$

The average annual benefit, $\overline{B}$, is calculated as:

$$\overline{B} = (8 + 7 + 6)/3$$

$$= 7.0 \text{ injury accidents prevented per year}$$

The C/E value was calculated as:

$$C/E = EUAC/\overline{B}$$

$$= \$6{,}134/7$$

$$= \$875 \text{ per injury accident saved}$$

The results of this analysis may be interpreted by comparing this C/E value with those from other similar highway safety projects to determine whether the findings are consistent and whether the project warrants future implementation for similar safety problems.

Example of Economic Analysis Using Benefit/Cost Ratio Technique

In an effort to reduce the number of rear-end collisions due to skidding of vehicles during wet-weather, the highway agency undertook a safety project of skid proofing a 1/2 mile roadway section by constructing a texturized pavement section at a cost of $200,000 in 1974. The estimated service life of the project is estimated as 10 years with a zero salvage value. The average annual maintenance cost of the grooved pavement is essentially zero. Following the AIS scheme outlined in the NHTSA document, the highway department estimates the dollar benefits of the project in terms of injuries prevented as $40,000, $45,000 and $50,000 for the years 1974, 1975 and 1976 respectively.

An interest rate of 10% was used in the analysis. The PWOC was calculated as:

$$PWOC = I + K\,(SPW_n^i) - T\,(PW_n^i)$$

Where:

$I = \$200,000$

$K = \$0$

$T = \$0$

From standard interest tables, for n = 10 and i = 10%, SPW_n^i and PW_n^i were found to be 6.1446 and 0.3855, respectively.

$$PWOC = \$200,000 + \$0 + \$0$$

$$= \$200,000$$

The PWOB was calculated as:

$$PWOB = ((\$40,000+\$45,000+\$50,000)/3)\ SPW_n^i$$

Substituting in the above equation:

$$PWOB = \$45,000\ (6.1446)$$

$$= \$276,507$$

The benefit/cost ratio is calculated as:

$$B/C = PWOB/PWOC$$

$$= \$276,507/\$200,000$$

$$= 1.38$$

When the B/C ratio is greater than unity, the benefits derived from the project outweigh the incurred costs. In this paritcular case, the advantage is on the order of 38% .

The B/C ratio may also be compared with the results of other similar highway safety projects to determine the degree of consistency between the results and the relative merits of this type of project in future highway safety efforts.

If the B/C technique is performed to determine which countermeasure at a problem location is the most advantageous an incremental B/C test should be performed.

FUNCTION F: Prepare Evaluation Documentation

This function enables the evaluator to:

1. Interpret the effectiveness of the highway safety project.

2. Interpret the validity of the evaluation study.

3. Identify evaluation results for incorporation into the effectiveness data base.

4. Write the evaluation study report.

Overview

In the previous functions, the changes in the MOE's, the statistical significance of these changes, and the economic impact of the highway safety project has been determined. The evaluator now must draw conclusions regarding the overall effectiveness and worth of the project and review the appropriateness of all activities of the evaluation study which lead to the final conclusions.

The determination of project effectiveness should address the following points:

1. Did the project accomplish the purpose for which it was intended?

2. Were the evaluation objectives accomplished?

3. To what degree were the evaluation objectives accomplished?

4. Did the study reveal any unexpected results or results which were contrary to the project purposes.

The evaluation study activities must be critically reviewed to determine possible inconsistencies in data quality, data collection and sampling procedures, the use of the selected experimental plan, and statistical and economical testing. In addition, decisions made in the Planning and Implementation Components of the HSIP should be reviewed for possible inconsistencies which may affect the observed effectiveness of the project.

If the evaluation study results are a valid representation of the effectiveness of the project, the evaluation data should be used in establishing an data base of project effectiveness for future use in planning and implementation decisions. This data base (see FUNCTION G) and a formal written account of the procedures and findings of the evaluation are the final outputs of Accident-Based Evaluation.

STEP F1 - ORGANIZE EVALUATION STUDY MATERIALS

The final determination of the effectiveness of the project and the validity of the evaluation study requires all data and evaluation materials to be brought together and carefully reviewed.

Because the evaluation study may span several years, the organization of all materials becomes an important element in writing the study report. A checklist of the materials and information required for this function is shown in Figure 44 along with the evaluation function from which the materials originated.

STEP F2 - DETERMINE THE EFFECTIVENESS OF THE PROJECT

The effectiveness of the project is determined from the changes in the MOE's and the statistical and economical significance of the observed changes. This information results from FUNCTIONS C, D and E, respectively. The evaluator must give careful consideration to the results of these three functions when concluding the effectiveness of this project.

Regardless of the outcome (effectiveness) of the project, the evaluator should also critically review each activity of the evaluation study for appropriateness in an attempt to establish the overall validity of the study and the effectiveness of the project. This review should include the selection of purposes, objectives, MOE, experimental plan, data, data collection procedures and data analysis procedures. If problems are observed, an attempt should be made to correct them. If corrections cannot be made, a brief written description of the problem and how it may affect the observed effectiveness of the project should be prepared and included in the final study report.

STEP F3 - IDENTIFY RESULTS FOR INCLUSION IN THE EFFECTIVENESS DATA BASE

One of the primary uses of the evaluation results is the development of a data base of the effectiveness of various highway safety projects. The aggregate data base should be developed to assist the agency in selecting remedial projects and countermeasures for specific highway safety problems and supplying expected accident reduction factors which may be utilized in evaluating alternative countermeasures for implementation. Data bases to be developed by the individual agencies should include reduction factors for accident types and severity categories from all evaluations found to be reliable in the preceding step (STEP F2).

Guidelines for determining accident reduction factors and developing an effectiveness data base are described in FUNCTION G, Develop and Update Effectiveness Data Base.

- ______ Justification Statement
- ______ Project Description
- ______ Funding Level
- ______ List of Project Purposes (Function A)
- ______ List of Evaluation Objectives and MOE (Function A)
- ______ Experimental Plan Uses with Justification (Function A)
- ______ List of Data Variables (Function A)
- ______ List of Control Sites with Selection Criteria (Function A)
- ______ Raw Data (Function B)
- ______ Reduced Data (Function B)
- ______ Data Collection Techniques Used (Function B)
- ______ Data Collection Personnel
- ______ Parametric Comparison Tables (Function C)
- ______ Percent Changes in MOE with Calculations (Function C)
- ______ Statistical Test Utilized (Function D)
- ______ Statistical Results (Function D)
- ______ Economic Data Including Implementation, Operation, Maintenance, etc. (Function E)
- ______ Economic Analysis Technique Used with Assumptions (Function E)
- ______ Economic Analysis Results (Function E)

Figure 44. Evaluation study materials checklist.

STEP F4 - WRITE THE EVALUATION STUDY REPORT

Whether or not the evaluation study results were appropriate for inclusion in the aggregate data base, the evaluation activities and results should be thoroughly discussed and documented in the study report. The documentation should include a concise and comprehensive coverage of all evaluation study activities and results and should follow a standardized format.

The following format is recommended.

1. Introduction
   - name of project
   - overview of the project and improvement type(s)
   - funding level and period
   - evaluation personnel

2. Exécutive Summary of Findings and Recommendations
   - summary of project performance
   - summary of successes, failures and probable causes
   - summary of unexpected impacts, with probable causes
   - recommendations for improvement of the project and/or evaluation activities
   - quantifiable support for conclusions

3. Identification and Discussion of the Highway Safety Problem
   - problem identification
   - discussion of problem
   - discussion of project appropriateness
   - opinions

4. Administrative Evaluation of the Project (refer to Administrative Evaluation).

5. Effectiveness Evaluation of the Project:
   - evaluation study (i.e., purposes, objectives, MOE, experimental plan, etc.)
   - variables measured
   - data collection and reduction procedures used in the study
   - data analysis technique
   - detailed project results relative to achievement of objectives
   - detailed project impact statement
   - problems encountered in the overall evaluation study

All information listed above should be incorporated into the final evaluation report worksheet shown in Figure 45.

FINAL REPORT

Introduction

Evaluation No:

Project No:

Date/Evaluator:

Project Location(s):

Countermeasure(s):

Code(s):

Initial Implementation Cost:

Annual Operating and Maintenance Cost:

Executive Summary

List Major Findings and Conclusions of the Evaluation Study

Figure 45. Final report worksheet.

Identification and Discussion of the Problem

Administrative Evaluation

List personnel and role in the evaluation study.

Person	Role

Estimate man-hours devoted to the evaluation by activity.

Activity	Man-hours
• Data Collection and Reduction	
• Data Analysis	
• Report Writing	

Time period over which the evaluation spanned:

Estimated cost of evaluation study:

Effectiveness Evaluation

List purposes:

Figure 45. Final report worksheet (continued).

List objectives and MOE's

List experimental plan used:

Discuss data collection activities, techniques, equipment used, analysis periods.

List % change in each MOE and statistical significance at selected level.

Discuss economic analysis technique used and results.

Figure 45. Final report worksheet (continued).

Discuss problems encountered, conclusions, and recommendations for future evaluation studies.

Figure 45. Final report worksheet (continued).

Summary of FUNCTION F

STEP F1 - ORGANIZE EVALUATION STUDY MATERIALS

- Accumulate information pertaining to all the evaluation activities.
- Complete the check list shown in Figure 44.

STEP F2 - EXAMINE THE EFFECTIVENESS OF THE HIGHWAY SAFETY PROJECT

- From FUNCTION C, identify whether the project reduced the safety deficiencies (MOE's) for which it was intended.
- From FUNCTION D, identify whether the project resulted in a statistically significant change in the MOE's.
- From FUNCTION E, identify whether the project resulted in benefits (or effectiveness) which are considered acceptable when compared to project cost.
- Based on the above information, establish the worth of the project and appropriateness of all evaluation activities.
- Justify, in writing, all evaluation study aspects found to be inappropriate.
- Review the purposes of the project and identify whether the countermeasures were reasonable for the observed deficiencies.

STEP F3 - IDENTIFY RESULTS FOR INCLUSION IN THE EFFECTIVENESS DATA BASE

- Identify evaluation results for inclusion to the data base for evaluation studies found to be reliable and continue with FUNCTION G.
- Exclude evaluation results from the data base for evaluation studies found to be subject to reliability questions.

STEP F4 - WRITE THE EVALUATION STUDY REPORT

- Prepare documentation of all activities and results of the evaluation study.
- Review final report for completeness.
- Distribute copies of report to all highway safety personnel and file original report in a highway safety evaluation study report file for future reference.

FUNCTION G: Develop and Update Data Base

This function enables the evaluator to:

1. Tabulate basic input data to be used in data base development
2. Compute accident reduction factors
3. Compute the expected range of the accident reduction factors.

Overview

An effectiveness data base is an accumulation of project evaluation results which are directly usable as input to the project selection and project priority ranking subprocesses of the HSIP Planning Component. The data base contains information on the accident reducing capabilities of a project. The data base must be continually updated with new effectiveness evaluation information as it becomes available.

The data base should contain evaluation results from only reliable and properly conducted evaluations. Thus, STEP F3 of the preceding function is extremely important as a screening mechanism to eliminate questionable evaluation results based on observed evaluation study deficiencies which are not correctable by the evaluator.

STEP G1 - ORGANIZE INPUT DATA

For project evaluation results to be included in the data base, the following information is required:

1. Description of the project including countermeasures, locations, and year of implementation.
2. Expected and actual accident frequencies by type and severity.
3. Traffic volume data representative of the before and after analysis periods.
4. The length of the before and after analysis periods.

Information on the description of the project is used to develop groups of projects with identical combinations of countermeasures implemented at similar location types. For example, a project involving shoulder stabalization should not be combined with projects involving edgelining only. Similarly, a project involving the installation of a traffic signal at an urban intersection should not be combined with signal installations at a rural intersection.

For projects within each group, a chronological listing (by date of implementation) of each project with accident frequencies, volumes and analysis period lengths for both the before and after periods should be maintained. An effectiveness data base summary form should be developed and used for tabulating these data.

The accident frequencies tabulated for each project should include:

1. Total accidents;

2. Fatal accidents and fatalities;

3. Injury accidents and injuries;

4. Property damage only accidents; and

5. Other accident types evaluated.

STEP G2 - COMPUTE ACCIDENT REDUCTION FACTORS AND EXPECTED RANGES

Accident Reduction (AR) Factors are estimates of project effectiveness, expressed as a percent reduction in accident experience. AR Factors should be computed for the accident and severity measures recorded for the individual projects listed in STEP G1 which have been implemented within the latest 5 year period. Eliminating projects older than 5 years insures current estimates of project effectiveness. For each AR Factor, an expected range (ER) of values within which the average reduction is expected to fall, with 95% confidence, must also be computed.

The following procedure should be used to compute AR Factors and ER's.

1. Compute Expected Accident Frequency (E_F)

   The expected accident frequency, E_F, should be computed using the equations shown in FUNCTION C for the experimental plan used in the evaluation. The expected frequency should be computed for each accident category identified in the evaluation objectives.

2. Calculate AR Factors

Use the following equation to compute the AR Factor:

$$\text{AR Factor} = 100 \left[1 - \frac{\Sigma A}{\Sigma E_F}\right]$$

Where:

A = Actual (after) accident frequency
E = Expected accident frequency (see FUNCTION C)

3. Calculate ER at the 95% Level of Confidence

Use the following equation to compute ER for each AR Factor:

$$ER = 200 \sqrt{\frac{n}{(n-1)(\Sigma E_F)^2}\left[\Sigma A^2 + \left(\frac{\Sigma A}{\Sigma E_F}\right)^2 \Sigma E_F^2 - 2\frac{\Sigma A}{\Sigma E_F}\Sigma E_F A\right]}$$

Where:

n = number of projects

STEP G3 - DEVELOP AND UPDATE THE DATA BASE

The AR Factors and corresponding ER's should be maintained in a format which can be easily updated as new evaluation results become available. A format similar to those shown in Figures 46 through 48 are appropriate formats. It is important that each time the data base entries are updated, a notation be recorded showing the date of the most recent update.

Summary of FUNCTION G

STEP G1 - ORGANIZE INPUT DATA

- Group projects into groups with identical countermeasures implemented at similar locations.
- Obtain expected and actual accident frequencies, volumes and analysis time period length.

STEP G2 - COMPUTE AR FACTORS AND ER'S

- Calculate expected and actual accident frequencies.
- Compute AR Factors and ER's for each group of projects developed in STEP G1.

STEP G3 - DEVELOP AND UPDATE DATA BASE

- Enter AR Factors and ER's into the data base format.
- Update as new evaluation results become available.

Improvement	Accident Reduction (Percent)													
	All	Fatal Injury	PDO	Head On	Rear End	Right Angle	Side Swipe	Left Turn	Rt. Turn	Fixed Obj.	Ped.	Night	Ran Off-Road	Wet Pvmt.
Improve Signals to Correspond to Manual on Uniform Traffic Control Devices					20	20	10	20	20			20		
Add Left-Turn Lane w/o Signal Turn Phase	≅19, 6[a]	≅80, ≅54[a]	≅18[a]											
Modify Signals	27													
Actuate					10	10	20	10	20					
Optically Programmed Signals				20	10	10		10						
Pedestrian Phase											60			
Remove Signal					90									
Add Signal					-1/ 2000 vpd	80								

a/ On two or more lanes.
b/ Two lanes.
c/ Minor street must be 35% or more of total intersection volumes; total intersection volume must be < 8,000 ADT.

Figure 46. Estimated accident reduction table.

Source: "Manual on Identification, Analysis and Correction of High Accident Locations", USDOT/FHWA

Improvement Type		Accident Reductions (Percent)										Estimated Cost Of Improvement
		Head-On	Rear-End	Right Angle	Sideswipe	Left Turn	Right Turn	Fixed Object	Pedestrian	Night Accident	Wet Pavement	
Pavement Markings				10	20	10	10		10	10		$ 500
Signs	Upgrade	20	10						10		20	500
	Overhead Lane		10		20							400
	Overhead Warning		20	20		20	20					400
Signals	Timing		10	10		10	10		10			100(E)
	12" Lens		10									800(E)
	MUTCD (1)		20	20	10	20	20			20		10,000(N)
	Turn Phase		10			50						200(E)
	Opt. Program	20	10	10		10						2,000(E)
	Actuate		10	10	20	10	20					1,500(E)
	Pedestrian Phase								60			300
	Remove Signal		90									400
	Add Signal		(3)	80								10,000
Roadway	Deslick										50	3,000
	Sight Distance	20		20		20	20					
	Turn Bay		20									5,000
	Reconstruct	20	10									50,000
Misc.	Close Median Opening (2)	100	50	100	50	100						1,000
	Relocate Fixed Objects							60				1,000
	Lighting									50		5,000
	Relocate Drives	20	20	10	10	10	10					2,000

(1)--Includes Timing, 12" Lens, Turn Phasing and Actuation
(2)--Percent of Accidents Involved at Median Opening
(3)--One Accident Increase Per 2000 VPD
(E)--Upgrading Existing Equipment
(N)--Replacing Existing With New Equipment

Figure 47. Accident reduction forecasts used by Mississippi State Highway Department

Source: "Methods for Evaluating Highway Safety Improvements", NCHRP 162.

Type of Improvement	Urban or Rural	Number of Lanes	Accident Reduction, Percent* All Accidents	Fatal Injury Accidents	Property Damage Only Accidents	Comments
Add pedestrian signals	U	2	13	56a	-	
Add pedestrian signals	U	2 plus	3a	42a	-	
Improve signals	U	2	31	35a	-	Changes to improve driver's response to signal-vision, attention, etc.
Improve signals	U	2 plus	-2	10b	-	
Improve signals	R	2 plus	42a	45b		
Improve signals	U	2 plus	-	57	-	T-Intersection
Curtail turning movement	U	2 plus	40	39	-	
Add left turn lane w/o signal	U	2	19a	80b	-	
Add left turn lane w/o signal	U	2 plus	6	54a	18b	
Add left turn lane w/o signal	R	2 plus	-6	-1b	-	
Add left turn lane w/o signal	U	2	79	79	-	T-Intersection
Add left turn lane w/o signal	U	2 plus	51a	62	-	
Add left turn lane w/o signal	R	2	33	5	-15	Y-Intersection
Add left turn lane & signal	U	2 plus	27	1	-7b	
Add left turn lane & signal	R	2 plus	43a	58a	-	
Add left torn lane & signal	R	2	-	-	-	T-Intersection
Add left turn lane & signal	R	2 plus	-42a	-26b	-	
Add left turn signal w/o turn lane	U	2	-	-	-	
Add left turn signal w/o turn lane	U	2 plus	39	57	-	
Add left turn lane, signal & illumination	U	2 plus	46	76	-	
Install new traffic signals	U & R	2 plus	29	50	-	Proven hazardous intersections, 60% right angle and left turn accidents
Deslicking	U	2 plus	20	15	-	
Rumble strips	R	2	27b	26b	24b	

* The symbols in the percentage reduction columns have the following meaning:

No symbol	Good estimate	0-30%
a	Rough estimate	30-70%
b	Very rough estimate	70-150%
-	No estimate made	over 150%

Figure 48. Accident reduction forecast from Evaluation of Criteria.

Source: "Methods of Evaluating Highway Safety Improvements", NCHRP 162.

Example of FUNCTION G

STEP G1 - ORGANIZE INPUT DATA

The effectiveness data base summary form shown in Figure 49 contains evaluation data for three projects which involved the installation of a separate left-turn phase signal and exclusive left-turn lane at three urban intersections.

STEP G2 - COMPUTE AR Factors and ER'S

The following calculations show the procedure used to compute AR Factors and ER's for left-turn accidents:

1. Before and after period lengths were the same for each project and no adjustment for unequal periods was needed. The total before accident frequency and total after accident frequency for all projects were used directly in the following calculations and AR Factors and ER.

2. $\text{AR Factor} = 100 \left[1 - \frac{\Sigma A}{\Sigma E_F}\right]$

$$= 100 \left(1 - \frac{15}{28}\right)$$

$$= 46\% \text{ (decrease)}$$

3. $ER = 200 \sqrt{\frac{n}{(n-1)(\Sigma E_F)^2} \left[\Sigma A^2 + \left(\frac{\Sigma A}{\Sigma E_F}\right)^2 \Sigma E_F{}^2 - 2\frac{\Sigma A}{\Sigma E_F} \Sigma E_F A\right]}$

$$= 200 \sqrt{\frac{3}{2(28)^2} \left[77 + \left(\frac{15}{28}\right)^2 (286) - 2\left(\frac{15}{28}\right)(143)\right]}$$

$$= 200 \sqrt{0.0019 \ [77+82.08-153.21]}$$

$$= 200 \sqrt{0.011}$$

$$= 200 \ (0.105)$$

$$= \pm \ 21\%$$

Based on these findings, it was concluded that the estimated accident reduction in left-turn accidents for future installations of left-turn phase/left-turn lane projects will average 46% with a range of ± 21% at the 95% level of confidence.

STEP G3 - DEVELOP AND UPDATE THE DATA BASES

The input to the effectiveness data base under this project type would be a 46% ± 21% reduction for the left-turn accident category.

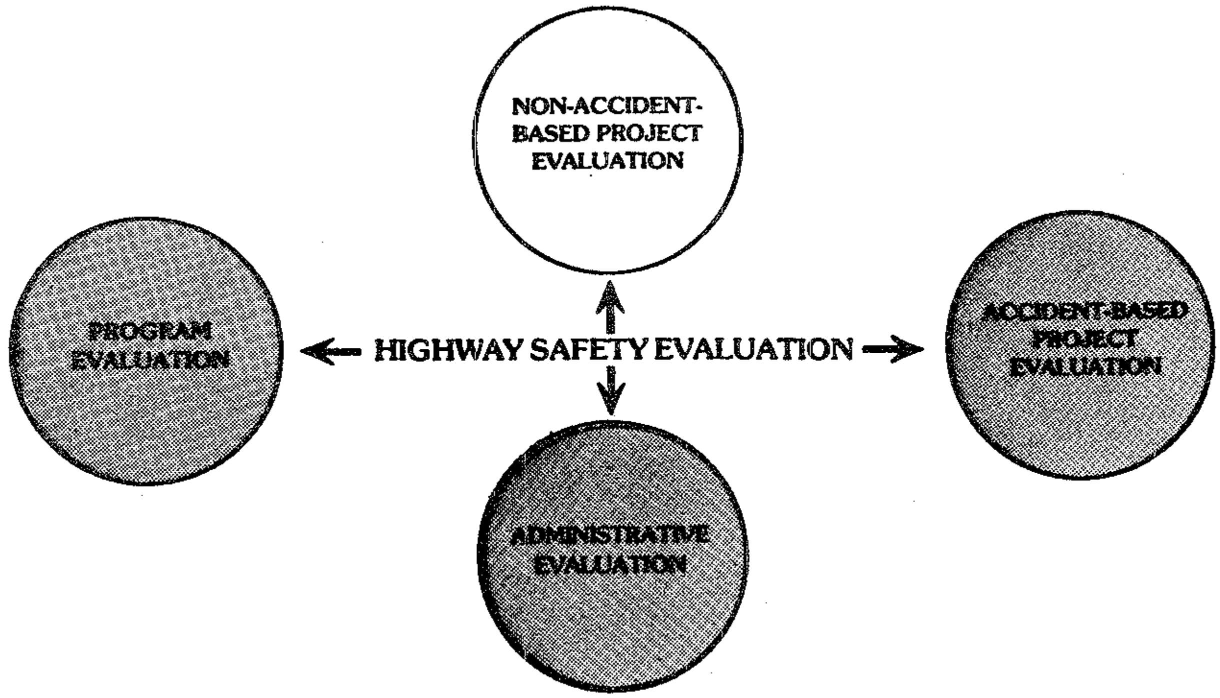
Project Description: Separate Left-Turn Lane Construction, Left-Turn Signal Phase Installation.

Location Description: Urban Signalized Intersections

Implementation Date	Project No.	Analysis Period Length		AADT		Accident Frequencies											
						Expected						After					
		Before	After	Before	After	Total	F(#)	I(#)	PD	LT		Total	F(#)	I(#)	PD	LT	
5 - 79	79-030	2 yr.	2 yr.	32,000	35,000	25	0(0)	7(9)	18	13		22	0(0)	3(3)	19	5	
7 - 79	79-042	2 yr.	2 yr.	30,000	34,000	19	1(1)	9(11)	10	6		19	0(0)	7(8)	12	4	
8 - 79	79-045	2 yr.	2 yr.	31,000	33,000	21	0(0)	13(15	8	9		15	0(0)	5(5)	10	6	

Figure 49. Effectiveness data base summary form.

NON-ACCIDENT-BASED PROJECT EVALUATION



The objective of Non-Accident-Based Project Evaluation is to provide guidelines for assessing the intermediate effectiveness of a completed highway safety project. The measures of intermediate effectiveness are observed changes in non-accident safety measures. This subprocess may be used when accident data are not available or are insufficient for Accident-Based Evaluation or when an indication of project effectiveness is desired sooner than the time necessary for Accident-Based Evaluation. Because accidents are not required for this type of evaluation, it may be performed as soon as traffic adjusts following project implementation. Non-accident measures are not intended to be a substitute for the ultimate safety measure (accident and severity reduction), since definitive quantitative relationships between accident experience and many non-accident measures have not been developed. Rather, they are measures which are logically related to accident experience and thus provide a measure of intermediate project effectiveness. The ultimate effectiveness however, must be determined through an Effectiveness Evaluation based on observed changes in accident experience which should be conducted if and when possible.

Non-Accident-Based Project Evaluation consists of seven functions. Each function contains a series of systematic steps which lead the evaluator through the activities and decisionmaking processes of a properly designed evaluation study.

The seven functions which comprise Non-Accident-Based Project Evaluation are:

FUNCTION A - Develop Evaluation Plan

FUNCTION B - Collect and Reduce Non-Accident Data

FUNCTION C - Compare Non-Accident Measures of Effectiveness (MOE's)

FUNCTION D - Perform Statistical Tests

FUNCTION E - Perform Economic Analysis

FUNCTION F - Prepare Evaluation Documentation

FUNCTION G - Develop and Update Effectiveness Data Base

These functions are common to all Effectiveness Evaluation subprocesses contained in this Procedural Guide. It is strongly recommended that the evaluator become familiar with the functional details of each subprocess prior to performing an evaluation using any single subprocess, since some of the information contained in program evaluation may be helpful in performing a project evaluation and vice versa.

FUNCTION A: Develop Evaluation Plan

This function enables the evaluator to:

1. Develop a plan for evaluating a highway safety project based on non-accident measures.

2. Identify and record the intermediate objectives and non-accident measures of effectiveness.

3. Select an appropriate experimental plan.

4. Establish a list of data needs.

5. Document the evaluation plan.

Overview

This function presents the steps to be taken in developing an evaluation plan for determining the intermediate effectiveness of a highway safety project. In this function the evaluator selects the projects to be evaluated, determines intermediate objectives, non-accident MOE's and experimental plans, and establishes the type and magnitude of data required for the study.

The objectives of this function are best accomplished by reviewing and becoming completely familiar with the evaluation planning steps of Accident-Based Evaluation. This review aids the evaluator in understanding the logical relationships between accident and non-accident-based safety measures and the sequential nature of the two evaluation subprocesses within the HSIP Evaluation Component. With an understanding of the accident-based evaluation planning steps, the steps contained in this function can be sequentially conducted to produce a written evaluation plan.

Although the titles of planning steps in this subprocess are identical to Accident-Based Evaluation, there are two basic differences between accident and non-accident evaluation planning. First, the evaluator's frame of reference must be expanded beyond addressing the question: What is the purpose of the project in terms of how it will affect accident experience at the project site? In this subprocess, the evaluator must also address the chain of events which leads to observed or potential accident experience, and how the introduction of a specific project alters these events and results in the achievement of the ultimate goal of the project, which is accident, severity and/or hazard potential reduction. The second difference is the timing at which evaluation planning takes place. Unlike Accident-Based Evaluation, the evaluator does not have the option of performing evaluation planning before or after project implementation. This subprocess requires that the evaluation plan be developed during the Planning Component of the HSIP (before project implementation) so that before evaluation data can be obtained.

The outcome of this function is a written evaluation plan which guides the evaluator through the remaining functions and steps of this evaluation subprocess.

STEP A1 - SELECT PROJECTS FOR EVALUATION

The purposes of a highway safety project may include one or a combination of the following:

- To reduce traffic accidents
- To reduce accident severity
- To reduce hazard potential

Also, a secondary purpose of the project may be to improve traffic performance.

Projects implemented for any of the above purposes may be evaluated with this subprocess. However, certain types of projects and certain evaluation requirements are well-suited to Non-Accident-Based Evaluation. These include:

1. Project impact on traffic performance. The primary purpose of a highway safety project is to reduce accident losses. However, traffic performance, driver behavior and other non-accident measures are often affected by the project. Further, the improvement of traffic performance may be a secondary purpose of the project. If the evaluator is interested in the affect of the project on traffic performance measures, the project should be selected and evaluated with this subprocess.

2. Need for a quick indication of project effectiveness. When the evaluator needs to know how well a project is performing soon after implementation and is willing to accept a change in non-accident measures as an indicator of ultimate project effectiveness, the project should be selected and evaluated with this subprocess.

3. Need for a relationship between accident and non-accident measures. Many non-accident measures such as speed, erratic maneuvers, traffic conflicts, and number of driveways have logical and in many cases proven correlative relationships with accident experience. If the evaluator is interested, however, in determining the association of the cause and effect relationships between changes in non-

accident and accident measures, the evaluator should select a project to be evaluated with both non-accident and accident measures.

4. Projects implemented to reduce hazard potential Many safety projects are implemented to meet recommended safety standards or to eliminate specific safety deficiencies before 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, this subprocess provides a means of evaluating the project if operational or behavioral non-accident measures can be identified. If such a project warrants evaluation, it should be selected and evaluated with this subprocess.

5. Presence of factors which affect "after" accident experience. Accident-Based Evaluation requires that after accident experience reflect only the change in accidents resulting from the project's implementation. If the evaluator has knowledge of future highway or environmental changes that may affect accident experience and thus the validity of the evaluation, the project should be selected and evaluated with this subprocess to obtain an indication of project effectiveness before the change takes place.

6. Projects involving staged countermeasure implementation. Individual countermeasures and countermeasure combinations which comprise a project may be evaluated with this process when project implementation is staged. The non-accident measures can be collected and evaluated between successive project implementation stages. This subprocess provides a means of evaluating countermeasures since the time periods between successive stages are generally too short to allow Accident-Based Evaluation.

Any project selected for Accident-Based Evaluation or one which corresponds to one of the above listed conditions may be selected and evaluated with Non-Accident-Based Evaluation.

Project Purpose

The evaluator should determine the purpose of the project and record it on the Project Purpose Listing form contained in the Appendix following the selection of a project. The guidelines of the Accident-Based Evaluation for recording the project purpose should be followed. When a project purpose is to reduce hazard potential only, the justification should specify the specific type of accident potential to be reduced or eliminated as well as the reason why the accident or severity reducing purposes are not appropriate.

Figure 50 illustrates a Project Purpose Listing for a project involving the installation of a flashing beacon on an advance school sign (S1-1) to be operated during times of heavy school pedestrian crossings.

STEP A2 - STRATIFY PROJECTS

If identical countermeasures are implemented at a number of sites with similar geometric, environmental and traffic characteristics, they should be grouped together as a single project. Performing Non-Accident-Based Evaluation for the group increases the sample size and the statistical reliability of the evaluation results.

If a large group results, the sampling procedure provided in STEP A2 of Accident-Based Evaluation may be used.

STEP A3 - SELECT INTERMEDIATE OBJECTIVES AND NON-ACCIDENT-BASED MOE'S

The selection of objectives and MOE's for Non-Accident-Based Evaluation is based on the evaluator's ability to describe the chain of events which leads to accidents or create potential safety hazards.

When describing the events, three factors must be specified. They include: 1) the major causal factor(s); 2) the major contributory factor(s); and 3) the safety problem. Major causal factors are the reasons why an actual or potential accident problem exists. They are specific hazardous elements associated with the highway environment or vehicle, or actions associated with the driver, which result in: 1) the potential for accidents when a causal factor exists by itself; or 2) an accident occurrence in the presence of major contributory factors. Major contributory factors are elements or activities which 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 which result from the existence of a causal factor and/or contributory factor. Figure 51 shows the relationship of these factors within the chain of causality.

Intermediate Objectives

The first step in selecting objectives is to develop the chain of causality for the highway safety project. Since the purpose of the project has already been established in STEP A1, the safety problem may be stated in terms of the actual or potential accident types to be reduced by the project. Next, the evaluator must identify and record the causal and contributory factors which lead to the safety problem. In many cases, the identification of these factors is straightforward since both causal and contributory factors are considered in the Planning Component where projects are developed.

For example, suppose the project involves the implementation of an advance train-actuated warning flasher on an existing railroad crossing advance warning sign on the west approach to a crossing with limited sight distance (Figure 52). The project purpose was to reduce the number and

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PROJECT PURPOSE LISTING

Evaluation No. 27

Date/Evaluator 3-23-80/ PDP Checked by HNJ

Project No. 1-231-S

Project Description and Location(s) Install flashing beacon on existing S1-1, Apple Ave., 200' N. of Apple Elementary School (12483 Apple Ave

Countermeasure(s)/Codes Upgrade existing sign (FHWA Code 60)

Project Purpose	Justification
1. To reduce pedestrian vehicle accident potential	1. Vertical alignment restricts southbound drivers visibility of crossing pedestrians. Existing S1-1 provides the only advance indication of school crossing. No accidents have occured to date. However, the adult crossing guard reports several near-accidents due to excessive speeds.
2. To reduce average speed in school crossing area during periods of school-aged pedestrians.	2. Vehicle speeds are considered too high on north approach to school crossing.

Figure 50. Example of completed project purpose listing form.

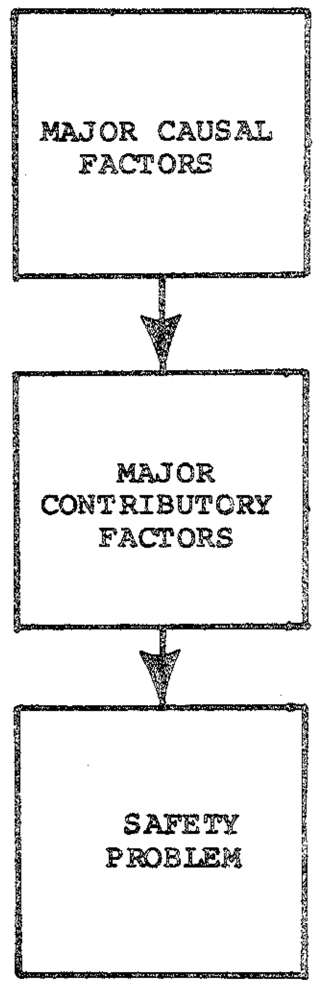

Figure 51. Chain of accident causality.

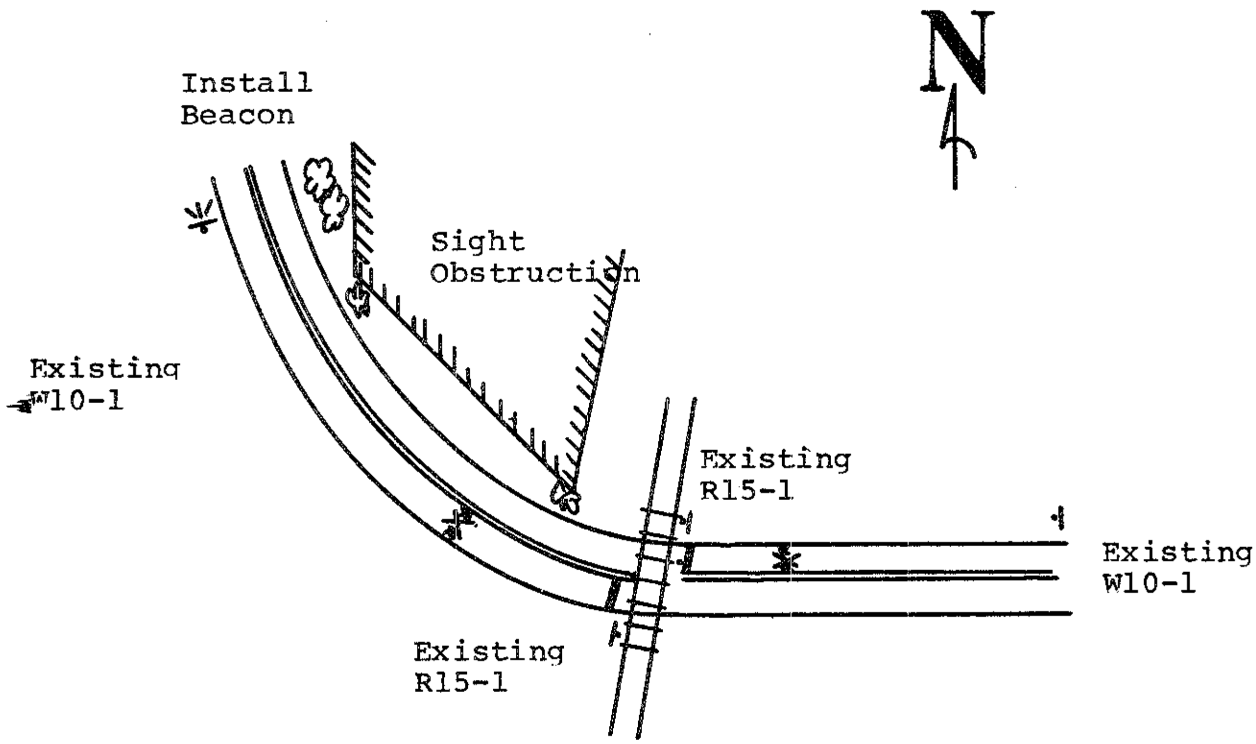

Figure 52. Site description of railroad/highway crossing example.

severity of vehicle-train accidents involving traffic approaching from the west.

The definition of the project and its purpose provide sufficient information to establish the chain of causality. The safety problem in this example is vehicle-train accidents, which specifically consists of two accidents involving two fatalities and five serious injuries during a two year period. The major causal factor is the failure of drivers on the west approach to perceive an occupied railroad crossing with sufficient time to stop and avoid an accident. The contributory causes are limited sight distance and excessive vehicular speed (for conditions) on the west approach to the crossing. Figure 53 shows the chain of accident causality for this example.

The evaluator must identify and record the intermediate objectives after establishing the chain of causality. This is accomplished by determining how each causal and contributory factor is affected by the introduction of the project.

Two types of project objectives are generated from this process; 1) intermediate objectives and 2) ultimate objectives. Intermediate objectives are short-term corrections or improvements in the causal and contributory factors. The underlying rationale of the approach is that if the intermediate objectives are acheived, the causal and contributing factors are eliminated, thereby eliminating the associated safety problem.

For the example involving the installation of the flashing beacon at the rail-highway crossing, the intermediate objectives were defined as 1) to reduce vehicle speeds between the flasher installation and the crossing, and 2) increase the frequency of drivers that visually check for oncoming trains. The ultimate goal is to reduce both the number and severity of vehicle-train accidents. Figure 54 illustrates the intermediate and ultimate objectives in relation to the chain of causality and the implementation of the project.

The chain of causality and associated intermediate and ultimate objectives should be developed for each project. The intermediate objectives should be recorded as evaluation objectives (see Accident-Based Evaluation), on the Intermediate Objectives and MOE Listing form shown in Figure 55 and provided in the Appendix.

Objectives such as: to determine the effect of the project on lane width, or: to determine the effect of the project on the number of advance warning signs on curves, should be avoided. These measures relate to countermeasures rather than the effect of the countermeasure and are not conducive to statistical analysis. These measures are generally addressed in Administrative Evaluation as opposed to Effectiveness Evaluation. In many cases, the types of objectives listed above can be translated into operational or behavioral objectives. For example, the first objective could be transformed to: to determine the effect of the project on the rate of vehicles running onto the shoulder or encroaching on an adjacent traffic lane. The second objective could be transformed into an objec-

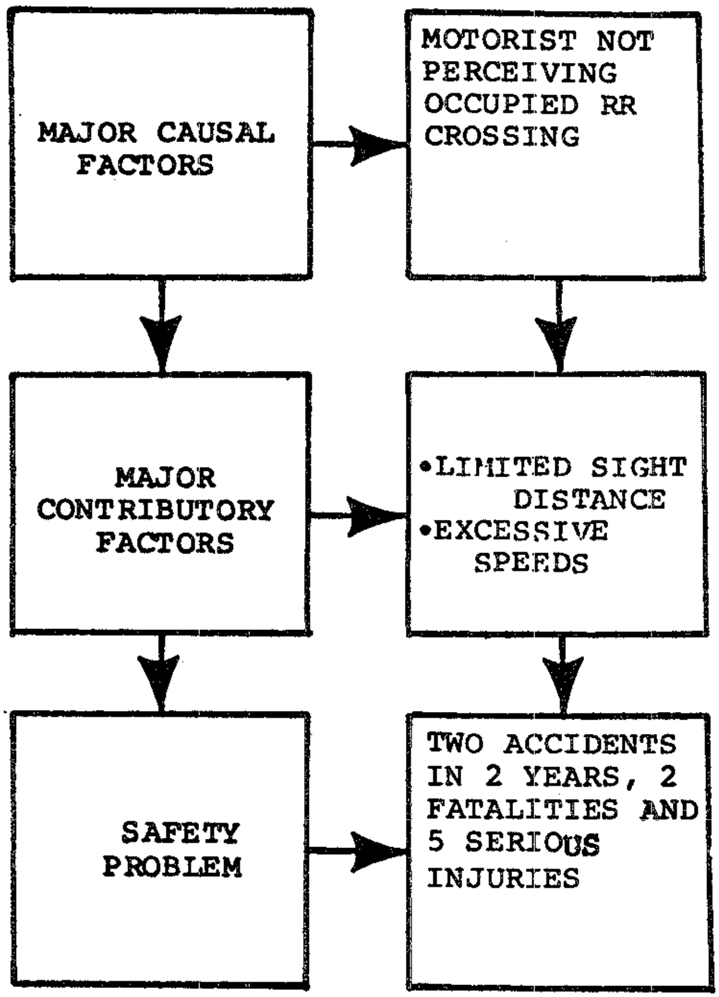

Figure 53. Example of chain of causality for a rail/highway safety project.

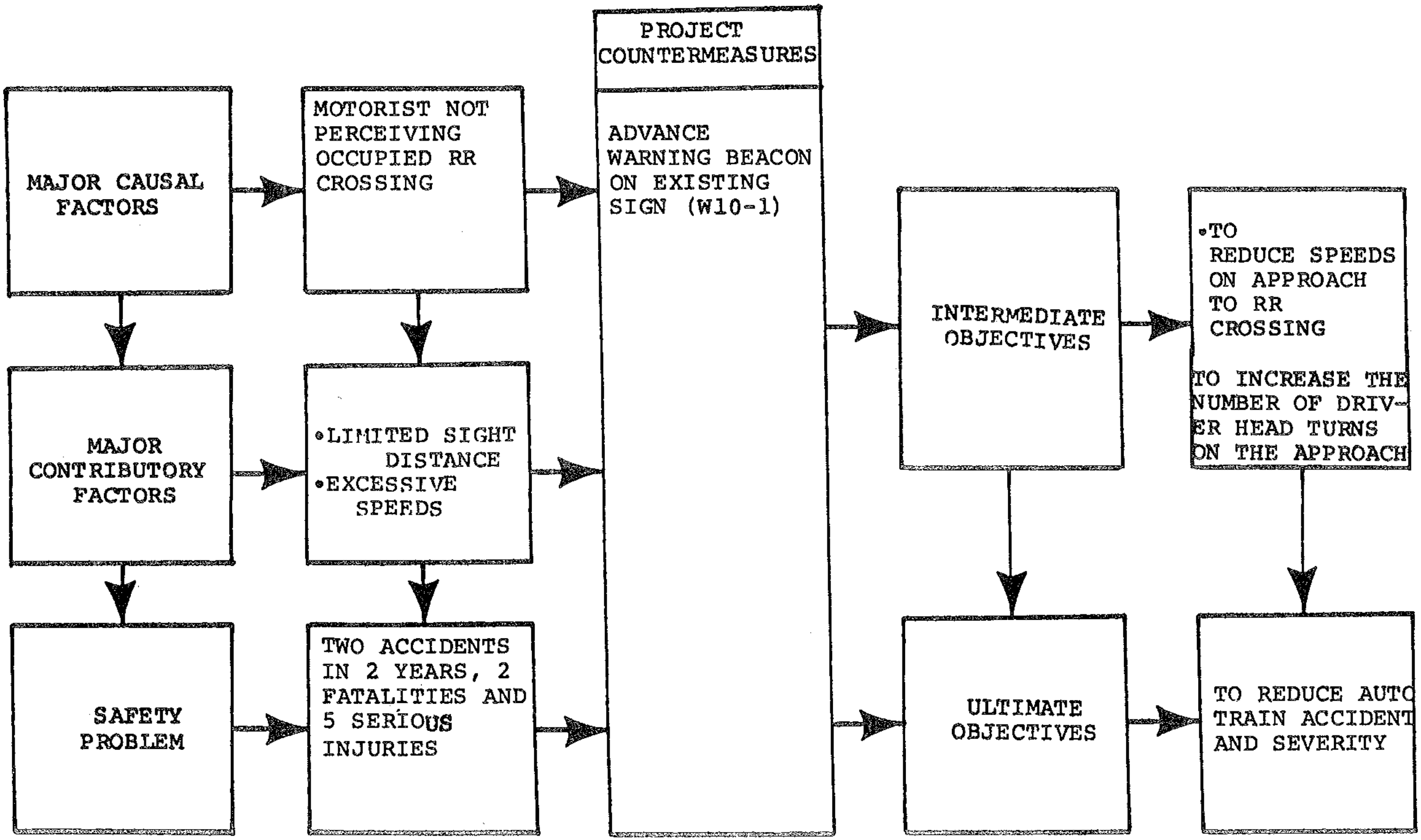

Figure 54. Completed chain of causality for rail/highway safety project.

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INTERMEDIATE OBJECTIVE
NON-ACCIDENT MOE LISTING

Evaluation No. ______________________

Date/Evaluator ______________________ **Checked by** ______________

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on:	Percent change in:
1.	1.
2.	2.
3.	3.
4.	4.

Figure 55. Intermediate objective and non-accident MOE listing form.

tive such as: to determine the effect of the project on vehicle speeds on the curves. Each of these objectives, logically related to accident occurrences, may be selected and statistically analyzed.

In addition, record an objective related to economic analysis contingent upon achieving a significant improvement in the non-accident MOE's.

Measures of Effectiveness

One or more MOE's must be specified for each intermediate objective. MOE's resulting from this process should be related to traffic operational or behavior characteristics which are expected to be affected by the project. MOE's expressed as frequency, rate, and/or percentage are appropriate.

The MOE should reflect the quantitative measurements and units to be taken in the field to evaluate each intermediate objective. The evaluator should be as specific as possible when listing the MOE's. It is suggested that the evaluator refer to the state-of-the-art of accident surrogate or proxy measures when selecting MOE's. As an example, a recently completed NCHRP Report (No. 219) lists specific traffic conflict types which may be affected by various safety improvements at signalized and unsignalized intersections (see Figures 56 through 58). Such information may provide valuable insight in selecting MOE's.

Figure 59 shows a completed Intermediate Objective and MOE Listing form for the example discussed in this step.

STEP A4 - SELECT EXPERIMENTAL PLAN

The experimental plans presented in Accident-Based Evaluation may be used in Non-Accident-Based Evaluation under the appropriate circumstances for each plan. However, because of the relatively short period of time between the before and after data collection periods and the requirement for developing the evaluation plan before project implementation, the simple before and after plan is appropriate under most conditions. The time period between the before and after data collection are generally only a few months (depending on the length of the construction period) as opposed to several years as required for Accident-Based Evaluation. Thus, it is not likely that significant changes other than the project itself will affect the MOE's and the results of the evaluation.

Evaluation plans involving control sites may be appropriate. If the time period between data collection periods becomes lengthy (i.e., more than one year), or if it is expected that atypical conditions may exist for either one or both periods, the control site experimental plans should be used. If only a subset of the identified locations are to be improved, the unimproved locations may serve as control sites for the evaluation. If control sites are required but not available, the evaluation should not be conducted and an Accident-Based Evaluation should be performed if feasible.

Improvement	Same Direction (Rear-End) Left-Turn	Same Direction (Rear-End) Right-Turn	Same Direction (Rear-End) Slow Vehicle	Same Direction (Rear-End) Lane Change	Same Direction (Rear-End) Total Rear-End	Opposing Left-Turn	Right Turn Cross Traffic From Left	Right Turn Cross Traffic From Right	Left Turn Cross Traffic From Left	Left Turn Cross Traffic From Right	Thru Cross Traffic From Left	Thru Cross Traffic From Right	Pedestrian
Add Signal	X	X			X				X	X	X	X	X
Left-Turn Bay	X					X							
Right-Turn Bay		X											
Right-Turn Radius or Roadway		X					X	X					
Pedestrian Barriers													X
Add Lanes	X	X	X		X		X						
Parking Restrictions	X	X											X
Improve Corner Sight Distance								X	X	X	X	X	X
Speed Zone	X	X	X		X			X	X	X	X	X	
Advance Warning or Sight Distance to Traffic Control	X	X	X		X			X					
Advance Street Name Sign	X	X	X		X								
Enforcement								X	X	X	X	X	

Figure 56. Possible conflict reduction measures for unsiganlized, 4-leg, 2-lane intersections.

Source: NCHRP 219

Improvement	Same Direction (Rear-End) Right Turn	Same Direction (Rear-End) Slow Vehicle	Same Direction (Rear-End) Lane Change	Same Direction (Rear-End) Total Rear-End	Right Turn Cross Traffic From Right	Left Turn Cross Traffic From Right	Pedestrian
Add Signal	X			X		X	X
Right-Turn Bay	X						
Right Turn Radius or Roadway	X				X		
Pedestrian Barriers							X
Add Lanes	X	X		X			
Parking Restrictions	X						X
Improve Corner Sight Distance					X	X	X
Speed Zone	X	X		X	X	X	
Advance Warning or Sight Distance to Traffic Control	X	X		X	X		
Advance Street Name Sign	X	X		X			
Enforcement					X	X	
RTOR Restrictions					X		

a/ Viewed from leg allowing thru and right-turn movements.

Figure 57. Possible conflict reduction measures for unsignalized, 3-leg, 2-lane intersections.

Source: NCHRP 219

Improvement	Same Direction (Rear-End): Left-Turn	Same Direction (Rear-End): Right-Turn	Same Direction (Rear-End): Slow Vehicle	Same Direction (Rear-End): Lane Change	Same Direction (Rear-End): Total Rear-End	Opposing Left-Turn	Right Turn Cross Traffic: From Left	Right Turn Cross Traffic: From Right	Left Turn Cross Traffic: From Left	Left Turn Cross Traffic: From Right	Thru Cross Traffic: From Left	Thru Cross Traffic: From Right	Pedestrian	Opposing RTOR
Left-Turn Bay	X			X		X								
Left-Turn Phase	X			X		X								
Left-Turn Restriction	X			X		X								
Right-Turn Bay		X		X										
Right-Turn Radius or Roadway		X		X			X	X						
Signal Cycle or Phase Length	X		X	X	X	X							X	
Actuated Signals								X	X	X	X	X		
Longer Amber or all Red Clearance					X			X	X	X	X	X		
RTOR Restrictions							X	X						X
Pedestrian Barriers													X	
Pedestrian Phase													X	
Add Lanes	X	X	X		X		X							
Parking Restrictions	X	X												
Install Median							X							
Improve Corner Sight Distance								X					X	
Speed Zone	X	X	X		X			X						
Advance Warning or Sight Distance Control	X	X	X	X	X			X						
Advance Street Name Sign	X	X	X	X	X									
Enforcement								X	X	X	X	X		

Figure 58. Possible conflict reduction measures for signlized, 4-leg, 4-lane intersections

Source: NCHRP 219

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INTERMEDIATE OBJECTIVE NON-ACCIDENT MOE LISTING

Evaluation No. 132

Date/Evaluator 9-14-79/DL Checked by LP

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on:	Percent change in:
1. Approach Speed (following sign)	1. Avg. speed 50' east of sign
2. Visual scan for approaching trains	2. No. of driver head turns on RR. approach

Figure 59. Sample objective and MOE listing form.

Generally, single point estimates are appropriate for all experimental plans. Trend analysis versions of experimental plans generally do not justify the added effort in data collection for this type of experimental plan.

STEP A5 - DETERMINE DATA NEEDS

A wider range of evaluation data may be required for this subprocess as opposed to Accident-Based Evaluation. Non-accident measures may range from traffic performance variables such as travel time, delay, and speeds to driver behavior variables such as traffic conflicts and erratic maneuvers.

The intermediate objectives and associated MOE's provide input to determining what types of field data are required. The evaluator should specify, to the extent possible, the exact type of data to be collected for each MOE and the data stratifications to be used for the collected data.

If an economic analysis is to be conducted, construction, maintenance and operating costs should be listed as data needs.

All data needs should be recorded on the Data Requirements Listing form contained in the Appendix.

STEP A6 - DETERMINE MAGNITUDE OF DATA REQUIREMENTS

The magnitude of data requirements refers to when the data are to be collected, how the data are to be collected, and how much data are required to obtain a statistically reliable sample. Information on these items are contained in many of traffic engineering references such as the ITE Manual of Traffic Engineering Studies and the ITE Traffic and Transportation Engineering Handbook. Excerpts from these and other references for commonly used traffic engineering studies which result in non-accident measures are provided below.

Spot Speeds

When? Off-peak periods:

9:00 A.M. to 11:30 A.M.
1:30 P.M. to 4:30 P.M.
7:00 P.M. to 10:00 P.M.

Data should be taken under favorable weather conditions and typical conditions. More than one day may be required for low-volume roads.

How? Manual method using stop watch and measured distance. Automatic method using electrical and/or mechanical devices (radar).

How Much? The following equation can be used to calculate the number of speeds to be measured:

$$N = \left(\frac{SK}{E}\right)^2$$

Where:

N = minimum sample size

S = estimated sample standard deviation (mph or kph)

K = constant corresponding to the desired confidence level (see Table 6)

E = permitted error in the speed estimate (mph or kph)

If the standard deviation of spot speeds at the study location has not been determined from a previous speed analysis, then an estimate for S can be made from Table 7.

Table 6. Constant corresponding to Level of Confidence.

Constant, K	Confidence Level (percent)
1.00	68.3
1.50	86.6
1.64	90.0
1.96	95.0
2.00	95.5
2.50	98.8
2.58	99.0
3.00	99.7

Table 7. Standard deviations of spot speeds for sample size determination.

Traffic Area	Highway Type	Average Standard Deviation	
		mph	kph
Rural	Two-lane	5.3	8.5
Rural	Four-lane	4.2	6.8
Intermediate	Two-lane	5.3	8.5
Intermediate	Four-lane	5.3	8.5
Urban	Two-lane	4.8	7.7
Urban	Four-lane	4.9	7.9
Rounded Value		5.0	8.0

If the statistic of interest is some value other than the mean speed, such as the 85th percentile speed, then the following formula is appropriate for determining the required sample size:

$$N = \frac{S^2K^2\ (2 + U^2)}{2E^2}$$

Where:

N = minimum sample size

S = estimated sample standard deviation (mph or kph)

K = constant corresponding to the desired confidence level

E = permitted error in the speed estimate (mph or kph)

U = constant corresponding to the desired speed statistic; mean speed, use 0.00

15th or 85th percentile, use 1.04

5th or 95th percentile, use 1.64

Travel Time and Delay

When? This study is often designed to reflect travel conditions during the peak hours and in the directions of heaviest traffic movements. Travel may also be compared between periods of peak and non-peak periods, although all of these time intervals are not required:

7:00 A.M. to 9:00 A.M. (peak)
9:30 A.M. to 11-30 A.M. (off-peak)
1:30 P.M. to 2:30 P.M. (off-peak)
4:00 P.M. to 6:00 P.M. (peak)
7:00 P.M. to 10:00 P.M. (off-peak)

Specific shift times at major industrial or commercial locations may require adjustments to the suggested time periods.

How? The license plate technique usually involves a two-person team, an observer and recorder, for each direction of travel at both the start and the end of the study route. Low volume routes may require only one person. A one- or two-person team for each direction of travel at each major intersection may be required where significant volumes of traffic are leaving the study route.

A study car is needed to collect the travel time and delay data by the test car method. Manual operation requires a driver, a recorder, and two stop watches for each test car in operation.

If an automatic recording device is used in the test car, then only the driver is needed. One person is generally able both to drive the vehicle and to operate the various control buttons that code the travel and delay information for the automatic recording device. Automatic recording devices are available for recording travel distance, travel time, and locations of delay or other significant points by a system of coded numbers that are imprinted on the continuous paper read-out.

How Much? The sample size for a travel time and delay study is based on the specific need for the information. The following suggested ranges of permitted errors in the estimate of the mean travel speed are related to the survey purpose:

1. Transportation planning and highway needs studies --- ± 3.0 to ± 5.0 mph (± 5.0 to ± 8.0 kph)

2. Traffic operation, trend analysis, and economic evaluations ---- ± 2.0 to ± 4.0 mph (±3.5 to ± 6.5 kph)

3. Before-and-after studies ---- ± 1.0 to ± 3.0 mph (± 2.0 to ± 5.0 kph)

The permitted error for other uses of travel time and delay results can be correlated with the above criteria to allow for the determination of minimum sample sizes.

Although the determination of sample size requirements is difficult for travel times or travel speeds, the information given in Table 8 provides an approximate value for designing travel time and delay studies. A sample size is determined for each direction of travel, and for each set of traffic and environmental conditions. The desired permitted error is first determined in accordance with the purpose of the study.

Intersection Delay

When? The intersection delay study should be performed during periods of congestion. Excessive delays generally occur during peak traffic periods which are identified from traffic counts. Intersection delay studies may be performed in off-peak periods to permit a comparative evaluation of the delay problem.

Table 8. Approximate minimum sample size requirements for travel time and delay studies with confidence level of 95.0 percent.

Average Range in Travel Speed (mph)	Minimum Number of Runs for Specified Permitted Error				
	±1.0 mph	±2.0 mph	±3.0 mph	±4.0 mph	±5.0 mph
2.5	4	2	2	2	2
5.0	8	4	3	2	2
10.0	21	8	5	4	3
15.0	38	14	8	6	5
20.0	59	21	12	8	6

Average Range in Travel Speed (kph)	Minimum Number of Runs for Specified Permitted Error				
	±2.0 kph	±3.5 kph	±5.0 kph	±6.5 kph	±8.0 kph
5.0	4	3	2	2	2
10.0	8	4	3	3	2
15.0	14	7	5	3	3
20.0	21	9	6	5	4
25.0	28	13	8	6	5
30.0	38	16	10	7	6

Source: ITE Manual of Traffic Engineering Studies, 4th Edition.

For before-and-after studies, similar conditions must exist at both times of data collection. Intersection delay studies should be performed in good weather and under normal traffic conditions. Observations are only made in inclement weather when it is necessary to determine delay characteristics under adverse conditions.

How? Intersection delay data can be collected by the manual method or with a delay meter that accumulates the number of vehicle-seconds of stopped-time delay. In most instances, one observer is required for each intersection approach that is being evaluated. If the traffic volume on the approach is too heavy for one observer to count and record, then other observers are assigned as needed or random samples are taken. For example, see the Berger-Robertson Method for measuring intersection delay.

Each observer requires a stop watch for the manual procedure. However, a delay meter or recorder is required for each observer if this equipment is available. Electric adding machines have been modified for the purpose of summing vehicle-seconds of delay.

How Much? The following equation provides a reasonable approximation of the minimum number of vehicles that should be observed on the selected intersection approach:

$$N = \frac{(1-p)\,X^2}{pd^2}$$

Where:

N = minimum sample size

p = proportion of vehicles that are required to stop on the intersection approach

X^2 = Chi-square value for the desired confidence level (see Table 9)

d = permitted error in the proportion estimate of stopping vehicles.

Sample size requirements are summarized in Table 10. The indicated sample is for each intersection approach that is to be evaluated and includes the sum of both the stopping and the non-stopping vehicles.

Traffic Conflicts

When? The conflict field study is usually performed during peak periods of traffic. Because directional distributions vary throughout the day, separate checks should be taken during the morning and the evening peak periods.

Table 9. Chi-Square value corresponding to the level of confidence.

Chi-Square X 2	Confidence Level (percent)
2.71	90.0
3.84	95.0
5.02	97.5
6.63	99.0
7.88	99.5

Source: ITE Manual of Traffic Engineering Studies, 4th Edition.

Table 10. Sample size requirements for intersection delay studies.

$(p = q = 0.5)$

Permitted Error, d	Confidence Level	
	90%	95%
5%	1080	1540
10%	270	380

Source: ITE Manual of Traffic Engineering Studies, 4th Edition.

Accident data or other information at some intersections may suggest obtaining conflicts at other times, such as during the early evening, or on Saturdays or Sundays.

Conflict studies are generally conducted in good weather and under normal traffic conditions. Counts are only made in inclement weather when data are required for such conditions. When an "after" study is performed, conditions, such as time, weather, volume, etc., must be similar to those in the "before" phase.

How? Counting of traffic conflicts is generally done by the manual method. An observer records conflicts and traffic volume at an intersection for one or more movements. If the volume is too large to permit one person to observe and record conflicts, separate observers may be assigned for each lane. Each observer must be equipped with the necessary volume and conflict count forms.

An agency should be aware that properly trained and experienced observers are necessary for success. Otherwise, inaccurate and unreliable data can be expected. Available options are: 1) contract such work with qualified consultants; or 2) train and maintain traffic technicians inhouse. The latter may be most cost effective if the use of conflict studies are to be widespread; the former may be more appropriate for occasional needs or unusual applications (e.g., nights or weekends).

How Much? The amount of data needed depends on the types of conflicts of interest, the traffic volumes, the type of intersection, and the precision required.

The following equation can be used to determine the minimum sample size:

$$N = \frac{pqK^2}{E^2}$$

Where:

N = minimum sample size

p = proportion of the vehicles that are involved in a specific traffic conflict for the observed flow of traffic.

q = 1-p

K = constant corresponding to the desired confidence level (Table 6)

E = permitted error in the proportion estimate of traffic conflicts

Table 11 provides additional guidance for sampling various types of conflicts.

The evaluator should specify, for each data item listed in STEP A5, the data collection procedures, the amount of data to be collected and when (to the extent possible) the data are to be collected. This information should be recorded on the Data Requirements Listing Form provided in the Appendix.

STEP A7 - PREPARE WRITTEN EVALUATION PLAN

An evaluation plan document should be prepared for each project to be evaluated. The plan document should summarize and specify the various decisions made and activities to be undertaken in the evaluation.

The Evaluation Plan should be similar to the plan document described in Accident-Based Evaluation and should include:

1) A Description of the Project(s)

   Describe the safety problems, project countermeasures and the reason for performing Non-Accident-Based Evaluation.

2) A Description of the Overall Evaluation Plan

   Include project purpose(s) and justification, intermediate evaluation objectives and non-accident MOE's.

3) An Outline of Evaluation Methods

   Clearly specify the experimental plan, measures of effectiveness, types of comparison employed and other details concerning data collection needs and procedures. The desirability and type of economic analysis and statistical testing should be addressed including values and assumptions.

   Appended to this document should be listings, forms and work sheets shown in the Appendix. These should be completed to the extent possible. All available data should be listed at the time the Plan is developed to facilitate later retrieval for subsequent evaluation activities.

Summary of FUNCTION A

STEP A1 - SELECT PROJECTS

- Review available documentation on highway safety projects programmed for implementation.

Table 11. Guidelines for traffic conflicts data collection amounts.

Conflict Category	Mean Hourly Count	Hours of Observation a/
Left-Turn, Same Direction	7.14	4.6
Right-Turn, Same Direction	4.89	5.1
Slow Vehicle	3.21	5.9
Opposing Left Turn	0.77	21.6
Right-Turn From Right	0.71	23.9
Cross Traffic From Right	0.31	39.3
Left-Turn From Right	0.59	24.5
Left-Turn From Left	0.78	18.1
Cross Traffic From Left	0.39	30.0
All Same Direction	15.48	3.4
All Cross Traffic From Left	0.82	20.0
All Cross Traffic From Right	1.45	14.8

a/ Hours of data required to estimate mean hourly count within ± 50% with 90% confidence.

Source: NCHRP 219

- Select specific projects which warrant Non-Accident-Based Evaluation.
- Determine the project purposes and list the specific accidents or accident potential problems.
- List the project purposes and justification for their selection on the provided form and save the form for future reference.

STEP A2 - STRATIFY PROJECTS

- Group similar countermeasures which are to be implemented at locations with similar site characteristics as a single project.
- If larger groups of projects result, sample the projects to be evaluated (if desired).
- List the projects to be evaluated.

STEP A3 - SELECT SAMPLED OBJECTIVES AND NON-ACCIDENT MOE'S

- Determine major causal and contributory factors for the safety problem to be corrected.
- Develop the chain of causality.
- Identify the intermediate objectives of the evaluation.
- Select non-accident MOE(s) for intermediate objectives.
- List intermediate objectives and non-accident MOE's on the provided form and save for future reference.

STEP A4 - SELECT EXPERIMENTAL PLAN

- Select the experimental plan based on the soundness of the experimental plan and the feasibility of its use.

STEP A5 - DETERMINE DATA VARIABLES TO BE COLLECTED

- Determine all data variables associated with the non-accident MOE's of the evaluation.
- List the variables on the provided form.

STEP A6 - DETERMINE MAGNITUDE OF DATA NEEDS

- Determine for each variable listed in STEP A5, the data collection procedure, the amount of data to be collected and when the data are to be collected.

- List the information on the form provided and save for future reference.

STEP A7 - PREPARE WRITTEN EVALUATION PLAN

- Assemble all completed forms, data, listings and other items used or developed in FUNCTION A.
- Prepare a written description of the project(s).
- Prepare a written outline of the evaluation plan.
- Prepare a written description of the anticipated method of analysis.
- Combine these descriptions into an Evaluation Plan document.
- Save the evaluation plan document for future reference.

Example of FUNCTION A

The City Engineer for Walkertown has programmed a highway safety project to reduce the number of pedestrian-auto accidents at five urban intersections. Project implementation is scheduled to start in 6 months. Each intersection is signalized for both vehicle and pedestrian traffic.

The project involves implementing an identical countermeasure at each of the five intersections. The countermeasure is the standardization of pedestrian signal indications from a two-phase operation (steady WALK (W) and DON'T WALK (DW) only) to a three-phase operation with a flashing DON'T WALK (FDW) clearance indication as recommended in the Manual of Uniform Traffic Control Devices (MUTCD). (The existing DW phase includes the pedestrian clearance interval).

The project was justified because of the high frequency of pedestrian-auto accidents occurring at the intersections over the last two years. During the period, each intersection experienced over 10 pedestrian accidents per year. Engineering studies conducted at the intersections resulted in the conclusion that the majority of accidents involved pedestrian violation of DW phase. It was felt that the FDW clearance interval would reduce violations by providing an advance indication of the DW phase. The addition of FDW would also reduce confusion associated with combined DW and clearance phases.

The decisions and activities involved in developing an evaluation plan for this project are described in the following steps:

STEP A1 - SELECT PROJECTS

At the time the project was programmed for implementation, it was decided that Accident-Based Evaluation would be conducted to determine the impact of the project on reducing pedestrian-auto accidents. It was estimated that a two year period following project implementation would be required to establish a representative "after" accident experience. Before the Accident-Based Evaluation can be conducted, the City Traffic Safety Council is planning to conduct a media campaign on pedestrian safety. In conjuction with this campaign, the City Engineer has been asked to provide input on past and upcoming pedestrian safety improvements in the City. To satisfy this request, the Engineer has decided to conduct a Non-Accident-Based Evaluation of the upcoming pedestrian signal improvement project. Sufficient time is available to perform the evaluation before the campaign is started and the campaign will not affect the outcome of the Non-Accident Evaluation.

The purpose of the project was determined to be: to reduce pedestrian-auto accidents at the five intersections treated with the pedestrian signal improvement countermeasure. The purpose was recorded in the Project Purpose Listing Form (Figure 60).

STEP A2 - STRATIFY PROJECTS

The project consists of adding a FDW phase at twenty intersection approaches to five urban intersections. All approaches were similar with respect to width, parking regulations, approach speeds, and pedestrian and vehicle volumes. It was decided that a statistically representative group of the approaches should be sampled to reduce data collection time required. The sampling was performed on the basis of total pedestrian accident frequency for two years for each approach.

Page 1 of 1

PROJECT PURPOSE LISTING

Evaluation No. 80-12-4

Date/Evaluator 5-27-80/GH Checked by HQ

Project No. 80-12-4-p

Project Description and Location(s) Pedestrian signalization improvements at five (5) downtown intersections

Countermeasure(s)/Codes Add flashing don't walk phase at 20 approaches to each of 5 intersections/

Project Purpose	Justification
1. To reduce pedestrian auto	1. Over 10 pedestrian-auto
accidents at 5 downtown	accidents per year have
intersections	occurred
	During the period 1977-1979
2. To reduce the frequency of pedestrian signal	2. Probable cause of pedestrian accidents is violation of
violations	don't walk phase. The additions of a clearance
	phase is expected to reduce violations.

Figure 60. Project purpose listing for FUNCTION A example.

Total two-year pedestrian accident frequencies aggregated by approach are:

Intersection	Approach	Two Year Accident Frequency
1. (Oakmont - 5th)	North	10
	East	3
	South	8
	West	5
2. (Allen - 4th)	North	0
	East	5
	South	11
	West	12
3. (Montcalm - 7th)	North	1
	East	8
	South	6
	West	6
4. (Edgemont - 4th)	North	14
	East	3
	South	2
	West	6
5. (Elm-Oakmont)	North	8
	East	9
	South	2
	West	10

The following equation was used to determine the sample size for the 95% level of confidence with an allowable departure from the mean accident frequency (E) of 3 accidents.

$$n_s = \frac{4\sigma^2}{E^2}$$

Where:

n_s = sample size
σ = standard deviation of groups
E = allowable departure from mean accident frequency

$$n_s = \frac{4(3.89)^2}{(3)^2}$$

$$= 6.71 \text{ or } 7$$

The following seven approaches were randomly selected from the list of twenty approaches using the random number table.

Intersection	Approach	Two-Year Accident Frequency
1	South	8
2	North	0
	East	5
	West	12
3	West	6
4	South	2
	West	6

The seven approaches listed above represent a statistically representative sample of the twenty approaches and will serve as the data collection sites for the evaluation.

STEP A3 - SELECT INTERMEDIATE OBJECTIVES AND NON-ACCIDENT MOE'S

The chain of accident causality shown in Figure 61 resulted in the selection of the objectives and MOE's listed in the Intermediate Objective and Non-Accident MOE Listing Form (Figure 62).

STEP A4 - SELECT EXPERIMENTAL PLAN

The before-after experimental plan was selected as the most feasible plan. The selection of this plan was based on the fact that control sites were not available and that reliable data on the MOE's could be collected and analyzed for the seven approaches with existing manpower.

STEP A5 - DETERMINE DATA NEEDS

The data variables to be collected for this evaluation were recorded in the Data Requirements Listing Form shown in Figure 63.

STEP A6 - DETERMINE MAGNITUDE OF DATA REQUIREMENTS

Figure 63 also describes the sample sizes required for each data variable to be collected. The sample size requirements were based on recommendations found in the reference, Model Pedestrian Safety Program Users' Manual, 78-6 Implementation Package, Federal Highway Administration, June 1978, Table 5-4, page 216.

STEP A7 - PREPARE WRITTEN EVALUATION PLAN

The evaluation plan document shown on the following pages was prepared for the evaluation study.

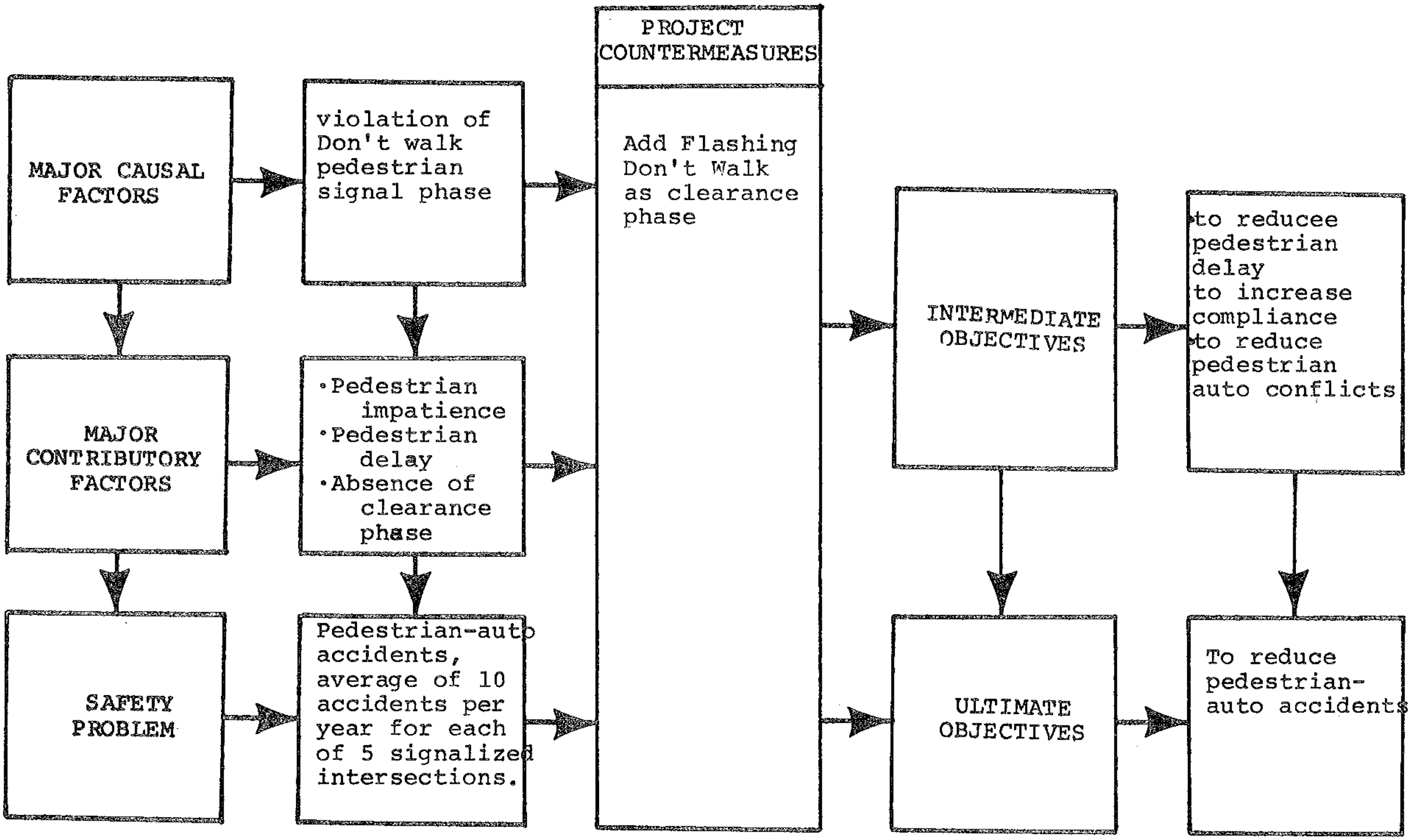

Figure 61. Chain of causality.

INTERMEDIATE OBJECTIVE NON-ACCIDENT MOE LISTING

Evaluation No. 80-12-4

Date/Evaluator 5-27-80/GH Checked by HQ

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on:	Percent change in:
1. Pedestrian Delay	1. a) Total pedestrian delay (seconds)
	b) Total intersection delay (seconds)
2. Pedestrian Compliance	2. a) Number and percent of DW violations
	b) Number and percent of FDW violations
3. Pedestrian-Auto Conflicts	3. Number and percent of:
	a) pedestrian backup or hesitation
	b) Moving vehicle and pedestrian occupying crosswalk at same time.
	c) pedestrian within 20' of turning vehicle
	d) pedestrian entering traffic lane with vehicle approaching that is unrestricted by traffic signal.
	e) pedestrian running due to (d) above.
	f) pedestrian running due to (c) above

Figure 62. Objective and MOE listing for FUNCTION A example.

DATA REQUIREMENTS LISTING

Evaluation No. 80-12-4

Date/Evaluator 5-27-80/GH **Checked by** HQ

Experimental Plan Before - After

Data Needs	Magnitude (Number of Sites, Time Period, Dates)
1. Pedestrian Delay	1. Collect pedestrian delay at the 7 sampled approaches at least two weeks before and following a 4 week adjustment period after implementation. Collect pedestrian delay for four hours for each approach on three consecutive days (Tuesday, Wednesday, & Thurs.) before and after project implementation. Use manual method and stopwatch and perform survey during midday peak period (11:30 am - 1:30 pm). Perform the survey during favorable weather.
2. Vehicle Delay	2. Collect vehicle delay during same time periods as in 1 above. Use manual method and stop watch.
3. Pedestrian Compliance	3. Record DW and FDW violations for at least 50 pedestrians at each approach. Collect during peak and off peak periods manually record violations.

Figure 63. Data requirements listing for FUNCTION A example.

DATA REQUIREMENTS LISTING

Evaluation No. 80-12-4

Date/Evaluator 5-27-80/GH Checked by HQ

Experimental Plan Before - After

Data Needs	Magnitude (Number of Sites, Time Period, Dates)
4. Pedestrian-Auto Conflicts	4. Record at least 30 conflicts of each type at all 7 approaches and corresponding pedestrian crossing volumes (opportunities). Collect during peak-periods.
	Manually record conflicts

Figure 63. Data requirements listing for FUNCTION example (continued).

EVALUATION PLAN

TITLE: Standardization of Pedestrian Signal Phases at Five Downtown Intersections

Date/Evaluation: May 27, 1980, GH Checked by: HQ

Evaluation: 80-12-4

DESCRIPTION OF THE SAFETY PROBLEM

A review of annual accident experience over the past two years revealed a high frequency of pedestrian-auto accidents occurring at five major downtown intersections. During the period, each intersection experienced over 10 pedestrian accidents per year. Engineering studies conducted at the intersections resulted in the conclusion that the majority of accidents involved pedestrian violation of the DW phase as a probable contributing factor.

DESCRIPTION OF THE PROJECT

The project involves implementing an identical countermeasure at each of the five intersections. The countermeasure was standardization of pedestrian signal indications from a two-phase operation (steady WALK (W) and DON'T WALK (DW) only) to a three-phase operation with a flashing DON'T WALK (FDW) clearance indication as recommended in the Manual of Uniform Traffic Control Devices (MUTCD).

EVALUATION PLAN STEPS

STEP A1 - SELECT PROJECTS

The project was selected for evaluation with both the Accident and Non-Accident-Based Evaluation subprocess. The Non-Accident-Based Evaluation is being performed to provide input to a pedestrian safety media campaign. The anticipated starting date for the campaign does not allow for the Accident-Based Evaluation to be performed prior to the start of the campaign.

The project purpose was determined to be:
To reduce pedestrian-auto accidents and pedestrian violations at the five intersections treated with the pedestrian signalization improvements (refer to Figure 60 for Project Purpose Listing).

STEP A2 - STRATIFY PROJECTS

The project involved improving pedestrian signalization across 20 intersection approaches at five urban intersections. All approaches were determined to be similar in geometry and vehicle and pedestrian traffic characteristics. To minimize data collection efforts, seven approaches were randomly sampled from the twenty treated approaches. The seven approaches were determined to be representative of the twenty approaches at the 95% level of confidence.

The approach selected for data collection are:

Oakmont - 5th, South approach

Allen - 4th, North, East and West approaches

Montcalm - 7th, West approach

Edgemont - 4th, South and West approaches

STEP A3 - SELECT INTERMEDIATE AND NON-ACCIDENT MOE'S

The evaluation objectives and MOE's are shown in Figure 62. The selection of these objectives and MOE's was based on the development of the causal chain of events leading to the observed accident problem (Figure 61).

STEP A4 - SELECT EXPERIMENTAL PLAN

The before-after plan was selected because control sites were unavailable.

STEP A5 - DETERMINE DATA NEEDS

The evaluation data needs are recorded in the Data Requirements Listing Form (Figure 63)

STEP A6 - DETERMINE THE MAGNITUDE OF DATA REQUIREMENTS

The sample size, data collection periods and collection procedures are listed in Figure 63 for each data requirement.

FUNCTION B: Collect and Reduce Non-Accident Data

This function enables the evaluator to:

1. Select and perform data collection techniques.

2. Perform data reduction and analysis activities to obtain MOE's.

Overview

This function presents field data collection and reduction guidelines and suggested procedures for obtaining the evaluation data needs specified in FUNCTION A. Because many types of field data may be needed for the evaluation, traffic engineering handbooks, manuals and reports should be consulted to determine the specific activities to be performed in this function.

Field data are required to develop the MOE's defined in the previous function. An analysis of the magnitude and statistical significance of observed changes in MOE's provide the basis for conclusions on intermediate project effectiveness.

This function requires field data collectors and basic traffic engineering data collection equipment. The number and level of involvement of field personnel varies with the type of field survey to be conducted as does the type of equipment. Generally, the evaluator has 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.

STEP B1 - SELECT CONTROL SITES (IF REQUIRED)

When an experimental plan is selected which requires control sites, data on key variables must be collected and analyzed. These data are required to select appropriate control sites which are similar to the project site before the improvement.

Any control site selected for this subprocess must be appropriate for subsequent Accident-Based Evaluation. Therefore, the guidelines for selecting control sites provided in FUNCTION B of Accident-Based Evaluation should be followed.

STEP B2 - COLLECT AND REDUCE NON-ACCIDENT DATA

A broad range of possible non-accident safety measures may require field data collection depending on the type of project, the MOE's and associated data requirements.

Traffic engineering studies which may be performed to obtain the non-accident measures may include the following (possible non-accident measures are listed for each study):

Traffic Volume Study - Performed to obtain values of average daily traffic, peak hour traffic volumes, turning movements, and intersection approach volumes.

Spot Speed Studies - Performed to obtain average and 85th percentile speeds, speed variance, and number of speed violators.

Travel Time and Delay Studies - Performed to obtain values of travel time between two points, route efficiency, number of stops, stopped time delay, total travel time delay, average speed between two points, service volumes, and capacities.

Intersection Delay Studies - Performed to obtain values of intersection efficiency, total intersection delay, average delay per stopped vehicle, average delay per approach vehicle, and percent of vehicles stopped.

Traffic Conflicts and Erratic Maneuvers Studies - Performed to obtain, observe, and record the number, type, rate, and percentage of evasive maneuvers, traffic violations and/or other traffic behavior measures.

Gap Studies - Performed to obtain the number and length of gaps in the traffic stream which are acceptable or unacceptable for certain traffic maneuvers.

Traffic Lane Occupancy Studies - Performed to obtain the percentage of time during which a point on either an intersection approach or section of roadway is occupied.

Queueing Studies - Performed to obtain the average queue length and waiting time at intersections and driveways.

School Crossing Studies - Performed to obtain the number and percentages of acceptable gaps, and school crossing behavior and compliance.

Traffic Control Observance Study - Performed to observe and record violations, compliance and behavior characteristics of traffic control devices at all types of locations.

Most engineering studies may be performed using manual or automatic procedures and equipment. This provides a high degree of flexibility and allows the study to be tailored to the available resources and equipment of the agency.

A detailed description of the alternative procedures associated with all possible field studies is beyond the scope of this Procedural Guide. Therefore, the evaluator is directed to the existing state-of-the-art on traffic engineering field studies for detailed information of data collection procedures. Table 12 provides suggested references on the traffic engineering field studies listed in this Step. Each reference has been categorized as a procedural or informational reference (denoted by P or I, respectively). Procedural references provide information on how to perform the study, what equipment is required and how raw data are reduced. Informational references provide details on specific aspects of the study procedure or the use of the resulting data.

STEP B3 - COLLECT AND REDUCE PROJECT COST DATA

Economic analysis should be performed for this type of evaluation. Sources of cost data include project files, invoice files, or the results of an Administrative Evaluation performed for the project. All cost data specified in STEP A5 should be obtained and recorded for later use. The Administrative Evaluation subprocess is recommended for determining project cost and other implementation information.

Summary of FUNCTION B

STEP B1 - SELECT CONTROL SITES

- Select control sites if required for the experimental plan selected in FUNCTION A, and if sites are available.

STEP B2 - COLLECT AND REDUCE NON-ACCIDIENT DATA

- Collect required non-accident data as specified in the Evaluation Plan.
- Reduce data to the form of the evaluation MOE's.

STEP B3 - COLLECT AND REDUCE PROJECT COST DATA

- Collect required project cost data as specified in the Evaluation Plan. The Administrative Evaluation subprocess is recommended.

Table 12. Summary of field data collection references.

REFERENCES \ DATA COLLECTION PROCEDURES	Volume Studies	Spot Speed Studies	Travel Time and Delay Studies	Intersection Delay Studies	Roadway and Intersection Capacity Studies	Traffic Conflict and Erratic Maneuvers Studies	Gap Studies	Traffic Lane Occupancy Studies	Queue Length Studies	School Crossing Studies	Traffic Control Device Observance Studies
Institute of Traffic Engineers, Transportation and Traffic Engineering Handbook, Prentice-Hall, Inc. (1976)	I	I	I	I	I	I	I	I	I	I	I
Pignataro, Louis J., Traffic Engineering: Theory and Practice, Prentice-Hall, Inc. (1973)	PI	PI	PI	PI	PI						
U.S. Department of Transportation, Federal Highway Administration, Traffic Control Systems Handbook (1976)		I	I	I	I		I	I	I		
Institute of Transportation Engineers, Manual of Traffic Engineering Studies (1968)	P	P	P	P		P					
ITE Technical Committee 7-G, "Volume Survey Devices", Traffic Engineering, March 1961	I										
ITE Informational Report, "Detector Locations," Traffic Engineering, (1969)	PI	PI						PI	PI		
ITE Informational Report, "Data Collection Guidelines and Analysis Techniques, Part I, Traffic Engineering, May (1975)	I	I	I	I							
Byrnes, Bernard F., Roberts, Robert R., King L., Ellis, and Arbogast, Ronald G. "Testing of the Tapeswitch System for Determining Vehicle Speed and Lateral Placement" Transportation Research Record No. 615. (1976)	I	I					I	I	I		
Prieto, E.L., and Mulinazzi, T.E., "Traffic Volume Counting Recorders," Transportation Engineering Journal of ASCE, p. 211, (1975)	I										
Covault, "Time-Lapse Movie Photography Used to Study Traffic Flow Characteristics," Traffic Engineering, March 1960	PI	PI	PI	PI			PI	PI	PI	PI	
Cyra, David J., "Traffic Data Collection Through Aerial Photography", Transportation Research Record No. 375, (1971)	I	I	I	I			I	I	I		
Welz and White, "Short Count Results" Traffic Engineering, 1948	PI										
Kunzman, "A Simplified Procedure to Determine Factors for Converting Volume Counts to ADT's," Traffic Engineering, October 1976	I										
Russell, Eugene R., Butcher, Thomas, and Michael, Harold L., "A Quick Inexpensive Data Collection Technique for Approach Speed Analysis," Traffic Engineering, May 1976		PI									
Oppenlander, J.C., "Sample Size Determination for Spot-Speed Studies at Rural, Intermediate and Urban Locations, Highway Research Record No. 35, pp. 78-80, 1963		I									

Table 12. Summary of field data collection references (continued).

DATA COLLECTION PROCEDURES / REFERENCES	Volume Studies	Spot Speed Studies	Travel Time and Delay Studies	Intersection Delay Studies	Roadway and Intersection Capacity Studies	Traffic Conflict and Erratic Maneuvers Studies	Gap Studies	Traffic Lane Occupancy Studies	Queue Length Studies	School Crossing Studies	Traffic Control Device Observance Studies
Oppenlander, J.C., "Sample Size Determination for Travel Time and Delay Studies," Traffic Engineering, September 1976			I								
Technical Council Committee-4H-M, "Areawide Traffic Performance Evaluation Measures," Traffic Engineering, September 1975	I	I	I	I	I						
Reilly, W.R., Gardner, C.C., and Kell, J.H., "A Technique for Measurement of Delay at Intersections," Vols. 1,2, & 3, FHWA-RD-76-135,136,137, (1976)				P I							
Robertson, H.D., and Berger, W.G., "Berger-Robertson Method for Measuring Intersection Delay," Transportation Research Record, No. 615 (1976)				P I							
Messer, Carroll B., and Fambro, Daniel B. "Critical Lane Analysis for Intersection Design," Transportation Research Record No. 644 (1977)					P I						
McInerney, H.B., and Petersen, S.G., "Intersection Capacity Measurement through Critical Movement Summations: a Planning Tool," Traffic Engineering, January 1971					P I						
Leisch, "Capacity Analysis Techniques for Design of Signalized Intersections," Installment No. 1, Public Roads, Aug. 1967					P I						
Leisch, "Capacity Analysis Technique for Design of Signalized Intersections," Installment No. 2, Public Roads, Oct. 1967					P I						
"Interim Materials on Highway Capacity" Transportation Research Board Circular 212, 1980					P I						
Baker, William, T., "Evaluating the Traffic Conflicts Technique," Federal Highway Administration (1971)						I					
Perkins, S.R. "GMR Traffic Conflicts Technique Procedures Manual," General Motors Research Publication GMR-895, August, 1969						P					
Hauer, Ezra, "The Traffic Conflicts Technique - Fundamental Issues, "University of Toronto, Dept. of Civil Engineering, January, 1975						I					
Glauz, W.D., and Migletz, D.J., "Application of Traffic Conflict Analysis at Intersections", NCHRP No. 219, February, 1980						P I					
Zegeer, C.V., and Deen, R.C., "Traffic Conflicts as a Diagnostic Tool in Highway Safety," Transportation Research Record No. 667, 1978						P I					
"Evaluation of the Traffic Conflicts Technique," Midwest Research Institute, FHWA (DOT-FH-11-8121), December, 1975						I					
Drew, Donald R., "Traffic Flow, Theory and Control," McGraw-Hill, Inc. 1968							I	I	I		

Table 12. Summary of field data collection references (continued).

DATA COLLECTION PROCEDURES / REFERENCES	Volume Studies	Spot Speed Studies	Travel Time and Delay Studies	Intersection Delay Studies	Roadway and Intersection Capacity Studies	Traffic Conflict and Erratic Maneuvers Studies	Gap Studies	Traffic Lane Occupancy Studies	Queue Length Studies	School Crossing Studies	Traffic Control Device Observance Studies
"A Program for School Crossing Protection," Institute of Traffic Engineers, 1962										PI	
"Traffic Safety Planning on School Sites," Institute of Transportation, Engineers, 1978										I	
"School Zone Hazard Rating," ITE Technical Notes, December, 1978										P	
Walton, George T., "School Crossing Guard Index," ITE Technical Notes, March, 1977										P	
"A User's Guide to Positive Guidance," Federal Highway Administration, Contract No. DOT-FH-11-8864, 1977											PI
David K. Witheford "Speed Enforcement Policies and Practicies," ENO Foundation for Transportation, 1970											I
U.S. Department of Transportation, Federal Highway Administration, Manual of Uniform Traffic Control Devices, Washington, D.C., U.S. Government Printing Office (1971)											I
Highway Research Board, Highway Capacity Manual, Washington, D.C., U.S. Government Printing Office Special Report No. 87 (1965)					PI						

FUNCTION C: Compare Non-Accident MOE's

This function enables the evaluator to:

1. Prepare non-accident MOE summary tables
2. Calculate percentage changes in the non-accident MOE's.

Overview

This function presents organizational and computational procedures for determining the change in the non-accident MOE's. Intermediate project effectiveness, as defined by a change in non-accident MOE's, is the percentage by which the expected value of the MOE differs from the value of the MOE observed following implementation of the project. This change provides an indication of the practical significance of the project. The method for determining the expected MOE and the percent change differs according to the experimental plan selected for the evaluation. The computational methods described in FUNCTION C of Accident-Based Evaluation are appropriate for this type of evaluation.

STEP C1 - PREPARE DATA SUMMARY TABLES

Non-accident MOE's data should be tabulated on the provided summary table which corresponds to the experimental plan selected for the evaluation. Figure 64 shows the general format of the summary of tables while Figures 65 through 68 illustrates modified versions of the summary table for before-after with control sites, before-after, comparative parallel and the before-during-after studies respectively.

STEP C2 - CALCULATE THE CHANGE IN THE NON-ACCIDENT MOE'S

This step requires that two computations be performed. The first is to compute the expected value of the MOE's if the project had not been implemented, E. The second is to compute the percent change in the MOE's between expected and after MOE values. The computational procedures for determining these quantities differ for each experimental plan.

Before-After with Control Sites

$$E = B_P(A_C/B_C)$$

Where:

E = Expected non-accident MOE at the project site if the improvement had not been made

B_P = Before MOE at the project site

A_C = After MOE at the control site(s)

Page ______ of ______

NON-ACCIDENT-BASED
MOE DATA COMPARISON WORKSHEET

Evaluation No. ______________________________

Date/Evaluator ______________________________ Checked by ____________

Experimental Plan ____

	Control		Project		Expected MOE	Percent Reduction
	Before	After	Before	After		
MOE	B_C	A_C	B_P	A_P	E	(%)

Figure 64. General form of the MOE comparison worksheet.

Page ______ of ______

NON-ACCIDENT-BASED
MOE DATA COMPARISON WORKSHEET

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by __________

Experimental Plan ______________________________

	Control		Project		Expected MOE	Percent Reduction
	Before	After	Before	After		
MOE	B_C	A_C	B_P	A_P	E	(%)

Figure 65. MOE comparison worksheet for before and after with control sites.

NON-ACCIDENT-BASED
MOE DATA COMPARISON WORKSHEET

Evaluation No. ______________________________
Date/Evaluator ______________________________ Checked by ____________
Experimental Plan ____

	Control		Project		Expected MOE	Percent Reduction
	Before	After	Before	After		
MOE	B_C	A_C	B_P	A_P	E	(%)

Figure 66. MOE comparison worksheet modified for before and after plan.

Page ______ of ______

NON-ACCIDENT-BASED
MOE DATA COMPARISON WORKSHEET

Evaluation No. ______________ ________
Date/Evaluator ________________________ Checked by __________
Experimental Plan ____

	Control		Project		Expected MOE	Percent Reduction
	Before	After	Before	After		
MOE	B_C	A_C	B_P	A_P	E	(%)

Figure 67. MOE comparison worksheet modified for comparative parallel plan.

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NON-ACCIDENT-BASED
MOE DATA COMPARISON WORKSHEET

Evaluation No. ______________________________

Date/Evaluator ______________________________ Checked by ____________

Experimental Plan ______________________________________

During Project

	~~Control~~		Project		Expected MOE	Percent Reduction
	~~Before~~	~~After~~	Before	After		
MOE	~~B_C~~	~~A_C~~	B_P	A_P	E	(%)

Figure 68. MOE comparison worksheet modified for before, during and after plan.

B_C = Before MOE at the control site(s)

and

Percent Change = [(E-Ap)/E)]100

Where:

E = Expected non-accident MOE at the project site if the improvement had not been implemented

A_P = After MOE at the project site.

Before-After Study

$E = B_P$

Where:

E = Expected non-accident MOE at the project site if the improvement had not been made

B_P = Before MOE at the project site

and

Percent Change = [(E-Ap)/E]100

Where:

E = Expected MOE at the project site if the improvement had not been made

A_P = After MOE at the project site

Comparative Parallel Study

$E = A_C$

Where:

E = Expected non-accident MOE at the project site if the improvement had not been made

A_C = After MOE at the control site(s)

and

Percent Change = [(E-Ap)/E)]100

Where:

E = Expected non-accident MOE at the project site if the improvement had not been made

A_P = After MOE at the project site

Before-During-After Study

As in Accident-Based Evaluation, there are three possible conditions that may be encountered in this experimental plan:

A. The MOE value after the project is completed and removed is lower than the MOE value before project implementation.

B. The MOE value after the project is completed and removed is higher than the MOE value before project implementation.

C. The MOE value after the project is completed and removed is the same or nearly the same as the MOE value before project implementation.

If either condition A or B is indicated, there is an implied residual effect from the temporary project. If condition C is indicated, it implies that there is no residual effect from the temporary project. The impact of the temporary project on the MOE's is assessed using three separate computations similar to the before-after study computations. The first measures the effect of the project by comparing the before MOE to the during MOE. The second measures the effect of the project by comparing the after MOE condition to the during MOE. The third measures the residual effect of the project using before and after MOE's only, neglecting MOE's during project implementation.

To compare the <u>during and before</u> MOE's,

$$E = Bp$$

Where:

E = Expected non-accident MOE if the improvement had not been implemented

Bp = Before MOE at the project site

and

Percent Change = [(E-Dp)/E]100

Where:

E = Expected non-accident MOE if the improvement had not been implemented

Dp = During MOE at the project site

To compare the <u>after and during</u> MOE's,

$$E = Dp$$

Where:

E = Expected non-accident MOE if the improvement had not been removed

Dp = During MOE at the project site

and

Percent Change = [(E-Ap)/E)]100

Where:

E = Expected non-accident MOE if the improvement had not been removed

A_p = After MOE at the project site

To compare the before and after (residual effect) MOE's,

$$E = B_p$$

Where:

E = Expected non-accident MOE if the improvement had not been made

B_p = Before MOE at the project site

and

$$\text{Percent Change} = [(E-A_p)/E]100$$

Where:

E = Expected non-accident MOE if the improvement had not been made

A_p = After MOE at the project site

Calculated values of the expected MOE's and percent changes should be recorded on the Non-Accident MOE Data Comparison Work Sheet for each MOE. (Figure 64).

Summary of FUNCTION C

STEP C1 - PREPARE SUMMARY TABLES

- Prepare summary tables of the collected data in FUNCTION B using the tabular format related to the experimental plan.
- Record non-accident MOE values in the summary table.

STEP C2 - CALCULATE THE CHANGE IN THE NON-ACCIDENT MOE'S

- Compute percent change for all MOE's.
- Compute the expected value of each MOE using the appropriate equation for selected experimental plan.

FUNCTION D: Perform Statistical Tests

This function enables the evaluator to:

1. Define the type of data for each non-accident MOE.

2. Select the appropriate statistical test based on the type of data and sample size of the MOE's.

3. Perform the statistical tests.

4. List conclusions regarding the intermediate effectiveness of the project.

Overview

In this function, statistical tests are selected and performed for each non-accident MOE collected and developed in FUNCTION B. To perform significance testing, the evaluator must possess a knowledge of the types of data variables which make up the MOE's and be able to select the appropriate statistical test for each data type. This function involves more activities than FUNCTION D of Accident-Based Evaluation since there are a greater number of types of non-accident-based MOE's which may be evaluated. It should be noted that only a few of the test statistics normally encountered in safety analyses are given in this section. For details on other statistical procedures, any standard statistical text should be consulted.

In this function, the evaluator is presented with definitions and examples of the types of data which may be encountered, the MOE summary formats, and the activities which must be undertaken for statistical testing.

STEP D1 - DEFINE THE TYPE OF DATA FOR EACH NON-ACCIDENT MOE

MOE's may be comprised of either discrete or continuous data. Discrete data fall into categories and have specific values only. For instance, one roll of a die can only result in a discrete integer value of 1,2,3,4,5 or 6. No other value is possible. The number of traffic conflicts and the number of shoulder encroachments are also examples of a discrete variables. These measures are recorded in discrete integer values of 1,2,3...etc.

Continuous data may have any value within a specified range of values. Height and weight are continuous data since an infinite number of values exist within any defined range of heights or weights. Vehicle speeds, delay and conflict rates are also examples of continuous data.

There are three types of categorical (discrete) data which are of major importance in deciding how to organize MOE data for statistical testing. These categorical data are nominal, ordinal, and scalar.

Nominal variables are categorical data which are classified by an unordered name or label. Examples of nominal data are pavement type, rural vs. urban location and signalized vs. unsignalized intersection. Ordinal variables are categorical data which are rank ordered by name or label. Examples of ordinal data include conflict severity levels (i.e., severe, moderate, routine). Scalar variables are categorical data which have names or labels with known distances apart. For example, roadways may be classified by the number of lanes, i.e., 1,2,3, etc. or width of the pavement, i.e., 10, 11 or 12 foot lanes, etc.

There are also two other types of data which may be either discrete or continuous which are of importance in organizing MOE data for statistical testing. These data are interval and ratio. The distinction between these variables is subtle in terms of selecting a format for significance testing, thus these two classes are not treated individually in this text. Examples of these data include the proportion of vehicles exceeding the speed limit or the ratio of speeds at two points on a roadway. Statistical procedures for analyzing interval and ratio variables constitute the largest and most important testing methods.

Selection of the appropriate statistical test is based on the type of MOE data and the number of variables involved. Statistical testing of categorical variables is usually performed with the use of non-parametric or distribution-free methods. Examples of non-parametric tests include the Chi-Square test, Wilcoxen rank sum test, and the Mann-Whitney U-Test.

Statistical testing of interval and ratio data is generally performed with parametric statistics. Parametric methods are used to examine differences between sampled estimates of population parameters such as the mean or variance. Parametric tests include the t-test, Z-test, and analysis of variance and covariance.

In addition to defining the type of data for each MOE, the evaluator should carefully review the selected evaluation objectives and MOE's to determine which types of statements must be answered in order to satisfy the evaluation objective(s). These statements are referred to as statistical hypotheses.

Two statistical hypotheses should be stated for statistical testing; a null hypothesis and an alternative hypothesis. The null hypothesis, H_o, as commonly expressed, asserts that no difference exists between the MOE's. For example, the null hypothesis expressed below implies there is no difference between the before mean, $\bar{X}_B$ and the after mean, $\bar{X}_A$:

$$H_o: \bar{X}_B - \bar{X}_A = 0$$

However, the null hypothesis may also be expressed as:

$$H_o: \bar{X}_B \geq \bar{X}_A$$

or

$H_0: \overline{X}_B < \overline{X}_A$

Statistical tests are performed to examine the correctness of the null hypothesis at a pre-specified level of confidence. The null hypothesis may be accepted, which implies that the project was not successful in changing the mean MOE at a specified level of confidence; or it may be rejected, which implies that the project was successful in creating a significant change in the before and after mean MOE. If the null hypothesis is rejected, the alternative hypothesis, H_1, is accepted;

$H_1: \overline{X}_B - \overline{X}_A \neq 0$ or $H_1: \overline{X}_B > \overline{X}_A$ or $H_1: \overline{X}_B < \overline{X}_A$

and the conclusion is made that the means are significantly different as a result of the project.

When the null hypothesis, Ho: $\overline{X}_B - \overline{X}_A = 0$ is stated, a non-directional or two-tailed test is used to test the statistical significance of the difference between two sample means. Results of a two-tailed test indicates significance of the absolute magnitude of the difference without regard for the direction (sign) of the difference.

A directional or one-tailed test is used when the null hypothesis, H_0: $\overline{X}_B \geq \overline{X}_A$ or $\overline{X}_B \leq \overline{X}_A$, is stated. The direction or sign of the difference is indicated as a result of performing the one-tailed test.

As an evaluation activity, each of the non-accident MOE's developed from the data collected in FUNCTION B must be identified as being either discrete or continuous and hypotheses to be statistically tested must be developed.

STEP D2 - SELECT THE STATISTICAL TEST

The type of non-accident MOE's, the evaluation objectives, the sample size, the experimental plan, and the hypotheses are the deciding factors in the selection of an appropriate statistical test. Several statistical techniques are provided in this step to enable the evaluator to test the statistical significance of changes in the MOE's. A description of each technique is provided along with the applicability of each technique, the type of data which may be evaluated and the assumptions which underly each technique.

Chi-Square Test

The Chi-Square test is used to test whether two discrete variables are independent of each other. The variables may be scalar, nominal or ordinal. In this non-parametric test, observed frequencies of non-accident MOE's are compared with expected frequencies which would exist if the two variables are truly independent of each other.

The variables to be tested are arranged in a contingency table which may be composed of any number of rows or columns. For example, the following contingency table consists of two rows which represent the before and after analysis periods for an evaluation and five columns which represent five similar sites at which the same countermeasure has been implemented. This contingency table is referred to as a 2 X 5 contingency table.

Col. / Row	Project Sites				
	1	2	3	4	5
Before	8	15	23	11	12
After	9	10	15	8	11

A requirement for all Chi-Square tests is that every cell within the contingency table must have at least five observations.

The Chi-Square may be used to test the independence of any discrete non-accident MOE. All experimental plans are appropriate for testing by Chi-Square.

t-Test

The t-test is a parametric statistic used to test the statistical significance of differences in the mean values of two sets of MOE's when the data are continuous and an assumption of normality and homogeneity of variance in the data can be made. Two variations of the t-test are provided; the paired t-test and the Student's t-test.

The paired t-test is applicable for the before-after experimental plan where differences in pairs of observations representing the before and after situation are to be tested. The statement to be addressed with this test is whether the before mean for a group of locations is significantly different from the after mean of the same locations. The paired t-test is not appropriate for testing differences between the project and control sites because the data are taken at different locations. Also, the paired t-test can be used to test differences in the mean for a group of pedestrians, vehicles, etc. at a before and after location or a project and a control site. The word "group" means the same location, or same the same pedestrian, etc.

The Student's t-test is appropriate for testing the difference between a project and control site. There is no requirement for paired observations or equal number of observations. It should be noted that the student's t-test can be used to test for differences in the mean for pedestrians, vehicles, or other items which are randomly drawn from the population. The assumption of approximately equal group variances is made in this test in addition to the assumption of normality. The statement to be addressed with this test is whether the two means are significantly different. The test is therefore applicable for testing differences between project and control sites during either the before or after period. In a situation where the assumption of equal variance cannot be reasonably made, a modification to the Student's t-test can be made. This modification is referred to as Yates' Correction Factor for Continuity.

Z-Test For Proportions

This test is applicable for continuous data which are expressed as proportions. The analysis question addressed by this test is whether the proportion of occurrences in one sample is significantly different from the proportion in a second sample. The assumptions underlying the test include the requirement that the data follow a binominal distribution (i.e., only two levels can make up the data set), that the observations are independent, and that a sample size of at least 30 is available. The sample size may be expressed in either values of the MOE or locations depending on the requirements of the evaluation. For example, the sample may be the number of recorded vehicle speeds for a case where the proportion of vehicle speeds in excess of the speed limit is to be evaluated. As with the Student's t-test, this technique is applicable for testing differences in proportions between different samples. Thus, the test may be used to examine the MOE difference between project and control sites during either the before or after period.

A modification of the Z-test may also be used to test for significant differences in proportions from two samples which are not independent (or correlated proportions). This test may be appropriate for use when a before-after experimental plan is used and the before and after MOE's are likely to be correlated due to the fact that paired measurements are taken at the same locations under similar conditions. This application of the Z-test accounts for the correlation between the paired measurements.

For example, suppose the MOE of interest is the proportion of 33 sites that exceed an average "no turn on red" violation rate of 20 violations per 1,000 opportunities before and after upgrading non-standard R10-1 signs (no turn on red) to MUTCD code. The proportion of sites that exceed the average rate before and after the project may be considered to be correlated. The following contingency table should be developed for this situation.

		Before Treatment	
		No. Exceeding Avg. Rate	No. Not Exceeding Avg. Rate
After Treatment	No. Not Exceeding Avg. Rate	9	9
	No. Exceeding Avg. Rate	10	5

F-Test

This test is applicable for continuous, non-accident MOE's expressed as variances. The analysis question addressed by this test is whether the variance of one population is significantly different from that of a second population. The assumptions underlying the test include the requirement that the underlying distribution of the population is normal and the data represent independent random samples drawn from the population. The test is applicable for testing MOE's using any experimental plan.

Based on the characteristics and requirements for each statistical test, the evaluator must select the most appropriate technique(s) for the evaluation. In addition, the level of confidence and the statistical null hypothesis must be recorded for each statistical test application.

STEP D3 - PERFORM THE STATISTICAL TEST

This step provides the evaluator with the activities which must be undertaken in performing each of the statistical tests described in the previous step. An example of each technique is provided. Following the examples, a procedure for selecting a test statistic is given.

Chi-Square Test

These activities should be performed when applying the Chi-Square test to address the following null hypothesis:

There is no significant difference between the observed frequencies and the expected frequencies of the two variables being tested, i.e., the variables are independent.

1. Select a level of confidence.

2. Arrange the observed frequencies in a contingency table format consisting of any number of rows and columns, as shown below.

		Columns							
		1	2	3	4	.	.	.	Row Sum
Rows	1 2 3 4 . . .								
Col. Sum									Grand Total

3. Compute expected frequencies for each cell of the contingency table developed in step 2 above and arrange the expected frequencies into a similar contingency table format. The expected frequencies for each cell are obtained by multiplying the row sum by the column sum and then dividing by the grand total.

$$\text{Expected Frequency for Row } i\text{, Column } j. = \frac{\text{Row Sum for Row } i \times \text{Col. Sum for Column } j.}{\text{Grand Total}}$$

4. Compute the Chi-Square value using the following equation:

$$\chi^2 = \sum_{\substack{\text{all} \\ i,j}} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

Where:

O_{ij} = Observed frequencies for row i, column j.

E_{ij} = Expected frequencies for row i, column j.

The following computational format may be helpful in computing Chi-Square.

Observed (O)	Expected(E)	O-E	$(O-E)^2$	$\frac{(O-E)^2}{E}$
			Sum =	

5. Determine the critical Chi-Square value from statistical tables contained in the Appendix using the degrees of freedom for the test;

Degrees of Freedom = (R-1) (C-1)

Where:

R = number of rows in the contingency table
C = number of columns in the contingency table

and the selected level of confidence (ie., 1 minus the level of significance).

6. Compare the calculated Chi-Square value with the critical Chi-Square value. If the calculated Chi-Square is greater than the critical value, reject the null hypothesis and conclude that the variables are not independent at the stated level of confidence. If calculated Chi-Square is less than the critical value, accept the null hypothesis and conclude that the MOE's are independent.

Example

A project to reduce accident severity and the number of ROR accidents at four high accident rural isolated curve roads involved the placement of an advisory speed panel on the curve advance sign. The non-accident MOE selected for the evaluation was the number of tire tracks on the shoulder before and after project installation. The before-after experimental plan was used in the evaluation. The null hypothesis was stated as:

The effect of the advisory speed signs on accident frequency is independent of the project site.

The following data represent the number of tire tracks observed at each of 4 curves at which the speed panel was installed during 10 days of visually recording (shoulders were raked after each daily visit) the number of tire tracks before and after project implementation.

Analysis Period	Project Site			
	1	2	3	4
Before	14	36	42	39
After	8	18	20	27

The above accident data were arranged in a 2 x 4 contingency table as follows:

Observed Frequencies

Analysis Period	Project Site				Row Sum
	1	2	3	4	
Before	14	36	42	39	131
After	8	18	20	27	73
Col. Sum	22	54	62	66	204

Next, the expected frequencies were calculated for each cell as follows:

$$\text{Expected Frequency for Row 2, Col. 1} = \frac{\text{Row Sum 2} \times \text{Col. Sum 1}}{\text{Grand Total}}$$

$$= \frac{73 \times 22}{204}$$

$$= 7.87$$

The following contingency table of expected frequencies was developed.

Expected Frequencies

Analysis Period	Project Site				Row Sum
	1	2	3	4	
Before	14.13	34.68	39.81	42.38	131.00
After	7.87	19.32	22.19	23.62	73.00
Col. Sum	22.00	54.00	62.00	66.00	204.00

Chi-Square was calculated as follows:

Observed (O)	Expected (E)	O-E	$(O-E)^2$	$\frac{(O-E)^2}{E}$
14	14.13	-.13	.02	.00
36	34.68	1.32	1.74	.05
42	39.81	2.19	4.80	.12
39	42.38	-3.38	11.42	.27
8	7.87	.13	.02	.00
18	19.32	-1.32	1.74	.09
20	22.19	-2.19	4.80	.22
27	23.62	3.38	11.42	.48
				Sum = 1.23

The critical Chi-Square value for the 95% level of confidence and (2-1) times (4-1) = 3 degrees of freedom was found to be 7.81 from the Chi-Square table contained in the Appendix. Since the calculated value is less than the critical value, the null hypothesis is accepted and the conclusion is that the frequency of tire tracks before and after project implementation are independent of the project site.

Paired t-Test

These activities should be performed when applying the paired t-test to address the following null hypothesis:

There is no significant difference between the before mean of a group and the after mean for the same group.

1. Select a level of confidence.
2. Arrange the MOE in the following form:

MOE Analysis Periods MOE Units	Locations (N=n) 1 2 3 4 . . n	Total	Avg. ($\overline{X}$)	Var. (S^2)
Before MOE Rate Dates: Units:				
After MOE Rate Dates: Units:				

3. Compute the t value using the following equation:

$$t = \frac{\overline{X}_B - \overline{X}_A}{S_D/\sqrt{N}}$$

and

$$S_D^2 = S_B^2 + S_A^2 - 2\left[\frac{1}{N-1}\sum_{i=1}^{N}(X_{Bi} - \overline{X}_B)(X_{Ai} - \overline{X}_A)\right]$$

Where: $\overline{X}_B$ = Before sample mean

$\overline{X}_A$ = After sample mean

S_B^2 = Before sample variance

S_A^2 = After sample variance

N = Number of cases

4. Determine the critical t value from statistical tables contained in the Appendix using the degrees of freedom (N-1) and the selected level of confidence.

5. Compare the calculated t value with the critical t value. If calculated t is greater than critical t, reject the null hypothesis and conclude that the means are different at the selected level of confidence.

   If calculated t is less than critical t, accept the null hypothesis and conclude that the means are not different.

   Example

A project to reduce the number of passing accidents on a two-lane rural highway involved the installation of left-hand side no-passing pennant signs (W14-3) at five identified high accident no passing zones (NPZ's). The non-accident MOE selected was the number of passing violations per 1,000 opportunities. The before-after experimental plan was selected. The analysis periods were chosen as 6 hours of direct observation per day for each of 5 consecutive days (Monday- Friday) taken before and after project implementation. The statistical analysis involved testing for significant differences between the before and after violation rates at the NPZ's. The null hypothesis was stated as:

> There is no difference in the before and after mean violation rates for the project sites at the 95% level of confidence.

The following data were tabulated for the before and after periods.

MOE and Analysis Period Units	Location (N=5)					Total	Avg. ($\bar{X}$)	Variance (S^2)
	1	2	3	4	5			
Before NPZ Violation Rate 8/6/79-8/10/79 Violations/1000 Opportunities	5.20	8.10	7.80	6.50	5.60	33.2	6.64	1.66
After NPZ Violation Rate 8/27/79-8/31/79 Violations/1000 Opportunities	6.00	6.20	4.30	6.40	2.10	25.0	5.00	3.33

Computing the t value for the group:

$$t = \frac{\overline{X}_B - \overline{X}_A}{S_D/\sqrt{N}}$$

Where:

$$\overline{X}_B = 6.64$$

$$\overline{X}_A = 5.00$$

$$S_B^2 = 1.66$$

$$S_A^2 = 3.33$$

$$N = 5$$

and

$$S_D^2 = 1.66 + 3.33-2\ [1/4[(-1.44)(1.00)+(1.46)(1.20)+(1.16)(-0.70)+(-0.14)(1.40)+(-1.04)(-2.90)]]$$

$$= 4.99 - 2(0.58)$$
$$= 3.83$$

then

$$t = \frac{6.64 - 5.00}{1.96/\sqrt{5}}$$

$$= 1.87 \text{ (calculated)}$$

From the statistical table of the t-distribution, the critical t was determined to be 2.776 for 4 degrees of freedom (5-1) and a 0.05 level of significance. Thus, the conclusion is that there was no significance difference in the before and after mean NPZ violation rate at the project sites.

Student's t-Test

These activities should be performed when applying the Student's t-test to address the following null hypothesis:

There is no significant difference between the mean accident rate for one group and the mean accident rate for another group.

1. Select a level of confidence.

2. Arrange the individual accident rates for each group in the following form:

MOE Analysis Period MOE Units	Locations	N	Total	Avg. ($\overline{X}$)	Var. (S^2)
Group 1 MOE Rate Dates Units:	1 2 3 4 5...				
Group 2 MOE Dates Units:	1 2 3 4 5 6...				

3. If the group variances are approximately equal in magnitude, compute the t value using the following equation.

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S\sqrt{(1/n_1) + (1/n_2)}}$$

and

$$S^2 = \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1 + n_2 - 2}$$

Where: $\overline{X}_1$ = Group 1 sample mean

$\overline{X}_2$ = Group 2 sample mean

n_1 = Number of locations in Group 1

n_2 = Number of locations in Group 2

S_1^2 = Group 1 sample variance

S_2^2 = Group 2 sample variance

If the group variances are not similar in magnitude, compute the t value using the following equation:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}$$

4. Determine the critical t value from statistical tables (from the Appendix). If the group variances are similar, the critical t value is determined using n_1+n_2-2 degrees of freedom and the selected level of confidence. If the variances are dissimilar, the critical t value is computed by the following equation:

$$t_c = \frac{\frac{S_1^2 t_1}{n_1} + \frac{S_2^2 t_2}{n_2}}{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}$$

where: t_c = critical t value at the selected level of confidence

t_1 = critical t value for $n_1 - 1$ degrees of freedom at the selected level of confidence.

t_2 = critical t value for $n_2 - 1$ degrees of freedom at the selected level of confidence.

5. Compare the calculated t value with the critical t value. If calculated t is greater than critical t, reject the null hypothesis and conclude that the project is effective at the stated level of confidence. If calculated t is less than critical t, accept the null hypothesis and conclude that the project is not effective.

Example

A project to reduce run-off-road (ROR) accidents on a two-lane rural winding section involved pavement edgelining and delineator installation. A non-accident MOE was selected to be the number of edgeline and shoulder encroachments per 1000 vehicles. The winding roadway section crossed the boundary of an adjacent county and thus the project was implemented on only 1 mile of the 2 mile roadway section. The untreated section of roadway was selected as a control site and necessary arrangements were made to collect non-accident MOE's in the neighboring county. Encroachment rates were collected at 6 locations on the project section and 7 locations on the control section. Comparison of before MOE's showed no significant differences between the two sections.

The following null hypothesis was stated:

There is no significant difference between the mean encroachment rate on the treatment and the mean encroachment rate on the control section at the 95% level of confidence.

The following encroachment data were collected.

MOE and Analysis Period MOE Units	Locations						N	Total	Avg. ($\overline{X}$)	Var. (S^2)
	1	2	3	4	5	6				
Group 1 (Project) Encroachment Rate 4/8/80 Units: Encroachments/1000 Vehicles	5.6	9.2	10.4	19.8	25.2	16.4	6	86.6	14.4	54.0

MOE and Analysis Period MOE Units	Locations							N	Tot.	Avg. ($\overline{X}$)	Var. (S^2)
	1	2	3	4	5	6	7				
Group 2 (Control) Encroachment Rate 4/29/80 Units: Encroachments/ 1000 Vehicles	9.0	23.2	19.6	20.4	18.8	30.2	10.44	7	131.6	18.8	53.2

Since the group variances were approximately equal, the t value was calculated as follows:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S\sqrt{(1/n_1) + (1/n_2)}}$$

Where: $\overline{X}_1 = 14.4$

$\overline{X}_2 = 18.8$

$n_1 = 6$

$n_2 = 7$

and

$$S^2 = \frac{(6-1)54.0 + (7-1)53.2}{6+7-2}$$

$$= \frac{689.2}{11}$$

$$= 53.6$$

then

$$t = \frac{14.4 - 18.8}{7.32\sqrt{(1/6+1/7)}}$$

$$= \frac{-4.40}{4.07}$$

$$= -1.08$$

The critical t value from the Appendix for a confidence level of 95% (0.05 level of significance) and 11 degrees of freedom (6 + 7 - 2) is 2.201. Since the critical t value is greater than the calculated value, the null hypothesis is accepted and the conclusion is made that the project had no effect on the mean encroachment rate.

Z-Test for Proportions

These activities should be performed when applying the Z-test to address the following null hypothesis:

> There is no significant difference in the proportion of occurrences in one sample compared to the proportion of occurrences in another sample.

1. Select a level of confidence.

2. If the two samples are assumed to be independent, arrange the proportions and sample size in the following form:

Group Analysis Periods	Total Sample (N)	Number of Occurrences (X)	Proportion (P)
Group 1 Dates			
Group 2 Dates			

3. If the two proportions being compared are from independent samples (i.e., comparison of program group proportions vs. a control site(s) proportion), calculate the Z value using the following equation:

$$Z = \frac{P_1 - P_2}{\sqrt{pq(1/N_1 + 1/N_2)}}$$

Where:

$$P_1 = \frac{X_1}{N_1}$$

$$P_2 = \frac{X_2}{N_2}$$

$$p = \frac{X_1 + X_2}{N_1 + N_2} = \frac{N_1P_1 + N_2P_2}{N_1 + N_2}$$

$q = 1-p$

X_1 = Number of occurrences in Group 1

X_2 = Number of occurrences in Group 2

N_1 = Total sample in Group 1

N_2 = Total sample in Group 2

4. If the two proportions being compared are from correlated samples (i.e., comparison of proportions of before and after pairs at the same sample, arrange the data in the following forms.

		Before No. of Occurrences	No. Non- Occurrences	
After	No. Non-Occurrences	A	B	A + B
	No. Occurrences	C	D	C + D
		A + C	B + D	N

5. If correlated samples are assumed, calculate the Z value using the following equation:

$$Z = \frac{D - A}{\sqrt{A + D}}$$

6. Determine the critical Z value from the statistical tables for the selected level of confidence.

7. Compare the calculated Z value with the critical Z value. If calculated Z is greater than critical Z, reject the null hypothesis and conclude that the project is effective at the stated level of confidence. If calculated Z is less than critical Z, accept the null hypothesis and conclude that the project is not effective.

Example

A project to reduce nighttime accidents involved the installation of improved street lighting at an intersection which had experienced an over-represented night to day accident ratio. The non-accident MOE was chosen as the proportion of total night traffic conflicts to total night plus day conflicts. Because another intersection was to receive a similar treatment for the same safety problem, the before-after study with control sites plan was chosen for the study. Traffic conflicts were collected for 1000 opportunities each during daylight and nighttime conditions.

Two null hypotheses were stated:

> There is no difference between the proportion of night to total traffic conflicts between the project and control site before and after implementation.

The following data were collected:

BEFORE PROJECT IMPLEMENTATION

Group Analysis Period	Possible Occurrences: Total Conflicts for Night Plus Day (N)	Number of Occurrences: Night Conflicts (X)	Proportion (P)
Group 1 (Project) 6/79	257	69	0.27
Group 2 (Control) 7/79	242	58	0.24

AFTER PROJECT IMPLEMENTATION

Group Analysis Period	Possible Occurrences: Total Conflicts for Night Plus Day (N)	Number of Occurrences: Night Conflicts (X)	Proportion (P)
Group 1 (Project) 6/79	275	35	0.13
Group 2 (Control) 7/79	289	75	0.26

The Z value for the independent samples was computed as follows:

$$Z = \frac{P_1 - P_2}{\sqrt{pq(1/N_1) + (1/N_2)}}$$

Where: $p_1 = 0.27$

$P_2 = 0.24$

$N_1 = 257$

$N_2 = 242$

$$p = \frac{69 + 58}{257 + 242} = 0.25$$

$$q = 1\text{-}p = 1 - 0.25 = 0.75$$

Substituting

$$Z = \frac{0.27 - 0.24}{\sqrt{(0.25)(0.75)(1/257 + 1/242)}}$$

$$= \frac{0.03}{0.04}$$

$$= 0.77$$

The critical Z value for the 0.05 level of significance was determined as 1.96. Since the calculated Z is less than the critical Z, the null hypothesis is accepted and the conclusion is made that there is no difference between the proportion of night conflicts for the project and control sites for the before period.

In a similar manner, the Z value was calculated between the project and control sites for the after period.

$$Z = \frac{0.13 - 0.26}{\sqrt{(0.20 \quad 0.80)(1/275 + 1/289)}}$$

$$= \frac{-0.13}{0.03}$$

$$= -3.86$$

Since the calculated Z is greater than the critical Z for the 0.05 level of significance, the null hypothesis is rejected and the conclusion is made that there is a significant difference in the proportion of night conflicts and that the project is effective.

F-Test

These activities would be performed when applying the F-test to address the following null hypothesis.

There is no significant difference between the variance of one population and that of another population.

1. Select level of confidence.

2. Arrange the number of observations N, the mean X and the variance S^2 of the populations in the following form:

Analysis Period Dates Units	Sample Size N	Mean $\overline{X}$	Variance S^2
Before Period Dates Units	N_B	$\overline{X}_B$	S^2_B
After Period Dates Units	N_A	$\overline{X}_A$	S^2_A

3. Compute the F-value using the following equation.

$F = S_B^2/S_A^2$, (assuming S_B^2 is the greater of the two, if not,

$$F = S_A^2/S_B^2)$$

S_B^2 = Before sample variance

$$\sum_i \frac{(X_{Bi} - \overline{X}_B)^2}{N_A - 1}$$

S_A^2 = After sample variance

$$\sum_i \frac{(X_{Ai} - \overline{X}_A)^2}{N_A - 1}$$

N_B and N_A = Before and After sample size.

$\overline{X}_B$ and $\overline{X}_A$ = Before and after sample means.

4. Determine the critical F-value from statistical tables contained in the Appendix using the degrees of freedom (N_B - 1) and (N_A - 1) and the selected level of confidence.

5. Compare the calculated F-value with the critical F-value. If the calculated F-value is greater than the critical F-value, reject the null hypothesis and conclude that the project is effective at the selected level of confidence. If the calculated F is less than the critical F, accept the null hypothesis and conclude the project had no significant affect on variance at the 95% level of confidence.

<u>Example</u>

A project to reduce total accidents and accident severity involved establishing a new speed zone on a section of rural highway. A non-accident MOE was selected as the speed variance of the speed distribution. The before-after experimental plan was selected. The following null-hypothesis was stated:

> There is no significant difference between the before and after speed variance at the 95% level of confidence.

The following speed data were collected:

Analysis Period Dates Units	Sample Size N	Mean $\bar{X}$	Variance S^2
Before Period 4/13/79 Miles Per Hour	120	55.4	49.3
After Period 5/6/79 Miles Per Hour	120	55.2	34.7

Computing the F value:

$$F = S_B^2/S_A^2$$

$$= 49.3/34.7$$

$$= 1.42$$

From the statistical table, the critical F value for 119 and 119 degrees of freedom at the 95% level of confidence was 1.35. Since the calculated F(1.42) was greater than the critical F(1.35), the null hypothesis is rejected and the conclusion is made that the project was effective in reducing speed variance at the 95% level of confidence.

Procedure for Selecting a Test Statistic

Table 13 summarizes the properties for each of the test statistics described in this function and provides guidelines for selecting a statistical test.

SUMMARY OF FUNCTION D

STEP D1 - DEFINE THE TYPE OF DATA FOR EACH MOE

- Review the selected intermediate evaluation objectives, non-accident MOE's, and experimental plan and determine the types of data to be evaluated (i.e., discrete or continuous).

- List the statement(s) (hypotheses) to be statistically tested for each intermediate evaluation objective.

STEP D2 - SELECT THE STATISTICAL TEST

- Select the appropriate statistical test based on objectives, the MOE's, experimental plan, and types of statements to be statistically tested.

Table 13. Procedure for selecting a test statistic

PROCEDURE FOR SELECTING A TEST STATISTIC

Tests of Significance	Properties				
	Type of Statistic	Type of Variable	Parameter Being Tested	Minimum Sample Size	Comments
Chi-Square	Non-Parametric	Discrete	Frequency	$\geq$5 for each cell	Test for independence between variables.
Student's t	Parametric	Continuous	Means	$\geq$6	Normality and equality of variance assumed. Samples are independent.
Paired t	Parametric	Continuous	Means	$\geq$6	Normality and equality of variance assumed. Samples are paired.
F	Parametric	Continuous	Variance	$\geq$6	Normality and equality of variance assumed.
Z	Parametric	Continuous	Proportions	$\geq$30	Binomial Distribution is assumed. Observations or samples are independent.

As a guide in selecting a test statistic for a set of data, the following procedure is suggested.

1. For the data under consideration, answer the following questions.

   a. What type of MOE is under consideration, i.e., can assumptions be made about the population parameters (parametric or non-parametric statistic)?

   b. Is the variable discrete or continuous?

   c. What is the parameter being tested, i.e., difference in means, variance, etc.?

   d. What is the size of the sample size, i.e., the number of observations?

   e. Are the samples independent?

2. Compare the answers to the above questions with the test statistic properties given above and select the statistical test which best meets these requirements. WHEN IN DOUBT, CONSULT A STATISTICIAN!

STEP D3 - PERFORM THE STATISTICAL TEST

- Select a level of confidence.
- Arrange the data in the format for the selected statistical test.
- Perform the necessary computations.
- Compare calculated statistical values with critical values taken from tables based on the selected level of confidence and the degrees of freedom.
- State conclusions on the intermediate effectiveness of the project based on the statistical testing results.

FUNCTION E: Perform Economic Analysis

This function enables the evaluator to:

1. Develop measures of project benefits and costs.
2. Perform an economic analysis.

Overview

This function presents an analysis technique for determining the cost of achieving one unit of improvement in a non-accident MOE. This information provides an additional perspective of the intermediate effectiveness of the safety project. It is entirely possible to have an extremely effective project in terms of improving the non-accident MOE's, but the project may be cost-prohibitive to the agency for future use under similar circumstances because of the high cost of achieving the desired level of effectiveness.

The objective of this function is accomplished through the use of the Cost-Effectiveness technique of economic analysis. In this technique, the project costs are valued on a dollar basis. The benefits are not assigned costs. Project benefits are expressed as the number of units of improvement in the MOE (e.g., number of miles per hour of speed reduction, number of traffic conflicts reduced, number of traffic conflicts reduced per 1000 opportunities, number of shoulder encroachments reduced, etc.). The ratio of project costs to benefits yields a measure which is expressed as the cost in dollars for each unit of improvement in the MOE.

It is important that the results of the economic analysis be representative of the effects of the project on the selected MOE's. Thus, it is recommended that the economic analysis be conducted for only those MOE's which were significantly changed at the selected level of confidence. The cost-effectiveness of a project based on MOE's which were reduced as a result of chance or random occurrence does not provide usable information for future project planning activities. Because the improvement of non-accident MOE's is the measure of benefit instead of number of accidents reduced, the output from this economic analysis may seem to be of limited usefulness in future planning activities. This however is not necessarily the case. With time, cost-effectiveness information on non-accident MOE's can be accumulated for similar types of projects and provide a basis for estimating the cost of achieving specified improvement levels in non-accident measures. Further, cost-effectiveness measures resulting from similar type of projects can be compared to determine whether the cost of achieving a unit of improvement was consistent with the cost of other highway improvements. Also, if current research efforts to investigate relationships between accident and non-accident measures result in accident surrogates, unit changes in non-accident measures (if they are identified as surrogates) can be translated to changes in accident experience and accident cost values developed by NSC, NHTSA and other Federal, State and local agencies may be applied.

STEP E1 - DETERMINE PROJECT BENEFITS AND COSTS

Inputs to the Cost-Effectiveness (C-E) technique are:

a) Cost of implementing, operating and maintaining the project;

b) Benefit derived from the project in terms of statistically significant non-accident MOE improvements.

Project Costs

Three types of project costs should be determined: 1) initial implementation costs, 2) net operating costs, and 3) net maintenance costs.

Initial Implementation Costs

This input includes all costs associated with implementation, placement or construction of the project. It should include right-of-way acquisition, construction, site preparation, labor, equipment, design, traffic maintenance, and other costs that may be associated with the project. Typically, such cost data are available from ROW, design and construction files and reports. Detailed cost information can also be obtained from an Administrative Evaluation of the project. Administrative Evaluation is highly recommended and should be conducted in accordance with the procedure provided in this Procedural Guide.

Net Operating Costs

Net operating costs are defined as the difference in operating an element of the highway system before and after project implementation (i.e. after operating cost minus before operating cost). The net operating cost may be positive (operating cost increase), negative (operating cost savings) in value, or it may be zero if the project does not change operating costs. For example, the installation of a flashing beacon on an advance warning sign has no operating cost before the beacon is installed but after installation the cost of power is an operating expense to the agency. In this case, the operating cost is positive. On the other hand, if a safety project involves providing increased highway lighting levels and the project involves the replacement of a mercury vapor lighting system with a low-pressure sodium lighting system, a negative (cost savings) net operating cost results. Net operating costs should be determined (or estimated if unknown) on an annual basis.

Net Maintenance Costs

Net maintenance costs are analogous to net operating costs. This cost component may also be positive (maintenance cost increase), negative (maintenance cost savings) or zero if the project does not change maintenance costs. Net maintenance costs should be determined (or estimated) on an annual basis.

Project Benefits

Project benefits for the purpose of this analysis are defined as the difference in the non-accident MOE's before and after project implementation. Depending on the MOE's of the evaluation, the following types of benefits may result.

- Number of miles per hour reduced
- Number of total or specific types of traffic conflicts reduced per hour
- Number of edgeline encroachments reduced per 1,000 vehicles
- Average number of tire tracks reduced per day
- Number of violations reduced per 1,000 vehicles.

Only MOE's found to be significantly changed at the selected level of confidence should be used in the analysis.

STEP E2 - PERFORM COST-EFFECTIVENESS ANALYSIS

When applying the Cost-Effectiveness technique, the following activities should be performed.

1. Assemble the project cost and benefit items determined in STEP E1.

2. Estimate the service life of the project based on patterns of historic depreciation of similar types of projects or facilities. For highway safety projects, the service life is that period of time which the project can be reasonably expected to impact accident experience. Generally, major construction or geometric improvements should have a maximum service life of 20 years. The prediction of service life for specific highway improvements can be made reasonably accurate if the agency maintains service life data and survivor curves for various types of improvements and projects. If service life data are not available to the agency, the service life criteria used by the Federal Highway Administration are provided in the Appendix, and may be used in the analysis. If a project containing countermeasures with differing service lives is encountered, the evaluator should refer to FUNCTION E of Accident-Based Evaluation for methods of dealing with such a situation.

3. Estimate the salvage value of the project after its primary service life has ended. Salvage value is defined as the monetary value of the residual elements of the project at the end of its

service life. In the absence of salvage value data, past experience and literature should be used to estimate the salvage value. Although salvage value is generally considered as a positive cost item, some projects may require an expenditure to remove the residual elements themselves. In these instances, the cost of removal should be deducted from the value of the scrap or residual elements in estimating the final salvage value. Salvage value can be positive, negative, or zero.

4. Determine the interest rate by taking into account the time value of money. Realistic estimates of interest rates are extremely important. The results of fiscal evaluations are very sensitive to small variations in interest rates and thus may influence the outcome of economic analysis. Therefore, it may be advisable to vary the interest rate to determine the change in the economic outcome of the analysis. The evaluator is directed to FUNCTION E of Accident-Based Evaluation for further details.

5. Calculate the present worth of costs (PWOC) for the project. PWOC is recommended for this application of economic analysis to be consistent with the short time frame over which the non-accident MOE's have been measured. That is, the change in the MOE is considered to be the current estimate of the impact of the project and not necessarily representative of the long-term impact of the project. Thus, both costs and benefits represent present as opposed to average annualized impacts of the project (which are reflected in the equivalent uniform annual cost, EUAC).

   PWOC is computed using the cost items determined in STEP E1 in the following equation:

$$PWOC = I + K\,(SPW_n^i) - T\,(PW_n^i)$$

PWOC = Present worth of costs ($)

I = Initial costs of the project ($)

i = Interest rate (%)

n = Estimated service life of the project or improvement (years).

T = Net salvage value ($)

K = Net uniform annual cost of operating and maintaining the improvement or project. ($/year)

PW_n^i = Present worth factor for n years at interest rate i.

SPW_n^i = Present worth factor of a uniform series payment for n years at interst rate i.

6. Compute the Cost-Effectiveness value using the following equation:

   C-E = PWOC/B

   where:

   C-E = Cost-Effectiveness Value ($/unit of benefit)

   PWOC = Present worth of costs ($)

   B = Benefit (number of units of change in the MOE resulting from the project)

The cost-effectiveness value provides a measure of the feasibility of project implementation from a cost versus benefit viewpoint. Cost-effectiveness values for individual projects may not be immediately usable nor meaningful. However, as Non-Accident Based Evaluations are completed for similar projects on the basis of identical non-accident measures, a basis for comparison of the values results.

Summary of FUNCTION E

STEP E1 - DETERMINE PROJECT BENEFITS AND COSTS

- Obtain and review project cost data including initial implementation cost, net operating cost and net maintenance costs.
- Determine project benefits as measured by the before and after values of the MOE's which were determined to be significantly changed.

STEP E2 - PERFORM COST-EFFECTIVENESS TECHNIQUE

- Select and/or finalize inputs to the economic technique.
- Perform economic analysis.
- Compare the resulting cost-effectiveness value with the values from similar projects if available.

Example of FUNCTION E

Recent residential development along a two-mile section of two-lane paved roadway in an outlying suburban area resulted in a significant increase in annual accident frequency and rate. A highway safety project involving lowering the posted speed limit from 50 to 35 miles per hour was implemented and evaluated with Non-Accident-Based Evaluation.

The intermediate evaluation objective was:

> To determine the effect of the speed zoning project on vehicle speeds on the two-mile roadway section.

The non-accident MOE was the 85th percentile speed.

The before-after plan was used and statistical tests resulting in the conclusion that the 85th percentile speed was significantly reduced at the 95% level of confidence from 52.1 to 44.3 mph.

The decisions and activities involved in performing an economic analysis for this project are described in the following steps:

STEP E1 - DETERMINE PROJECT BENEFITS AND COSTS

An Administrative Evaluation was conducted following the implementation of the project. The evaluation report was obtained and reviewed to determine the cost of the project.

The project consisted of removing four existing speed signs and replacing each with new speed limit signs. Removal and installation costs were $57.98 per sign or $230.00 for the combined project. Net maintenance and operating costs were zero.

The benefit resulting from the project, as determined by the significantly reduced non-accident MOE was determined from earlier evaluation functions to be a 7.8 mph reduction in the 85th percentile speed.

STEP E2 - PERFORM COST EFFECTIVENESS TECHNIQUE

The inputs to the cost-effectiveness technique were determined to be as follows:

Service Life, n = 6 years
Salvage Value, T = Negligible
Interest Rate, i = 10% per year
Initial Cost, I = $230.00
Net Annual Operating and Maintenance Costs, k = Negligible

Present Worth factor, PW_n^i for i = 10% and n = 6 years = 0.5645

Series Present Worth Factor, SPW_n^i = 4.3553

Benefit, B = 7.8 mph

The economic analysis inputs were substituted into the following equation to determine the present worth of costs (PWOC).

$$PWOC = I + K\,(PW_n^i) - T(SPW_n^i)$$

$$= 230.00 + 0 - 0$$

$$= 230.00$$

The cost-effectiveness value was determined by the following equation:

$$C\text{-}E = PWOC/B$$

$$= 230.00/7.8$$

= \$30.00 per mile per hour reduction in the 85th percentile speed.

FUNCTION F: Prepare Evaluation Documentation

This function enables the evaluator to:

1. Interpret the intermediate effectiveness of the highway safety project.

2. Interpret the validity of the evaluation results.

3. Identify evaluation results for incorporation to the data base containing changes in non-accident measures.

4. Write an evaluation study report.

<u>Overview</u>

This function presents guidelines for determining the intermediate effectiveness of the project based on the observed change in the MOE's, the statistical significance of the change, and the cost of achieving the change. This function also involves a review of all functional activities of the evaluation study to determine the appropriateness of the decisions, assumptions, procedures and interpretations. If the evaluation study results are determined to be a valid representation of the intermediate effectiveness of the project, the evaluation results should be used in establishing a data base of changes in the non-accident MOE's for future use in highway safety planning and implementation.

<u>STEP F1 - ORGANIZE EVALUATION STUDY MATERIALS</u>

The determination of the intermediate effectiveness of the project requires that all data and evaluation study findings be brought together. A checklist of the materials and information required for this function is shown in Figure 69 along with the function from which these materials originate.

<u>STEP F2 - DETERMINE THE INTERMEDIATE EFFECTIVENESS OF THE PROJECT</u>

The final determination of intermediate effectiveness requires information on three aspects of the evaluation:

1) The changes in the MOE's according to the experimental plan used;
2) The statistical significance of changes in the MOE's; and
3) The results of the economic analysis.

The evaluator must develop from these information sources, a conclusion of the intermediate effectiveness of the project. Regardless of whether a conclusion is positive (sucess), negative (failure) or otherwise, the evaluator must critically assess the validity of the entire evaluation

______	Statement of the Safety Problem
______	Project Description
______	Funding Level
______	List of Project Purposes (FUNCTION A)
______	List of Intermediate Objectives and Non-Accident MOE's (FUNCTION A)
______	Experimental Plan Used with Justification (FUNCTION A)
______	List of Data Variables (FUNCTION A)
______	List of Control Sites with Selection Criteria (FUNCTION B)
______	Raw Data (FUNCTION B)
______	Reduced Data (FUNCTION B)
______	Data Collection Techniques Used (FUNCTION B)
______	Data Collection Personnel
______	MOE Comparison Tables (FUNCTION C)
______	Calculations of Expected Values and Percent Changes in the MOE's (FUNCTION C)
______	Statistical Test Procedure (FUNCTION D)
______	Statistical Results (FUNCTION D)
______	Economic Data Including Implementation, Operation, Maintenance, etc. (FUNCTION E)
______	Economic Analysis Technique Used with Assumptions (FUNCTION E)
______	Economic Analysis Results (FUNCTION E)

Figure 69. Evaluation study materials checklist.

procedure. The review should be carried out on a function-by-function basis and address the following questions:

FUNCTION A

1. Was the project appropriate for achieving its intended purpose?

2. Were the chain of accident causality and the resulting intermediate objectives and non-accident MOE's appropriate?

3. Was the experimental plan appropriate? What were the threats to validity which were not or could not be overcome?

FUNCTION B

1. Were the non-accident and cost data reliable and complete? What were the actual or suspected problems which were not correctable?

2. Were the control site(s) appropriate? What were the trade-off's made in control site selection?

FUNCTION C

1. Were problems encountered in computing expected MOE values or percent changes in the MOE's?

FUNCTION D

1. Was the statistical technique appropriate for the type of MOE and the desired evaluation objective?

2. Was the selected level of confidence appropriate?

3. Were statistical test results reasonable?

FUNCTION E

1. Were economic analysis inputs including accident cost figures, interest rate, expected life, and salvage value appropriate?

2. Were the economic analysis results reasonable?

In addition to reviewing the evaluation study procedures, it is also important to review the appropriateness of decisions and activities which took place in the Planning and Implementation Components of the HSIP. It is important to recognize: 1) whether the project was properly selected and appropriate for the safety deficiency; and 2) whether 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 the problems.

If the problem is not correctable, this fact should be noted and accompany the conclusions on intermediate project effectiveness.

STEP F3 - IDENTIFY RESULTS FOR INCLUSION IN THE INTERMEDIATE EFFECTIVENESS DATA BASE

One of the primary purposes of conducting formal evaluation is to feedback evaluation results to improve decisionmaking in future HSIP Planning, Implementation and Evaluation Components. The evaluator must, therefore, be certain that only reliable evaluation results enter the feedback loop. If serious uncorrectable problems were identified (in STEP F2), the evaluation results should not be combined with the results of evaluations which do not experience similar problems. Allowing questionable evaluation results to enter the feedback loop reduces the overall reliability of the data base and may result in inappropriate future decisions regarding similar projects.

STEP F4 - WRITE THE EVALUATION REPORT

The evaluation activities and results should be thoroughly discussed and documented in an evaluation study report. The documentation should include a concise and comprehensive coverage of all Non-Accident-Based Evaluation aspects. The report should follow the format shown in STEP F4 of the Accident-Based Project Evaluation, substituting non-accident for accident-based evaluation findings.

The report should be distributed to those persons in the agency who benefit most from evaluation results.

Summary of FUNCTION F

STEP F1 - ORGANIZE EVALUATION STUDY MATERIALS

- Obtain information pertaining to all the evaluation activities.
- Review the material for completeness.

STEP F2 - EXAMINE THE INTERMEDIATE EFFECTIVENESS OF THE PROJECT

- From FUNCTION C, identify whether the project reduced the safety deficiencies for which it was intended.
- From FUNCTION D, identify whether the project resulted in a statistically significant change in the MOE's.
- From FUNCTION E, identify whether the project resulted in benefits which are considered acceptable when compared to project costs.

- Review the appropriateness of evaluation decisions and activities in FUNCTIONS A-E, and the activities associated with HSIP Planning and Implementation.

- Correct observed deficiencies, if possible.

- Record all non-correctable problems encountered.

STEP F3 - IDENTIFY RESULTS FOR INCLUSION IN THE INTERMEDIATE EFFECTIVENESS DATA BASE

- Identify changes in the MOE's for inclusion to the data base.

- Identify evaluation results for which inconsistencies were identified and exclude these from the effectiveness data base.

STEP F4 - WRITE THE EVALUATION REPORT

- Prepare the final evaluation study report following the recommended report outline.

- Review final report.

- Distribute copies of report to appropriate highway safety personnel.

FUNCTION G: Develop and Update Data Base

This function enables the evaluator to:

1. Tabulate basic input data for the data base
2. Compute the average difference in the non-accident measure.
3. Compute the expected range of the difference
4. Examine relationships between accident and non-accident measures

OVERVIEW

A data base containing Non-Accident-Based Evaluation results is developed in this function. The data base is analogous to the data base developed in FUNCTION G of Accident-Based Evaluation except entries are changes in the non-accident MOE's.

This data base has two primary uses. First, it provides feedback information useful in planning and implementing future projects for which Non-Accident-Based Evaluation may be performed. Second, it provides a quantitative cause and effect relationship between a project and its impact on non-accident measures. This relationship, if analyzed with the cause and effect relationship between the same project and accident measures, may result in identifying accident surrogates for evaluation.

Guidelines for developing and maintaining the data base and suggested data analysis procedures for investigating possible relationships between accident and non-accident measures are provided in this function.

STEP G1 - ORGANIZE INPUT DATA

Information for data base development may be obtained directly from the final study report. The information required includes:

1. Description of the project including countermeasures, location and year of implementation.

2. Expected and actual values of all non-accident MOE's.

3. Sample size and dates of before and after data.

The project description allows the evaluator to establish categories of project types and location, which may be updated with new evaluation results as similar types of projects are evaluated. The year of implementation is used to eliminate outdated evaluation results (i.e., greater than 5 years) from the data base. Before and after values of the non-accident MOE's are used to compute average percent changes due to project implementation. Sample size information, including the dates and length of data collection periods are necessary to ensure that the data base entries represent statistically reliable input data.

STEP G2 - COMPUTE PERCENT CHANGES IN NON-ACCIDENT MOE'S

Estimates of intermediate project effectiveness, expressed as a percent change in the non-accident MOE, is input to the data base. Percent changes should be computed for each MOE for individual projects. Average percent change values should be computed if more than one project is contained in a single project category. Percent change averages should not contain projects older than 5 years to insure that only current estimates are contained in the data base.

Percent changes for individual projects are calculated as follows:

$$\text{Percent Change} = \frac{\text{Expected MOE - After MOE}}{\text{Expected MOE}} \times 100$$

Caution should be exercised when interpreting the "sign" of the percent change value. A decrease in speed variance is considered an improvement while a decrease in the speed differential at points in advance and following an advance warning device is not considered an improvement.

STEP G3 - DEVELOP AND UPDATE THE DATA BASE

The percent changes should be maintained in a format which can be easily updated as new evaluation results become available. A format similar to those used to record accident reduction factors such as the examples shown in Figures 45, 46 and 47 of Accident-Based Project Evaluation can be used. It is important that each time the data base entries are updated, a notation be recorded showing the date of the most recent information.

STEP G4 - INVESTIGATE RELATIONSHIPS BETWEEN ACCIDENT AND NON-ACCIDENT MEASURES

When both Accident-Based and Non-Accident-Based Evaluation are performed for a number of similar projects, the evaluator has the opportunity to determine if there is a statistically significant relationship between accident and non-accident measures. If a strong, logical relationship is observed, a non-accident measure may be used as an accident surrogate.

A two step process is suggested for determining whether a relationship exists and if it does, establishing the relationship itself.

1. Correlation Analysis

Correlation analyses should be performed between pairs of absolute changes in accident and non-accident measures. Correlation provides a single number (the correlation coefficient) which numerically quantifies the relationship between two variables. Correlation coefficients indicate the degree to which variation (or change) in one variable has an influence on the variation (change) in another. A correlation coefficient mathematically defines the strength of association between a pair of variables. In this application, the variable pair is the change in the non-accident MOE, and the change in the accident MOE for the same project. A set of data points representing variable pairs for a group of ten similar projects is given in Table 13 and a plot of these pairs is shown in Figure 70.

Two types of correlations may be used: nonparametric and parametric. Nonparametric techniques require no assumptions about the distribution of the variables. Examples include: Spearman's RHO and Kendall's TAU correlation technique. Parametric techniques require that the variables be normally distributed. An example of a parametric correlation technique is the Pearson Product Moment Technique. Details on these techniques are available in most statistics texts.

The coefficient which results from the correlation techniques ranges from -1.0 to +1.0. A negative coefficient indicates an inverse linear relationship (one variable tends to increase as the other decreases or vice versa). A perfect inverse linear relationship is denoted by -1.0.

A positive coefficient indicates that the variables tend to increase (or decrease) together. Perfect positive linear correlation is denoted by +1.0. A coefficient of zero denotes the absence of a linear relation. The significance of each coefficient should be examined for statistical reliability.

Correlation coefficients and confidence levels should be computed for combinations of changes in all available types of accident and non-accident measures. For example, suppose several projects involving the posting of lower advisory speed panels at isolated curves were evaluated on the basis of changes in average speed and changes in total, fatal, injury, property damage and run-off-road accidents. In this case, correlation analysis should be performed between the change in speed <u>and</u> the change in accidents for each individual accident MOE (i.e. five correlations should be performed).

In general, if a correlation coefficient of at least 0.83 is observed at a confidence level of 95% or greater (a significance level of 0.05 or less), regression analysis should be performed to determine the relationship between the accident and non-accident measures. Several pairs of data are needed to formulate a conclusion based on regression analysis.

2. <u>Regression Analysis</u>

The most common statistical procedure for fitting a line to a set of data points utilizes the method of least-squares. This method

Table 14. Pairs of data points for 10 similar projects.

Pair No.	Change In	
	Accident MOE	Non-Accident MOE
1	5.5	4.9
2	5.1	7.5
3	4.2	4.2
4	3.6	5.8
5	2.8	3.9
6	2.1	6.0
7	2.0	4.0
8	1.9	2.2
9	1.9	8.0
10	1.0	2.5

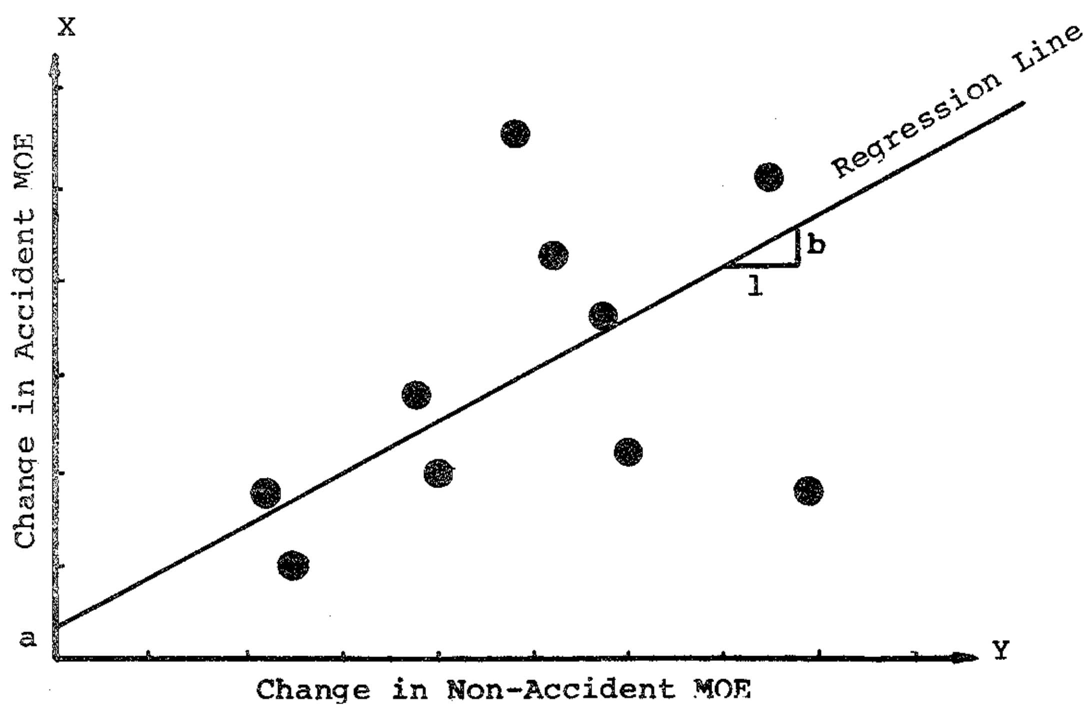


Figure 70. Plot of data points for 10 similar projects.

is based on determining the best-fit line for which the vertical distances of all the points from the line are minimized. The line itself is called the regression line.

The most common type of regression is linear regression. The objective of the procedure is to locate the best-fitting straight line. Linear regression is most commonly used because it gives a simple summary of the relationship. Most variables of interest are assumed to be related in a straightline manner, although this assumption is not necessarily true for all variables. The general formula for a straight line is:

$$Y = a + bX$$

In this formula, "a" is called the intercept and is the value of Y at the point where the line crosses the Y (vertical) axis (X is zero there), and b is the slope of the line (it denotes how much Y changes for a one unit change in X, see Figure 70). The values of a and b are calculated using the least-squares regression method.

The evaluator should consult a statistics textbook for the details of performing linear regression. The method is also described in FUNCTION C of Accident-Based Evaluation.

The result of the regression analysis is a linear relationship (equation) between the dependent variable (Y) which represents a change in accidents and the independent variable (X) which represents a change in the non-accident measure. For example, a regression equation for the speed panel installation project described above may take the form of the following hypothetical relationship:

$$Y = 0.3 + 0.1X$$

Where:

Y = Unit change in run-off-the-road accidents
X = Unit change in average speed on the curve

This relationship implies that for a 1 mph reduction (X = -1.0 mph) in average speed (due to the installation of reduced advisory speed panel), a reduction in run-off-road accidents of 0.2 accidents (Y = -0.2) can be expected. Statistical indices such as R^2, may be obtained for the regression equation to help the evaluator quantify the reliability of the regression equation. The evaluator should become familiar with those indices and compute these statistical values according to procedures contained in statistics textbooks. One of the most important precautions that must be observed is to identify and stay within the range of the independent and dependent variables used in developing the equation. Extrapolation outside of known points violates the assumptions used in developing the relationship and can lead to erroneous results.

Summary of FUNCTION G

STEP G1 - ORGANIZE INPUT DATA

- From the evaluation study report obtain information on the project description, before and after values of MOE's, and sample size and data collection procedures.
- Review information for completeness.

STEP G2 - COMPUTE PERCENT CHANGES IN NON-ACCIDENT MOE'S

- Compute the percent changes between the before and after values of the MOE's.
- Compute average percent changes for similar projects.

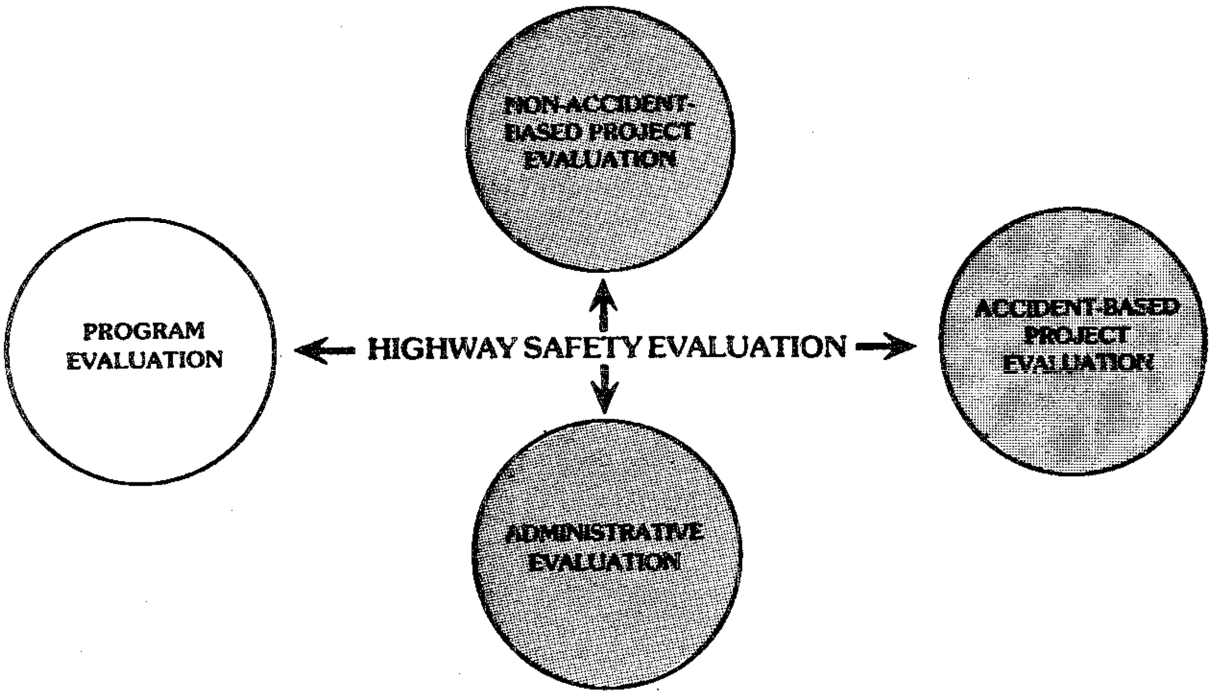
STEP G3 - DEVELOP AND UPDATE DATA BASE

- Devise a format for recording and updating percent changes.
- Incorporate non-accident changes into the data base.

STEP G4 - INVESTIGATE RELATIONSHIPS BETWEEN ACCIDENT AND NON-ACCIDENT MEASURES

- When several similar projects have been evaluated by both Accident and Non-Accident-Based Evaluation, perform correlation analyses for combinations of accident and non-accident measures.
- If significant correlations are observed, perform regression analyses to determine the relationship between the accident and non-accident (potential surrogate) measures.

PROGRAM EVALUATION



A highway safety program is a group of projects (not necessarily similar in type or location), implemented to achieve a common highway safety goal of reducing the number and severity of accidents and decreasing the potential for accidents on all roads.

The objective of Program Evaluation is to provide guidelines for assessing the value of a completed or ongoing highway safety program. The measures of program effectiveness are observed changes in the number, rate and severity of traffic accidents resulting from the implementation of the program. Program effectiveness is also examined with respect to the benefits derived from the program given the cost of implementing the program.

Program Evaluation consists of seven functions. Each function contains a series of systematic steps which lead the evaluator through the activities and decisionmaking processes of a properly designed evaluation study.

The seven functions which comprise Program Evaluation are:

FUNCTION A - Develop Evaluation Plan

FUNCTION B - Collect and Reduce Data

FUNCTION C - Compare Measures of Effectiveness (MOE's)

FUNCTION D - Perform Tests of Significance

FUNCTION E - Perform Economic Analysis

FUNCTION F - Prepare Evaluation Documentation

FUNCTION G - Develop and Update Effectiveness Data Base

FUNCTION A addresses the necessary planning activities which must be considered prior to performing an evaluation of a completed or ongoing highway safety program. The evaluation objectives and MOE's, the analytical framework for the evaluation (experimental plan) and data requirements are established in this function. FUNCTION B provides guidelines for collecting, reducing and presenting evaluation data. FUNCTION C presents various methods for comparing MOE's according to the experimental plan selected for the evaluation. FUNCTION D provides a framework for testing the statistical significance of the changes in the MOE's. FUNCTION E presents economic analysis techniques for conducting a fiscal evaluation of program effectiveness. Guidelines for documenting the observed effectiveness of the program are presented in FUNCTION F. FUNCTION G provides a format for maintaining information on program effectiveness to be used as feedback to the Planning and Implementation Components of the HSIP.

These functions are common to all Effectiveness Evaluation subprocesses contained in this Procedural Guide. It is strongly recommended that the evaluator become familiar with the functional details of each subprocess prior to performing an evaluation using any single subprocess, since some of the information contained in project evaluation may be helpful in performing a program evaluation and visa versa.

FUNCTION A: Develop Evaluation Plan

This function enables the evaluator to:

1. Develop an analysis plan for evaluating the effectiveness of a highway safety program.

2. Identify and record the evaluation objectives and measures of effectiveness (MOE's)

3. Select an appropriate experimental plan for use in the evaluation.

4. Establish a list of data needs for evaluating the program.

5. Document the evaluation plan.

Overview

The development of an evaluation plan is the first important step toward transforming Effectiveness Evaluation into an efficient and worthwhile activity in the Highway Safety Improvement Program (HSIP). During plan development, the evaluator is required to think through the entire evaluation process. With proper planning, the time and effort required for evaluation can be efficiently utilized to produce high-quality program Effectiveness Evaluation results. Thus, the plan development process can be considered as the singlemost critical activity in any evaluation study.

The evaluation plan may be developed before program implementation (during the Planning Component of the HSIP) or following implementation. Evaluation planning before implementation is highly recommended. Prior planning makes it possible to select and utilize more reliable experimental plans and to plan data collection activities in advance of actual data collection so that crucial "before" data are not overlooked.

Many project and program evaluation planning activities are similar and are not duplicated here. Rather, supplemental discussions are provided to enhance the evaluator's understanding of the steps to be performed. The evaluator should be familiar with the plan development function of Accident-Based Project Evaluation to develop a total picture of the activities and decisions which must be made.

STEP A1 - DETERMINE THE PROGRAM GOAL

A program consists of a group of individual projects with a common highway safety goal. Programs may be categorized as: 1) established safety programs, or 2) designed safety programs which consist of projects that have been selectively combined for evaluation purposes. Examples of established programs include those administered by Federal agencies (e.g., Safer-Off-System Roads, Hazard Elimination, Pavement Marking Demonstration, and Rail-Highway Crossing), subsets of projects within a single program (e.g., elimination of roadside obstacles on two-lane rural winding sections), and other programs established and administered by governmental agencies.

In addition to established programs, it may be desirable to evaluate a program consisting of several projects, all of which have a common goal. For example, suppose an agency is considering a program to identify and correct locations on rural highways with a high incidence of wet-pavement accidents. An important input to the decision to implement this type of a program is the effectiveness of past countermeasures used to reduce wet-weather accidents, such as:

- Placement of an open-graded friction course on signalized intersection approaches.
- Longitudinal grooving on highway section.
- Installation of "Slippery When Wet"(W8-5) signing.

These project types could be combined to form a program whose common goal is the reduction of wet-pavement accidents. The evaluation of this program would provide the administrator and planner with information concerning the effectiveness of a wet-weather accident reduction program.

Statement of the Goal

The first activity in Program Evaluation is to determine the highway safety goal to be evaluated. The goal must be stated in a brief but concise statement in accordance with the following criteria:

1. The program scope as defined by the type(s) of accident and/or severity measures which are expected to be affected by the program. These measures should be specific to the program but general enough to be appropriate for all possible projects within the program;

2. The program objective defined should always be the improvement of safety. (Operational improvement and maintenance may be a secondary goal of the program but not the primary goal);

3. The location type(s) included in the program (i.e., intersections, curves, tangents, or combinations of location types);

4. The geographic program area affected by program activities (i.e., City, State, county, road class, etc.).

If an established program is to be evaluated, the elements of the highway safety goal are generally derived from the program statement and a knowledge of the types of projects which make up the program. Therefore, the evaluator must know the types of projects which have been (or will be) implemented under the program, the types of project sites and the geographic area(s) which are affected by the program. This information can be obtained through discussions with program planners, a review of program or project files and referral to stated program objectives established prior to initiation of program activities. For example, a possible goal of a program implemented under the FHWA Rail-Highway Crossing Program was stated as follows:

> To reduce fatalities, injuries and property damage associated with auto-train accidents through improved safety at all at-grade rail crossing locations on the State road system.

In this goal statement, the type of accident and/or severity measures (the scope of the program) are auto-train accident fatalities, injuries and property damage; the objective of the safety activities is to reduce the stated accident measures; the location types are all rail/highway grade crossings; and the program area is the State road system.

For Program Evaluations which require the selection of completed projects, the goal statement is helpful in project selection and therefore should precede the selection process. In many instances the evaluator receives a general description of the program to be evaluated from managerial, planning or supervisory personnel. The evaluator must transform the general description into a goal statement utilizing the four criteria described above.

The goal statement should always be reviewed and finalized by the person requesting the evaluation before program development (project selection) begins.

The statement of the highway safety goal must be documented in the evaluation plan (STEP A5) and used for future reference in the preparation of the Program Evaluation Report.

STEP A2 - SELECT AND STRATIFY PROJECTS

After identifying and recording the statement of the highway safety goal, the evaluator should select highway safety projects to be evaluated. Project review and selection must be done whether the evaluation is being conducted on an established program or on a program to be developed. Review and selection are important because some projects may not be appropriate for evaluation due to data unavailability, atypical accident experience, etc. In addition to selecting projects which make up the program, there may be a need to divide the program into groups of projects which have similar countermeasure and locational characteristics. Stratification of the program into subsets should be performed when the evaluator is interested in determining the contribution of specific types of projects to the overall effectiveness of a program or when the program consists of radically different project and location types. If an established program is being evaluated, a list should be prepared of all projects which are a part of the program.

Project Selection

The evaluator should review available information for each completed project and make a list of projects to be included in the program. If projects are not already categorized under an established program, projects meeting the four goal criteria in STEP A1 should be selected for detailed review. Projects implemented more than five years ago should generally not be selected because of the possibility of changes, other than the project, which may influence accident experience at the project site. This rule helps the evaluator to make the trade-off between the need to obtain enough before and after accident data to collect a representative sample of the "true" before and after accident experience and the need to minimize the introduction of geometric, traffic and/or environmental changes (other than the project) which may influence accidents during the before and after analysis periods.

Other factors which should be considered when preparing a list of projects include data availability and data sufficiency. Each of these factors are described in detail in STEP A1 of the Accident-Based Project Evaluation. Projects with incomplete, unavailable, or questionable accident data should be eliminated from the program.

All candidate projects which satisfy the selection criteria may be used to form the final highway safety program. The following information should be recorded for each project within the final program.

- Implementation date (start and end date)
- Type of countermeasure(s) within each project
- Project location

Stratify Projects

It is advisable to stratify the projects into program subsets with similar project and location characteristics if the program includes several types of projects. Stratification into program subsets makes it possible to determine the contribution of various types of projects at specific location types to the overall program effectiveness. Thus, the effectiveness of the program can be determined by evaluating the effectiveness of each program subset. For example, the evaluator may be interested in the effectiveness of the following program subsets within a Statewide program to reduce accidents at rail-highway grade crossings.

- Installation of flashing lights

- Relocation of the crossing

- Illumination

- Installation of automatic gates
- Signing and/or marking
- Surface improvements
- Sight distance improvements
- Combinations of two or more project types

Each of these improvements could be established as a program subset.

The total Highway Safety Improvement Program itself may be the subject of evaluation. This program may consist of railroad-highway crossing projects, signalization projects, pavement marking projects, etc. For this program, it is necessary to group all railroad-highway crossing projects together into one program subset, all signalization projects into another subset, and so forth, since the effectiveness of the combined program would be of limited usefulness for future decisions and also the combined effectiveness may mask highly effective or ineffective program subsets.

Less extensive programs may or may not warrant stratification. For example, a countywide edgelining program may, at the discretion of the evaluator, be stratified into road class subsets such as county primary, county secondary and county local; or it may be stratified by alignment such as tangent and curves. It may also be evaluated as a single program without stratification.

If a large number of projects (i.e., greater than 20-30) are included in a single program subset, it may be possible to sample projects which statistically represent the total subset. To determine the minimum number of projects, the evaluator should use the project sampling procedure described in STEP A2 (STRAFIFY PROJECTS) of Accident-Based Project Evaluation. If project sampling is employed, the sampling procedure and the selected sample projects should be indicated in the program definition (project listing).

STEP A3 - SELECT EVALUATION OBJECTIVES AND MOE'S

A fundamental step in Effectiveness Evaluation is the formal selection of evaluation objectives and MOE's.

Evaluation Objectives

An evaluation objective is a brief statement describing the desired outcome of the evaluation study. Program evaluation objectives are different than program goals which describe the specific safety problem to be corrected by the program. Evaluation objectives must be established for each program subset and relate to the desired outcome of the evaluation study. All objectives selected for the evaluation should be recorded on the provided forms and be included in the evaluation plan document to be prepared in STEP A5.

The evaluation objectives should be stated in a brief but concise form which lends itself to quantitative measurement, and they should be realistic and attainable. When writing an objective, start with the phrase "to determine the effect of the program (or program subset) on:", followed by a single accident measure to be evaluated. Because the programs being evaluated must have a goal related to highway safety (as opposed to operations or maintenance goals), the effect of the program on an accident measure will always be the primary objective(s) of the evaluation. In some cases, however, additional (secondary) evaluation objectives may be specified which relate to changes in non-accident measures (evaluation of non-accident measures is beyond the scope of Program Evaluation - refer to Non-Accident-Based Project Evaluation).

Four fundamental evaluation objectives should always be selected for every program. These objectives are:

To determine the effect of the program on:

- total accidents
- fatal accidents
- personal injury accidents
- property damage accidents

Additional accident-related evaluation objectives should be selected which relate specifically to the program being evaluated. These objectives may be related to the program goal or to any other accident measure which may be affected (either positively or negatively) by the program. For instance, evaluation objectives (in addition to the four fundamental objectives) which may be of interest to the evaluator for a program subset of road resurfacing and delineation on two-lane rural highways may be: To determine the effect of the program on 1) run-off-road accidents, 2) fixed object accidents, and 3) the number of injury accidents as a percentage of total run-off-road accidents.

The rationale for selecting these additional objectives is that resurfacing and delineation countermeasures are expected to reduce run-off-road and fixed object accidents through increased skid resistance and delineation. In addition, the new surface may result in increased vehicle speeds which may result in a higher percentage of injury accidents when a fixed object is struck. It may also be of interest in this case, to evaluate (if possible) the effect of the program on vehicle speed as a secondary, non-accident evaluation objective. This information may be of assistance in analyzing the evaluation study results. Of course, the selection of an evaluation objective related to speed is dependent on whether vehicle speed data are available prior to program implementation.

Evaluation objectives related to the economic effect of the program should also be stated during plan development. Although the final decision on whether to perform an economic evaluation is generally dependent on the observation of a statistically significant change in the accident MOE, the intent to conduct an economic analysis should be stated. It must be remembered that the person responsible for plan development may not be present at the time the actual evaluation study is conducted. Therefore, all planned steps of the study must be recorded for future reference.

To simplify the evaluation process, the number and nature of the evaluation objectives should be limited to the four fundamental objectives plus those objectives of critical interest to the evaluator.

Measures of Effectiveness (MOE's)

One or more MOE's must be assigned to each evaluation objective to transform it into a quantifiable measure which provides evidence of the effectiveness of the program. For Program Evaluation, MOE's must be assigned for each objective selected. It is not necessary that all program subsets have the same MOE's. These measures may be related to accident frequency, severity, rate, proportion, or percentage. It is recommended that rate-related (as opposed to frequency) units be used whenever possible. Rate MOE's generally reflect more realistic accident conditions at a site by allowing the evaluator to compare the accident population to the total population at risk.

Frequency MOE's are expressed as the number of accidents (often stratified by severity i.e., fatal accidents, injury accidents, etc.). Rate MOE's are expressed as the number of accidents (by severity) per unit vehicle exposure (opportunity for accidents). Exposure units are expressed either as vehicle-miles (or a multiple thereof e.g., million vehicle-miles) or entering vehicles (or some multiple thereof e.g., million entering vehicles). The selection of an exposure unit is based on the nature of the program subset. If the project within a subset are implemented on a roadway section, vehicle-miles is appropriate for use as an exposure unit. If projects are implemented at an intersection or a spot location, vehicles (or entering vehicles) should be used as the exposure unit. A discussion and set of recommendations for the appropriate selection of exposure units are provided in STEP A3 of Accident-Based Project Evaluation.

Other MOE's include accident type or severity as a proportion or percentage of total accidents (or a subset of total accidents). Examples of these MOE's include; wet to dry accident ratio, the night to day accident ratio, injury accidents as a percent of total accidents, or "A" severities as a percent of total persons injured.

After determining appropriate units for the measurement of each objective, the MOE for each objective should be recorded. The MOE should take the form of "The change in:" followed by the accident measure stated in the evaluation objective and the assigned units and time period. MOE examples include:

The change in:

a) the number of total accidents for a three year period (frequency);

b) average number of run-off-the-road accidents per million vehicle-miles per year (rate);

c) the ratio of "severe" injuries to total injuries per year (proportion); and

d) the annual average number of injury plus fatal accidents as a percent of total accidents (percentage).

MOE's should also be assigned to economic evaluation objectives. If possible, the evaluator should specify whether the measure is to be a benefit/cost ratio or the cost for reducing one unit of an accident type or severity (cost-effectiveness). The criteria for this decision is generally whether the evaluator (or agency) is willing to place a monetary value on an accident fatality or injury as an input to the economic analysis. If costs are assigned the benefit/cost ratio should be specifed as the MOE. If not, a cost-effectiveness approach can be employed.

All evaluation objectives and MOE's should be recorded on the form provided in the Appendix and documented in the evaluation plan.

STEP A4 - SELECT EXPERIMENTAL PLAN

After the evaluation objectives and MOE's have been selected, the evaluator must next select the experimental plan for comparing the MOE's for each program subset. Generally, the selected experimental plan is used for all subsets within a program, but this is not a requirement. The selected experimental plan is an important issue in the evaluation plan because it enables the evaluator to plan for the method of data collection, time periods, and locations for which data must be obtained.

There are several experimental plans which are appropriate for use in evaluating highway safety programs. Thus, the evaluator must be able to select a plan which is appropriate for the evaluation and to assess the feasibility of applying the plan under prevailing resource limitations. This requires the evaluator to possess an understanding of each plan, its strengths, weaknesses, limitations, and assumptions.

Theoretical Selection Considerations

Experimental plan selection should be based on maximizing the validity of the evaluation study. Validity is defined as the assurance that observed changes in the MOE's result entirely from the implementation of the program (and its component projects) and for no other reasons. The type of experimental plan selected for the evaluation directly affects the ability of the investigator to achieve high levels of validity.

There are several factors (often referred to as threats to validity) which must be recognized and overcome in the evaluation of highway safety programs (and projects). They include:

a) Changes in the values of the MOE's caused by factors other than the program (referred to in the literature as a "history" threat). As an example, the initiation of a selective law enforcement program at one or more high accident intersections during the after evaluation period may affect the accident experience and mask the effectiveness of the program.

b) Trends in the values of the MOE'S over time (referred to in the literature as "maturation"). As an example, a comparison of total accident rates before and after program implementation may show a large decrease in the total accident rate (Figure 71). This may be a result of the program or it may be that the decrease is an extension of a long-term decreasing trend in total accident rates at the program sites (Figure 72).

c) Regression to the mean. Regression-to-the-mean is a phenomenon which may result when sites are selected on the basis of extreme values (i.e., high accident experience). Regression is the tendency of a response variable such as accidents to fluctuate about the true mean value. As an example, the decrease in accident rates shown in Figure 71 may be a result of the program or it may be the regression (natural fluctuation) of the accident rate about the mean accident rate (Figure 73).

d) Random data fluctuations (instability). Accident data are particularly subject to random variations when measured over time or at a small number of locations.

The evaluator must recognize and attempt to overcome the validity threats. Threats (a), (b) and (c) may be minimized through appropriate experimental plan selection and use. Threat (d) may be overcome using statistical techniques.

Practical Selection Considerations

Recognizing and attempting to overcome the above described threats to validity is an important step toward selecting a sound experimental plan. However, the evaluator must also recognize the real-world constraints which limit (and often dictate) the type of experimental plan which can be used in the evaluation study. Among the constraints which must be considered are the manpower and fiscal capabilities of the evaluating agency, the availability of accident data, the availability of control sites (or

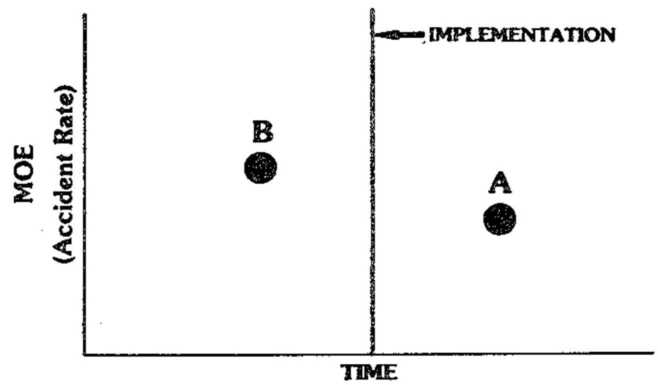


Figure 71. Assumed change in MOE's Before and After Project Implementation.

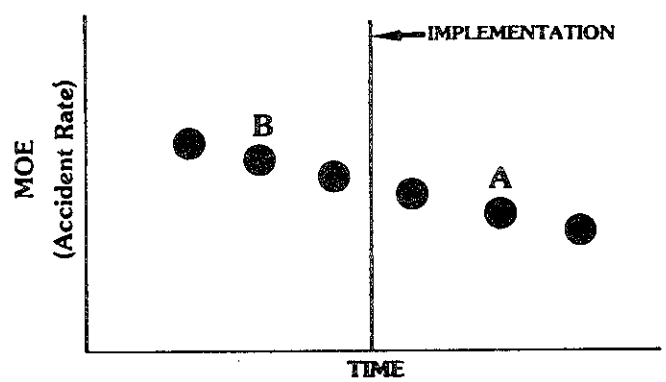


Figure 72. Trends in MOE's over time.

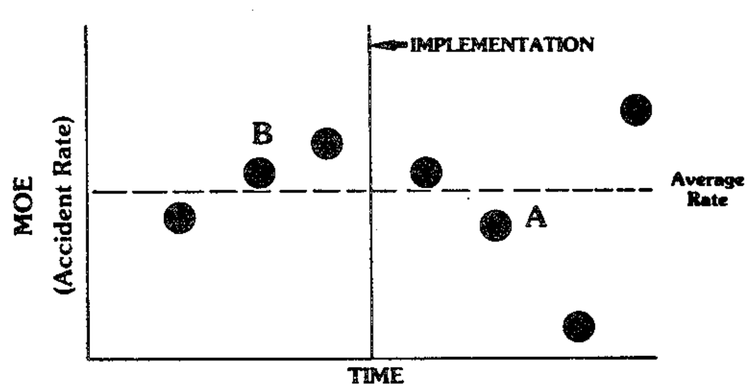


Figure 73. Regression-to-the-mean influences on MOE's

groups), and the point in time (with respect to implementation) that evaluation plan development is undertaken.

Agency Capabilities

In many cases, the size of the agency, its facilities, and the number of persons available for conducting evaluations is a deciding factor in the selection of an experimental plan. Plans which require control sites also require significantly higher levels of effort (in data collection requirements associated with control site selection) than do plans which do not require control sites. This is especially true if accident data are not maintained in a computerized format and must be manually extracted and summarized from historic accident files. However, it should be remembered that plans which include control sites provide more reliable results compared to other experimental plans.

Accident Data Availability

The validity of any evaluation study is dependent on the ability of the investigator to obtain values for the MOE's which are indicative of the "true" conditions which exist during the evaluation periods. Since the evaluation objectives and MOE's for this subprocess are always related to changes in accidents, the quality of accident data is of paramount importance in selecting an experimental plan. Each program site must be reviewed to determine if any geometric, operational or environmental changes other than the project, has occurred (this is a check of the "history" threat to validity). In general, this review should include a period of at least three years before and three years after project implementation. The review of site characteristics should be accompanied by a critical review of accident experience for the same time period. The annual accident frequency and rate should be similar for each year before the program is implemented. Also, the frequency and rate should be similar for each year following completion of the program. Years with significantly higher or lower accident experience may indicate a change at the site other than the improvement (this is a check of "maturation" and "history"). Also, law enforcement agencies should be contacted to determine if changes in accident reporting and/or enforcement characteristics have occurred during the study period.

If serious problems are observed or suspected with respect to either the accident data or factors which affect accident experience at the sites during the before or after periods, steps must be taken to alleviate the problem. For example, if the changes affect a large area within which the program sites are located, it may be possible to identify and use control sites. If the change is site specific and/or temporary in nature, control sites are not appropriate for accounting for the effects of within-site variability and analysis periods may need to be shortened to eliminate the periods for which the change took place. If accident data are incomplete or serious problems are observed in the period before implementation, the before period may be eliminated from consideration, given that parallel control sites exist. If these accident data problems cannot be overcome, the project should be removed from the program subset.

Control Site Availability

Threats to the validity of the evaluation study can generally be overcome or minimized through the use of experimental plans which utilize control sites. The ability of the evaluator to use such experimental plans to improve the validity of the evaluation study depends on the availability of control sites. Control sites (also referred to as comparison sites) must have similar accident, geometric and environmental characteristics as those of the project site or sites in the program subset prior to program implementation. If inappropriate control sites are selected and used in the evaluation, other serious validity problems associated with control site bias may result. Control site selection guidelines are provided in FUNCTION B (Collect and Reduce Data) of this subprocess as well as in Accident-Based Project Evaluation.

A technique for controlling possible validity threats in the selection of control sites is to randomly select sites for improvement from groups of sites which warrant improvement. The use of this technique provides the evaluator with an extremely powerful plan for controlling the validity threats to the evaluation. However, evaluation planning is required before implementation for the use of this technique.

Evaluation Plan Timing

Evaluation plan development can occur at two points. The evaluation plan can be developed within the Planning Component of the HSIP or the evaluation plan can be developed after the program has been implemented. Ideally, evaluation plan development should be an integral part of the Planning Component to provide the evaluator with the opportunity to select and develop a reliable experimental plan. This is especially true for a program which involves large safety expenditures and a wide-range of safety activities. If the evaluation plan is selected following implementation, the evaluator is somewhat limited in the available experimental plan options. Without pre-implementation planning, random assignment of program treatments to program sites within a subset cannot be made. Further, when planning is done after implementation, it is less likely that adequate control sites can be identified.

Experimental Plans

The four experimental plans and the variations of each plan (i.e., trend analysis vs. single point estimates) presented in the project evaluation subprocess are applicable for Program Evaluation. The four plans include:

A. Before and After Study With Control Groups;
B. Before and After Study;
C. Comparative Parallel Study;
D. Before, During and After Study.

It is important that the evaluator recognize the strengths and weaknesses of each plan. These issues are discussed at length in STEP A4 of Accident-Based Project Evaluation. In this function of Program Evaluation, these strengths and weaknesses are discussed in terms of overcoming or minimizing the threats to evaluation validity. In addition, one new variation is presented for the before and after study with control groups plan (i.e., randomized assignment of treatments). This variation, when properly implemented, is one of the soundest experimental plans.

It should be recognized that all possible experimental plans and variations are not presented in this Guide. The plans that are presented provide experimental plan options which range from designing an extremely strong evaluation study (randomized assignment) to designing an evaluation study from the standpoint of operating under limited resource conditions and real-world constraints (i.e., before and after study).

Before and After Study With Control Groups (Single Point Estimates, See Figure 8)

The strength (soundness) of this experimental plan (also presented in STEP A4 of Accident-Based Project Evaluation) is based entirely on the ability of the evaluator to select control sites and develop a control group which is similar to the program subset.

This experimental plan may be selected whether evaluation plan development precedes or follows actual implementation. If the evaluation plan precedes the program, the probability of obtaining the strongest possible design is increased since control groups may be planned. When the evaluation occurs after the program has been implemented, care must be taken in the selection of control sites.

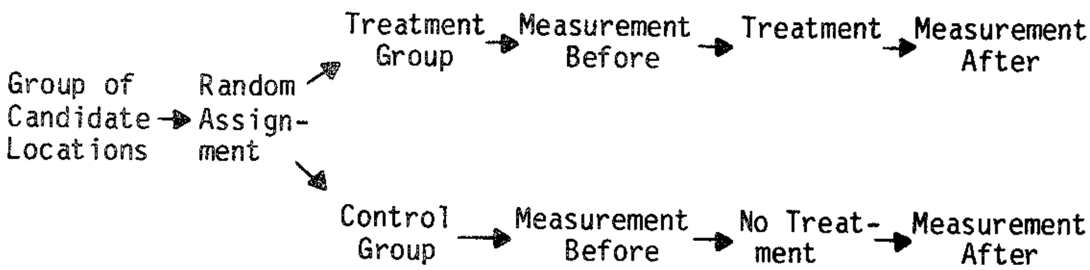
Factors which affect the MOE's (other than the program) which exist locally at one or several of the program sites is not controlled by the use of this plan. Site specific long-term trends cannot be controlled. However, when these characteristics exist for all program and control sites, the plan can adequately control for these threats.

Before and After Study With Control Groups (Trend Analysis, See Figure 9)

This experimental plan also requires the selection of a group of control sites which are similar to the program sites. The plan is somewhat more powerful than the single point estimate by virtue of its control over the threats of long-term trends and regression. This plan is only appropriate when significant increasing or decreasing trends are observed in the before period when program and control groups accident experience is combined (see STEP A4 of Accident-Based Project Evaluation).

Before and After Study With Randomized Control Groups

This experimental plan is one of the strongest plans available to the evaluator. The use of this plan requires that evaluation plan development be performed prior to the implementation of the program. The model of the experimental plan is shown below:



This plan is a third version of the Before-After with Control Groups in which all candidate sites are randomly assigned to either the program group or the control group. Random assignment of sites insures that the program group and control group are drawn from the same population. Thus, any improvement in the treatment sites can be attributed to the program treatment. (The minimum size of each group may be determined using the sampling size determination procedure in STEP A2 of the Accident-Based Project Evaluation). All threats to validity previously described are controlled by this plan except when enforcement of other external changes are not applied uniformly to both groups.

Before and After Study (Single Point Estimates, See Figure 10)

This experimental plan, although simple and straightforward in application is one of the weakest plans with respect to controlling validity threats. This plan provides the evaluator with an experimental plan which should be used only when an evaluation must be performed, control sites are not available and, for practical reasons, the use of other plans are not possible (see STEP A4 of Accident-Based Project Evaluation).

Before and After Study (Trend Analysis, See Figure 11)

When control groups cannot be used, and significant trends are observed in the before accident experience, this experimental plan provides a relatively strong alternative to the single point estimate before and after study plan. It controls for both long-term trends and regression. It does not, however, control for the presence of factors during the analysis periods other than the programs which may impact the MOE's (See STEP A4 of Accident-Based Project Evaluation for further details).

Comparative Parallel Study (See Figure 12)

This experimental plan is useful when before values of the MOE's do not exist or are considered unacceptable. The plan utilizes control groups with the similarities between the program and control groups being assumed but not validated. The plan is rather weak with respect to controlling for the threats to validity. However, its use may be appropriate when the before MOE values are not acceptable and the evaluation must be performed (See STEP A4 of Accident-Based Project Evaluation).

Before, During, and After Study (See Figure 13)

This plan is appropriate for use when an evaluation must be performed on a program which is temporary or experimental in nature and is to be discontinued (See STEP A4 of Accident-Based Project Evaluation).

The experimental plans described above are applicable for evaluating individual program subsets within a program. The purpose of each plan is to determine the difference between a changed condition (resulting from the program) and the condition which would be expected to exist had the program not been implemented. There are other types of programs, however, that consist of implementing distinct levels of improvements at similar program sites. An example of such a program is a longitudinal grooving program consisting of different groove depths and spacing on different roadway sections. Experimental plans for this type of Program Evaluation include Latin Squares design and factorial designs. If such a program is encountered, the evaluator is directed to experimental design texts listed in the bibliography.

Experimental Plan Selection

The evaluator now has sufficient information to select an experimental plan for the evaluation. If the program consists of subsets, an experimental plan must be selected for each subset. In selecting the plan, the evaluation should begin with the strongest plan (the one which minimizes threats to validity) and analyze the practical aspects of applying that plan. Should the use of the strongest plan be infeasible, the next most powerful plan should be considered until a feasible plan is selected. This process results in using the most powerful plan feasible for the evaluation.

When selecting the plan, the evaluator should be thoroughly familiar with both the theoretical and practical considerations of each experimental plan. These considerations are described above and in STEP A4 of Accident-Based Project Evaluation.

Each experimental plan selected for the evaluation should be recorded along with the rationale for its selection and the program subset for which it is to be applied. If sample size determinations are appropriate (in the Before and After Study with Randomized Control Groups), the minimum sample size should be determined and documented.

STEP A5 - DETERMINE DATA NEEDS

Evaluation data needs must reflect the evaluation MOE's and the type of experimental plan selected for the evaluation. The possible types of data which may be needed include field and accident data on key variables at each candidate control site, accident frequencies, traffic volumes, and program costs including implementation, maintenance and operating costs. The time periods, possible data sources, and data collection procedures must be specified for each item of data.

Data Needs for Control Group Selection

The ideal control group contains sites which are identical to the sites within a program subset before program treatments are implemented. The use of randomized assignment insures the selection of control sites that are similar to the program sites. However, when randomized assignment is not possible, the use of properly selected control sites strengthen the experimental plan. The evaluator should avoid the use of a single control site, especially when trend analysis is not employed. Obviously, the larger the number of sites within the control group, the greater the probability that the group is representative of the population of possible control sites. The results of an evaluation which utilizes a single control site or section often raises more questions regarding the validity of the findings than if the control was not used, since validity questions must be dealt with for both the program sites and the single control site.

As stated in the previous step, the minimum number of program and control sites must be determined through statistical sampling procedures when the evaluation is planned before the implementation of the program. When the evaluator is faced with selecting control sites for implemented programs, as many control sites as practical and, at least, the minimum number as determined by statistical sampling procedures should be used.

Data needs for control site selection must be determined separately for each program subset. The evaluator must critically review the type of location which has been or will be improved to identify key variables (geometric, operational and/or environmental) which may affect the MOE values (other than the program treatments) and must therefore be controlled for by the use of the control group.

For example, an evaluation of a program to provide clear zones on rural highways may consist of evaluating a program subset implemented on two-lane rural isolated curves. Geometric variables may include degree of curvature, lane width, shoulder width, superelevation, sight distance and side slope angle. Operational variables may include traffic volume, posted speed, and vehicle approach speed. Environmental variables may include annual amount of rainfall, number of days of dense fog and amount of snowfall. Since research on defining the term "similarity" is limited, the evaluator may accept as a rule of thumb, a variation of 10% between the values of the MOE's and key variables at the program sites and control sites. The procedure suggested in FUNCTION B, STEP B1 of Accident-Based Project Evaluation should be consulted for additional information.

Data Needs Related to MOE's

Data needs related to evaluation MOE's consist of accident and, in most cases, traffic volumes. MOE data needs must also relate directly to the selected experimental plan. If the trend analysis plan is to be used, several years of accident data must be obtained. If control groups are involved, the before accident experience for the program group must be similar (within 10% is recommended) to the control group accident experience. Accident data must always provide accidents by type, time of day, location, severity, etc. for a period of one (minimum) to three (recommended) years before and after implementation. If the MOE's are rate-related, traffic volumes for periods corresponding to accident data must be obtained.

Data Needs Related to Economic Analysis

If one of the evaluation objectives is to determine the economic aspects of the program, program cost data must be collected. If the benefit/cost ratio technique is to be used, accident severity data are also required. The economic technique may require severity data depending on the economic evaluation objectives. Cost data needs include the following for each project within a program subset 1) total implementation cost; 2) program operating costs; and 3) program maintenance costs. These data may be obtained from the Administrative Evaluation of the program.

All data to be collected for the evaluation should be documented in a detailed format which specifies the type of data, locations, time periods and other data related characteristics. Data requirement listing forms con- tained in the Appendix should be used to record the data for projects within each program subset.

STEP A6 - DOCUMENT EVALUATION PLAN

This step consists of organizing the decisions made during STEPS A1 - A5 and the rationale for these decisions along with the listing of objectives, MOE's, selected experimental plans and data needs. It must be remembered that the evaluation periods may span several years (in the case where the plan is developed before program implementation) and it is possible that the evaluator who developed the plan may not be present to implement the plan and perform the evaluation. Therefore, a rather detailed description of the plan is required. The evaluation plan document also provides input to the evaluation final report and may be referenced when unexpected evaluation results are observed which may have evolved from inappropriate decisions made at the plan development stage.

The evaluation plan document should consist of: 1) a description of the safety problem and the recommended program; 2) the rationale for program initiation; 3) a full description and discussion of each planning issue; and 4) the criteria used to address each issue and the resulting decisions. Copies of completed forms should be provided in the document.

Summary of FUNCTION A

STEP A1 - DETERMINE THE PROGRAM GOAL

- Determine from the person(s) requesting the evaluation, whether the program to be evaluated consists of specified highway safety projects or whether a program is to be developed for evaluation purposes.
- Obtain available program and project information from files and through discussions with planning personnel to determine;
  - the scope of the program,
  - the objective of the program,
  - the types of locations to be treated by the program, and
  - the geographic area of the program.
- Write the program goal in a brief but concise format.
- Review the program goal statement with the person(s) requesting the evaluation.
- Finalize the program goal statement and save for future reference.

STEP A2 - SELECT AND STRATIFY PROJECTS

- If an established program is being evaluated, list all projects which are a part of the program.
- If projects are to be selected to form the program, list all projects which satisfy the program goal statement.
- Obtain before accident data for each listed project. Eliminate any projects with incomplete, unavailable or questionable accident data. As a general rule, eliminate projects implemented earlier than five years ago.

- For each of the remaining projects, record implementation dates, the types of countermeasures for each project and the location of the project.

- Assign projects to program subsets based on the type of project (and countermeasure) and location.

- Sample projects for evaluation from within program subsets if desired (see STEP A2, of Accident-Based Project Evaluation).

STEP A3 - SELECT EVALUATION OBJECTIVES AND MOE'S

- Write the fundamental evaluation objectives related to reducing total, fatal, injury, and property damage accidents for each program subset. Use the form provided in the Appendix.

- Specify additional evaluation objectives related specifically to the program subset and of interest to the evaluator.

- Specify evaluation objectives related to the economic evaluation.

- Assign one or more MOE's to each evaluation objective.

- List the objectives and MOE's for each program subset. Use the form provided in the Appendix.

STEP A4 - SELECT EXPERIMENTAL PLANS

- Select the strongest possible experimental plan which can be used under existing manpower and resource constraints for each program subset.

- Record the experimental plan selected for each subset.

STEP A5 - DETERMINE DATA NEEDS

- List the key variables to be collected which must be similar for both the program and control groups if a control group is required for the experimental plan(s) selected in STEP A4.

- List data variables associated with the selected MOE's. Record locations, collection periods, and procedures for each data variable.

- List data variables associated with the economic analysis.

- Record data needs for each project within a program subset on the form provided in the Appendix.

STEP A6 - DOCUMENT EVALUATION PLAN

- Assemble all completed forms, data, listings and other items used in the development of the evaluation plan.
- Write the Evaluation Plan document and record the decisions and rationale used in each step of FUNCTION A and attach all completed forms.
- Save the evaluation plan document for future reference.

Example of FUNCTION A

In 1976, the Mountain County Road Commission completed a study of the accident characteristics on the county road system. Among the findings of the study was the identification of an overrepresentation of passing-related accidents on two-lane highways. A follow-up field inspection and a review of maintenance records indicated that standard no-passing zone pavement markings existed on the rural system and that all pavement marking including edgelines, centerlines and striping were well-maintained as part of routine maintenance. Traffic signs including DO NOT PASS (R4-1) and PASS WITH CARE (R4-2) were found to be in conformance with the Manual of Uniform Traffic Control Devices (MUTCD). Further study resulted in a recommendation for placement of NO PASSING ZONE pennants (W14-3) at all no passing zones to supplement existing traffic control devices. In 1977, a program was initiated to install signs at all (87) no passing zones on two-lane highways throughout the county. The program was started and completed in the same year. A request in the form of an inter-office memo was received to perform an Effectiveness Evaluation of the completed program. The evaluation plan development activities were performed as follows.

STEP A1 - DETERMINE THE PROGRAM GOAL

A meeting was scheduled between the evaluator and members of the department requesting the evaluation to discuss the program and obtain any information relative to the evaluation. During the meeting, a thorough discussion was conducted regarding the program and its justification in terms of the observed accident problem. From these discussions, the evaluator suggested the following goal statement for the program:

> "The goal of the no passing zone pennant installation program is to reduce accidents at no passing zones including head-on, sideswipe, and run-off-the-road accidents, associated accident severity, and the proportion of nighttime passing accidents at all marked no passing zones on two-lane highways on the county road system."

The goal statement was considered by those in attendence to be appropriate and representative of the anticipated outcome of the program. During the meeting, the requesting department supplied the evaluator with sign installation work orders for all 87 zones. Each work order contained the distance of the new sign installation to the nearest intersection.

STEP A2 - SELECT AND STRATIFY PROJECTS

From the work orders, a list was developed containing all 87 no passing zones. Two technicians were assigned to pull and photocopy all accident reports which occurred in the years 1975-1979 on sections containing one of the no passing zones (these years included two years before and two years after the program).

While the accident files were being searched, the evaluator visited each sign installation and recorded the length of each no passing zone and the roadway alignment (horizontal curve, vertical curve or combination). The number of zones falling within each category was:

Alignment	Frequency	Average Length
Horizontal Curve	21	.38 miles
Vertical Curve	36	.32 miles
Both	30	.35 miles
Total	87	

Based on these observations, three program subsets were specified since it was felt that the effectiveness of the program treatments may differ depending on the alignment of the no passing zone. The effect of the no passing zone length was considered not to be an influencing factor.

It was observed from a review of the accident reports that construction-related accidents had occurred between 1975-1979 at six project sites (2 in each subset). These projects were eliminated from further consideration. Before and after accident data for the remaining sites were considered complete and reliable. A listing of the projects remaining in each of the three subsets including the work order number, the no passing zone location, and length and the date of sign installation was prepared.

It was decided that sampling of projects within each subset was not warranted since accident data were easily obtainable and manageable in size.

STEP A3 - SELECT EVALUATION OBJECTIVES AND MOE'S

The objectives and MOE's were selected and recorded on the appropriate summary form (see Figure 74 to 76). The objectives were the same for each subset and rate MOE's were selected for all objectives.

STEP A4 - SELECT EXPERIMENTAL PLAN

Experimental plan selection considered the fact that all no passing zones in the county were treated by the program and that control groups were not available. Further, a check of the before accident data showed that there was no trend in the accident data before program implementation. Thus, the before-after experimental plan was chosen as the best possible plan under the prevailing circumstances.

STEP A5 - DETERMINE DATA NEEDS

Evaluation data are required from the project sites which comprise each subset. Data requirements include accidents by type, direction of travel, time of day, and involvement (i.e., passing accidents and non-passing accidents), accidents by severity, and traffic volumes for the accident evaluation phase of the study. Only accidents occurring in the no passing zone or within 300 feet in advance of the zone (and sign) were considered to be affectable by the program.

For economic analyses, the number of fatalities and injuries resulting from passing accidents are required. The evaluation periods were specified as 1975 and 1976 for the before period and 1978 and 1979 for the after period. 1977 was considered as the program implementation period. The data needs for each subset were recorded in the appropriate forms Figures 77 to 79.

STEP A6 - DOCUMENT THE EVALUATION PLAN

All forms, data, and discussion notes were obtained and reviewed for the purpose of documenting the evaluation plan. The plan was developed as follows:

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OBJECTIVE AND MOE LISTING

Evaluation No. 80-4-11 (Horizontal Alignment)

Date/Evaluator 4/1/80, LM Checked by HF

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on: (fundamental)	Percent change in: (check one) Rate ✓ or Frequency ____ (fundamental)
1. Total Accidents	1. Total Accidents/
2. Fatal Accidents	2. Fatal Accidents/
3. Injury Accidents	3. Injury Accidents/
4. PDO Accidents	4. PDO Accidents/
(project purpose)	(project purpose)
5. Head-on Accidents	5. Head-on Accidents/MVM
6. Sideswipes accidents	6. Sideswipes accidents/MVM
7. ROR accidents	7. ROR Accidents/MVM
8. Passing accident fatalities	8. Passing fatalities/MVM
9. Passing accident injuries	9. Passing injuries/MVM
10. Passing accident PDO involvements	10. Passing PDO Involvements per MVM
11. Nightime passing accidents.	11. Percent nightime passing accidents of total passing accidents.
12. B/C Ratio	12. B/C Ratio

Figure 74. Objective and MOE listing form for horizontal alignments.

OBJECTIVE AND MOE LISTING

Evaluation No. 80-4-11 (Vertical Alignment)

Date/Evaluator 4/1/80, LM Checked by HF

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on: (fundamental)	Percent change in: (check one) Rate ✓ or Frequency ____ (fundamental)
1. Total Accidents	1. Total Accidents/
2. Fatal Accidents	2. Fatal Accidents/
3. Injury Accidents	3. Injury Accidents/
4. PDO Accidents	4. PDO Accidents/
(project purpose)	(project purpose)
5. See Page	5. See Page
1 of 3	1 of 3

Figure 75. Objective and MOE listing form for verticle alignments.

OBJECTIVE AND MOE LISTING

Evaluation No. 80-4-11 (Combined Alignments)

Date/Evaluator 4/1/80, LM Checked by HF

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on: (fundamental)	Percent change in: (check one) Rate ✓ or Frequency ____ (fundamental)
1. Total Accidents	1. Total Accidents/
2. Fatal Accidents	2. Fatal Accidents/
3. Injury Accidents	3. Injury Accidents/
4. PDO Accidents	4. PDO Accidents/
(project purpose)	(project purpose)
5. See page	5. See Page
1 of 3	1 of 3

Figure 76. Objective and MOE listing form for combined alignments.

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DATA REQUIREMENTS LISTING

Evaluation No. 80-4-11 (Horizontal Alignment)

Date/Evaluator 4/1/80, LM Checked by HF

Experimental Plan Before - After

Data Needs	Magnitude (Number of Sites, Time Period, Dates)
1. Accident Reports	1. 39 NPZ's (Refer to horizontal NPZ list in project file # 135X for locations and limits), all accident reports for years 1975, 1976, 1978, 1979.
2. Traffic Volumes	2. AADT's for years 1975, 1976, 1978, 1979. For all locations stated in 1 (above)
3. Field Measurements - length of NPZ	3. Length - Measurements for all NPZ locations stated in 1 (above)
4. Costs	4. Total sign installation cost for placement of pennants at all locations stated in 1 (above). Annual total maintenance costs for years 1975, 1976, 1978, 1979.

Figure 77. Data requirements listing form for horizontal alignments.

DATA REQUIREMENTS LISTING

Evaluation No. 80-4-11 (Vertical Alignment)

Date/Evaluator 4/2/80, LM Checked by HF

Experimental Plan Before-After

Data Needs	Magnitude (Number of Sites, Time Period, Dates)
1. Accident Reports	1. 34 NPZ's (Refer to vert. NPZ list in project file # 135x for locations and limits), all reports for years 1975, 1976, 1978, 1979
2. Traffic volumes	2. AADT's for years 1975, 1976 1978, 1979 for all locations stated in 1 (above)
3. Field Measurements	3. Length for all NPZ locations in 1 (above)
4. Costs	4. Total sign installation costs and annual maintenance for years 1975, 1976, 1978, 1979

Figure 78. Data requirements listing form for verticle alignments.

DATA REQUIREMENTS LISTING

Evaluation No. 80-4-11 (Combined H + V Alignments)

Date/Evaluator 4/1/80, LM Checked by HF

Experimental Plan

Data Needs	Magnitude (Number of Sites, Time Period, Dates)
1. Accident reports	1. 28 NPZ's (refer to project file 135 x for locations and limits), all reports for years 1975, 1976, 1978, 1979.
2. Traffic Volumes	2. AADT's for years 1975, 1976 1978, 1979 for all locations in 1 (above)
3. Field Measurements	3. Length for all NPZ locations in 1 (above)
4. Costs	4. Total sign installation costs and annual maintenance costs for years 1975, 1976, 1978, 1979

Figure 79. Data requirements listing form for combined alignments.

EVALUATION PLAN

Title: No Passing Zone Pennant Installation Program

Date/Evaluator: 4/1/80 LM Checked by HF

Evaluation: #80-4-11

DESCRIPTION OF THE SAFETY PROBLEM: The countywide safety needs study conducted in 1976 revealed a significant safety problem associated with passing maneuvers at or near marked rural two-lane no passing zones (refer to Countywide Safety Needs Study, 1976).

PROGRAM DESCRIPTION: Engineering studies for the above described safety problems resulted in the recommended installation of no passing zone pennants (W14-3) at 87 zones to supplement existing traffic control features (signs and pavement markings) at no passing zones.

EVALUATION PLAN DEVELOPMENT STEPS

STEP A1 - Program Goal

The following goal statements were developed for the program:

"The goal of the no passing zone pennant installation program is to reduce accidents in no passing zones including head-on, sideswipe, and run-off-the-road accidents, associated accident severity, and the proportion of nighttime passing accidents at all marked no passing zones on two-lane highways on the county road system".

STEP A2 - Project Selection and Stratification

Six of the 87 project sites were eliminated from the evaluation due to construction during the period 1975-1979. The remaining 81 sign installation projects were stratified into 3 program subsets based on roadway alignment. The subsets and the number of projects in each are:

Alignment	Frequency of NPZ
Horizontal Curve	19
Vertical Curve	34
Combination of Horizontal and Vertical Curves	28
TOTAL	81

Accident data were obtained and reviewed for each project. Data were considered both complete and reliable and usable in an effectiveness evaluation subject to the results of a critical accident data review in FUNCTION B.

STEP A3 - Objectives and MOE's

The evaluation objectives and MOE's were selected and are shown in Figures 74 to 76 for each of the three subsets respectively.

STEP A4 - Experimental Plan

Since control sites were not available and trends in the before accident data were not observed, the before-after study was selected.

STEP A5 - Data Needs

The data needs and sample size requirements for each subset are recorded in Figures 77 to 79.

FUNCTION B: Collect and Reduce Data

This function enables the evaluator to:

1. Collect data necessary for the selection of control groups.

2. Collect and critically review accident and volume data for individual projects which make up the program and control group.

3. Collect cost data for use in economic analyses.

Overview

FUNCTION B of Accident-Based Project Evaluation provides guidelines for the collection and reduction of the data required for a project evaluation. Those guidelines are appropriate and applicable for Program Evaluation as well.

Accident and volume data are used most often as the evaluation criterion on which program effectiveness and (partially) control group selection is based. The Overview section of FUNCTION B of Accident-Based Project Evaluation should be consulted to enable the evaluator to recognize and minimize problems associated with the use of accident and volume data in Effectiveness Evaluations.

STEP B1 - SELECT CONTROL GROUPS

The evaluator may be faced with either selecting control groups for a completed program or randomly assigning program treatments to a portion of a group of sites which warrant improvement.

Selecting Control Groups for Completed Programs

In STEP A4, candidate control sites were identified which had geometric similarities to the program sites prior to program implementation. In addition, a listing of key variables was developed for data collection. These variables along with accident data must be collected for all candidate control sites as well as the program sites.

The first activity in control site selection is to collect or obtain accident and exposure data for the program sites and all candidate control sites. These data should cover a period of one to three years prior to the implementation of the program depending on the before analysis period length. All accident and exposure data should be carefully reviewed to determine whether any of the potential data reliability problems discussed earlier in this function exist. Any observed data deficiencies should be recorded.

Next, the values of the before period MOE's for all candidate control and program sites should be calculated. The evaluator must select a subset of candidate control sites whose accident experience is similar to that of the program group. The evaluator should avoid matching a single candidate control site with a single program site on a one-to-one basis since this may introduce a control site selection bias to the evaluation. Candidate control sites which have MOE values significantly lower or higher than the program group should be eliminated from further consideration.

Field data for the key variables identified in STEP A4 must also be collected. Again, a comparison must be made between the key variables collected at the candidate control and program sites. Candidate control sites which have key variables which are significantly different from the program group should be eliminated from further consideration.

The remaining candidate control sites now constitute the control group for the evaluation.

Selecting Control Groups Through Random Assignment

When the Before and After Study with Randomized Control Groups experimental plan is to be used in the evaluation, the control group is determined in a different way. As discussed in STEP A3 - SELECT EXPERIMENTAL PLAN, the use of this plan requires that the evaluation plan be developed before program implementation. Thus, the evaluator has a group of similar locations, all of which warrant safety improvement with nearly equal priority-ranking. If a decision has been made to correct only a selected number of the sites (this decision is probably based on safety funds, manpower, and/or scheduling limitations), the sites to receive improvement can be randomly selected to meet the minimum sample size determined through a statistical sampling procedure in STEP A4. This can be accomplished by flipping a "fair" coin for each site, for example, heads indicating a site to be improved, tails indicating a control site. Random selection can also be accomplished using the random numbers table provided in the Appendix (i.e., an odd number indicating an improvement site; an even number indicating a control site). The minimum sample size requirement should be satisfied by both groups (program and control).

STEP B2 - COLLECT AND REDUCE ACCIDENT AND VOLUME DATA

In this step, accident and exposure data must be utilized to develop the MOE's for the evaluation study.

Accident data must be reviewed for the possible deficiencies and problems referred to earlier in this step. Also, it is important that all possible accident data sources are identified to ensure that all available accident data are being used. This is particularly important when a statewide computerized accident data base is the primary accident data source. The evaluator should determine if all local jurisdictions submit accident reports to the agency which maintains the data base. It may be necessary to manually collect accident data from non-participating agencies.

All accident data should be tabulated on the accident summary table form provided in the Appendix. One summary table form should be used for each program and control site within a subset.

Annual (or other time period duration, i.e., monthly, depending on the MOE's and experimental plan) exposure data is also required when the MOE's are rate-related. Again, the data should be critically reviewed with regard to the potential problems discussed earlier. If exposure (or volume) data are not directly obtained for the program or control sites, it may be necessary to collect sample data to check the validity of existing volume counts. For instance, if the wet-pavement accident rate is one of the MOE's, the evaluator may need to take wet-pavement volume counts and estimate the change in wet-pavement exposure compared to total exposure. Historic annual rainfall data can then be used to develop annual wet-pavement exposure rates. Volume data for all evaluation locations should be tabulated on the exposure work sheet provided in the Appendix.

The availability of these two data sets enables the evaluator to develop the MOE's selected for the evaluation (frequency, rate, proportion, or percentage).

STEP B3 - COLLECT AND REDUCE PROGRAM COST DATA

If an economic analysis is to be performed, program cost data must be collected. Cost data must be obtained for each program site. Sources of cost data include project files, invoice files, and the results of an administrative evaluation study performed for the program. All cost data specified in STEP A4 should be obtained and recorded for later use. In addition, the number of before and after fatalities, injuries, and property damage involvements or accident types may be required depending on the economic analysis technique to be used.

Summary of FUNCTION B

STEP B1 - SELECT CONTROL GROUP

Selecting control groups for completed programs:

- Collect data related to key variables at all program sites and candidate control sites according to STEP A4 data requirement listings.
- Obtain and critically review accident and exposure data for candidate control and program sites. Record observed deficiencies.

- Calculate values of before period MOE's for candidate control and program sites.

- Eliminate candidate control sites which are not comparable with the program MOE's.

- Eliminate candidate control sites which are not comparable with the program group.

- List the candidate sites which now comprise the control group.

Selecting control groups for random assignment:

- Select a random sampling technique (i.e., coin flipping, random numbers table, etc.).

- Apply the sampling technique and assign sites to either the program or control group.

STEP B2 - COLLECT AND REDUCE ACCIDENT AND VOLUME DATA

- Collect and critically review accident and exposure data according to the MOE data needs listed in STEP A4.

- Summarize the data, by site and analysis period using the appropriate forms provided in the Appendix.

STEP B3 - COLLECT AND REDUCE PROGRAM COST DATA

- Obtain and record program cost data according to the data needs for the economic analysis listed in STEP A4.

Example of FUNCTION B

In 1977, the traffic engineering department of a major east coast city initiated a five year highway safety improvement program to reduce total accidents throughout the city by identifying and correcting high accident locations. An Effectiveness Evaluation of the program was to be conducted following the program period due to the magnitude and importance of the program.

Program planning resulted in a wide range of high and low cost projects which were subsequently scheduled for construction throughout the five year program period, 1977-1981. Among the high cost program improvements were major road widening projects consisting of widening nine narrow, four-lane urban arterials from widths of 35 to 37 feet to 48 feet.

Program scheduling called for the widening of four arterials in 1977 (one widening project each for the north, south, east and west sides of the city) and the remaining five in the 1980, 1981 construction seasons.

Because of rising construction costs, it was decided that program evaluation activities should be moved up to determine the effectiveness of early (1977) program improvements. Evaluation of the four 1977 widening projects was of special interest due to the upcoming decision to request bids for the remaining five widening projects.

Evaluation plan development consisted of combining the four widening projects into a single program subset since all arterials were similar in alignment and geometrics (all sections were tangents ranging in length from 3/4 to 1 mile) and had identical project countermeasures (widening to four, 12-foot lanes and 6-inch curb). Evaluation objectives and MOE's consisted of the fundamental objectives (total, fatal, injury and property damage accidents) measured in units of accidents per million vehicle-miles. The before-after study with control groups was selected with the five unwidened arterials as candidate control sites. The analysis periods were selected as 1975 and 1976 for the before period and 1978 and 1979 for the after period.

The following key variables in addition to total accident rate for the before period were specified in the evaluation plan as criteria for control site selection.

Section length
Traffic volume
Number of signalized intersections
Number of commercial and residential driveways
Land use

Data on each key variable were obtained for each of the nine arterials.

Total accident rates were calculated for each of the nine sections using total accidents for 1975 and 1976, average AADT volumes for the same period and the lengths of the project sections.

PROGRAM GROUP (WIDENED ARTERIALS)

	Accidents	AADT(avg.)	Length	Exposure MVM	Accident Rate
1.	87	29,100	0.95 Mi.	20.18	4.31 Acc./MVM
2.	102	25,600	0.90 Mi.	16.82	6.06 Acc./MVM
3.	71	19,900	0.70 Mi.	10.17	6.98 Acc./MVM
4.	79	22,500	1.00 Mi.	16.43	4.81 Acc./MVM
	339			63.60	

CANDIDATE CONTROL GROUP (UNWIDENED ARTERIALS)

	Accidents	AADT (avg.)	Length	Exposure MVM	Accident Rate
1.	92	19,900	0.75 Mi.	10.90	8.44 Acc./MVM
2.	85	25,400	0.90 Mi.	16.69	5.09 Acc./MVM
3.	105	28,500	1.00 Mi.	20.81	5.05 Acc./MVM
4.	65	22,300	0.70 Mi.	11.40	5.70 Acc./MVM
5.	89	29,900	0.90 Mi.	19.64	4.53 Acc./MVM
	436			79.44	

The average accident rate (accidents/MVM) for the program group was calculated as 5.33. The rates for candidate control sites 2, 3 and 4 were similar (i.e. within ± 10%). Candidates 1 and 5 were eliminated from further consideration as control sites.

Key variables for each group were compared. From the above data, it was observed that section length and traffic volumes for the control group were similar to the program groups. A review of the number of signalized intersections indicated 3 to 4 signals per section for all sections within either group. A review of land uses indicated that candidate control section 3 was primarily light-industrial as compared to the program sections which were all a combination of commercial and residential land uses. Candidate sections 2 and 4 and the program group had similar land uses. Thus, section 3 was eliminated as a candidate control site. It was also observed that candidate control section 3 had one third as many driveways (commercial and residential combined) as the average number of driveways for the program group, to further justify the elimination of candidate control site 3.

The average total accident rate for the final control group after eliminating sections 1, 3, and 5 was calculated to be 5.34 accidents/MVM (150/28.09) which is within 10% of the rate for the program group.

It was decided that candidate control Sections 2 and 4 were appropriate sites for the control group.

FUNCTION C: Compare MOE's

This function enables the evaluator to:

1. Prepare MOE summary tables
2. Calculate percentage changes in the MOE's

Overview

The first step in determining the effectiveness of a highway safety program is to compute the change between the expected value of the MOE without the program and the value of the MOE observed following implementation of the program. This change, expressed as a percentage, provides an indication of the value of the program in terms of its impact on the MOE's. However, these estimates provide only a limited view of the true effectiveness of the program. Thus, both statistical and economic analyses are performed in subsequent functions to determine if the observed changes are statistically significant and if each program subset is economically feasible for future or continued use.

The method for determining the expected MOE and the percent change differs according to the experimental plan selected for the evaluation. The computational methods described in FUNCTION C of Accident-Based Project Evaluation are appropriate for program evaluation.

STEP C1 - PREPARE DATA SUMMARY TABLES

MOE Data Comparison Worksheets (with modifications for each experimental plan) provided in STEP C1 of Accident-Based Project Evaluation and in the Appendix are appropriate for the experimental plans discussed in this Procedural Guide. MOE's for each program subset should be tabulated on the appropriate MOE Data Comparison Worksheets using accident and exposure data collected and recorded for individual projects in each subset in FUNCTION B. The evaluator must determine before and after MOE's which represent both the program group or the control group depending on the evaluation plan.

STEP C2 - CALCULATE PERCENT CHANGE IN THE MOE'S

In this step, the expected value of the MOE is determined and compared with the actual MOE value and a percent difference is calculated. The percent change provides a measure of the program's impact on the objectives and MOE's of the evaluation.

The evaluator should refer to STEP C2 of Accident-Based Project Evaluation for the computational procedure for calculating the expected MOE values and percent changes for each experimental plan.

Summary of FUNCTION C

STEP C1 - PREPARE DATA SUMMARY TABLES

- Modify the general form of the MOE Data Comparison Worksheet for the experimental plans being used.
- Record accident and exposure data for each program subset using the data collected in FUNCTION B.
- Compute the MOE's for each program subset for the periods and groups which correspond to the experimental plan.

STEP C2 - CALCULATE PERCENT CHANGE IN THE MOE'S

- Calculate the expected value of the MOE's for each program subset.
- Calculate the percent change of each MOE for each program subset.

Example of FUNCTION C

Total accident rates (accidents/MV) were computed from accident and volume data collected in FUNCTION B for each of seven projects within a program subset and for each of the six sites within a control group. The before-after study with control groups was selected for the evaluation. The total accident frequency and exposure for the program group was 121 accidents and 16.33 MV for the before period and 111 accidents and 16.78 MV for the after period. For the control group, accidents and exposure were 105 accidents and 14.81 MV for the before period and 119 accidents and 16.5 MV for the after period.

STEP C1 - PREPARE DATA SUMMARY TABLES

Combined total accident rates were calculated for the before and after period for each group. The computed rates were determined to be:

Before, Program Group Average = 7.41 accidents/MV

After, Program Group Average = 6.62 accidents/MV

Before, Control Group Average = 7.09 accidents/MV

After, Control Group Average = 7.21 accidents/MV

These average accident rates were recorded on the data comparison work sheet shown in Figure 80.

STEP C2 - CALCULATE PERCENT CHANGE IN THE MOE'S

The expected value of the total accident rate MOE was calculated to be 7.54 accidents/MV as follows:

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

$$= 7.41\ (7.21/7.09)$$

$$= 7.54 \text{ accidents/MV}$$

The percent change was calculated as a 12.2% decrease using the following equation:

$$\text{Percent Change} = [(E_R - A_{PR})/E_R]100$$

$$= [(7.54 - 6.62)/7.54]100$$

$$= 12.2\% \text{ (decrease)}$$

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MOE DATA COMPARISON WORKSHEET

Evaluation No. 12345X

Date/Evaluator 4/2/79 - HB Checked by PD

Experimental Plan Before - After with control groups

	Control		Project		Expected After Rate X or Freq. __	Percent Reduction (%)
	Before	After	Before	After		
MOE Data Summary	(B_{CF})	(A_{CF})	(B_{PF})	(A_{PF})		
Accidents:						
(Fundamental)						
Total Accidents	105	119	121	111		
Fatal Accidents						
Injury Accidents						
PDO Accidents						
(Project Purpose)						
Exposure						
units: M V, or __ VM	14.81	16.50	16.33	16.78		
MOE Comparison Rate X or Frequency __	B_{C_R}	A_{C_R}	B_{P_R}	A_{P_R}	E_R	(%)
Total Accidents/ MV	7.09	7.21	7.41	6.62	7.54	12.2 (Decr)
Fatal Accidents/						
Injury Accidents/						
PDO Accidents/						

Figure 80. FUNCTION C example MOE data comparison worksheet.

FUNCTION D: Perform Statistical Tests

This function enables the evaluator to:

1. Define the type of data for each MOE;

2. Select the appropriate statistical test based on the type of data and sample size of the MOE's;

3. Perform the statistical tests; and

4. List conclusions regarding the effectiveness of the program based on the statistical test results.

Overview

Statistical tests must now be selected and performed on the MOE's developed in FUNCTION B. To accomplish this, the evaluator must possess a knowledge of the types of data variables which make up the MOE's and the appropriate statistical tests for each data type. This function involves more activities than FUNCTION D of Accident-Based Project Evaluation since the sample size (number of program subsets and projects in each subset) is likely to be larger for programs and there are a greater number of types of MOE's which may be evaluated.

In this function, the evaluator is presented with definitions and examples of the types of data which may be encountered, the MOE summary formats, and the activities which must be undertaken for statistical testing.

STEP D1 - DEFINE THE TYPE OF DATA FOR EACH MOE

MOE data may exist either as a discrete or continuous variable. Discrete data fall into categories and have specific values only. For instance, one roll of a die can only result in a discrete integer value of 1, 2, 3, 4, 5 or 6. No other value is possible. Accident frequency is also an example of a discrete variable. Accidents are reported in discrete integer values of 1, 2, 3...etc. Continuous data may have any value within a specified range of values. Height and weight are continuous data since an infinite number of values exist within any defined range of heights or weights. Accident rates and severity rates are also examples of continuous data.

There are three types of categorical (discrete) data which are of major importance in deciding how to organize MOE data for statistical testing. These categorical data are called nominal, ordinal, and scalar variables.

Nominal variables are categorical data which are classified by an unordered name or label. Examples of nominal data are pavement type, rural vs. urban location, signalized vs. unsignalized intersection, etc. Ordinal variables are categorical data which are rank ordered by name or label. Examples of ordinal data include injury scales, i.e., A (incapacitating), B (non-incapacitating), C (possible injury), or severity scales, i.e., fatal, injury, and property damage. Scalar variables are categorical data which have names or labels with known distances apart. For example, roadways may be classified by the number of lanes, i.e., 1, 2, 3, etc., or width of the pavement, i.e., 10, 11 or 12 foot lanes, etc.

There are also two other types of data which may be either discrete or continuous which are of importance in organizing MOE data for statistical testing. These data are interval and ratio. The distinction between these variables is subtle in terms of selecting a format for significance testing, thus these two classes are not treated individually in this text. Examples of these data include accident frequency at a location, accident rates, night-to-day accident ratio, etc. Statistical procedures for analyzing interval and ratio variables constitute the largest and most important testing methods.

Selection of the appropriate statistical test is based on the type of MOE data and the number of variables involved. Statistical testing of categorical variables is usually performed with the use of non-parametric or distribution-free methods. Examples of non-parametric tests include the Chi-Square test, Wilcoxen rank sum test, and the Mann-Whitney U-Test.

Statistical testing of interval and ratio data is generally performed with parametric statistics. Parametric methods are used to examine differences between sample estimates and population parameters such as the mean or variance. Parametric tests include the t-test, Z-test and analysis of variance and covariance.

In addition to defining the type of data for each MOE, the evaluator should carefully review the selected evaluation objectives and MOE's to determine which types of statements must be answered to satisfy the evaluation objective(s). For example, consider a program with a goal of reducing severity associated with fixed object accidents occurring in freeway exit gore areas. Suppose the program has been stratified into two program subsets consisting of 15 projects each; 1) crash cushion installations, and 2) fixed object removal.

Suppose that for each program subset, the following evaluation objectives were selected:

To determine the effect of the program subset on:

1. Total accidents;
2. Fatal accidents;
3. Injury accidents;
4. PDO accidents; and
5. Severity of ROR accidents in the gore.

MOE's for objectives 1-4 were selected as "the change in total, fatal, injury and PDO accidents per 100 million exiting vehicles". Objective 5 was assigned two MOE's; 1) the change in the number of ROR fatal plus injury accidents as a percent of total ROR accidents, and 2) the ratio of type "A" severity injuries resulting from ROR accidents as a percent of total ROR accident injuries. The experimental plan selected for each program subset was the Before and After Study with Control Groups (single point estimate).

As a program evaluation activity, each of the MOE's developed from the data collected in FUNCTION B must be identified as being either discrete or continuous and what types of statements are to be tested statistically.

For this example, MOE's for objectives 1-4 are continuous. The statements to be tested for these objectives are whether there is a statistically significant difference between the mean accident rate for total, fatal, injury and PDO accidents in the program group and the mean accident rates in the control group (after implementation).

The two MOE's for objective 5 are also continuous since the MOE is a percentage of total ROR accidents and total ROR injuries. The statement to be tested for each of these MOE's is whether there is a statistically significant difference between the percentage of ROR injury accidents and ROR "A" injuries between the control group and the program group after implementation.

STEP D2 - SELECT THE STATISTICAL TEST

The type of MOE's, the evaluation objectives, the sample size and the experimental plan are the deciding factors in the selection of an appropriate statistical test. Several statistical techniques are provided in this step to enable the evaluator to test the statistical significance of changes in the MOE's. The following description of each technique is provided to acquaint the evaluator with the applicability of each technique, the type of data which may be evaluated and the assumptions which underlie each technique.

Poisson Test

This statistical technique is presented in FUNCTION D, STEP D1 of Accident-Based Project Evaluation. It is applicable for testing whether a significant difference exists between an expected and observed MOE (as measured by a percent change in the MOE) when the MOE can be expressed as a discrete variable. The test is appropriate when the sample size (number of locations and expected number of accidents) is relatively small. The Poisson test requires as input, the percent change in the MOE and the expected value of the MOE. Percent changes in either frequency or rate-related MOE's may be tested by this technique as long as a translation is made to a discrete variable (frequency). Since all of the experimental plans produce an expected MOE and a percent change (as described in FUNCTION C), the test is applicable for all experimental plans.

Chi-Square Test

The Chi-Square test is used to test whether two discrete variables are independent of each other. The variables may be nominal or ordinal. In this nonparametric test, observed frequencies of accidents, injuries, etc., are compared with expected frequencies which would exist if the two variables were truly independent of each other.

The variables to be tested are arranged in a contingency table which may be composed of any number of rows or columns. For example, the following contingency table consists of two rows which represent the before and after analysis periods for an evaluation and five columns which represent five project sites within a program subset. This contingency table is referred to as a 2 X 5 contingency table.

	Program Sites				
	1	2	3	4	5
Before	8	15	23	11	12
After	9	10	15	8	11

The only requirement for the Chi-Square test is that every cell within the contingency table must have at least five observations.

The Chi-Square may be used to test the independence of discrete MOE's such as accident frequencies, severity level frequencies, PDO accident frequencies, and specific types of accidents. All experimental plans are appropriate for testing by Chi-Square.

t-Test

The t-test is a parametric statistic used to test the statistical significance of differences in the mean values of two sets of MOE's when the data are continuous and an assumption of normality in the data can be made. Two variations of the t-test are provided: the paired t-test and the Student's t-test.

The paired t-test is applicable for the before-after experimental plan where differences in pairs of observations representing the before and after situation are to be tested. The statement to be addressed with this test is whether the before mean for a group of locations is significantly different from the after mean of the same locations. The paired t-test is not appropriate for testing differences between the program and control groups because the data are taken at different locations.

The Student's t-test is appropriate for testing the difference between control and program groups. There is no requirement for paired observations or equal number of observations in each group. The assumption of approximately equal group variances is made in this test in addition to the assumption of normality. The statement to be addressed with this test is whether the mean of one group is significantly different from the mean of another group. The test is therefore applicable for testing differences between program and control groups during either the before or after period. In a situation where the assumption of equal variance cannot be reasonably made, a modification to the Student's t-test can be made (Yates' Correction Factor for Continuity).

Z-Test For Proportions

This test is applicable for continuous data which are expressed as proportions. The analysis question addressed by this test is whether the proportion of occurrences in one group is significantly different from the proportion in another group. The assumptions underlying the test include the requirement that the data follow a binominal distribution (i.e., only two levels can make up the data set), that the observations are independent, and that a sample size of at least 30 is available for each group. If the samples are not independent (i.e., correlated) a Z-test for correlated samples may be used (see FUNCTION D of Non-Accident-Based Evaluation for details). The sample size may be expressed in either accidents or locations depending on the requirements of the evaluation. For example, the sample may be the number of accidents for an evaluation where the proportion of injury to total accidents is to be evaluated. As an alternative, the sample may be the number of locations for a case where the proportion of locations which experience an accident frequency greater than 25 is to be evaluated. In still another example, the sample may be a subset of the total number of accidents as in the case where the number of ROR injury accidents expressed as a proportion of total ROR accidents is of interest. As with the Student's t-test, this technique is applicable for testing group differences. Thus, the test may be used to test the difference between a program and control group during either the before or after period. Testing for differences between the before and after period for a single group (program or control) may not be appropriate since the observations may not be independent.

F-Test

The F-test is applicable for testing the significance of differences in the variance of two populations. The evaluator is directed to FUNCTION D of Non-Accident-Based Project Evaluation for further details of this test and its application.

Based on the characteristics and requirements for each statistical test, the evaluator must select the most appropriate technique(s) for the evaluation. In addition, the level of confidence and the null hypothesis must be recorded for each statistical test application. For discussion of these statistical testing aspects, the evaluator is directed to FUNCTION D of Accident and Non-Accident-Based Project Evaluation.

STEP D3 - PERFORM THE STATISTICAL TEST

This step provides the evaluator with the activities which must be undertaken in performing each of the statistical tests described in the previous step. An example of each technique is provided. Following the examples, a procedure for selecting a test statistic is given.

Poisson Test

These activities should be followed when applying the Poisson test to address the following null hypothesis:

> There is no significant difference between the expected value of the MOE (as determined from the program group, the control group or both) and the observed MOE.

1. Select a level of confidence for the test. If the program is a medium to high-cost program, select a relatively high level of confidence such as 95% or 99%. If the program is a low-cost program, select a relatively low level of confidence such as 80% or 90%.

2. Obtain the value of the expected accident frequency without the treatment and the percent change for each MOE from FUNCTION C, STEP C2.

3. Locate the point of intersection of the expected accident frequency and the percent change on Figure 40 (See FUNCTION D of Accident-Based Project Evaluation).

4. If the point of intersection is below the curve for the selected level of confidence, the change was not statistically significant at the selected confidence level. (It may be of interest to compare the point of intersection with lower confidence levels since the MOE may not be significant at the 95% level, but significant at the 90% or 80% level).

5. If the point of intersection is above the curve, the change was significant at the selected confidence level and we conclude that the program was effective in changing the particular MOE being tested. (Again it may be of interest to identify the level of confidence at the point of intersection and note the level in the final report).

Example

A program to reduce accidents at all isolated horizontal curves on rural, two-lane roads involved upgrading curve advance warning signs and pavement markings to MUTCD Code. The before-after experimental plan was selected. Frequency-related MOE's for two years before and after the implementation of the program was chosen since there was no appreciable increase in the before and after exposure rates. The null hypothesis to be tested was stated as:

> "There is no difference in the frequency of total accidents between two years before and two years after the implementation of the program treatments (at the 95% level of confidence)".

The following accident data were collected:

Accident Type	Before			After		
	1975	1976	Total	1978	1979	Total
Total Accident Frequency	13	15	28	12	8	20

The expected accident frequency was determined to be 17 (equal to the before accident frequency) and the percent change was 28.6% (decrease). Entering expected accident frequency of 17 into Figure 38 (page 110 of Accident-Based Project Evaluation) resulted in a required percent change of 30%. Since the observed percent change was 28.6% (less than 30%), the null hypothesis was accepted at the 95% level of confidence.

Chi-Square Test

These activities should be performed when applying the Chi-Square test to address the following null hypothesis:

> There is no significant difference between the observed frequencies and the expected frequencies of the variables being tested, i.e., the variables are independent.

1. Select a level of confidence.

2. Arrange the observed frequencies in a contingency table format consisting of any number of rows and columns.

		Columns							
		1	2	3	4	.	.	.	Row Sum
Rows	1 2 3 4 . . .								
Col. Sum									Grand Total

3. Compute expected frequencies for each cell of the contingency table developed in Step 2 above and arrange the expected frequencies into a similar contingency table format. The expected frequencies for each cell are obtained by multiplying the row sum by the column sum and then dividing by the grand total.

$$\text{Expected Frequency for Row } i, \text{ Column } j. = \frac{\text{Row Sum for Row } i \times \text{Col. Sum for Column } j.}{\text{Grand Total}}$$

4. Compute the Chi-Square value using the following equation:

$$\chi^2 = \sum_{\text{all } i,\, j} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

Where:

O_{ij} = Observed frequencies for row i, column j.
E_{ij} = Expected frequencies for row i, column j.

5. Determine the critical Chi-Square value from statistical tables contained in the Appendix using the degrees of freedom for the test;

Degrees of Freedom = (R-1) (C-1)

Where:

R = number of rows in the contingency table
C = number of columns in the contingency table

and the selected level of confidence.

6. Compare the calculated Chi-Square value with the critical Chi-Square value. If the calculated Chi-Square is greater than the critical value, reject the null hypothesis and conclude that the variables are not independent at the stated level of confidence. If the calculated Chi-Square is less than the critical value, accept the null hypothesis and conclude that the MOE's are independent.

Example

A program to reduce accident severity on rural roads involved the installation of guardrails on isolated curves which experience a significant number of run-off-the-road, fixed-object accidents. The MOE's selected for the evaluation included the changes in the frequency of fatalities, "A" injuries, "B" injuries, and "C" injuries. The comparative parallel experimental plan was used in the evaluation. The null hypothesis was stated as:

Accident severity is independent of the existence of guardrails.

The following accident data were obtained for the program and control groups:

	Severity Level			
	F	A	B	C
Program Group	8	18	20	27
Control Group	14	36	42	39

The above accident data were arranged in a 2 x 4 contingency table as follows:

Observed Frequencies

	Severity Level				
Group	F	A	B	C	Row Sum
Program	8	18	20	27	73
Control	14	36	42	39	131
Col. Sum	22	54	62	66	204

Next, the expected severity frequencies were calculated for each cell as follows:

$$\text{Expected Frequency for Row 1, Col. 1} \quad \frac{\text{Row Sum 1} \times \text{Col. Sum 1}}{\text{Grand Total}}$$

$$= \frac{73 \times 22}{204}$$

$$= 7.87$$

The following contingency table of expected frequencies was developed.

Expected Frequencies

	Severity Level				
Groups	F	A	B	C	Row Sum
Program	7.87	19.32	22.19	23.62	73.00
Control	14.13	34.68	39.81	42.38	131.00
Col. Sum	22.00	54.00	62.00	66.00	204.00

Chi-Square was calculated as follows:

Observed (0)	Expected (E)	0-E	$(0-E)^2$	$\frac{(0-E)^2}{E}$
8	7.87	.13	.02	.00
18	19.32	-1.32	1.74	.09
20	22.19	-2.19	4.80	.22
27	23.62	3.38	11.42	.48
14	14.13	-.13	.02	.00
36	34.68	1.32	1.74	.05
42	39.81	2.19	4.80	.12
39	42.38	-3.38	11.42	.27
				Sum = 1.23

The critical Chi-Square value for the 95% level of confidence and (2-1) (4-1) = 3 degrees of freedom was found to be 7.81 from the Chi-Square table. Since the calculated value is less than the critical value, the null hypothesis is accepted and the conclusion is that the severity levels are independent of the groups of accidents (program and control).

Paired t-Test

These activities should be performed when applying the paired t-test to address the following null hypothesis:

There is no significant difference between the before mean of a group and the after mean for the same group.

1. Select a level of confidence.

2. Arrange the individual accident rates for each location within the following form:

MOE Analysis Periods MOE Units	Locations (N=n) 1 2 3 4 . . n	Total	Avg. ($\overline{X}$)	Var. (S^2)
Before Accident Rate Dates: Units: Accidents/				
After Accident Rate Dates: Units: Accidents/				

3. Compute the t value using the following equation:

$$t = \frac{\overline{X}_B - \overline{X}_A}{S_D / \sqrt{N}}$$

and

$$S_D^2 = S_B^2 + S_A^2 - 2 \left[\frac{1}{N-1} \sum_{i=1}^{N} (X_{Bi} - \overline{X}_B)(X_{Ai} - \overline{X}_A) \right]$$

Where: $\overline{X}_B$ = Before sample mean

$\overline{X}_A$ = After sample mean

S_B^2 = Before sample variance

S_A^2 = After sample variance

N = Number of cases

4. Determine the critical t value from statistical tables (see Appendix) using the degrees of freedom (N-1) and the selected level of confidence.

5. Compare the calculated t value with the critical t value. If calculated t is greater than critical t, reject the null hypothesis and conclude that the program is effective at the selected level of confidence. If calculated t is less than critical t, accept the null hypothesis and conclude that the program is not effective.

Example

A program to reduce the number of passing accidents on two-lane rural highways involved the installation of no-passing pennant signs (W14-3). The before-after with control sites experimental plan was selected. The units of the MOE was selected as head-on accidents per million vehicle miles of no-passing zone. The analysis periods were chosen as 2 years before and after program implementation. The statistical analysis involved testing for significant differences between the before and after periods at both the control and program groups. The null hypotheses were stated as:

There is no difference in the before mean head-on accident rate for a) the program group and b) the control group as compared to their respective after head-on accident rates at the 95% level of confidence.

The following data were tabulated for the program and control groups.

Program Group

MOE Analysis Period Units	Location (N=5) 1	2	3	4	5	Total	Avg. ($\overline{X}$)	Variance (S^2)
Before Head-On Accident Rate 6/74-12/76 Accidents/MVM	5.20	8.10	7.80	6.50	5.60	33.2	6.64	1.66
After Head-On Accident Rate 6/77-12/79 Accidents/MVM	6.00	6.20	4.30	6.40	2.10	25.0	5.00	3.33

Control Group

MOE Analysis Period Units	Locations (N=4) 1	2	3	4	Total	Avg. ($\overline{X}$)	Variance (S^2)
Before Head-On Accident Rate 6/74-12/76 Accidents/MVM	6.60	7.80	5.40	7.30	27.10	6.78	1.08
After Head-On Accident Rate 6/77-12/76 Accidents/MVM	15.60	12.80	13.70	12.90	55.00	13.75	1.68

Computing the t value for the program group:

$$t = \frac{\overline{X}_B - \overline{X}_A}{S_D/\sqrt{N}}$$

Where:

$\overline{X}_B = 6.64$

$\overline{X}_A = 5.00$

$S_B^2 = 1.66$

$S_A^2 = 3.33$

$N = 5$

and

$$S_D^2 = 1.66 + 3.33-2\ [1/4[(-1.44)(1.00)+(1.46)(1.20)+ (1.16)(-0.70)+(-0.14)(1.40)+(-1.04)(-2.90)]]$$

$$= 4.99 - 2(0.58)$$

$$= 3.83$$

then

$$t = \frac{6.64 - 5.00}{1.96/\sqrt{5}}$$

$$= 1.87 \text{ (calculated)}$$

From the statistical table of the t-distribution (see Appendix) the critical t was determined to be 2.776 for 4 degrees of freedom (5-1) and a 0.05 level of significance. Thus, the conclusion is that there was no significant difference in the before and after mean accident rate for the program group.

Computing the t value for the control group:

$$t = \frac{6.78 - 13.75}{1.97/\sqrt{4}}$$

$$= -7.08$$

The critical t value for 3 degrees of freedom (4-1) at the 0.05 level of significance is 3.182. Since the calculated t is greater than the critical t, the null hypothesis is rejected.

The overall conclusion to be drawn from the statistical analysis is that the program was effective in reducing the rate of head-on accidents.

That is, the control group experienced a significant increase in the MOE which did not occur for the program group.

Student's t-Test

These activities should be performed when applying the Student's t-test to address the following null hypothesis:

> There is no significant difference between the mean accident rate for a group of locations and the mean accident rate for another group.

1. Select a level of confidence.

2. Arrange the individual location accident rates for each group in the following form:

MOE Analysis Period MOE Units	Locations	N	Total	Avg. ($\bar{X}$)	Var. (S^2)
Group 1 Accident Rate Dates Units: Accidents/	1 2 3 4 5...				
Group 2 Accident Rate Dates Units: Accidents/	1 2 3 4 5 6...				

3. If the group variances are approximately equal in magnitude, compute the t value using the following equation.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S\sqrt{(1/n_1) + (1/n_2)}}$$

and

$$S^2 = \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}$$

Where:

$\overline{X}_1$ = Group 1 sample mean

$\overline{X}_2$ = Group 2 sample mean

n_1 = Number of locations in Group 1

n_2 = Number of locations in Group 2

S_1^2 = Group 1 sample variance

S_2^2 = Group 2 sample variance

If the group variances are not similar in magnitude, compute the t value using the following equation:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

4. Determine the critical t value from statistical tables (see Appendix). If the group variances are similar, the critical t value is determined using $n_1 + n_2 - 2$ degrees of freedom and the selected level of confidence. If the variances are dissimilar, the critical t value is computed by the following equation:

$$t_c = \frac{\frac{S_1^2 t_1}{n_1} + \frac{S_2^2 t_2}{n_2}}{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}$$

t_c = critical t value at the selected level of confidence

t_1 = critical t value for $n_1 - 1$ degrees of freedom at the selected level of confidence.

t_2 = critical t value for $n_2 - 1$ degrees of freedom at the selected level of confidence.

5. Compare the calculated t value with the critical t value. If calculated t is greater than critical t, reject the null hypothesis and conclude that the program is effective at the stated level of confidence. If calculated t is less than critical t, accept the null hypothesis and conclude that the program is not effective.

Example

A program to reduce run-off-the-road (ROR) accidents on two-lane rural winding sections involved pavement edgelining and delineator installation. A MOE was selected to be the number of ROR accidents per mile per year. Since the police agency, having jurisdiction for the improved sections, had changed during the program implementation period, it was decided that a comparative parallel study would be used to reduce the problems of differing accident reporting characteristics between the before and after period (reporting differences did exist between the police agencies) and a control group was selected. The following null hypothesis was stated:

There is no significant difference between the mean ROR accident rate for the program group and the mean ROR accident rate for the control group at the 95% level of confidence.

The following accident data were collected.

MOE Analysis Period MOE Units	Locations 1	2	3	4	5	6	7	N	Total	Avg. ($\overline{X}$)	Var. (S^2)
Group 1 (Program) ROR Accident Rate 1977-1978 Units: ROR Acc./Mile/Yr.	5.6	9.2	10.4	19.8	25.2	16.4		6	86.6	14.4	54.0
	1	2	3	4	5	6	7	N	Tot.	Avg. ($\overline{X}$)	Var. (S^2)
Group 2 (Control) ROR Accident Rate 1977-1978 Units: ROR Acc./Mile/Yr.	9.0	23.2	19.6	20.4	18.8	30.2	10.4	7	131.6	18.8	53.2

Since the group variances were approximately equal, the t value was calculated as follows:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S\sqrt{(1/n_1) + (1/n_2)}}$$

Where: $\overline{X}_1 = 14.4$

$\overline{X}_2 = 18.8$

$n_1 = 6$

$n_2 = 7$

and

$$S^2 = \frac{(6-1)54.0 + (7-1)53.2}{6 + 7 - 2}$$

$$= 53.6$$

then

$$t = \frac{14.4 - 18.8}{7.32\sqrt{(1/6 + 1/7)}}$$

$$= \frac{-4.40}{4.07}$$

$$= -1.08$$

The critical t value (see Appendix) for a confidence level of 95% (0.05 level of significance) and 11 degrees of freedom (6 + 7 - 2) is 2.201. Since the critical t value is greater than the calculated value, the null hypothesis is accepted and the conclusion is made that the program had no effect on the mean number of ROR accidents.

Z-Test for Proportions

These activities should be performed when applying the Z-test to address the following null hypothesis:

> There is no significant difference in the proportion of occurrences in one group compared to the proportion of occurrences in another group.

1. Select a level of confidence.
2. Arrange the proportions and sample size in the following form:

Group Analysis Periods	Total Sample (N)	Number of Occurrences (X)	Proportion (P)
Group 1 Dates			
Group 2 Dates			

3. If the two proportions being compared are from independent samples (i.e., comparison of program group proportions vs. a control group proportion), calculate the Z value using the following equation.

where:

$$Z = \frac{P_1 - P_2}{\sqrt{pq\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

$$P_1 = \frac{X_1}{N_1}$$

$$P_2 = \frac{X_2}{N_2}$$

$$p = \frac{X_1 + X_2}{N_1 + N_2} = \frac{N_1P_1 + N_2P_2}{N_1 + N_2}$$

$$q = 1-p$$

X_1 = Number of occurrences in Group 1

X_2 = Number of occurrences in Group 2

N_1 = Total sample in Group 1

N_2 = Total sample in Group 2

4. If the samples are correlated, develop a contingency table and calculate the Z value for correlated sample (see FUNCTION D of Non-Accident-Based Evaluation).

5. Determine the critical Z value from the statistical tables for the selected level of confidence.

6. Compare the calculated Z value with the critical Z value. If calculated Z is greater than critical Z, reject the null hypothesis and conclude that the program is effective at the stated level of confidence. If calculated Z is less than critical Z, accept the null hypothesis and conclude that the program is not effective.

Example

A program to reduce nighttime accidents involved the installation of improved street lighting at randomly selected intersections which experience an overrepresentation of the night-to-day accident ratio. The MOE was chosen as the proportion of night accidents to total accidents since exposure data stratified by light conditions were not available. The before-after study with randomized control group was chosen for the study. The program and control groups consisted of ten locations each.

The two null hypotheses to be tested include:

There is no difference between the proportion of night accidents to total accidents between the program and control groups before and after program implementation.

The following data were collected:

BEFORE PROGRAM IMPLEMENTATION

Group Analysis Period	Possible Occurrences: Total Accidents for Analysis Period (N)	Number of Occurrences: Night Accidents For Period (X)	Proportion (P)
Group 1 (Program) 6/76 - 6/77	257	69	0.27
Group 2 (Control) 1/76 - 6/77	242	58	0.24

AFTER PROGRAM IMPLEMENTATION

Group Analysis Period	Possible Occurrences: Total Accidents for Analysis Period (N)	Number of Occurrences: Night Accidents For Period (X)	Proportion (P)
Group 1 (Program) 6/78 - 6/79	275	35	0.13
Group 2 (Control) 6/78 - 6/79	289	75	0.26

The Z value for the before period was computed as follows:

$$Z = \frac{P_1 - P_2}{\sqrt{pq(1/N_1 + 1/N_2)}}$$

Where:

$P_1 = 0.27$

$P_2 = 0.24$

$N_1 = 257$

$N_2 = 242$

$$p = \frac{69 + 58}{257 + 242} = 0.25$$

$q = 1 - p = 1 - 0.25 = 0.95$

Substituting

$$Z = \frac{0.27 - 0.24}{\sqrt{(0.25)(0.75)(1/257 + 1/242)}}$$

$$= \frac{0.03}{0.04}$$

$$= 0.77$$

The critical Z value for the 0.05 level of significance was determined to be 1.96. Since the calculated Z is less than the critical Z, the null hypothesis is accepted and the conclusion is made that there is no difference between the proportion of nighttime accidents for the program and control groups for the before period.

In a similar manner, the Z value was calculated for the after period.

$$Z = \frac{0.13 - 0.26}{\sqrt{(0.20)(0.80)(1/275 + 1/289)}}$$

$$Z = \frac{-0.13}{0.03}$$

$$= -3.86$$

Since the calculated Z is greater than the critical Z for the 0.05 level of significance, the null hypothesis is rejected and the conclusion is made that there is a significant difference in the proportion of nighttime accidents and that the program is effective.

F-Test

The use of the F-Test is generally of limited use in the evaluation of accident statistics. Rather, its primary use is in the testing of difference in distributions for which the variance of the distribution is of interest (i.e., speed distribution). The evaluator is directed to Non-Accident-Based Evaluation for a discussion and example of the test.

Procedure for Selecting a Test Statistic

The procedure for selecting a test statistic (Table 3 in FUNCTION D of Non-Accident-Based Evaluation) should be used to select the test statistic for the evaluation. If there is uncertainty regarding the selection of the appropriate test however, it is recommended that a statistician be consulted.

Summary of FUNCTION D

STEP D1 - DEFINE THE TYPE OF DATA FOR EACH MOE

- Review the selected evaluation objectives, MOE's, and experimental plan and determine the types of data to be evaluated (i.e., discrete or continuous).
- List the statement(s) to be statistically tested for each evaluation objective.

STEP D2 - SELECT THE STATISTICAL TEST

- Select the appropriate statistical test based on objectives, the MOE's, experimental plan, sample size, and types of statements to be statistically tested.

STEP D3 - PERFORM THE STATISTICAL TEST

- Select a level of confidence
- Arrange the data in the format for the selected statistical test.
- Perform the necessary computations.
- Compare calculated statistical values with critical values taken from tables based on the selected level of confidence and the degrees of freedom.
- State conclusions on the effectiveness of the program based on the statistical testing results.

FUNCTION E: Perform Economic Analysis

This function enables the evaluator to:

1. Select an economic analysis technique, and

2. Perform an economic analysis.

Overview

The economic analysis techniques provided in FUNCTION E of Accident-Based Project Evaluation include the benefit/cost ratio technique and the cost-effectiveness technique. Both methods are appropriate for determining the economic impact of a program. It should be noted that the economic analysis should only be conducted for programs for which the MOE's were found to be significantly changed at the selected level of confidence.

When applying the techniques to safety programs, the evaluator should perform an economic analysis for each program subset as well as the entire program. The values of equivalent uniform annual costs (EUAC) and present worth of costs (PWOC) are a summation of the program cost items (implementation, operating and maintenance costs) for each project within the program subset. This measure provides insight to the feasibility of implementing similar future program subsets from an economic viewpoint.

The evaluator is directed to FUNCTION E of the project evaluation subprocess. The procedures and decision criteria are similar for both projects and programs.

STEP E1 - SELECT ECONOMIC ANALYSIS TECHNIQUE

The economic technique selection criteria for programs are identical for projects. The criteria are summarized below:

a. Willingness to Assign Dollar Values to Accident Outcomes - If the evaluator (agency) is willing to place a dollar value on accident fatalities, injuries, or property damages, the benefit/cost ratio technique is appropriate. If not, the cost-effectiveness technique may be applied without the requirement of using accident costs as an input to the analysis.

b. Availability of Acceptable Accident Cost Values - The evaluator (agency) may be willing to assign accident cost values but may not agree with a dollar figure for various accident outcomes. If the agency has developed its' own accident cost values, or existing values suggested by organizations such as NHTSA and NSC are acceptable to the agency for evaluation purposes, the benefit/cost ratio technique is appropriate. If not, the cost-effectiveness technique may be applied.

c. Type of MOE - If the MOE is related to reducing accident losses associated with severity, the benefit/cost ratio technique provides an appropriate measure of economic effectiveness (i.e., ratio of accident loss benefits to program costs). If the MOE is related to a specific accident type (total accidents or a subset of total accident such as ROR accidents, etc.), for which cost figures are non-existent, the cost-effectiveness technique provides an appropriate measure of economic effectiveness (i.e., cost per accident forestalled).

STEP E2 - PERFORM BENEFIT/COST RATIO TECHNIQUE

The benefit/cost ratio (B/C) of a program can be determined using equivalent uniform annual cost and benefits or by using present worth of costs and benefits. Activities 1-8 of the procedure provided in STEP E2 of Accident-Based Project Evaluation should be followed when evaluating either an entire program or program subset. However, the elements of the equations represent the summation of costs and benefits within the entire program subset.

When present worth is utilized in the analysis, similar changes must be made to the equations for PWOC and PWOB to allow for the determination of costs and benefits for several projects.

The B/C analysis worksheet provided in STEP E2 of Accident-Based Project Evaluation should be completed for each subset evaluated in the program. Projects within the same subset are thus combined to determine the economic effectiveness.

STEP E3 - PERFORM C-E TECHNIQUE

If the cost-effectiveness technique was selected, STEP E3, of Accident-Based Project Evaluation should be followed. The modifications for EUAC and PWOC shown in STEP E2 of this function should be used.

Summary of FUNCTION E

STEP E1 - SELECT ECONOMIC ANALYSIS TECHNIQUE

- Determine the need for economic analysis by assessing whether a statistically significant change occurred in the MOE's at the selected level of confidence.

- Select the economic analysis technique on the basis of the willingness to assign dollar values to accident outcomes, availability of acceptable cost data and the type of MOE.

STEP E2 and E3 - PERFORM THE ECONOMIC ANALYSIS USING B/C TECHNIQUE OR PERFORM ECONOMIC ANALYSIS USING THE C-E TECHNIQUE

- Finalize accident and cost inputs.
- Perform the selected technique.

Example of FUNCTION E

Suppose that in the example provided in FUNCTION A, Program Evaluation, a statistically significant change in the mean total passing accident rate was observed for the horizontal and combined alignment subsets only and an economic analysis is to be conducted. Referral to the objective and MOE listing form shows that a B/C ratio is desired. From the accident and cost data collected in FUNCTION B, the following data were summarized:

Cost Data (Unit Cost)

Initial installation cost per sign = $75.00

Annual Average maintenance per sign = $5.00

Salvage value per sign = $10.00

Accident Severity Data (Horizontal Alignment Subset)

Before fatalitites = 2/yr., After fatalities = 2/yr.

Before injuries = 12/yr., After injuries = 10/yr.

Before PDO accidents = 25/yr., After PDO accidents = 11/yr.

Accident Severity Data (Combined Alignment Subset)

Before fatalities = 1/yr., After fatalities = 0.5/yr.

Before injuries = 19/yr., After injuries = 15/yr.

Before PDO accidents = 26/yr., After accidents = 20/yr.

NSC accident cost figures and the equivalent uniform annual benefits were chosen to be used in determining the B/C ratio.

Other cost-related inputs to the economic technique include:

Interest Rate = 12%

Expected Life = 6 years

Capital Recovery Factor = 0.2432

Sinking Fund Factor = 0.1232

The B/C ratio was determined for each subset using the B/C Analysis Work Sheet (see Figures 81 and 82). The B/C ratio for the horizontal alignment subset was 58.8. The B/C ratio for the combined alignment was 178.6.

A comparison of these ratios with the B/C ratios of other evaluated edgelining programs subsets revealed that this program exceeded the previously determined ratios by a factor of 2. The program was, therefore, concluded to be cost-effective based on a comparison of past evaluation results.

B/C ANALYSIS WORKSHEET

Evaluation No: *80-4-11 (Horizontal Alignment)*

Date/Evaluator: *4/1/80, LM*

1. Initial Implementation Cost, I: $ *19 x $75 = $1425*

2. Annual Operating and Maintenance Costs Before Project Implementation: $ *0*

3. Annual Operating and Maintenance Cost After Project Implementation: $ *19 x $5.00 = $95*

4. Net Annual Operating and Maintenance Costs, K (3-2): $ *95*

5. Annual Safety Benefits in Number of Accidents Prevented:

Severity	Expected	-	Actual	=	Annual Benefit
a) Fatal Accidents	2	-	1		
(Fatalities)	(2)		(2)		(0)
b) Injury Accidents	10	-	8		
(Injuries)	(12)		(10)		(2)
c) PDO Accidents	25	-	11		
(Involvement)	(25)		(11)		(14)

6. Accident Cost Values (Source *NSC (1979)*):

Severity	Cost
a) Fatal Accident (Fatality)	$ 160,000
b) Injury Accident (Injury)	$ 6,200
c) PDO Accident (Involvement)	$ 870

7. Annual Safety Benefits in Dollars Saved, $\overline{B}$:

5a) x 6a) = *0 x 160,000 = 0*

5b) x 6b) = *2 x 6,200 = $12,400*

5c) x 6c) = *14 x 870 = $12,180*

Total = *$ 24,580*

Figure 81. B/C analysis worksheet for horizontal alignments.

8. Services life, n: 6 yrs

9. Salvage Value, T: $19 x $10.00 = $190

10. Interest Rate, i: 12 % = 0.12

11. EUAC Calculation:

CR_n^i = 0.2432

SF_n^i = 0.1232

EUAC = $I\ (CR_n^i) + K - T\ (SF_n^i)$

= 1425 (0.2432) + 95 - 190 (0.1232) = $418.15

12. EUAB Calculation:

EUAB = $\overline{B}$

= $24,580

13. B/C = EUAB/EUAC = $24,580/$418 = 58.8

14. PWOC Calculation:

PW_n^i =

SPW_n^i =

PWOC = $I + K\ (SPW_n^i) - T\ (PW_n^i)$

15. PWOB Calculation:

PWOB = $\overline{B}(SPW_n^i)$

16. B/C = PWOB/PWOC =

Figure 81. B/C analysis worksheet for horizontal alignments (continued).

B/C ANALYSIS WORKSHEET

Evaluation No: *80-4-11 (Combined alignments)*

Date/Evaluator: *4/1/80, LM*

1. Initial Implementation Cost, I: $ *28 x $75 = $2100*

2. Annual Operating and Maintenance Costs Before Project Implementation: $ *0*

3. Annual Operating and Maintenance Cost After Project Implementation: $ *28 x $5.00 = $140*

4. Net Annual Operating and Maintenance Costs, K (3-2): $ *140*

5. Annual Safety Benefits in Number of Accidents Prevented:

Severity	Expected	-	Actual	= Annual Benefit
a) Fatal Accidents	*1*		*1*	
(Fatalities)	*(1)*	-	*(0.5)*	*(0.5)*
b) Injury Accidents	*12*		*9*	
(Injuries)	*(19)*	-	*(15)*	*(4)*
c) PDO Accidents	*26*		*20*	
(Involvement)	*(26)*	-	*(20)*	*(6)*

6. Accident Cost Values (Source *NSC*):

Severity	Cost
a) Fatal Accident (Fatality)	$ *160,000*
b) Injury Accident (Injury)	$ *6,200*
c) PDO Accident (Involvement)	$ *870*

7. Annual Safety Benefits in Dollars Saved, $\overline{B}$:

5a) x 6a) = *0.5 x $160,000 = $80,000*

5b) x 6b) = *4 x $ 6,200 = $24,800*

5c) x 6c) = *6 x $ 870 = $ 5,220*

Total = *$110,020*

Figure 82. B/C analysis worksheet for combined alignments.

8. Services life, n: 6 yrs

9. Salvage Value, T: $ 28 x $10.00 = $280

10. Interest Rate, i: 12 % = 0.12

11. EUAC Calculation:

CR_n^i = 0.2432

SF_n^i = 0.1232

EUAC = $I\ (CR_n^i) + K - T\ (SF_n^i)$

= 2100 (0.2432) + 140 - 280 (0.1232) = $616.22

12. EUAB Calculation:

EUAB = $\overline{B}$

= $110,020

13. B/C = EUAB/EUAC = $110,020/$616 = 178.6

14. PWOC Calculation:

PW_n^i =

SPW_n^i =

PWOC = $I + K\ (SPW_n^i) - T\ (PW_n^i)$

15. PWOB Calculation:

PWOB = $\overline{B}(SPW_n^i)$

16. B/C = PWOB/PWOC =

Figure 82. B/C analysis worksheet for combined alignments (continued).

FUNCTION F: Prepare Evaluation Documentation

This function enables the evaluator to:

1. Interpret the effectiveness of the highway safety program;

2. Interpret the validity of the evaluation results;

3. Identify evaluation results for incorporation to the effectiveness data base;

4. Write the evaluation study report.

Overview

The effectiveness of a highway safety program must be described in terms of the effectiveness of the individual subsets which make up the program. The preceding functions are directed toward evaluating the effectiveness of each program subset. The evaluator must organize the results of FUNCTIONS C, D and E for each subset and address the following critical program evaluation issues:

1. Which program subsets resulted in a significant contribution toward achieving the program goal? Which subsets did not contribute? Which made a marginal contribution?

2. Were the evaluation objectives accomplished?

3. Were any problems or unexpected results produced by the program?

Answers to these questions enable the evaluator to draw conclusions regarding the effectiveness of the program, based on the evaluation study results.

In addition to program effectiveness, a criticial review of the evaluation study itself must be made in order to determine the extent to which the evaluation results may be used in future planning, implementation and evaluation decisions. The review should address the appropriateness of all decisions made during the study and the reasonableness and limitations of the evaluation results. Observed or suspected deficiencies in any of these areas may limit the use of the evaluation results in future decision-making activities.

STEP F1 - ORGANIZE EVALUATION STUDY MATERIALS

The evaluation study may have spanned several years between the time of evaluation plan development and the final analysis of evaluation data.

At this time, all material relating to the evaluation study must be gathered to allow for an orderly review of the evaluation activities undertaken since the beginning of the evaluation.

The evaluation materials should be thoroughly reviewed to ensure that all pertinent information has been obtained. The materials should be stratified by information relating to the total program (i.e., goals, projects, locations, project stratification and sampling, etc.) and by information related to individual program subsets.

STEP F2 - DETERMINE EFFECTIVENESS OF THE PROGRAM

The final determination of program effectiveness requires information on three aspects of the evaluation subprocess for each program subset: 1) the observed changes in the MOE's according to the experiemental plan used; 2) the statistical significance of changes in the MOE's; and 3) the results of the economic analysis. The evaluator must develop from these information sources, a conclusion on the effectiveness on each program subset.

Whether a conclusion is positive (success), negative (failure) or otherwise, the evaluator must critically assess the validity of the evaluation procedure in light of the completed evaluation study. The review should be carried out on a function-by-function basis and address the following issues:

FUNCTION A

1. The appropriateness of the program goal for the types of projects and program subsets evaluated.

2. Appropriateness of the selected evaluation objectives and MOE's.

3. The appropriateness of the selected experimental plan including the threats to validity which were not or could not be overcome.

FUNCTION B

1. Quality and completeness of accident, volume and cost data including actual or suspected problems which were not correctable.

2. The appropriateness of the control groups including the tradeoff's made in control site selection.

FUNCTION C

1. Problems encountered with computing expected MOE values or changes in the MOE's.

FUNCTION D

1. Appropriateness of the selected statistical technique.

2. Appropriateness of the selected level of confidence.

3. Reasonableness of statistical testing results.

FUNCTION E

1. Appropriateness of the selected economic technique.

2. Appropriateness of economic analysis inputs including accident cost figures, interest rate, expected life, and salvage value.

3. Reasonableness of economic analysis results.

In addition to reviewing the evaluation study procedures, it is also important to review the appropriateness of decisions and activities which took place in the planning and implementation components of the HSIP. For example, if some of the program sites were not actually "hazardous" and/or the projects and countermeasures were not appropriate for the safety problems that existed, the program may prove to be ineffective when, in actuality, the program is effective when properly applied. If the evaluator fails to recognize this, effective programs and projects may be overlooked in the future. The evaluator must recognize both the effectiveness of the program and the appropriateness of its use.

The same type of problem may arise from improper implementation activities. For example, suppose an advance warning sign is designed to be installed 200 feet (based on sight distance and stopping distance characteristics) in advance of a "blind intersection." If the sign is installed 100 feet in advance of the intersection, the effectiveness of the project is likely to be reduced. Without knowledge of the improper implementation, the sign would be considered to be ineffective when actually the ineffectiveness is due to improper installation and not the sign itself.

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

STEP F3 - IDENTIFY RESULTS FOR INCLUSION IN THE EFFECTIVENESS DATA BASE

One of the primary purposes of conducting Effectiveness Evaluations is to feed back effectiveness information to improve decisionmaking in future planning, implementation and evaluation components. The evaluator must therefore be certain that only reliable evaluation results enter the feedback loop for future use in the HSIP decisions. If serious problems were identified (in STEP F2) for the evaluation study procedure or the activities which preceded the Evaluation Component, the evaluation results should not be combined with more reliable evaluation results. Allowing questionable evaluation results to enter the loop will reduce the reliability of effectiveness estimates and may result in inappropriate decisions.

It is important to note that evaluation study shortcomings which are common in all studies should not necessarily be grounds for excluding evaluation results from the data base. For instance, it is a well-established fact that only a portion of all accidents are reported and available for use in evaluations. Although this is a problem in effectiveness evaluation, it is a problem which is common to all evaluations. Should the percentage of reported accidents change for reasons such as a change in minimum accident cost reporting thresholds, then the magnitude of the problem is no longer constant for evaluations performed before and after the change and it is advisable to develop a new data base which represents the effectiveness of programs under the new accident reporting procedures.

STEP F4 - WRITE THE EVALUATION REPORT

The evaluation activities and results should be thoroughly discussed and documented in the study report. The documentation should include concise and comprehensive coverage of all evaluation study aspects and should follow a standardized format. The following format is recommended:

1. Introduction: name of program, program goal statement, projects in the program, funding level and period.

2. Executive Summary of Findings and Recommendations: summary of program performance; summary of success, failures and probable causes; summary of unexpected impacts, with probable causes; recommendations for improvement of the program and/or evaluation activities; and quantifiable support for conclusions.

3. Identification and Discussion of the Highway Safety Problem: problem identification; discussion of problem; discussion of program appropriateness; and opinions.

4. Administrative Evaluation of the Program (refer to the Administrative Evaluation Subprocess)

5. Effectiveness Evaluation of the Program: program subset descriptions; evaluation study elements (i.e., objectives, MOE's, experimental plan, etc.); data collection and reduction procedures used in the study; data analysis technique; detailed evaluation results relative to achievement of objectives; detailed program effectiveness statement; and problems encountered in the evaluation study.

Summary of FUNCTION F

STEP F1 - ORGANIZE EVALUATION STUDY MATERIALS

- Obtain information pertaining to all the evaluation activities.
- Review the material for completeness.

STEP F2 - EXAMINE THE EFFECTIVENESS OF THE PROGRAM

- Identify whether each subset reduced the safety deficiencies for which it was intended from FUNCTION C.
- Identify whether each subset resulted in a statistically significant change in the MOE's from FUNCTION D.
- Identify whether each subset resulted in benefits (or effectiveness) which are considered acceptable when compared to program costs from FUNCTION E.
- Determine the effectiveness of each subset and the appropriateness of all evaluation activities, and the activities associated with planning and implementation.
- Correct observed deficiencies if possible.
- Record all problems encountered.

STEP F3 - IDENTIFY RESULTS FOR INCLUSION IN THE EFFECTIVENESS DATA BASE

- Identify changes in the MOE's from sound evaluation studies for inclusion to the effectiveness data base.
- Identify evaluation results for which inconsistencies were identified and exclude these from the effectiveness data base.

STEP F4 - WRITE THE EVALUATION REPORT

- Prepare the final evaluation study report following the recommended guidelines.
- Review final report.
- Distribute copies of report to all highway safety personnel.

FUNCTION G: Develop and Update Data Base

This function enables the evaluator to:

1. Record basic input data to be used in data base development;

2. Compute average accident reduction factors; and

3. Compute the expected range of accident reduction factors.

Overview

Individual projects are the building blocks of highway safety programs. Therefore, to provide planning personnel with a useful tool for improving their ability to estimate expected benefits for projects and programs, a data base of accident reduction factors should be developed for projects. Planners are then able to combine expected benefit estimates for any combination of project types which may comprise a program.

Evaluation data for individual projects within a program or program subset are required as input to the data base in the form of accident reduction factors (AR Factors) and associated expected ranges (ER's). Therefore, the steps for this function are identical to the steps and activities described in FUNCTION G of Accident-Based Project Evaluation. The evaluator is directed to FUNCTION G for details on organizing input data, computing AR Factors and ER's, and developing (or updating) the effectiveness data base.

STEP G1 - ORGANIZE INPUT DATA

Accident, volume and time period lengths for individual projects within each program subset identified for inclusion to the effectiveness data base are used to develop (or update existing) AR Factors and ER's.

The evaluator should follow the procedure described in STEP G1 of the project evaluation subprocess and use the data summary form provided in the Appendix. If project categories similar to the projects within the program have already been established, the new data should be added to existing data and STEPS G2 and G3 should be performed to update the data base.

STEP G2 - COMPUTE AR FACTORS AND ER'S

The evaluator is directed to STEP G2 of the project evaluation subprocess for details on computing initial and/or updating existing values of the AR Factors and ER's using the newly obtained evaluation data.

STEP G3 - DEVELOP AND UPDATE THE DATA BASE

If the projects evaluated in the program represent new project categories, the AR Factors and ER's should be added to the existing data base as a new project category. If AR Factors and ER's already exist, the values of new AR Factors and ER's should be updated into the data base.

Summary of FUNCTION G

STEP G1 - ORGANIZE INPUT DATA

- Obtain evaluation data for individual projects which make up the evaluated program.
- Develop new project categories or add to existing categories following the procedure and using the forms provided in STEP G1 of Accident-Based Project Evaluation.

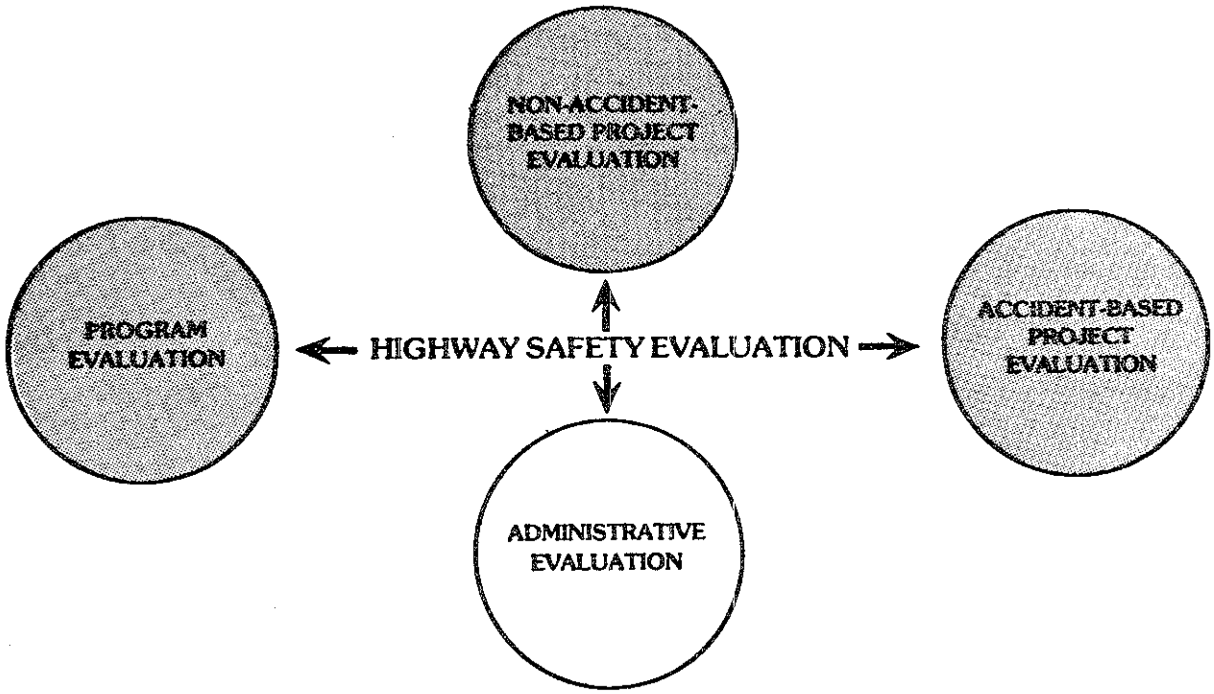
STEP G2 - COMPUTE AR FACTORS AND ER'S

- Compute AR Factors and ER's using the procedure described in STEP G2 of Accident-Based Project Evaluation.

STEP G3 - DEVELOP AND UPDATE DATA BASE

- Add new project categories or update existing AR Factors and ER's in the effectiveness data base.

ADMINISTRATIVE EVALUATION



Administrative Evaluation is the assessment of the activities undertaken during the implementation of a highway safety project or program. This type of evaluation is a fundamental part of the Evaluation Component of the Highway Safety Improvement Program (HSIP). It is a supplement to but not a substitute for Effectiveness Evaluation. Administrative Evaluation does not address the outcome or effectiveness of a safety project or program on accidents or accident severity.

Administrative Evaluation explores three basic implementation issues:

1. Actual resource expenditures.
2. Planned versus actual resource expenditures.
3. Productivity of implementation activities.

Administrative Evaluation addresses both implementation resource expenditures (estimated and actual) and productivity. Resource expenditures are defined as: 1) the level of manpower involvement, 2) the amount of time used to complete specific activities or meet implementation milestones, 3) the quantities of materials used, and 4) the cost of manpower and materials. Productivity is defined as the amount of work produced (e.g. lineal feet of guardrail installed, miles of edgelining completed) for the amounts of time, cost and manpower expended.

Benefits of Administrative Evaluation

Information on implementation provides valuable input to future decisions which must be made in all three components of the HSIP. In the Planning Component, priorities must be made on the basis of comparisons between benefit and cost estimates for competing projects and programs. Administrative Evaluation results can be used to improve cost estimating procedures by providing data on the actual costs and material requirements of past similar projects or programs. Administrative Evaluation can only improve cost estimates. Estimates of project and program benefits can be improved through the use of sound Effectiveness Evaluation results.

In the Implementation Component, scheduling decisions must be made based on estimates of manpower and time requirements for specific activities. Information on the appropriateness of scheduling decisions and the productivity of previous implementation activities can significantly improve future scheduling capabilities for similar projects and programs. This can result in a more optimal use of available time and manpower resources.

In the Evaluation Component, Administrative Evaluation provides cost information for economic analyses which accompany Effectiveness Evaluation. Administrative Evaluation also insures that the Effectiveness Evaluation is being performed on the project or program as it was actually implemented and not as it was planned. There are many times when planned projects do not coincide with the project implemented in the field.

Administrative Evaluation Scope

Administrative Evaluation is performed to assess implementation activities and to produce feedback information to all HSIP components. An understanding of the Implementation Component aids in defining the scope of the Administrative Evaluation.

The Implementation Component consists of the following:

1. Scheduling

Scheduling involves determining when each project (by itself or within a program) should be started and completed under real-world constraints such as weather and funding availablility. Scheduling input comes from the Planning Component in the form of a selected highway safety project or program. Scheduling output is a time schedule including estimates of the start date, duration, and completion date for the project and/or the other major implementation elements (i.e., design, construction, operational review). This information is often recorded in the form of a milestone chart, Gantt Chart, CPM Chart, etc.

2. Design

Design involves the preparation of plans, specifications, and estimates (PS and E). Design may involve highway agency personnel, a contractor, or both. For high-cost projects, design may involve conducting topographic surveys, preparing construction drawings and specifications, advertising and analyzing bid quotations, etc. Low-cost project design may involve the submission of a traffic control work order for a sign installation.

3. Construction

Construction involves placement or installation. Construction may involve highway agency personnel or contractors.

4. Operational Review

Operational review involves observation and adjustment of the countermeasures following construction to ensure smooth and safe traffic flow at the project location. The review usually involves an on-site survey of traffic operations and may or may not be conducted depending on whether or not the project affects traffic flow (e.g., fixed object removal projects generally do not affect traffic flow).

Administrative Evaluation is recommended for all projects and programs. The decision on whether to perform the evaluation should be made when the improvement is programmed for implementation. If Administrative Evaluation is to be conducted, it may be conducted after implementation or during implementation. The latter approach (during implementation) is recommended because: 1) the evaluation becomes a monitoring procedure and implementation activities may be modified as problems arise; and 2) data for the evaluation can be collected on a continuing basis, reducing the chance that vital data will be overlooked.

Administrative Evaluation may be performed at various levels of detail, depending on the amount of administrative information desired from the evaluation. The most detailed level of evaluation involves defining and evaluating specific work activities within each of the four implementation elements. As an example, the activities in the design element of a traffic signal installation project may include: 1) signal timing design,

2) interconnect and wiring design, 3) signal head location design, and 4) signal hardware purchase. Construction activities may include: 1) construction zone traffic control, 2) signal head installation, 3) wiring, 4) temporary flash operation, and 5) stop-go operation. In this example, the administrative issues of resource expenditures and productivity would be addressed for each work activity listed above. High-cost projects and programs which involve a number of definable implementation activities may warrant this level of evaluation detail.

The least detailed level involves evaluating implementation scheduling, design, construction and operational review, without regard to specific activities within each. Information on resource expenditures, comparisons and productivity are only desired on an aggregate, project (program)-wide basis for each element. This level of detail is generally appropriate for low-cost projects and programs.

Evaluation Steps

Administrative Evaluation consists of eight steps (refer to Figure 83):

1. Select Evaluation Subjects
2. Review Project (Program) Details
3. Identify Administrative Issues
4. Obtain Available Data Sources
5. Prepare Administrative Data Summary Tables
6. Evaluate Administrative Issues
7. Prepare and Distribute the Evaluation Report
8. Develop and Update Data Base

STEP #1 - SELECT EVALUATION SUBJECTS

This step involves selecting future or past projects and programs to receive Administrative Evaluation. Administrative Evaluations should be conducted for all projects and programs. Due to resource limitations, however, this may not always be possible. Formal Administrative Evaluation should be given high priority for the following highway safety projects and programs:

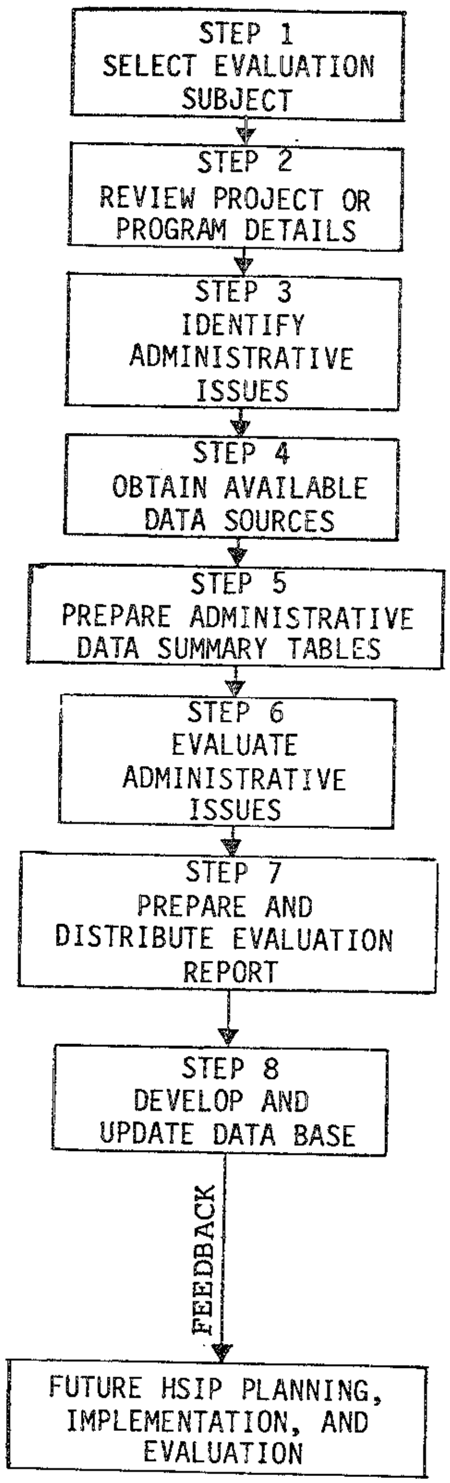


Figure 83. Administrative evaluation flow chart.

- Safety improvements likely to be implemented or considered for implementation in the future

- Safety improvements which warrant or require detailed effectiveness evaluation

- Safety improvements being implemented for the first time

- Safety improvements which are experimental or innovative

- Safety improvements which warrant or require continual monitoring of implementation activities

The decision on whether to conduct Administrative Evaluation (and Effectiveness Evaluation) should be made when the improvement is programmed for implementation. Preliminary evaluation planning activities should also commence at this time.

A periodic review of past projects and programs should be performed to determine if evaluation of completed projects may benefit current highway safety efforts.

STEP #2 - REVIEW PROJECT (PROGRAM) DETAILS

The evaluator must understand the what, where and how aspects of the project(s) to be evaluated. After selecting the evaluation subject, the evaluator should become familiar with the types of project(s), countermeasures, and locations through a review of project files and/or discussions with planning and implementation personnel.

The purpose of the review and information gathering process is to obtain necessary input to prepare a written description of the project or projects to be evaluated.

The written description of the project should include the following information. (If a program is being evaluated, each project should be individually described.):

1. Project identification number and funding source.

2. Project location.

3. Purpose of the project or goal of the program (the safety problem and description of how the improvement will remedy the problem should be provided).

4. Individual countermeasures within the project.

5. Person(s), department, contractor, etc. responsible for each implementation element including scheduling, design, construction and operational review.

The description of the project(s) should be brief but concise and convey a clear description of the characteristics of the project(s). This allows easy reference and retrieval of the Administrative Evaluation results for similar types of projects.

STEP #3 - IDENTIFY ADMINISTRATIVE ISSUES

This step presents guidelines for determining the administration issues to be evaluated. In this step, the evaluator must specify the manpower categories, the activities, the milestones, and the materials to be evaluated in each implementation element.

The number of categories, activities, milestones and materials specified for each element directly affects the level of detail of the Administrative Evaluation. Several factors must be considered when the level of detail is established. These include the cost of the project or program, the relative cost of scheduling, design, construction and operational review, the importance of the evaluation results in future decision-making for similar projects and programs, and the required data and manpower to conduct the evaluation. Input on the evaluation details may be obtained from the person requesting the evaluation, the persons who will use the results of the evaluation, or based on the evaluators knowledge of the project and past evaluation experience.

Other constraints may limit the level of evaluation detail. A detailed evaluation of scheduling, design, construction and review activities may not be warranted for low-cost improvements which are not likely to be implemented again. Also, data must be available or derivable for each activity and manpower category. If they are not, detailed evaluation may not be feasible.

The level of evaluation detail may vary for each implementation element. If scheduling for a particular project is a straightforward, low-cost activity, it may be acceptable to perform a simple Administrative Evaluation of all scheduling activities combined. For the same project, however, the design and construction elements may warrant a detailed evaluation of specific resource expenditure and productivity aspects of specific design and construction activities.

When the level of Administrative Evaluation detail has been established, a form such as that shown in Figure 84 should be used to

ADMINISTRATIVE ISSUES LISTING

Administrative Issues	Implementation Elements			
	SCHEDULING	DESIGN	CONSTRUCTION	REVIEW
MANPOWER CATEGORY List categories for which information is desired on the level of effort expended.				
ACTIVITIES List activities for which information is desired on the total cost of achieving the activity.				
TIME SCHEDULE List the major milestones for which information is desired on the start and completion dates.				
MATERIALS List material items for which information is desired on cost and quantity.				
PRODUCTIVITY List productivity measures to be evaluated.				
OTHER List other specific administrative issues to be evaluated.				

Figure 84. Administrative issues listing.

record specific implementation issues to be evaluated. The following guidelines may be helpful when completing the form:

Manpower Category

Manpower categories should reflect only the major types of manpower involvement required to perform the activities within each implementation element. Scheduling and operational review manpower categories are likely to be very general such as "engineer", "technician", and "other". Design and construction manpower categories are likely to be required in much greater detail, depending on the project type. For example, design manpower may include engineers by discipline (i.e., civil, structural, electrical), surveyors, draftspersons, reviewers, specification writers, etc. Construction manpower may include heavy equipment operators, laborers, field engineers, inspectors and others used by the agency or contractor for billing purposes.

Activities

Only major activities within an implementation element should be listed. The level of detail may vary for each element. Design and construction activities should reflect specific work tasks and activities.

Time Schedule

As a minimum, time scheduling includes the start date, end date, and duration of each implementation element. For some elements specific milestones should be listed if they have been established.

Materials

This heading generally relates to the construction element and to a lesser extent, the design elements. Construction materials should include the specific materials being placed in the field, i.e. guardrailing, signs and supports, paint (for striping), asphalt, concrete, etc.

After the level of evaluation detail has been established, specific questions to be answered in the Administrative Evaluation must be determined. Questions on actual resource expenditures, planned versus actual resource expenditures, and productivity must be specified for each implementation element.

The following questions are recommended as the minimum which need to be answered for each implementation element to the level of detail established in this step. The evaluator should add questions to the list to ensure that all administrative issues relating to the specific project or program are addressed in the evaluation:

Actual Resource Expenditures

1. For the major manpower categories, what was the actual level of effort (number of days, hours, etc.) expended by each?

2. What was the actual cost for performing major activities within the implementation element?

3. What was the actual start date, end date, and duration of each element and its major activities?

Actual Versus Planned Resource Expenditures

1. How did the planned manpower categories compare with actual categories?

2. How did the planned levels of effort for each manpower category compare with the actual level of effort?

3. How did the estimated cost compare with the actual costs?

4. How did the scheduled start date, end date, and duration compare with actual events and durations?

Productivity

1. What was the productivity of output produced per unit of manpower expended?

2. What was the productivity of output produced per unit of cost incurred?

3. What was the productivity of output produced per unit of time expended?

The productivity questions are appropriate only when a tangible output is produced from the elements such as an installed sign, installed guardrail, pavement striping, object removed, etc. Thus, productivity questions are more appropriate for the construction element than the scheduling, design, and review for which the outputs may be of less importance to the evaluation (i.e., plans, visits, etc.).

When developing the administrative questions, the evaluator should coordinate with those individuals who are most likely to use the results of the evaluations, i.e., program planners, administrators, project engineers, etc. This ensures that all pertinent questions are listed and that steps to secure necessary data are taken. Eventually, a standard list of questions to be addressed in an Administrative Evaluation may be developed so that this step requires only minimal time on the part of the evaluator.

STEP #4 - OBTAIN AVAILABLE DATA SOURCES

Data required for Administrative Evaluation include planned (estimated) and actual expenditures of time, cost, manpower, and material. Data on planned implementation resource expenditures may be obtained from several sources including the following:

1. Construction schedules
2. Milestone and CPM Charts
3. Bid quotations
4. Plan, Specification and Estimate (PS and E) documents
5. Project files

Data on actual resource expenditures may be obtained from several other sources including:

1. Invoices
2. Inspection reports
3. Progress reports
4. Data maintained as a funding requirement
5. As-built drawings
6. Project files.

Data from both sources provide the majority of input to the evaluation. Depending on the detail of the evaluation, additional data related to specific activities may be required.

The data sources should be thoroughly reviewed during this evaluation step to ensure that data on the administrative issues specified in STEP #3 are available. If not, the evaluator must identify additional data and information sources to meet the evaluation needs.

STEP #5 - PREPARE ADMINISTRATIVE DATA SUMMARY TABLES

This step involves organizing the evaluation data in a format which allows the evaluator to efficiently conduct the evaluation. Manpower, cost, time, material and other resource information obtained in STEP #4 must be summarized to simplify the task of addressing the administrative issues listed in STEP #3. The data summary table shown in Figure 85 is suggested for summarizing pertinent administrative data.

Four summary tables should be prepared for each project to be evaluated; one each for scheduling, design, construction and operational review.

The manpower categories, activities, milestones, and materials listed in the Detailed Administrative Issues Listing (developed in STEP #3) should be transferred to the appropriate Summary Table.

Data from the sources obtained in STEP #4 should be recorded on the Summary Tables. If data required on the summary form are not available, note this fact under the "Comments" heading on the Summary Table. Steps should be taken to obtain data from other sources and to ensure that the missing data are maintained for future similar projects.

STEP #6 EVALUATE ADMINISTRATIVE ISSUES

The administrative issues listed in STEP #3 can be directly addressed using the Summary Table prepared in STEP #5. Answers to the questions on actual resource expenditures may be taken directly from the Summary Tables.

Issues on planned versus the actual resource expenditures may be addressed by computing the percent differences between planned and actual quantities and costs. When large or unexpected differences are observed between the planned and actual expenditures, a follow-up investigation should be performed to determine the reasons for such differences. Discussions with project engineers, inspectors or contractors may be helpful in the investigation.

Issues relating to productivity may be obtained by computing ratios between project output measures and input measures such as

Project No.____________
Evaluation No.__________

__Scheduling
__Design
__Construction
__Op. Review

ADMINISTRATIVE DATA SUMMARY TABLE

MANPOWER

Category	Role	Manpower Involvement						Comments
		Planned		Actual		Differences		
		#Persons	Person Hrs.	#Persons	Person Hrs.	Hrs.		

ACTIVITY COSTS

Major Activity	Activity Costs		Differences		Comments
	Planned	Actual	$	%	

TIME SCHEDULE

Event or Milestone	Time Duration		Differences		Comments
	Planned	Actual	Time	%	

MATERIAL

Item	Material Requirements		Differences		Comments
	Planned	Actual	Amount	%	

PRODUCTIVITY

Input Measure	Output Measure	Ratio	Comments

COMMENTS

Figure 85. Administrative data summary table.

manpower, time and cost. Answers to the administrative issues dealing with productivity should be recorded in the "Productivity" section of the Summary Table.

The results of follow-up discussions to determine reasons for large differences between planned and actual conditions should be recorded in the "Comments" section.

The completed Summary Tables provide a full description of the actual resource and planned resource expenditures and information on implementation productivity. These tables, therefore, are the primary product of the Administrative Evaluation.

STEP #7 - PREPARE AND DISTRIBUTE THE EVALUATION REPORT

A brief written report on the evaluation results should be prepared after all administrative questions have been answered. The report should describe the project, the implementation data and answers to pertinent administrative questions. Lengthy discussions of theories, possibilities, and explanations should be avoided. The report should include the following:

1. Project Description

    a. Evaluation number,

    b. Project number,

    c. Date evaluation began,

    d. Date evaluation ended,

    e. Project location,

    f. Codes,

    g. Funding source,

    h. Estimated total project cost,

    i. Project purpose, and

    j. Implementation coordinators;

2. Executive Summary - A listing of conclusions on the administrative issues relative to scheduling, design, construction and operational review. This information can be taken directly from the Summary Tables;

3. Recommendations; and

4. Appendix - Attach copies of Summary Tables.

If the Administrative Evaluation is being conducted to supplement an Effectiveness Evaluation, it may be included in the Effectiveness Evaluation Report. However, the Administrative Evaluation Report may not be reviewed or usable by the same personnel who are primarily interested in the Effectiveness Evaluation Report, there fore, copies of the reports should be distributed to the appropriate personnel.

STEP #8 - DEVELOP AND UPDATE DATA BASE

An Administrative Evaluation Report provides information on a specific project or program which is usable in future planning and implementation decisions. As the number of evaluations increases for similar types of highway improvements, the reliability and quality of decision criteria becomes stronger. Thus, the development of a filing system for which Administrative Evaluation Reports and data contained in the Summary Tables may be maintained and updated is essential.

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(NOTE: Parenthetical letters following references indicate the evaluation function(s) which are discussed in the reference.)

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GLOSSARY OF TERMS

ACCEPTANCE REGION - Set of values of a test statistic that imply acceptance of the null hypothesis.

ACCIDENT-BASED-EVALUATION - The assessment of a highway safety project or program in terms of the extent to which the number and severity of accidents are reduced.

ACCIDENT CAUSALITY CHAIN - The chain of events (major causal factor - major contributory factor - safety problem) which lead to accident experience or accident potential.

ACCIDENT FREQUENCY - The number of accidents which occur during a specified period of time (i.e., accidents per year, accidents per three years).

ACCIDENT POTENTIAL - An impending accident situation characterized by an unsafe roadway condition.

ACCIDENT RATE - The number of accidents which occur during a specified period of time, divided by a measure of the degree of vehicular exposure over the same period (see EXPOSURE).

ACCIDENT REDUCTION FACTORS (ARF's) - Values of percent accident reduction derived from the observed accident reductions of one or several highway safety projects or programs.

ACCIDENT SEVERITY - The number of proportion of accidents measured by the seriousness or violence of the accident. Accident severity may be expressed in terms of the number of fatalities, injuries or property damage accidents or involvements which occur during a specified period of time.

ACCIDENT SURROGATE (PROXY) - Measurable traffic operational or driver behavioral characteristics which have a quantitative relationship with accident measures and thus can be used as a substitute for accident experience.

ADMINISTRATIVE EVALUATION - The assessment of project or program implementation activities exploring such issues as resource expenditures, planned versus actual resource expenditures, and productivity.

ADMINISTRATIVE ISSUES - Areas of interest related to project/program implementation, which may be subject to administrative evaluation. These issues are: 1) manpower categories, 2) implementation activities, 3) time schedule requirements, 4) material requirements, 5) productivity, and 6) other specific administrative issues.

ALTERNATIVE HYPOTHESIS - Hypothesis to be accepted if null hypothesis is rejected.

ANALYSIS OF VARIANCE - A statistical technique that tests for significance differences in the mean values between two or more data sets.

BEHAVIORAL NON-ACCIDENT MEASURES - (See NON-ACCIDENT MEASURES).

BIAS - Any effect that systematically distorts the outcome of an experiment.

BINOMIAL DISTRIBUTION - A distribution describing the probability of observing one of two possible outcomes given a specified number of trials.

CATEGORICAL PROGRAMS - Highway safety improvement classification provided in FHPM 6-8-2-1.

CHI-SQUARE DISTRIBUTION - Distribution of test statistic used to test the null hypothesis of "independence" for two or more variables.

CLASS BOUNDARY - Dividing point between two cells in a frequency histogram.

CONFIDENCE INTERVAL - A range of numbers computed from sample data, that form an interval which has a probability of including the population parameter.

CONFIDENCE LIMITS - The upper and lower limits of the confidence interval.

CONSTRUCTION (IN THE IMPLEMENTATION COMPONENT) - The placement or installation of highway safety projects/programs countermeasures.

CONTINGENCY TABLE - A matrix composed of variables to be statistically tested by the Chi-Square technique.

CONTINUOUS DATA - Possible data values that can take on an infinite number of values within a defined range.

CONTROL SITE(S) - A site or group of sites with similar characteristics which are not exposed to the same countermeasure as the project site, used to aid in determining if the results achieved by the treatment group are a consequence of the countermeasure rather than the result of some outside influence.

CORRELATION COEFFICIENT - An index whose value lies between -1 and 1 and describes the degree of association between two variables.

COST/BENEFIT ANALYSIS - A form of economic evaluation in which input is measured in terms of dollar costs and output is measured in terms of economic benefit of a project as compared to the incurred cost of the project.

COST/EFFECTIVENESS ANALYSIS - A form of economic evaluation in which input is measured in terms of project effectiveness and output is measured in terms of the cost of achieving one unit of the desired measure of effectiveness.

COUNTERMEASURE - A single highway safety treatment or corrective activity designed to alleviate a safety problem.

CRITICAL VALUE OF A TEST STATISTIC - Value(s) that separate the rejection and acceptance regions in a statistical test.

DATA BASE - The document collection or file of collected data which serves as the basis of an information retrieval system.

DATA COLLECTION - The process of accumulating statistical information relating to the empirical effects of a highway safety project.

DATA SET - A set of data pertaining to a single site or a single data collection period.

DATA TABULATION - The process of displaying experimental results in a table so that the information can more readily be interpreted.

DEGREES OF FREEDOM - The number of independent observations for a source of variation minus the number of independent parameters estimated in computing the variation.

DESIGN (IN THE IMPLEMENTATION COMPONENT) - The preparation of plans, specifications, and estimates (PS and E) for highway safety projects/programs.

DEVIATION FROM THE MEAN - Distance between a sample observation and the sample mean, $\bar{x}$.

DISCRETE DATA - Possible data values that fall into categories and have specific values only.

EFFECTIVENESS DATA BASE - A matrix of information showing the effectiveness of various countermeasures or projects in terms of their impact on total accidents, accidents by type, time of day and prevailing conditions and accident severity. Accident reductions for specific projects or countermeasures are stratified by the type of location (four-legged intersection, tee-intersection, urban, rural, two-laned section, etc.).

EFFECTIVENESS EVALUATION - A statistical and economic assessment of the extent to which a highway safety project or program achieves reductions in the number and severity of accidents (accident-based evaluation), or the intermediate impact of a project on observed traffic operations and road user behavior (see non-accident-based evaluation).

EMPIRICAL RULE - Rule that describes the variability of data that possess a mound shaped frequency distribution.

EDPO, EQUIVALENT PROPERTY DAMAGE ONLY (ACCIDENTS) - A measure of accident experience, based on attaching weights to accident severity categories as multiples of property damage only accidents.

ESTIMATE - Number computed from sample data used to approximate a population parameter.

EVALUATION - A comparison process that measures an item of activity against certain predetermined standards or criteria. A judgement of value or worth.

EVALUATION COMPONENT (HSIP) - The third of three HSIP components. This component consists of one process and four subprocesses which involves the determination of the effect of highway safety improvements through the appropriate use of 1) non-accident-based project evaluation, 2) accident-based project evaluation, 3) program evaluation, and 4) administrative evaluation.

EVALUATION OBJECTIVE - A brief statement describing the desired outcome of an evaluation study.

EXPECTED RANGES (ER'S) - Estimates of the variance associated with accident reduction factors (See ACCIDENT REDUCTION FACTORS).

EXPERIMENTAL PLAN - A method of evaluation involving alternate techniques which allow for a determination of project impact. The experimental plan selection criteria depends on project characteristics and data availability.

EXPOSURE - The quantity of vehicles, vehicle-miles of travel or other volume and/or time related factor which measures the degree of vehicular exposure to a particular situation.

F-DISTRIBUTION (F-TEST) - Distribution of test statistic used to compare variances from two normal populations. (See ANALYSIS OF VARIANCE).

FHPM - Federal-Aid Highway Program Manual.

FREQUENCY - Number of observations falling in a cell or classification category.

FUNDAMENTAL OBJECTIVES - Four evaluation objectives which should always be included in accident-based evaluation. These objectives are to determine the effect of the project/program on 1) total accidents, 2) fatal accidents, 3) injury accidents, and 4) property damage accidents.

HAZARD - Conditions which exist on the highway system which are conducive to future accident occurrences.

HAZARDOUS LOCATION - Highway spots, intersections or sections experiencing abnormally high accident occurrences or accident potential.

HAZARD POTENTIAL - (See ACCIDENT POTENTIAL)

HIGH COST PROJECT - Major highway safety projects which require a significant initial cost outlay. Examples include lane additions, bridge replacements, roadway alignment changes, constructing highway grade separations, etc.

HIGHWAY SAFETY GOAL - Expected safety improvements resulting from a highway safety program.

HIGHWAY SAFETY PROJECT - One or more remedial countermeasures instituted to improve specific safety deficiencies on the highway or its environs.

HIGHWAY SAFETY TREATMENT - A single remedial countermeasure instituted to improve the overall safety environment of the highway system.

HISTOGRAM - Graphical method for describing a set of data.

HSIP - Highway Safety Improvement Program, defined in FHPM 8-2-3.

IMPLEMENTATION COMPONENT (HSIP) - The second of the three HSIP components. This component consists of one process and three subprocesses which involve 1) the scheduling, 2) the design and construction, and 3) the operational review of the project(s).

INTERMEDIATE OBJECTIVE - Expected short term improvements in the causal and contributory factors of a non-accident-based project evaluation.

ITE - Institute of Transportation Engineers.

LEVEL OF CONFIDENCE - Probability of accepting the null hypothesis when it is true ($1-\alpha$).

LEVEL OF SIGNIFICANCE - Probability of rejecting the null hypothesis when it is true. (Type I error (α)).

LOW COST PROJECT - Highway safety projects which require low or moderate initial cost outlays. Examples include pavement edgelining, traffic signal timing modifications, traffic sign installation, roadway delineator installations, etc.

MAJOR CAUSAL FACTORS - Specific hazardous elements associated with the highway, environment or vehicle, or actions associated with the road user which describe why an actual or potential accident problem exists.

MAJOR CONTRIBUTORY FACTOR - Elements or activities which lead to or increase the probability of a failure in the road user, the vehicle or the highway environment.

MEAN - Average of a set of measurements. The symbols x and m denote the means of a sample and a population, respectively.

MEASURE OF CENTRAL TENDENCY - A measure of the center of the distribution.

MEASURE OF EFFECTIVENESS (MOE) - A measurable unit or set of units assigned to each evaluation objective. The data collected in the units of the MOE will allow for a determination of the degree of achievement for that objective.

MEASURE OF VARIABILITY - A measure of dispersion of a distribution.

MEDIAN - Middle measurement when a set of data is ordered according to numerical value.

MILESTONE - The point of completion of a major implementation element or activity.

MUTCD - Manual of Uniform Traffic Control Devices.

NCHRP - National Cooperative Highway Research Program.

NHTSA - National Highway Traffic Safety Administration.

NOMINAL VARIABLES - Categorical data which are classified by an unordered name or label.

NON-ACCIDENT-BASED PROJECT EVALUATION - An assessment of the intermediate effect of a project on observed changes in traffic operations and road user behavior.

NON-ACCIDENT MEASURE - A measurable unit of safety which is logically related to accident measures such as traffic performance and operation (travel time, delay, and speeds) and road user behavior (traffic control violations and erratic driver maneuvers).

NON-PARAMETRIC METHOD - A statistical significance test where no assumptions are made about the underlying distributions or parameters. Examples of non-parametric tests are 1) Wilcoxen Rank Sum Test, and 2) Mann-Whitney U-Test.

NORMAL DISTRIBUTION - A symetrial bell-shaped probability distribution. Many events in nature have frequency distributions which closely approximate the normal distribution.

NSC - National Safety Council

NULL HYPOTHESIS - The hypothesis, tested in statistical analysis, assumes that there is no difference between the before and after accident experience.

OBJECTIVE - The specific accident or severity measures which are to be evaluated by the evaluation study. There are two types of objectives: 1) Fundamental objectives refer to those measures which must be evaluated in all studies. They are total accidents, fatal accidents, personal injury accidents and property damage only accidents; 2) Objectives relating to project purposes. These objectives may include one or more of the purposes of the project (See PURPOSE).

ONE-TAILED TEST - A statistical test where the direction (sign) of the difference between two sample means is of interest. The null hypothesis to be tested is $H_0: X_B > X_A$ or $H_0: X_B < X_A$ (X_B = Before mean, X_A = After mean).

OPERATIONAL NON-ACCIDENT MEASURE - (See NON-ACCIDENT MEASURE)

OPERATIONAL REVIEW (IN THE IMPLEMENTATION COMPONENT) - The observation and adjustment of constructed countermeasures for the purpose of ensuring smooth and safe traffic flow at the location(s) and that the improvement was constructed as designed.

ORDINAL VARIABLES - Categorical data which are rank ordered by name or label.

PARAMETER - Numerical descriptive measures of a population.

PARAMETRIC METHODS - Statistical significance tests which require assumptions regarding the underlying distribution.

PLANNING COMPONENT (HSIP) - The first of the three HSIP components. This component consists of four processes (and associated subprocesses) which involve; 1) identifying hazardous locations and elements, 2) conducting engineering studies, 3) developing candidate countermeasures, 4) developing projects based on the candidate countermeasures, and 5) prioritizing the developed safety improvement project.

POISSON DISTRIBUTION - A distribution which often appears in observed events which are very improbable compared to all possible events, but which occur occasionally since so many trials occur, e.g., traffic deaths, industrial accidents, and radioactive emissions. The mean and variance of the poisson distribution are equal.

POPULATION - The total set of items defined by a characteristic of the items.

PRE-PROJECT (OR BASELINE) DATA - Data collected or maintained prior to project implementation for use in describing conditions before an improvement.

PROBABILITY DISTRIBUTION - Representation of the theoretical frequency distribution for a random variable.

PRODUCTIVITY - The amount of work produced (e.g., linear feet of guardrail installed, miles of edgelining completed) for the amounts of time, cost and manpower expended.

PROGRAM - A group of projects (not necessarily similar in type or location) implemented to achieve a common highway safety goal.

PROGRAM/PROJECT BENEFIT - A measure of the positive effect of a highway safety program or project given in terms of accident or non-accident measure reduction.

PROGRAMMED PROJECTS - A highway safety project, formally planned for implementation at some later point in time. Projects contained in the Annual Work Program (AWP) are programmed projects.

PROGRAM SUBSET - A group of projects, within a highway safety program, which can be stratified according to similarities in project types and location characteristics.

PROJECT - One or more countermeasures implemented to reduce identified or potential safety deficiencies at a location on the highway or its environs. Also, a project may consist of identical countermeasures implemented at several similar locations, which have been grouped to increase the evaluation sample size.

PROJECT IMPACT - Project effectiveness in achiving the evaluation objectives; also any unexpected consequences of the project such as public reaction.

PROJECT JUSTIFICATION STATEMENT - A formal statement of the perceived need for implementing a particular highway safety project. This statement is generally submitted to State funding agencies as a request for project finding. The statement generally provides a quantitative justification in terms of the existing adverse conditions (accidents) as well as the expected benefits to be derived from the project.

PURPOSE - The reason for which the highway safey project was implemented. The purposes refers to the reduction or elimination of a specific highway safety deficiency such as a type of accident, a severity class, a hazard potential indicator and/or a traffic performance variable.

RANDOM SELECTION - A process by which every element in a population has an equal probability of being chosen.

RANGE OF A SET OF MEASUREMENTS - Difference between the largest and smallest members of the set.

REJECTION REGION - Set of values of a test statistic that indicates rejection of the null hypothesis.

RESOURCE EXPENDITURES - Elements used in the implementation of a project or program such as: 1) the level of manpower involvement, 2) the amount of time used to complete specific activities or meet implementation milestones, 3) the quantities of materials used, and 4) the cost of manpower and materials.

SAFETY PROBLEM (NON-ACCIDENT-BASED EVALUATION) - Specific types of accidents or potential accidents which result from the existence of a causal and/or contributory factor.

SALVAGE VALUE - Estimated residual worth of program or project components at the end of their expected service lives.

SAMPLE - A subgroup of the population. A finite portion of a population or universe.

SCALAR VARIABLES - Categorical data which have names or labels with known distances apart.

SCHEDULING (IN THE IMPLEMENTATION COMPONENT) - The determination of when highway safety projects (individually or as part of a program) should be started and completed under real-world constraints.

SERVICE LIFE - The period of time, in years, in which the components of a program or project can be expected to actively affect accident experience.

SINGLE POINT ESTIMATE - An average of individual MOE's for either the before or after period when accident trends are not observed.

STANDARD DEVIATION - Measure of data variation. Square root of the variance represents the population standard deviation, represents the sample standard deviation.

STATISTICAL SIGNIFICANCE - The determination of whether an observed change in an MOE (by use of a selected statistical technique) constitutes a significant change within a selected level of confidence.

T-TEST (PAIRED T) - A statistical technique used to test the difference between the before and after means of a group of locations.

T-TEST (STUDENT'S T) - A statistical technique for testing the Null Hypothesis, i.e., that the mean scores from two groups do not differ in a statistically significant way. Applicable to the test of the hypothesis that a random sample of observations is from a normal population with mean and with the variance unspecified. This test can be used when the sample size is less than 30.

TEST OF PROPORTIONS - A statistical technique based on a contingency table to test the hypothesis that two proportions are or are not equal. The Z-Statistic calculated in this test is compared to a tabulated Z .

TEST STATISTIC - A statistic used to provide a test of some statistical hypothesis.

TWO-TAILED TEST - A statistical test where no assertion is made about the direction (sign) of the difference between two sample means. The null hypothesis to be tested is $H_o:\overline{X}_B-\overline{X}_A=0$. ($\overline{X}_B$ = Before mean, $\overline{X}_A$ = After mean).

TYPE I ERROR (α) - Probability of rejecting the null hypothesis when it is true.

TYPE II ERROR (β) - Probability of accepting the null hypothesis when it is false.

ULTIMATE SAFETY OBJECTIVES - A significant reduction in the number and severity of accidents.

VALIDITY THREATS - Factors which influence the change in a specified MOE but are not a direct result of program/project implementation.

VARIANCE - Measure of data variation. σ^2 represents population variances, s^2 represents sample variance.

Z-STATISTIC - Standardized normal random variable that is freqently used as a test statistic.

The t-distribution for 1-tail test. (Values of t_c where a equals the area under the t-distribution to the right of t).

Degrees of Freedom	α-level 0.20	0.10	0.05	0.01
1	1.376	3.078	6.314	31.821
2	1.061	1.886	2.920	6.965
3	0.978	1.638	2.353	4.541
4	0.941	1.533	2.132	3.747
5	0.920	1.476	2.015	3.365
6	0.906	1.440	1.943	3.143
7	0.896	1.415	1.895	2.998
8	0.889	2.397	1.860	2.896
9	0.883	1.383	1.833	2.821
10	0.879	1.372	1.812	2.764
11	0.876	1.363	1.796	2.718
12	0.873	1.356	1.782	2.681
13	0.870	1.350	1.771	2.650
14	0.868	1.345	1.761	2.624
15	0.866	1.341	1.753	2.602
16	0.866	1.337	1.746	2.583
17	0.863	1.333	1.740	2.567
18	0.862	1.330	1.734	2.552
19	0.861	1.328	1.729	2.539
20	0.860	1.325	1.725	2.528
21	0.859	1.323	1.721	2.518
22	0.858	1.321	1.717	2.508
23	0.858	1.319	1.714	2.500
24	0.857	1.318	1.711	2.492
25	0.856	1.316	1.708	2.485
26	0.856	1.315	1.706	2.479
27	0.855	1.314	1.703	2.473
28	0.855	1.313	1.701	2.467
29	0.854	1.311	1.699	2.462
30	0.854	1.310	1.697	2.457
40	0.851	1.303	1.684	2.423
60	0.848	1.296	1.671	2.390
120	0.845	1.289	1.658	2.358
∞	0.842	1.282	1.645	2.326

The t-distribution for 2-tail test. (Values of t_c where a equals the sum of the area under the t-distribution to the right of t_c and to the left of $-t_c$).

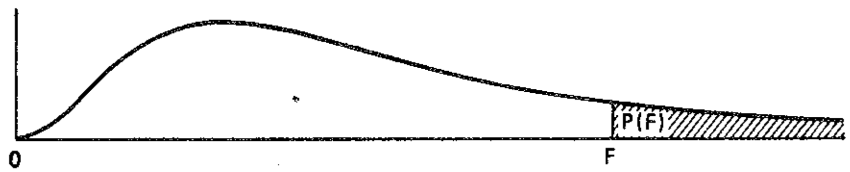
Degrees of Freedom	α-level			
	0.20	0.10	0.05	0.01
1	3.078	6.314	12.706	63.657
2	1.886	2.920	4.303	9.925
3	1.638	2.353	3.182	5.841
4	1.533	2.132	2.776	4.604
5	1.476	2.015	2.571	4.032
6	1.440	1.943	2.447	3.707
7	1.415	1.895	2.365	3.499
8	2.397	1.860	2.306	3.355
9	1.383	1.833	2.262	3.250
10	1.372	1.812	2.228	3.169
11	1.363	1.796	2.201	3.106
12	1.356	1.782	2.179	3.055
13	1.350	1.771	2.160	3.012
14	1.345	1.761	2.145	2.977
15	1.341	1.753	2.131	2.947
16	1.337	1.746	2.120	2.921
17	1.333	1.740	2.110	2.898
18	1.330	1.734	2.101	2.878
19	1.328	1.729	2.093	2.861
20	1.325	1.725	2.086	2.845
21	1.323	1.721	2.080	2.831
22	1.321	1.717	2.074	2.819
23	1.319	1.714	2.069	2.807
24	1.318	1.711	2.064	2.797
25	1.316	1.708	2.060	2.787
26	1.315	1.706	2.056	2.779
27	1.314	1.703	2.052	2.771
28	1.313	1.701	2.048	2.763
29	1.311	1.699	2.045	2.756
30	1.310	1.697	2.042	2.750
40	1.303	1.684	2.021	2.704
60	1.296	1.671	2.000	2.660
120	1.289	1.658	1.980	2.617
∞	1.282	1.645	1.960	2.576

The X^2 distribution for 2-tail test. (Values of X_c where a equals the area under the X^2 distribution to the right of X_c).

Degrees of Freedom	α-level 0.20	0.10	0.05	0.01
1	1.642	2.706	3.841	6.635
2	3.219	4.605	5.991	9.210
3	4.642	6.251	7.815	11.345
4	5.989	7.779	9.488	13.277
5	7.289	9.236	11.070	15.086
6	8.558	10.645	12.592	16.812
7	9.803	12.017	14.067	18.475
8	11.030	13.362	15.507	20.090
9	12.242	14.684	16.919	23.209
10	13.442	15.987	18.307	23.209
11	14.631	17.275	19.675	24.725
12	15.812	18.549	21.026	26.217
13	16.985	19.812	22.362	27.688
14	18.151	21.064	23.685	29.141
15	19.311	22.307	24.996	30.578
16	20.465	23.542	26.296	32.000
17	21.615	24.769	27.587	33.409
18	22.760	25.989	28.869	34.805
19	23.900	27.204	30.144	36.191
20	25.038	28.412	31.410	37.566
21	26.171	29.615	32.671	38.932
22	27.301	30.813	33.924	40.289
23	28.420	32.007	35.172	41.638
24	29.553	33.196	36.415	42.980
25	30.675	34.382	37.652	44.314
26	31.795	35.563	38.885	45.642
27	32.912	36.741	40.113	46.963
28	34.027	37.916	41.337	48.278
29	35.139	39.087	42.537	49.588
30	36.250	40.256	43.773	50.892
35	41.778	46.059	49.802	57.342
40	47.269	51.805	55.758	63.691
45	52.729	57.505	61.656	69.957
50	58.164	63.167	67.505	76.154
60	68.972	74.397	79.082	88.379
70	79.715	85.527	90.531	100.425
80	90.405	96.578	101.879	112.329
90	101.054	107.565	113.145	124.116
100	111.667	118.498	124.342	135.806
120	132.806	140.233	146.567	158.950
140	153.854	161.827	168.613	181.840
160	174.828	183.311	190.516	204.530
180	195.743	204.704	212.304	227.056
200	216.609	226.021	233.994	249.445

The z-distribution for 1- and 2-tail tests. (Values of z_c where a equals the area in the tail(s) of the distribution).

	α-level				
	0.20	0.15	0.10	0.05	0.01
1-tailed	0.84	1.04	1.28	1.64	2.33
2-tailed	1.28	1.44	1.64	1.96	2.58



Critical Points on the F-Distribution

$$P(F) = \int_F^{\infty} \frac{[(f_1 + f_2 - 2)/2]!}{[(f_1 - 2)/2]!\,[(f_2 - 2)/2]!} f_1^{f_1/2} f_2^{f_2/2} F^{(f_1-2)/2} (f_2 + f_1 F)^{-(f_1+f_2)/2}\, dF$$

NOTE: The number of degrees of freedom for the numerator is f_1, for the denominator, f_2.

$P(F) = 0.10$

f_2 \ f_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	39.86	49.50	53.59	55.83	57.24	58.20	58.91	59.44	59.86	60.20	60.70	61.22	61.74	62.00	62.26	62.53	62.79	63.06	63.33
2	8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38	9.39	9.41	9.42	9.44	9.45	9.46	9.47	9.47	9.48	9.49
3	5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24	5.23	5.22	5.20	5.18	5.18	5.17	5.16	5.15	5.14	5.13
4	4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.94	3.92	3.90	3.87	3.84	3.83	3.82	3.80	3.79	3.78	3.76
5	4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32	3.30	3.27	3.24	3.21	3.19	3.17	3.16	3.14	3.12	3.10
6	3.78	3.46	3.29	3.18	3.11	3.04	3.01	2.98	2.96	2.94	2.90	2.87	2.84	2.82	2.80	2.78	2.76	2.74	2.72
7	3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72	2.70	2.67	2.63	2.59	2.58	2.56	2.54	2.51	2.40	2.47
8	3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56	2.54	2.50	2.46	2.42	2.40	2.38	2.30	2.34	2.32	2.29
9	3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44	2.42	2.38	2.34	2.30	2.28	2.25	2.23	2.21	2.18	2.16
10	3.28	3.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35	2.32	2.28	2.24	2.20	2.18	2.16	2.13	2.11	2.08	2.06
11	3.23	2.86	2.68	2.54	2.45	2.39	2.34	2.30	2.27	2.25	2.21	2.17	2.12	2.10	2.08	2.05	2.03	2.00	1.97
12	3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21	2.19	2.15	2.10	2.06	2.04	2.01	1.99	1.96	1.93	1.90
13	3.14	2.76	2.56	2.43	2.35	2.28	2.23	2.20	2.16	2.14	2.10	2.05	2.01	1.98	1.96	1.93	1.90	1.88	1.85
14	3.10	2.73	2.52	2.39	2.31	2.24	2.19	2.15	2.12	2.10	2.05	2.01	1.96	1.94	1.91	1.89	1.86	1.83	1.80
15	3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09	2.06	2.02	1.97	1.92	1.90	1.87	1.85	1.82	1.79	1.76
16	3.05	2.67	2.46	2.33	2.24	2.18	2.13	2.09	2.06	2.03	1.99	1.94	1.89	1.87	1.84	1.81	1.78	1.75	1.72
17	3.03	2.64	2.44	2.31	2.22	2.15	2.10	2.06	2.03	2.00	1.96	1.91	1.86	1.84	1.81	1.78	1.75	1.72	1.60
18	3.01	2.62	2.42	2.29	2.20	2.13	2.08	2.04	2.00	1.98	1.93	1.89	1.84	1.81	1.78	1.75	1.72	1.69	1.66
19	2.99	2.61	2.40	2.27	2.18	2.11	2.06	2.02	1.98	1.96	1.91	1.86	1.81	1.79	1.76	1.73	1.70	1.67	1.63
20	2.97	2.59	2.38	2.25	2.16	2.09	2.04	2.00	1.96	1.94	1.89	1.84	1.79	1.77	1.74	1.71	1.68	1.64	1.61
21	2.96	2.57	2.38	2.23	2.14	2.08	2.02	1.98	1.95	1.92	1.88	1.83	1.78	1.75	1.72	1.69	1.66	1.62	1.59
22	2.95	2.56	2.35	2.22	2.13	2.06	2.01	1.97	1.93	1.90	1.86	1.81	1.76	1.73	1.70	1.67	1.64	1.60	1.57
23	2.94	2.55	2.34	2.21	2.11	2.05	1.99	1.95	1.92	1.89	1.84	1.80	1.74	1.72	1.69	1.66	1.62	1.59	1.55
24	2.93	2.54	2.33	2.19	2.10	2.04	1.98	1.94	1.91	1.88	1.83	1.78	1.73	1.70	1.67	1.64	1.61	1.57	1.53
25	2.92	2.53	2.32	2.18	2.09	2.02	1.97	1.93	1.89	1.87	1.82	1.77	1.72	1.69	1.66	1.63	1.59	1.56	1.52
26	2.91	2.52	2.31	2.17	2.08	2.01	1.96	1.92	1.88	1.86	1.81	1.76	1.71	1.68	1.65	1.61	1.58	1.54	1.50
27	2.90	2.51	2.30	2.17	2.07	2.00	1.95	1.91	1.87	1.85	1.80	1.75	1.70	1.67	1.64	1.60	1.57	1.53	1.49
28	2.89	2.50	2.29	2.16	2.06	2.00	1.94	1.90	1.87	1.84	1.79	1.74	1.69	1.66	1.63	1.59	1.56	1.52	1.48
29	2.89	2.50	2.28	2.15	2.06	1.99	1.93	1.89	1.86	1.83	1.78	1.73	1.68	1.65	1.62	1.58	1.55	1.51	1.47
30	2.89	2.49	2.28	2.14	2.05	1.98	1.93	1.88	1.85	1.82	1.77	1.72	1.64	1.64	1.61	1.57	1.54	1.50	1.46

Source: Pignataro, "Traffic Engineering Theory and Practice", Prentice-Hall, 1973.

Critical Points on the F-Distribution (continued).

$P(F) = 0.10$

f_2 \ f_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
40	2.84	2.44	2.23	2.09	2.00	1.93	1.87	1.83	1.79	1.76	1.71	1.66	1.61	1.57	1.54	1.51	1.47	1.42	1.38
60	2.79	2.39	2.18	2.04	1.95	1.87	1.82	1.77	1.74	1.71	1.66	1.60	1.54	1.51	1.48	1.44	1.40	1.35	1.29
120	2.75	2.35	2.13	1.99	1.90	1.82	1.77	1.72	1.68	1.65	1.60	1.54	1.48	1.45	1.41	1.37	1.32	1.26	1.19
∞	2.71	2.30	2.08	1.94	1.85	1.77	1.72	1.67	1.63	1.00	1.55	1.49	1.42	1.39	1.34	1.30	1.24	1.17	1.00

$P(F) = 0.05$

f_2 \ f_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	161,45	199.50	215.71	224.56	230.16	233.99	236.77	238.88	240.54	241.88	243.91	245.95	248.01	249.05	250.09	251.14	252.20	253.25	254.32
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.00	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.84	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.00	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.74	1.79	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.48	2.29	2.18	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.23
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

Source: Pignataro, "Traffic Engineering Theory and Practice", Prentice-Hall, 1973.

SHORT TABLE OF RANDOM NUMBERS

46	96	85	77	27	92	86	26	45	21	89	91	71	42	64	64	58	22	75	81	74	91	48	46	18
44	19	15	32	63	55	87	77	83	29	45	00	31	34	84	05	72	90	44	27	78	22	07	62	17
84	89	80	62	24	83	31	67	26	11	84	79	26	85	84	23	09	94	00	80	55	31	63	27	91
74	97	80	80	65	07	71	30	01	84	47	45	89	70	74	13	04	90	51	27	61	34	63	87	44
22	14	61	60	86	86	23	71	18	33	72	08	16	18	50	56	45	51	29	48	30	93	45	66	29
40	03	96	40	03	47	24	60	09	21	21	18	00	05	86	52	85	40	73	73	57	65	26	83	91
52	33	76	44	56	15	47	75	78	78	76	19	87	06	98	47	48	02	62	03	42	05	82	55	02
37	59	20	40	93	17	82	24	19	90	80	87	82	74	59	84	24	49	79	17	23	75	83	42	00
11	02	55	57	48	64	74	36	22	67	19	20	15	92	53	37	13	75	54	89	56	73	23	39	07
10	33	79	26	84	54	71	83	89	74	65	48	23	17	49	18	81	05	52	85	70	05	73	11	17
67	59	28	25	47	89	11	65	65	20	42	23	96	41	64	20	30	89	87	64	37	93	36	96	35
93	50	75	20	09	18	54	34	68	02	54	87	23	05	43	36	98	29	97	93	37	08	30	92	98
24	43	23	72	80	64	34	27	23	46	15	36	10	63	21	59	69	76	02	62	31	62	47	60	34
89	91	63	18	86	27	10	78	88	84	42	32	00	97	92	00	04	94	50	05	75	82	70	80	35
74	62	19	67	54	18	28	92	33	69	98	96	74	85	72	11	68	25	08	95	31	79	11	79	54
91	03	85	60	81	16	61	97	25	14	78	21	22	05	25	47	26	37	80	39	19	06	41	02	00
42	57	66	76	72	91	03	63	48	46	44	01	83	53	62	28	80	59	55	05	02	16	13	17	54
06	86	63	06	15	03	72	38	01	58	25	37	66	48	56	19	56	41	29	28	76	49	74	39	50
92	70	96	70	89	80	87	14	25	49	25	94	62	78	26	15	41	39	48	75	64	69	61	06	38
91	05	88	53	52	13	04	82	23	00	26	36	47	44	04	08	84	80	07	44	76	51	52	41	59
68	85	97	74	47	63	90	05	90	84	87	48	25	01	11	05	45	11	43	15	60	40	31	84	59
59	54	13	09	13	80	42	29	63	03	24	64	12	43	28	10	01	65	62	07	79	83	05	59	61
89	18	82	69	33	46	58	19	84	03	59	28	97	81	02	65	47	47	70	89	74	17	80	22	65
67	43	31	09	12	60	19	57	63	78	11	80	10	97	15	70	04	89	81	78	54	84	87	83	42
61	75	37	19	56	90	75	89	03	56	49	92	72	95	27	52	87	47	12	52	54	62	43	23	13
78	10	91	11	00	63	19	63	74	58	69	03	51	38	60	86	53	56	77	06	69	03	89	91	24
93	23	71	58	09	78	08	03	07	71	79	32	25	19	61	04	40	33	12	06	78	91	97	88	95
37	55	48	82	63	89	92	59	14	72	19	17	22	61	90	20	03	64	96	60	48	01	95	44	84
62	13	11	71	17	23	29	25	13	85	33	35	07	69	25	68	57	92	57	11	84	44	01	33	66
29	89	97	47	03	13	20	86	22	45	59	98	64	53	89	64	94	81	55	87	78	81	58	46	42
16	94	85	82	89	07	17	30	29	89	89	80	98	86	25	36	53	02	49	14	34	03	52	09	20
04	93	10	59	75	12	98	84	60	93	68	16	87	60	11	50	46	56	58	45	88	72	50	46	11
95	71	43	68	97	18	85	17	13	08	00	50	77	50	46	92	45	26	97	21	48	22	23	08	82
86	05	39	14	35	48	68	18	36	57	09	62	40	28	87	08	74	79	91	08	27	12	43	82	03
59	80	60	10	41	31	00	69	63	77	01	89	94	60	19	02	70	88	72	33	38	88	20	60	86
05	45	85	40	54	03	98	96	76	27	77	84	80	08	64	60	44	34	54	24	85	20	85	77	32
71	85	17	74	66	27	85	19	55	56	51	86	48	92	82	44	60	47	10	88	22	52	42	29	96
80	20	82	80	98	00	40	92	57	51	52	83	14	55	31	99	73	23	40	07	64	54	44	99	21
13	50	78	02	73	39	66	82	01	28	67	51	75	66	33	97	47	58	42	44	88	09	28	58	06
67	92	65	41	45	86	77	96	46	21	14	39	56	36	70	15	74	43	62	69	82	30	77	28	77
72	56	73	44	26	04	62	81	15	85	79	26	99	57	28	22	25	94	80	62	95	48	98	23	86
26	86	85	64	94	11	58	78	45	86	84	45	91	88	51	10	68	36	87	81	16	77	30	19	36
69	57	40	80	44	94	60	82	94	93	98	01	48	50	57	69	60	77	69	60	74	22	05	77	17
71	20	03	80	79	25	74	17	78	34	54	45	04	77	42	59	75	78	64	99	37	03	18	03	36
89	98	55	98	22	45	12	49	82	71	57	83	28	69	50	59	15	09	25	79	39	42	84	18	70
58	74	82	81	14	02	01	05	77	94	65	57	70	89	42	48	56	84	31	59	18	70	41	74	60
50	54	73	81	91	07	81	26	25	45	49	61	22	88	41	20	00	15	59	93	51	60	65	65	63
49	33	72	90	10	20	65	28	44	63	95	86	75	78	69	24	41	65	86	10	84	10	32	00	93
11	85	01	43	65	02	85	69	56	88	84	29	64	85	48	15	70	11	77	83	01	34	82	91	04
84	22	46	41	84	74	27	02	57	77	47	93	72	02	95	63	75	74	69	69	61	84	31	92	13

Source: Experimental Statistics - Handbook 91, United States Department of Commerce, National Bureau of Standards, August 1, 1963

(Continued).

05	57	23	06	26	23	08	66	16	11	75	28	81	56	14	62	82	45	65	80	36	02	76	55	68
37	78	16	06	57	12	46	22	90	97	78	67	39	06	63	60	51	02	07	16	75	12	90	41	16
23	71	15	08	82	64	87	29	01	20	46	72	05	80	19	27	47	15	76	51	58	67	06	80	54
42	67	98	41	67	44	28	71	45	08	19	47	76	30	26	72	33	69	92	51	95	23	26	85	76
05	83	03	84	32	62	83	27	48	83	09	19	84	90	20	20	50	87	74	93	51	62	10	23	30
60	46	18	41	23	74	73	51	72	90	40	52	95	41	20	89	48	98	27	38	81	33	83	82	94
32	80	64	75	91	98	09	40	64	89	29	99	46	35	69	91	50	73	75	92	90	56	82	93	24
79	86	53	77	78	06	62	37	48	82	71	00	78	21	65	65	88	45	82	44	78	93	22	78	09
45	13	23	32	01	09	46	36	43	66	37	15	35	04	88	79	83	53	19	13	91	59	81	81	87
20	60	97	48	21	41	84	22	72	77	99	81	83	30	46	15	90	26	51	73	66	34	99	40	60
67	91	44	83	43	25	56	33	28	80	99	53	27	56	19	80	76	32	53	95	07	53	09	61	98
86	50	76	93	86	35	68	45	37	83	47	44	92	57	66	59	54	16	48	39	26	94	54	66	40
66	73	38	38	23	36	10	95	16	01	10	01	59	71	55	99	24	88	31	41	00	73	13	80	62
55	11	50	29	17	73	97	04	20	39	20	22	71	11	43	00	15	10	12	35	09	11	00	89	05
23	54	33	87	92	92	04	49	73	96	57	53	57	08	93	09	69	87	83	07	46	39	50	37	85
41	48	67	79	44	57	40	29	10	34	58	63	51	18	07	41	02	39	79	14	40	68	10	01	61
03	97	71	72	43	27	36	24	59	88	82	87	26	31	11	44	28	58	99	47	83	21	35	22	88
90	24	83	48	07	41	56	68	11	14	77	75	48	68	08	90	89	63	87	00	06	18	63	21	91
98	98	97	42	27	11	80	51	13	13	03	42	91	14	51	22	15	48	67	52	09	40	34	60	85
74	20	94	21	49	96	51	69	99	85	43	76	55	81	36	11	88	68	32	43	08	14	78	05	34
94	67	48	87	11	84	00	85	93	56	43	99	21	74	84	13	56	41	90	96	30	04	19	68	73
58	18	84	82	71	23	66	33	19	25	65	17	90	84	24	91	75	36	14	83	86	22	70	86	89
31	47	28	24	88	49	28	69	78	62	23	45	53	38	78	65	87	44	91	93	91	62	76	09	20
45	62	31	06	70	92	73	27	83	57	15	64	40	57	56	54	42	35	40	93	55	82	08	78	87
31	49	87	12	27	41	07	91	72	64	63	42	06	65	82	71	28	36	45	31	99	01	03	35	76
69	37	22	23	46	10	75	83	62	94	44	65	46	23	65	71	69	20	89	12	16	56	61	70	41
93	67	21	56	98	42	52	53	14	86	24	70	25	18	23	23	56	24	03	86	11	06	46	10	23
77	56	18	37	01	32	20	18	70	79	20	85	77	89	28	17	77	15	52	47	15	30	35	12	75
37	07	47	79	60	75	24	15	31	63	25	93	27	66	19	53	52	49	98	45	12	12	06	00	32
72	08	71	01	73	46	39	60	37	58	22	25	20	34	30	02	03	62	68	58	38	04	06	89	94
55	22	48	46	72	50	14	24	47	67	84	37	32	84	82	64	97	13	69	86	20	09	80	46	75
69	24	98	90	70	29	34	25	33	23	12	69	90	50	38	93	84	32	28	96	03	65	70	90	12
01	86	77	18	21	91	66	11	84	65	48	75	26	94	51	40	51	53	36	39	77	69	06	25	07
51	40	94	06	80	61	34	28	46	28	11	48	48	94	60	65	06	63	71	06	19	35	05	32	56
58	78	02	85	80	29	67	27	44	07	67	23	20	28	22	62	97	59	62	13	41	72	70	71	07
33	75	88	51	00	33	56	15	84	34	28	50	16	65	12	81	56	43	54	14	63	37	74	97	59
58	60	37	45	62	09	95	93	16	59	35	22	91	78	04	97	98	80	20	04	38	93	13	92	30
72	13	12	95	32	87	99	32	83	65	40	17	92	57	22	68	98	79	16	23	53	56	56	07	47
22	21	13	16	10	52	57	71	40	49	95	25	55	36	95	57	25	25	77	05	38	05	62	57	77
97	94	83	67	90	68	74	88	17	22	38	01	04	33	49	38	47	57	61	87	15	39	43	87	00
09	03	68	53	63	29	27	31	66	53	39	34	88	87	04	35	80	69	52	74	99	16	52	01	65
29	95	61	42	65	05	72	27	28	18	09	85	24	59	46	03	91	55	38	62	51	71	47	37	38
81	96	78	90	47	41	38	36	33	95	05	90	26	72	85	23	23	30	70	51	56	93	23	84	80
44	62	20	81	21	57	57	85	00	47	26	10	87	22	45	72	03	51	75	23	38	38	56	77	97
68	91	12	15	08	02	18	74	56	79	21	53	63	41	77	15	07	39	87	11	19	25	62	19	30
29	33	77	60	29	09	25	09	42	28	07	15	40	67	56	29	58	75	84	06	19	54	31	16	53
54	13	39	19	29	64	97	73	71	61	78	03	24	02	93	86	69	76	74	28	08	98	84	08	23
75	16	85	64	64	93	85	68	08	84	15	41	57	84	45	11	70	18	17	60	47	80	10	13	00
36	47	17	08	79	03	92	85	18	42	95	48	27	37	99	98	81	94	44	72	06	95	42	31	17
29	61	08	21	91	23	76	72	84	98	26	23	66	54	86	88	95	14	82	57	17	99	16	28	99

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03	46	86	56	84	81	20	89	68	52	45	41	01	71	55	14	18	05	16	01	74	94	50	66	07
74	12	14	57	26	12	48	83	67	04	88	69	05	27	23	68	84	23	52	07	21	67	13	52	01
06	23	73	51	23	92	93	05	54	32	84	46	61	33	92	13	30	91	73	11	30	44	21	71	20
99	21	80	24	79	30	18	06	96	20	62	06	47	96	07	04	82	93	01	56	62	70	43	22	85
96	82	59	89	28	22	20	95	72	00	24	85	63	57	75	88	05	79	13	75	78	64	25	89	85
62	16	18	23	64	60	90	57	60	54	04	96	09	06	17	14	63	17	80	80	56	10	17	11	57
21	40	82	41	45	41	41	89	46	18	55	86	94	32	57	44	12	64	75	12	78	01	18	69	81
13	83	48	82	60	78	96	80	57	13	40	26	10	24	48	78	60	92	70	16	72	86	54	09	76
29	65	83	93	92	99	26	01	86	11	85	42	48	86	59	24	96	35	07	87	67	31	25	89	62
17	49	05	12	13	53	01	98	80	17	83	85	88	14	79	82	83	56	44	51	85	40	70	68	22
14	86	47	29	15	14	22	27	62	93	15	60	43	13	05	25	75	40	08	85	44	70	89	64	13
78	09	76	61	07	48	81	27	48	28	96	11	26	95	03	06	86	81	52	72	66	74	71	60	25
83	17	94	26	89	01	48	68	56	97	05	76	82	89	15	66	81	63	81	96	12	44	71	57	43
87	12	89	46	85	58	09	94	89	92	09	08	76	54	88	82	73	24	94	39	02	79	07	58	27
44	80	80	40	85	96	84	99	87	03	93	03	00	74	18	67	18	97	11	12	59	80	54	51	66
54	56	85	50	81	82	42	53	60	86	98	03	65	10	60	26	52	64	74	35	28	13	24	65	23
65	99	80	88	88	44	91	22	60	72	61	95	90	98	80	65	03	45	04	27	88	70	88	40	49
55	56	01	94	09	94	02	71	85	10	27	20	51	27	86	09	15	11	62	41	03	22	82	10	60
55	78	63	40	57	16	20	17	73	02	76	09	62	95	85	67	75	45	99	63	59	55	88	27	99
83	78	98	67	23	38	95	61	06	58	69	07	85	82	10	35	61	61	66	06	75	45	83	33	70
20	14	56	25	85	78	33	37	84	15	50	63	78	74	56	49	84	72	58	00	93	68	11	47	46
48	04	07	78	13	43	03	62	46	20	06	94	09	27	69	00	71	51	43	84	21	12	86	03	51
61	10	14	39	57	87	76	60	77	02	06	50	15	60	46	22	27	52	87	43	69	58	65	79	02
64	91	36	96	42	22	57	18	13	44	46	81	95	15	37	91	81	63	33	38	39	50	47	45	94
89	53	11	10	33	10	46	41	63	84	20	46	86	41	05	82	95	56	76	23	03	13	94	28	49
96	45	86	42	40	85	95	17	28	74	65	20	70	90	34	33	61	11	01	31	37	28	81	00	31
84	11	25	89	49	31	80	86	53	51	35	48	22	28	25	27	06	38	71	90	50	77	40	41	58
29	75	56	28	89	23	26	12	23	48	89	28	84	08	52	21	05	73	08	04	83	42	91	01	91
68	92	40	82	19	49	20	85	82	69	84	17	99	11	56	39	15	67	55	53	65	29	15	51	32
94	19	67	99	27	70	71	04	43	18	44	18	75	11	70	53	21	60	78	80	92	54	21	02	42
36	84	68	46	85	58	91	23	65	24	71	19	67	18	79	90	83	47	86	32	48	69	97	10	87
63	22	84	35	10	02	05	03	47	93	45	70	25	27	90	82	98	41	45	96	39	86	91	78	79
42	53	20	46	19	11	16	93	21	93	14	91	74	92	31	97	68	24	20	85	19	54	75	37	84
87	90	76	51	68	49	25	68	28	69	55	55	73	10	22	66	79	28	80	03	51	11	00	81	37
20	12	97	40	25	45	94	85	18	65	10	99	81	24	42	14	53	78	41	79	36	57	79	19	76
24	11	65	19	92	46	11	76	64	37	83	23	96	23	73	93	99	53	14	49	40	01	63	17	74
98	21	62	16	29	73	52	06	26	85	80	52	74	61	20	57	45	86	36	54	75	29	64	49	43
02	82	14	07	19	72	77	97	89	77	25	82	60	89	04	04	88	65	47	20	81	72	40	65	48
97	20	87	54	01	93	88	53	07	88	61	00	22	95	65	79	69	26	90	49	24	61	78	19	40
17	86	81	84	82	29	40	23	66	71	14	91	93	75	02	10	13	86	27	32	59	36	40	06	61
75	50	70	16	34	21	99	87	09	37	27	40	66	07	73	13	44	06	10	43	91	11	73	13	97
47	53	77	58	88	52	47	37	21	60	83	58	21	59	82	88	05	35	17	66	33	62	15	09	88
20	93	99	76	58	93	00	89	77	75	59	89	49	61	13	68	11	80	07	72	81	65	95	94	53
91	02	65	18	16	57	93	64	76	45	21	49	51	58	96	12	62	42	10	79	57	44	97	85	66
58	49	25	97	76	12	90	94	85	25	36	40	97	46	71	83	36	55	41	38	49	98	82	70	96
98	51	20	18	77	75	86	22	62	68	86	87	02	47	99	68	80	27	34	10	09	22	84	59	33
05	32	54	17	81	87	20	77	78	80	98	42	48	42	47	41	76	11	41	79	41	48	26	94	59
40	96	49	91	79	57	18	61	50	48	06	07	68	43	07	01	04	06	22	03	11	11	75	95	02
58	43	93	93	53	01	61	75	76	90	25	97	08	76	69	35	65	24	83	85	00	49	37	05	46
76	98	36	43	60	47	85	65	78	62	66	15	98	17	20	43	96	27	87	53	57	37	92	86	46

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24	81	06	14	98	24	93	58	63	68	58	26	24	45	65	91	42	68	67	42	61	74	77	93	46
75	55	54	29	67	02	81	01	67	54	08	81	34	00	79	62	38	52	14	88	38	66	59	41	97
49	71	80	54	37	73	34	11	74	14	91	86	82	41	02	76	12	36	71	88	43	72	84	36	27
04	19	48	35	54	98	00	41	47	44	63	13	27	50	18	75	16	72	40	90	02	45	87	82	15
68	15	52	42	22	91	22	96	38	41	03	27	15	67	26	36	81	75	11	82	94	33	62	08	94

10	80	17	67	83	05	31	23	08	07	40	00	60	44	65	70	16	31	73	05	46	41	47	64	68
40	42	27	55	76	82	88	42	76	51	58	49	58	75	38	23	57	06	64	69	46	90	09	55	68
95	57	21	21	25	12	05	41	70	28	03	59	97	37	64	48	69	48	59	60	89	76	35	83	05
57	27	64	94	98	88	93	70	86	59	46	84	08	32	31	75	61	19	49	11	28	46	76	79	28
80	56	69	49	63	83	78	78	76	36	89	51	16	47	35	86	69	96	69	88	91	22	47	24	84

44	51	75	51	08	17	43	53	31	09	60	34	34	61	93	66	01	94	37	18	24	09	75	29	21
55	42	48	76	50	13	89	69	00	05	99	45	82	01	53	86	68	81	36	50	75	20	17	94	47
80	50	67	83	01	97	76	21	64	34	62	43	02	84	38	13	60	26	32	36	81	43	17	56	41
03	64	65	44	02	75	41	33	91	28	82	97	57	38	49	27	26	97	34	44	26	12	00	68	24
14	53	75	37	91	43	95	15	13	26	33	27	45	48	33	80	80	26	69	76	04	87	83	58	32

01	64	43	36	30	71	24	75	92	73	07	81	13	35	46	88	62	80	64	69	86	25	73	92	98
39	38	79	42	17	77	99	55	32	85	13	35	48	49	80	83	59	06	34	94	06	03	61	85	02
74	96	24	94	89	54	66	29	35	88	50	46	65	50	26	62	45	80	61	95	07	99	57	10	54
21	16	54	55	77	46	38	33	88	55	21	56	18	93	32	94	24	80	97	03	78	39	73	87	70
58	51	99	53	96	73	60	77	21	06	76	59	78	55	96	99	07	53	91	95	99	60	56	61	79

46	98	27	95	19	22	29	41	56	76	83	48	49	82	79	79	20	00	26	40	22	50	14	30	73
58	46	36	76	19	18	00	60	50	28	32	44	18	35	99	28	91	50	53	62	21	61	26	46	81
43	05	50	00	20	39	25	46	84	39	27	39	92	42	59	04	64	15	09	35	07	11	25	51	17
84	07	33	83	87	14	33	79	07	66	60	43	66	57	57	57	59	01	78	80	13	77	63	58	10
93	54	23	72	70	09	36	16	24	04	74	05	65	29	64	67	37	28	13	98	01	48	29	75	89

54	46	72	02	34	52	81	38	52	96	14	54	27	32	41	74	84	83	90	01	97	59	87	66	41
43	60	84	28	32	93	91	76	70	31	50	22	09	40	89	64	85	82	76	91	16	71	99	98	70
64	80	80	16	92	46	42	46	47	22	87	16	20	65	82	01	45	21	49	80	17	39	70	74	03
78	70	39	30	06	59	65	14	84	04	82	28	46	64	05	89	81	80	09	89	56	11	27	81	44
14	88	67	03	59	32	15	83	04	01	20	82	92	25	34	88	84	80	76	69	25	10	04	86	02

69	28	06	18	56	78	97	49	14	85	01	58	31	16	20	53	74	03	27	05	80	39	15	67	49
99	68	09	96	36	54	10	77	95	88	90	84	52	16	52	58	87	51	31	71	68	53	11	85	50
01	66	22	15	54	63	83	64	15	30	21	86	48	17	11	68	92	16	17	49	36	05	17	80	24
67	85	26	91	23	14	28	01	76	47	65	12	58	24	27	61	59	43	20	15	93	47	30	56	27
13	91	16	76	91	97	85	48	99	50	40	96	30	66	97	82	66	06	90	97	65	28	44	98	08

95	82	20	95	52	65	95	03	48	75	64	25	04	13	85	80	13	37	08	18	09	28	63	07	69
44	06	82	49	28	27	34	53	42	35	44	12	40	64	35	06	28	14	37	23	97	38	07	60	80
99	22	26	64	15	71	06	96	22	93	77	46	73	57	51	22	54	82	37	99	96	27	25	87	77
08	44	25	12	87	72	42	13	57	77	61	07	94	24	62	17	76	19	45	18	98	11	47	40	31
14	96	76	06	37	32	09	72	81	22	87	70	81	93	78	93	37	22	32	25	38	45	38	03	31

27	86	41	53	58	16	49	99	19	03	62	98	79	81	98	15	03	62	32	93	68	24	14	44	50
99	67	81	61	25	52	97	87	98	15	85	99	01	86	59	00	11	39	32	53	49	18	62	51	65
89	14	37	94	03	22	32	45	42	61	97	83	04	26	30	48	49	40	99	99	69	96	13	94	21
84	13	53	15	32	42	02	58	32	14	83	73	02	82	49	25	62	91	14	94	70	72	64	50	51
72	11	79	75	79	36	07	12	92	61	89	93	77	82	08	23	74	75	67	56	37	45	35	13	44

19	72	57	61	99	08	62	02	26	82	52	90	72	51	94	84	59	79	34	19	95	76	21	49	91
96	99	76	63	90	27	60	94	15	70	17	74	92	31	85	24	47	55	64	51	91	47	13	39	69
44	15	86	78	18	15	57	29	51	62	95	84	20	83	01	11	90	66	80	81	40	43	65	87	35
33	83	94	07	50	18	89	86	16	50	09	97	04	76	51	41	20	56	50	20	33	53	70	10	22
53	07	06	16	30	84	43	40	57	32	18	09	47	16	69	41	03	38	24	02	16	41	58	39	58

6% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT		EQUAL PAYMENT SERIES			
	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.060	0.9434	1.000	1.0000	0.9434	1.0600
2	1.124	0.8900	2.060	0.4854	1.8334	0.5454
3	1.191	0.8396	3.184	0.3141	2.6730	0.3741
4	1.262	0.7921	4.375	0.2286	3.4651	0.2886
5	1.338	0.7473	5.637	0.1774	4.2124	0.2374
6	1.419	0.7050	6.975	0.1434	4.9173	0.2034
7	1.504	0.6651	8.394	0.1191	5.5824	0.1791
8	1.594	0.6274	9.897	0.1010	6.2098	0.1610
9	1.689	0.5919	11.491	0.0870	6.8017	0.1470
10	1.791	0.5584	13.181	0.0759	7.3601	0.1359
11	1.898	0.5268	14.972	0.0668	7.8869	0.1268
12	2.012	0.4970	16.870	0.0593	8.3838	0.1193
13	2.133	0.4688	18.882	0.0530	8.8527	0.1130
14	2.261	0.4423	21.015	0.0476	9.2950	0.1076
15	2.397	0.4173	23.276	0.0430	9.7122	0.1030
16	2.540	0.3936	25.673	0.0390	10.1059	0.0990
17	2.693	0.3714	28.213	0.0354	10.4773	0.0954
18	2.854	0.3503	30.906	0.0324	10.8276	0.0924
19	3.026	0.3305	33.760	0.0296	11.1581	0.0896
20	3.207	0.3118	36.786	0.0272	11.4699	0.0872
21	3.400	0.2942	39.993	0.0250	11.7641	0.0850
22	3.604	0.2775	43.392	0.0230	12.0416	0.0830
23	3.820	0.2618	46.996	0.0213	12.3034	0.0813
24	4.049	0.2470	50.816	0.0197	12.5504	0.0797
25	4.292	0.2330	54.865	0.0182	12.7834	0.0782
26	4.549	0.2198	59.156	0.0169	13.0032	0.0769
27	4.822	0.2074	63.706	0.0157	13.2105	0.0757
28	5.112	0.1956	68.528	0.0146	13.4062	0.0746
29	5.418	0.1846	73.640	0.0136	13.5907	0.0736
30	5.743	0.1741	79.058	0.0126	13.7648	0.0726
31	6.088	0.1643	84.802	0.0118	13.9291	0.0718
32	6.453	0.1550	90.890	0.0110	14.0840	0.0710
33	6.841	0.1462	97.343	0.0103	14.2302	0.0703
34	7.251	0.1379	104.184	0.0096	14.3681	0.0696
35	7.686	0.1301	111.435	0.0090	14.4982	0.0690
36	8.147	0.1227	119.121	0.0084	14.6210	0.0684
37	8.636	0.1158	127.268	0.0079	14.7368	0.0679
38	9.154	0.1092	135.904	0.0074	14.8460	0.0674
39	9.704	0.1031	145.058	0.0069	14.9491	0.0669
40	10.286	0.0972	154.762	0.0065	15.0463	0.0665
41	10.903	0.0917	165.048	0.0061	15.1380	0.0661
42	11.557	0.0865	175.951	0.0057	15.2245	0.0657
43	12.250	0.0816	187.508	0.0053	15.3062	0.0653
44	12.985	0.0770	199.758	0.0050	15.3832	0.0650
45	13.765	0.0727	212.744	0.0047	15.4558	0.0647
46	14.590	0.0685	226.508	0.0044	15.5244	0.0644
47	15.466	0.0647	241.099	0.0041	15.5890	0.0641
48	16.394	0.0610	256.565	0.0039	15.6500	0.0639
49	17.378	0.0575	272.958	0.0037	15.7076	0.0637
50	18.420	0.0543	290.336	0.0034	15.7619	0.0634

8% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

	SINGLE PAYMENT		EQUAL PAYMENT SERIES			
YEAR	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.080	0.9259	1.000	1.0000	0.9259	1.0800
2	1.166	0.8573	2.080	0.4808	1.7833	0.5608
3	1.260	0.7938	3.246	0.3080	2.5771	0.3880
4	1.360	0.7350	4.506	0.2219	3.3121	0.3019
5	1.469	0.6806	5.867	0.1705	3.9927	0.2505
6	1.587	0.6302	7.336	0.1363	4.6229	0.2163
7	1.714	0.5835	8.923	0.1121	5.2064	0.1921
8	1.851	0.5403	10.637	0.0940	5.7466	0.1740
9	1.999	0.5002	12.488	0.0801	6.2469	0.1601
10	2.159	0.4632	14.487	0.0690	6.7101	0.1490
11	2.332	0.4289	16.645	0.0601	7.1390	0.1401
12	2.518	0.3971	18.977	0.0527	7.5361	0.1327
13	2.720	0.3677	21.495	0.0465	7.9038	0.1265
14	2.937	0.3405	24.215	0.0413	8.2442	0.1213
15	3.172	0.3152	27.152	0.0368	8.5595	0.1168
16	3.426	0.2919	30.324	0.0330	8.8514	0.1130
17	3.700	0.2703	33.750	0.0296	9.1216	0.1096
18	3.996	0.2502	37.450	0.0267	9.3719	0.1067
19	4.316	0.2317	41.446	0.0241	9.6036	0.1041
20	4.661	0.2145	45.762	0.0219	9.8181	0.1019
21	5.034	0.1987	50.423	0.0198	10.0168	0.0998
22	5.437	0.1839	55.457	0.0180	10.2007	0.0980
23	5.871	0.1703	60.893	0.0164	10.3711	0.0964
24	6.341	0.1577	66.765	0.0150	10.5288	0.0950
25	6.848	0.1460	73.106	0.0137	10.6748	0.0937
26	7.396	0.1352	79.954	0.0125	10.8100	0.0925
27	7.988	0.1252	87.351	0.0114	10.9352	0.0914
28	8.627	0.1159	95.339	0.0105	11.0511	0.0905
29	9.317	0.1073	103.966	0.0096	11.1584	0.0896
30	10.063	0.0994	113.283	0.0088	11.2578	0.0888
31	10.868	0.0920	123.346	0.0081	11.3498	0.0881
32	11.737	0.0852	134.214	0.0075	11.4350	0.0875
33	12.676	0.0789	145.951	0.0069	11.5139	0.0869
34	13.690	0.0730	158.627	0.0063	11.5869	0.0863
35	14.785	0.0676	172.317	0.0058	11.6546	0.0858
36	15.968	0.0626	187.102	0.0053	11.7172	0.0853
37	17.246	0.0580	203.070	0.0049	11.7752	0.0849
38	18.625	0.0537	220.316	0.0045	11.8289	0.0845
39	20.115	0.0497	238.941	0.0042	11.8786	0.0842
40	21.725	0.0460	259.057	0.0039	11.9246	0.0839
41	23.462	0.0426	280.781	0.0036	11.9672	0.0836
42	25.339	0.0395	304.244	0.0033	12.0067	0.0833
43	27.367	0.0365	329.583	0.0030	12.0432	0.0830
44	29.556	0.0338	356.950	0.0028	12.0771	0.0828
45	31.920	0.0313	386.506	0.0026	12.1084	0.0826
46	34.474	0.0290	418.426	0.0024	12.1374	0.0824
47	37.232	0.0269	452.900	0.0022	12.1643	0.0822
48	40.211	0.0249	490.132	0.0020	12.1891	0.0820
49	43.427	0.0230	530.343	0.0019	12.2122	0.0819
50	46.902	0.0213	573.770	0.0017	12.2335	0.0817

10% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT		EQUAL PAYMENT SERIES			
	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.100	0.9091	1.000	1.0000	0.9091	1.1000
2	1.210	0.8264	2.100	0.4762	1.7355	0.5762
3	1.331	0.7513	3.310	0.3021	2.4869	0.4021
4	1.464	0.6830	4.641	0.2155	3.1699	0.3155
5	1.611	0.6209	6.105	0.1638	3.7908	0.2638
6	1.772	0.5645	7.716	0.1296	4.3553	0.2296
7	1.949	0.5132	9.487	0.1054	4.8684	0.2054
8	2.144	0.4665	11.436	0.0874	5.3349	0.1874
9	2.358	0.4241	13.579	0.0736	5.7590	0.1736
10	2.594	0.3855	15.937	0.0627	6.1446	0.1627
11	2.853	0.3505	18.531	0.0540	6.4951	0.1540
12	3.138	0.3186	21.384	0.0468	6.8137	0.1468
13	3.452	0.2897	24.523	0.0408	7.1034	0.1408
14	3.797	0.2633	27.975	0.0357	7.3667	0.1357
15	4.177	0.2394	31.772	0.0315	7.6061	0.1315
16	4.595	0.2176	35.950	0.0278	7.8237	0.1278
17	5.054	0.1978	40.545	0.0247	8.0216	0.1247
18	5.560	0.1799	45.599	0.0219	8.2014	0.1219
19	6.116	0.1635	51.159	0.0195	8.3649	0.1195
20	6.727	0.1486	57.275	0.0175	8.5136	0.1175
21	7.400	0.1351	64.002	0.0156	8.6487	0.1156
22	8.140	0.1228	71.403	0.0140	8.7715	0.1140
23	8.954	0.1117	79.543	0.0126	8.8832	0.1126
24	9.850	0.1015	88.497	0.0113	8.9847	0.1113
25	10.835	0.0923	98.347	0.0102	9.0770	0.1102
26	11.918	0.0839	109.182	0.0092	9.1609	0.1092
27	13.110	0.0763	121.100	0.0083	9.2372	0.1083
28	14.421	0.0693	134.210	0.0075	9.3066	0.1075
29	15.863	0.0630	148.631	0.0067	9.3696	0.1067
30	17.449	0.0573	164.494	0.0061	9.4269	0.1061
31	19.194	0.0521	181.943	0.0055	9.4790	0.1055
32	21.114	0.0474	201.138	0.0050	9.5264	0.1050
33	23.225	0.0431	222.252	0.0045	9.5694	0.1045
34	25.548	0.0391	245.477	0.0041	9.6086	0.1041
35	28.102	0.0356	271.024	0.0037	9.6442	0.1037
36	30.913	0.0323	299.127	0.0033	9.6765	0.1033
37	34.004	0.0294	330.039	0.0030	9.7059	0.1030
38	37.404	0.0267	364.043	0.0027	9.7327	0.1027
39	41.145	0.0243	401.448	0.0025	9.7570	0.1025
40	45.259	0.0221	442.593	0.0023	9.7791	0.1023
41	49.785	0.0201	487.852	0.0020	9.7991	0.1020
42	54.764	0.0183	537.637	0.0019	9.8174	0.1019
43	60.240	0.0166	592.401	0.0017	9.8340	0.1017
44	66.264	0.0151	652.641	0.0015	9.8491	0.1015
45	72.890	0.0137	718.905	0.0014	9.8628	0.1014
46	80.180	0.0125	791.795	0.0013	9.8753	0.1013
47	88.197	0.0113	871.975	0.0011	9.8866	0.1011
48	97.017	0.0103	960.172	0.0010	9.8969	0.1010
49	106.719	0.0094	1057.190	0.0009	9.9063	0.1009
50	117.391	0.0085	1163.909	0.0009	9.9148	0.1009

11% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

	SINGLE PAYMENT		EQUAL PAYMENT SERIES			
YEAR	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.110	0.9009	1.000	1.0000	0.9009	1.1100
2	1.232	0.8116	2.110	0.4739	1.7125	0.5839
3	1.368	0.7312	3.342	0.2992	2.4437	0.4092
4	1.518	0.6587	4.710	0.2123	3.1024	0.3223
5	1.685	0.5935	6.228	0.1606	3.6959	0.2706
6	1.870	0.5346	7.913	0.1264	4.2305	0.2364
7	2.076	0.4817	9.783	0.1022	4.7122	0.2122
8	2.305	0.4339	11.859	0.0843	5.1461	0.1943
9	2.558	0.3909	14.164	0.0706	5.5370	0.1806
10	2.839	0.3522	16.722	0.0598	5.8892	0.1698
11	3.152	0.3173	19.561	0.0511	6.2065	0.1611
12	3.498	0.2858	22.713	0.0440	6.4924	0.1540
13	3.883	0.2575	26.212	0.0382	6.7499	0.1482
14	4.310	0.2320	30.095	0.0332	6.9819	0.1432
15	4.785	0.2090	34.405	0.0291	7.1909	0.1391
16	5.311	0.1883	39.190	0.0255	7.3792	0.1355
17	5.895	0.1696	44.501	0.0225	7.5488	0.1325
18	6.544	0.1528	50.396	0.0198	7.7016	0.1298
19	7.263	0.1377	56.939	0.0176	7.8393	0.1276
20	8.062	0.1240	64.203	0.0156	7.9633	0.1256
21	8.949	0.1117	72.265	0.0138	8.0751	0.1238
22	9.934	0.1007	81.214	0.0123	8.1757	0.1223
23	11.026	0.0907	91.148	0.0110	8.2664	0.1210
24	12.239	0.0817	102.174	0.0098	8.3481	0.1198
25	13.585	0.0736	114.413	0.0087	8.4217	0.1187
26	15.080	0.0663	127.999	0.0078	8.4881	0.1178
27	16.739	0.0597	143.079	0.0070	8.5478	0.1170
28	18.580	0.0538	159.817	0.0063	8.6016	0.1163
29	20.624	0.0485	178.397	0.0056	8.6501	0.1156
30	22.892	0.0437	199.021	0.0050	8.6938	0.1150
31	25.410	0.0394	221.913	0.0045	8.7331	0.1145
32	28.206	0.0355	247.324	0.0040	8.7686	0.1140
33	31.308	0.0319	275.529	0.0036	8.8005	0.1136
34	34.752	0.0288	306.837	0.0033	8.8293	0.1133
35	38.575	0.0259	341.590	0.0029	8.8552	0.1129
36	42.818	0.0234	380.164	0.0026	8.8786	0.1126
37	47.528	0.0210	422.982	0.0024	8.8996	0.1124
38	52.756	0.0190	470.511	0.0021	8.9186	0.1121
39	58.559	0.0171	523.267	0.0019	8.9357	0.1119
40	65.001	0.0154	581.826	0.0017	8.9511	0.1117
41	72.151	0.0139	646.827	0.0015	8.9649	0.1115
42	80.088	0.0125	718.978	0.0014	8.9774	0.1114
43	88.897	0.0112	799.065	0.0013	8.9886	0.1113
44	98.676	0.0101	887.963	0.0011	8.9988	0.1111
45	109.530	0.0091	986.639	0.0010	9.0079	0.1110
46	121.579	0.0082	1096.169	0.0009	9.0161	0.1109
47	134.952	0.0074	1217.747	0.0008	9.0235	0.1108
48	149.797	0.0067	1352.700	0.0007	9.0302	0.1107
49	166.275	0.0060	1502.497	0.0007	9.0362	0.1107
50	184.565	0.0054	1668.771	0.0006	9.0417	0.1106

12% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT COMPOUND AMOUNT FACTOR	SINGLE PAYMENT PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES SINKING FUND FACTOR	EQUAL PAYMENT SERIES PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES CAPITAL RECOVERY FACTOR
1	1.120	0.8929	1.000	1.0000	0.8929	1.1200
2	1.254	0.7972	2.120	0.4717	1.6901	0.5917
3	1.405	0.7118	3.374	0.2963	2.4018	0.4163
4	1.574	0.6355	4.779	0.2092	3.0373	0.3292
5	1.762	0.5674	6.353	0.1574	3.6048	0.2774
6	1.974	0.5066	8.115	0.1232	4.1114	0.2432
7	2.211	0.4523	10.089	0.0991	4.5638	0.2191
8	2.476	0.4039	12.300	0.0813	4.9676	0.2013
9	2.773	0.3606	14.776	0.0677	5.3282	0.1877
10	3.106	0.3220	17.549	0.0570	5.6502	0.1770
11	3.479	0.2875	20.655	0.0484	5.9377	0.1684
12	3.896	0.2567	24.133	0.0414	6.1944	0.1614
13	4.363	0.2292	28.029	0.0357	6.4235	0.1557
14	4.887	0.2046	32.393	0.0309	6.6282	0.1509
15	5.474	0.1827	37.280	0.0268	6.8109	0.1468
16	6.130	0.1631	42.753	0.0234	6.9740	0.1434
17	6.866	0.1456	48.884	0.0205	7.1196	0.1405
18	7.690	0.1300	55.750	0.0179	7.2497	0.1379
19	8.613	0.1161	63.440	0.0158	7.3658	0.1358
20	9.646	0.1037	72.052	0.0139	7.4694	0.1339
21	10.804	0.0926	81.699	0.0122	7.5620	0.1322
22	12.100	0.0826	92.503	0.0108	7.6446	0.1308
23	13.552	0.0738	104.603	0.0096	7.7184	0.1296
24	15.179	0.0659	118.155	0.0085	7.7843	0.1285
25	17.000	0.0588	133.334	0.0075	7.8431	0.1275
26	19.040	0.0525	150.334	0.0067	7.8957	0.1267
27	21.325	0.0469	169.374	0.0059	7.9426	0.1259
28	23.884	0.0419	190.699	0.0052	7.9844	0.1252
29	26.750	0.0374	214.583	0.0047	8.0218	0.1247
30	29.960	0.0334	241.333	0.0041	8.0552	0.1241
31	33.555	0.0298	271.293	0.0037	8.0850	0.1237
32	37.582	0.0266	304.848	0.0033	8.1116	0.1233
33	42.092	0.0238	342.429	0.0029	8.1354	0.1229
34	47.143	0.0212	384.521	0.0026	8.1566	0.1226
35	52.800	0.0189	431.663	0.0023	8.1755	0.1223
36	59.136	0.0169	484.463	0.0021	8.1924	0.1221
37	66.232	0.0151	543.599	0.0018	8.2075	0.1218
38	74.180	0.0135	609.831	0.0016	8.2210	0.1216
39	83.081	0.0120	684.010	0.0015	8.2330	0.1215
40	93.051	0.0107	767.091	0.0013	8.2438	0.1213
41	104.217	0.0096	860.142	0.0012	8.2534	0.1212
42	116.723	0.0086	964.359	0.0010	8.2619	0.1210
43	130.730	0.0076	1081.083	0.0009	8.2696	0.1209
44	146.418	0.0068	1211.813	0.0008	8.2764	0.1208
45	163.988	0.0061	1358.230	0.0007	8.2825	0.1207
46	183.666	0.0054	1522.218	0.0007	8.2880	0.1207
47	205.706	0.0049	1705.884	0.0006	8.2928	0.1206
48	230.391	0.0043	1911.590	0.0005	8.2972	0.1205
49	258.038	0.0039	2141.981	0.0005	8.3010	0.1205
50	289.002	0.0035	2400.018	0.0004	8.3045	0.1204

13% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT COMPOUND AMOUNT FACTOR	SINGLE PAYMENT PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES SINKING FUND FACTOR	EQUAL PAYMENT SERIES PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES CAPITAL RECOVERY FACTOR
1	1.130	0.8850	1.000	1.0000	0.8850	1.1300
2	1.277	0.7831	2.130	0.4695	1.6681	0.5995
3	1.443	0.6931	3.407	0.2935	2.3612	0.4235
4	1.630	0.6133	4.850	0.2062	2.9745	0.3362
5	1.842	0.5428	6.480	0.1543	3.5172	0.2843
6	2.082	0.4803	8.323	0.1202	3.9975	0.2502
7	2.353	0.4251	10.405	0.0961	4.4226	0.2261
8	2.658	0.3762	12.757	0.0784	4.7988	0.2084
9	3.004	0.3329	15.416	0.0649	5.1317	0.1949
10	3.395	0.2946	18.420	0.0543	5.4262	0.1843
11	3.836	0.2607	21.814	0.0458	5.6869	0.1758
12	4.335	0.2307	25.650	0.0390	5.9176	0.1690
13	4.898	0.2042	29.985	0.0334	6.1218	0.1634
14	5.535	0.1807	34.883	0.0287	6.3025	0.1587
15	6.254	0.1599	40.417	0.0247	6.4624	0.1547
16	7.067	0.1415	46.672	0.0214	6.6039	0.1514
17	7.986	0.1252	53.739	0.0186	6.7291	0.1486
18	9.024	0.1108	61.725	0.0162	6.8399	0.1462
19	10.197	0.0981	70.749	0.0141	6.9380	0.1441
20	11.523	0.0868	80.947	0.0124	7.0248	0.1424
21	13.021	0.0768	92.470	0.0108	7.1016	0.1408
22	14.714	0.0680	105.491	0.0095	7.1695	0.1395
23	16.627	0.0601	120.205	0.0083	7.2297	0.1383
24	18.788	0.0532	136.831	0.0073	7.2829	0.1373
25	21.231	0.0471	155.620	0.0064	7.3300	0.1364
26	23.991	0.0417	176.850	0.0057	7.3717	0.1357
27	27.109	0.0369	200.841	0.0050	7.4086	0.1350
28	30.633	0.0326	227.950	0.0044	7.4412	0.1344
29	34.616	0.0289	258.583	0.0039	7.4701	0.1339
30	39.116	0.0256	293.199	0.0034	7.4957	0.1334
31	44.201	0.0226	332.315	0.0030	7.5183	0.1330
32	49.947	0.0200	376.516	0.0027	7.5383	0.1327
33	56.440	0.0177	426.463	0.0023	7.5560	0.1323
34	63.777	0.0157	482.903	0.0021	7.5717	0.1321
35	72.069	0.0139	546.681	0.0018	7.5856	0.1318
36	81.437	0.0123	618.749	0.0016	7.5979	0.1316
37	92.024	0.0109	700.187	0.0014	7.6087	0.1314
38	103.987	0.0096	792.211	0.0013	7.6183	0.1313
39	117.506	0.0085	896.198	0.0011	7.6268	0.1311
40	132.782	0.0075	1013.704	0.0010	7.6344	0.1310
41	150.043	0.0067	1146.486	0.0009	7.6410	0.1309
42	169.549	0.0059	1296.529	0.0008	7.6469	0.1308
43	191.590	0.0052	1466.078	0.0007	7.6522	0.1307
44	216.497	0.0046	1657.668	0.0006	7.6568	0.1306
45	244.641	0.0041	1874.165	0.0005	7.6609	0.1305
46	276.445	0.0036	2118.806	0.0005	7.6645	0.1305
47	312.383	0.0032	2395.251	0.0004	7.6677	0.1304
48	352.992	0.0028	2707.633	0.0004	7.6705	0.1304
49	398.881	0.0025	3060.626	0.0003	7.6730	0.1303
50	450.736	0.0022	3459.507	0.0003	7.6752	0.1303

14% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR	SINGLE PAYMENT: PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES: COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES: SINKING FUND FACTOR	EQUAL PAYMENT SERIES: PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES: CAPITAL RECOVERY FACTOR
1	1.140	0.8772	1.000	1.0000	0.8772	1.1400
2	1.300	0.7695	2.140	0.4673	1.6467	0.6073
3	1.482	0.6750	3.440	0.2907	2.3216	0.4307
4	1.689	0.5921	4.921	0.2032	2.9137	0.3432
5	1.925	0.5194	6.610	0.1513	3.4331	0.2913
6	2.195	0.4556	8.536	0.1172	3.8887	0.2572
7	2.502	0.3996	10.730	0.0932	4.2883	0.2332
8	2.853	0.3506	13.233	0.0756	4.6389	0.2156
9	3.252	0.3075	16.085	0.0622	4.9464	0.2022
10	3.707	0.2697	19.337	0.0517	5.2161	0.1917
11	4.226	0.2366	23.045	0.0434	5.4527	0.1834
12	4.818	0.2076	27.271	0.0367	5.6603	0.1767
13	5.492	0.1821	32.089	0.0312	5.8424	0.1712
14	6.261	0.1597	37.581	0.0266	6.0021	0.1666
15	7.138	0.1401	43.842	0.0228	6.1422	0.1628
16	8.137	0.1229	50.980	0.0196	6.2651	0.1596
17	9.276	0.1078	59.118	0.0169	6.3729	0.1569
18	10.575	0.0946	68.394	0.0146	6.4674	0.1546
19	12.056	0.0829	78.969	0.0127	6.5504	0.1527
20	13.743	0.0728	91.025	0.0110	6.6231	0.1510
21	15.668	0.0638	104.768	0.0095	6.6870	0.1495
22	17.861	0.0560	120.436	0.0083	6.7429	0.1483
23	20.362	0.0491	138.297	0.0072	6.7921	0.1472
24	23.212	0.0431	158.659	0.0063	6.8351	0.1463
25	26.462	0.0378	181.871	0.0055	6.8729	0.1455
26	30.167	0.0331	208.333	0.0048	6.9061	0.1448
27	34.390	0.0291	238.499	0.0042	6.9352	0.1442
28	39.204	0.0255	272.889	0.0037	6.9607	0.1437
29	44.693	0.0224	312.094	0.0032	6.9830	0.1432
30	50.950	0.0196	356.787	0.0028	7.0027	0.1428
31	58.083	0.0172	407.737	0.0025	7.0199	0.1425
32	66.215	0.0151	465.820	0.0021	7.0350	0.1421
33	75.485	0.0132	532.035	0.0019	7.0482	0.1419
34	86.053	0.0116	607.520	0.0016	7.0599	0.1416
35	98.100	0.0102	693.573	0.0014	7.0700	0.1414
36	111.834	0.0089	791.673	0.0013	7.0790	0.1413
37	127.491	0.0078	903.507	0.0011	7.0868	0.1411
38	145.340	0.0069	1030.998	0.0010	7.0937	0.1410
39	165.687	0.0060	1176.338	0.0009	7.0997	0.1409
40	188.884	0.0053	1342.025	0.0007	7.1050	0.1407
41	215.327	0.0046	1530.909	0.0007	7.1097	0.1407
42	245.473	0.0041	1746.236	0.0006	7.1138	0.1406
43	279.839	0.0036	1991.709	0.0005	7.1173	0.1405
44	319.017	0.0031	2271.548	0.0004	7.1205	0.1404
45	363.679	0.0027	2590.565	0.0004	7.1232	0.1404
46	414.594	0.0024	2954.244	0.0003	7.1256	0.1403
47	472.637	0.0021	3368.838	0.0003	7.1277	0.1403
48	538.807	0.0019	3841.475	0.0003	7.1296	0.1403
49	614.239	0.0016	4380.282	0.0002	7.1312	0.1402
50	700.233	0.0014	4994.521	0.0002	7.1327	0.1402

15% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT COMPOUND AMOUNT FACTOR	SINGLE PAYMENT PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.150	0.8696	1.000	1.0000	0.8696	1.1500
2	1.323	0.7561	2.150	0.4651	1.6257	0.6151
3	1.521	0.6575	3.473	0.2880	2.2832	0.4380
4	1.749	0.5718	4.993	0.2003	2.8550	0.3503
5	2.011	0.4972	6.742	0.1483	3.3522	0.2983
6	2.313	0.4323	8.754	0.1142	3.7845	0.2642
7	2.660	0.3759	11.067	0.0904	4.1604	0.2404
8	3.059	0.3269	13.727	0.0729	4.4873	0.2229
9	3.518	0.2843	16.786	0.0596	4.7716	0.2096
10	4.046	0.2472	20.304	0.0493	5.0188	0.1993
11	4.652	0.2149	24.349	0.0411	5.2337	0.1911
12	5.350	0.1869	29.002	0.0345	5.4206	0.1845
13	6.153	0.1625	34.352	0.0291	5.5831	0.1791
14	7.076	0.1413	40.505	0.0247	5.7245	0.1747
15	8.137	0.1229	47.580	0.0210	5.8474	0.1710
16	9.358	0.1069	55.717	0.0179	5.9542	0.1679
17	10.761	0.0929	65.075	0.0154	6.0472	0.1654
18	12.375	0.0808	75.836	0.0132	6.1280	0.1632
19	14.232	0.0703	88.212	0.0113	6.1982	0.1613
20	16.367	0.0611	102.444	0.0098	6.2593	0.1598
21	18.822	0.0531	118.810	0.0084	6.3125	0.1584
22	21.645	0.0462	137.632	0.0073	6.3587	0.1573
23	24.891	0.0402	159.276	0.0063	6.3988	0.1563
24	28.625	0.0349	184.168	0.0054	6.4338	0.1554
25	32.919	0.0304	212.793	0.0047	6.4641	0.1547
26	37.857	0.0264	245.712	0.0041	6.4906	0.1541
27	43.535	0.0230	283.569	0.0035	6.5135	0.1535
28	50.066	0.0200	327.104	0.0031	6.5335	0.1531
29	57.575	0.0174	377.170	0.0027	6.5509	0.1527
30	66.212	0.0151	434.745	0.0023	6.5660	0.1523
31	76.144	0.0131	500.957	0.0020	6.5791	0.1520
32	87.565	0.0114	577.100	0.0017	6.5905	0.1517
33	100.700	0.0099	664.666	0.0015	6.6005	0.1515
34	115.805	0.0086	765.365	0.0013	6.6091	0.1513
35	133.176	0.0075	881.170	0.0011	6.6166	0.1511
36	153.152	0.0065	1014.346	0.0010	6.6231	0.1510
37	176.125	0.0057	1167.498	0.0009	6.6288	0.1509
38	202.543	0.0049	1343.622	0.0007	6.6338	0.1507
39	232.925	0.0043	1546.165	0.0006	6.6380	0.1506
40	267.864	0.0037	1779.090	0.0006	6.6418	0.1506
41	308.043	0.0032	2046.954	0.0005	6.6450	0.1505
42	354.250	0.0028	2354.997	0.0004	6.6478	0.1504
43	407.387	0.0025	2709.246	0.0004	6.6503	0.1504
44	468.495	0.0021	3116.633	0.0003	6.6524	0.1503
45	538.769	0.0019	3585.128	0.0003	6.6543	0.1503
46	619.585	0.0016	4123.898	0.0002	6.6559	0.1502
47	712.522	0.0014	4743.482	0.0002	6.6573	0.1502
48	819.401	0.0012	5456.005	0.0002	6.6585	0.1502
49	942.311	0.0011	6275.405	0.0002	6.6596	0.1502
50	1083.657	0.0009	7217.716	0.0001	6.6605	0.1501

16%.INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT COMPOUND AMOUNT FACTOR	SINGLE PAYMENT PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.160	0.8621	1.000	1.0000	0.8621	1.1600
2	1.346	0.7432	2.160	0.4630	1.6052	0.6230
3	1.561	0.6407	3.506	0.2853	2.2459	0.4453
4	1.811	0.5523	5.066	0.1974	2.7982	0.3574
5	2.100	0.4761	6.877	0.1454	3.2743	0.3054
6	2.436	0.4104	8.977	0.1114	3.6847	0.2714
7	2.826	0.3538	11.414	0.0876	4.0386	0.2476
8	3.278	0.3050	14.240	0.0702	4.3436	0.2302
9	3.803	0.2630	17.519	0.0571	4.6065	0.2171
10	4.411	0.2267	21.321	0.0469	4.8332	0.2069
11	5.117	0.1954	25.733	0.0389	5.0286	0.1989
12	5.936	0.1685	30.850	0.0324	5.1971	0.1924
13	6.886	0.1452	36.786	0.0272	5.3423	0.1872
14	7.988	0.1252	43.672	0.0229	5.4675	0.1829
15	9.266	0.1079	51.660	0.0194	5.5755	0.1794
16	10.748	0.0930	60.925	0.0164	5.6685	0.1764
17	12.468	0.0802	71.673	0.0140	5.7487	0.1740
18	14.463	0.0691	84.141	0.0119	5.8178	0.1719
19	16.777	0.0596	98.603	0.0101	5.8775	0.1701
20	19.461	0.0514	115.380	0.0087	5.9288	0.1687
21	22.574	0.0443	134.841	0.0074	5.9731	0.1674
22	26.186	0.0382	157.415	0.0064	6.0113	0.1664
23	30.376	0.0329	183.601	0.0054	6.0442	0.1654
24	35.236	0.0284	213.978	0.0047	6.0726	0.1647
25	40.874	0.0245	249.214	0.0040	6.0971	0.1640
26	47.414	0.0211	290.088	0.0034	6.1182	0.1634
27	55.000	0.0182	337.502	0.0030	6.1364	0.1630
28	63.800	0.0157	392.503	0.0025	6.1520	0.1625
29	74.009	0.0135	456.303	0.0022	6.1656	0.1622
30	85.850	0.0116	530.312	0.0019	6.1772	0.1619
31	99.586	0.0100	616.162	0.0016	6.1872	0.1616
32	115.520	0.0087	715.747	0.0014	6.1959	0.1614
33	134.003	0.0075	831.267	0.0012	6.2034	0.1612
34	155.443	0.0064	965.270	0.0010	6.2098	0.1610
35	180.314	0.0055	1120.713	0.0009	6.2153	0.1609
36	209.164	0.0048	1301.027	0.0008	6.2201	0.1608
37	242.631	0.0041	1510.191	0.0007	6.2242	0.1607
38	281.452	0.0036	1752.822	0.0006	6.2278	0.1606
39	326.484	0.0031	2034.273	0.0005	6.2309	0.1605
40	378.721	0.0026	2360.757	0.0004	6.2335	0.1604
41	439.317	0.0023	2739.478	0.0004	6.2358	0.1604
42	509.607	0.0020	3178.795	0.0003	6.2377	0.1603
43	591.144	0.0017	3688.402	0.0003	6.2394	0.1603
44	685.727	0.0015	4279.546	0.0002	6.2409	0.1602
45	795.444	0.0013	4965.274	0.0002	6.2421	0.1602
46	922.715	0.0011	5760.718	0.0002	6.2432	0.1602
47	1070.349	0.0009	6683.433	0.0001	6.2442	0.1601
48	1241.605	0.0008	7753.782	0.0001	6.2450	0.1601
49	1440.262	0.0007	8995.387	0.0001	6.2457	0.1601
50	1670.704	0.0006	10435.649	0.0001	6.2463	0.1601

17% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

	SINGLE PAYMENT		EQUAL PAYMENT SERIES			
YEAR	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.170	0.8547	1.000	1.0000	0.8547	1.1700
2	1.369	0.7305	2.170	0.4608	1.5852	0.6308
3	1.602	0.6244	3.539	0.2826	2.2096	0.4526
4	1.874	0.5337	5.141	0.1945	2.7432	0.3645
5	2.192	0.4561	7.014	0.1426	3.1993	0.3126
6	2.565	0.3898	9.207	0.1086	3.5892	0.2786
7	3.001	0.3332	11.772	0.0849	3.9224	0.2549
8	3.511	0.2848	14.773	0.0677	4.2072	0.2377
9	4.108	0.2434	18.285	0.0547	4.4506	0.2247
10	4.807	0.2080	22.393	0.0447	4.6586	0.2147
11	5.624	0.1778	27.200	0.0368	4.8364	0.2068
12	6.580	0.1520	32.824	0.0305	4.9884	0.2005
13	7.699	0.1299	39.404	0.0254	5.1183	0.1954
14	9.007	0.1110	47.103	0.0212	5.2293	0.1912
15	10.539	0.0949	56.110	0.0178	5.3242	0.1878
16	12.330	0.0811	66.649	0.0150	5.4053	0.1850
17	14.426	0.0693	78.979	0.0127	5.4746	0.1827
18	16.879	0.0592	93.406	0.0107	5.5339	0.1807
19	19.748	0.0506	110.285	0.0091	5.5845	0.1791
20	23.106	0.0433	130.033	0.0077	5.6278	0.1777
21	27.034	0.0370	153.139	0.0065	5.6648	0.1765
22	31.629	0.0316	180.172	0.0056	5.6964	0.1756
23	37.006	0.0270	211.801	0.0047	5.7234	0.1747
24	43.297	0.0231	248.808	0.0040	5.7465	0.1740
25	50.658	0.0197	292.105	0.0034	5.7662	0.1734
26	59.270	0.0169	342.763	0.0029	5.7831	0.1729
27	69.345	0.0144	402.032	0.0025	5.7975	0.1725
28	81.134	0.0123	471.378	0.0021	5.8099	0.1721
29	94.927	0.0105	552.512	0.0018	5.8204	0.1718
30	111.065	0.0090	647.439	0.0015	5.8294	0.1715
31	129.946	0.0077	758.504	0.0013	5.8371	0.1713
32	152.036	0.0066	888.449	0.0011	5.8437	0.1711
33	177.883	0.0056	1040.486	0.0010	5.8493	0.1710
34	208.123	0.0048	1218.368	0.0008	5.8541	0.1708
35	243.503	0.0041	1426.491	0.0007	5.8582	0.1707
36	284.899	0.0035	1669.994	0.0006	5.8617	0.1706
37	333.332	0.0030	1954.894	0.0005	5.8647	0.1705
38	389.998	0.0026	2288.225	0.0004	5.8673	0.1704
39	456.298	0.0022	2678.224	0.0004	5.8695	0.1704
40	533.869	0.0019	3134.522	0.0003	5.8713	0.1703
41	624.626	0.0016	3668.391	0.0003	5.8729	0.1703
42	730.813	0.0014	4293.017	0.0002	5.8743	0.1702
43	855.051	0.0012	5023.830	0.0002	5.8755	0.1702
44	1000.410	0.0010	5878.881	0.0002	5.8765	0.1702
45	1170.479	0.0009	6879.291	0.0001	5.8773	0.1701
46	1369.461	0.0007	8049.770	0.0001	5.8781	0.1701
47	1602.269	0.0006	9419.231	0.0001	5.8787	0.1701
48	1874.655	0.0005	11021.500	0.0001	5.8792	0.1701
49	2193.346	0.0005	12896.155	0.0001	5.8797	0.1701
50	2566.215	0.0004	15089.502	0.0001	5.8801	0.1701

18%. INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT COMPOUND AMOUNT FACTOR	SINGLE PAYMENT PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES SINKING FUND FACTOR	EQUAL PAYMENT SERIES PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES CAPITAL RECOVERY FACTOR
1	1.180	0.8475	1.000	1.0000	0.8475	1.1800
2	1.392	0.7182	2.180	0.4587	1.5656	0.6387
3	1.643	0.6086	3.572	0.2799	2.1743	0.4599
4	1.939	0.5158	5.215	0.1917	2.6901	0.3717
5	2.288	0.4371	7.154	0.1398	3.1272	0.3198
6	2.700	0.3704	9.442	0.1059	3.4976	0.2859
7	3.185	0.3139	12.142	0.0824	3.8115	0.2624
8	3.759	0.2660	15.327	0.0652	4.0776	0.2452
9	4.435	0.2255	19.086	0.0524	4.3030	0.2324
10	5.234	0.1911	23.521	0.0425	4.4941	0.2225
11	6.176	0.1619	28.755	0.0348	4.6560	0.2148
12	7.288	0.1372	34.931	0.0286	4.7932	0.2086
13	8.599	0.1163	42.219	0.0237	4.9095	0.2037
14	10.147	0.0985	50.818	0.0197	5.0081	0.1997
15	11.974	0.0835	60.965	0.0164	5.0916	0.1964
16	14.129	0.0708	72.939	0.0137	5.1624	0.1937
17	16.672	0.0600	87.068	0.0115	5.2223	0.1915
18	19.673	0.0508	103.740	0.0096	5.2732	0.1896
19	23.214	0.0431	123.414	0.0081	5.3162	0.1881
20	27.393	0.0365	146.628	0.0068	5.3527	0.1868
21	32.324	0.0309	174.021	0.0057	5.3837	0.1857
22	38.142	0.0262	206.345	0.0048	5.4099	0.1848
23	45.008	0.0222	244.487	0.0041	5.4321	0.1841
24	53.109	0.0188	289.494	0.0035	5.4509	0.1835
25	62.669	0.0160	342.603	0.0029	5.4669	0.1829
26	73.949	0.0135	405.272	0.0025	5.4804	0.1825
27	87.260	0.0115	479.221	0.0021	5.4919	0.1821
28	102.967	0.0097	566.481	0.0018	5.5016	0.1818
29	121.501	0.0082	669.447	0.0015	5.5098	0.1815
30	143.371	0.0070	790.948	0.0013	5.5168	0.1813
31	169.177	0.0059	934.319	0.0011	5.5227	0.1811
32	199.629	0.0050	1103.496	0.0009	5.5277	0.1809
33	235.563	0.0042	1303.125	0.0008	5.5320	0.1808
34	277.964	0.0036	1538.688	0.0006	5.5356	0.1806
35	327.997	0.0030	1816.652	0.0006	5.5386	0.1806
36	387.037	0.0026	2144.649	0.0005	5.5412	0.1805
37	456.703	0.0022	2531.686	0.0004	5.5434	0.1804
38	538.910	0.0019	2988.389	0.0003	5.5452	0.1803
39	635.914	0.0016	3527.299	0.0003	5.5468	0.1803
40	750.378	0.0013	4163.213	0.0002	5.5482	0.1802
41	885.446	0.0011	4913.591	0.0002	5.5493	0.1802
42	1044.827	0.0010	5799.038	0.0002	5.5502	0.1802
43	1232.896	0.0008	6843.865	0.0001	5.5510	0.1801
44	1454.817	0.0007	8076.760	0.0001	5.5517	0.1801
45	1716.684	0.0006	9531.577	0.0001	5.5523	0.1801
46	2025.687	0.0005	11248.261	0.0001	5.5528	0.1801
47	2390.311	0.0004	13273.948	0.0001	5.5532	0.1801
48	2820.567	0.0004	15664.259	0.0001	5.5536	0.1801
49	3328.269	0.0003	18484.825	0.0001	5.5539	0.1801
50	3927.357	0.0003	21813.094	0.0000	5.5541	0.1800

19% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT COMPOUND AMOUNT FACTOR	SINGLE PAYMENT PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.190	0.8403	1.000	1.0000	0.8403	1.1900
2	1.416	0.7062	2.190	0.4566	1.5465	0.6466
3	1.685	0.5934	3.606	0.2773	2.1399	0.4673
4	2.005	0.4987	5.291	0.1890	2.6386	0.3790
5	2.386	0.4190	7.297	0.1371	3.0576	0.3271
6	2.840	0.3521	9.683	0.1033	3.4098	0.2933
7	3.379	0.2959	12.523	0.0799	3.7057	0.2699
8	4.021	0.2487	15.902	0.0629	3.9544	0.2529
9	4.785	0.2090	19.923	0.0502	4.1633	0.2402
10	5.695	0.1756	24.709	0.0405	4.3389	0.2305
11	6.777	0.1476	30.404	0.0329	4.4865	0.2229
12	8.064	0.1240	37.180	0.0269	4.6105	0.2169
13	9.596	0.1042	45.244	0.0221	4.7147	0.2121
14	11.420	0.0876	54.841	0.0182	4.8023	0.2082
15	13.590	0.0736	66.261	0.0151	4.8759	0.2051
16	16.172	0.0618	79.850	0.0125	4.9377	0.2025
17	19.244	0.0520	96.022	0.0104	4.9897	0.2004
18	22.901	0.0437	115.266	0.0087	5.0333	0.1987
19	27.252	0.0367	138.166	0.0072	5.0700	0.1972
20	32.429	0.0308	165.418	0.0060	5.1009	0.1960
21	38.591	0.0259	197.847	0.0051	5.1268	0.1951
22	45.923	0.0218	236.438	0.0042	5.1486	0.1942
23	54.649	0.0183	282.362	0.0035	5.1668	0.1935
24	65.032	0.0154	337.010	0.0030	5.1822	0.1930
25	77.388	0.0129	402.042	0.0025	5.1951	0.1925
26	92.092	0.0109	479.431	0.0021	5.2060	0.1921
27	109.589	0.0091	571.522	0.0017	5.2151	0.1917
28	130.411	0.0077	681.112	0.0015	5.2228	0.1915
29	155.189	0.0064	811.523	0.0012	5.2292	0.1912
30	184.675	0.0054	966.712	0.0010	5.2347	0.1910
31	219.764	0.0046	1151.387	0.0009	5.2392	0.1909
32	261.519	0.0038	1371.151	0.0007	5.2430	0.1907
33	311.207	0.0032	1632.670	0.0006	5.2462	0.1906
34	370.337	0.0027	1943.877	0.0005	5.2489	0.1905
35	440.701	0.0023	2314.214	0.0004	5.2512	0.1904
36	524.434	0.0019	2754.914	0.0004	5.2531	0.1904
37	624.076	0.0016	3279.348	0.0003	5.2547	0.1903
38	742.651	0.0013	3903.424	0.0003	5.2561	0.1903
39	883.754	0.0011	4646.075	0.0002	5.2572	0.1902
40	1051.668	0.0010	5529.829	0.0002	5.2582	0.1902
41	1251.484	0.0008	6581.496	0.0002	5.2590	0.1902
42	1489.266	0.0007	7832.981	0.0001	5.2596	0.1901
43	1772.227	0.0006	9322.247	0.0001	5.2602	0.1901
44	2108.950	0.0005	11094.474	0.0001	5.2607	0.1901
45	2509.651	0.0004	13203.424	0.0001	5.2611	0.1901
46	2986.484	0.0003	15713.075	0.0001	5.2614	0.1901
47	3553.916	0.0003	18699.559	0.0001	5.2617	0.1901
48	4229.160	0.0002	22253.475	0.0000	5.2619	0.1900
49	5032.701	0.0002	26482.636	0.0000	5.2621	0.1900
50	5988.914	0.0002	31515.336	0.0000	5.2623	0.1900

20% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

	SINGLE PAYMENT		EQUAL PAYMENT SERIES			
YEAR	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.200	0.8333	1.000	1.0000	0.8333	1.2000
2	1.440	0.6944	2.200	0.4545	1.5278	0.6545
3	1.728	0.5787	3.640	0.2747	2.1065	0.4747
4	2.074	0.4823	5.368	0.1863	2.5887	0.3863
5	2.488	0.4019	7.442	0.1344	2.9906	0.3344
6	2.986	0.3349	9.930	0.1007	3.3255	0.3007
7	3.583	0.2791	12.916	0.0774	3.6046	0.2774
8	4.300	0.2326	16.499	0.0606	3.8372	0.2606
9	5.160	0.1938	20.799	0.0481	4.0310	0.2481
10	6.192	0.1615	25.959	0.0385	4.1925	0.2385
11	7.430	0.1346	32.150	0.0311	4.3271	0.2311
12	8.916	0.1122	39.581	0.0253	4.4392	0.2253
13	10.699	0.0935	48.497	0.0206	4.5327	0.2206
14	12.839	0.0779	59.196	0.0169	4.6106	0.2169
15	15.407	0.0649	72.035	0.0139	4.6755	0.2139
16	18.488	0.0541	87.442	0.0114	4.7296	0.2114
17	22.186	0.0451	105.931	0.0094	4.7746	0.2094
18	26.623	0.0376	128.117	0.0078	4.8122	0.2078
19	31.948	0.0313	154.740	0.0065	4.8435	0.2065
20	38.338	0.0261	186.688	0.0054	4.8696	0.2054
21	46.005	0.0217	225.026	0.0044	4.8913	0.2044
22	55.206	0.0181	271.031	0.0037	4.9094	0.2037
23	66.247	0.0151	326.237	0.0031	4.9245	0.2031
24	79.497	0.0126	392.484	0.0025	4.9371	0.2025
25	95.396	0.0105	471.981	0.0021	4.9476	0.2021
26	114.475	0.0087	567.377	0.0018	4.9563	0.2018
27	137.371	0.0073	681.853	0.0015	4.9636	0.2015
28	164.845	0.0061	819.223	0.0012	4.9697	0.2012
29	197.814	0.0051	984.068	0.0010	4.9747	0.2010
30	237.376	0.0042	1181.882	0.0008	4.9789	0.2008
31	284.852	0.0035	1419.258	0.0007	4.9824	0.2007
32	341.822	0.0029	1704.109	0.0006	4.9854	0.2006
33	410.186	0.0024	2045.931	0.0005	4.9878	0.2005
34	492.224	0.0020	2456.118	0.0004	4.9898	0.2004
35	590.668	0.0017	2948.341	0.0003	4.9915	0.2003
36	708.802	0.0014	3539.009	0.0003	4.9929	0.2003
37	850.562	0.0012	4247.811	0.0002	4.9941	0.2002
38	1020.675	0.0010	5098.373	0.0002	4.9951	0.2002
39	1224.810	0.0008	6119.048	0.0002	4.9959	0.2002
40	1469.772	0.0007	7343.858	0.0001	4.9966	0.2001
41	1763.726	0.0006	8813.629	0.0001	4.9972	0.2001
42	2116.471	0.0005	10577.355	0.0001	4.9976	0.2001
43	2539.765	0.0004	12693.826	0.0001	4.9980	0.2001
44	3047.718	0.0003	15233.592	0.0001	4.9984	0.2001
45	3657.262	0.0003	18281.310	0.0001	4.9986	0.2001
46	4388.714	0.0002	21938.572	0.0000	4.9989	0.2000
47	5266.457	0.0002	26327.286	0.0000	4.9991	0.2000
48	6319.749	0.0002	31593.744	0.0000	4.9992	0.2000
49	7583.698	0.0001	37913.492	0.0000	4.9993	0.2000
50	9100.438	0.0001	45497.191	0.0000	4.9995	0.2000

TABLE E-2

SAFETY IMPROVEMENT PROJECT CODES, DESCRIPTIONS, AND SERVICE LIVES USED IN EFFECTIVENESS EVALUATION

Code	Description	Service Life (Years)
	Intersection Projects	
10	Channelization, left-turn bay	10
11	Traffic signals	10
12	Combination of 10 and 11	10
13	Sight distance improved	10
19	Other intersection, except structures	10
	Cross Section Projects	
20	Pavement widening, no lanes added	20
21	Lanes added without new median	20
22	Highway divided, new median added	20
23	Shoulder widening or improvement	20
24	Combination of 20-23	20
25	Skid treatment - grooving	10
26	Skid treatment - overlay	10
27	Flattening, clearing side slopes	20
29	Other cross section or combinations of 20-27	20
	Structures	
30	Widening bridge or major structure	20
31	Replace bridge or major structure	30
32	New bridge or major structure (except 34 and 51)	30
33	Minor structure	20
34	Pedestrian over- or under-crossing	30
39	Other structure	20
	Alignment Projects	
40	Horizontal alignment changes (except 52)	20
41	Vertical alignment changes	20
42	Combination of 40 and 41	20
49	Other alignment	20
	Railroad Grade Crossing Projects	
50	Flashing lights replacing signs	10
51	Elimination by new or reconstructed grade separation	30
52	Elimination by relocation of highway or railroad	30
53	Illumination	10
54	Flashing lights replacing active devices	10
55	Automatic gates replacing signs	10
56	Automatic gates replacing active devices	10
57	Signing, marking	10
58	Crossing surface improvement	10
59	Other RR grade crossing	10
5A	Any combination of 50, 53, 54, 55, 56, 57, 58	10
	Roadside Appurtenances	
60	Traffic signs	6
61	Breakaway sign or luminaire supports	10
62	Road edge guardrail	10
63	Median barrier	15
64	Markings, delineators	2
65	Lighting	15
66	Improve drainage structures	20
67	Fencing	10
68	Impact attenuators	10
69	Other roadside	10
6A	Combination of 60-64	10
6C	Combination of 60 and 62	8
6D	Combination of 60 and 64	4
	Other Safety Improvements	
90	Safety provisions for roadside features and appurtenances	20
99	All projects not otherwise classifiable	20

PROJECT PURPOSE LISTING

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by ____________________

Project No. ____________________

Project Description and Location(s) ____________________

Countermeasure(s)/Codes ____________________

Project Purpose	Justification
1.	1.

PROJECT SAMPLING WORKSHEET

Evaluation No. ______________________

Date/Evaluator ______________________ Checked by ______________________

Departure From Mean, Error= ______________________

Sample Size= __________ Sites

Site No.	Location	Total Accidents Xi	$(X_i - \mu)^2$
n_g=		ΣX_i = μ = σ =	$\Sigma (X_i - \mu)^2$ =

$$\mu = \frac{\Sigma X_i}{n_g} \qquad \sigma = \sqrt{\frac{\Sigma (X_i - \mu)^2}{n_g - 1}} \qquad n_s = \frac{4\ \sigma^2}{\text{Error}^2}$$

OBJECTIVE AND MOE LISTING

Evaluation No. ______________________

Date/Evaluator ______________________ Checked by ______________

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on: (fundamental)	Percent change in: (check one) Rate ________ or Frequency ________ (fundamental)
1. Total Accidents	1. Total Accidents/
2. Fatal Accidents	2. Fatal Accidents/
3. Injury Accidents	3. Injury Accidents/
4. PDO Accidents	4. PDO Accidents/
(project purpose)	(project purpose)
5.	5.

DATA REQUIREMENTS LISTING

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by ________________________

Experimental Plan ____

Data Needs	Magnitude (Number of Sites, Time Period, Dates)
1.	1.

ACCIDENT SUMMARY TABLE

Evaluation No. ______________________

Date/Evaluator ______________________ **Checked by** ______________

Data Source ______________________

Location ______________ Check one: [Project Site(s): Before ________ or After ______] [Control Site(s): Before ________ or After ______]

Time Period _____ **to** ______

Accident Category	Total Accidents	Fatal Acc.	Fatalities	Injury Acc.	Injuries	PDO Acc.	Invol.
Surface Condition							
Dry							
Wet							
Snowy/Icy							
Other							
Total							
Accident Type							
Overturn							
Collision with:							
Motor veh.							
Pedestrian							
Pedal cycle							
Animal							
Fixed Object							
Other							
Total							
Two Veh. Accidents							
Opposite Direction							
Same direction							
One Veh. stopped							
One Veh. entering ramp							
One Veh. exiting ramp							
Other							
Total							
Two Veh. Accident Types							
Head-on							
Rear-end							
Sideswipe							
Angle							
Other							
Total							

Acc. = Accidents

EXPOSURE WORKSHEET

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by: ______________

Data Source ____

Location ____

Time Period ______________ to ______________________

Check one: Project Site(s) Before ________ or After __________

Control Site(s) Before ________ or After __________

Site	Project* Length	Length of Time Period	AADT	Exposure Veh. ____ or Veh. Mi. ____
1.		1.	1.	
Total				

*For vehicle-mile units of exposure (only)

LINEAR REGRESSION WORKSHEET

Evaluation No. ______________________

Date/Evaluator ______________________ Checked by ________________

Check one: Frequency MOE _____ or Rate MOE _____

X_i Eval. Period (Yrs.) (1)	Y_i Meas. of MOE (2)	$X_i-\bar{X}$ Col. (1)-$\bar{X}$ (3)	$(X_i-\bar{X})^2$ $(\text{Col. (3)})^2$ (4)	$Y_i-\bar{Y}$ Col. (2)-$\bar{Y}$ (5)	$(X_i-\bar{X})(Y_i-\bar{Y})$ Col. Col. (3) X (5) (6)	X_i^2 $(\text{Col. (1)})^2$ (7)	Y_i^2 $(\text{Col. (2)})^2$ (8)	$X_i Y_i$ Col. Col. (1) X (2) (9)
$\Sigma =$ $\bar{X} =$	$\Sigma =$ $\bar{Y} =$		$\Sigma =$		$\Sigma =$	$\Sigma =$	$\Sigma =$	$\Sigma =$

MOE DATA COMPARISON WORKSHEET

Evaluation No. ______________________

Date/Evaluator ______________________ Checked by ____________

Experimental Plan ______________________________________

	Control		Project		Expected After Rate ___ or Freq. ___	Percent Reduction (%)
	Before	After	Before	After		
MOE Data Summary	(B_{CF})	(A_{CF})	(B_{PF})	(A_{PF})		
Accidents:						
(Fundamental)						
Total Accidents						
Fatal Accidents						
Injury Accidents						
PDO Accidents						
Exposure						
units: ___V, or ___VM						
MOE Comparison Rate ____ or Frequency ____	B_{C} _	A_{C} _	B_{P} _	A_{P} _	$\grave{E}$ _	(%)
Total Accidents/						
Fatal Accidents/						
Injury Accidents/						
PDO Accidents/						

STATISTICAL TEST WORKSHEET

Evaluation No. ____________________________

Date/Evaluator ____________ Checked by ____________________

Confidence Level __________ Statistical Test Technique ____________

Evaluation Objective	After Frequency ____ Years		Percent Reduction		Significant For ____ yrs(s)
	Observed (A_{PF})	Expected (E_F)	Observed	Required	(Yes or No)*
(Fundamental)					
Total Accidents					
Fatal Accidents					
Injury Accidents					
PDO Accidents					
(Project Purpose)					

* Too small to test

INTERMEDIATE OBJECTIVE
NON-ACCIDENT MOE LISTING

Evaluation No. ____________________

Date/Evaluator ____________________ Checked by ____________________

Evaluation Objective	Measure of Effectiveness (MOE)
Determine the effect of the project on:	Percent change in:
1.	1.
2.	2.
3.	3.
4.	4.

NON-ACCIDENT-BASED
MOE DATA COMPARISON WORKSHEET

Evaluation No. ______________________________

Date/Evaluator ______________________________ Checked by ____________

Experimental Plan ____

	Control		Project		Expected MOE	Percent Reduction
	Before	After	Before	After		
MOE	B_C	A_C	B_P	A_P	E	(%)

ADMINISTRATIVE ISSUES LISTING

Administrative Issues	Implementation Elements			
	SCHEDULING	DESIGN	CONSTRUCTION	REVIEW
MANPOWER CATEGORY List categories for which information is desired on the level of effort expended.				
ACTIVITIES List activities for which information is desired on the total cost of achieving the activity.				
TIME SCHEDULE List the major milestones for which information is desired on the start and completion dates.				
MATERIALS List material items for which information is desired on cost and quantity.				
PRODUCTIVITY List productivity measures to be evaluated.				
OTHER List other specific administrative issues to be evaluated.				

Project No. ______________
Evaluation No. ______________

__ Scheduling
__ Design
__ Construction
__ Op. Review

ADMINISTRATIVE DATA SUMMARY TABLE

MANPOWER

Category	Role	Manpower Involvement						Comments
		Planned		Actual		Differences		
		#Persons	Person Hrs.	#Persons	Person Hrs.	Hrs.	%	

ACTIVITY COSTS

Major Activity	Activity Costs		Differences		Comments
	Planned	Actual	$	%	

TIME SCHEDULE

Event or Milestone	Time Duration		Differences		Comments
	Planned	Actual	Time	%	

MATERIAL

Item	Material Requirements		Differences		Comments
	Planned	Actual	Amount	%	

PRODUCTIVITY

Input Measure	Output Measure	Ratio	Comments

COMMENTS

*U.S. GOVERNMENT PRINTING OFFICE : 1982 0-367-449/614