METHODS FOR EVALUATING
HIGHWAY SAFETY IMPROVEMENTS
TRANSPORTATION RESEARCH BOARD 1975

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TRANSPORTATION ADMINISTRATION
HIGHWAY SAFETY

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1975
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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Printed in the United States of America.
This report will be of interest to highway agency administrators and others charged with managing highway safety programs, as well as to technical staff personnel in safety and traffic engineering fields who are concerned with developing effective solutions to highway safety problems. The report is structured in two parts. The second part is a self-contained user-oriented manual that presents a comprehensive methodology for evaluating highway safety programs. The first part is a description of the research procedures that led to the manual's development, supported by appendices that describe safety-related procedures employed by many highway organizations at the time this study was made. Together, the two parts meet a prime objective of the project, which was to produce a single-volume compendium of procedures that would eliminate the need for multiple reference sources of material pertinent to program evaluations.

Although procedures for evaluating the effectiveness of highway safety programs have been documented by a number of research reports, the methods recommended in these prior publications have not received wide application. Consequently, it seemed desirable to develop a synthesis of existing methodology and present it in a form both comprehensible to potential users and capable of implementation. Thus, this project was initiated to produce a single document for guiding technical staffs in appropriate procedures for program evaluation. Such guidance was to be designed so as to ensure that results gained by using the methodology would be implementable by the decision makers establishing priorities and budgets for future programs.

The research was undertaken by Roy Jorgensen and Associates. Their approach to the project was to develop an evaluation system after first making a review of current state and other public agency practices, then test the proposed methodology by having it reviewed by selected potential users, and finally refine the methodology as needed within the six-step framework of the manual that evolved.

The survey of practice revealed a broad range of sophistication in safety program development procedures and program evaluation. The recommended procedures presented in the manual reflect a middle ground, between both extremes. Although a principal value of the report appendices is to serve as a reference source for alternative procedures that may be preferred by some users, the manual can be used alone as the basis for developing a safety program evaluation system.
ACKNOWLEDGMENTS

The research reported herein was conducted by Roy Jorgensen Associates, Inc., with the University of Maryland and Washington University as subcontractors. The Principal Investigators for the project were John C. Laugnian, Planning and Safety Engineer, Roy Jorgensen Associates; Dr. Lonnie E. Haefer, Assistant Professor, Department of Civil Engineering, Washington University; and Dr. Jerome W. Hall, Associate Professor of Civil Engineering, University of Maryland. Dean R. Clough was Project Manager for Roy Jorgensen Associates. Others associated with the project included Ralph D. Johnson and Dr. Everett C. Carter, administrative officers for Roy Jorgensen Associates and the University of Maryland, respectively; Douglas A. Edwards and James R. Ball II, programmed-learning specialists, Roy Jorgensen Associates; Donald F. Park, management systems specialist, Roy Jorgensen Associates; Frederick K. Arzt, Jr., research assistant, University of Maryland; and Dr. Jerry T. Bigosinski, economic consultant.

Grateful acknowledgment also is made to the personnel of the many agencies that contributed to the study.
Highway safety program funding has increased significantly in the past few years, particularly since the Federal Highway Safety Act of 1966. In most cases, the administrative frameworks of highway agencies have not kept pace. NCHRP Project 17-2A was established (1) to review current highway safety improvement evaluation practices of highway agencies and evaluate the state of the art, and (2) to develop a model system for evaluation of highway safety improvements that is readily adaptable to installation in a typical highway agency.

A model system was developed to ensure that evaluations are made in their proper context and with the best information available. The model, diagrammed and discussed in Appendix Q, “Users’ Manual,” consists of six elements, as follows:

1. Identifying hazardous locations.
2. Selecting alternative improvements.
3. Evaluating alternative improvements.
4. Programming and implementing improvements.
5. Evaluating implemented improvements.
6. Evaluating the highway safety program.

A library search was initially conducted to identify the current highway safety improvement evaluation practices. In addition, a questionnaire was sent to 86 highway agencies to identify their current practices and any recently developed methods. The questionnaire, with a summary of the significant responses, is included in Appendix M.

All potentially applicable techniques were classified as basic, advanced, or complementary. The basic techniques were analyzed in order to determine which should be included in the Users’ Manual. In the case of duplicate techniques—different methods that achieve identical results—the simpler or more commonly used technique is included in the Users’ Manual. The alternative basic techniques, as well as the advanced and complementary techniques, can be found in the appendices to this report.

The Users’ Manual was field tested in selected highway safety agencies to ensure its usefulness and readability.

Further research is needed to develop a data base from which estimates of improvement performance can be made. Development of a national data base was begun in 1966 with the publication of Evaluation of Criteria for Safety Improvements on the Highway by Jorgensen and Westat (136). These data are presented in Appendix A of the Users’ Manual. More recent data from Mississippi and California are also presented as the basis by which individual agencies may develop their own forecasts.

There is a need for an updated national data base which will greatly aid highway safety agencies.
CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT

The problem statement for NCHRP Project 17-2A expressed the specifics of the study as follows:

Methodology for measuring the effectiveness of potential safety improvements has been established. This methodology includes statistical design and analysis for parallel and before-and-after studies. In addition, cost-benefit methodology has been documented in the research literature. However, in terms appropriate to engineers and technicians who actually do the studies, there apparently does not exist a single document that contains the techniques for applying all aspects of the above-mentioned analytical tools.

The objective of the research is to provide a detailed technique in the form of guidelines, from which calculations can be made, that will allow officials to judge the effectiveness of highway improvements in terms not only of reduced accidents but also of the cost-benefits of such improvements.

The objective has two parts: (1) provide a document to be used by "doers" to guide them in collecting data, selecting the appropriate analysis method, and making calculations; and (2) ensure that the information generated by the "doers" is directly responsive to the needs of the "users," who make decisions on future capital improvement projects (budgets) and who establish priorities among alternatives.

This report is a response to the need for a compilation of all the techniques for applying existing methodology in order to obtain measurements of the effectiveness of safety improvements. It documents the background, research, and logic used to evaluate the state of the art of effectiveness measurements. The report also contains a complete methodology for evaluating the effectiveness of highway safety improvements and increasing the objectivity in highway safety programming.

Appendices A through P include detailed descriptions of methods, a summary of survey results, tables, and a bibliography. Appendix Q is a practicable user-oriented guide organized as a highway safety management system. The guide is a collection of diverse evaluation techniques described either in published reports or in responses to a questionnaire circulated to highway departments and other selected agencies.

RESEARCH APPROACH

To achieve the objective, the research was divided into six tasks, as follows:

1. Review current state of the art. Libraries were used widely in order to determine current practices in evaluating improvements. Libraries at Jorgensen, the University of Maryland, and the U.S. Department of Transportation, and the Library of Congress were major sources of research material. A questionnaire was sent to 86 highway agencies to determine their current practices and to learn of newly developed methodologies that may be in use, but whose development may not have been publicized. Appendix M includes the questionnaire and a summary of significant responses.

2. Determine deficiencies. Questionnaire responses and library materials were reviewed to determine organizational, technical, and informational deficiencies. These deficiencies are described in Chapter Two.

3. Develop methodology. The techniques identified in Task 1 and those previously developed by the research team were used to design a highway safety evaluation system. Alternative techniques and procedures were evaluated. Those methods determined most appropriate and effective were chosen for inclusion in the Users' Guide. If two or more methods are equally appropriate, the attributes of both are discussed and the selection is left to the user. Methods not included in the Users' Guide are presented in the other appendices.

4. Field testing. A field test method was developed to measure how well the typical user could implement the highway safety evaluation system using his own resources and without outside consultation. The field test consisted of three parts:

   a. A management review by middle- and top-level management.
   b. A procedural review by the individual—the analyst—most likely to be using the guide to analyze highway safety improvements.
   c. A management review by the analyst.

The management review was used to determine the adaptability of the system and system components to operations in the department. The procedural review consisted of solving four sample problems using sample data and the Users' Guide. The management review by the analyst was similar to the middle- and top-level management review but was intended to determine the perspective of the user. The results of these reviews are documented in Appendix N of this report.

5. Revision of the methodology. Based upon the findings of the field tests, the methods, descriptions, and procedures presented in the manual were modified principally to clarify the discussions and procedures.

6. Final report. The revised Users' Guide and the research report were completed and submitted to the NCHRP.
In this chapter, highway safety improvement evaluation methods are discussed in two main sections: under two major topics—highway safety in general and managing highway safety improvements. The first topic concerns the environment within which highway safety improvements take place. The second includes a description of a model management framework for carrying out highway safety improvements and a commentary on existing practices within surveyed agencies relative to the described framework.

HIGHWAY SAFETY IN GENERAL

The current highway safety environment problem is comprised of numerous aspects:

1. The highway safety problem is serious, but highway engineering deficiencies are only one part of the problem.
2. The magnitude of the highway safety problem is not clearly known, much less the contribution of each of the numerous factors of the problem.
3. Funding levels may not be related to problem size. Federal funding is small and partially earmarked for specific types of solutions.
4. Success is measured using average values computed from data that frequently are inadequate or incorrect.
5. The potential effectiveness of most improvements is not known. Estimates of effectiveness are based on average experience and, as a result, their reliability varies and is open to question.
6. Some states do not accept the highway safety theories that are held, promoted, and required by the Federal government.
7. Most agencies lack a definite long-range plan for solving the highway safety problem.
8. Knowledge of the accident "cause-and-effect" relationships is primitive.
9. There is a lack of feedback from implemented improvements of all types. Also, that many agencies do not use evaluation feedback when it is available is a fact.
10. Highway safety improvements are programmed independently of regular construction projects.
11. Some traffic engineers do not publish the results of improvements due to fear of public comment and political considerations.

Highway safety improvement programs are carried on in an environment that is not clearly in focus. A poorly defined problem, apparently insufficient funds, uncertain effectiveness, and lack of long-range safety planning contribute to making the picture fuzzy. Decision-making in this kind of environment tends to be risky at best.

Therefore, it is necessary to base decisions on the best available data and evaluations. A methodical management process using the techniques of statistical and economic analyses gives the decision maker maximum information from existing data. Through the evaluation of results, overall knowledge can be increased.

HIGHWAY SAFETY EVALUATIONS

Highway safety improvements must be evaluated twice—before implementation and after implementation. Each proposed improvement must first be identified and evaluated to assure that it has a high likelihood of reducing the number and/or the severity of accidents sufficiently to result in over-all economic benefits.

Following implementation, each improvement must be evaluated in order to compare actual effectiveness with predicted results. This post-implementation evaluation identifies actual benefits and provides an objective basis for forecasting benefits of future improvements.

The various types of evaluations are briefly described in the following.

Pre-Implementation Evaluations

Several different types of evaluations are needed before any specific improvement is actually implemented:

1. Hazardous location evaluation. The entire road or street system should be evaluated to identify locations that have hazardous characteristics. Normally this will be based on reported accident data. The purpose is to direct attention to sites that should be considered for safety improvements.
2. Potential improvements evaluation. At each site, analysis and evaluation of contributory causes will lead to identification of several potential improvements, any or all of which may alleviate the situation.
3. Accident reduction evaluation. Evaluation of the results of previous improvement efforts by the agency, or by others, will provide a basis for predicting the effect of a particular improvement in terms of reduced numbers of accidents or accident severity.
4. Alternative evaluations. Using data on costs of implemented improvements and on the estimated resulting benefits, economic evaluations will define which particular improvements should be implemented at a particular location.
5. Programming evaluations. Relative evaluations of costs and benefits at individual improvement locations will guide establishment of improvement priorities for current work programs.
Post-Implementation Evaluations

The effect of each implemented improvement should be evaluated periodically following implementation to identify:

1. The actual accident reduction and resulting benefits as compared to predicted benefits.
2. Incorrect assumptions regarding the accident cause-and-effect relationships.
3. Any unexpected side effects of the improvement.

MANAGING HIGHWAY SAFETY PROGRAMS

This research identified the following basic elements of a model highway safety evaluation system:

1. Identifying hazardous locations.
2. Selecting alternative improvements.
3. Evaluating alternative improvements.
4. Programming and implementing improvements.
5. Evaluating implemented improvements.
6. Evaluating the highway safety program.

Research findings relative to each of these elements are discussed.

Identifying Hazardous Locations

Almost all agencies currently rely principally on traffic accident data for identifying hazardous locations. This approach has been followed in the Users' Guide (Appendix Q) because it is relatively simple and generally accepted.

However, research has pointed out that accident histories take a long time to develop and much pain and suffering could be averted if a compatible method to predict the accident potential of a location in a shorter time could be developed. To this end, researchers have attempted to develop methods that do not rely on accident experience.

Several promising new methods are presented—not necessarily recommended—in Appendix B. Most of these methods are in the developmental stage, and, unless complete testing has been accomplished since this writing, the user is advised to conduct a pilot study before applying any of these methods on an agency-wide basis. For the present, results of these new methods should be compared with the hazardous location list resulting from the analysis of traffic accidents. These measurements can complement accident data.

The new methods are divided into two categories: (1) those oriented toward testing or measuring the roadway and (2) those oriented toward testing or measuring the drivers.

Methods oriented toward testing or measuring the roadway include:

1. Skid testing. To identify those locations that are slippery under either wet or dry conditions.
2. Hazard indicator reporting. To identify those locations or conditions contributing to the cause or severity of highway accidents.
3. Correlation of geometrics. To identify those circumstances that have a “cause-and-effect” relationship with traffic accidents.

4. Accident risk factor. To develop a risk factor that is a function of exposure to hazardous events, the consequences of a hazardous event, and the probability that the hazardous event will lead to adverse consequences.

5. Formula methods. To rate the accident potential of a hazard in the form of an index based on past accident experience, traffic volume, number of traffic lanes, etc.

6. Field observation. To view the highway as would a driver in an attempt to identify hazardous locations that might cause traffic accidents.

Methods oriented toward testing or measuring the driver's viewpoint and response are:

1. Conflict analysis. To identify those locations that have conflicting situations with a potential for accidents. Conflict data are also useful to identify the highway safety problems at hazardous locations.
2. Speed distribution skew. To identify hazardous locations by the way drivers adjust their speed at a given location. (Proposed by the 3M Company.)
3. Correlation of speed changes with accident rates. To identify hazardous locations by the mean number of absolute 4-mph speed changes. (Proposed by North Carolina State University.)
4. Accident rate vs. minimum safe headway. To identify as hazardous those locations where there is a large percentage of headways that are less than the minimum reaction headway.
5. Physiological response testing. To measure changes in physiological responses, such as heart rate and galvanic skin measurements, to various driving tasks. This method is based on the theory that as conflicts and driving tasks increase the potential hazard increases.

Deficiencies

The most common deficiency is the incompleteness, thus unreliability, of the information used to identify the hazardous locations, select improvements, and predict future accident rate.

It has been found that:

- A high percentage of accidents are not reported.
- Many accidents that are reported are not reported with a sufficient degree of accuracy.
- Seldom is there any statistical analysis of accident report data.

Studies made in Illinois, California, and metropolitan Washington, D.C., indicate that 16, 49, and 36 percent, respectively, of all accidents are reported. A more recent report of the U.S. Department of Transportation indicates that the percentage of total accidents reported for Illinois, California, and Mississippi is 36%, 81%, and 53%, respectively.

However, most of the unreported accidents were property damage only ("fender-benders") and, therefore, their inclusion adds little to the potential accident reduction benefits. Almost all of the few vital—fatal and serious injury—
accidents are reported. Therefore, if some of the many trivial—minor injury and property damage only—accidents are not reported, the system can still operate effectively.

The accuracy of accident location reporting is important although it is not often accurately obtained. For example, one state reported the following percentages of accuracy in accident reporting:

<table>
<thead>
<tr>
<th>REPORTING AGENCY</th>
<th>SAMPLE SIZE</th>
<th>PERCENTAGE OF LOCATIONS NOT REPORTED WITHIN 0.01 MILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Police</td>
<td>95</td>
<td>3</td>
</tr>
<tr>
<td>Sheriffs Office</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>City Police</td>
<td>203</td>
<td>18</td>
</tr>
</tbody>
</table>

It is generally accepted that ±50-ft proximity of an accident to geometric characteristics is needed to establish a relationship. However, there may be a fallacy in this concept. The location reported by the accident investigator usually is the point at which the vehicle is stopped. In the case of a dead-stop fixed-object accident, correlated data on the accident location and geometrics may be meaningful. However, if the accident causal events occurred up to 0.3 mile away from the reported vehicle resting place, the contribution of specific geometrics may be difficult or impossible to determine. In the minds of some researchers, this raises the question of whether or not 0.01-mile reporting accuracy is any better than 0.1-mile reporting accuracy. So far, the question has not been satisfactorily answered. To add to the problem, four states still do not consider traffic volume in identifying hazardous locations.

Selecting Alternative Improvements

Like most problem solving, the analyst should recall what worked in the past. If no experience is available, a process of logical deduction can be used to identify alternative improvements.

The nature and cause of the accident problem first must be identified. Analysts of accident-prone locations often must determine whether the percentage of accidents having a common characteristic—wet pavement, for example—is unusually high. This is done by comparing the actual percentage of accidents at the location with the average percentage of that type of accident at similar locations. A big difference between actual and average percentages may point to a specific problem. For example, if nighttime accidents comprise 25 percent of all accidents on the average, but the actual percent at a location is 80 percent, it is obvious that there is an abnormal safety problem at night. Unfortunately, problems are not always that obvious. To be more certain that an abnormal condition exists, statistical analysis is used. Appendix C describes the applicable statistical tests.

More systematic methods of identifying accident causes are being developed. Three promising techniques currently in use and discussed in the Users’ Guide are:

1. **Conflicts analysis.** This technique is used by the Washington, Ohio and Virginia state highway agencies. It is used to identify the conflicts—potential accidents—that drivers face at a hazardous location. This technique is also under consideration for identifying hazardous locations.

2. **Accident pattern tables.** This technique is used by the Mississippi State Highway Department. The deductive reasoning used by an analyst to identify the highway safety problem is documented in table form.

3. **Fault tree analysis.** This technique places the contributing circumstances in perspective and affords an estimate of the effectiveness of a potential improvement.

Several other promising techniques have been developed and are discussed in Appendix D:

1. **Near-miss scale of danger.** To compare near-misses to their closeness to the crucial avoidance time.
2. **Branching analysis.** To place contributing circumstances in their correct relationships.
3. **Behavioral sequence model.** To develop a chain of events for each participant contributing to the accident.
4. **True critical point.** To analyze the driver’s processes of controlling the vehicle.
5. **Operations analysis.** To analyze the required driver operations to gain an understanding of the driver’s actions.

Deficiencies

Most state highway safety agencies do not document the logic used to select applicable improvements. This limits the growth of widely available experience and quite often leads to excuses, rather than reasons, for an improvement failure.

Three states use only engineering judgment to analyze accident data and select alternative improvements. Although engineering judgment is an essential part of any highway safety evaluation, its use should be restricted to situations where facts cannot provide a logical deduction.

Evaluating Alternative Improvements

The first step in evaluating applicable improvements is to estimate the following inputs:

1. Average value of accidents.
2. Interest rate.
3. Inflation rate.
4. For each alternative improvement, estimate:
   a. Initial cost.
   b. Annual cost.
   c. Terminal value.
   d. Service life.
   e. Accident reduction.

The next step is the actual evaluation. It is influenced by the fiscal objectives of the user agency. There is much confusion over fiscal objectives. The factors influencing choice of methods are discussed following the description of inputs.
**Average Value of Accidents**

Should $1,000,000 be spent to save one life? Should $100,000 be spent to save one life? Is it fair to ask individuals to make such a judgment? Fair or not, in the highway safety business one is required to assign values to human lives and injuries to persons and property. Assigning costs to accidents has been the subject of numerous studies. Unfortunately, the difficulty in assigning cost increases with accident severity.

In theory, property damage cost can be determined to the penny from automobile insurance claims. The average injury cost is harder to determine because of the difficulties in estimating the cost of pain and suffering. The cost of human life is hardest to define. Tangible costs that the motorist pays for accidents include wage loss, medical costs, and insurance administration and claim costs.

Despite the difficulties, several accident cost studies have been conducted by the States of Massachusetts, Utah, Illinois, and California and by Washington, D.C., as well as the National Highway Traffic Safety Administration and the National Safety Council. Table 1 presents the data for each study. Table 2 identifies the cost factors included.

The choice of average costs per accident can affect the selection, ranking, and economic justification of alternatives. For example, alternative C (in the tabulation) is not economically justifiable based on California costs but is economically justifiable based on NHTSA costs. On the basis of net annual benefits, alternative B would appear to be the best choice using California costs. But if NHTSA costs are used, Alternative D shows the greatest net annual benefit.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>ACCIDENT COST STUDIES DATA</th>
</tr>
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<tbody>
<tr>
<td><strong>STUDY CONDUCTED BY</strong></td>
<td><strong>YEAR</strong></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Massachusetts</td>
<td>1953</td>
</tr>
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<td>Utah</td>
<td>1955</td>
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<tr>
<td>Illinois</td>
<td>1959</td>
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<tr>
<td>California</td>
<td>1964</td>
</tr>
<tr>
<td>(Rural)</td>
<td>(7,700)</td>
</tr>
<tr>
<td>(Urban)</td>
<td></td>
</tr>
<tr>
<td>Washington, D.C.</td>
<td>1966</td>
</tr>
<tr>
<td>National Highway Traffic Safety Administration</td>
<td>1971</td>
</tr>
<tr>
<td>National Safety Council</td>
<td>1972</td>
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</table>

* Value estimated by assuming 1.95 vehicles per accident.

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>COST FACTORS USED IN ACCIDENT COST STUDIES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FACTOR</strong></td>
<td><strong>MASS.</strong></td>
</tr>
<tr>
<td>Property damage</td>
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<tr>
<td>Injury costs</td>
<td>x</td>
</tr>
<tr>
<td>Worktime lost</td>
<td>x</td>
</tr>
<tr>
<td>Loss of use of vehicle</td>
<td>x</td>
</tr>
<tr>
<td>Legal costs</td>
<td>x</td>
</tr>
<tr>
<td>Damage awards</td>
<td>x</td>
</tr>
<tr>
<td>Unreported accidents</td>
<td>-</td>
</tr>
<tr>
<td>Potential loss of future earnings</td>
<td>-</td>
</tr>
<tr>
<td>Funeral expenses</td>
<td>-</td>
</tr>
<tr>
<td>Pain and suffering</td>
<td>-</td>
</tr>
<tr>
<td>Insurance payments</td>
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</tr>
<tr>
<td>Insurance administrative costs</td>
<td>-</td>
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</table>
ANNUAL NET DOLLAR BENEFITS

<table>
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<tr>
<th>ALTERNATIVE</th>
<th>UNIFORM COST</th>
<th>ANNUAL BENEFIT</th>
<th>CALIFORNIA STUDY</th>
<th>NHTSA STUDY</th>
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<tbody>
<tr>
<td>A</td>
<td>5,000</td>
<td>4</td>
<td>5,600</td>
<td>11,200</td>
</tr>
<tr>
<td>B</td>
<td>10,500</td>
<td>8</td>
<td>11,200</td>
<td>22,400</td>
</tr>
<tr>
<td>C</td>
<td>15,000</td>
<td>10</td>
<td>14,000</td>
<td>28,000</td>
</tr>
<tr>
<td>D</td>
<td>20,500</td>
<td>15</td>
<td>21,000</td>
<td>42,000</td>
</tr>
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</table>

Interest Rate

To use or not to use an interest rate is a basic decision that the analyst must make prior to making fiscal evaluations, but first, consider these points:

- Initial and annual costs of safety improvements are small enough that money need not be borrowed for financing. As a result, interest is not paid on the money used for these projects.
- Money has an investment value over time. Interest rates reflect this.
- Government funds spent on highway safety improvements cannot be spent for other purposes.
- Taxpayers finance highway safety projects. It would be unfair to them to spend their money on projects with less return than available from private investments.
- The public is foregoing the opportunity to invest. They should be compensated with a reasonable rate of return.

The recommendation to use an interest rate or some comparable procedure is based on the above points. One comparable procedure is the rate-of-return method.

Not all states use an interest rate. This is the same as using an interest rate of zero. The formulas given in this text may be used with zero interest rate. The values for zero interest rate are given in Table F-2 in Appendix F.

The choice of an interest rate should be based on knowledge of other investment opportunities throughout the local economy. Especially, examine the interest rates associated with long-term borrowing for highway construction. For example, in 1971 the interest rate for state bonds for the construction of highways ranged from 3.04 percent in New Mexico to 6.04 percent in Alaska. Remember, the current rates are of important consideration. These can be obtained from The Bond Buyer.*

For further discussion, see any engineering economy textbook.

Inflation

The economic analysis of highway safety improvements involves future costs and benefits. Therefore, it is relevant to consider the effects of inflation. In Highway Research Record No. 100, Lee and Grant (94) examined the use of inflation factors in the evaluation of highway improvements. They examined the existing practice in the fields of highway construction and water resources. Their conclusion, and the opinion of other experts, was to not include an inflation rate in economic studies made from a national viewpoint. Their main reasons were:

1. Inherent uncertainty of future economy.
2. Federal Government commitment to price stabilization.
3. The possible contribution of Federal programs to inflation if they are justified in part by inflating benefits.

Lee and Grant recommended:

In view of the findings of this paper there is no justification for including inflation rates in highway economy studies when taking the national viewpoint. Even from the local viewpoint, such a practice is hard to justify because of the difficulties in predicting future inflation rates.

To illustrate the difficulty of predicting inflation, the analyst need only look at the current situation. For example, during the first phase of this project (February through July 1973), the Federal Government’s estimate of the annual rate of inflation for 1973 went from 3 percent in January to 6 percent in March to 9 percent in June. For the month of May alone, the inflation rate was 2.1 percent. The final rate of inflation, as reflected by the Consumer Price Index, was 8.8 percent.

Although the use of an inflation rate is not recommended, an analyst who decides not to follow this recommendation can use an inflation rate by adjusting the rate of interest to reflect both the time value of money and the rate of inflation as:

$$\text{Adjusted } i = [(1 + i)(1 + \text{inflation rate})] - 1$$

where $i$ equals interest rate expressed as a decimal.

This adjusted interest rate should be rounded to the nearest one-half percent so that interest tables can be used. This rounding will have little effect on the analysis due to the roughly estimated rate of inflation. For example, if the analyst wants to use a 4-percent inflation rate and an 8-percent interest rate, he can simplify the calculations by using a 12.5-percent interest rate. He technically should use 12.32, but a 12.5-percent interest rate is the same as an 8-percent interest rate and an inflation rate of 4.17 percent.

* Published daily and weekly by the Bond Buyer Incorporated, 67 Pearl Street, N.Y. 10004.
† Italic numbers in parentheses indicate entry in Bibliography, Appendix P.
Initial Cost of Each Improvement
An estimate of the initial cost of each improvement is best obtained from historical costs at similar locations. In the absence of historical costs, the estimate of initial cost can be based on the total estimated cost of each component or piece of hardware.

Annual Cost of Each Improvement
An estimate of the annual cost can best be obtained from historical operating costs. The annual cost for some improvements will be either zero or so small that it can be ignored.

Terminal Value of Each Improvement
The terminal value is the difference between the monetary value at the end of the period of service and the future cost of removal, repair, transfer, and/or sale. For a safety improvement, examples are signing that is usable at another location, salvageable guardrail, or pavement that can be used as a base for a new roadway. If a proposed improvement has an associated terminal value, it should be included in the analysis. However, most improvements have very little terminal value.

Service Life of Each Improvement
The service life of an improvement is the period of time that the improvement can be expected to affect accident rates. In economic analysis, the service life of the alternative is the analysis period for that alternative.

Winfrey (168) warns that the analysis period should not extend beyond the period of reliable forecast. Thus, the estimated service life should not be greater than the length of time that estimated accident reduction can reasonably be expected. For example, given a strong possibility of an intervening solution such as vehicle redesign and traffic diversion, the service lives of the alternatives should be adjusted to reflect the shorter planning horizon.

A hazardous location on a highway temporarily serving as Interstate traveled-way is an example of a situation where the above considerations apply. Estimates of accident reduction benefits once the highway ceases to be an Interstate traveled-way would be very unreliable and quite possibly nonexistent.

Accident Reduction Benefit of Each Improvement
Accident reduction benefit can be estimated in terms of:

1. Number-of-accidents method:
   a. Reduced number of accidents.
   b. Reduction to an average number of accidents.
   c. Percentage reduction in number of accidents.
2. Accident rate method:
   a. Reduction to an average accident rate.
   b. Percentage reduction in accident rate:
      (1) For all accidents.
      (2) By accident type.
3. Severity rate method:
   a. Reduction to an average severity rate:
      (1) All above-average severity classes.
      (2) All significantly high severity classes.
   b. Percentage reduction in severity rate:
      (1) For all accidents.
      (2) By accident type.

The number-of-accidents method is not recommended because it is reliable only when traffic volumes in the after-improvement period are the same as in the before-improvement period.

The percentage reduction in accident rate is the method recommended in the Users’ Guide. All of the accident rate and severity rate methods are detailed in Appendix E.

Calculation of Evaluation Indexes
Having estimated the benefits from each improvement, the analyst now must assign values, referred to as evaluation indexes, to these benefits. Evaluation indexes help the analyst select his agency’s fiscal program within the constraints of its budget. He must (1) select an improvement from each group of mutually exclusive improvements and (2) assign funding priorities to the “selected” improvements (now independent).

Discussion of Selection from Mutually Exclusive Alternatives
The research team found that the method of analysis chosen to select from mutually exclusive improvements at a location depends upon the fiscal objective of the agency making the selection. The two fiscal objectives found were:

1. Optimum improvement objective. The goal of the optimum improvement objective is to obtain the most net benefit from each investment opportunity; in other words, the “optimum” improvement is selected at each location or for each specific problem.

2. Benefit maximization objective. The goal of the benefit maximization objective is to obtain the most net benefit from the funds budgeted; in other words, the set of alternatives from several locations that provides the most net benefit for the budget is selected.

Under the optimum improvement objective, investments in an opportunity continue as long as each increment of investment is less than its increment of benefit. The method of analysis for selecting from mutually exclusive alternatives under the optimum improvement objective is the incremental benefit/cost ratio or equivalent method.*

Under the benefit maximization objective, combinations of improvements are compared to determine the combination that provides the most benefit for the capital budget.

For example, Table 3 gives a listing of candidate projects from six problem locations. Candidates at each location are mutually exclusive and $5,000 has been budgeted for safety improvements.

Under the optimum improvements objective, the candidate projects with the highest net benefit for each location are F-1, C-1, A-3, B-2, E-2, and D-2. From this group,

* Net annual benefit, net present worth, incremental internal rate of return, or incremental cost-effectiveness analysis.
improvements F-1, C-1, and A-3 will use up the $5,000 budget and provide the most benefit. Three locations will have been optimally improved for a total annual benefit of $3,070.

Under the benefit maximization objective, the candidates from each location selected on the basis of highest benefit/cost ratio are E-1, A-1, D-1, F-1, C-1, and B-2. Improvements E-1, A-1, D-1, F-1, and C-1 will use up the $5,000 budget. Five locations will have been improved—although only two of them optimally—for a total annual benefit of $4,000.

However, the benefit maximization objective is only valid when it appears that funding constraints will not permit a comprehensive solution to highway safety problems within the agency’s jurisdiction. If funds were plentiful, locations E, A, and D would need to be improved again to remove hazards not affected by improvements E-1, A-1, and D-1.

The benefit maximization objective is forced on managers by lack of positive action at the highest levels.

The reasoning for using the benefit maximization objective is illustrated in the introduction to the Highway Safety Budgeting System that Dr. David B. Brown of Auburn University developed for the Alabama Highway Department:

There are thousands of roadway locations in Alabama which are potentially dangerous and need to be improved. Unfortunately, the money is not currently available to fix every one of these to the greatest degree possible. Therefore, it is necessary to allocate the funds that are available to those locations and projects which are going to bring the greatest return for the citizens of Alabama.

The dynamic programming procedures developed by Dr. Brown for Alabama are detailed in Appendix H.

The theoretically correct fiscal objective is the optimum improvement objective. Therefore, it is the fiscal objective recommended in the Users’ Guide. However, benefit maximization is a legitimate fiscal objective in commercial business and is used by at least one state highway department (Alabama). Therefore, it is discussed as a viable fiscal objective.

**Discussion of Assignment of Improvement Priorities.**

Having studied many individual safety problems and selected an improvement for each from among alternatives according to the user’s fiscal objective, the user must now organize the improvements into a program for the coming year. Or, in other words, the user must determine which improvements are to be implemented first.

Winfrey (168) makes the following statements regarding the assignment of improvement priorities:

The process of getting together a program of highway construction for a specific year or period of years should take into consideration the relative economic merit of the independent projects which will make up the total program. (This is discussed further in Chapter 26.) The analysis for economy is one possible ranking factor.

In Chapter 24, the sufficiency index and the present serviceability index are described in connection with the needs studies. These ratings may also be used as tools in establishing construction priorities for programming purposes. Other tools are the prospective economy to be achieved by the improvement as measured by the benefit/cost ratio or rate-of-return solution in the economic analysis.

Dr. G. A. Fleischer of the University of Southern California points out that the use of the benefit/cost ratio to assign priorities “can lead to misallocation of resources.” He further states that “rank ordering projects on the basis of benefit/cost ratio does not assure that wealth will be maximized.”

The Users’ Guide recommends the benefit/cost ratio as a basis for establishing priorities for program selection. However, several cautions are necessary. First, priorities based on benefit/cost ratios can be overridden by the need to obtain the most benefit from the budget. For example, if selected projects are assigned to the annual program
according to benefit/cost ratio, it is more than likely that, as the remaining funds become smaller, eventually the next improvement on the priority list will exceed the amount of remaining funds. This project can be skipped, and the next one also, until a project is found that reasonably fits the remaining funds.

Comment on Inherent Problems. One of the problems encountered in the research of evaluation indexes was that the selection of a highway safety program is not altogether related to common engineering economic analysis problems, nor is it the same as the selection of a highway construction program or a plant expansion program. A highway safety program deals with a fluid problem. It changes size and shape according to many influences. The true scope of the problem is difficult to define. This problem makes fiscal decisions less cut.

Another difference is that a highway safety program is a one-year program. Near the end of the program year, hazardous locations will again be identified using the latest accident data. These hazardous locations are analyzed to develop the following year’s program. The locations that were classified as hazardous the first year, but not included in that year’s program, may or may not be classified as hazardous during succeeding years.

An additional problem encountered was the practicality of examples (examples can be contrived to prove almost anything). For this reason, typical highway safety improvements were collected during the field testing of the Users’ Guide. The typical improvements are presented in Appendix L.

Alternative Methods. The procedure recommended in the Users’ Guide uses net annual benefit and benefit/cost ratio analyses. Alternative analyses are discussed in Appendix F.

Alternatives to the benefit/cost ratio analysis are rate of return, payback period, and cost/effectiveness. Alternatives to the incremental benefit/cost ratio analysis are incremental benefit/cost ratio, incremental rate of return, net present worth, and incremental cost/effectiveness.

In the calculation of evaluation indexes, there is often considerable uncertainty in the input data. To measure the effect of and to compensate for these uncertainties, the analyst can perform sensitivity and risk analyses. The procedures for sensitivity analysis and for risk analysis are detailed in Appendix G.

Deficiencies. Three states use an inflation rate for accident reduction benefits. This may result in an overestimation of benefits and, thus, an overstatement of an improvement’s economy. Lee and Grant (94) studied the use of an inflation rate and concluded that its use is improper.

Programming and Implementing Improvements

The evaluation of applicable improvements continues until the alternatives at all of the locations on the “hazardous location list” have been analyzed.* The analyst must then select his agency’s fiscal program within the constraints of its budget from the improvements which survive the evaluation at each hazardous location.

The development of a highway safety program is a selection from independent alternatives. Therefore, benefit/cost ratio, internal rate of return, cost effectiveness ratio or payback period analyses should be used. The benefit/cost ratio is the method recommended in the Users’ Guide because of its common use.

Evaluating Implemented Improvements

After an improvement has been implemented, it is essential that its performance be monitored. The monitoring process should determine:

- Whether the improvement is performing—in other words, has the accident or severity rate decreased? If not, why?
- Whether the improvement is performing as expected? If not, why?

The method for measuring improvement performance recommended in the Users’ Guide is the before-and-after study. Alternative methods are detailed in Appendix I of this report.

The measured reduction must be tested to determine whether the reduction could have occurred by chance. Chapter Six of the Users’ Guide contains procedures for testing for significant accident reduction using a 95-percent level of confidence. Appendix J contains additional graphs necessary for using 80-, 90-, and 99-percent levels of confidence.

One of the major byproducts of the postimplementation evaluations is the refinement of forecasted performance. Each implementation evaluation result expands the database available for developing the forecasts of improvement performance.

Deficiencies

Many states do not evaluate implemented improvements, nor do they review their predictions of improvement effectiveness after the improvement is functioning. This lack of evaluation and feedback is a serious hindrance to the development of an effective highway safety program based on the most current information available.

For example, many states use the 1966 data published in Evaluation of Criteria for Safety Improvements on the Highway,∗ by Jorgensen and Westat (136) verbatim even though seven years of more current data are available.

Evaluating the Highway Safety Program

The evaluation of implemented improvements provides the highway safety analyst with the management information he needs. Similarly, the evaluation of the highway safety program provides top management with the management information it requires.

This management information should include:

* See Appendix A of the Users’ Guide.
• Information on the accomplishment of the program. This information will allow the top management to assess the current funding level for highway safety.
• Information on the accomplishment of each phase of the program. This information will allow the top management to assess the emphasis of the program and the division of funds within the highway safety program.

The program and phase evaluations can be expressed as:
• Benefit/cost ratio. The ratio of accrued benefit to accrued cost.
• Cost effectiveness. The cost per reduced accident or fatality.

These topics are discussed in detail in Appendix K of this report.

Deficiencies
Many states do not review their highway safety programs to evaluate either the funding level or the division of funds among the various phases of the program. Thus, many top managers do not have complete information upon which to make decisions concerning funding level and program emphasis.

Potential Benefits
The implementation of the model process recommended in the Users' Guide can be expected to produce the following types of benefits:

1. Consistently greater benefits. Reduced accident, severity and fatality rates. For example, California, whose highway safety program is similar to the model process, regularly receives a rate of return greater than 65-percent from its highway safety funds.
2. Better management information for top management. This will allow top management to evaluate the current highway safety funding level as well as the funding of each phase of the program.
3. Justification for higher funding level. The demonstrable need for additional funds and consistently high returns should result in more highway safety funds.

4. Higher success rate. The feedback of refined forecasts of improvement performance should result in the choice of successful improvements more frequently.

The model process installed in a highway agency can fulfill a critical need right now. It is relatively simple and can readily be adapted to the needs of a particular agency. It represents a synthesis of the best approaches currently used and is a sound base around which future refinements can be developed.

An Example
The model system can be applied to any highway safety agency from the smallest county to the largest state. The degree of sophistication varies with the agency. Many of the highway safety systems can be divided into the basic components of the model system. For example, Nebraska's system for accident identification and location can be divided into the six basic components as shown in Figure 1. Some existing systems do not contain all six of the model system components.

Field Tests
The effectiveness of a Users' Guide is measured by how well the user can implement the method using his own resources and without outside consultation. Field tests conducted by the authors of a manual in which the authors are readily available for guidance cannot be considered completely valid. Therefore, a field study was designed to include:

• A test conducted by a state with which the authors were familiar, but without their assistance.
• A test conducted by a state with which the authors were not familiar and without their assistance.

To test the over-all usefulness of the Users' Guide, field tests were also conducted in one large county and three large cities. The results are documented in Appendix N of this report.

CHAPTER THREE
APPRAISAL AND IMPLEMENTATION

Since the moment when travel in motor vehicles first began, traffic accidents have been a major concern. In the last decade, officials at all levels of government have resolved to do something to solve the problems. Vehicle standards, spot improvements, state highway safety programs, and many other efforts have become parts of the highway safety scene.

With all of these new approaches to the accident problem, the need to fight both accidents and the wasteful use of methods or approaches also has grown. In this research
### Identifying Hazardous Locations

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Assess incident types and locations</td>
</tr>
<tr>
<td>2.</td>
<td>Identify critical locations</td>
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<tr>
<td>3.</td>
<td>Evaluate potential countermeasures</td>
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</table>

### Selecting Alternative Countermeasures

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<th>Action</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Select alternative countermeasures</td>
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<tr>
<td>2.</td>
<td>Evaluate alternative countermeasures</td>
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### Evaluating Alternative Countermeasures

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<th>Action</th>
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<tbody>
<tr>
<td>1.</td>
<td>Determine effectiveness of countermeasures</td>
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<tr>
<td>2.</td>
<td>Implement improvements</td>
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### Evaluating the Highway Safety Program

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<th>Step</th>
<th>Action</th>
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<tbody>
<tr>
<td>1.</td>
<td>Evaluate implemented countermeasures</td>
</tr>
<tr>
<td>2.</td>
<td>Evaluate the highway safety program</td>
</tr>
</tbody>
</table>

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**Figure 1.** Nebraska's Highway Safety System Divided into the Six Basic Components of the Model System.
project, a management system for efficiently using evaluation tools has been developed.

In this chapter an appraisal is made of the research findings and the potential of highway safety improvement management systems in highway agencies. Management actions for implementing such a system are also discussed.

APPRAISAL

Evaluation Systems Today

Few highway agencies have a complete safety evaluation system. Because no system goes much beyond analyses based on simplified assumptions, each agency has an opportunity to improve its system.

The system presented in the Users' Guide can help some agencies upgrade procedures. Other agencies will find the guide useful as a framework from which to make their own improvements. The Users' Guide does not represent the ultimate state of the art. The ultimate would not be usable except in the most advanced agencies. It presents a system that can be used by many agencies. Advanced concepts that fit into the system structure are discussed in the appendices of this research report.

The system for evaluating highway safety improvements presented in this report fits into the evolutionary process toward more refined and effective highway safety improvement programs.

Agency Self-Appraisal

The agency seeking to refine its system should review its existing processes to identify those that can be improved, replaced, or deleted. The agency seeking to implement a completely new system should review its existing processes to identify those that can be incorporated into the new system. Regardless of the viewpoint, the self-appraisal review should be the basis for the development of a plan to accomplish the desired system.

One of the most effective methods to review a process or a system composed of processes is to ask questions about each process. The subject of these inquiries should include inputs, outputs, results, and the process itself. Chapter Seven of the Users' Guide contains recommended questions that are intended to be the minimum review of an agency's existing situation. Additional questions may be added by an agency to fit its existing situation.

Program Appraisal

Next, an agency should appraise the results of its highway safety program. Are over-all program objectives being met? Each phase of the program should also be appraised in terms of its own objectives. Results of these appraisals may be expressed as either the reduction of hazards or a comparison of the funds expended to the hazard reduction obtained. The reductions may be expressed as decreases in:

1. Accident rates and/or severity at improved sites.
2. Total accident costs.
3. Total number of accidents.
4. Fatalities.

The comparisons to funds expended may be expressed as:

1. Rate of return.
2. Cost/effectiveness.

The latter two methods of comparison are detailed in Appendix K of this report. Rate of return is discussed in Appendix F.

For comparison between each phase of the program, the improvements should be grouped by type and/or purpose.

MANAGEMENT ACTION FOR IMPLEMENTATION

Numerous practical research reports and users' manuals are not being used because administrators have not taken the actions required for successful implementation. Obviously, it is not sufficient simply to put a users' manual into the hands of an analyst. The methods in the manual must fit into the over-all mission of the department. Policy decisions must be made. Resources must be made available. The highway department administrator—not the analyst—is responsible for ensuring successful implementation of the methods.

Previous successful implementations of management systems and related users' manuals provide examples of necessary key management actions. The key actions taken by management to successfully implement management systems and users' manuals are:

1. Commitment. Top management expresses the department's commitment to the concepts and objectives of a highway safety improvement system.
2. Organization. Top management commits and organizes qualified staff and other required resources to develop the system.
3. Scheduling. Top management prepares a detailed implementation schedule and commits the department to stay on schedule and to meet the target date for completion.
4. Coordination. Top management assures cooperation and participation by all department divisions in developing the system. Cooperation in obtaining basic information is particularly crucial.

Top Management Commitment

As a result of recent lawsuits, some highway agencies have been hesitant to accept responsibility for—or even acknowledge—the existence of hazardous locations. With the development of detailed procedures to routinely identify and correct hazardous locations, highway agencies now may be negligent in not doing so.

Highway agencies must recognize and accept responsibility for hazardous locations—the potentially dangerous as well as the accident-proven locations. Once this responsibility is accepted, top management must commit the agency to aggressive identification and correction of hazardous locations. Policies and procedures must be developed and communicated to all levels of highway organization.

Top management's initial action should be positive commitment to the concepts involved. A formal statement of
policy from the chief administrator or the official policy-

making body is one good way of expressing this commit-

ment.

The policy statement should define:

1. The official interpretation of basic safety objectives of the department.
2. A policy for specific highway safety improvement programs.
3. The organizational responsibilities for developing and operating highway safety improvement systems.
4. A target date for full-scale implementation.

Experience indicates that systems developed by middle managers without top management commitment often result in ineffective or incomplete systems. The enthusiastic support of a top manager is gained by giving him the information he needs in order to understand the problem and to decide to act. Top management support results in serious attention to the system by operating personnel.

**Organization and Staffing**

- **Part-time implementation is slow and ineffective. Developmental efforts get squeezed out of the schedule in competition with routine responsibilities. Therefore, a full-time project staff is essential to the development and implementation of the system.**

Because safety is a basic objective and responsibility of a department, it is preferable that the basic responsibility for development and implementation of the system be assigned to an assistant chief administrator who normally has responsibility for many divisions or is responsible in the planning and programming area. The project team should be responsible directly to this person.

Highway safety improvement systems involve the use of traffic data and result in traffic-related improvements. The leadership of the project team logically should be assigned to a person trained in traffic engineering. Ideally, this person should also have experience or understanding in statistics, computer programming, and engineering economics.

**Evaluation Systems Tomorrow**

Early in the research project systems analysis methods, such as dynamic programming, as discussed in Appendix H, were investigated. It was subsequently decided not to use complex methods.

For one thing, simple approaches better ensure that the user understands each decision that is being made. With the systems analysis approach, the major project output would be a computer program that agencies might be reluctant to use. The use of systems models is the recommended method for the near future. Alabama already has developed a dynamic programming model to maximize the safety return from the annual safety improvement budget. This is considered a significant step forward.

As systems analysis becomes more commonly used, it may become practical for a national research agency to develop a battery of computer programs for all parts of the highway safety evaluation system.

**Implementation Work Schedule**

To develop and implement a system, a detailed work schedule is needed. The development of a highway safety improvement system can be divided into four phases:

1. **System design.** The system design consists of identifying system objectives, defining the outputs required to meet objectives, selecting procedures which produce desired outputs and, finally, identifying data requirements.

   The Users' Guide provides a structure for the system and describes procedures and their data requirements. This should be quite helpful during Phase I. A period of two to six months, depending upon the staff effort, should be sufficient. It is extremely important that all potential users of the output be included in the design of the system.

2. **Data subsystem design.** The effort to complete this phase depends on the capability of existing data systems to provide required data. New reports and data files may be required.

   Data documentation is discussed at the end of each chapter in the Users' Guide. Much of the recommended documentation is needed to provide continuity between components of the system.

3. **Computer programming.** The computer programming phase may be scheduled over a period of one to two years. The major variable in scheduling is the availability of data for evaluating the effectiveness of completed projects. If adequate "before" data are not available at the beginning of the project, an effectiveness evaluation program will be of little use until enough time has passed to permit the build-up of a useful "before" record.

   Because the programs are specialized and deal in uncommon procedures, it is beneficial to maintain the same programming staff throughout the project.

4. **Total implementation.** Monitoring is required throughout implementation to ensure that individual components work efficiently and that interfaces between components function properly.

**Information Reporting**

Reporting is the lifeblood of a management system. Managers should have all of the pertinent information available before making decisions. Information should be accurate and up-to-date.

Information needs will have been defined in the systems design phase. It is the manager's responsibility to carry out data collection processes. One way of keeping information flowing smoothly is to be sure that the people who collect and handle the data understand why data are needed and how they are used.

The recommended minimum documentation is given for each component of the model system in the Users' Guide. The coordination of the documentation of each component is depicted in Figure 7 of the Users' Guide.

**Coordination**

The evaluation system probably will be developed and operated by one unit in the department. However, the success or failure of the system can be influenced by the amount of coordination and cooperation between the op-
erating unit and other units inside and outside the department. The data processing unit must be involved. Without coordination, data processing schedules will not be met. In addition, police agencies need to cooperate in providing accurate data.

Integrating the safety improvement program into the total highway development program is another level of coordination. Most safety program funds are earmarked. Although earmarking protects safety funds from being invaded, it also can prevent significant growth in funding.

**BROADENED APPLICATIONS**

The scope of this research was narrow. The definition of "safety improvement" must be broadened to include all operational activities—construction, maintenance, and traffic operations. Safety is a characteristic of all operational environments. Spot improvements are fine for correcting oversights. But ultimately it is necessary to incorporate safety considerations into every facet of transportation. The innovative highway engineer can use this report as a base from which to expand the scope of safety considerations.

**FURTHER RESEARCH NEEDED**

Further research is needed to develop a data base from which estimates of improvement performance can be made. Development of a national data base was begun in 1966 with the publication of *Evaluation of Criteria for Safety Improvements on the Highway* by Jorgensen and Westat (136). These data are presented in Appendix A of the Users' Manual. More recent data from Mississippi and California are also presented as the basis by which individual agencies may develop their own forecasts. There is a need for an updated national data base that will greatly aid highway safety agencies.

**PROBABILITY**

The reader undoubtedly is familiar with expressions of probability used in everyday life:

- There's a good chance that the Red Dogs will win the game.
- It rarely rains in Death Valley.
- You have an even bet that the first card drawn from the deck will be black.
- There is a good chance of rain.

Each of these statements indicates the degree of chance that a particular event will or will not occur. In order to make such statements useful for consistent analysis, they must be expressed mathematically. The mathematical probability framework has the following properties:

- The numerical value of the probability, \( P \), must be between zero and one.
- An event which is impossible has a probability of zero, for example, the sun never setting.
- An event which is certain to occur has a probability of one, for example, the sun rising tomorrow.
- If \( P \) is the probability that an event will occur, then \( 1 - P \) is the probability that the event will not occur.

In most highway safety applications, probabilities are estimated on the basis of existing data. This may be done by comparing the frequency of a particular type of event to all of the alternatives to the event.

**Example**

The accidents at a particular intersection were classified by type of collision with the following results:

- A-1
- A-2
<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Number of Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear End</td>
<td>47</td>
</tr>
<tr>
<td>Left Turn</td>
<td>42</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>34</td>
</tr>
<tr>
<td>Head On</td>
<td>19</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>4</td>
</tr>
</tbody>
</table>

On the basis of these 146 accidents, the probability that the next (the 147th) accident will be a rear end collision is estimated to be:

\[
P(\text{Rear End}) = P(\text{R}) = \frac{R}{R + \text{all other accidents}} = \frac{47}{146} = 0.32
\]

Similar calculations could be made for the other accident types. Note that the sum of all the probabilities must equal 1:

\[
P(\text{R}) + P(\text{L}) + P(\text{S}) + P(\text{N}) + P(\text{P}) = 0.32 + 0.29 + 0.23 + 0.13 + 0.03 = 1
\]

The probability that the next accident is not a rear end collision is estimated to be:

\[
P(\text{not R}) = 1 - P(\text{R}) = 0.68
\]

Under certain circumstances, probabilities may be added or multiplied. The probability that the next accident is either rear end or left turn is \( P(\text{R}) + P(\text{L}) = 0.61 \). The probability that the next two independent accidents will both be rear end is \( P(\text{R}) \times P(\text{R}) = 0.10 \).

The results of this analysis are true only for the intersection which was studied. By applying logic and engineering judgment, these results may be extended to other locations.

DATA PARAMETERS

One of the first steps in analyzing a set of data is to determine those parameters which characterize the data. In general this involves two values: a measure of central tendency and a measure of dispersion.

**Sample Mean**

The sample mean is the most useful measure of central tendency. For a set of \( n \) data values, \( x_1, x_2, \ldots, x_n \), the sample mean \( \bar{x} \) is calculated as follows:

\[
\bar{x} = \frac{1}{n} \sum x_i
\]

When working with probability distributions, the mean can be calculated:

\[
\bar{x} = \sum x_i \cdot P(x_i)
\]

**Sample Variance**

To distinguish among several sets of data which have the same mean, it is necessary to calculate a second parameter which characterizes the spread or dispersion of data around the mean. A commonly used measure of dispersion is the sample variance. When the sample mean has been calculated, the sample variance, \( s^2 \), can be calculated:

\[
s^2 = \frac{\sum x_i^2 - n \bar{x}^2}{n-1}
\]

DISTRIBUTIONS

Experience indicates that some events have a higher probability — that is, occur with a greater frequency—than other events. The relative frequencies can be described as a probability distribution. The description may be in one or more of the following forms:

- A table specifying the probability of each event.
- A graph indicating the probability of each event or set of events.
- A formula which describes the method of calculating the probability of each event.

Tabular or graphical formats are the most useful in describing an actual set of data. The actual frequencies or (estimated) probabilities are specified for each observed event.

In many problems related to highway safety, the data have a distribution which can be described using a formula. The formula relates the probability (for a discrete distribution) or the probability density (for a continuous distribution) to the variable. Typically, a formula does not exactly fit real data. Therefore, the analyst should examine the data and determine how well it agrees with a theoretical distribution.

When working with probability distributions, variance can also be calculated:

\[
s^2 = \sum (x_i - \bar{x})^2 \cdot P(x_i)
\]

The positive square root of the sample variance is called the sample standard deviation, \( s \). In most cases, the sample standard deviation, which has the same units as sample variance, is the estimated parameter used to describe the dispersion of the data.

The means of the probability distribution \( f_1 \) and \( f_2 \) in Figure A-1 are both 8 but the variances are 1 and 8.75, respectively. The variance of distribution \( f_1 \) is calculated:

\[
s^2 = (6-8)^2(1/64) + (7-8)^2(1/64) = 1
\]

The variance of distribution \( f_2 \) is calculated:

\[
s^2 = (2-8)^2(1/64) + (3-8)^2(1/64) + (4-8)^2(1/64) + (5-8)^2(1/64) + (6-8)^2(1/64) + (7-8)^2(1/64) + (8-8)^2(1/64) + (9-8)^2(1/64) + (10-8)^2(1/64) + (11-8)^2(1/64) + (12-8)^2(1/64) + (13-8)^2(1/64) + (14-8)^2(1/64) = 8.75
\]
POPULATION PARAMETERS

The objective of taking a sample of data and analyzing it is to determine some information about the nature of the variables being studied. The totality of all elements under consideration is called the population. For example, a population can consist of all rear-end collisions in a state, or all accidents occurring at three-way intersections. In most cases, it is not possible to survey the entire population. Instead, a limited sample is taken, and is assumed to be generally representative of the population. The conclusions drawn from analysis of the sample are applied to the population.

The population will have parameters similar to those calculated for the data. To distinguish the population parameters from the sample parameters, the following terms are used:

Population mean = \( \mu \) (Greek "mu")
Population variance = \( \sigma^2 \) (Greek "sigma")

Without examining the entire population, it is impossible to know the correct values of \( \mu \) and \( \sigma^2 \). However, under certain conditions, it may be appropriate to estimate these values on the basis of the corresponding sample parameters \( \bar{x} \) and \( s^2 \).

ERROR TYPES

The general procedure in statistical analysis is to form a hypothesis, about the true mean, \( \mu \), of a set of accident data, and then to perform a test to determine if the hypothesis should be accepted or rejected. Even in the most carefully conducted tests, there is a possibility of making an error. The error is due primarily to the uncertainty associated with accidents. Two classifications of error will be considered:

Type I - the null hypothesis is rejected when it is actually true.
Type II - the null hypothesis is accepted when it is actually false.

The probability of committing type I error is referred to by symbol \( \alpha \) (Greek "alpha"), the probability of making a type II error is referred to by the symbol \( \beta \) (Greek "beta"). It is, of course, desirable to have \( \alpha \) and \( \beta \) be as small as possible. In most cases, the analyst has the opportunity of selecting a value of \( \alpha \), which is also called the level of significance. Typical values for \( \alpha \) are 0.1, 0.05 and 0.01.

Another term which is frequently used in statistical analysis is the level of confidence. It reflects the probability of accepting the null hypothesis when it is actually true and is equal to one minus \( \alpha \). The frequently used values for the level of confidence are 0.90, 0.95 and 0.99.

Levels of significance and confidence may also be expressed in percentages or odds. These expressions may be more easily understood by non-technical users of this manual.

CENTRAL TENDENCY OF A DISTRIBUTION

Because the locations that receive highway safety improvements usually are known for their extreme number of accidents or accident rates, there is a possibility that the phenomenon known as "regression to the mean" will affect the outcome of the treatment evaluation. This is the tendency of the accident rate for a given location with an extreme value in one sampling period to "regress", or move closer, to its actual mean in subsequent periods. For example, if it is assumed that accident occurrences at a given location are random, the value for the rate in accidents per mile on rural interstate highways is 4.2 would be:

\[ H_0: \mu = 4.2 \]
\[ H_1: \mu \neq 4.2 \]

The analyst usually can specify the null hypothesis with which he is concerned. Depending upon the specific problem, however, there are several alternate hypotheses which may be of concern. In addition to the one shown above, the alternate hypotheses \( H_1: \mu < 4.2 \) or \( H_1: \mu > 4.2 \) could be considered.

Figure A-1. Distribution Having the Same Means and Different Variances
Appendix B

COMPLEMENTARY METHODS OF IDENTIFYING HAZARDOUS LOCATIONS

This Appendix describes procedures for conducting each of the complementary methods listed below.

- Roadway oriented
  - Skid Testing
  - Hazard Indicator Reporting
  - Correlation of Geometrics and Accidents
  - Accident Risk Factor
  - Formula Methods
  - Field Observations

- Driver oriented
  - Conflicts Analysis
  - Speed Distribution Skew
  - Correlation of Speed Changes with Accident Rates
  - Correlation of Accident Rate and Minimum Headway
  - Physiological Response Testing

Several states have begun routine skid testing of their state highways under both wet and dry conditions in an attempt to identify those locations that are or can become slippery when wet. This testing may be done at high or low speed. (81) Many of the states calculate a "skid number" that reflects the severity of the condition at each location. These numbers are used to establish priorities for an anti-skid program.

**a. Procedure**

A detailed description of the procedure for using skid testing to identify hazardous locations is documented in Highway Research Record 1376 and NCHRP Synthesis of Highway Practice #14.

**Discussion**

The assumption behind skid testing is that the lack of friction, as measured by skid resistance, is a measure of a location's potential for skidding accidents.

The basic data requirement of skid testing is the coefficient of sliding friction of the location under study for both wet and dry conditions.

The initial skid resistance and deceleration speed gradient on asphalt concrete depends mainly on the shape of the coarse aggregates, whether rounded or angular. On Portland cement, the surface texture or finish determines initial skid resistance and deceleration speed gradient. The resistance of the surface to wear determines to what extent skid resistance is retained over the service life of the pavement. Friction between the tires makes the surface texture of the pavement smooth by wearing off the tops of the aggregates, by breaking coarse aggregates and by displacing fine aggregates. As a result, the cross-sectional area for water to escape is reduced.

Recent advancements in providing skid resistant pavements include specifications for bituminous construction which do not allow easily polished aggregates in the wearing surface. Remedial measures to upgrade skid resistance include overlay, slurry seals, Epoxy and grooving. New York has etched concrete pavements with hydrochloric acid. Several states, including Alabama and Maryland, have used "open-graded" asphalt overlays.

This method is designed to identify hazardous locations by the use of physical indicators of danger. It may be used on all systems.

The assumptions behind hazard indicator reporting are:

- Hazards and hazardous locations may be identified by methods other than accidents.
- Near and minor accidents occur at a higher frequency than more severe accidents.

The data requirements of the hazard indicator reporting are the correct locations and descriptions of:

- observed minor accidents;
- observed near accidents;
- evidences of dangerous incidents; and
- potential hazards.

**Discussion**

The objective of hazard indicator reporting is to identify locations or conditions that help cause or increase the severity of highway accidents. Highway agency personnel identify and analyze potentially hazardous locations "before the fact." These analyses supplement "after the fact" analyses of major accidents.

Four distinct indications of hazards are reported. They are described below.

1) **Observed Minor Accident** -- a minor accident involving some degree of property damage, but not requiring police investigation and which apparently has not been and will not be reported to a police officer. Because accident severity may depend in part upon chance, all minor accidents observed shall be reported under this procedure.
2) Observed Near Accident — a near accident, including skidding, panic stops or run-off-the-road events which do not result in injury or property damage.

3) Evidence of a Dangerous Incident — an indicator that a hazardous event that was not actually observed occurred. Skid marks, guardrail damage and tire marks are examples.

4) Potential Hazard — a physical feature which may be hazardous because it is fixed, promotes, obstructs vision, is too close to the traveled way or does not perform a desired safety function. Also, physical features within the right-of-way may promote incorrect driver decisions and make vehicles less controllable. They also may contribute to vehicle damage. For these potential hazards that cannot be corrected by routine maintenance, a hazard inventory may be developed.

Examples of potential hazards are shown in Figure B-1, (160).

- Order the list according to magnitude of the calculated rates.

Compare the hazard indicator locations against the hazardous locations developed with accident records data. Make a separate analysis of hazard indicator locations as required.

Observed potential hazard reports are processed as follows:

1. Evaluate the reports mutually to determine whether a hazard can be removed by maintenance action within the near future.

2. If a hazard is removed by maintenance action, the hazard report may be destroyed.

3. Reports of hazards which are not removable by maintenance action are batched, punched and edited.

4. Develop a hazards inventory by county and route and update it quarterly.

5. Check the hazards inventory when evaluating whether or not locations should be improved.

These data should not be the basis for an expensive state campaign to eliminate all hazards of a type. Discretion should be used to ensure effective expenditure of funds. All data shall be edited for accuracy. Reporting of locations on the Hazardous Indicator Reports should be to within 1/1000 of a mile.

The relationship between hazardous indicator report processing and procedures to identify hazardous locations using accident reports as used in Nebraska is illustrated in Figure B-2.
c. Example

Examples of hazard indicator reports are shown in Figures 8-3 and B-4.

HAZARD INDICATOR REPORT

<table>
<thead>
<tr>
<th>ROADWAY</th>
<th>GEOMETRIC FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-374</td>
<td>Maryland</td>
</tr>
<tr>
<td>142-244</td>
<td>Virginia</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OBSERVED SEVERITY</th>
<th>OBSERVED HAZARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>Minor</td>
</tr>
</tbody>
</table>

Figure 8-3

The method may be used by agencies with (1) compatible accident and geometric files and (2) reporting accuracy to ± 50 feet. Most attempts to use this method have been hampered by the lack of the second condition.

The assumptions behind the correlation of geometrics and accidents are as follows:

- There is a "cause and effect" relationship between highway geometrics and accidents.
- Correlations can identify these "cause and effect" relationships.
- The locations of these geometrics are hazardous.

The data requirements of a correlation of geometrics and accidents are:

- The locations of all accidents with an accuracy of ± 50 feet.
- The roadway geometrics for the street and highway system.

Discussion

This method of identifying hazardous locations has been used increasingly with the development of computerized regression analyses. Unfortunately, many of the results have not been too significant.

The fallacy of many of these studies is a failure to recognize that "correlation does not identify a cause and effect." For example, a recent study found a close correlation between the number of accidents and the percent of nitrous oxide in the air during the AM and PM rush hour. However, nitrous oxide would be an unlikely cause of the accidents. Instead, both the number of accidents and the percentage of nitrous oxide are likely to be related to increases and decreases in traffic flow.

Figure 8-4

a. Procedure

The procedure for using correlation of geometrics and accidents to identify hazardous locations is as follows:

1. Describe roadway geometries at each accident site using appropriate measurements.
2. Identify geometric elements common to accident sites.
3. Identify the locations of these common elements for the entire highway system.
4. Determine the correlation between the occurrence of accidents and the occurrence of these common geometric elements. Many computer installations have programs to determine the correlation.
5. Classify the locations of the geometric elements with a high coefficient of correlation as hazardous.

b. Example

An example of a correlation of total accident rates on conventional two-lane highways with three or four geometric features present in NCHRP Report 047 is shown in Figure 8-5.
This methodology is applicable to rating hazardous locations based on the number of hazardous events occurring at the location and the accident history.

With further development and testing, the method may prove to be applicable for identifying hazardous locations.

The assumption behind the accident risk factor method is that the rating assigned to each factor are measures of the relative hazard at a location.

The data requirements of the accident risk factor method are:

- the accident history of the location
- the frequency of a hazardous event
- the probability of an accident resulting from a hazardous event

Discussion

This approach to ranking hazardous locations was proposed in the December 1971 issue of the Journal of Safety Research. (52)

This technique develops a "risk" factor, which is a function of hazard exposure, consequences of the hazardous event and the probability of the hazardous event occurring or leading to some adverse consequence.

\[ R = (C)(F)(P) \]

Where:

- **C** = Consequences--the most probable results of a potential accident resulting from identified hazardous events, including injuries and property damage. The rating selected depends on an appraisal of the entire situation surrounding the hazard and accident experience. Factor 1 in Figure B-1 gives degrees of consequence ranging from minor to catastrophic. A numerical rating associated with each level appears in the column at the right. If an identified hazard has the potential of producing a catastrophe involving numerous fatalities, damages over $1,000,000 and major distribution of activities, the consequence factor will have a rating of 100. The rest of the values may be read directly from the remaining items under Factor 1.

- **F** = Exposure--the frequency of a hazardous event--based on identifying a hazard and persons or activities that can start an accident sequence as a result of a hazardous event. Factor 2 in Figure B-1 gives the various levels of exposure and the numerical rating associated with each level. Selection of the appropriate exposure level is based on observation, past experience and knowledge of the activity concerned. Events that occur continuously, or many times daily, receive a rating of 10; events that are only remotely possible receive a rating of 0.5.

- **P** = Probability--the likelihood that, once the event occurs, the complete accident sequence will follow with the necessary timing and coincidence to result in the accident and consequences. This is determined by considering the cause-and-effect relationships from event to consequence. Factor 3 in Table B-1 gives various probability levels and ratings.

A cost justification score, J, can be obtained by dividing the risk factor by the cost factor and the degree of correction.

\[ J = \frac{R}{(CF)(DC)} \]

Where:

- **CF** = Cost Factor--the cost (in dollars) of the proposed countermeasure or improvement.
- **DC** = Degree of Correction--an estimate of the effectiveness of the proposed measure in results of the degree to which the hazard will be reduced.

Formulas

These methods can be used to rank hazardous locations. With further testing and development, formula methods may prove to be applicable to identifying hazardous locations. The assumptions behind the formula methods is that relative hazard can be calculated by using measurable independent variables. The data requirements of the formula methods depend on the independent variables required for calculation. Several attempts have been made to identify hazardous locations by using formulas that include factors other than accidents.

One study by Crowther and Shumate (38) achieved reasonable success (R = 0.703) predicting the total number of multiple vehicle accidents per mile over a period of four years of daylight, excluding bad weather, with the formula:

\[ Y = 2.834 \times 172.655A + 610.139B + 1720.888C - 962.097D + 45.588E \]

Where:

- **Y** = Total number of multiple vehicle accidents per mile over a period of four years of daylight, excluding bad weather
- **A** = Traffic volume in vehicles per second
- **B** = Headways less than two seconds per second of sampling time, direction 1
- **C** = Headways less than two seconds per second of sampling time, direction 2
- **D** = Passes per mile per second of sampling time
- **E** = Meetings per mile per second of sampling time

Formulas traditionally have been used to rate the relative hazard of railroad grade crossings. One of the most common is the exposure formula:

\[ \text{Exposure} = (\text{Average 24-hour automobile volume})(\text{Average 24-hour train volume}) \]
This formula is used often to determine the type of protection that is warranted, for example, flashing lights, flashing lights and gates, or grade separations.

Another popular formula used to rate the relative hazard of railroad crossings is the Peabody and Dimnick formula, also known as the BPR formula. \( A_s = 1.28 \left( \frac{0.170 + 0.151}{P_c} \right) + K \)

Where:
- \( A_s \) = Expected number of accidents in 5 years
- \( V \) = Average 24-hour traffic volume
- \( T \) = Average 24-hour train volume
- \( P_c \) = Protection coefficient
- \( K \) = Additional parameter

Additional formulas for railroad crossing hazard indexes are described in detail in NCHRP Report 550 (143) and Chapter 1 of Traffic Control and Roadway Elements - Their Relationship to Highway Safety (6).

a. Procedure

The procedure for using the formula methods to identify hazardous locations is:

1. Determine values for all necessary inputs.
2. Calculate the hazard rating using the selected formula.

b. Alternative Procedure

Steps for using the alternative procedure are:

1. Obtain copies of accident reports.
2. Drive the locations where accidents have occurred.
3. Note and report conditions which could have contributed to the accident.

These observations can be made during the routine travels of highway agency personnel such as maintenance foremen.

Field Observation

Field observation is always applicable to all systems. It is most valuable when observers are taught an understanding of accident causation.

The assumption behind field observation is that hazardous locations can be identified by a trained observer.

There are normally no data requirements of field observations. However, if field personnel are provided copies of accident reports they may make observations more selectively.

Many hazardous locations are obvious to drivers and additional hazardous locations can be identified by trained observers. These observations may be made during routine field trips or during special trips over a highway section experiencing a high accident frequency. Using this method, hazardous locations are identified by judgment. For example, an unlighted intersection, by intuition, is more hazardous than a lighted one. Also, a steep fill slope may be judged hazardous because a vehicle out of control would be likely to turn over. Hazards identified in this way may not always be the site of more than average accidents because drivers, recognizing the hazards, may drive more cautiously.

The photologging systems being implemented in most states would be adaptable to this method of identifying hazardous locations.

b. Procedure

Steps for using field observation to identify hazardous locations are:

1. Drive the highway system.
2. Note those locations that appear to be hazardous.

Conflicts Analysis

With further development and testing, conflicts analysis may prove to be applicable for identifying hazardous locations. Currently, it can be used as a measure of change in traffic hazard characteristics between the periods before and after improving a location.

The assumptions behind conflicts analysis are:

- Each traffic conflict is a potential accident.
- The volume of conflicts is a measure of the potential for accidents.
- Different types of conflicts are indicative of different types of accidents.

A report of potential hazard or traffic flow problem is the basis for studying conflicts. The following data must then be collected in the field:

- Numbers of conflicts within individual traffic lanes
- Volume of traffic by traffic lanes
- Time of day
- Weather
- Lighting
- Surface conditions.

A traffic conflict is presumed to occur when the paths of two vehicles impinge on each other, or one on the other, by reason of differences in direction or speed, so that a collision could be caused by driver error. In other words, a traffic conflict is a potential accident. Relative hazard can be determined by counting and analyzing the number of traffic conflicts at a highway site.

Four common types of conflicts are shown in Figure B-6. In each case, vehicle \( f_1 \) is the offending vehicle and vehicle \( f_2 \) is the offended vehicle.
Conflicts analysis has been proposed both for identifying hazardous locations and for prescribing applicable improvements. The most promising use is for the prescription of applicable improvements. (See the detailed discussion in Chapter Three of the Users' Manual.)

a. Procedure

Steps for using conflicts analysis to identify hazardous locations are:

1. Obtain traffic volume counts.
2. Count and classify traffic conflicts.
3. Analyze the locations with a high number of conflicts.

The laws of chance decree that such speeds will be distributed randomly unless outside factors affect the distribution. A random distribution weights heavily to the middle and tapers off "uniformly" toward the ends as shown in Figure 8-7.

![Random Distribution](image)

Figure 8-7

Random Distribution

If the distribution profile in a random distribution is sliced down the middle, one side will be the mirror image of the other side.

When something other than "randomness" affects the distribution of speeds, "skews" occur as indicated in Figure 8-8.

![Skewed Distribution](image)

Figure 8-8

Skewed Distribution

Speed Distribution Skew

Most agencies conduct speed studies. These data may be used to analyze the distribution of speeds. With further development and testing, this method may prove to be applicable for identifying hazardous locations.

The assumption behind speed distribution skew is that accident occurrences increase as speed differentials between vehicles increase. Therefore, a skewed speed distribution representing wide speed differentials is indicative of potential hazard.

The data requirements of speed distribution skew are:

- Spot speed data.
- Type of location.
- Geometrics—sight distance.

This method, proposed by 3M Corporation in The Price of Not Walking (23), asks the question, "How much of a factor is speed in accident frequency?"

Several research studies sought to answer that question. The best answer found was that speed is inversely related to accident frequency up to about the 85th percentile speed. After that point, it correlates positively. In other words: slow speeds contribute to accident frequency, average to slightly high speeds reduce frequency, and very high speeds increase frequency.

On this evidence, 3M concluded that: "a driver who drives slightly faster than average has fewer accidents per mile driven. Drivers who go either much faster or slower than average have more accidents per mile driven."

The following is a paraphrase of the 3M study conclusions.

- This should hold true for vehicle speeds anywhere. Unless something affects the distribution of these speeds, they should be random. 3M does not indicate how the random distribution may be influenced by legal speed limits.

When the actual distribution of vehicle speeds is skewed, an abnormal situation exists. If the skew is negative (left or slow), 3M theorizes that some drivers are having perception problems—or that more cautious drivers, with higher margins for error, have entered the traffic. On a positive (right or faster) skew, 3M concludes that either more "reckless" drivers have entered the traffic—or that a perceptual phenomenon leads some drivers to think the road is "safer" than it actually is.

Procedure

Steps for using speed distribution skew to identify hazardous locations are:

1. Obtain available spot speed data.
2. Evaluate speed distributions.
3. Analyze locations where the distribution is skewed.
Correlation of Speed Changes With Accident Rates

With further development and testing, this method may prove to be applicable for identifying hazardous locations.

The assumption behind the correlation of speed changes with accident rates method is that the number of vehicle speed changes is an indication of the accident potential of a section of highway.

In its study, Developing Traffic Flow Indices for the Detection of High Accident Potential Highways in North Carolina (27), North Carolina State University found a correlation of the mean number of absolute 4 MPH speed changes with accident rate for 5 out of 6 locations tested. The data are shown in Figure B-9.

Correlation of Accident Rate and Minimum Headway

This method provides an additional use for available headway data. With further development and testing, this method may prove to be applicable for identifying hazardous locations and worthy of special data collection. However, it is recommended that the operating expenses be evaluated. It could be an expensive method.

The assumption behind the correlation of accident rate and minimum headway is that the potential hazard increases when relative velocity is high and headways are short.

The data requirements of the correlation of accident rate and minimum headway are:

- Headway measurements
- Speed data.

In NCHRP Report 551 (135), Rockwell and Treiterer hypothesized, "If the relative velocity is high and the headway is short, a dangerous situation exists." To test this hypothesis, they performed a least squares analysis of headway distribution (reaction time) vs. accident rate to test this hypothesis. The results of this analysis are:

<table>
<thead>
<tr>
<th>Reaction Time (sec)</th>
<th>Minimum Headway</th>
<th>Coefficient of Correlation (R)</th>
<th>R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>44</td>
<td>0.64</td>
<td>0.414</td>
</tr>
<tr>
<td>0.75</td>
<td>66</td>
<td>0.62</td>
<td>0.383</td>
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<td>88</td>
<td>0.59</td>
<td>0.345</td>
</tr>
<tr>
<td>1.25</td>
<td>110</td>
<td>0.63</td>
<td>0.395</td>
</tr>
<tr>
<td>2.00</td>
<td>150</td>
<td>0.60</td>
<td>0.358</td>
</tr>
</tbody>
</table>

A graphical representation of the correlation and the linear relationship developed for a minimum headway of 44 feet is shown in Figure B-10.

The speed change data was obtained by using the Greenshield-Platt Drivometer— which measured the number of absolute 4 MPH speed changes per minute during a particular run.

a. Procedure

Steps for using the correlation of speed changes with accident rates to identify hazardous locations are:

1. Measure the number of absolute 4 MPH speed changes at appropriate locations.
2. Analyze the locations with an above average number of 4 MPH speed changes.

The authors concluded: "Any program which is successful in reducing the number of vehicles following at short headways is likely also to reduce the accident rate."

Thus, likely hazardous locations are those where there is a large percentage of vehicles operating at less than the minimum reaction headway.

a. Procedure

The procedure for using correlation of accident rate and minimum headway to identify hazardous locations is:

1. Measure the velocity and headways at appropriate locations.
2. Analyze those locations with high velocities and short headways.
Physiological Response Testing

 Physiological response testing requires (1) specialized equipment, not ordinarily found in a highway agency, and (2) tight control over the selection of test subjects. Currently, this method is limited to research projects.

The assumptions behind physiological response testing are:

- Hazard is directly related to tension created by the driving task.
- Tension created by the driving task may be measured by monitoring human subjects performing the driving task.

The data requirements of physiological response testing are readings of physiological response monitoring devices correlated with highway location, speed, time of day and traffic.

Galvanic skin response has been used on at least one research project. The resulting volume of data is extremely voluminous and requires extensive data reduction.

Heart beat measurements tend to require less data and are a relatively reliable measure of driving stress.

A major difficulty in using human responses is the variability among people. This variability requires extensive control in the selection of subjects and the conduct of the data collections.

a. Procedure

The general procedure for using physiological response testing to identify hazardous locations is:

1. Drive the highway system while monitoring the physiological responses of the driver.
2. Analyze those locations where the driver was under a high amount of tension.

Binomial Test - Normal Approximation

The procedure for using the Normal Distribution Test to determine if accident characteristics are significant is described below.

1. Establish the hypothesis to be tested. Using the terminology of Appendix A, these are generally of the form:
   - $H_0$: An accident characteristic at a particular site is identical to that at a larger group of reference sites.
   - $H_1$: An accident characteristic at a particular site is greater than (or less than) that at a larger group of reference sites.

2. Select a level of confidence (0.95 is recommended).

3. Determine a value for $Z$ from the table below:

<table>
<thead>
<tr>
<th>Level of Confidence</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.995</td>
<td>2.576</td>
</tr>
<tr>
<td>0.990</td>
<td>2.326</td>
</tr>
<tr>
<td>0.950</td>
<td>1.645</td>
</tr>
<tr>
<td>0.900</td>
<td>1.282</td>
</tr>
<tr>
<td>0.800</td>
<td>0.842</td>
</tr>
</tbody>
</table>

4. Calculate $z$:

$$ z = \frac{X - \bar{X}}{\sqrt{\frac{X(100-X)}{n} + \frac{N-n}{N-1}}} $$

Where:
- $\bar{X} =$ mean percentage of that type of accident at similar locations
- $N =$ total number of accidents at similar locations
- $X =$ percentage of the given type of accident at the location under study
- $n =$ total number of accidents at the location under study

5. Compare $z$ to $Z$.

If $z$ is greater than $Z$, (or less than $Z$), the null hypothesis, $H_0$, must be rejected at the selected level of confidence.

APPENDIX C

STATISTICAL TESTS FOR SIGNIFICANT ACCIDENT CHARACTERISTICS

The recommended statistical tests for significant accident characteristics are:

- Binomial Test - Normal Approximation

- Poisson Distribution Test

- Chi-Square Distribution Test

These tests are used to determine if an unusually large number of accidents of a certain type were observed at a particular site. For more information on statistical testing, see bibliography references 20, 44, 57, 69, 107 or 144.
c. Example
At a hazardous location, eighteen of the sixty accidents occurred on wet pavement.

<table>
<thead>
<tr>
<th>Pavement Condition</th>
<th>Study Site</th>
<th>Similar Locations Statewide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>18</td>
<td>400</td>
</tr>
<tr>
<td>Other</td>
<td>42</td>
<td>1,600</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>2,000</td>
</tr>
</tbody>
</table>

Because the number of accidents is greater than 50 and the number of wet pavement accidents is greater than 5, use the Normal Distribution Test.

1. \( H_0: \) percent of wet pavement accidents at the study site is identical to the percent of wet pavement accidents at similar statewide locations

2. Level of Confidence = 95\% = 0.950

4. \[ z = \frac{30 - 20}{\sqrt{\frac{20(180)}{60} + \frac{2,000 - 60}{1}}} = 1.96 \]

5. Since \( z \) is greater than \( Z_0 \), the null hypothesis must be rejected, and it must be concluded at the 95\% confidence level that the percent of wet pavement accidents at this site is significantly higher than the percent at similar locations statewide.

Poisson Distribution Test

The procedure for using the Poisson Distribution Test to determine if accident characteristics are significant is described below.

1. Calculate the expected number of accidents, \( m = nP \)

Where:
- \( n \) = total number of accidents at the location under study
- \( P \) = percentage of that type of accident at similar locations expressed as a decimal

2. Calculate the probability of fewer than \( K \) accidents, \( P(<K) \).

\[
P(<K) = P(0) + P(1) + \ldots + P(K) = \sum_{i=0}^{K} e^{-m} \frac{m^i}{i!}
\]

3. By subtraction \( P(>K) = 1 - P(<K) \). This gives the probability of the event of finding \( K \) or more accidents at this site when the expected number of accidents is \( m \).

4. If \( P(>K) \) is small, say less than .10, conclude that this site has an unusually large number of accidents compared to other similar statewide locations.

c. Example
At a hazardous location, 5 of the 12 accidents occur on wet pavement.

Chi-Square Distribution Test

The procedure for using the Chi-Square Distribution Test to determine if accident characteristics are significant is described below.

1. Select a Level of Confidence. (0.95 is recommended)

2. Determine a value for \( \chi^2 \) from the table below.

<table>
<thead>
<tr>
<th>Level of Confidence</th>
<th>( \chi^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.995</td>
<td>7.879</td>
</tr>
<tr>
<td>0.990</td>
<td>6.635</td>
</tr>
<tr>
<td>0.975</td>
<td>5.024</td>
</tr>
<tr>
<td>0.950</td>
<td>3.841</td>
</tr>
<tr>
<td>0.900</td>
<td>2.706</td>
</tr>
<tr>
<td>0.800</td>
<td>1.642</td>
</tr>
</tbody>
</table>

3. Calculate \( \chi^2 \)

For study locations where \( Fe \) is fewer than 100 accidents,

\[
\chi^2 = \sum \frac{(Fo - Fe)^2}{Fe}
\]

For study locations where \( Fe \) is greater than 100 accidents,

\[
\chi^2 = \sum \frac{(Fo - Fe)^2}{n}
\]

Where:
- \( Fo \) = the observed number of a given type of accident at the location under study
- \( Fe \) = the expected number of a given type of accident at the location under study
- \( n \) = total number of accidents at location under study
- \( P \) = percent of a given type of accident at similar locations

4. Compare \( \chi^2 \) to \( \chi^2 \) at the 95\% confidence level.
1. Level of Confidence = 0.95 (95 out of 100)

2. \( X^2 > x^2 \) is less than \( X^2 \). Therefore, the 10 wet pavement accidents at the location under study are not significantly unusual.

### Table C-1

<table>
<thead>
<tr>
<th>Pavement Condition</th>
<th>Study Site</th>
<th>Similar Locations Statewide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>10</td>
<td>400</td>
</tr>
<tr>
<td>Other</td>
<td>20</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>2,200</td>
</tr>
</tbody>
</table>

- Example

At a hazardous location, 10 out of 30 accidents occur on wet pavement. The data are of expected quality; therefore, use the Chi-Square Test to determine whether or not the accident experience at the study site is significantly from the state-wide experience.

1. Level of Confidence = 0.95 (95 out of 100)
2. \( X^2 = 3.861 \)
3. Calculate \( X^2 \)

\[
X^2 = \frac{\left(10 - 6 \right) - \left(120 - 24 \right)}{6} + \frac{\left(20 - 15 \right) - \left(30 - 24 \right)}{15}
\]

\[
= 2.04 + 0.51 = 2.55
\]

4. \( X^2 < x^2 \), therefore, the 10 wet pavement accidents at the location under study are not significantly unusual.
Table C-1 (Continued). Poisson Cumulative Distribution

<table>
<thead>
<tr>
<th>n</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>1.000</td>
</tr>
<tr>
<td>10.0</td>
<td>0.999 1.000</td>
</tr>
<tr>
<td>10.5</td>
<td>0.999 0.999 1.000</td>
</tr>
<tr>
<td>11.0</td>
<td>0.998 0.999 1.000</td>
</tr>
<tr>
<td>11.5</td>
<td>0.996 0.998 0.999 1.000</td>
</tr>
<tr>
<td>12.0</td>
<td>0.994 0.997 0.999 0.999 1.000</td>
</tr>
<tr>
<td>12.5</td>
<td>0.991 0.995 0.998 0.999 0.999 1.000</td>
</tr>
<tr>
<td>13.0</td>
<td>0.986 0.992 0.996 0.998 0.999 1.000</td>
</tr>
<tr>
<td>13.5</td>
<td>0.980 0.989 0.994 0.997 0.999 0.999 1.000</td>
</tr>
<tr>
<td>14.0</td>
<td>0.971 0.983 0.991 0.995 0.999 0.999 1.000</td>
</tr>
<tr>
<td>14.5</td>
<td>0.960 0.976 0.986 0.992 0.996 0.998 0.999 1.000</td>
</tr>
<tr>
<td>15.0</td>
<td>0.947 0.967 0.978 0.988 0.994 0.997 0.999 1.000</td>
</tr>
</tbody>
</table>
Branching Analysis

Branching analysis helps to place the contributing circumstances in perspective and offers an estimate of the probable effectiveness of a potential improvement.

The assumption behind branching analysis is that the cause-and-effect relationship of accidents follows a logical flow which can be documented.

The data requirements of branching analysis are:

- completed accident reports with detailed narratives
- results of in-depth field studies— if they are available.

This method of analysis is similar to fault tree analysis. The primary difference is that probabilities of occurrence are not developed, although numbers of occurrences may be included. The sequence of events that may lead to a collision are identified. By following the successive branches, identification of the most common sequence of events is possible. This should allow the analyst to identify the problem and select applicable improvements. This technique is adaptable to computer analysis.

a. Procedure

The steps for using branching analysis to prescribe applicable improvements are:

1. Outline sequences of events leading to each accident as branches on a tree.
2. Identify each event and its interrelationship.
3. Sort and count accident data to obtain numbers of accidents fitting a particular branch pattern.
4. Identify the frequency of each branch occurrence.
5. Select improvements that interrupt the prevalent sequences of events.

b. Example

This method is an analysis of contributing factors. It was used by Operations Research, Incorporated, in their report, Pedestrian Safety: The Identification of Precipitating Factors and Possible Countermeasures (15) to analyze pedestrian-vehicle collisions. An example of their use of branching analysis on a sample of 2162 is shown below. While designed specifically for pedestrian accidents, this analysis could also be applied to other types of collisions.

![Figure D-1](image1)

Branching Analysis Example

In Figure D-1, the most common sequence of events is 1 - 2 - 4 - 8 - 14, a pedestrian running across traffic at a location other than a crosswalk and being struck by a vehicle moving at a sustained speed.

Example of applicable improvements for this location are:

- prohibiting mid-block crossing by pedestrians
- providing a mid-block crosswalk and a traffic signal
- providing an overpass or a tunnel for pedestrians.

Behavioral Sequence Model

The behavioral sequence model is a specialized event tree in which a specific set of behavioral event categories is assumed. Using these categories, a chain of events is developed for each participant contributing to the accident. The categories in each chain are as follows:

- Search -- For example, a pedestrian searching for potential threats
- Detection -- Perceiving a threat or the presence of the other participant
- Evaluation -- Recognizing danger
- Decision -- Determining the proper action for successful avoidance of danger
- Action -- Performing of proper action
- Vehicle Response -- Obtaining desired mechanical response
- Roadway Response -- Desired functioning of roadway element (Friction between tire and roadway maintained above skid level or energy attenuation device functioning properly).

The assumption behind the behavioral sequence model is that the human element is the major factor in accident causations.

The data requirements of the behavioral sequence model are complete accident reports with detailed narratives and, if available, the results of in-depth field studies.
This basic model was expanded in Figure 0-3 to include the factors that influence the driver and vehicle as well as the pedestrian and the environment.

In normal driving, a driver faces a continuing series of "true critical points." Although some points are related, in most cases, they are independent of previous points. One situation may intervene between a previously perceived situation and create a new and often more immediate critical point.

The driver's comprehension produces his personal version of the true critical point called a "mental point." This is the point the driver believes to be the last instant in which he can avoid an accident. The driver's comprehension results from his perception, mainly visual, of both the danger and the avoidance forces.

The relationship between the true critical point and the mental point is shown in Figure 0-5.

The question is whether the wrong mental point or the inadequate margin for error is the cause of accidents. Does an accident happen because the driver guessed wrong or because he took too big a gamble?

The conclusion of 3M is that placing the mental point past the true point is the cause of accidents. They reason that in no instance would a driver put his action point beyond his mental point unless he was intentionally seeking to have an "accident."

a. Procedure

In attempting to identify the problem and to prescribe applicable improvements, the analyst should ask:

1. Why did the driver place his mental point past the true point?
2. Was there an incorrect perception of the danger?
3. If so, what can be done to correct this lack of perception?
4. What can be done to extend the true critical point?
Operation Analysis

This method of analysis aids the analyst in understanding erratic driver actions that cause accidents at a particular location by asking the question, "Were the drivers required to observe many events and make several decisions in a short period of time?"

With further development and testing, this method may prove helpful in prescribing applicable improvements.

The assumptions behind operations analysis are:

- The more observations a driver makes, the more decisions he must make.
- The more decisions a driver makes, the more chance of incorrect decisions.
- The more incorrect decisions the driver makes, the more chance accidents will occur.

The data requirements of operations analysis are the observations and decisions that a driver must make when approaching the hazardous location.

This method was developed by Fletcher N. Platt (127) of the Ford Motor Company in 1958. It has served as the basis for the development of several models of driver/environmental interactions.

As the motorist drives down the street or highway he observes a wide variety of features and events. Examples of events and features observed by a driver are listed below.

Assume traffic events occur at a rate of 200 events per mile. The odds that other related results will occur are demonstrated below.

<table>
<thead>
<tr>
<th>Results</th>
<th>Odds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decisions at one per 10 events</td>
<td>20 per mile</td>
</tr>
<tr>
<td>Errors at one per 40 decision</td>
<td>1 every two miles</td>
</tr>
<tr>
<td>Near collisions at one per 250 errors</td>
<td>1 every 300 miles</td>
</tr>
<tr>
<td>Collisions at one per 122 near collisions</td>
<td>1 every 61,000 miles</td>
</tr>
<tr>
<td>Fatalities at one per 250 collisions</td>
<td>1 every 16,000,000 miles</td>
</tr>
</tbody>
</table>

The logic of this approach to traffic safety is substantiated by data showing low accident rates on freeways where few items change and drivers have to make very few decisions. When the traffic volumes increase and drivers have more events to observe and more decisions to make, the accident rates increase.

Operations analysis does not consider the problem of "freeway hypnosis" which often results when drivers have very few or no events to observe. There may be an optimum rate of observations that keeps drivers stimulated but not overtaxed.
The number-of-occident methods are not recommended because they are reliable only if traffic volumes in the after period are the same as in the before period.

The accident rate and severity rate methods are detailed on the following pages.

Definitions—Appendix E

The variables used in the formulas in this appendix are defined below.

\[ C_a = \text{average cost of an overage accident} \]
\[ C_f = \text{average cost of a fatal accident} \]
\[ C_l = \text{average cost of a property-damage-only accident} \]
\[ L = \text{section length in miles} \]
\[ P_a = \text{average percentage for a severity class} \]
\[ P_d = \text{systemwide average percent of accidents that are fatal, expressed as a decimal} \]
\[ P_e = \text{systemwide average percent of accidents that are injuries, expressed as a decimal} \]
\[ P_p = \text{systemwide average percent of accidents that are property damage only, expressed as a decimal} \]
\[ P_{f%} = \text{expected fatal severity rate reduction percentage, expressed as a decimal} \]
\[ P_{i%} = \text{expected injury severity rate reduction percentage, expressed as a decimal} \]
\[ P_{p%} = \text{expected property-damage-only severity rate reduction percentage, expressed as a decimal} \]
\[ V_f = \text{future traffic volume in vehicles per day (VPD)} \]
\[ Z = \text{A constant in the quality control equation} \]

**ACCIDENT RATE METHODS**

**Reduction to an Average Accident Rate**

This method of estimating accident reduction benefits is applicable when average rates are available for various locations and should be used only when accident reduction forecasts for individual improvements are not available. The average rates used in identifying hazardous locations may be used.

The assumption behind the Reduction to an Average Accident Rate method is that all applicable improvements will reduce the accident rate to the systemwide average for the type of location.

The data requirements of the Reduction to an Average Accident Rate method are:

- Systemwide average accident rate for each type of location, for example, a 4-leg, traffic actuated, signalized intersection
- Previous accident experience and traffic volumes at the location.

**Procedure**

Estimates of accident reduction based on assumed reduction to an average accident rate are calculated in this manner:

1. Determine the systemwide accident rate for the type of location under study.
2. Estimate the future accident rate, \( R_f \), that would occur if there would be no improvement implemented. The past average accident rates can be assumed to be applicable unless the analyst can demonstrate a change in relationships on which these rates are based. For example, the analyst may be able to demonstrate that one or more of the rates are dependent upon traffic volume, in which case the demonstrated relationships should be used.
3. Calculate the expected accident reduction for each year of the service life of the improvement.
2. Use the accident rate on the 0.4 mile expressway location under study for the past 5 years to predict the rate that would prevail for 4 years in the future if there were no improvements.

<table>
<thead>
<tr>
<th>Year</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 years ago</td>
<td>4.4 Acc/MVM</td>
</tr>
<tr>
<td>4 years ago</td>
<td>4.2</td>
</tr>
<tr>
<td>3 years ago</td>
<td>4.6</td>
</tr>
<tr>
<td>2 years ago</td>
<td>5.0</td>
</tr>
<tr>
<td>Last year</td>
<td>4.8</td>
</tr>
<tr>
<td>5 year average</td>
<td>4.6 = Rf</td>
</tr>
</tbody>
</table>

3. Calculate the annual accident reduction for the 0.4 mile section using the average accident rate for the system from the graph relating this rate to ADT.

<table>
<thead>
<tr>
<th>Year After Implementation</th>
<th>Traffic Volume (VPD)</th>
<th>Future Accident Rate (Rf)</th>
<th>Average Accident Rate (Ra)</th>
<th>Estimated Accident Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58,000 VPD</td>
<td>4.6 Acc/MVM</td>
<td>3.00 Acc/MVM</td>
<td>3.4 Acc</td>
</tr>
<tr>
<td>2</td>
<td>60,000</td>
<td>4.6</td>
<td>3.05</td>
<td>3.4</td>
</tr>
<tr>
<td>3</td>
<td>63,000</td>
<td>4.6</td>
<td>3.15</td>
<td>3.6</td>
</tr>
<tr>
<td>4</td>
<td>67,000</td>
<td>4.6</td>
<td>3.24</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Note: A simple average is developed in Step 2 in this example. Another method is to develop a trend line using Least Squares Analysis. Most elementary statistics textbooks describe the Least Squares method.

Percentage Reduction of Accident Rate

This method of estimating accident reduction benefits is applicable to all improvements for which reliable forecasts of accident reduction are available. (See Chapter 7 of the Users' Manual for the procedures for developing forecasts). The reductions can be calculated for all accident types or for each accident type (manner of collision).

The assumptions behind this method are:

- The conditions contributing to the danger of the location will continue to make the location hazardous without the application of an improvement.
- The mix of severity among accidents does not change between the before-and-after periods; thus, accident rate changes reflect changes in severity rates.

The data requirements of the percentage reduction of accident rate method are:

- post accident rates
- estimates of future traffic volumes
- expected accident rate reduction percentages
  + by accident type, or
  + for all accident types.

a. Procedure--Equal Accident Reduction of All Accident Types

Estimates of accident reduction using the rate of reduction in accident rate for all accident types method are calculated:

1. Obtain the expected accident rate reduction percentage, R%. If this percentage is not available, it should be calculated from past experience with this type of improvement.
2. Estimate the future accident rate, Rf, that would occur if there would be no improvement implemented. The post average accident rate can be assumed to be applicable unless the analyst can demonstrate a change in relationship on which this rate is based. For example, the analyst may be able to demonstrate that the rate is dependent upon traffic volume, in which case the demonstrated relationships should be used.
3. Calculate the accident reduction for each year of the service life of the improvement.

$$\text{Annual Accident Reduction} = \frac{365 (\text{VI}) (\text{Rf-Ra})}{10^6}$$  
for spot locations

$$\text{Annual Accident Reduction} = \frac{365 (\text{VI}) (\text{Rf-Ra}) (L)}{10^6}$$  
for sections
c. Procedure--Accident Reduction by Accident Type

Estimates of accident reduction using the rate of percentage reduction in accident rate by type are calculated in this manner:

1. Obtain the estimated accident rate reduction percentages, $R\%$, for each accident type.

   If these rates are not available, they may be calculated using past experience with this type of improvement. Fault tree or risk analysis may also be used to obtain these rates. (See Chapter 3 of the User's Manual for a discussion of these methods.)

2. For each type of accident, estimate future accident rates, $R^f$, that would occur if no improvement were implemented. The past average accident rates can be assumed to be applicable unless the analyst can demonstrate a change in relationships on which these rates are based. For example, the analyst may be able to demonstrate that one or more of the rates are dependent upon traffic volume, in which case the demonstrated relationships should be used.

3. Calculate the accident reduction for each accident type for each year of the service life of the improvement.

   $$\text{Annual Accident Reduction} = \frac{365 (R^f)(VF)(R%)i}{10^6} \quad \text{For spot locations}$$

   $$\text{Annual Accident Reduction} = \frac{365 (R^f)(VF)^2(R%)i}{10^6} \quad \text{For sections}$$

4. Sum all accident reductions for each year.

   d. Example

   The following is an example of estimating accident reduction using the percentage reduction of accident rate by accident type.

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Estimated Accident Rate Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head on</td>
<td>0%</td>
</tr>
<tr>
<td>Rear end</td>
<td>10%</td>
</tr>
<tr>
<td>Right Angle</td>
<td>10%</td>
</tr>
<tr>
<td>Side Swipe</td>
<td>20%</td>
</tr>
<tr>
<td>Left Turn</td>
<td>10%</td>
</tr>
<tr>
<td>Right Turn</td>
<td>20%</td>
</tr>
<tr>
<td>Others</td>
<td>0%</td>
</tr>
</tbody>
</table>

   For each type of accident, future accident rates are estimated assuming no improvement. For simplicity, use the average rates at the location for the past 4 years.

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Future Accident Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head on</td>
<td>0.2 Acc/MV</td>
</tr>
<tr>
<td>Rear end</td>
<td>0.8</td>
</tr>
<tr>
<td>Right Angle</td>
<td>1.9</td>
</tr>
<tr>
<td>Side Swipe</td>
<td>0.7</td>
</tr>
<tr>
<td>Left Turn</td>
<td>2.3</td>
</tr>
<tr>
<td>Right Turn</td>
<td>1.4</td>
</tr>
<tr>
<td>Others</td>
<td>0.3</td>
</tr>
</tbody>
</table>

   Total: 7.6

SEVERITY RATE METHODS

Reduction to an Average Severity Rate

When it is not possible to forecast the reductions in severity rates due to improvements, but average severity rates are known, this method may be used.

The reduction to the average severity rate may be for all severity classes or only those classes significantly higher than the statewide average. The latter method was developed in California.

The assumption behind the reduction to an average severity rate method is that all applicable improvements will reduce the severity rate to the system-wide average for the type of location.

The data requirements of the reduction to an average severity rate method are:

- Systemwide average severity rate for each type of location, for example, a 4-leg, traffic-actuated, signalized intersection
- Previous accident severity experience and traffic volumes at the location.

a. Procedure--Reduction of all Severity Classes that are Above Average

   Estimates of accident reduction using reductions to an average severity rate for all above average severity classes are calculated in this manner:

   1. Determine the systemwide average percentage of each severity class for the type of location under study.
   2. Determine the percentage of each accident type by severity class at the location under study.
3. Estimate the potential future accident rate, \( R_f \), that would occur if no improvement were implemented. The past average accident rate can be assumed to be applicable unless the analyst can demonstrate a change in relationship on which this rate is based. For example, the analyst may be able to demonstrate that the rate is dependent upon traffic volume, in which case the demonstrated relationships should be used.

4. Determine future traffic volumes, \( V_f \).

5. Calculate the expected accident reduction for each severity category with an above average percentage, for each year of the service life of the improvement.

   \[
   \text{Annual Accident Reduction} = \frac{365(V_f)(R_f)}{10^6} \left[ (P_f - P_{f0}) + (P_i - P_{i0}) + (P_p - P_{p0}) \right] \quad \text{For spot locations}
   \]

   \[
   \text{Annual Accident Reduction} = \frac{365(V_f)(R_f)(L)}{10^6} \left[ (P_f - P_{f0}) + (P_i - P_{i0}) + (P_p - P_{p0}) \right] \quad \text{For sections}
   \]

b. Example--Reduction of all Above Average Severity Classes

The following is an example of estimating accident reduction using the reduction to an average severity rate for all above average severity classes.

1. Determine the systemwide average percentage of each severity class.

<table>
<thead>
<tr>
<th>Severity Class</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>3.0 (Pf = 0.03)</td>
</tr>
<tr>
<td>Injury</td>
<td>23.0 (Pi = 0.23)</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>75.0 (Pp = 0.75)</td>
</tr>
</tbody>
</table>

\[
\text{E-12}
\]

\[
365(V_f)(6400)(6.5) \left[ (0.06 - 0.03) + (0.43 - 0.22) \right] = 3.2 \text{ Acc} \\
\text{E-14}
\]

2. Calculate the expected accident reduction considering only severity categories with above average percentages (percentage of property damage accidents is not above average).

\[
\text{Annual Fatal Accident Reduction} = \frac{365(V_f)(R_f)(L)}{10^6} (P_f - P_{f0}) \quad \text{for spot locations}
\]

\[
\text{Annual Injury Accident Reduction} = \frac{365(V_f)(R_f)(L)}{10^6} (P_i - P_{i0}) \quad \text{for spot locations}
\]

\[
\text{Annual Property Damage Only Accident Reduction} = \frac{365(V_f)(R_f)(L)}{10^6} (P_p - P_{p0}) \quad \text{for spot locations}
\]

This method may produce very small fatal accident reductions. But when multiplied by the high cost of fatal accidents, the benefits are substantial.

5. Determine a value of \( Z \) for that level of confidence.

\[
\begin{array}{c|c}
\text{Level of Confidence} & Z \\
\hline
0.995 & 2.576 \\
0.990 & 2.326 \\
0.980 & 2.054 \\
0.975 & 1.960 \\
0.950 & 1.645 \\
0.900 & 1.282 \\
0.850 & 1.036 \\
0.800 & 0.842 \\
\end{array}
\]

\[
\text{E-15}
\]
d. Example—By Severity Class

The following is an example of estimating accident reduction using the reduction to an average severity rate by severity class:

1. The systemwide average percentages of each severity class for the type of location under study are:

<table>
<thead>
<tr>
<th>Severity Class</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>3.5</td>
</tr>
<tr>
<td>Injury</td>
<td>28.5</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>68.0</td>
</tr>
</tbody>
</table>

2. The percentage of accidents by severity class at the location under study are:

<table>
<thead>
<tr>
<th>Severity Class</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>7.0</td>
</tr>
<tr>
<td>Injury</td>
<td>53.0</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>40.0</td>
</tr>
</tbody>
</table>

3. Estimate potential future accident rates assuming no improvements. Use the average rates at the location for the past 3 years, RF.

4. Forecast future traffic volume constant at 1,000 VPD.

5. Use a level of confidence of 0.90.


7. Calculate Critical Percentages for each year of service life.

---

**Percentage Reduction of Severity Rate**

This method of estimating accident reduction benefits is applicable to all improvements for which reliable forecasts of severity reduction are available. (See Chapter 7 of the Users Manual for the procedures for developing forecasts.) The reductions can be calculated for all accident types or for each accident type (manner of collision).

The assumptions behind this method is that the conditions contributing to the danger of the locations will continue to make the location hazardous without the application of an improvement.

The data requirements of the percentage reduction of a severity rate method are:

- estimates of future accident rates
- estimates of future traffic volumes
- expected severity rate reduction percentages by accident type, or for all accident types
- percentages of accidents by severity class
- average accident cost for all accidents and for each severity class.

a. Procedure—Equal Severity Reduction of All Accident Types

Estimates of accident reductions using the percentage reduction in severity rate for all accident types are calculated in this manner:

1. Obtain the expected severity rate reduction percentage for each severity class. If this percentage is not available, it should be calculated from past experience with this type of improvement.
2. Obtain average accident costs for fatal, injury, PDO and all accidents.
3. Obtain the percentage of accidents by severity class.
4. Estimate future traffic volumes, VF.
5. Estimate the future accident rate, RF, and project the severity cost that would occur if no improvements were implemented. The past average accident rate can be assumed to be applicable unless the analyst can demonstrate a change in relationship on which this rate is based. For example, the analyst may be able to demonstrate that the rate is dependent upon traffic volume, in which case the demonstrated relationship should be used.

---

**Severity Class**

<table>
<thead>
<tr>
<th>Severity Class</th>
<th>Critical Percentage (Ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>3.5</td>
</tr>
<tr>
<td>Injury</td>
<td>28.5</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>68.0</td>
</tr>
</tbody>
</table>

**Expected Reductions**

<table>
<thead>
<tr>
<th>Severity Class</th>
<th>Expected Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>60% (Sp% = 0.60)</td>
</tr>
<tr>
<td>Injury</td>
<td>29% (Sp% = 0.29)</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>5% (Sp% = 0.05)</td>
</tr>
</tbody>
</table>

**Average Cost**

<table>
<thead>
<tr>
<th>Severity Class</th>
<th>Average Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>$235,000 + Cf</td>
</tr>
<tr>
<td>Injury</td>
<td>11,200 + C</td>
</tr>
<tr>
<td>PDO</td>
<td>300 + Cp</td>
</tr>
<tr>
<td>All</td>
<td>2,800 + C</td>
</tr>
</tbody>
</table>

---

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E-18

E-19

E-20
3. Determine the percent of accident by severity class.

<table>
<thead>
<tr>
<th>Severity Class</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>2% (Pt = 0.02)</td>
</tr>
<tr>
<td>Injury</td>
<td>58% (Pi = 0.58)</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>40% (Pp = 0.40)</td>
</tr>
</tbody>
</table>

4. Estimate future traffic volume.

<table>
<thead>
<tr>
<th>Year After Implementation</th>
<th>Traffic Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,000</td>
</tr>
<tr>
<td>2</td>
<td>5,500</td>
</tr>
<tr>
<td>3</td>
<td>6,000</td>
</tr>
</tbody>
</table>

5. The average accident rate for past 5 years is 5.5 Acc/MV. Use an RE of 5.5 Acc/MV. The projected severity cost for the three year period is calculated in this manner:

\[
\frac{365 \times (5.5)(5,000 + 5,500 + 6,000)}{10^6} \left[ (0.02)(235,000) + (0.58)(11,200) + (0.40)(500) \right] = 377,470
\]

6. Estimates of severity cost reduction for each of the 3 years of an improvement's service life are calculated in this manner:

<table>
<thead>
<tr>
<th>Year After Implementation</th>
<th>Estimated Severity Cost Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$41,440</td>
</tr>
<tr>
<td>2</td>
<td>$45,640</td>
</tr>
<tr>
<td>3</td>
<td>$49,840</td>
</tr>
</tbody>
</table>

Total Estimated Severity Cost Reduction = $136,920

7. Estimate percent reduction in severity cost.

\[
\text{Estimated Severity Cost Reduction} = \frac{136,920}{377,470} \times 100 = 36\%
\]

In this case the projected accident reduction would have been 15%.

c. Procedure—Severity Reduction by Accident Type

Estimates of accident reduction in severity rate by accident type are calculated in this manner:

1. Obtain the expected severity rate reduction percentage for each severity class for each accident type. If this percentage is not available, it should be calculated from past experience with this type of improvement.
2. Obtain average accident costs for fatal, injury, PDO and all accidents.
3. Calculate the percentage of accidents by severity class for each accident type.
4. Estimate future traffic volume, Vf.
5. Estimate the future accident rate, Rf, and project the severity costs for each type of accident that would occur if no improvements were implemented. The past average accident rate can be assumed to be applicable unless the analyst can demonstrate a change in relationship on which this rate is based. For example, the analyst may be able to demonstrate that the rate is dependent upon traffic volume, in which case the demonstrated relationships should be used.

6. Calculate and sum the estimates of severity cost reduction for each accident type to each year of the service life of the improvement.

\[
\text{Annual Severity Cost Reduction} = \sum \left( \frac{365 \times (5.5)(Vf)}{10^6} \right) \left[ (Pi)(5\%)(Cp)+(Pi)(5\%)(Cp)ight]
\]

For locations

\[
\text{Annual Severity Cost Reduction} = \sum \left( \frac{365 \times (5.5)(Vf)}{10^6} \right) \left[ (Pi)(5\%)(Cp)+(Pi)(5\%)(Cp)ight]
\]

For sections

7. Calculate the estimated percent reduction in severity cost by dividing the accumulated annual severity cost reductions by the total projected severity cost for the "no improvement" alternative, and multiply by 100.

d. Example

The following is an example of estimating accident reduction using the percentage reduction of severity rate by accident type.

1. The expected accident rate reductions by severity class for each type of accident are:

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Accident Severity Reduction Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
</tr>
<tr>
<td>Head on</td>
<td>90%</td>
</tr>
<tr>
<td>Rear end</td>
<td>40%</td>
</tr>
<tr>
<td>Right angle</td>
<td>80%</td>
</tr>
<tr>
<td>Others</td>
<td>10%</td>
</tr>
</tbody>
</table>

2. Use NHTSA cost estimates.

<table>
<thead>
<tr>
<th>Severity Class</th>
<th>Average Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>$235,000</td>
</tr>
<tr>
<td>Injury</td>
<td>$11,200</td>
</tr>
<tr>
<td>PDO</td>
<td>$500</td>
</tr>
<tr>
<td>All</td>
<td>$2,800</td>
</tr>
</tbody>
</table>

3. The actual percentages of accidents by severity class for each accident type are:

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Percentages of Accidents by Severity Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
</tr>
<tr>
<td>Head on</td>
<td>3%</td>
</tr>
<tr>
<td>Rear end</td>
<td>1</td>
</tr>
<tr>
<td>Right angle</td>
<td>2</td>
</tr>
<tr>
<td>Others</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
</tr>
</tbody>
</table>

4. Estimate future traffic volume.

<table>
<thead>
<tr>
<th>Year After Implementation</th>
<th>Traffic Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7,500</td>
</tr>
<tr>
<td>2</td>
<td>8,000</td>
</tr>
<tr>
<td>3</td>
<td>8,500</td>
</tr>
</tbody>
</table>

5. Average accident rate for past 5 years = 5.5 Acc/MV. Use RE = 5.5 Acc/MV. The projected severity cost for the three year period is calculated in this manner:

\[
\frac{365 \times (5.5)(7,500 + 8,000 + 8,500)}{10^6} \left[ (0.02)(235,000) + (0.62)(11,200) + (0.36)(500) \right] = 569,680
\]
6. The estimate of severity cost reduction for the three year after period is:

\[
\text{Accident type} \quad \text{Total estimated severity cost reduction} = \frac{3650.2(0.5)(24,000)}{10^5} = \text{\$17,720}
\]

\[
\text{Right angle} \quad \frac{3650.2(0.5)(24,000)}{10^5} = \text{\$74,870}
\]

\[
\text{Others} \quad \frac{3650.2(0.5)(24,000)}{10^5} = \text{\$38,130}
\]

Total estimated severity cost reduction = \$256,167

7. Estimate percent reduction in severity cost.

\[
\begin{align*}
\text{Estimated Severity Cost Reduction} &= \frac{\text{Total estimated severity cost reduction}}{100} \\
&= \frac{\text{\$256,167}}{100} \\
&= \text{\$256,167} \\
\text{Projected Severity Cost with no Improvement} &= \text{\$584,680} \\
&= \text{45%}
\end{align*}
\]

The projected accident reduction would have been 31%.

---

**Example—Weighted Severity Cost Values**

The severity cost values used by Nebraska are shown in Table E-1. Also shown are smaller numbers called Relative Severity Indexes, RSI. The RSI, besides being smaller and easier-to-use numbers, avoid expressing severity in dollars. They use the least expensive accident type (one car entering parked position) as the denominator when calculating the relative severity indexes.

**E-25**

**Table E-1**

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Multi-Vehicle</th>
<th>Urban</th>
<th>Rural</th>
<th>Multi-Vehicle</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head on</td>
<td>3.047</td>
<td>0.636</td>
<td>0.169</td>
<td>2.032</td>
<td>0.354</td>
<td>0.083</td>
</tr>
<tr>
<td>R. Angle</td>
<td>3.473</td>
<td>0.949</td>
<td>0.235</td>
<td>2.317</td>
<td>0.459</td>
<td>0.119</td>
</tr>
<tr>
<td>Others</td>
<td>3.147</td>
<td>0.818</td>
<td>0.193</td>
<td>2.460</td>
<td>0.498</td>
<td>0.125</td>
</tr>
</tbody>
</table>

**F-1**

**Alternative Methods of Evaluating Potential Improvements**

There are four basic categories of evaluations. These are:

- Evaluation methods based solely on costs. These methods can be used when the benefits from the alternatives are approximately equal or can be disregarded. These methods are not applicable to evaluating alternative highway safety improvements and, therefore, are not discussed further.

- Evaluation methods based solely on benefits. The methods can be used when the costs of the alternatives are approximately equal or can be disregarded. These methods are not applicable to evaluating alternative highway safety improvements due to budgetary restrictions and, therefore, are not discussed further.

- Evaluation methods based on both costs and benefits. These methods are divided into two categories:
  - Methods for evaluating independent alternatives
    - Benefits/cost ratio
    - Rate of Return
    - Payback period
  - Methods for evaluating mutually exclusive alternatives
    - Incremental cost/effectiveness
    - Incremental benefit/cost ratio
    - Net present worth
    - Incremental benefit/cost ratio

- Evaluation methods based on cost effectiveness. These may be used in lieu of benefit/cost comparisons when the analyst chooses to avoid assigning dollar values to death, injury and loss.

- Methods for evaluating independent alternatives
  - Cost/effectiveness ratio

- Methods for evaluating mutually exclusive alternatives
  - Incremental cost effectiveness
Definitions—Appendix F

The variables used in the formulas in this appendix are defined below:

\[ B \] = Annual Benefit

\[ B/c \] = Benefit/Cost Ratio

\[ C/E \] = Cost Effectiveness

\[ CR^n \] = Capital Recovery Factor* for \( n \) years and an interest rate \( i \)

\[ D \] = Uniform annual increase in benefit

\[ EUAB \] = Equivalent Uniform Annual Benefit

\[ EUAC \] = Equivalent Uniform Annual Cost

\[ G \] = Uniform annual increase in cost

\[ I \] = Initial cost

\[ IB/CE \] = Incremental Benefit/Cost Effectiveness

\[ J \] = Annual percent increase in benefit

\[ K \] = Annual cost

\[ m \] = Annual index of the year that takes on all values from 1 through \( n \)

\[ o \] = Uniform annual increase in cost

\[ P \] = Annual percent increase in cost

\[ PW_i \] = Present Worth Factor* for \( i \) year and an interest rate \( i \)

\[ PWOB \] = Present Worth of Benefits

\[ PWOC \] = Present Worth of Costs

\[ RR \] = Rate of Return

\[ SF \] = Sinking Fund Factor* for \( n \) year and an interest rate \( i \)

\[ SPW^n_i \] = Series Present Worth Factor* for \( n \) years and an interest rate \( i \)

\[ T \] = Terminal value

\[ \sum_{m=1}^{n} ( ) \] = Summation of the terms with the parentheses for all years 1 through \( n \)

*These values may be found in interest tables or calculated by the formulas in Figure F-2.

CALCULATION OF COMMON INPUTS

All of the methods require one or more of the following calculations:

- Equivalent Uniform Annual Cost
- Equivalent Uniform Annual Benefits
- Present Worth of Costs
- Present Worth of Benefits

The procedures for transforming estimated cost and benefit data into these formats are described in the following sections. All of the procedures assume the end-of-period convention. This means that all costs and benefits, although they may actually occur uniformly, periodically, or sporadically throughout the year, are assumed to occur as lump sum payments at the end of the year. This convention simplifies the calculations.

In the case of most highway safety improvements, it is reasonable to conclude that the annual costs, \( K \), and the annual benefits, \( B \), will remain constant from year to year. Calculations based upon this assumption are considerably simpler than those based upon the assumption of variable costs and benefits. As a practical matter, there are several factors which can contribute to such variation. These include inflation, technological changes, traffic volume changes, and other highway operational improvements. In addition, a level of uncertainty is associated with many of the cost and benefit elements. If the analyst feels that he can satisfactorily resolve all of these factors to the point where the costs and benefits of a project are more accurately described by a gradient function involving an annual increase (or decrease) in annual costs or benefits, analysis procedures are available to convert these cash flows to equivalent annual or present worth formats. A detailed discussion of these procedures, together with the appropriate tables to assist with the calculations can be found in several engineering economics textbooks. (43)(61)(168)

\[ P.4 \]

**Equivalent Uniform Annual Cost**

Costs may vary from year to year throughout the service life of an improvement. For comparison purposes, it is desirable to convert the costs to a uniform annual amount. The data requirements for calculating the equivalent uniform annual cost of an improvement are:

- initial cost
- annual costs
- terminal value
- service life
- interest rate.

- Procedure

  1. Estimate \( I \), \( K \), \( T \), and \( n \).
  2. Select an interest rate, \( i \), and obtain the appropriate table of economic factors.
  3. Calculate the EUAC as follows:

     \[ EUAC = (T) CR_n^n + K - (T) SF_n^n \]

     If the annual costs, \( K_m \), are assumed to vary from year to year over the service life of the improvement, the EUAC can be calculated by a more lengthy process

     \[ EUAC = CR_n^n (I) - \sum_{m=1}^{n} (K_m) PW_m^i - (T) SF_n^n \]

     where \( K_m \) is the annual cost (e.g., maintenance, operation) which is incurred in year \( m \), and \( PW_m^i \) is the Present Worth factor for \( m \) years at an annual interest rate of \( i \).

     The calculated EUAC represents the constant annual expenditure for \( n \) years which would be equivalent to the projected costs, at the specified interest rate.

- Example

  Find the EUAC for a safety improvement, having a twelve year lifetime, if its initial cost is $40,000, the annual maintenance and operation costs are $750/yr., and the estimated terminal value is $1,000. Assume that the appropriate interest rate is 10%.

  \[ EUAC = (T) CR_{12}^{10\%} + K - (T) SF_{12}^{10\%} \]

  \[ = (1)(40,000)(0.14676) + 750 - (1000)(0.04676) \]

  \[ = 5871 + 750 - 47 \]

  \[ = $6574/yr. \]

  At an interest rate of 10% for a 12 year period, the indicated expenditures are equivalent to a constant annual expenditure of $6,574.
Equivalent Uniform Annual Benefit

Benefits may vary from year to year throughout the service life of an improvement. For comparison purposes, it is desirable to convert these benefits to a uniform annual amount.

The data requirements for calculating the equivalent uniform annual benefit of an improvement are:
- annual benefits
- service life
- interest rate.

Procedure

The Equivalent Uniform Annual Benefit, EUAB, of an improvement is calculated in this manner:

1. Estimate the annual benefits.
2. Estimate the service life, n.
3. Select an interest rate, i.
4. Calculate the Equivalent Uniform Annual Benefit, EUAB.

If the benefits are constant over the service life of the improvement,
$$EUAB = \text{Annual Benefit}$$

If the benefits vary from year to year,
$$EUAB = CR \cdot \sum_{m=1}^{n} B_m \cdot PW_m$$

Present Worth of Costs

Costs may vary from year to year throughout the service life of an improvement. For comparison purposes, it may be desirable to convert the costs to present costs.

The data requirements for calculating the present worth of costs of an improvement are:
- initial cost
- annual costs
- terminal value
- service life
- interest rate.

Procedure

The Present Worth of Costs, PWOC, of an improvement is calculated in this manner:

1. Estimate I, K, T and n.
2. Select an interest rate, i.
3. Calculate the PWOC.

If the annual costs are constant over the service life of the improvement,
$$PWOC = I - T \cdot (PW^I_n) + (K)(SPW^I_n)$$

If the annual costs vary from year to year over the service life of the improvement,
$$PWOC = I - T \cdot PW^I_n + \sum_{i=1}^{n} K_i \cdot PW^I_i$$
b. Example

The following is an example of calculating the present worth of costs of an improvement.

1. Initial cost = $40,000
2. Annual cost = $1,000
3. Terminal value = $2,500
4. Service life = 10 years
5. Interest rate = 10%
6. Calculate the Present Worth of Costs, PWOC,

\[ PWOC = I - T \left( PW_{A}^{1} \right) + K \left( SPW_{A}^{1} \right) \]

\[ = 40,000 - 2,500 \times 0.3855 + 1000 \times 6.1446 \]

\[ = 45,180 \]

Present Worth of Benefits

Benefits may vary from year to year throughout the service life of an improvement. For comparison purposes, it may be desirable to convert the costs to present costs.

The data requirements for calculating the present worth of costs of an improvement are:
- annual benefits
- service life
- interest rate

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b. Example

The following is an example of calculating the present worth of benefits of an improvement.

1. Annual benefits = $5,000
2. Service life = 10 years
3. Interest rate = 10%
4. Calculate the present worth of benefits, PWOB:

\[ PWOB = B \times SPW_{A}^{1} \]

\[ = 5,000 \times 6.1446 \]

\[ = 30,720 \]

BASIC EXAMPLE

The examples in the remainder of this Appendix and the examples in Chapter 4 of the Users’ Manual are based on the data shown in Figure F-1 below.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Data Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Cost</td>
<td>$200,000</td>
<td>$100,000</td>
<td>$50,000</td>
<td>$75,000</td>
<td></td>
</tr>
<tr>
<td>Annual Cost</td>
<td>$4,000</td>
<td>2,000</td>
<td>1,000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Terminal Value</td>
<td>20,000</td>
<td>10,000</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Service Life</td>
<td>20 years</td>
<td>15 years</td>
<td>10 years</td>
<td>10 years</td>
<td></td>
</tr>
<tr>
<td>Annual Benefits (constant)</td>
<td>$80,000</td>
<td>$55,000</td>
<td>$25,000</td>
<td>$40,000</td>
<td></td>
</tr>
<tr>
<td>Interest Rate</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td></td>
</tr>
</tbody>
</table>

F-13

To compare alternatives using present worth of benefits, the analysis of each improvement must be for the same period of time. Therefore, if the service lives of the improvements are not equal, the analyst must assume the ability to re-apply the improvement and factor the number of implementations accordingly.

a. Procedure

The Present Worth of Benefits, PWOB, of an improvement is calculated in this manner:

1. Estimate annual benefits.
2. Estimate the service life, n.
3. Select an interest rate, i.
4. Calculate the Present Worth of Benefits, PWOB.

If the annual benefits are constant over the service life of an improvement,

\[ PWOB = B \times SPW_{A}^{1} \]

If the annual benefits vary from year to year over the service life of the improvements,

\[ PWOB = \sum_{n=1}^{n} B_{m} \times PW_{m}^{1} \]

F-14

METHODS FOR EVALUATING INDEPENDENT ALTERNATIVE IMPROVEMENTS

Benefit/Cost Ratio

Because of its common usage and ease of calculation, the Benefit/Cost Ratio method is the recommended method of evaluating independent alternative improvements. It is discussed in Chapter Four of the Users’ Manual. The complete procedures are detailed below.

The assumption behind the benefit/cost ratio method is that the relative merit of an improvement is measured by its benefit/cost ratio.

If the alternative improvements have different service lives, the following additional assumption is applicable when using equivalent uniform annual benefits and costs.
- If an improvement with a service life shorter than the longest service life is selected, the annual cost and benefit for its successor will be the same as its annual cost and benefit.

If the improvements have different service lives, the following additional assumption is applicable when using present worths of benefits and costs.
- Each improvement can be re-applied at the end of its service life.

The data requirements of the benefit/cost ratio method are:
- initial cost
- annual costs
- terminal value
- service life
- benefits
- interest rate.
Procedure

Steps for using the benefit/cost ratio to rank independent improvements are:

1. Estimate I, K, T and n of each improvement.
2. Estimate the benefits of each improvement.
3. Select an interest rate, i.
4. Express benefits as Equivalent Uniform Annual Benefits, EUAB (see procedure on page F-8) or as Present Worth of Benefits, PWOB (see procedure on page F-12).
5. Express costs as Equivalent Uniform Annual Costs, EUAC (see procedure on page F-6) or as Present Worth of Costs, PWOC (see procedure on page F-10).
6. Calculate the benefit/cost ratio, B/C, of each improvement:

\[ \frac{B/C}{EUAB} = \frac{PWOB}{EUAC} \]

7. Order the improvements by magnitude of the B/C Ratios, largest to smallest.

Note: The AASHTO benefit/cost ratio convention is used. The various aspects of this convention are discussed by Winfrey on pages 148-150 of Reference No. 151 and Fleischer in Highway Research Record No. 383.

Example

The following is an example of using the benefit/cost ratio method to rank improvements.

The data in Table F-1 on page F-13 are used for steps 1-3.

\[ \text{EUAB} \] \[
A \quad 80,000
B \quad 55,000
C \quad 25,000
D \quad 40,000
\]

\[ \text{EUAC} \] \[
A \quad (200,000)(0.11746) + 4000 - (20,000)(0.01746) = \$27,143
B \quad (100,000)(0.13147) + 2000 - (10,000)(0.03147) = \$9,137
C \quad (50,000)(0.16275) + 1000 = \$12,206
D \quad (75,000)(0.16275) = \$17,206
\]

The order by magnitude for these independent alternatives is B, D, A, C.

Rate of Return

This method does not require the selection of an interest rate prior to the analysis. However, a computer may be required in order to perform the large number of computations.

The assumptions behind the rate-of-return method as presented here are:

- The relative merit of an improvement is measured by the interest rate that sets its benefits equal to its costs.
- The costs and benefits remain constant each year.
- If the improvements have different service lives, the additional assumption is applicable.
  - Each improvement can be re-applied at the end of its service life.
- The data requirements of the rate-of-return method are:
  - initial cost
  - annual cost
  - terminal value
  - service life
  - annual benefits.

Procedure

Steps for using the internal rate of return to rank independent improvements are:

1. Estimate I, K, T and n, for each improvement.
2. Estimate the benefits for each improvement.
3. Calculate the internal rate-of-return, RR, that sets either of the following formulas equal to zero.

\[ 0 = i = \frac{B-K}{PW_{n}} - T \times PW_{n} \]

4. Calculate the Equivalent Uniform Annual Benefit, EUAB, of each improvement:

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80,000</td>
</tr>
<tr>
<td>B</td>
<td>55,000</td>
</tr>
<tr>
<td>C</td>
<td>25,000</td>
</tr>
<tr>
<td>D</td>
<td>40,000</td>
</tr>
</tbody>
</table>

5. Calculate the EUAC for each improvement:

\[ EUAC = \frac{I}{R_{n} + K - (T) S_{n}} \]

For improvement A:

\[ EUAC = \frac{200,000}{0.11746} + 4000 - (20,000)(0.01746) = \$27,143 \]

Similarly for the other improvements, using the appropriate interest factors:

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>9,137</td>
</tr>
<tr>
<td>C</td>
<td>12,206</td>
</tr>
<tr>
<td>D</td>
<td>17,206</td>
</tr>
</tbody>
</table>

6. Calculate the benefit cost ratio for each improvement:

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Benefit/Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.95</td>
</tr>
<tr>
<td>B</td>
<td>3.71</td>
</tr>
<tr>
<td>C</td>
<td>2.74</td>
</tr>
<tr>
<td>D</td>
<td>3.28</td>
</tr>
</tbody>
</table>

7. The order by magnitude for these independent alternatives is B, D, A, C.

Payback Period

The measure of an improvement's merit is expressed in terms of time required for the improvement to pay for itself. This method is preferred by some analysts because it is less abstract than a number or ratio. However, if salvage values vary the resulting rankings may differ slightly from those obtained using the benefit/cost ratio.

The data requirements of the payback period method are:

- initial cost
- annual cost
- terminal value
- service life
- benefits
- interest rate.
a. Procedure

The steps for using the payback period method to rank independent improvements are:

1. Estimate the I, K, and T of each improvement.
2. Estimate the benefits of the improvement.
3. Select an interest rate.
4. Calculate the payback period, P, for each improvement. The payback period is the number of years that will satisfy the equation
   \[ I = K_1 PW_1 + K_2 PW_2 + \ldots + K_p PW_p \]
   where \( I \) is the initial investment, \( K_i \) are the annual benefits, and \( P \) is the payback period.

   If an improvement will not repay its cost within its service life, it should be removed from consideration.

5. Rank the improvements by magnitude of the payback period, smallest to largest.

b. Example

The following is an example of using the payback period method to rank independent improvements.

The data in Table F-1 on page F-13 are used for step 1-3.

4. Calculate the payback period:

   Payback Period of A:
   \[ \$200,000 = (80,000-4,000)(0.909)+(80,000-4,000)(0.826) \]
   \[ = \$203,956 \]
   Improvement A will repay its cost in just under 3 years.

   Payback Period of B:
   \[ \$100,000 = (55,000-2,000)(0.909)+(55,000-2,000)(0.826) \]
   \[ = \$100,215 \]
   Improvement B will repay its cost in slightly under 2 years.

   Payback Period of C:
   \[ \$50,000 = (25,000-1,000)(0.909)+(25,000-1,000)(0.826) \]
   \[ + (25,000-1,000)(0.751) \]
   \[ = \$59,664 \text{ in 3 years} \]
   Improvement C will repay its cost in 2\frac{1}{2} years.

   Payback Period of D:
   \[ \$75,000 = (40,000)(0.909)+(40,000)(0.826) \]
   \[ = \$69,400 \text{ in } 1 \frac{1}{2} \text{ years} \]
   Improvement D will repay its cost in a little over 2 years.

5. Improvement B is Best

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Best</td>
</tr>
<tr>
<td>D</td>
<td>Second Best</td>
</tr>
<tr>
<td>C</td>
<td>Third Best</td>
</tr>
<tr>
<td>A</td>
<td>Fourth Best</td>
</tr>
</tbody>
</table>

Note that the array obtained from the benefit/cost ratio is B, D, A and C. The reversed ranking of C and A is attributable to the inability of the payback period method to simply take into consideration a wide range of salvage values.

Cost/Effectiveness

Cost/effectiveness is a comparison of cost to achievement of a given unit of effect. Cost/effectiveness is similar to benefit/cost ratio. It is the average cost per unit of benefit.

Comparisons of costs and benefits require the analyst to assign a dollar value to human life and injury. Although this practice makes cost-benefit comparison apparently more sound or explainable in terms of economic theory, the fact remains that some analyst may not wish to presume to assign value to human life. In this case, the analyst may select the cost-effectiveness approach which answers the question, "How much does it cost to save one life, or one injury accident, or one accident?" without having to assign dollar values to them.

Of course, dollar value is implied if the ratio is used to economically justify improvements but the explicit decision to assign value is avoided. However, if the ratio is used only to judge the relative merits of improvements, the assignment of a dollar value to a human life can be avoided.

The data requirements of the cost/effectiveness method are:

- initial cost
- annual costs
- terminal value
- service life
- interest rate
- annual benefits.

A decision must be made as to which benefit unit is to be used for assigning priority. For example, cost per fatal accident and cost per death are not comparable terms and can result in different priorities.

The cost/effectiveness method divides the equivalent uniform annual cost by the average annual benefit. This method avoids assigning cost to a human life--it merely indicates how much it costs to save a human life--if that is the measurement being used.

The major problem with this method is the lack of a basis for mixing fatalities, injuries and PDO's. For example, a project is expected to cost $20,000 per year and result in annual savings of 30 accidents (20 PDO, 9 injury, and 1 fatal). The array of cost/effectiveness values of this improvement may be stated as follows:

- $667 per accident
- $2,222 per injury accident
- $20,000 per fatal accident

The fatalities and injuries can be combined and the cost/effectiveness can be stated as:

- $2,000 per fatal/injury accident

However, combining fatalities and injuries implies a low value to human life.

A possible way of using the three measurements is to develop a ratio between either the numbers reduced or the costs per number reduced. For example, the ratio of numbers of property damage accidents to injury accidents to fatal accidents from the example above is 20:9:1. The analyst can use these ratios to indicate severity of accident occurrence since the ratios express the relationship between more severe and less severe results. The ratios also might provide a convenient way of converting accident terms.

Another difficulty of cost/effectiveness is with non-uniform benefits. This is common where the traffic volume is not constant. This difficulty can be overcome by calculating the average annual benefit.
1. Estimate the $I$, $K$, $T$ and $n$ of each improvement.

2. Select an interest rate, $i$, expressed as a decimal.

3. Calculate equivalent uniform annual costs, EUAC, of each improvement. (See procedure on page F-6.)

4. Select a unit of effectiveness, for example, accidents, fatal accidents and fatal/injury accidents.

5. Estimate the average annual reductions in the unit of effectiveness selected.

6. Calculate the cost/effectiveness by dividing the equivalent uniform annual cost by the estimated annual reductions in the unit of effectiveness selected.

7. Array the improvements by cost/effectiveness ratio, lowest to highest.

**Example**

The following is an example of using the cost/effectiveness method to rank independent improvements.

The data in Table F-1 on page F-13 are used in steps 1-2.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$27,150</td>
</tr>
<tr>
<td>B</td>
<td>$14,850</td>
</tr>
<tr>
<td>C</td>
<td>$9,150</td>
</tr>
<tr>
<td>D</td>
<td>$12,100</td>
</tr>
</tbody>
</table>

**Method for Evaluating Mutually Exclusive Alternative Improvements**

**Net Annual Benefit**

Because of its ease of calculation, the net annual benefit method is the recommended method of evaluating mutually exclusive alternatives. It is discussed in Chapter 4 of the Users' Manual.

The assumption behind the net annual benefit method is that the relative merit of an improvement is measured by its net annual benefit.

If the improvements have different service lives, the following additional assumption is applicable.

- If an improvement with a service life shorter than the longest service life is selected, the annual cost and benefit for its successor will be the same as its annual cost and benefit.

**Requirements**

- Initial cost
- Annual costs
- Terminal value
- Service life
- Benefits
- Interest rate

**Procedure**

Steps for using the net annual benefit method to select from mutually exclusive improvements are:

1. Estimate the $I$, $K$, $T$ and $n$ of each improvement
2. Estimate the benefits of each improvement. The benefits should be expressed in dollars.
3. Select an interest rate, $i$.
4. Express benefits as an Equivalent Uniform Annual Benefit, EUAB. (See procedure on page F-8.)
5. Express costs as an Equivalent Uniform Annual Cost, EUAC. (See procedure on page F-6.)
6. Calculate the Net Annual Benefit, NAB, of each improvement.

\[
NAB = EUAB - EUAC
\]

The improvement with the largest, positive net annual benefit is the best.

**Example**

The following is an example of using the net annual benefit method to select from mutually exclusive alternatives.

The data in Table F-1 on page F-13 are used for steps 1-3.

4. Calculate the EUAB of each improvement.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80,000</td>
</tr>
<tr>
<td>B</td>
<td>55,000</td>
</tr>
<tr>
<td>C</td>
<td>25,000</td>
</tr>
<tr>
<td>D</td>
<td>40,000</td>
</tr>
</tbody>
</table>

5. Calculate the EUAC of each improvement.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$27,143</td>
</tr>
<tr>
<td>B</td>
<td>$14,833</td>
</tr>
<tr>
<td>C</td>
<td>$9,137</td>
</tr>
<tr>
<td>D</td>
<td>$12,206</td>
</tr>
</tbody>
</table>
an improvement is measured by its net present worth. However, the present worth of benefits and costs is used thus making the method much simpler.

The assumption behind the net present worth method is that the relative merit of an improvement is measured by its net annual benefits. If the service lives of the improvements are not equal, the analysts must assume the next lower priced alternative to its increase in costs over the next lower priced alternative.

The data requirements of the incremental benefit/cost ratio method are:
- initial cost
- annual costs
- terminal value
- service life
- benefits
- interest rate.

The analysis of each improvement must be for the same period of time. Therefore, if the service lives of the improvements are not equal, the analysts must assume the ability to re-apply the improvements and factor the number of implementations accordingly.

Steps for using the net present worth method to select from mutually exclusive improvements are:

1. Estimate the I, K, T and n of each improvement.
2. Estimate the benefits of each improvement.
3. Select an interest rate, i.
4. Calculate the present worth of costs. (See procedure on page F-10)
5. Calculate the net present worth of benefits. (See procedure on page F-12)
6. Calculate the net present worth, NWP, of each improvement.
   \[ NWP = PWOB - EWOC \]
7. Select the improvement with the greatest net present worth.

The following is an example of using the net present worth method to select from mutually exclusive alternatives:

The data in Table F-1 on page F-13 are used for steps 1-3.

Because the improvements have different service lives, use a 40-year analysis period. Thus, improvement A will be replaced twice, improvement B will be replaced four times and improvements C and D will be replaced six times. The benefits and annual cost can be treated as a uniform series of payments for sixty years.

   \[ PWOC = \text{Initial Cost} + \text{Annual Cost} \times \text{PW of an Annuity} \]

5. Calculate Present Worth of Benefits.
   \[ PWOB = \text{ Benefit of Improvement} \times \text{PW of an Annuity} \]

   \[ NWP = PWOB - PWOC \]

7. Select improvement A because it has the highest net present worth.

### Incremental Benefit/Cost Ratio

This method is used to select an improvement from mutually exclusive alternatives. The assumption behind the incremental benefit/cost ratio method is that the relative merit of an improvement is measured by the ratio of its increased benefits over the next lower priced alternative to its increase in costs over the next lower priced alternative.

### Example

The following is an example of using the incremental benefit/cost ratio method to select from mutually exclusive alternatives:

The data in Table F-1 on page F-13 are used for steps 1-3.

Because the improvements have different service lives, use a 40-year analysis period. Thus, improvement A will be replaced twice, improvement B will be replaced four times and improvements C and D will be replaced six times. The benefits and annual cost can be treated as a uniform series of payments for sixty years.

   \[ PWOC = \text{Initial Cost} + \text{Annual Cost} \times \text{PW of an Annuity} \]

5. Calculate Present Worth of Benefits.
   \[ PWOB = \text{ Benefit of Improvement} \times \text{PW of an Annuity} \]

   \[ NWP = PWOB - PWOC \]

7. Select improvement A because it has the highest net present worth.
spent on this project only if there are no projects where the $10,000 could be invested to obtain a return greater than 1.2.

This comparison of increments of cost to the resulting increment in benefits is the incremental benefit/cost ratio method. Each applicable improvement is compared to the next higher cost improvement to determine whether additional costs results in an equal increase in benefits.

If the analyst has selected the minimum acceptable rate-of-return as the interest rate, additional investments where the increase in discounted costs results in an equal or greater increase in discounted benefits should be made.

If the present worths of costs and benefits are used, the analysis of each improvement must be for the same period of time. Therefore, if the service lives of the improvements are not equal, the analyst must assume the ability to reapply the improvements and factor the number of implementations accordingly.

a. Procedure

The steps for using the incremental benefit/cost ratio method to select from mutually exclusive alternatives are:

1. Estimate the i, n, T, and of each improvement.
2. Estimate the benefits of each improvement.
3. Select an interest rate, i.
4. Express benefits and costs as either present worths or as equivalent uniform annual amounts. When using present worths, the period of analysis must be the same for each improvement. If the service lives are different, the analysis period should be the smallest number of years divisible by all service lives. This additional criterion is not applicable when using equivalent uniform annual amounts.

Present Worth of Costs (PWOC)

(See procedure on page F-10)

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8. Continue, in order of increasing costs, to calculate the incremental benefit cost ratio, IB/IC, for each improvement compared to the best lower cost improvement.

\[
IB/IC = \frac{B_i - B_0}{C_i - C_0}
\]

Where:

- \(B_i\) = Benefits of improvement under consideration
- \(B_0\) = Benefits of the best lower cost improvement
- \(C_i\) = Cost of improvement under consideration
- \(C_0\) = Cost of the best lower cost improvement

If this IB/IC is greater than 1, the improvement under consideration is better. It now becomes the best lower cost improvement.

If this IB/IC is not greater than 1, the improvement under consideration is not better. The best lower cost improvement continues to be best.

9. After all improvements have been compared to the best lower cost improvements, the most expensive improvements with an increment benefit/cost ratio greater than 1 is the most desirable.

b. Example

The following is an example of using the incremental benefit/cost ratio method to select from mutually exclusive alternatives.

The data in Table F-1 on page F-13 are used for steps 1-3.

Equivalent Uniform Annual Costs (EUAC)

(See procedure on page F-6)

Equivalent Uniform Annual Benefits (EUAB)

(See procedure on page F-8)

5. Calculate the benefit/cost ratio for each improvement, B/C

\[
B/C = \frac{PWB}{PWOC}
\]

6. List the improvements with a B/C greater than 1 in order of increasing cost, either present worth or equivalent uniform annual cost.

7. Calculate the incremental benefit/cost ratio, IB/IC, for the second improvement compared to the first.

\[
IB/IC = \frac{B_2 - B_1}{C_2 - C_1}
\]

Where:

- \(B_1\) = Benefits of lowest cost improvement
- \(B_2\) = Benefits of second lowest cost improvement
- \(C_1\) = Cost of lowest cost improvement
- \(C_2\) = Cost of second lowest cost improvement

If this IB/IC ratio is greater than 1, the second lowest cost improvement is more desirable than the lowest cost improvement, assuming feasibility with budget constraints.

4. Calculate costs and benefits.

Although either present worths or equivalent uniform annual amounts may be used in the benefit cost ratio, it is easier to use the latter, to avoid correcting for the different service lives.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAC</th>
<th>EUAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$27,143</td>
<td>$80,000</td>
</tr>
<tr>
<td>B</td>
<td>14,832</td>
<td>55,000</td>
</tr>
<tr>
<td>C</td>
<td>9,138</td>
<td>15,000</td>
</tr>
<tr>
<td>D</td>
<td>12,206</td>
<td>40,000</td>
</tr>
</tbody>
</table>

5. Calculate the benefit/cost ratio.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Benefit/Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80,000/27,143 = 2.95</td>
</tr>
<tr>
<td>B</td>
<td>55,000/14,832 = 3.71</td>
</tr>
<tr>
<td>C</td>
<td>15,000/9,138 = 2.74</td>
</tr>
<tr>
<td>D</td>
<td>40,000/12,206 = 3.28</td>
</tr>
</tbody>
</table>

6. List the improvements with B/C greater than 1, in order of increasing costs.

<table>
<thead>
<tr>
<th>Improvements</th>
<th>EUAC</th>
<th>EUAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>9,138</td>
<td>25,000</td>
</tr>
<tr>
<td>D</td>
<td>12,206</td>
<td>40,000</td>
</tr>
<tr>
<td>B</td>
<td>14,832</td>
<td>55,000</td>
</tr>
<tr>
<td>A</td>
<td>17,143</td>
<td>80,000</td>
</tr>
</tbody>
</table>
1. Calculate the incremental benefit/cost ratio of D to C.

\[
\frac{IC}{IC} = \frac{50,000 - 25,000}{12,006 - 9,138} = 4.89
\]

The increased benefit of D over C is 4.89 times the increased cost. Therefore, the increased cost of D is warranted assuming it is desired to spend money at this level.

2. Calculate the incremental ratio of B to D.

\[
\frac{IC}{IC} = \frac{55,000 - 40,000}{14,832 - 12,006} = 5.71
\]

The increased benefit of B over D is 5.71 times the increased cost. Therefore, the increased cost of B is warranted.

3. Calculate the incremental ratio of A to B.

\[
\frac{IC}{IC} = \frac{80,000 - 55,000}{77,143 - 14,832} = 2.03
\]

The increased benefit of A over B is 2.03 times the increased cost. Therefore, the increased cost of A is warranted.

4. Using the incremental benefit/cost analysis procedure, improvement A is the best improvement.

Incremental Cost/Effectiveness

Incremental cost/effectiveness is similar to incremental benefit/cost ratio. It is the average incremental cost per unit of incremental benefit. Like incremental benefit/cost ratio, its theoretically correct use is to select or rank mutually exclusive alternatives. (1613)

The assumption behind incremental cost/effectiveness is that the relative merit of an improvement is measured by the ratio of the change in accidents or other severity units reduced, to the increase in costs over the next lower priced alternative.

The data requirements of incremental cost/effectiveness are:

- initial cost
- annual costs
- terminal value
- service life
- interest rate
- annual benefits

Procedure

Steps for using incremental cost/effectiveness to select from mutually exclusive alternatives are:

1. Estimate the I, K, T and n of each improvement.
2. Select an interest rate, i.
3. Calculate equivalent uniform annual cost of each improvement. (See procedure on page F-6)
4. Select a unit of effectiveness, for example, accidents, fatal accidents and fatal/injury accidents.
5. Estimate the average annual reduction in the unit of effectiveness selected.
6. List the improvements in order of increasing equivalent uniform annual cost.

Example

The following is an example of the incremental cost/effectiveness method to select from mutually exclusive alternatives.

Data below are used for steps 1 and 2.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Cost, I</td>
<td>$500</td>
<td>$5,000</td>
<td>$10,000</td>
<td>$50,000</td>
</tr>
<tr>
<td>Annual Cost, K</td>
<td>0</td>
<td>500</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>Terminal Value, T</td>
<td>100</td>
<td>0</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Service Life, n</td>
<td>10</td>
<td>5</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>Interest Rate, i = 10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Calculate equivalent uniform annual costs.

\[
\text{EUAC} = \frac{C_i - C_b}{E_i - E_b} \times I + K + T + S \times (1 + i)^n \times \frac{1}{1 - (1 + i)^{-n}}
\]

4. Use accidents reduced annually as the unit of effectiveness.

5. Continue, in order of increasing costs, to calculate the incremental cost-effectiveness until all alternatives have been compared.

If the cost per unit of additional effectiveness is deemed justifiable, the improvement under consideration becomes the best lower cost improvement.

If the cost per unit of additional effectiveness is not deemed justifiable, the lower cost improvement remains the best lower cost improvement.

10. Continue, in order of increasing costs, to calculate the incremental cost-effectiveness until all alternatives have been compared.

b. Example

The following is an example of the incremental cost/effectiveness method to select from mutually exclusive alternatives.

Data below are used for steps 1 and 2.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Cost, I</td>
<td>$500</td>
<td>$5,000</td>
<td>$10,000</td>
<td>$50,000</td>
</tr>
<tr>
<td>Annual Cost, K</td>
<td>0</td>
<td>500</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>Terminal Value, T</td>
<td>100</td>
<td>0</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Service Life, n</td>
<td>10</td>
<td>5</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>Interest Rate, i = 10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Calculate equivalent uniform annual costs.

\[
\text{EUAC} = \frac{C_i - C_b}{E_i - E_b} \times I + K + T + S \times (1 + i)^n \times \frac{1}{1 - (1 + i)^{-n}}
\]

4. Use accidents reduced annually as the unit of effectiveness.

5. Continue, in order of increasing costs, to calculate the incremental cost-effectiveness until all alternatives have been compared.
6. List improvements in order of increasing equivalent uniform annual cost.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$75</td>
</tr>
<tr>
<td>C</td>
<td>$1,992</td>
</tr>
<tr>
<td>B</td>
<td>$1,820</td>
</tr>
<tr>
<td>D</td>
<td>$7,562</td>
</tr>
</tbody>
</table>

7. Compare C to A.

\[
\text{IC/E} = \frac{1,592 - 25}{10 - 25} = \frac{1,567}{-15}
\]

= $69 per additional accident reduced

8. The analyst judges this cost to be reasonable. C becomes the best lower cost improvement.

9. Compare B to C.

\[
\text{IC/E} = \frac{1,820 - 1,592}{10 - 25} = \frac{228}{-15}
\]

Value is minus, therefore, B is excluded and C remains the best lower cost improvement.

10. Compare D to C.

\[
\text{IC/E} = \frac{7,542 - 1,592}{30 - 25} = \frac{5,950}{5}
\]

= $1,190 per additional accident reduced.

The analyst judges this cost not to be justifiable. Therefore, improvement C is selected.

---

**TABLES FOR INTEREST/DISCOUNT RATE**

Interest factors for interest/discount rate equal to ten percent are presented in Figure F-3 on the following page. Additional values can be found in engineering handbooks, engineering economics texts, The Handbook of Chemistry and Physics, or CRC Mathematical Tables From Handbook of Chemistry and Physics.

Often the terminology may be different from that used in this manual. Therefore, guides for using tables with different notation and the formula for calculating each factor are presented below in Table F-2.

---

**Table F-2**

Formulas and Synonyms for Interest Factors

<table>
<thead>
<tr>
<th>Compound Annual Factor (CAF)</th>
<th>Amount of Compound Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present Amount Factor (PAF)</td>
<td>( P = (1 + i)^n )</td>
</tr>
</tbody>
</table>

**Table F-3**

Interest Factors for \( i = 10\% \)

<table>
<thead>
<tr>
<th>Single Payment</th>
<th>Uniform Series of Payments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**F-40**
SENSITIVITY ANALYSIS

To properly conduct an evaluation involving economic consequences, it is essential that consideration be given to the uncertainty of estimated values. In many cases, moderate changes in forecasts can have a sizable impact on the comparison of alternatives. This is of special concern in the analysis of highway safety improvements, where there is an inherent degree of variability in several of the estimates.

In some cases, the results of the evaluation process will remain the same if there are changes in one or more of these factors. In others, a small change may reverse the choice between alternatives.

The assumptions behind sensitivity analysis are:

- The estimates of accident reduction or improvement cost can be in error.
- It is desirable to determine what affect possible errors in cost or benefit estimates will have on the analysis.

In addition to the data that are required for the evaluation of possible alternatives--initial costs, annual costs, terminal value, service life, annual benefits and an interest rate--it is necessary to make a reasonable judgment of what level of variation could be expected for these factors.

Sensitivity analysis need not be conducted in all evaluations. The primary value of this analysis is to give the analyst a sense of how much the final answer is changed as a result of increments of change in the inputs. The ultimate objective is to improve the inputs. But, until the analysis has reliable feedback from previous experiences, sensitivity analysis can be used.

Procedure

The procedure for conducting a sensitivity analysis is as follows:

1. Perform the economic analysis of each improvement using the estimated values for $l$, $K$, $T$, $n$, $B$ and $i$. See definitions in Appendix E or F.
2. Lower one of the estimated values for each improvement. A ten-percent reduction usually will be sufficient, although experience may indicate that a different reduction is appropriate.
3. Re-analyze the improvements using these lowered values.
4. Now increase this one value for each improvement. A ten-percent increase over the original estimate usually will be sufficient.
5. Re-analyze the improvements using these increased values.
6. If the results of the economic analysis vary greatly for each magnitude of this value (original decreased and increased), its calculation or estimation for each improvement should be reviewed for accuracy.
7. Repeat Steps 2 through 6 for each of the applicable values listed in Step 1.

Example

Site X, a three-mile section of rural state highway, has been determined to be a hazardous location. Average annual accident experience at this site includes two fatalities, 30 injury accidents and 70 property damage accidents. Two alternative improvements are being investigated. Costs and estimated accident reduction potential are shown below.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>EUAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>49</td>
</tr>
<tr>
<td>2</td>
<td>49</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accident/yr</th>
<th>Alternative</th>
<th>EUAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>Injury</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>PDO</td>
<td>10</td>
<td>60</td>
</tr>
</tbody>
</table>

The costs for $l$, $K$ and $T$ are best judgment values. Each alternative has a lifetime of 8 years, and 7% has been selected as the minimum attractive rate of return. In accord with the state's policy, it has been decided that costs assigned to accidents will be $50,000, $3,000 and $800 for fatal, injury and PDO accidents, respectively. Under the existing conditions, the current annual accident cost is:

\[
\text{Accident Cost} = 2(50,000) + 30(3,000) + 70(800) = 246,000
\]

In a similar manner the annual accident costs for alternatives 1 and 2 are $176,000 and $108,000, respectively. The Equivalent Uniform Annual Cost, EUAC, for each alternative is calculated by the procedure discussed earlier in this chapter.

Procedure

The procedure for conducting a sensitivity analysis is as follows:

1. Perform the economic analysis of each improvement using the estimated values for $l$, $K$, $T$, $n$, $B$ and $i$. See definitions in Appendix E or F.
2. Lower one of the estimated values for each improvement. A ten-percent reduction usually will be sufficient, although experience may indicate that a different reduction is appropriate.
3. Re-analyze the improvements using these lowered values.
4. Now increase this one value for each improvement. A ten-percent increase over the original estimate usually will be sufficient.
5. Re-analyze the improvements using these increased values.
6. If the results of the economic analysis vary greatly for each magnitude of this value (original decreased and increased), its calculation or estimation for each improvement should be reviewed for accuracy.
7. Repeat Steps 2 through 6 for each of the applicable values listed in Step 1.

Table G-2

<table>
<thead>
<tr>
<th>Condition</th>
<th>Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 vs. No Change</td>
<td>2 vs. 1</td>
</tr>
<tr>
<td>A. Base Conditions</td>
<td>1.25</td>
</tr>
<tr>
<td>B. Decrease $n$ from 8 to 7 years</td>
<td>1.14</td>
</tr>
<tr>
<td>C. Increase $l$ from 7% to 8%</td>
<td>1.21</td>
</tr>
<tr>
<td>D. Increase $l$ and $K$ by 15%</td>
<td>1.04</td>
</tr>
<tr>
<td>E. No fatal accident reduction</td>
<td>1.23</td>
</tr>
<tr>
<td>F. No injury accident reduction</td>
<td>1.11</td>
</tr>
<tr>
<td>G. No PDO accident reduction</td>
<td>1.04</td>
</tr>
<tr>
<td>H. No fatal accident reduction</td>
<td>0.36</td>
</tr>
<tr>
<td>I. PDO accident cost = $600/acc</td>
<td>1.22</td>
</tr>
<tr>
<td>J. Injury accident cost = $1,500/acc</td>
<td>1.15</td>
</tr>
<tr>
<td>K. Fatal accident cost = $10,000/acc</td>
<td>1.07</td>
</tr>
<tr>
<td>L. PDO accident cost = $20,000/acc</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Sensitivity to Service Life

Consider a slight change in the analysis assumptions, namely that $n = 7$ years. The annual benefits will not be affected, but the annual costs will increase, since the initial investment is spread out over a fewer number of years. Line 8 of Table G-2 indicates the result of this comparison. Alternative 2 remains the best, but the ratios are closer to unity, indicating the marginal nature of the investment. If $n$ was decreased to 6 years, the no change alternative would be the best. With an increase in the lifetime to 10 years, for example, Alternative 2 would improve its ratio with respect to both the no change alternative and Alternative 1.
RISK ANALYSIS

Risk analysis is applicable to all methods of economic evaluation. By incorporating a measure of probability for each input, the decision-maker is provided with more information for deciding between alternatives.

The possible errors in estimation of improvement costs and benefits can be examined to determine which alternative is the most likely to produce favorable results.

The data requirements for risk analysis are identical to those for sensitivity analysis, with the exception that estimates must be made of the probability that a cost or benefit will differ from the "best judgment" value.

The sensitivity analysis described in the previous section adds some insight into the variability of the evaluation results as a function of changes in the input data. However, it requires the analyst to determine whether those factors on which the results of the analysis are sensitive are likely to be estimated incorrectly. The probability that these variables will differ from the best judgment value used in the initial analysis (the base conditions) may be quite small. In other words, the analysis could be quite sensitive to a factor which isn't unlikely to differ from the best judgment value. It is obvious that some additional knowledge concerning the relative likelihood of the variations assumed in the sensitivity analysis would be useful in the decision-making process. This can be accomplished through the use of risk analysis.

This procedure assigns a probability to a set of the possible values which an input variable could have. A probability of occurrence (or correctness) is established for each value. In accord with probability laws, the probabilities for each factor must be between 0 (the impossible event) and 1 (the certain event), and must sum to unity.

The procedure itself is not overly sensitive to small errors in the assignment of probabilities, primarily because of the large number of combinations of factors. The probabilistic approach lessens the pressure occasionally placed on the analyst to select a single estimate which tends to support a particular alternative. While risk analysis requires more information than do other forms of analysis, it makes more use of the data. The additional effort which is required to conduct a risk analysis may be warranted for projects involving a moderate level of uncertainty.

Although computer programs are available for an extensive risk analysis, a simplified analysis can be performed manually using the expected value of each data item. These expected values are calculated using the probability of each logically expected value.

Procedure

The procedure for conducting a risk analysis is as follows:

1. Estimate the probability, P, of each possible value for each data item I, K, T, n, B and i.

   The possible values should all be logically expected values. It is not necessary to include all possible values. The ± 10% range suggested for sensitivity analysis may be appropriate. Check the total of the probabilities for each data item to make sure that it is 1.

2. Calculate the expected value, E, of each item of data:

   \[ E = \sum (x_i) P_i \]

   Where:
   \[ x_i \] = Each possible value of the data
   \[ P_i \] = Probability of the data having that value

   Since P is a summation for all possible values of the data

3. Use the expected value of each data item in the economic analysis.

G-5

Sensitivity to Accident Reduction

Two elements could be examined in relation to the benefits received from the improvement. The first of these is the level of accident reduction. As previously discussed, the accident reduction characteristics of some types of improvements can be estimated rather closely but, in other instances, sizable errors may be made. Modifying the base conditions for the improvements at Site X to reflect no reduction in PDO accidents for Alternatives 1 or 2, the annual accident costs for these alternatives increase to $184,000 and $116,000, respectively. This has a moderate effect on the B/C ratios, as shown in Line F of Table G-1, although Alternative 2 remains the best. The ratios are very sensitive to changes in the reduction of injury and fatal accidents. If there is no reduction in injury accidents, line G shows that Alternative 1 is marginally acceptable, and Alternative 2 must be rejected. If PDO and injury accidents are reduced according to the base conditions, but fatal accidents are not reduced, line H of Table G-1 indicates that neither alternative has a favorable B/C ratio.

The estimated terminal value, because it is a forecast for the comparatively distant future, can easily be in error. However, an error in its estimation usually has a small effect on the results of the analysis, as shown by Line E of Table G-1 which assumes that the terminal value is zero for both Alternatives 1 and 2. In this example, the assumption of zero terminal value has about the same impact as an increase of 1 percent in the interest rate. Using incremental benefits/cost analysis, Alternative 2 remains the best proposal.

Conclusion

While the results of a sensitivity analysis do not produce a specific answer, they do indicate the effect which variations in the input parameters can have on the evaluation procedure. In the example from Site X, the results were very sensitive to the accident reduction benefit associated with fatal accidents, and moderately sensitive to construction costs and injury reduction benefits. The calculations and estimations associated with these factors should be examined to ensure their correctness.

G-6

Sensitivity to Assigned Accident Costs

The second accident-benefit related item which should be considered in the sensitivity analysis is the cost assigned to accidents. This is especially important in the case of improvements at Site X, where the most notable reduction occurs in the category of fatal accidents. A change in the estimated cost of property damage accidents from $800 to $600 has an insignificant effect on the ratios. A reduction in the cost of an injury accident, from $3,000 to $1,500, is substantial enough that Alternative 1 becomes the best improvement. Reduction of fatal accident costs to $40,000/injury accident also favors Alternative 1, while with a cost of $30,000 per fatal accident neither alternative is justified.

The second of these is the level of accident costs. As previously discussed, the accident cost characteristics of some types of improvements can be estimated rather closely but, in other instances, sizable errors may be made. Modifying the base conditions for the improvements at Site X to reflect no reduction in PDO accidents for Alternatives 1 or 2, the annual accident costs for these alternatives increase to $184,000 and $116,000, respectively. This has a moderate effect on the B/C ratios, as shown in Line F of Table G-1, although Alternative 2 remains the best. The ratios are very sensitive to changes in the reduction of injury and fatal accidents. If there is no reduction in injury accidents, line G shows that Alternative 1 is marginally acceptable, and Alternative 2 must be rejected. If PDO and injury accidents are reduced according to the base conditions, but fatal accidents are not reduced, line H of Table G-1 indicates that neither alternative has a favorable B/C ratio.

Sensitivity to Terminal Value

The estimated terminal value, because it is a forecast for the comparatively distant future, can easily be in error. However, an error in its estimation usually has a small effect on the results of the analysis, as shown by Line E of Table G-1 which assumes that the terminal value is zero for both Alternatives 1 and 2. In this example, the assumption of zero terminal value has about the same impact as an increase of 1 percent in the interest rate. Using incremental benefits/cost analysis, Alternative 2 remains the best proposal.

G-7

Sensitivity to Interest Rate

The effect of changes in the minimum attractive rate of return should also be investigated. Using a lifetime of 8 years, and increasing the interest rate to 8 percent, the values of EUAC for Alternatives 1 and 2 will increase, while annual benefits will remain the same. The B/C ratios for this condition are shown in line C of Table G-1. The table indicates that Alternative 2 is still the best. In comparison with line B of the table, it can be seen that for this example, the ratios are less sensitive to a one percent change in the interest rate than to a one year change in the lifetime. A decrease in the interest rate would favor Alternative 2, with its high initial expenditure.

G-8

G-5

Risk Analysis

Risk analysis is applicable to all methods of economic evaluation. By incorporating a measure of probability for each input, the decision-maker is provided with more information for deciding between alternatives.

The possible errors in estimation of improvement costs and benefits can be examined to determine which alternative is the most likely to produce favorable results.

The data requirements for risk analysis are identical to those for sensitivity analysis, with the exception that estimates must be made of the probability that a cost or benefit will differ from the "best judgment" value.

The sensitivity analysis described in the previous section adds some insight into the variability of the evaluation results as a function of changes in the input data. However, it requires the analyst to determine whether the factors on which the results of the analysis are sensitive are likely to be estimated incorrectly. The probability that these variables will differ from the best judgment value used in the initial analysis (the base conditions) may be quite small. In other words, the analysis could be quite sensitive to a factor which isn't unlikely to differ from the best judgment value. It is obvious that some additional knowledge concerning the relative likelihood of the variations assumed in the sensitivity analysis would be useful in the decision-making process. This can be accomplished through the use of risk analysis.

This procedure assigns a probability to a set of the possible values which an input variable could have. A probability of occurrence (or correctness) is established for each value. In accord with probability laws, the probabilities for each factor must be between 0 (the impossible event) and 1 (the certain event), and must sum to unity.

The procedure itself is not overly sensitive to small errors in the assignment of probabilities, primarily because of the large number of combinations of factors. The probabilistic approach lessens the pressure occasionally placed on the analyst to select a single estimate which tends to support a particular alternative. While risk analysis requires more information than do other forms of analysis, it makes more use of the data. The additional effort which is required to conduct a risk analysis may be warranted for projects involving a moderate level of uncertainty.

Although computer programs are available for an extensive risk analysis, a simplified analysis can be performed manually using the expected value of each data item. These expected values are calculated using the probability of each logically expected value.

Procedure

The procedure for conducting a risk analysis is as follows:

1. Estimate the probability, P, of each possible value for each data item I, K, T, n, B and i.

   The possible values should all be logically expected values. It is not necessary to include all possible values. The ± 10% range suggested for sensitivity analysis may be appropriate. Check the total of the probabilities for each data item to make sure that it is 1.

2. Calculate the expected value, E, of each item of data:

   \[ E = \sum (x_i) P_i \]

   Where:
   \[ x_i \] = Each possible value of the data
   \[ P_i \] = Probability of the data having that value

   Since P is a summation for all possible values of the data

3. Use the expected value of each data item in the economic analysis.

G-7

G-8
Example

Risk analysis will be applied to the proposed improvements at Site X that were discussed in the sensitivity example.

1. As a first step, probabilities will be assigned to each data item. For example, the best judgment value for the initial cost of Alternative I is $315,000. Based upon past experience, the analyst concludes that this is the most likely cost. However, this estimate could be too high or too low.

   a) There is a possibility that new technology, materials, construction techniques and/or favorable weather conditions could lower the cost by about 10%, to $283,500. The analyst decides that the probability of this occurring is 0.30.

   b) There is also a possibility that unusual increases in the price of materials, design modifications and/or construction delays could increase the cost by about 10%, to $346,500. Previous experience indicates that the probability of this occurrence is 0.20.

   c) The best judgment cost, $315,000, is assigned a probability of 0.5.

In a similar manner, probabilities are assigned to other data items, including Annual Cost, Terminal Value, Service life, Interest Rate and Annual Accidents by severity classification. These probabilities are shown in Table G-2.

The expected value of a particular data item is calculated. For the initial cost of Alternative I,

\[ E(I_1) = \sum P \cdot I \]

\[ = (0.3)(283,500) + (0.2)(346,500) + (0.5)(315,000) \]

\[ = 311,850 \]

Similar calculations are made for the other data items.

2. The expected value of a particular data item is calculated. For the initial cost of Alternative I,

\[ E(I_1) = \sum P \cdot I \]

\[ = (0.3)(283,500) + (0.2)(346,500) + (0.5)(315,000) \]

\[ = 311,850 \]

Similar calculations are made for the other data items.

3. Using the expected values, an economic analysis can be conducted with any of the cost and benefit evaluation techniques. For the expected values shown in Table G-2, an incremental benefit/cost ratio was calculated for each pair of alternatives.

\[
\text{Condition} \quad \begin{array}{l} 
\text{No change vs. 1} \quad 1.71 \\
\text{No change vs. 2} \quad 1.00 \\
\text{1 vs. 2} \quad 0.78 \\
\end{array}
\]

In this case, both alternatives are economically feasible with a benefit/cost ratio of 1.00, but Alternative 1 is clearly the best.

More Detailed Risk Analysis

Computer programs are available for conducting a more extensive risk analysis. In this procedure, values are selected for the factors in accord with their assigned probabilities (for example, a factor with a probability of 0.9 would be selected with nine times the frequency of a factor with a probability of 0.1). Excluding factors having a probability of zero, there are in excess of 3.4 billion possible combinations of values for the factors shown in Table G-2. Even the most probable combination of factors has a comparatively low probability \((1.77 \times 10^{-5})\). The computer can easily calculate benefit/cost ratios (or other decision criteria variables) for several hundred sets of assumptions concerning the factors. On the basis of these calculations, it is possible to estimate the relative frequency with which the different alternatives would be the most favorable. If it is found that the no change alternative is desirable under 10 percent of the possibilities, Alternative 1 under 60 percent, and Alternative 2 under 30 percent, then Alternative 1 would be judged to be the least risky of the proposed improvements. Further discussion is contained in a doctoral dissertation by Haefner. (67)
Realizing that there are thousands of roadway locations that are potentially dangerous and need to be improved, and, that money to fix each location to the greatest degree possible is not currently available, the Alabama Highway Department decided that it was necessary to allocate the funds to those locations and projects that would bring the greatest return. Dr. David B. Brown of Auburn University was contacted to accomplish this objective. This appendix describes the procedures developed by Dr. Brown.

**PROCEDURE**

Hazardous locations were identified using accident reports on file with the Alabama Department of Public Safety. Each location was analyzed to identify the probable accident causes and to prescribe applicable improvements. The results of this analysis were summarized on Form BM 172 shown in Figure H-1.

The data on the forms for each hazardous location were keypunched and processed to determine the cost and benefit of each alternative. These costs and benefits were used to determine the combination of alternatives that would yield most benefit for the given budget. The "best" combination was obtained using an optimization technique called "dynamic programming". The computer program developed by Dr. Brown is listed on pages H-4 through H-13.

The FORTRAN language program listing is in two parts. They are:

- the Cost/Benefit Module (CBM) that calculates the cost/benefit for each alternative proposed project; and
- the Dynamic Programming Module (DPM) that develops a set of projects for obtaining maximum safety return from given levels of expenditure.

The documentation for this program package is contained in Dr. Brown's recently completed book, *Systems Analysis for Safety*.

**RESULTS**

"Best" combinations were determined for budgets from $100,000 to $3,000,000 in increments of $100,000. The alternatives selected at locations 101 to 125 (see Appendix I for description of alternatives) for budgets of $200,000 to $3,000,000 in increments of $200,000 are listed in Table H-1 on page H-14.

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H-1

Page of

ALABAMA'S HIGHWAY SAFETY
BUDGET MAXIMIZATION SYSTEM

Appendix H

REMEMBER TO USE A FORM BM 172 FOR EACH LOCATION.

High Accident Location Investigation Form

(1) Location:
(2) Time Period of Accident History (Years):
(3) Data on Form BM 172 Used:
(4) Investigations:

Page of 4

Figure H-1: Form BM 172 Used as Input

High Accident Location Investigation Form

(1) Location:
(2) Time Period of Accident History (Years):
(3) Data on Form BM 172 Used:
(4) Investigations:

Page 4 of

Figure H-1: Form BM 172 Used as Input

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First introduced by Richard Bellman. (11)

H-2

Computer Program to Select the Combination of Alternatives that Produce the Most Benefit for a Given Budget.

COST/BENEFIT MODULE (CBM)

DIMENSION TITL (19), X LOC (17), SEV (8, 8), CSEF (20, 11), B (8)
READ (5, 10) IOP1, IOP2, IOP3, IOP4, (TITL (I), 1=19)
10 FORMAT (I9, A8)
READ (5, 10) CFAT, CINJ, CPDO, RURB, RURR
11 FORMAT (F2.0, A8)
READ (6, 15) (TITL (I), 1=1,19)
15 FORMAT (3X, 19A4)
WRITE (6, 16) IOP1, IOP2, IOP3, IOP4
16 FORMAT (' OPTION 1 2 3 4 '/ 9 X, 4A4)
WRITE (6, 17) RURB, RURR
17 FORMAT (' INJ/RATIOS: URBAN= ', F2.0, ', RURAL=', F2.0)
WRITE (6, 18) CFAT, CINJ, CPDO
18 FORMAT (' NEG UTILITY FATALITY= ', F2.0, ', INJURY= ', F2.0, ' PER DM= ', F2.0, ' / (2/2)')

The above reads and prints the basic parameters constant for the entire program.

Below is the input which is executed for each accident location.

1 READ (5, 20) NO1, XLOC (1), I=1, 16, ILOC, TIME, NMO, NYR, NCAU
20 FORMAT (I4, 16A4, 2X, F4.0, I2, 2, 11)
98 CONTINUE
80 CONTINUE
IF (NO1 EQ 0) GO TO 122
122 WRITE (6, 123) NO1, XLOC (1), I=1, 16
123 FORMAT (F4, 2X, 16A4)
READ (5, 30) NO2, (SEV (I, J), J=1,4)
30 FORMAT (2X, 3F2.0)
NCAU = N/2
1123 WRITE (6, 22) NO1, XLOC (1), I=1, 16
22 FORMAT (I4)
WRITE (6, 1127)
```
1127 FORMAT ('/ / REF NO')
1128 CONTINUE
1129 WRITE (6, 125)
1130 FORMAT (1X, 'OUTPUT OF SEVERITIES AND TOTALS.'
1131 'ROUTINE TO CHECK CARD SEQUENCE CODE.'
1132 'SECOND CARD INPUT FOR EACH CRITICAL LOCATION (SEVERITIES).'
1133 'ROUTINE FOR ASSISTING RURAL OR URBAN RATIOS BELOW.'
1134 106 CONTINUE
1135 107 FORMAT (13,7F10.0/F10.0,/,8F10.0)
1136 XNO1=NO1
1137 1128 CONTINUE
1138 WRITE (6, 125)
1139 FORMAT (1X, 'AREA CONSIDERED RURAL.')
1140 WRITE (6,25)
1141 FORMAT (17,F23.2,F14.2,F16.4)
1142 CALL EXIT
1143 105 CONTINUE
1144 106 CONTINUE
1145 WRITE (6,95) I,XMAIN,TMCST, CBNM
1146 WRITE (6,96) I,XMAIN,TMCST, CBNM
1147 WRITE(7, 107)NALT, (B(I),I=1, NALT),XNO1
1148 WRITE(7, 107) NALT, (CSEF(I,1), 1=1, NALT),XNO1
1149 WRITE(6,97) I,XMAIN,TMCST, CBNM
1150 WRITE(6,98) I,XMAIN,TMCST, CBNM
1151 WRITE(6,99) I,XMAIN,TMCST, CBNM
1152 WRITE (6,100) NDEC, (B(I), I=1, NDEC)
1153 WRITE (6,101) NSTG, NBJ, XINC, K1, K2, XNO2
1154 WRITE (6,102) NSTG, NBJ, XINC, K1, K2, XNO2
1155 100 CONTINUE
1156 CONTINUE
1157 IF(IPNS, EQ, 1) GO TO 1030
1158 WRITE (6, 94)
1159 WRITE (6, 95)
1160 FORMAT ('/ / COST/BENEFIT ANALYSIS, MAINTENANCE INCLUDED')
1161 WRITE (6, 96)
1162 FORMAT ('/ / ALTERNATIVE MAINTENANCE TOTAL COST/BENEFIT')
1163 WRITE (6, 97) NALT, (CSEF(I,1), 1=1, NALT)
1164 CONTINUE
1165 WRITE (6, 98) I, XMAIN, TMST, CBNM
1166 WRITE(6,99) I, XMAIN, TMST, CBNM
1167 WRITE(6,100) NDEC, (B(I), I=1, NDEC)
1168 WRITE (6,101) NSTG, NBJ, XINC, K1, K2, XNO2
1169 WRITE (6,102) NSTG, NBJ, XINC, K1, K2, XNO2
1170 CONTINUE
1171 IF(IPNS, EQ, 1) GO TO 1030
1172 WRITE (6, 94)
1173 WRITE (6, 95)
1174 FORMAT ('/ / ALTERNATIVE MAINTENANCE TOTAL COST/BENEFIT')
1175 WRITE (6, 96)
1176 FORMAT ('/ / ALTERNATIVE MAINTENANCE TOTAL COST/BENEFIT')
1177 WRITE (6, 101) NSTG, NBJ, XINC, K1, K2, XNO2
1178 WRITE (6,102) NSTG, NBJ, XINC, K1, K2, XNO2
1179 CONTINUE
1180 CONTINUE
1181 IF(IPNS, EQ, 1) GO TO 1030
1182 WRITE (6, 94)
1183 WRITE (6, 95)
1184 FORMAT (H-5)
1185 H-6
1186 IF(IPNS, EQ, 1) GO TO 1030
1187 WRITE (6, 94)
1188 WRITE (6, 95)
1189 FORMAT (H-6)
1190 H-7
1191 IF(IPNS, EQ, 1) GO TO 1030
1192 WRITE (6, 94)
1193 WRITE (6, 95)
1194 FORMAT (H-7)
1195 H-8
1196 IF(IPNS, EQ, 1) GO TO 1030
1197 WRITE (6, 94)
1198 WRITE (6, 95)
1199 FORMAT (H-8)
READ(100) NDEC, (RX(I), IC=1,NDEC), XNO1(I)
DO 302 IC=1,NDEC
   ICPR=IC
   RXC=RX(1)
   DO 206 IC=1,NDEC
      RXC=RX(1)
      RXC=RXC+IC
      IF (IC .LT. ICPR) RXC=RXC+IC
      CONTINUE
   ICPR=IC
   RXC=RXC+IC
   CONTINUE
206 CONTINUE
   RXC=RXC+IC
   IF (IC .LT. ICPR) RXC=RXC+IC
   CONTINUE
302 CONTINUE
   RXC=RXC+IC
   RXC=RXC+IC
   CONTINUE

THIS SUBROUTINE INCREMENTS THE STATE VARIABLE OR BUDGET NUMBER FIGURE BY THE APPROPRIATE AMOUNT.

SUBROUTINE XING(I,J,XIN,XINC)
   XINC=(J-1)*XINC
   RETURN
END

SUBROUTINE XOUI(I,IST,XIN,K,TDEC,KICK,XINC,C)
   KICK=1
   XINC=(J-1)*XINC
   RETURN
END

 THIS SUBROUTINE CALCULATES THE OUTPUT STATE NUMBER RESULTING FROM THE INPUT XIN AND SAFETY MEASURE K; IT ALSO DETERMINES THE COST OF A PARTICULAR SAFETY MEASURE CORRESPONDING TO STAGE I.

SUBROUTINE XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
   DIMENSION C(30,31)
   TDEC=C(I)
   OUT=IN-TDEC
   IF (OUT) 10, 20, 20
   KICK=1
   XINC=(J-1)*XINC
   GO TO 30
   KICK=1
   GO TO 30
   XINC=(J-1)*XINC
   RETURN
END
This subroutine determines the return associated with safety measure $K$.

```plaintext
SUBROUTINE RET(I, XIN, TDEC, VRET, R, K)
DIMENSION R(31)
VRET=R(K)
RETURN
END
```

APPENDIX I

ALTERNATIVE TECHNIQUES OF MEASURING IMPROVEMENTS EFFECT

Improvement effect can be measured by comparing improvement experience with:

- experience at the same location before the improvement
- experience at other similar locations without the improvement
- standards of performance.

The respective types of analysis are:

- **Before and After Analysis** -- This analysis compares accident experience at a location before and after improvement implementation. To obtain statistically reliable data for evaluating a type of improvement, the before and after accident experience at several locations may be grouped together.

- **Parallel Analysis** -- This analysis compares accident experience at the improvement location with accident experience at similar locations not receiving improvements. The experience at these “control group” locations may be experience during the “after” period or the trend in experience from “before” to “after.” Both approaches are described. They are called Comparative Parallel Analysis and Before and After Parallel Analysis.

- **Performance Standard Analysis** -- This analysis compares improvement performance with standard performance for that improvement. This analysis is applicable only when performance standards have been established.

Before and After Analyses have been used more extensively than the other techniques. This may be attributable to the difficulty associated with finding truly similar control locations. For this same reason, the Before and After Analysis is the recommended method and is presented in the user's manual. The other two methods are discussed below.

Table I-1: Alternative Selected at Locations 101 to 125 for Budgets of $200,000 to $5,000,000 in Increments

<table>
<thead>
<tr>
<th>Location</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
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</table>

Comparative Parallel Study

A comparative parallel analysis should be conducted when it is not possible to collect valid data for the before periods. This analysis takes less time to conduct but requires more locations.

The analysis compares the experience of two locations or groups of locations over the same time period and under the same conditions except for the improvement. One location or group has been treated with the improvement and the other has not.

All sites should have similar traffic volumes, traffic patterns, vehicle populations, geometrics, roadside developments and other major environmental characteristics.

All locations must be similar in the following characteristics:

- **Exposure** -- When analyzing the results of an improvement, care must be taken to consider the effect of increases or decreases in traffic volumes.
  The best way to include exposure in the analyses is to calculate the accident rates per million vehicles passing the improvement.

- **Geometrics** -- When choosing locations for control testing, care must be exercised to ensure that the locations are physically similar to the implementation site. The similarities should include terrain, alignment, and speed limit. Whenever possible, several locations should be included in each group. This will help to negate the peculiarities of any individual location.

- **Traffic Patterns and Characteristics** -- Traffic patterns and characteristics at potential control locations should be studied before declaring them similar to the implementation site. Considerations should include peak-period volumes, operating speeds, off-peak volumes, percentage of trucks and average trip lengths.
Other Environmental Considerations — In addition to the physical and vehicular considerations at the test and control locations, the analyst should be aware of the environmental changes that may occur away from the site. These changes may drastically change the accident potentials of the locations. For example, the opening of a school near one of the locations might increase the occupancy of each vehicle and thus tend to increase the severity of each accident.

If all locations are approximately similar, the only additional data required for a comparative parallel study are the measurement units to be tested, such as accidents or conflicts.

e. Procedure

Steps for using a comparative parallel study to measure improvement effects are:

1. Identify the characteristics of the implementation site.
2. Select control sites that match the characteristics of the implementation site.
3. Collect the necessary data.
4. Determine the miles of highway, the number of vehicles, or the vehicle miles for all section or locations.
5. Determine the rate of accidents per mile or per million vehicle miles.
6. Determine the percent change as follows:

\[
\% \text{ Change} = \frac{Ac - Ai}{Ac} \times 100
\]

Where:
- \( Ac \) = After Results at Control Site(s).
- \( Ai \) = After Effect at Implementation Site(s).

b. Example

The following is an example of using a comparative parallel study to measure improvement effects.

<table>
<thead>
<tr>
<th>Section</th>
<th>Miles</th>
<th>Accidents During Test Period</th>
<th>Accidents Per Mile*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implementation (Edge Marked)</td>
<td>61</td>
<td>126</td>
<td>2.07</td>
</tr>
<tr>
<td>Control (Not Edge Marked)</td>
<td>55</td>
<td>167</td>
<td>3.04</td>
</tr>
</tbody>
</table>

* ADT on control and implementation sections equal.

\[
\% \text{ Change} = \frac{2.07 - 3.04}{3.04} \times 100 = -31\% \text{ Accidents Per Mile}
\]

Assuming that the implementation sections had the same accident rate as the control section prior to improvement, the number of before accidents would have been 185. Referring to Figure J-3 in Appendix J and using either curve, a percent reduction of 31%—from 185 to 126 accidents—is significant at the 99% level.

Before and After Parallel Study

A before and after parallel study uses a control section to reflect area-wide trends. Because the criteria and data requirements of both the before and after study and the control group study must be met, it is the most difficult study to conduct.

The assumption behind the before and after parallel study is that all locations are similar.

The data requirements for such a study are the same as the comparative parallel studies.

e. Procedure

Steps for using a before and after parallel study to measure the effect of an improvement are:

1. Identify characteristics of the implementation site.
2. Select control sites which match the characteristics of the implementation sites and for which "before" data are available.
3. Collect data.
4. Project the results anticipated for the test site based on the experience at the control site using the following equation:

\[
R_i = B_i \frac{Ac}{Bc}
\]

Where:
- \( R_i \) = Anticipated experience at the implementation site(s) if the improvement has not been implemented.
- \( B_i \) = Before experience at the implementation site(s).
- \( Ac \) = After experience at the control site(s).
- \( Bc \) = Before experience at the control site(s).

5. Determine the percent change as follows:

\[
\% \text{ Change} = \frac{E_i - R_i}{R_i} \times 100
\]

Where:
- \( E_i \) = Actual effect at the Implementation sites.

b. Example

The following is an example of a Before and After Parallel Study.

In 1957, the Ohio Department of Highways initiated a program of pavement edge marking on all 2-lane rural state highways which were at least 20 feet wide. No prior research on pavement edge marking in Ohio was available, therefore, 12 pairs of sections of the programmed edge marking were selected as test samples.

Each pair of sections consisted of a test section (pavement edge marked) and a control section (pavement not edge marked). These test and control sections were located as nearly as possible adjacent to each other and were selected so that the geometric design characteristics and culture surrounding each of the sections were similar in nature. The volume and character of traffic on each of the sections within a pair were comparable. The section chosen for edge marking within each pair was selected by "tossing a coin." This eliminated any bias due to section selection.

One pair of sections was located in 9 of the 12 highway department divisions within the state. A total of 116 miles of highway was selected for study, including 61 miles of test sections (edge marked) and 55 miles of control sections (not edge marked). (51)

The results of this parallel study are:
Performance Standard Study

This method is generally applicable where adequate experience has been accumulated to determine average values for measurement modes such as percent reduction, rates, or numbers. It is recommended that standards be based on statistical analyses of previous experience. However, lack of experience may require the use of judgment to set standards. The performance standards may vary from statistically proven facts to educated guesses.

An improvement is determined to be a success or failure on the basis of a standard effect. The determination of success can be answered by either "yes" or "no." Considerations when using performance standards are:

- Similarity of Situation -- The location under consideration should be similar to those locations used to develop the performance standard.
- Applicability of Improvement -- The improvement should be applied to the problem or problem it is intended to solve. For example, a safety lighting improvement applied at a location that is experiencing a high percentage of skidding accidents will not achieve the results expected by its performance standard.
- Exposure -- When analyzing the effects of an improvement, care must be taken to consider the effect of different traffic volumes. This problem can be avoided by analyzing the effect that the improvement had on accident rates. For example, a de-slicking improvement is expected to produce a 50% reduction in wet pavement accidents. When applied to a location that has had a change in traffic volume, the performance standard should be expressed as a 50% reduction in accidents/million vehicles.

The data requirements of a performance standard study will vary with the performance standard. As a minimum, data needed are:

- A description of the improvement that is adequate to determine what standard applies to the improvement
- An indication that the improvement was appropriate to the problem; and
- Data to calculate the measurement used as a standard.

Procedure

The procedure for using a performance standard study to measure improvement effect is simple. Calculate the actual accident reduction and compare it to the standard.

Standards may be based on the forecasts developed in Chapter 8 of the Users' Manual. If forecasts are not available, average rates or critical rates may be used as standards. In lieu of other data, standards may be established on the basis of logic.

Example

Mississippi has developed performance standards for several types of improvements as shown on Table 1-1.

<table>
<thead>
<tr>
<th>Improvement Type</th>
<th>Accident Reductions (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Treatment</td>
</tr>
<tr>
<td>Low-Velocity</td>
<td>10</td>
</tr>
<tr>
<td>High-Velocity</td>
<td>10</td>
</tr>
<tr>
<td>Median Speed</td>
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<td>Traffic Light</td>
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<td>Pedestrian Safety</td>
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<tr>
<td>Traffic Signal</td>
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<td>Glass</td>
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<td>Sight Distance</td>
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<td>Turn Bay</td>
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<td>Roughness</td>
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<td>Median Strip</td>
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<td>Reflective Strip</td>
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</tr>
<tr>
<td>Lighting</td>
<td>10</td>
</tr>
<tr>
<td>Reflective Driver</td>
<td>10</td>
</tr>
</tbody>
</table>

(1) Includes Traffic, 12' Lane, Turn-Marking and Median
(2) Presence of Accidents Involved in Accident Opening
(3) The Accident Increase Per 2000 Yards
(4) Upgrading Existing Equipment
(5) Replacing Existing With New Equipment
APPENDIX J
ADDITIONAL GRAPHS FOR TESTING ACCIDENT REDUCTION SIGNIFICANCE

The Users' Manual contains a graph for testing significant accident reduction at a 95% level of confidence (the recommended level). Figures J-1, J-2 and J-3 are graphs for testing significant accident reduction at 80%, 90% and 99% levels of confidence, respectively.

To use these graphs:

1. Select the level of confidence and the test to be used.
2. Find the number of before accidents on the abscissa.
3. Project vertically from this point to the appropriate test curve.
4. From this point on the test curve, plot horizontally to the ordinate.
5. Read the ordinate. If the actual percent reduction is equal to or exceeds the value read from the ordinate, the reduction is considered statistically significant at the given level of confidence.
ALTERNATIVE METHODS OF EVALUATING COMPLETED HIGHWAY SAFETY PROGRAMS

The evaluations of completed highway safety programs provide a basis for making decisions concerning:

- the adequacy of the current highway safety funding level, and
- the emphasis of future highway safety programs.

The evaluations should be of the entire program and the individual phases of the program, for example, signing, safety lighting, channelization, and roadside object removal. These evaluations can be made using either of the following methods:

- Benefit/cost ratio—the ratio of the present worth of accrued benefits to the present worth of accrued cost. Did the project or program pay for itself?
- Cost/effectiveness—the cost to reduce an accident, injury or fatality.

These methods are discussed on the following pages.

Benefit/Cost Ratio

The benefit/cost ratio is applicable to evaluating the completed highway safety program and to evaluating each phase of the completed program.

The data requirements of the benefit/cost ratio method are:

- Initial construction costs
- Annual operating costs
- Annual benefits
- Interest rate
- Implementation date.

Procedure

The procedure for using the benefit/cost ratio to evaluate a completed program or the phases of the program is:

1. Group the improvements.

The following is an example of using the benefit/cost ratios to evaluate one phase of a three-year program.

1-4. Develop the basic data.
7. Calculate B/C:

\[
\text{Lighting B/C} = \frac{1,17}{66,200} = 0.00175
\]
\[
\text{Signing B/C} = \frac{2.40}{56,550} = 0.00042
\]
\[
\text{De-slicking B/C} = \frac{1.11}{147,900} = 0.000076
\]

Thus, the signing phase of the 1970 program is producing more benefits per dollar spent than the lighting and de-slicking phases. The comparison of these ratios gives top management an indication of the relative merits of each phase of the program. Such knowledge helps managers making decisions about future programs.

Cost/Effectiveness

This method is applicable to evaluating the entire highway safety program and to evaluating each phase of the highway safety program.

The assumption behind the cost/effectiveness method of evaluating a highway safety program or its phases is that the merit of a group of improvements is reflected by its cost per unit of effectiveness.

The data requirements of the cost/effectiveness method are:

- Initial construction cost
- Annual cost
- Annual benefits in the desired units of effectiveness
- Interest rate
- Implementation date.

The cost/effectiveness is the average cost per unit of effectiveness—accidents, injuries, or fatalities reduced.

a. Procedure

Steps for using cost/effectiveness to evaluate a highway safety program or its phases are:

1. Group the improvements.

   If the evaluation is for one specific year’s program, combine all of the improvements from that year’s program.
   If the evaluation is for a specific phase of one specific year’s program, for example, FY 74 signing, combine all of the improvements in that phase from that year’s program.

2. Determine the actual initial construction cost of each improvement.

9. Calculate the cost/effectiveness array:

\[
\text{C/E} = \frac{\text{PWOC}}{\sum B}
\]

Where:

- \( \text{B} \) = the average annual benefit of a year’s program in the desired units of effectiveness
- \( \text{PWOC} \) = Present worth of cost of a group of improvements
- \( \sum B \) = \( \sum \) annual benefits in the desired units of effectiveness of all years’ programs included in the group of improvements
- \( SF \) = Sinking fund factor for m years and interest rate i. (The above formula for cost/effectiveness may be found in interest tables or calculated by the formulas in Figure F-2.)

b. Example

The following is an example of using cost/effectiveness to evaluate the phases of three years’ programs:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>40,000</td>
<td>8,000</td>
<td>4,000</td>
<td>9,000</td>
<td>8,000</td>
<td>8,000</td>
<td>8,000</td>
</tr>
<tr>
<td>Signing</td>
<td>5,000</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>De-slicking</td>
<td>100,000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>15</td>
<td>18</td>
</tr>
</tbody>
</table>

*Unit of effectiveness = accidents reduced

6. Interest rate, \( i = 10\% \).
7. Calculate the present worth of costs, PWOC.

\[ \text{Lighting PWOC} = (40,000)(1.331) + (1,000)(1.210) + (1,000)(1.100) + 1,000 = \$56,550 \]

\[ \text{Signing PWOC} = (5,000)(1.331) + (500)(1.210) + (400)(1.100) + 500 = \$8,200 \]

\[ \text{Dc-sucking PWOC} = (100,000)(1.331) = \$133,100 \]

8. Calculate the average annual benefit, \( B \).

\[ \text{Program - Phase B} \]

\[ \begin{align*}
\text{Lighting} & \quad \frac{8+8+4}{3} = 8.00 \text{ Accidents} \\
\text{Signing} & \quad \frac{2+2+3}{3} = 2.33 \text{ Accidents} \\
\text{Dc-sucking} & \quad \frac{15+15+18}{3} = 16.00 \text{ Accidents}
\end{align*} \]

9. Calculate the cost/effectiveness ratio:

\[ \text{Program - Phase C/E} \]

\[ \begin{align*}
\text{Lighting} & \quad \frac{0.302(56,550)}{8.00} = \$2,135 \text{ per accident} \\
\text{Signing} & \quad \frac{0.302(8,200)}{2.33} = \$1,061 \text{ per accident} \\
\text{Dc-sucking} & \quad \frac{0.302(133,100)}{16.00} = \$2,512 \text{ per accident}
\end{align*} \]

---

**APPENDIX L—**

**TYPICAL HIGHWAY-SAFETY IMPROVEMENTS**

One of the problems encountered in discussions of economic methods of evaluating alternative improvements was the practicality of examples. For this reason, the eighteen agencies conducting the field tests were asked to provide examples of typical highway safety improvements. The Alabama Highway Department responded with the list of improvements shown in Table L-1.

The equivalent uniform annual cost is calculated using the interest rate used by the agency supplying the example. The equivalent uniform annual benefit and cost are rounded to the nearest five dollars.

### Table L-1

<table>
<thead>
<tr>
<th>Location/Alternative</th>
<th>Improvement Description</th>
<th>Service (Yr.</th>
<th>Initial Cost (1000)</th>
<th>Annual Cost (1000)</th>
<th>Benefit/Year (1000)</th>
<th>Equivalent Uniform Annual Cost (1000)</th>
<th>Equivalent Uniform Annual Benefit (1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>101-A</td>
<td>Roadway Signs</td>
<td>6</td>
<td>400</td>
<td>20</td>
<td>0</td>
<td>2,110</td>
<td>130</td>
</tr>
<tr>
<td>101-B</td>
<td>Reflectors, Bridge</td>
<td>6</td>
<td>2,000</td>
<td>125</td>
<td>0</td>
<td>6,450</td>
<td>510</td>
</tr>
<tr>
<td>101-C</td>
<td>All. A and All. B</td>
<td>6</td>
<td>2,700</td>
<td>145</td>
<td>0</td>
<td>10,300</td>
<td>820</td>
</tr>
<tr>
<td>101-D</td>
<td>Guardrail</td>
<td>76</td>
<td>19,100</td>
<td>150</td>
<td>0</td>
<td>10,470</td>
<td>1,165</td>
</tr>
<tr>
<td>101-E</td>
<td>All. A, All. B and All. D</td>
<td>18</td>
<td>25,000</td>
<td>275</td>
<td>0</td>
<td>13,840</td>
<td>3,915</td>
</tr>
<tr>
<td>102-A</td>
<td>Redesign Intersection</td>
<td>20</td>
<td>10,000</td>
<td>50</td>
<td>0</td>
<td>1,650</td>
<td>250</td>
</tr>
<tr>
<td>102-B</td>
<td>Install left turn lane</td>
<td>10</td>
<td>12,700</td>
<td>400</td>
<td>0</td>
<td>4,970</td>
<td>1,470</td>
</tr>
<tr>
<td>102-C</td>
<td>All. A and All. B</td>
<td>20</td>
<td>25,700</td>
<td>450</td>
<td>0</td>
<td>6,770</td>
<td>1,825</td>
</tr>
<tr>
<td>103-A</td>
<td>Roadway Signs</td>
<td>6</td>
<td>2,000</td>
<td>30</td>
<td>0</td>
<td>1,625</td>
<td>350</td>
</tr>
<tr>
<td>103-B</td>
<td>pavement markings</td>
<td>4</td>
<td>5,000</td>
<td>30</td>
<td>0</td>
<td>1,250</td>
<td>1,200</td>
</tr>
<tr>
<td>103-C</td>
<td>All. A and All. B</td>
<td>3</td>
<td>7,000</td>
<td>100</td>
<td>0</td>
<td>1,700</td>
<td>1,300</td>
</tr>
<tr>
<td>104-A</td>
<td>Roadway Signs</td>
<td>6</td>
<td>250</td>
<td>30</td>
<td>0</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>104-B</td>
<td>Left turn lane</td>
<td>3</td>
<td>600</td>
<td>25</td>
<td>0</td>
<td>2,600</td>
<td>270</td>
</tr>
<tr>
<td>104-C</td>
<td>All. A and All. D</td>
<td>4</td>
<td>1,000</td>
<td>45</td>
<td>0</td>
<td>3,990</td>
<td>295</td>
</tr>
<tr>
<td>105-A</td>
<td>install right turn lane</td>
<td>10</td>
<td>15,000</td>
<td>200</td>
<td>0</td>
<td>1,150</td>
<td>1,700</td>
</tr>
<tr>
<td>105-B</td>
<td>Roundabout</td>
<td>10</td>
<td>75,000</td>
<td>50</td>
<td>0</td>
<td>2,110</td>
<td>2,000</td>
</tr>
<tr>
<td>105-C</td>
<td>All. A and All. B</td>
<td>10</td>
<td>30,000</td>
<td>350</td>
<td>0</td>
<td>2,310</td>
<td>2,700</td>
</tr>
<tr>
<td>106-A</td>
<td>Roadway Signs</td>
<td>6</td>
<td>450</td>
<td>30</td>
<td>0</td>
<td>875</td>
<td>105</td>
</tr>
<tr>
<td>106-B</td>
<td>Replace Bridge Structure</td>
<td>20</td>
<td>70,000</td>
<td>200</td>
<td>0</td>
<td>2,240</td>
<td>4,700</td>
</tr>
<tr>
<td>107-A</td>
<td>Roadway Signs</td>
<td>6</td>
<td>600</td>
<td>20</td>
<td>0</td>
<td>110</td>
<td>120</td>
</tr>
<tr>
<td>107-B</td>
<td>Roundabouts and median</td>
<td>6</td>
<td>1,450</td>
<td>40</td>
<td>0</td>
<td>650</td>
<td>315</td>
</tr>
<tr>
<td>107-C</td>
<td>Additional pavement</td>
<td>4</td>
<td>2,250</td>
<td>60</td>
<td>0</td>
<td>760</td>
<td>435</td>
</tr>
<tr>
<td>108-A</td>
<td>Roadway Signs</td>
<td>6</td>
<td>210</td>
<td>20</td>
<td>0</td>
<td>210</td>
<td>51</td>
</tr>
<tr>
<td>108-B</td>
<td>Reflectors on each side</td>
<td>6</td>
<td>290</td>
<td>20</td>
<td>0</td>
<td>1,455</td>
<td>85</td>
</tr>
<tr>
<td>108-C</td>
<td>All. A and All. B</td>
<td>6</td>
<td>600</td>
<td>40</td>
<td>0</td>
<td>1,745</td>
<td>140</td>
</tr>
<tr>
<td>109-A</td>
<td>Geometric Intersection</td>
<td>20</td>
<td>2,000</td>
<td>50</td>
<td>0</td>
<td>140</td>
<td>150</td>
</tr>
<tr>
<td>109-B</td>
<td>Roundabout</td>
<td>10</td>
<td>38,000</td>
<td>400</td>
<td>0</td>
<td>970</td>
<td>2,390</td>
</tr>
<tr>
<td>109-C</td>
<td>All. A and All. B</td>
<td>12</td>
<td>38,000</td>
<td>450</td>
<td>0</td>
<td>1,150</td>
<td>2,700</td>
</tr>
<tr>
<td>110-A</td>
<td>Roadway Signs</td>
<td>6</td>
<td>300</td>
<td>20</td>
<td>0</td>
<td>1,060</td>
<td>70</td>
</tr>
<tr>
<td>110-B</td>
<td>All. A and Channelization</td>
<td>15</td>
<td>1,100</td>
<td>40</td>
<td>0</td>
<td>2,130</td>
<td>115</td>
</tr>
<tr>
<td>110-C</td>
<td>grade change for trucks</td>
<td>10</td>
<td>300,000</td>
<td>600</td>
<td>0</td>
<td>7,550</td>
<td>15,400</td>
</tr>
<tr>
<td>111-A</td>
<td>Widening of roadway to</td>
<td>5</td>
<td>15,000</td>
<td>600</td>
<td>0</td>
<td>13,110</td>
<td>3,800</td>
</tr>
</tbody>
</table>

(Using a 6% interest rate)
### L-3

#### Using a 0% interest rate

<table>
<thead>
<tr>
<th>Item (Description)</th>
<th>Impression Description</th>
<th>Service Life (Year)</th>
<th>Initial Cost (Value)</th>
<th>Annual Cost</th>
<th>Terminal Value</th>
<th>Equilibrium Uniform Annual Benefit Award</th>
<th>Equilibrium Uniform Annual Cost Award</th>
<th>Impression Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>151-A</td>
<td>Installing monitored stop signs</td>
<td>10</td>
<td>2,900</td>
<td>250</td>
<td>6,990</td>
<td>490</td>
<td></td>
<td>151-A</td>
</tr>
<tr>
<td>152-B</td>
<td>Installing monitored stop signs and shoulder signs</td>
<td>15</td>
<td>10,000</td>
<td>400</td>
<td>1,165</td>
<td>1,365</td>
<td></td>
<td>152-B</td>
</tr>
<tr>
<td>153-C</td>
<td>Contract grade separation</td>
<td>20</td>
<td>1,000,000</td>
<td>3,000</td>
<td>2,044</td>
<td>72,500</td>
<td></td>
<td>153-C</td>
</tr>
<tr>
<td>154-A</td>
<td>Installing grade signs at bridge ends</td>
<td>10</td>
<td>2,000</td>
<td>250</td>
<td>6,950</td>
<td>450</td>
<td></td>
<td>154-A</td>
</tr>
<tr>
<td>155-B</td>
<td>Deliverance</td>
<td>5</td>
<td>1,500</td>
<td>290</td>
<td>1,560</td>
<td>590</td>
<td></td>
<td>155-B</td>
</tr>
<tr>
<td>156-C</td>
<td>FHWA and AASHTO</td>
<td>5</td>
<td>3,000</td>
<td>460</td>
<td>2,720</td>
<td>1,000</td>
<td></td>
<td>156-C</td>
</tr>
<tr>
<td>157-A</td>
<td>Widening of pavement and shoulder widening cost</td>
<td>10</td>
<td>30,000</td>
<td>500</td>
<td>6,760</td>
<td>1,500</td>
<td></td>
<td>157-A</td>
</tr>
<tr>
<td>158-A</td>
<td>Upgrading traffic signal</td>
<td>15</td>
<td>700</td>
<td>300</td>
<td>3,310</td>
<td>242</td>
<td></td>
<td>158-A</td>
</tr>
<tr>
<td>159-A</td>
<td>Upgrading traffic signal</td>
<td>15</td>
<td>24,000</td>
<td>1,500</td>
<td>6,825</td>
<td>2,900</td>
<td></td>
<td>159-A</td>
</tr>
<tr>
<td>160-A</td>
<td>Ramps, 0.5%, etc. of A, B, C</td>
<td>10</td>
<td>40,000</td>
<td>1,000</td>
<td>2,315</td>
<td>3,900</td>
<td></td>
<td>160-A</td>
</tr>
<tr>
<td>161-B</td>
<td>Roadway grade and shoulder widening cost</td>
<td>10</td>
<td>15,000</td>
<td>2,500</td>
<td>3,260</td>
<td>1,000</td>
<td></td>
<td>161-B</td>
</tr>
<tr>
<td>162-A</td>
<td>Install Guard rail</td>
<td>10</td>
<td>3,200</td>
<td>100</td>
<td>580</td>
<td>430</td>
<td></td>
<td>162-A</td>
</tr>
<tr>
<td>163-A</td>
<td>Street lighting and street signs</td>
<td>20</td>
<td>85,000</td>
<td>500</td>
<td>11,450</td>
<td>4,120</td>
<td></td>
<td>163-A</td>
</tr>
<tr>
<td>164-A</td>
<td>Install guardrail</td>
<td>10</td>
<td>3,300</td>
<td>100</td>
<td>455</td>
<td>430</td>
<td></td>
<td>164-A</td>
</tr>
<tr>
<td>165-A</td>
<td>Install traffic control signs</td>
<td>30</td>
<td>4,650</td>
<td>100</td>
<td>2,990</td>
<td>500</td>
<td></td>
<td>165-A</td>
</tr>
<tr>
<td>166-A</td>
<td>Install traffic control signs</td>
<td>10</td>
<td>2,000</td>
<td>100</td>
<td>4,180</td>
<td>2,150</td>
<td></td>
<td>166-A</td>
</tr>
</tbody>
</table>

### L-4

#### Using a 0% interest rate

<table>
<thead>
<tr>
<th>Item (Description)</th>
<th>Impression Description</th>
<th>Service Life (Year)</th>
<th>Initial Cost (Value)</th>
<th>Annual Cost</th>
<th>Terminal Value</th>
<th>Equilibrium Uniform Annual Benefit Award</th>
<th>Equilibrium Uniform Annual Cost Award</th>
<th>Impression Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>161-A</td>
<td>Widening roadway</td>
<td>10</td>
<td>3,000</td>
<td>0</td>
<td>360</td>
<td>590</td>
<td></td>
<td>161-A</td>
</tr>
<tr>
<td>162-B</td>
<td>Widening pavement and shoulder widening cost</td>
<td>10</td>
<td>4,000</td>
<td>0</td>
<td>0</td>
<td>2,300</td>
<td></td>
<td>162-B</td>
</tr>
<tr>
<td>163-A</td>
<td>4-lane road (87 mi.)</td>
<td>20</td>
<td>10,000,000</td>
<td>40,000</td>
<td>46,370</td>
<td>540</td>
<td></td>
<td>163-A</td>
</tr>
<tr>
<td>164-A</td>
<td>Roadway widening and cross section</td>
<td>20</td>
<td>15,000,000</td>
<td>50,000</td>
<td>4,050</td>
<td>3,150</td>
<td></td>
<td>164-A</td>
</tr>
<tr>
<td>165-B</td>
<td>Reconstruction of 4-lane facility</td>
<td>5</td>
<td>3,000</td>
<td>0</td>
<td>970</td>
<td>120</td>
<td></td>
<td>165-B</td>
</tr>
<tr>
<td>166-A</td>
<td>Contract grade separation</td>
<td>20</td>
<td>2,000,000</td>
<td>0</td>
<td>2,000</td>
<td>250</td>
<td></td>
<td>166-A</td>
</tr>
<tr>
<td>166-B</td>
<td>Uplifting signs and marking</td>
<td>4</td>
<td>3,000</td>
<td>750</td>
<td>2,840</td>
<td>1,300</td>
<td></td>
<td>166-B</td>
</tr>
<tr>
<td>166-C</td>
<td>Traffic calming</td>
<td>20</td>
<td>3,000</td>
<td>1,000</td>
<td>6,900</td>
<td>3,900</td>
<td></td>
<td>166-C</td>
</tr>
<tr>
<td>166-D</td>
<td>Roadway widening and cross section</td>
<td>20</td>
<td>2,000,000</td>
<td>0</td>
<td>6,875</td>
<td>113,300</td>
<td></td>
<td>166-D</td>
</tr>
<tr>
<td>166-E</td>
<td>Uplifting signs and marking</td>
<td>10</td>
<td>30,000</td>
<td>500</td>
<td>2,280</td>
<td>2,300</td>
<td></td>
<td>166-E</td>
</tr>
<tr>
<td>166-F</td>
<td>Uplifting signs and marking</td>
<td>20</td>
<td>10,000</td>
<td>0</td>
<td>2,780</td>
<td>1,300</td>
<td></td>
<td>166-F</td>
</tr>
<tr>
<td>166-G</td>
<td>Upgrading signs and marking</td>
<td>4</td>
<td>1,000</td>
<td>0</td>
<td>1,214</td>
<td>270</td>
<td></td>
<td>166-G</td>
</tr>
<tr>
<td>166-H</td>
<td>Widening roadway</td>
<td>30</td>
<td>500,000</td>
<td>1,000</td>
<td>215</td>
<td>11,200</td>
<td></td>
<td>166-H</td>
</tr>
<tr>
<td>166-I</td>
<td>Roadway widening and cross section</td>
<td>3</td>
<td>5,000</td>
<td>350</td>
<td>215</td>
<td>110</td>
<td></td>
<td>166-I</td>
</tr>
<tr>
<td>166-J</td>
<td>Uplifting signs and marking</td>
<td>20</td>
<td>150,000</td>
<td>1,000</td>
<td>215</td>
<td>870</td>
<td></td>
<td>166-J</td>
</tr>
<tr>
<td>166-K</td>
<td>Uplifting signs and marking</td>
<td>3</td>
<td>10,000</td>
<td>300</td>
<td>220</td>
<td>320</td>
<td></td>
<td>166-K</td>
</tr>
<tr>
<td>166-L</td>
<td>Uplifting signs and marking</td>
<td>30</td>
<td>500,000</td>
<td>1,000</td>
<td>2,510</td>
<td>590</td>
<td></td>
<td>166-L</td>
</tr>
</tbody>
</table>

### L-5

#### Using a 0% interest rate

<table>
<thead>
<tr>
<th>Item (Description)</th>
<th>Impression Description</th>
<th>Service Life (Year)</th>
<th>Initial Cost (Value)</th>
<th>Annual Cost</th>
<th>Terminal Value</th>
<th>Equilibrium Uniform Annual Benefit Award</th>
<th>Equilibrium Uniform Annual Cost Award</th>
<th>Impression Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>161-A</td>
<td>Widening roadway</td>
<td>10</td>
<td>3,000</td>
<td>0</td>
<td>360</td>
<td>590</td>
<td></td>
<td>161-A</td>
</tr>
<tr>
<td>162-B</td>
<td>Widening pavement and shoulder widening cost</td>
<td>10</td>
<td>4,000</td>
<td>0</td>
<td>0</td>
<td>2,300</td>
<td></td>
<td>162-B</td>
</tr>
<tr>
<td>163-A</td>
<td>4-lane road (87 mi.)</td>
<td>20</td>
<td>10,000,000</td>
<td>40,000</td>
<td>46,370</td>
<td>540</td>
<td></td>
<td>163-A</td>
</tr>
<tr>
<td>164-A</td>
<td>Roadway widening and cross section</td>
<td>20</td>
<td>15,000,000</td>
<td>50,000</td>
<td>4,050</td>
<td>3,150</td>
<td></td>
<td>164-A</td>
</tr>
<tr>
<td>165-B</td>
<td>Reconstruction of 4-lane facility</td>
<td>5</td>
<td>3,000</td>
<td>0</td>
<td>970</td>
<td>120</td>
<td></td>
<td>165-B</td>
</tr>
<tr>
<td>166-A</td>
<td>Contract grade separation</td>
<td>20</td>
<td>2,000,000</td>
<td>0</td>
<td>2,000</td>
<td>250</td>
<td></td>
<td>166-A</td>
</tr>
<tr>
<td>166-B</td>
<td>Uplifting signs and marking</td>
<td>4</td>
<td>3,000</td>
<td>750</td>
<td>2,840</td>
<td>1,300</td>
<td></td>
<td>166-B</td>
</tr>
<tr>
<td>166-C</td>
<td>Traffic calming</td>
<td>20</td>
<td>3,000</td>
<td>1,000</td>
<td>6,900</td>
<td>3,900</td>
<td></td>
<td>166-C</td>
</tr>
<tr>
<td>166-D</td>
<td>Roadway widening and cross section</td>
<td>20</td>
<td>2,000,000</td>
<td>0</td>
<td>6,875</td>
<td>113,300</td>
<td></td>
<td>166-D</td>
</tr>
<tr>
<td>166-E</td>
<td>Uplifting signs and marking</td>
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<td>30,000</td>
<td>500</td>
<td>2,280</td>
<td>2,300</td>
<td></td>
<td>166-E</td>
</tr>
<tr>
<td>166-F</td>
<td>Uplifting signs and marking</td>
<td>20</td>
<td>10,000</td>
<td>0</td>
<td>2,780</td>
<td>1,300</td>
<td></td>
<td>166-F</td>
</tr>
<tr>
<td>166-G</td>
<td>Upgrading signs and marking</td>
<td>4</td>
<td>1,000</td>
<td>0</td>
<td>1,214</td>
<td>270</td>
<td></td>
<td>166-G</td>
</tr>
<tr>
<td>166-H</td>
<td>Widening roadway</td>
<td>30</td>
<td>500,000</td>
<td>1,000</td>
<td>215</td>
<td>11,200</td>
<td></td>
<td>166-H</td>
</tr>
<tr>
<td>166-I</td>
<td>Roadway widening and cross section</td>
<td>3</td>
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<td>350</td>
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<td></td>
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<td>166-J</td>
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<td>166-K</td>
<td>Uplifting signs and marking</td>
<td>3</td>
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<td>300</td>
<td>220</td>
<td>320</td>
<td></td>
<td>166-K</td>
</tr>
<tr>
<td>166-L</td>
<td>Uplifting signs and marking</td>
<td>30</td>
<td>500,000</td>
<td>1,000</td>
<td>2,510</td>
<td>590</td>
<td></td>
<td>166-L</td>
</tr>
</tbody>
</table>
Table 1-1 (Cont’d.)

<table>
<thead>
<tr>
<th>Location Attribution</th>
<th>Improvement Description</th>
<th>Service Life (Years)</th>
<th>Initial Cash Investment (dollars)</th>
<th>Annual Cash Investment (dollars)</th>
<th>Total Discounted Value (dollars)</th>
<th>Equivalent Uniform Annual Value at 8% Discount (dollars)</th>
<th>Equivalent Uniform Annual Value at 10% Discount (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>172-A</td>
<td>Implement signing &amp; install emergency lane</td>
<td>6</td>
<td>3,000</td>
<td>50</td>
<td>7,010</td>
<td>460</td>
<td>550</td>
</tr>
<tr>
<td>172-B</td>
<td>Roadside Install signs for diversion</td>
<td>7</td>
<td>156,000</td>
<td>100</td>
<td>2,010</td>
<td>13,743</td>
<td>15,597</td>
</tr>
<tr>
<td>172-C</td>
<td>Alt A and Alt B</td>
<td>8</td>
<td>111,500</td>
<td>150</td>
<td>1,091</td>
<td>14,079</td>
<td>14,079</td>
</tr>
<tr>
<td>173-A</td>
<td>Implement signing, design &amp; install &amp; construct roundabout</td>
<td>3</td>
<td>700</td>
<td>150</td>
<td>7,095</td>
<td>790</td>
<td>790</td>
</tr>
<tr>
<td>172-A</td>
<td>Implement traffic signs at exit 1</td>
<td>4</td>
<td>700</td>
<td>50</td>
<td>3,000</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>172-A</td>
<td>Install guardrail on north and south side of roadway and median shoulder for recovery area</td>
<td>30</td>
<td>6,500</td>
<td>100</td>
<td>4,510</td>
<td>470</td>
<td>470</td>
</tr>
<tr>
<td>174-A</td>
<td>Install 3-Way Flasher at intersection and place wayfinding signage on Co. Rd. 712</td>
<td>10</td>
<td>775</td>
<td>150</td>
<td>2,689</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td>175-A</td>
<td>Lower grade on west bound lane to level of east bound lane</td>
<td>10</td>
<td>17,600</td>
<td>150</td>
<td>6,770</td>
<td>168</td>
<td>168</td>
</tr>
<tr>
<td>176-A</td>
<td>Install left turn lane on east and west bound lanes</td>
<td>15</td>
<td>1,500</td>
<td>100</td>
<td>3,540</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>177-A</td>
<td>Install 4-way flashes</td>
<td>10</td>
<td>775</td>
<td>50</td>
<td>530</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>178-A</td>
<td>Flashes fail current zone and FRONT vertical signs</td>
<td>15</td>
<td>3,500</td>
<td>5,000</td>
<td>11,705</td>
<td>25,100</td>
<td>25,100</td>
</tr>
<tr>
<td>179-A</td>
<td>Replace of existing median from Dallas Ave. to I-30 @ exit 1</td>
<td>10</td>
<td>32,000</td>
<td>2,000</td>
<td>16,735</td>
<td>7,000</td>
<td>7,000</td>
</tr>
<tr>
<td>180-A</td>
<td>Install bridge rail on an existing and a new shoulder bridge</td>
<td>15</td>
<td>70,000</td>
<td>500</td>
<td>1,800</td>
<td>1,833</td>
<td>1,833</td>
</tr>
</tbody>
</table>

*Using 8% Interest Rate

A questionnaire was sent to ninety-one highway and safety agencies to determine:
- characteristics of potential users of safety evaluation systems
- techniques currently used by the agencies
- organization structures for performing safety evaluations.

This appendix includes:
- List of Agencies Canvassed
- Questionnaire Cover Letters
- Summary of Questionnaire Responses

AppxM

Ages Conversed

Alabama State Highway Department
Alaska Department of Highways
Arkansas State Highway Department
Texas Department of Transportation
California Department of Transportation
Colorado Department of Highways
Connecticut Department of Transportation
Delaware Department of Transportation
District of Columbia Department of Transportation
Florida Department of Transportation
Georgia Department of Transportation
Illinois Department of Transportation
Indiana Department of Transportation
Iowa Department of Transportation
Kansas Department of Transportation
Kentucky Department of Transportation
Louisiana Department of Transportation
Maine Department of Transportation
Maryland Department of Transportation
Massachusetts Department of Transportation
Michigan Department of State Highways
Minnesota Department of Transportation
Mississippi Department of Transportation
Missouri Department of Transportation
Montana Department of Transportation
Nebraska Department of Transportation
Nevada Department of Highways
New Hampshire Department of Highways
New Jersey Department of Transportation
New Mexico Department of Transportation
New York Department of Transportation
North Carolina Department of Transportation
Ohio Department of Transportation
Oregon Department of Transportation
Pennsylvania Department of Transportation
Rhode Island Department of Transportation
South Dakota Department of Transportation
Tennessee Department of Transportation
Texas Department of Transportation
Utah Department of Transportation
Virginia Department of Transportation
West Virginia Department of Transportation
Wisconsin Department of Transportation
Wyoming Department of Transportation

*Agencies canvassed by previous research team
SUMMARY OF CANVAS

The significant responses to each question in the canvass of existing highway safety practices are detailed below.

PRE-IMPLEMENTATION EVALUATION

A. IDENTIFYING THE SAFETY PROBLEM

For an evaluation to be accurate, the correct improvement must be applied at the correct location. The first set of questions relate to techniques of identifying the safety problem.

DO YOU USE OR PLAN TO USE ACCIDENT EXPERIENCE TO IDENTIFY YOUR SAFETY PROBLEM LOCATIONS?

If yes, go to the next question.

If no, describe briefly reasons for not using accident experience.

Typical Responses

All 51 of the organizations responding answered yes.

Other Responses

In Michigan, some projects are based on "preventive" measures--before accidents develop. Illustration--widening roadway in front of a shopping center under construction; widening approaches to an intersection that has met signal warrants.

ARE YOU USING THE TECHNIQUES CONTAINED IN THE ATTACHMENT TO PPM-21-16 OR THE REPORT "EVALUATION OF CRITERIA FOR SAFETY IMPROVEMENTS ON THE HIGHWAY"?

If yes, have you modified these techniques?

Describe the modifications and why they were made. If modifications are documented in a generally available published report, please give a bibliographical reference.

Typical Response

Most states answered yes. Exceptions were California, Hawaii, Iowa, Indiana, Oregon, South Dakota and Vermont.

Of the states answering "yes," 70% have modified the techniques. This indicates that there is a wide range of thinking among the users.

ARE YOU USING TECHNIQUES BASED ON OTHER PREVIOUS RESEARCH REPORTS?

If yes, please indicate the research report and describe modifications and the reasons for modification.

Typical Response

Thirty-six states indicated they are not using other research reports. The other states generally did not indicate the titles of other research reports.

Other Responses


HAVE YOU DEVELOPED YOUR OWN TECHNIQUE FOR USING ACCIDENT EXPERIENCE TO IDENTIFY ACCIDENT LOCATION PROBLEMS?

If yes, describe the technique including theoretical basis, objectives, method, inputs, outputs and application of output.

Typical Response

They were evenly divided between "yes" and "no."

Other Responses

Methods listed included:
- milepost increment method
- number and rate method
- pin maps
- severity index
- cluster reports
- fatal spot location
- ranking techniques
- critical rate factors
- computerized analysis
- California TASAS System.

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the system involve the ranking of spot locations and sections less than one mile long with a general listing of standard one-mile sections.

- We experience considerable delay in obtaining basic data from the Police Department necessary to prepare data processing tabulations for current monthly accident data.

WHAT ARE THE DATA REQUIREMENTS OF THE ABOVE DESCRIBED TECHNIQUE(S)?

Typical Response

In general:
- traffic volume
- accident records
- roadway inventory.

HOW MANY YEARS DATA ARE USUALLY ANALYZED?

<table>
<thead>
<tr>
<th>Number of Years</th>
<th>Number of States Responding</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

IS THERE A MINIMUM VOLUME OF DATA?

If yes, describe:

SET H19284H1101H1208H1119

DESCRIBE ANY DEFICIENCIES IN THE TECHNIQUE BEING USED. DEFICIENCIES MAY BE RELATED TO FACTORS SUCH AS LACK OF DATA, DATA PROCESSING DIFFICULTY OR BASIC THEORETICAL INADEQUACIES OF THE METHOD. BASICALLY, WE WANT TO KNOW IF THE TECHNIQUE DOES NOT WORK AS WELL AS EXPECTED AND IF SO, WHY IT DOESN'T.

Typical Responses

Common problems included:
- coding problems;
- lack of roadway inventory;
- lack of data;
- failure to work with extreme conditions;
- time lag (with data or computer); and
- technical staff shortages.

Other Responses

Several examples of responses are:
- The name and code number being used has many duplications of names and codes; roads and streets with no names, new roads without names, and outdated maps. These deficiencies are in the process of being corrected.
- Difficulty has been encountered in achieving an equitable means of ranking proposed high and low volume highway sections. Hazard indices calculated for highways exhibiting a low volume are disproportionately high when compared to those for highways carrying a much greater volume. B/C ratios are likewise affected when one of the small number of accidents under consideration involves a fatality. It would be an improvement to merge these two measurements into one that would consider both number of accidents (as a function of travel) and severity. Further deficiencies in

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Typical Responses

Yes—Twenty states, minimum ranged from 1 to 3 years of data. Two states required 15 years of data.
No—22 states.

ARE ANY STATISTICAL TESTS APPLIED TO THE DATA?

If yes, describe:

WHAT CONFIDENCE LEVEL DO YOU USE?

Typically, they use:

- Poisson
- Normal/Quality Rate Method

Other methods used include:

- Binomial
- Severity Index
- Chi-Square

Confidence limits used range from 75% to 99.5%. The typical limit is 85 - 95%.

DOES YOUR TECHNIQUE PROVIDE FOR CONSIDERATION OF PUBLIC COMPLAINTS TO IDENTIFY ACCIDENT PROBLEM LOCATIONS?

If yes, how are the public complaints used and how are these uses productive?

Most states respond to public complaints with field investigations. Five states indicated a firm "no."
One state indicated that these follow-ups were less important than an improved accident analysis system. However, several states indicated that valid complaints may lead to corrective action.

**WHAT IS THE SOURCE OF ACCIDENT DATA?**

If yes, describe:

**DO YOU HAVE ANY PROBLEMS ASSESSING THIS DATA?**

If yes, describe:

**Source of Accident Data**

Commonly, the officer's accident reports or officer's report in conjunction with the driver's report are used.

**Records Maintenance**

Twenty highway departments maintain the accident records. In the other states, this is done by the State Police or the Department of Motor Vehicles.

**Accident Data Problems**

Four major data problems were identified. They were:

- Time lags due to computer services
- Physical separation of user agencies
- Inadequate retention of old records
- Poor distribution of data to users.

---

**HOW DO YOU INTEGRATE NON-ACCIDENT BASED SAFETY PROBLEM INFORMATION WITH ACCIDENT-BASED INFORMATION?**

**Typical Response**

Engineering judgment.

**Other Responses**

Eleven states do not try to.

Some states use sufficiency ratings.

**DO YOU CONDUCT FIELD INVESTIGATIONS AT IDENTIFIED HIGHWAY SAFETY PROBLEM LOCATIONS?**

If yes, review the following list of field investigations methods and check those being used.

<table>
<thead>
<tr>
<th>Method</th>
<th>Used</th>
<th>Not Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic counts</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>Short counts by movement</td>
<td>36</td>
<td>5</td>
</tr>
<tr>
<td>Conflict counts</td>
<td>16</td>
<td>25</td>
</tr>
<tr>
<td>Photographic study</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>Night investigation</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>Skid testing</td>
<td>33</td>
<td>8</td>
</tr>
<tr>
<td>Driving the location</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>Physiological testing such as</td>
<td>0</td>
<td>41</td>
</tr>
<tr>
<td>galvanic skin response</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychological response measurements</td>
<td>0</td>
<td>41</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**ARE YOU IDENTIFYING POTENTIALLY HAZARDOUS LOCATIONS USING NON-ACCIDENT INFORMATION SUCH AS OBSERVED TRAFFIC CONFLICTS OR HAZARDOUS GEOMETRIC OR ROADSIDE FEATURES?**

If no, skip the next question.

If yes, please describe the procedures used. Enclose sample form if formalized reporting is used.

**Typical Responses**

No—16

Yes—26

Among the "yes" responses the following techniques are being used:

- AASHTO Yellow Book—Connecticut, New York, Minnesota, Michigan, and Washington
- Photo logs—Delaware and New Jersey
- Special Teams—Nevada, North Carolina, New Hampshire, Mississippi, and Wisconsin
- Skid Test—Pennsylvania
- Conflicts Study—Colorado, Ohio, Virginia, and Washington

**BRIEFLY STATE THE OBJECTIVE AND OUTPUT OF THE COMPUTER PROGRAMS ASSOCIATED WITH THE IDENTIFICATION OF SAFETY PROBLEMS.**

Responses were not detailed enough. However, there is a computer program available for almost every component of the evaluation system.

**IN WHAT FORMAT ARE THE RESULTS OF FIELD INVESTIGATIONS PRESENTED? AND TO WHOM? ATTACH A SAMPLE COMPLETED FORM.**

**Type of Format**

<table>
<thead>
<tr>
<th>Format</th>
<th>Number of States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Form</td>
<td>7</td>
</tr>
<tr>
<td>Memorandum (letters)</td>
<td>5</td>
</tr>
<tr>
<td>Technical report</td>
<td>21</td>
</tr>
<tr>
<td>No format</td>
<td>6</td>
</tr>
</tbody>
</table>

**HOW ARE THE RESULTS OF FIELD STUDIES USED? FOR EXAMPLE, IF THEY ARE AN END RESULT IN THEMSELVES, IDENTIFY THE OBJECTIVE OF THE END RESULT, OR IF THEY ARE AN INPUT TO ANOTHER PROCESS IDENTIFY THE PROCESS.**

**Typical Response**

Results of field studies are used as input to remedial action programs.

**Other Responses**

Two states indicated that results may lead to design standard changes. One state cited research as another use.

**DO YOU USE ACCIDENT DATA TO DETERMINE THE CAUSE OF IDENTIFIED HIGHWAY SAFETY PROBLEMS?**

If yes, review the following list of analytical techniques and check those being used by your organization.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Used</th>
<th>Not Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision diagram</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>Accident Profiles (analysis of the actual distribution of accident types.)</td>
<td>25</td>
<td>16</td>
</tr>
</tbody>
</table>
3. Detection of specific significant accident characteristics such as:
   a. Time of day ................. 39 2
   b. Weather ................... 39 2
   c. Road surface condition ...... 39 2
4. Other ............................. 6

DO YOU USE ACCIDENT EXPERIENCE FROM SIMILAR LOCATIONS TO DRAW CONCLUSIONS ABOUT THE CAUSE OF ACCIDENTS AT PROBLEM LOCATIONS?

If yes, describe the justification for relating these similar data to the problem locations including underlying assumptions and criteria for defining similarity.

Typical Response

About half the respondents indicated "no."

DO YOU DRAW CONCLUSIONS OF CAUSE-AND-EFFECT RELATIONSHIP FROM PURELY THEORETICAL OR LOGIC-BASED ANALYSES?

If yes, review the following list of techniques, indicate the technique used and describe the procedure and the input of the technique.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Used</th>
<th>Not Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Common sense .................</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>2. Probability models including trees</td>
<td>0</td>
<td>41</td>
</tr>
<tr>
<td>3. Deterministic modeling ......</td>
<td>0</td>
<td>41</td>
</tr>
<tr>
<td>4. Other ........................</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DO YOU USE THE PUBLISHED RESULTS OF PREVIOUS EXPERIENCE FROM OTHER AGENCIES IN DETERMINING THE POTENTIAL VALUE OF A PROPOSED SAFETY PROBLEM SOLUTION?

Typical Responses

Yes - 25
No - 17
Commonly used previous research.

DO YOU USE THE RESULTS OF SPECIAL IN-HOUSE RESEARCH TO DETERMINE THE POTENTIAL VALUE OF PROPOSED SAFETY PROBLEM SOLUTIONS?

Typical Response

Yes - 18
No - 22

DOES YOUR ORGANIZATION MAINTAIN ROUTINE REVIEWS OF PREVIOUSLY IMPLEMENTED HIGHWAY SAFETY IMPROVEMENTS?

If yes, are these reviews used to determine the potential value of a proposed safety problem solution?

If yes, outline the procedure.

Typical Response

Approximately 75 percent of the states have routine review processes. Of the 31 states responding in the affirmative, 25 indicated that the reviews used to determine the potential value of safety improvements. The most common procedure cited was B/A studies (16).

HOW DO YOU DEVELOP COSTS FOR POTENTIAL SOLUTIONS?

<table>
<thead>
<tr>
<th>Method</th>
<th>Used</th>
<th>Not Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Average cost table, for example, needs study costs?</td>
<td>15</td>
<td>25</td>
</tr>
</tbody>
</table>
| 2. Rough estimate based on cursory review. 
   If used, describe briefly: 
   Previous experience 
   Engineering practice 
   Similar work | 22   | 18       |
| 3. Design quantities estimate? 
   If used, describe briefly: 
   Previous costs 
   Bid estimates 
   Field study | 29   | 11       |
| 4. Other? Describe briefly: 
   Ruling unit prices |      |          |

DO YOU USE THE RESULTS OF SPECIAL IN-HOUSE RESEARCH TO DETERMINE THE POTENTIAL VALUE OF PROPOSED SAFETY PROBLEM SOLUTIONS?

Typical Response

Yes - 18
No - 22

DO YOU USE THE PUBLISHED RESULTS OF PREVIOUS EXPERIENCE FROM OTHER AGENCIES IN DETERMINING THE POTENTIAL VALUE OF A PROPOSED SAFETY PROBLEM SOLUTION?

Typical Responses

Yes - 25
No - 17
Commonly used previous research.

DO YOU USE THE RESULTS OF SPECIAL IN-HOUSE RESEARCH TO DETERMINE THE POTENTIAL VALUE OF PROPOSED SAFETY PROBLEM SOLUTIONS?

Typical Response

Yes - 18
No - 22

DOES YOUR ORGANIZATION MAINTAIN ROUTINE REVIEWS OF PREVIOUSLY IMPLEMENTED HIGHWAY SAFETY IMPROVEMENTS?

If yes, are these reviews used to determine the potential value of a proposed safety problem solution?

If yes, outline the procedure.

Typical Response

Approximately 75 percent of the states have routine review processes. Of the 31 states responding in the affirmative, 25 indicated that the reviews used to determine the potential value of safety improvements. The most common procedure cited was B/A studies (16).

HOW ARE BENEFITS (ACCIDENT AND SEVERITY REDUCTION AND OTHER USERS' BENEFITS) DETERMINED?

<table>
<thead>
<tr>
<th>Method</th>
<th>Used</th>
<th>Not Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NHTSA Tables ..................</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td>2. National Safety Council ......</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>3. NCHRP Research Tables ........</td>
<td>6</td>
<td>34</td>
</tr>
<tr>
<td>4. In-house accident cost studies</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>5. Other? Describe:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DO YOU USE A RATING OR INDEX TO DESCRIBE THE SEVERITY OF ACCIDENTS?

If yes, describe.

Typical Response

Yes - 24
No - 17
Rating Used

<table>
<thead>
<tr>
<th>Rating Used</th>
<th>Number of Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Council</td>
<td>5</td>
</tr>
<tr>
<td>Severity Index</td>
<td>8</td>
</tr>
<tr>
<td>TAD or other numerical ratings</td>
<td>4</td>
</tr>
<tr>
<td>B/C</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
</tr>
</tbody>
</table>

WHAT METHOD OF EVALUATION IS USED?

<table>
<thead>
<tr>
<th>Method</th>
<th>Used</th>
<th>Not Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present worth</td>
<td>4</td>
<td>37</td>
</tr>
<tr>
<td>Rate of return</td>
<td>7</td>
<td>34</td>
</tr>
<tr>
<td>Benefit-cost ratio</td>
<td>32</td>
<td>9</td>
</tr>
<tr>
<td>Incremental Benefit-cost ratio</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Total benefit</td>
<td>10</td>
<td>31</td>
</tr>
<tr>
<td>Other, describe</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IS ANY INFLATION RATE APPLIED TO THE VALUE OF FUTURE BENEFITS?

Typical Response

Yes, what rate

Typical Response

No

Exceptions

Four states apply inflation rates ranging from 5.0% to 7.36%.

WHAT IS THE AVERAGE ELAPSED TIME BETWEEN THE DECISION TO CONSTRUCT A SPECIFIC HIGHWAY SAFETY IMPROVEMENT AND THE COMPLETION OF CONSTRUCTION OF THAT IMPROVEMENT?

<table>
<thead>
<tr>
<th>Elapsed time</th>
<th>Number of Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than one year</td>
<td>4</td>
</tr>
<tr>
<td>One to four years</td>
<td>20</td>
</tr>
<tr>
<td>6 years</td>
<td>1</td>
</tr>
<tr>
<td>Varies</td>
<td>12</td>
</tr>
</tbody>
</table>

DO YOU MAKE ANY POST-IMPLEMENTATION REVIEWS?

Typical response

No - 11
Yes - 30

IS ANY DOCUMENT SUCH AS AN "IMPROVEMENT REPORT" COMPLETED DURING THE FISCAL PROGRAMMING OF A HIGHWAY SAFETY IMPROVEMENT FOR LATER USE IN REVIEWING THE EFFECTIVENESS OF THAT IMPROVEMENT?

Typical response

No, with five exceptions.

IF THERE IS NO SPECIAL DOCUMENT, DO YOU REVIEW ANY OF THE PRE-IMPLEMENTATION EVALUATIONS AFTER IMPLEMENTATION?

Typical response

No - 12
Yes - 11

DO YOU HAVE A MINIMUM ELAPSED TIME BEFORE ANY POST-IMPLEMENTATION REVIEW IS MADE?

Typical response

Yes, with seven exceptions. Most responses cited one year as the minimum elapsed time, although six months and two years also were cited.

DO YOU MAKE ANY STATISTICAL TEST OF THE POST-IMPLEMENTATION DATA?

Typical response

No - 11
Yes - 17

Among the "yes" responses, six mentioned the Chi-Square method. One state has a quality rate check, another uses a contingency table while another uses the normal distribution.

DOES YOUR ORGANIZATION REVIEW THE EFFECTIVENESS OF THE OVERALL SAFETY PROBLEM SOLVING TECHNIQUES?

Typical response

No - 15
Yes - 15

LIST ANY REFINEMENTS IN SAFETY PROBLEM SOLVING TECHNIQUES.

Refinements listed are:
- Accident profile analysis
WHAT SUGGESTIONS DO YOU HAVE FOR IMPROVING THE 
EVALUATION AND POST-IMPLEMENTATION REVIEW PROCESS?

Few responses were received. But, from those responses the following
suggestions were gleaned.

- More field reviews are needed using an operations review team.
- A Federal clearinghouse for data is needed.
- Improve computer hardware and software.
- Improve evaluation programs.

FIELD TESTING PARTICIPANTS

- Cecil W. Colson, Jr. - Alabama State Highway Department
- Allen Brecher - City of Austin, Texas
- A. C. Estep - California Department of Transportation
- Oscar L. Sebastian - Delaware Department of Highways and Transportation
- Archie Bumham, Jr. - Georgia Department of Transportation
- Eugene D. Brenning - Illinois Department of Transportation
- Donald F. Patty - Indiana State Highway Commission
- Thomas Hicks - Maryland Department of Transportation
- K. C. Townley - Missouri State Highway Commission
- Dennis Oelschlagel - Nebraska Department of Roads
- Walter F. Mead - New Hampshire Department of Public Works and Highways
- George J. Collins - New Jersey Department of Transportation
- Duane Bents - North Dakota Highway Department
- Robert Janecko - Pennsylvania Department of Transportation
- W. G. Van Gelder - City of Seattle, Washington
- James F. Baum - City of St. Louis, Missouri
- Richard F. Daykin - St. Louis County, Missouri
- Ken F. Kozlatski - West Virginia Department of Highways

This Appendix includes:
- A list of selected agencies and field testing participants
- Typical letters to selected agencies
- Sample problems
- Summary of analyst reviews
- Summary of management reviews
Dear

Earlier this year your agency responded to our canvass of highway agencies to identify current practices in evaluating highway safety improvements. Based on the results of this canvass, and in accordance with our work plan for NCHRP Project 17-2A, we have developed a user-oriented manual for evaluating highway safety improvements.

To ensure that the manual is user-oriented, it is essential that experienced, potential users review it and make test applications from it. We are inviting your Department, among others, to cooperate in this effort. The “testing” is expected to range from a review for understanding to actual application of components of the manual, and to include management and technical considerations. The amount of testing within the selected agencies will vary according to each agency’s interest and personnel availability.

Cooperation in this effort will cost your Department about three to five man days of work. Obviously it will contribute a great deal to the usefulness of the manual. We would appreciate two things from you: (1) assurance that your Department will participate in the testing phase, unless something unusual occurs, and (2) the name and title of the person you want us to work with on this.

Sincerely yours,

KERMIT L. BERGSTRAH
Vice President

ROY JORGENSEN ASSOCIATES, INC.
Engineering and Management Consultants

Dear

We have entered into a contract with the Highway Research Board to conduct National Cooperative Highway Research Program Project 17-2A entitled “Methods for Evaluating Highway Safety Improvements.” The objective of this study, recommended to NMB by AASHO, is to provide a detailed technique in the form of a user-oriented manual for determination of the effectiveness of highway safety improvements. In accordance with our work plan, we have developed a user-oriented manual for evaluating highway safety improvements.

To ensure that the manual is user-oriented, it is essential that experienced, potential users review it and make test applications from it. We are inviting your Department, among others, to cooperate in this effort. The “testing” is expected to range from a review for understanding to actual application of components of the manual, and to include management and technical considerations. The amount of testing within the selected agencies will vary according to each agency’s interest and personnel availability.

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Sincerely yours,

KERMIT L. BERGSTRAH
Vice President

ROY JORGENSEN ASSOCIATES, INC.
Engineering and Management Consultants

Figure N-1. Letter to Agencies Responding to Initial Canvas

Figure N-2. Letter to Agencies Not Responding to Initial Canvas

Figure N-3. Letter to Agencies Accepting Invitation to Participate

Figure N-4. Field Test Cover Letter
SAMPLE PROBLEMS AND QUESTIONS

There are four problems. The analyst is to answer each problem using the basic data and the Users Manual.

All data are hypothetical and shortened to simplify the problems.

Table N-1. Average Accident Cost

<table>
<thead>
<tr>
<th>SEVERITY</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>$200,000</td>
</tr>
<tr>
<td>Injury</td>
<td>10,000</td>
</tr>
<tr>
<td>PDO</td>
<td>500</td>
</tr>
<tr>
<td>Average</td>
<td>3,000</td>
</tr>
</tbody>
</table>

Table N-2. Systemwide Average Accident Rate

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>AVERAGE ACCIDENT RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural 2-Lane State Highway</td>
<td>2.0 Acc/MV</td>
</tr>
<tr>
<td>Rural 4-Lane State Highway</td>
<td>1.8</td>
</tr>
<tr>
<td>Rural State Highway RR Crossings</td>
<td>1.9 Acc/MV</td>
</tr>
</tbody>
</table>

Table N-3. Potential Improvement Data.

<table>
<thead>
<tr>
<th>IMPROVEMENTS</th>
<th>COST</th>
<th>SERVICE TERMINAL</th>
<th>VALUE</th>
<th>ACCIDENT REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>101 - Curve Signing</td>
<td>$5,000</td>
<td>5 yrs.</td>
<td>500</td>
<td>40 percent of all accidents</td>
</tr>
<tr>
<td>102 - Resurfacing Curves</td>
<td>$7,500</td>
<td>8 yrs.</td>
<td>0</td>
<td>50 percent of all skidding and wet pavement accidents</td>
</tr>
<tr>
<td>103 - Signing, Resurfacing and Painting Curve</td>
<td>$10,000</td>
<td>7 yrs.</td>
<td>1,000</td>
<td>80 percent of all skidding wet pavement and night accidents</td>
</tr>
<tr>
<td>104 - Signing and Speed Reduction</td>
<td>$1,500</td>
<td>5 yrs.</td>
<td>0</td>
<td>30 percent of rural intersection accidents</td>
</tr>
<tr>
<td>105 - Channelization</td>
<td>$12,000</td>
<td>10 yrs.</td>
<td>150</td>
<td>60 percent of all intersection accidents</td>
</tr>
<tr>
<td>106 - Traffic Signals</td>
<td>$8,000</td>
<td>10 yrs.</td>
<td>500</td>
<td>75 percent of running and associated accidents</td>
</tr>
<tr>
<td>107 - Grade Separation</td>
<td>$500,000</td>
<td>50 yrs.</td>
<td>0</td>
<td>95 percent of all intersection accidents</td>
</tr>
<tr>
<td>108 - Flashing Lights</td>
<td>$10,000</td>
<td>10 yrs.</td>
<td>1,000</td>
<td>40 percent of RR crossing accidents</td>
</tr>
<tr>
<td>109 - Flashing Lights and Gates</td>
<td>$15,000</td>
<td>10 yrs.</td>
<td>1,000</td>
<td>70 percent of RR crossing accidents</td>
</tr>
<tr>
<td>110 - Railroad Grade Separation</td>
<td>$300,000</td>
<td>50 yrs.</td>
<td>0</td>
<td>100 percent of RR crossing accidents</td>
</tr>
<tr>
<td>111 - Removal of Fixed Object</td>
<td>$2,000</td>
<td>Perpetual</td>
<td>0</td>
<td>100 percent of fixed object accidents</td>
</tr>
<tr>
<td>112 - Guardrail Placement Around Fixed Object</td>
<td>$1,000</td>
<td>10 yrs.</td>
<td>0</td>
<td>80 percent reduction in fixed object accident severity</td>
</tr>
<tr>
<td>113 - Guardrail Placement At Bridge</td>
<td>$5,000</td>
<td>10 yrs.</td>
<td>100</td>
<td>50 percent reduction in severity</td>
</tr>
<tr>
<td>114 - Bridge Widening</td>
<td>$50,000</td>
<td>25 yrs.</td>
<td>0</td>
<td>40 percent of accidents</td>
</tr>
</tbody>
</table>

Table N-4. Accidents Occurring on State Highway 1

<table>
<thead>
<tr>
<th>DATE</th>
<th>LOCATION</th>
<th>SEVERITY</th>
<th>CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan. 4</td>
<td>4.48</td>
<td>PDO</td>
<td>Rear end, night, dry</td>
</tr>
<tr>
<td>Jan. 13</td>
<td>6.76</td>
<td>1 Injury</td>
<td>Last control, night, wet</td>
</tr>
<tr>
<td>Jan. 16</td>
<td>7.80</td>
<td>PDO</td>
<td>Sideswipe, night, dry</td>
</tr>
<tr>
<td>Feb. 2</td>
<td>2.00</td>
<td>2 Injuries</td>
<td>Head on, night, dry</td>
</tr>
<tr>
<td>Feb. 7</td>
<td>2.50</td>
<td>PDO</td>
<td>Hit abutment, day, dry</td>
</tr>
<tr>
<td>Feb. 12</td>
<td>5.50</td>
<td>2 Fatalities</td>
<td>Left turn, day, dry</td>
</tr>
<tr>
<td>Mar. 8</td>
<td>1.43</td>
<td>1 Fatality</td>
<td>Head on, day, wet</td>
</tr>
<tr>
<td>April 1</td>
<td>5.52</td>
<td>1 Injury</td>
<td>Right angle, day, wet</td>
</tr>
<tr>
<td>May 12</td>
<td>6.75</td>
<td>3 Injuries</td>
<td>Rear end, day, wet</td>
</tr>
<tr>
<td>May 15</td>
<td>3.75</td>
<td>PDO</td>
<td>Left turn, day, wet</td>
</tr>
<tr>
<td>May 15</td>
<td>8.10</td>
<td>2 Injuries</td>
<td>Head on, dry, day</td>
</tr>
<tr>
<td>June 6</td>
<td>1.44</td>
<td>3 Injuries</td>
<td>Sideswipe, night, wet</td>
</tr>
<tr>
<td>June 25</td>
<td>6.77</td>
<td>PDO</td>
<td>Rear end, night, dry</td>
</tr>
<tr>
<td>July 7</td>
<td>1.70</td>
<td>PDO</td>
<td>Rear end, night, wet</td>
</tr>
<tr>
<td>July 26</td>
<td>6.78</td>
<td>1 Fatality</td>
<td>Train-car, day, dry</td>
</tr>
<tr>
<td>Aug. 8</td>
<td>1.42</td>
<td>PDO</td>
<td>Last control, day, wet</td>
</tr>
<tr>
<td>Aug. 10</td>
<td>1.44</td>
<td>PDO</td>
<td>Sideswipe, night, wet</td>
</tr>
<tr>
<td>Aug. 29</td>
<td>6.79</td>
<td>1 Fatality</td>
<td>Train-car, night, wet</td>
</tr>
<tr>
<td>Sept. 2</td>
<td>1.80</td>
<td>PDO</td>
<td>Last control, day, dry</td>
</tr>
<tr>
<td>Sept. 15</td>
<td>9.80</td>
<td>PDO</td>
<td>Rear end, night, dry</td>
</tr>
<tr>
<td>Oct. 17</td>
<td>9.52</td>
<td>3 Fatalities</td>
<td>Hit Abutment, night, wet</td>
</tr>
<tr>
<td>Nov. 1</td>
<td>3.25</td>
<td>PDO</td>
<td>Sideswipe, night, dry</td>
</tr>
<tr>
<td>Nov. 22</td>
<td>9.50</td>
<td>1 Injury</td>
<td>Hit Abutment, night, wet</td>
</tr>
<tr>
<td>Dec. 10</td>
<td>0.20</td>
<td>PDO</td>
<td>Left turn, day, dry</td>
</tr>
<tr>
<td>Dec. 22</td>
<td>8.70</td>
<td>1 Fatality</td>
<td>Last control, night, dry, DWI</td>
</tr>
</tbody>
</table>

Table N-5. Accidents Occurring on State Highway 1

<table>
<thead>
<tr>
<th>DATE</th>
<th>LOCATION</th>
<th>SEVERITY</th>
<th>CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 10</td>
<td>0.20</td>
<td>PDO</td>
<td>Left turn, day, dry</td>
</tr>
<tr>
<td>Aug. 8</td>
<td>1.42</td>
<td>PDO</td>
<td>Last control, day, wet</td>
</tr>
<tr>
<td>Mar. 8</td>
<td>1.43</td>
<td>1 Fatality</td>
<td>Head on, day, wet</td>
</tr>
<tr>
<td>June 6</td>
<td>1.44</td>
<td>3 Injuries</td>
<td>Sideswipe, night, wet</td>
</tr>
<tr>
<td>Aug. 10</td>
<td>1.44</td>
<td>PDO</td>
<td>Sideswipe, night, wet</td>
</tr>
<tr>
<td>July 7</td>
<td>1.70</td>
<td>PDO</td>
<td>Rear end, night, dry</td>
</tr>
<tr>
<td>Sept. 2</td>
<td>2.00</td>
<td>2 Injuries</td>
<td>Head on, night, dry</td>
</tr>
<tr>
<td>Feb. 7</td>
<td>2.50</td>
<td>PDO</td>
<td>Hit abutment, day, dry</td>
</tr>
<tr>
<td>Nov. 1</td>
<td>2.25</td>
<td>PDO</td>
<td>Sideswipe, day, dry</td>
</tr>
<tr>
<td>May 15</td>
<td>3.75</td>
<td>PDO</td>
<td>Left turn, day, wet</td>
</tr>
<tr>
<td>Dec. 4</td>
<td>4.48</td>
<td>PDO</td>
<td>Left turn, dry, night</td>
</tr>
<tr>
<td>Feb. 12</td>
<td>5.50</td>
<td>2 Fatalities</td>
<td>Left turn, day, dry</td>
</tr>
<tr>
<td>April 1</td>
<td>5.52</td>
<td>1 Injury</td>
<td>Right angle, day, wet</td>
</tr>
<tr>
<td>May 12</td>
<td>6.75</td>
<td>3 Injuries</td>
<td>Rear end, day, wet</td>
</tr>
<tr>
<td>Jan. 13</td>
<td>6.76</td>
<td>PDO</td>
<td>Last control, day, wet</td>
</tr>
<tr>
<td>June 25</td>
<td>6.77</td>
<td>PDO</td>
<td>Rear end, night, dry</td>
</tr>
<tr>
<td>July 26</td>
<td>6.78</td>
<td>1 Fatality</td>
<td>Train-car, day, dry</td>
</tr>
<tr>
<td>Aug. 29</td>
<td>6.79</td>
<td>1 Fatality</td>
<td>Train-car, night, wet</td>
</tr>
<tr>
<td>Jan. 16</td>
<td>7.80</td>
<td>PDO</td>
<td>Sideswipe, night, dry</td>
</tr>
<tr>
<td>May 15</td>
<td>8.10</td>
<td>2 Injuries</td>
<td>Head on, day, dry</td>
</tr>
<tr>
<td>Dec. 22</td>
<td>8.70</td>
<td>1 Fatality</td>
<td>Last control, night, dry, DWI</td>
</tr>
<tr>
<td>Nov. 22</td>
<td>9.50</td>
<td>1 Injury</td>
<td>Hit Abutment, night, wet</td>
</tr>
<tr>
<td>Oct. 17</td>
<td>9.52</td>
<td>3 Fatalities</td>
<td>Hit Abutment, night, wet</td>
</tr>
<tr>
<td>Seal. 15</td>
<td>9.80</td>
<td>PDO</td>
<td>Rear end, night, wet</td>
</tr>
</tbody>
</table>
PROBLEM 1

1-1 Complete the two attached Hazardous Location Identification Worksheets (Form 101) for the two most hazardous locations on SH 1.

1-2 What method did you use to identify the two most hazardous locations? Rate Quality Control

Why? It is the method recommended for state highway systems.

1-3 Which of the two locations identified in Question 1-1 is most hazardous? 6.75 to 6.79 Why? Most accidents & highest severity.

1-4 Complete the attached Probable Accident Cause Analysis Worksheet (Form 102) for the location identified in Question 1-3.

1-5 Complete the attached Potential Improvement Identification Worksheet (Form 103) for the hazardous location identified in Question 1-3. (Use the potential improvements given in Table 3.)

1-6 Complete an Improvement Analysis Worksheet (Form 104) for each potential improvement from Table 3 for the location identified in Question 1-3. Use an interest rate of 8%.

1-7 Complete the attached Improvement Evaluation Worksheet (Form 105) for the hazardous location identified in Question 1-3.

N-11

Hazardous Location Identification Worksheet

LOCATION: State Highway 1 from 6.40 to 6.79

CATEGORY: Rural

DESCRIPTION: Sketch on back of sheet.

ACCIDENT EXPERIENCE:

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SYSTEMWIDE AVE. RATE FOR CATEGORY: 1.3 Aoo/MV

CRITICAL RATE FOR LOCATION: 3.3 Aoo/MV

INDEX OF SEVERITY:

COMMENTS:

N-12

Probable Accident Cause Analysis Worksheet

LOCATION: State Highway 1 from 6.75 to 6.79

COLLISION DIAGRAM: Sketched

ACCIDENT CHARACTERISTICS:

<table>
<thead>
<tr>
<th>Type of Accident</th>
<th>No. of Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SYSTEMWIDE AVE. RATE FOR CATEGORY: 1.9 Aoo/MV

CRITICAL RATE FOR LOCATION: 3.5 Aoo/MV

INDEX OF SEVERITY:

COMMENTS: RR crossing at 6.77 with crossbucks only.
### Potential Improvement Identification Worksheet

**Location:** State Highway 1 from 6.75 to 6.79

**Applicable Improvements:**

<table>
<thead>
<tr>
<th>Improvement Code</th>
<th>Improvement Analysis</th>
<th>Expected Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>108 -- Flashing lights</td>
<td>40% reduction of railroad crossing accidents</td>
<td>Naturally desirable</td>
</tr>
<tr>
<td>109 -- Flashing lights and gates</td>
<td>70% reduction of railroad crossing accidents</td>
<td>Naturally desirable</td>
</tr>
<tr>
<td>110 -- Railroad Grade Separation</td>
<td>100% reduction at 44 crossing accidents</td>
<td>Naturally desirable</td>
</tr>
</tbody>
</table>

**Special Comments:**

### Improvement Analysis Worksheet

**Location:** State Highway 1 from 6.75 to 6.79

**Improvement Code:** 108

**Improvement Description:** Flashing lights

**Estimated Service Life:** 10 yrs.

**Current 1973 AADT:** 2,000

**Estimated Accident Reduction:**

- By Type:
  - Left turn
  - Head on
  - Rear-end
  - Right angle
  - Side swipe
  - Fixed object
  - Lost control

- By Severity:
  - Slidding
  - Wet pavement
  - Night
  - RR crossing
  - Total

**Equivalent Uniform Annual Benefits:**

- From accident reduction: $10,500
- From speeder control:  

**Total:** $10,500

**Estimated Costs:**

- Initial implementation: $15,000
- Annual operation and maintenance: $1,000
- Terminal value: $1,000
- Equivalent uniform annual cost: $3,954

**Net Annual Benefit:** $17,354

**Benefit/Cost Ratio:** 3.32

**Special Comments:**
IMPROVEMENT EVALUATION WORKSHEET

LOCATION: State Highway 1 from 6.75 to 6.79

SUMMARY OF EVALUATION:

<table>
<thead>
<tr>
<th>Code</th>
<th>10A</th>
<th>10B</th>
<th>110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Flashing lights</td>
<td>Flasing 86</td>
<td>Grade Separation</td>
</tr>
<tr>
<td>Initial cost</td>
<td>$10,000</td>
<td>$1,000</td>
<td>$100,000</td>
</tr>
<tr>
<td>Annual cost</td>
<td>$1,000</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Benefit value</td>
<td>$5,000</td>
<td>$1,000</td>
<td>$0</td>
</tr>
<tr>
<td>Benefit/cost ratio</td>
<td>2.43</td>
<td>3.32</td>
<td>0.93</td>
</tr>
</tbody>
</table>

REJECTED IMPROVEMENTS (and explanation):

- Improvement 10A is not economically justified.

ELIGIBLE IMPROVEMENTS AND RANKING:

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Benefit/cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>10A</td>
<td>Flashing lights and gates</td>
<td>3.32</td>
</tr>
</tbody>
</table>

COMMENTS:

N-19

IMPROVEMENT ANALYSIS WORKSHEET

LOCATION: Problem 2

IMPROVEMENT CODE: 10A

IMPROVEMENT DESCRIPTION: Channelization

ESTIMATED SERVICE LIFE: 10 YRS.

CURRENT 19 79 AADT = 4,000

ESTIMATED ACCIDENT REDUCTION:

- By Type:
  - Left turn: 5%
  - Head on: 5%
  - Right angle: 5%
  - Fixed object: 5%
  - Last control: 5%

- By Severity:
  - Skidding: 5%
  - Fatality: 5%
  - Injuries: 5%
  - PDO: 5%
  - Total: 5%

EQUIVALENT UNIFORM ANNUAL BENEFITS:

- From accident reduction: $1,320
- From other benefits: $1

Total: $1,320

ESTIMATED COSTS:

- Initial implementation: $10,000
- Annual operation and maintenance: $1,000
- Terminal value: $0
- Equivalent uniform annual cost: $1,320

NET ANNUAL BENEFIT: $1,320

BENEFIT/COST RATIO: 8.71

SPECIAL COMMENTS:

N-20
IMPROVEMENT ANALYSIS WORKSHEET

LOCATION: Problem 3.2

IMPROVEMENT CODE: 107

IMPROVEMENT DESCRIPTION: Grade separation

ESTIMATED SERVICE LIFE: 50 YES.
CURRENT AADT: 4,000
EST. AADT: 5,000

ESTIMATED ACCIDENT REDUCTION:

Type: By Severity:

- Left turn: % Skidding % Fatal
- Head on: % Wet pavement % Injuries
- Rear end: % Night % PDO
- Right angle: % RR crossing % Total
- Side swipe: % 
- Fixed object: % 
- Last control: % All Accidents

- Equivalent annual uniform benefits: $159,640

- Estimated costs:
  - Initial implementation: $500,000
  - Annual operation and maintenance: $1,500

- Net annual benefit: $149,160

SPECIAL COMMENTS:

3-1 What are the accident rates and accident rate reductions for the 5 improvements listed below?

<table>
<thead>
<tr>
<th>IMPROVEMENTS</th>
<th>AADT</th>
<th>ACCIDENT RATE</th>
<th>AADT</th>
<th>ACCIDENT RATE</th>
<th>REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2,000</td>
<td>8</td>
<td>1,000</td>
<td>5</td>
<td>52.9%</td>
</tr>
<tr>
<td>B</td>
<td>3,000</td>
<td>10</td>
<td>3,000</td>
<td>5</td>
<td>39.8%</td>
</tr>
<tr>
<td>C</td>
<td>4,000</td>
<td>15</td>
<td>5,000</td>
<td>6</td>
<td>49.9%</td>
</tr>
<tr>
<td>D</td>
<td>5,000</td>
<td>15</td>
<td>5,000</td>
<td>5</td>
<td>59.7%</td>
</tr>
<tr>
<td>E</td>
<td>10,000</td>
<td>35</td>
<td>10,500</td>
<td>15</td>
<td>59.2%</td>
</tr>
</tbody>
</table>

3-2 Which of these reductions are significant using the following tests?

- Poison Distribution: IMPROVEMENTS WITH SIGNIFICANT REDUCTIONS
- Poison Comparison of Means: D & E

4-1 What is your forecast of an improvement cost and accident reduction for an improvement type based on the data below?

<table>
<thead>
<tr>
<th>COUNTERMEASURE</th>
<th>FORECAST OF ACCIDENT RATE REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE-LOCATION</td>
<td>INITIAL COST</td>
</tr>
<tr>
<td></td>
<td>BEFORE</td>
</tr>
<tr>
<td>A-1</td>
<td>$15,000</td>
</tr>
<tr>
<td>A-2</td>
<td>$12,500</td>
</tr>
<tr>
<td>A-3</td>
<td>$14,000</td>
</tr>
<tr>
<td>B-1</td>
<td>$50,000</td>
</tr>
<tr>
<td>B-2</td>
<td>60,000</td>
</tr>
<tr>
<td>C-1</td>
<td>1,800</td>
</tr>
<tr>
<td>C-2</td>
<td>2,000</td>
</tr>
<tr>
<td>C-3</td>
<td>2,100</td>
</tr>
<tr>
<td>C-4</td>
<td>2,000</td>
</tr>
<tr>
<td>C-5</td>
<td>2,800</td>
</tr>
</tbody>
</table>

4-2 What is your forecast of an improvement cost and accident reduction for an improvement type based on the data below?

<table>
<thead>
<tr>
<th>COUNTERMEASURE</th>
<th>FORECAST OF ACCIDENT RATE REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE-LOCATION</td>
<td>INITIAL COST</td>
</tr>
<tr>
<td></td>
<td>BEFORE</td>
</tr>
<tr>
<td>A-1</td>
<td>$15,000</td>
</tr>
<tr>
<td>A-2</td>
<td>$12,500</td>
</tr>
<tr>
<td>A-3</td>
<td>$14,000</td>
</tr>
<tr>
<td>B-1</td>
<td>$50,000</td>
</tr>
<tr>
<td>B-2</td>
<td>60,000</td>
</tr>
<tr>
<td>C-1</td>
<td>1,800</td>
</tr>
<tr>
<td>C-2</td>
<td>2,000</td>
</tr>
<tr>
<td>C-3</td>
<td>2,100</td>
</tr>
<tr>
<td>C-4</td>
<td>2,000</td>
</tr>
<tr>
<td>C-5</td>
<td>2,800</td>
</tr>
</tbody>
</table>

N-23

PROBLEM 4

4-1 What is your forecast of an improvement cost and accident reduction for an improvement type based on the data below?

<table>
<thead>
<tr>
<th>COUNTERMEASURE</th>
<th>FORECAST OF ACCIDENT RATE REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE-LOCATION</td>
<td>INITIAL COST</td>
</tr>
<tr>
<td></td>
<td>BEFORE</td>
</tr>
<tr>
<td>A-1</td>
<td>$15,000</td>
</tr>
<tr>
<td>A-2</td>
<td>$12,500</td>
</tr>
<tr>
<td>A-3</td>
<td>$14,000</td>
</tr>
<tr>
<td>B-1</td>
<td>$50,000</td>
</tr>
<tr>
<td>B-2</td>
<td>60,000</td>
</tr>
<tr>
<td>C-1</td>
<td>1,800</td>
</tr>
<tr>
<td>C-2</td>
<td>2,000</td>
</tr>
<tr>
<td>C-3</td>
<td>2,100</td>
</tr>
<tr>
<td>C-4</td>
<td>2,000</td>
</tr>
<tr>
<td>C-5</td>
<td>2,800</td>
</tr>
</tbody>
</table>

N-24

PROBLEM 3

3-1 What are the accident rates and accident rate reductions for the 5 improvements listed below?

<table>
<thead>
<tr>
<th>IMPROVEMENTS</th>
<th>ACCIDENT RATE</th>
<th>ACCIDENT RATE</th>
<th>REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2,000</td>
<td>8</td>
<td>1,000</td>
</tr>
<tr>
<td>B</td>
<td>3,000</td>
<td>10</td>
<td>3,000</td>
</tr>
<tr>
<td>C</td>
<td>4,000</td>
<td>15</td>
<td>5,000</td>
</tr>
<tr>
<td>D</td>
<td>5,000</td>
<td>15</td>
<td>5,000</td>
</tr>
<tr>
<td>E</td>
<td>10,000</td>
<td>35</td>
<td>10,500</td>
</tr>
</tbody>
</table>

3-2 Which of these reductions are significant using the following tests?

- Poison Distribution: IMPROVEMENTS WITH SIGNIFICANT REDUCTIONS
- Poison Comparison of Means: D & E

* Assume Before & After Periods are Both 1 Year
SUMMARY OF ANALYST REVIEWS

The analyst that worked the sample problems was asked to answer several questions based on his use of the manual to work the sample problems. The answers are summarized on the following pages. The replies are in the order that they were received, that is, California's reply was received first, New Hampshire's reply was received second and so on.

A. SAMPLE PROBLEMS

1. HOW MUCH TIME DID YOU REQUIRE TO FINISH EACH PROBLEM?

The results of question A1 are presented below.

<table>
<thead>
<tr>
<th>TIME TO COMPLETE PROBLEM</th>
<th>Shortest</th>
<th>Longest</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROBLEM 1</td>
<td>15 minutes</td>
<td>10 hours</td>
<td>4.8 hours</td>
</tr>
<tr>
<td>PROBLEM 2</td>
<td>20 minutes</td>
<td>4 hours</td>
<td>2.4 hours</td>
</tr>
<tr>
<td>PROBLEM 3</td>
<td>10 minutes</td>
<td>1 hour</td>
<td>45 minutes</td>
</tr>
<tr>
<td>PROBLEM 4</td>
<td>1 hour</td>
<td>5 hours</td>
<td>2.7 hours</td>
</tr>
</tbody>
</table>

The short completion times were related to the length of time out of school. For example, the reviewer with the quickest times was the most recent engineering graduate. He brought to the problems extensive knowledge of economics and statistics. This reflects the general trend in engineering curricula today.

2. IF YOU ENCOUNTERED DIFFICULTIES IN WORKING THE PROBLEMS, PLEASE DESCRIBE THE DIFFICULTY.

There was no consensus. Each reviewer had his own little problem. Types of problems included:

1. Practicality of values in problems;
2. Lack of familiarity with forms;
3. Complex terminology
4. Problem instructions.

All comments were considered in preparing the Final Users' Manual.

B. SUFFICIENCY OF MANUAL

1. WHAT CHANGES WOULD YOU SUGGEST TO IMPROVE THE FOLLOWING CHARACTERISTICS OF THE MANUAL?

In general most reviewers suggested the manual be a little less technical. The point was made that students would have less trouble with the manual than practicing professionals. More sample problems were requested.

2. WHAT CHANGES, IF ANY, WOULD YOU SUGGEST FOR THE WORKSHEETS?

Only one reviewer had trouble with the worksheets. It was suggested (1) the accident history be expanded to three years, and (2) the equations be printed on the forms.

C. POTENTIAL APPLICATIONS

Describe potential applications of the manual in your own operations.

California

The manual could be applied to California's highway Safety Program, however, in its present form it is too detailed to be of practical use (too many forms and too much mathematical precision). Besides, we have a successful system that has been in operation for about 8 years.

New Hampshire

In urban areas, spot and section analysis would be helpful.

St. Louis

We have a plan for cost benefit program. This can be of service in getting improvement costs and reduction estimates. Many of the initial review of intersection are already used.

Delaware

Analyst 1: Accident reduction factors which we are still developing from before and after experience with improvements.
Analyst 2: Being involved in the area of safety studies, I find extensive potential use of the manual provided that further investigation finds it compatible with our objectives.

West Virginia

Will serve to organize our safety program better and, above all, will standardize our methods of computation.

Pennsylvania

We will probably use the manual for before and after evaluations. We don't readily foresee the use of sophisticated methods for B/C ratios or for forecasting accident reductions.
Nebraska
Reasonably comparable to our developing system.

Georgia
I think the manual can serve our office in an excellent manner to analyze safety improvements in the complete procedures indicated. If the manual can be written to explain all situations or if a seminar can be developed to educate the users, I think this can be one of the most effective tools ever developed for safety evaluations.

2. WHAT PROBLEMS MIGHT YOU ENCOUNTER IN MAKING THESE APPLICATIONS?

New Hampshire
Urban areas are not within the jurisdiction of this department.

St. Louis
We have very large amounts of data and will need to incorporate computer which is in design.

Delaware
Delaware has own method of arriving at a severity index.

West Virginia
The manual, in present form, will be difficult for technicians to understand and apply.

Pennsylvania
Problems in manpower unless we can computerize some of the methods. Some of the data that we would need for these methods would not be available now or in the near future, i.e., ADT at intersections, etc.

Nebraska
Availability of necessary data, availability of necessary personnel.

Georgia
1. Proper use of the procedures
2. Being sure we are applying the methods in the correct manner for all the various situations.

Note: Most procedures in the manual can be computerized.

3. WHAT ARE THE COMMUNICATION REQUIREMENTS BETWEEN RESPONSIBLE BRANCHES TO ENSURE ADEQUATE OPERATION?

California
1. Guidelines are prepared by Headquarters Traffic Branch.
2. Phone calls from Districts to Headquarters.
3. In-person visits to Districts are made by Headquarters personnel who prepare the guidelines.

New Hampshire
Because of the size of the state, communication problems are rare.

St. Louis
Input of reported accidents needs to be received from Police Department. Justification of funds need to be communicated to Budget Division.

Delaware
Coordination by the Highway Safety Section through the Highway Safety Committee that is composed of Chiefs of Planning, Design, Traffic, Construction, Maintenance, Materials and Research, and Highway Safety Engineer.

West Virginia
Traffic Engineering usually takes lead -- communication consists of memo documenting problem, plus much face-to-face contact between responsible section heads as design progresses.
SUMMARY OF MANAGEMENT REVIEWS

The management review was intended to determine the adaptability of the management system and its components to the operations in that agency. The replies are in the order that they were received, that is, California’s reply was received first, New Hampshire’s reply was received second and so on.

A. ORGANIZATION

1. DOES CHAPTER ONE ADEQUATELY DESCRIBE THE USE OF THE MANUAL? YES  IF NOT, EXPLAIN.

   Unanimous yes with one qualification indicating the description is quite general.

   a. ARE THE COMPONENTS OF THE MANAGEMENT SYSTEM LOGICAL?__ YES  IF NOT, EXPLAIN.

      Unanimous yes with one qualification, “The third item should be superfluous since item two should have taken effectiveness into consideration. Since this is a safety program, the foremost goal would be severity reduction. Other benefits would be secondary.”

2. WHAT ARE THE PROBABLY ASSIGNMENTS OF BASIC SYSTEM COMPONENTS WITHIN OUR AGENCY? PLEASE INDICATE DIVIDED RESPONSIBILITY.

   There were no surprises in the responses. Traffic engineering bureaus, highway safety sections and police agencies were mentioned.

B. IMPLEMENTING COMPONENTS

   THE FOLLOWING QUESTIONS DEAL WITH PROBLEMS THAT MIGHT BE ENCOUNTERED IN THE IMPLEMENTATION OF A HIGHWAY SAFETY EVALUATION SYSTEM IN YOUR AGENCY.

1. ARE THE METHODS DESCRIBED COMPATIBLE WITH PROCEDURES EXISTING IN YOUR AGENCY? IF NOT, EXPLAIN.

   In general, the responses indicated overall compatibility. It is expected that most agencies would want to make modifications to fit their own philosophies and existing operative systems.

   California

      They are similar but not as technically refined. The use of each District Traffic Engineer’s judgment in selecting an improvement is relied upon as compared to the manual’s mathematical proof of choice.

   St. Louis

      Yes, but the methods are more detailed as compared to present system.

   Delaware

      No, the State of Delaware shies away from using dollar values for each category of accident and uses instead, the proportions 1:6:111 for property damage only, non-fatal injury accidents and fatalities, respectively.

Pennsylvania

   Bureau of Traffic Engineering is the overall coordinator and prime mover of the safety program. Initial responsibility for identifying locations for study and reviewing improvements is designated to the Bureau of Traffic Engineering. Since the Bureau of Traffic Engineering maintains records of hazardous locations that have had studies made, they inform the Bureau of Maintenance, Economic Research and Programming to program projects. The Bureau of Traffic Engineering keeps records of construction and implementation so that the evaluation process may be done.

Nebraska

   Regular, frequent meetings of a committee composed of managers from all responsible branches.

Georgia

   Offices are in contact with each other on a daily, informal basis and with formal communication such as submission of hazardous location lists, programming documents, request for review of preliminary plans, preliminary plans field inspection, final plans submission, and traffic engineering evaluation reports.

N-35

N-36

2. ASSUME YOU WERE TO APPLY THE METHODS IN THE USERS’ MANUAL. WHAT PROBLEMS WOULD YOU HAVE IN IMPLEMENTING EACH METHOD? FOR EXAMPLE, QUALIFIED PERSONNEL, DATA AVAILABILITY OR CONTINUITY WITH OTHER METHODS?

   Lack of personnel and inadequate data were cited most frequently as problems in applying the Users’ Manual. Lack of money also was mentioned. One reviewer indicated that the Users’ Manual methods were more precise than those used in his agency.

3. WHICH METHODS WOULD BE OF GREATEST VALUE TO YOUR AGENCY? WHY?

   METHOD OF GREATEST VALUE NUMBER OF REVIEWERS
   None 1
   Identify Hazardous Locations 1
   Selecting Alternative Improvements 1
   Evaluating Alternative Improvements 4
   Programming --
   Evaluating Implemented Improvements 3
   Evaluating the Highway Safety Program 2
   All 1
   Couldn’t Decide 1

4. WAS THE EXPLANATION OF THE METHODS ADEQUATE? YES  IF NOT, DESCRIBE DEFICIENCIES.

   Six “yeses” and two “noes.” One of the “noes” said that the manual needed to be simplified.
5. DID YOU HAVE TO CHECK ADDITIONAL REFERENCES TO UNDERSTAND THE MANUAL? _________ IF YES, PLEASE LIST THESE REFERENCES.

Six reviewers said "no" and two said "yes."

C. POTENTIAL USE IN YOUR ORGANIZATION

I. WHAT CHANGES TO THE SYSTEM WOULD YOU RECOMMEND PRIOR TO IMPLEMENTATION IN YOUR AGENCY?

California

Would not be useful as previously stated. The system could be useful to agencies that do not have a method. The number of forms could be reduced as suggested by one reviewer.

St. Louis

The complementary techniques on page 39 probably would not be used. The cost figure from N.S.C. on a "per death" basis may be considered as an alternative method of calculation since it is easier to use.

Delaware

a. Proportion of fatalities to injuries to P.O. should be used in lieu of dollars.
b. Accident analysis should consider severity -- not just numbers or rate or averages.
Example: A location has 5 accidents/year with 4 total fatalities and 1 injury per crash; P.D. is enormous. An improvement increases number of accidents to 10 but with no fatalities, no injuries and only slight P.D. This is a successful improvement in Delaware's opinion.

West Virginia

Must "cut and try" in actual applications.

N-39

D. OPTIONS

1. DO YOU THINK THE USERS' MANUAL PROVIDES ENOUGH OPTIONS. IS IT TOO RIGID? IF SO, EXPLAIN AND INDICATE THE OPTIONS THAT YOU WOULD LIKE TO SEE ADDED.

Five reviewers thought there were enough options. Three reviewers thought it was too rigid.

2. WHICH ACCIDENT COSTS -- NHTSA or NSC -- DO YOU PREFER TO USE? _______

The NHTSA costs were preferred by two reviewers because of the higher cost assigned to fatalities. Three reviewers preferred National Safety Council.

Reasons given included:

- NHTSA method is too detailed in regards to type of disabilities.
- NSC costs are more conservative and because the occurrence of one or two fatal accidents during the analysis period is less likely to have a disproportionately large effect on the computations.
- The difference between fatality and injury producing accidents is a narrow margin. Too much emphasis on fatalities may lead to a priority for locations where two or three fatal accidents occurred whereas a location that has fifteen injury accidents may lose out.

The other three reviewers either developed their own cost, considered the choice immaterial or preferred a system independent of changing costs.

Pennsylvania

I personally believe that intricate statistical methods for accident costs, which I have found to be inaccurate in a number of places, does not give a realistic interpretation because of the use of inaccurate data. Instead of using such strict statistical measures, I recommend use of more engineering logic into the scheme of things.

Nebraska

Such recommendations would require more extensive evaluation of options.

Georgia

A. Attempt to make manual less technical wording.
B. Utilize more specific examples.

2. WOULD YOU BE WILLING TO RECOMMEND IMPLEMENTATION OF THE SYSTEM OR COMPONENTS OF THE SYSTEM CONTAINED IN THE USERS' MANUAL? _______ IF NOT, PLEASE EXPLAIN.

Five reviewers would recommend the method. Two others would not commit themselves without more experience and one reviewer would not recommend the method.

N-40

3. WHO DECIDED WHICH COSTS TO USE?

WAS THERE ANY RELUCTANCE TO ASSIGN DOLLAR VALUES TO FATALITIES?

IF YES, WOULD YOU PREFER AN ALTERNATIVE TECHNIQUE THAT IS LESS EXPLICIT IN ASSIGNING VALUE TO HUMAN LIFE? _______

The choice was made by management. There was no reluctance to assign dollar values to fatalities.

4. SUPPLEMENTARY, COMPLEMENTARY AND ADVANCED METHODS ARE PRESENTED IN THE APPENDICES OF THE RESEARCH REPORT, WOULD YOU CHOOSE TO DEVELOP THESE METHODS AS AN INTEGRAL PART OF YOUR SYSTEM?

One "yes" response, three "noos" and the rest want to wait and see.

5. IF YOU ARE SATISFIED WITH YOUR PRESENT SYSTEM, WOULD YOU CHOOSE TO ADD ANY OF THESE ADVANCED METHODS? _______ IF SO, WHICH ONES AND WHY?

Three reviewers answered with a "no." New Hampshire is in the formulation stage and is interested in refining their techniques.

6. THE MANUAL PRESENTS THE OPTIMUM IMPROVEMENT (AS DEFINED BY ENGINEERING ECONOMY) APPROACH TO SELECTING FROM ALTERNATIVES AT A LOCATION. WOULD YOU EVER HAVE OCCASION TO USE AN APPROACH THAT WOULD MAXIMIZE THE BENEFITS FROM YOUR ANNUAL BUDGET? _______ IF SO, UNDER WHAT CIRCUMSTANCES?

It appeared that perhaps the reviewers misunderstood the question.

N-41
7. DO YOU FEEL THE MANUAL IS TOO TECHNICAL?

    TOO TECHNICAL
    California
        Yes.
    Delaware
        Use of formula may be reduced. Simplicity is desired for use by multi-level personnel.
    West Virginia
        Computations will be turned over to technicians who have little or no previous training in statistics, engineering economy, or other applicable subjects. Certain parts of the manual were obviously written by engineers for engineers. Manual should be carefully reviewed, and background information added where applicable.
    Georgia
        The general impression received after having read and used the manual is that additional editing to reduce the technical aspects would be beneficial. This manual represents an outstanding opportunity for development and utilization of orderly methods in the identification, selection, evaluation, and implementation of the highway safety program. With a few finishing touches and perhaps even some very short workshops (8-12 hours) the impact of this concept could be substantial.

    TOO GENERAL
    None of the reviewers thought that the manual was too general.

NEITHER
    New Hampshire and Nebraska

    St. Louis
        Not too technical for major cities, however, perhaps a modified version should be stated for small urban areas.
    Pennsylvania
        I feel the manual is very good and well presented.

Example

The following is an example of using the percentage reduction of accident rate method to estimate the accident reduction of a 1.0 mile realignment using California's percentages:

Existing Accident Rate = 4.0 Acc/MVM
Future AADT = 6500 VPD (Assumed constant to simplify example)

Estimated Accident Reduction = (0.50)(4.0)(365)(6,500) x 10^6
= 2.75 Accidents Per Year

SAFETY BENEFITS OF REGULAR HIGHWAY CONSTRUCTION

Although this manual is oriented toward improvements specifically designed to reduce accidents, improvements or projects considered "regular construction" also have safety benefits. In some cases, these benefits may be significant enough to make consideration of them worthwhile in the priority programming of these projects.

The expected accident reduction resulting from regular construction may be estimated by two methods.

Percentage Reduction of Accident Rate

Accident reduction is a percentage of the existing accident rate.

California uses Method A to calculate the safety benefits for regular construction projects. The percentages used by California in Method A are given below:

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Accident Rate Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realignment</td>
<td>50%</td>
</tr>
<tr>
<td>Superelevation</td>
<td>50%</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>29%</td>
</tr>
<tr>
<td>Combinations and Miscellaneous</td>
<td>25%</td>
</tr>
</tbody>
</table>
Reduction to a Statewide Average Accident Rate

Accident reduction is the present accident rate minus the statewide average for the type of road to be constructed.

California uses Method B for “spot improvements” over 0.50 miles in length. If the construction is a significantly higher design standard than the existing standard, California calculates the reduction to 0.8 of the statewide average for the type of road to be constructed. The statewide averages used by California are shown in Figure O-1.

Figure O-1

Example: Statewide Averages

The following is an example of using the reduction to a statewide average method to estimate the accident reduction of the reconstruction of 2.0 miles of 4-lane rural expressway using California’s statewide rates:

Existing Accident Rate = 4.8 Acc/MVM
Future ADT = 22,000 VPD (Assumed constant to simplify example)
Statewide Average AADT for 22,000 VPD = 2.3 Acc/MVM
Estimated Accident Reduction = (4.8 - 2.3)(365)(22,000)

= 20.1 Accidents Per Year

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APPENDIX Q

USERS' GUIDE TO METHODS FOR EVALUATING HIGHWAY SAFETY IMPROVEMENTS

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
PROJECT 17-2A

METHODS FOR EVALUATING
HIGHWAY SAFETY IMPROVEMENTS

USERS' MANUAL

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Chapter One

HOW TO USE THE MANUAL

Current highway safety improvement efforts vary considerably among highway agencies. The Federal Government is providing incentive for carrying out safety improvements through the establishment of safety standards—and through financial assistance programs. But different approaches have been used for planning and scheduling improvements and the results are not consistently effective.

Some states have established processes involving highly sophisticated computer programs for analysis of data and development of programs. Smaller agencies follow much less complicated procedures. And with these wide variables it becomes difficult to prepare a manual universally applicable for all conditions. But under all circumstances the basic objective remains the same—to reduce the frequency and severity of traffic accidents.

A principal weakness in past experience has been lack of effective evaluation processes—evaluation of proposed improvements to make certain the best choice is made for the money to be spent, and after-construction evaluations of the effect of the improvements. This manual places a great deal of emphasis on how best to make these evaluations. And at the same time, these evaluations are placed in proper context as part of an overall system for effective management of safety improvement programs.

THE MANAGEMENT SYSTEM

With modifications and adjustments to meet individual needs, the systems approach defined in this manual can be adopted by any highway agency—large or small; with or without computer systems.

Any management system basically involves establishing an end-result objective and defining those procedures needed to accomplish the objective most effectively.

The procedures usually are described as a series of actions in a particular sequence. The results of one action influence subsequent actions. The total series of actions in proper sequence constitutes a system. And consistent adherence to a well-designed system is the best way of attaining the desired results.

The management system for carrying out the safety improvement program consists of the following sequence of actions:

- Identify hazardous locations
- Identify potential corrective improvements
- Evaluate alternative improvements in terms of effectiveness, costs and benefits—and establish priorities for improvements
- Program and implement improvements
- Evaluate actual results of implemented improvements
- Evaluate the total highway safety improvements program

ORGANIZATION OF THE MANUAL

The manual is organized by chapters, each of which provides guides, criteria and procedures for carrying out one of the specific actions of the overall management system described in the preceding section.
The sequence of chapters is in the same order that the actions normally would be undertaken. This relationship is shown in Figure 1.

Figure 1
Model System

Agencies introducing safety improvements programs for the first time will find the arrangement convenient for a logical sequence of "how-to-do-it" instructions.

Agencies with on-going programs can seek out specific sections for guides and suggestions for improving their processes.

The manual attempts to avoid highly technical discussions. The intent is to be readily understandable for practical application of the current best known techniques and procedures. Those persons seeking more extensive information and background data should refer to the complete comprehensive report for NCHRP Project 17-2A.

Before studying the specific details of the management system procedures, several general considerations should be discussed and thoroughly understood. These considerations involve top management decisions as to the basic approach to safety improvement programs.

COMMITMENT

To what degree is an agency to commit resources to highway safety? With full knowledge of the problem and the potential for improvements, top management can make a realistic commitment of resources, manpower and dedication to accomplishment of effective improvements.

The basic objectives and policies of a highway safety program should be clearly set forth in a policy statement defining:

- general goals in terms of accident reduction, saving lives, reducing property damage and providing economic benefits,
- a framework for safety program management—criteria and procedures for planning, scheduling and implementing safety improvements—and for evaluating and reporting the results,
- the relationship between safety programs and other improvement programs of the agency,
- bases for funding safety programs—including policies for allocating both earmarked safety funds and regular capital investment funds of the agency,
- organizational responsibilities for carrying out safety programs and for coordination with other agencies.

Safety programs cannot be truly effective as an incidental function of an agency subdivision. The program must be an integral part of the total operation—with the full backing and commitment of top management.

RELIABILITY OF INPUT DATA

The safety improvement management system is largely dependent on realistic evaluations of alternative actions as bases for management decisions. Evaluations in turn depend on analyses of data. And unless that input data is reasonably reliable, it is likely that the evaluations may be misleading and the subsequent decisions may not truly reflect the most effective option.
Accident data are a principal area of concern with respect to reliability. The first requirement is that there be statistical reliability in the total coverage by the accident reporting system. What percentage of all accidents are actually being reported? Is bias being introduced because of incomplete reporting? Is the reporting consistent from different sources?

Take time to investigate the data to be used and determine the reliability of reported information on items such as:

- The location of the accident
- The type of accident
- Severity of accident
- Traffic volume

Statistical analysis can pinpoint the degree of reliability. Seldom is data 100% reliable. A 95% level of confidence is recommended. This will be discussed in more detail later in the manual.

APPLICATION

The systems approach for managing safety improvement programs can be used by any highway agency, large or small. The degree of sophistication for data collection and analysis may vary from one agency to another—and agencies may select slightly different operational procedures. But the basic concepts and management framework presented herein are universally applicable.

Larger agencies will find that computer processing of data is almost essential. Computer programs have been developed and are operating successfully in many agencies.

Chapter Two

IDENTIFYING HAZARDOUS LOCATIONS

The purpose of this step is to identify those locations on the highway system which may be hazardous, and for which some type of safety improvement might significantly reduce the number or severity of accidents.

First, how is a location defined? Three types of location conditions will be used in the manual.

1. **Spots**—Specific identifiable points anywhere on the highway system.

2. **Intersections**—An intersection with another highway, including the approaches thereto.

3. **Highway Sections**—A particular length of highway having consistent geometrics and characteristics.

The accuracy of identifying locations is very important. Federal Highway Safety Standard No. 9 requires accidents to be reported to the nearest 0.01 mile (+ 50 feet).
Secondly, what constitutes a hazard and how can a hazard be recognized?

1. Accidents—Accident experience is by far the best indicator of a potentially hazardous location. If accident experience at a particular location is considerably higher than the rest of the road system, there is a good chance that something about the roadway facility may be contributing to accident occurrence.

2. Non-Accident Analysis—Identification can be made by observation and judgment, analysis of near-accidents, skid testing, conflict analysis and numerous theoretical investigations. Some of these have considerable merit—but are not consistently as reliable as the use of actual accident data.

The guides and procedures for hazardous location identification in this manual will be limited to the use of accident data. Description of some of the non-accident investigation approaches can be found in the Research Report of NCHRP Project 17-2A.

Current federal policy requires that the identification of hazardous locations be based on analysis of accident experience. Four different analysis techniques commonly are used:

1. Number of accidents method
2. Rate of accidents method
3. Number-rate method
4. Rate-quality control method

Methods 1 and 2 above are quite simple and readily adaptable to the smaller highway and street systems. Data requirements are minimal, accident recording is simple and analyses can be made manually.

Methods 3 and 4 are recommended for larger systems with higher traffic volumes and wider variations of traffic.

The data requirements, criteria and procedures for each method are described in the following sections.

Data Requirements

Data requirements for identifying hazardous locations vary depending on the analysis method selected. The basic types of data are described below:

Time Period—A time period needs to be established for the period of analysis. Reported accident data usually is compiled by months and summarized quarterly, semiannually, annually or for periods of several years. Whatever period might be selected for analysis, all other data should be for the corresponding period.

Accident Locations—All reported accident locations should be reported to the nearest 0.01 mile (+ 50 ft.). For simple applications the information can be recorded with pins on a system spot map. For more complex analysis, it is necessary to record the information in ways compatible with computer processing techniques.

Section Lengths—The highway system should be divided into sections, each having consistent characteristics of geometrics, traffic volumes and condition (most highway agencies already have established such sections). The length of each section should be identified.

Traffic Volumes—Average traffic volumes (ADT) must be available for each established section of the system.

Categories of Highways—Some analyses will consider individual types of highways—types such as:

- Urban
  - 2 lane
  - 4 or more lane undivided
  - 4 or more lane divided
  - Freeway

- Rural
  - 2 lane
  - 4 or more lane undivided
  - 4 or more lane divided
  - Freeway
Average Accident Rates—Average accident rates must be available, both systemwide and for individual categories of highways and intersections as defined above. Normally these are expressed as accidents per million vehicles or per million vehicle miles. If the information is not developed routinely by the agency, it can readily be prepared using basic data on accident locations, section lengths and traffic volumes.

The following table shows the basic data requirements for each of the four methods of analysis.

<table>
<thead>
<tr>
<th>Basic Data Requirements</th>
<th>Number of Accidents Method</th>
<th>Accident Rate Method</th>
<th>Number-Rate Method</th>
<th>Rate-Quality Control Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Accident locations</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Section lengths</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Traffic volumes</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Average accident rates</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Categories of highways</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

The data described above is sufficient for the purpose of identifying hazardous locations. However, additional information will be needed later for evaluating alternative safety improvements and preparing programs—information such as:

- type of accident
- severity of accident
- time of day
- lighting conditions
- weather conditions
- type of traffic control

This type of information is included in standard accident reports.

Criteria for Hazardous Locations

The analyses described in this chapter will be directed to identifying hazardous locations. Specific units of measurement will be used throughout.

For sections of roadway:

- Number of accidents per mile—the actual number of accidents within a section divided by the section length.
- Number of accidents per million vehicle miles—the number of accidents within a section for each one million vehicle miles of traffic passing through the section.

For spots or intersections:

- Number of accidents—the actual number of accidents recorded.
- Number of accidents per million vehicles—the number of accidents for each million vehicles passing the point or passing through the intersection.

For definition purposes, a point is limited to a distance of 0.01 mile or less—and the traffic through an intersection is the through plus the crossroad volumes.

The following table shows which of the criteria measurement units are applicable to each of the alternative methods of analysis.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Number of Accidents Method</th>
<th>Accident Rate Method</th>
<th>Number-Rate Method</th>
<th>Rate-Quality Control Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sections:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accidents per mile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accidents per MVM</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Intersections and Spots:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of accidents</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Accidents per MV</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>


Suggestions for establishing specific values for the criteria are presented with the instructions for each method.

NUMBER OF ACCIDENTS METHOD

This system can be used effectively for small town street systems, local street systems in larger cities and low volume county roads. Consideration of the exposure factor is not as significant as on systems with higher traffic volumes or wider ranges of traffic volumes.

This is the simplest and most direct approach. All accidents are recorded by location and by the time period during which they occurred (usually months). Use of an accident spot map has proven to be one of the best ways to document the information. This involves the following procedures:

1. Obtain a map of street or highway system.
2. Locate each accident on the map.
3. Mark the location with a spot pin or tack. Different colors can be used to identify differences in severity.
4. At the end of a designated time period—a month, a quarter or a year, depending on the number of accidents—copy the map to record the clusters.
5. Identify the locations with the most spots.
6. Start a new spot map.

The simplicity of this approach is justified because of low traffic volumes. There will not be many accidents and few clusters of accidents will be found. But where clusters do show up, there will be an objective basis for investigation to determine if some element of roadway facility may be contributing to the accidents.

ACCIDENT RATE METHOD

Analysis by number of accidents alone can lead to misleading conclusions when there is considerable variation in traffic volumes throughout the road or street system. Two locations having the same number of accidents should not reflect the same degree of hazard potential if one carries twice as much traffic as the other. The accident rate method considers this variable.

In addition to the basic information on accidents and their locations, we must also know the traffic volumes at all locations—and we must be able to compute systemwide accident rates for comparison with specific locations.

The accident-rate method involves the steps described below. With relatively small systems, the processes and calculations can be performed manually—with larger systems a computer should be used for calculations and processing of data.

1. Locate all accidents on spot maps or through computer input.
2. Identify number of accidents in each established section and at individual intersections and spots.
3. Calculate the actual accident rate for each established section during the study period.

\[
\text{Rate}/\text{MVM} = \frac{(\text{no. of accidents on section})(10^6)}{(\text{ADT})(\text{no. of days})(\text{section length})}
\]

4. Calculate the actual accident rate for each intersection or spot during the study period.

\[
\text{Rate}/\text{MV} = \frac{(\text{no. of accidents at intersection or spot})(10^6)}{(\text{ADT at location})(\text{no. of days})}
\]

Note: In this case and others, count only entering traffic at intersections to avoid double counting of vehicles.
5. For the same period, calculate the systemwide average accident rates for sections, intersections and spots—using the formulas above and the summation of total accidents, total vehicle miles and total vehicles respectively for each category of location.

6. Select accident rate cut-off values as criteria for identifying hazardous locations. A value about twice the systemwide rate usually is realistic and practical.

7. If actual rates exceed the minimum established criteria, the location is identified as hazardous and placed on the list for investigation and analysis.

Selection of the cut-off value (step 6) is not as critical as it might appear. The principal purpose is to control the size of the list of locations to be investigated—a shorter list with high values, a longer list with low values. Experience will disclose the proper level for a particular agency.

The accident rate method is more complex than the accident numbers method—and usually gives better results. But compromises are made in detail of specific and overall statistical reliability. Some of these limitations are overcome by the rate quality control method and the number-rate method. Most agencies with large complex systems should adopt one of these later two methods.

NUMBER-RATE METHOD

The number-rate method is applicable to all highway or street systems—regardless of size of system or variations in traffic volumes.

When we identify hazardous locations, it is important that we make certain the locations truly have an abnormally high accident experience. One of the dangers in relying solely on accident numbers or accident rates is that figures can be misleading when we are dealing with wide ranges of traffic volumes.

A location with relatively high numbers of accidents or accidents per-mile may appear to be quite hazardous. But if the traffic volume is exceptionally high at the location, the accident rate may not be abnormal—and the situation may not be as bad as it appears.

On the other hand, a location with relatively few accidents may show a very high accident rate because of extremely low traffic volumes. And again, the situation may not be as abnormal as it appears.

If both the number of accidents and accident rate at a location greatly exceed the average, we can be reasonably sure that the accident record is abnormal—and that conditions should be examined. The number-rate method is based on this concept. Additionally, this method considers variables related to categories of highways and types of intersections—categories differentiating between rural and urban locations, number of lanes, divided or undivided and access control.

Data Requirements

The basic data requirements include:

- Time period
- Accident locations
- Section lengths
- Traffic volumes
- Categories of highways

Average Accident Data

It is necessary to establish average accident experience data for each category of highway or street.
For sections:

- Average number of accidents per mile
- Average number of accidents per MVM

For spots or intersections:

- Average number of accidents per location
- Average number of accidents per MV passing the location

These data will serve as a base starting point for identifying hazardous locations.

Criteria for Hazardous Locations

Those locations with accident experience considerably higher than average should be investigated. The precise level is not critical. Cut-off values about twice the systemwide average for a particular category reflect a reasonable initial judgment.

Longer or shorter lists of potentially hazardous locations can be obtained by adjusting the cut-off values.

Those sections, spots or intersections with accident experience exceeding the cut-off values for both the numbers of accidents and accident rates should be placed on the hazardous location list.

Procedures

The number-rate method involves the following steps in addition to the basic recording of accidents and their locations.

1. For sections of highway, compute average accidents per mile for each category of highway—based on total data for all sections of each category.

   \[
   \text{Av. accidents per mile} = \frac{\sum (\text{number of accidents})}{\sum (\text{miles of category})}
   \]

2. Identify all clusters of accidents (2 or more with 0.01 mile) at spots and intersections, and compute average accidents per location and per million vehicles for each category of highway.

   \[
   \text{Av. accidents per location} = \frac{\text{total number of accidents}}{\text{total number of locations}}
   \]

   \[
   \text{Av. accidents per MV} = \frac{(\text{total number of accidents})(10^6)}{\sum (\text{location ADT})(\text{no. of days})}
   \]

3. Select cut-off values for each of the criteria above—start with values about twice the systemwide average for each highway category.

4. For each section, calculate both the actual number of accidents per mile and per vehicle mile.

5. For each cluster of accidents (spot or intersection) calculate both the number of accidents and the accidents per million vehicles passing the location.

6. All locations with numbers of accidents and accident rates both higher than the critical cut-off values should be placed on the hazardous location list.

Comparisons must be made with criteria for the particular category of highway being analyzed.

Processing of accident data and calculating accident rates is readily adaptable to computer programming. Table 1 shows an example computer output with accident rates for sections listed in descending order of rates.
RATE QUALITY CONTROL METHOD

The rate quality control method is applicable to systems of all sizes and ranges of traffic volumes. As with the number-rate method, consideration is made of various categories of highway—rural, urban, 2 lane, 4 lane, etc. But the rate quality control method assures control of the quality of the analyses by applying a statistical test to determine whether a particular accident rate is unusual, as related to a predetermined average accident rate for locations having similar characteristics. The tests applied are based on the commonly accepted assumptions that accidents fit the Poisson distribution.

Data Requirements

Basic data requirements are the same as for the number-rate method:

- Time period
- Accident locations
- Section lengths
- Traffic volumes
- Category of highways

Average Accident Data

It is necessary to establish average accident experience data for each category of highways or streets:

For sections:
- Average number of accidents per MVM

For intersections or spots:
- Average number of accidents per MV
Criteria for Hazardous Locations

A critical accident rate is calculated for each location being studied. Individual locations with accident rates exceeding the critical rate are included on the hazardous location list.

The critical rate is determined statistically as a function of the systemwide average accident rate for the category of highway and the vehicle exposure (vehicles or vehicle miles) at the location being studied.

Critical rates are computed by the following formula:

\[ R_c = R_a + K \sqrt{\frac{R_a}{m}} - 0.5 \]

Where:
- \( R_c \) = Critical accident rate
  (For sections - accidents per MVM)
  (For intersections or spots - accidents per MV)
- \( R_a \) = Systemwide average accident rate by highway category
  (For sections - accidents per MVM)
  (For intersections or spots - accidents per MV)
- \( m \) = vehicle exposure during study period (MV or MVM)
- \( K \) = constant

The value of \( K \) determines the level of confidence that accident rates above the critical rate are significant and have not resulted by chance. A 99.5% level of confidence is desirable. Example values of \( K \) for various levels of confidence are shown below.

<table>
<thead>
<tr>
<th>Level of Confidence</th>
<th>( K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.995</td>
<td>2.576</td>
</tr>
<tr>
<td>0.95</td>
<td>1.645</td>
</tr>
<tr>
<td>0.90</td>
<td>1.282</td>
</tr>
</tbody>
</table>

From the practical standpoint, variations in the value of \( K \) will result in different numbers of locations which will appear on the hazardous location list. The list will be longer with low values for \( K \) and shorter with high values. A suggested starting value for \( K \) is 1.5.

Procedures

The rate quality control method involves the following steps in addition to the basic recording of accidents and their locations.

1. Compute systemwide average number of accidents per MVM for each category of highway--based on total data for all sections of each category.
   \[ \text{Av. accidents per MVM} = \frac{\text{(no. of accidents)}(10^6)}{\text{(section ADT)}(\text{no. of days})(\text{section length})} \]

2. Identify all clusters of accidents 2 or more within 0.1 mile) at spots and intersections, and compute systemwide average accidents per MV at such locations by categories of highways.
   \[ \text{Av. accidents per MV} = \frac{\text{(no. of cluster accidents)}(10^6)}{\text{(ADT at clusters)}(\text{no. of days})} \]

3. For each individual location, determine the vehicle exposure, \( m \), during the study period.

   For Sections:
   \[ m = \frac{\text{(section ADT)}(\text{no. of days})(\text{section length})}{10^6} = \text{MVM} \]

   For Intersections and Spots:
   \[ m = \frac{\text{(location ADT)}(\text{no. of days})}{10^6} = \text{MV} \]
4. For each location, compute the critical accident rate, \( R_c \), by the formula:

\[
R_c = R_a + K \frac{\sqrt{R_a}}{m} - 0.05
\]

Where:
- \( R_a \) = Average accident rate for category of highway being studied (MVM for sections--MV for intersections and spots)
- \( m \) = Vehicle exposure at location (MVM for sections--MV for intersections and spots)
- \( K \) = constant

Start with a value of \( K = 1.5 \). A larger value of \( K \) will reduce the length of the hazardous location listing--but will increase the level of confidence that the locations truly are hazardous. A smaller value of \( K \) will produce a longer list with a lower level of confidence.

5. Compute the actual observed accident rate at each location for the same time period.

For Sections:

\[
\text{Accidents per MVM} = \frac{\text{no. of accidents}}{\text{millions of vehicle miles}}
\]

For Intersections and Spots:

\[
\text{Accidents per MV} = \frac{\text{no. of accidents}}{\text{millions of vehicles}}
\]

6. Compare the actual accident rate with the critical rate at each location and prepare a list of all locations (sections, intersections and spots) with rates exceeding the critical value.

PRIORITY LISTING

The process of hazardous location identification will produce a listing of potentially hazardous locations. The next step is to investigate each location and determine what corrective actions, if any, should be taken. But where do you start?

Each location is identified with a particular number of accidents or an accident rate--and it would appear that the highest numbers and rates should be checked out first. But one other factor should be considered--the severity of the accident and the resulting costs.

Experience has shown that cost values can be related to various types of accidents and injuries. Information on accident cost data can be found in Chapter Four. By summarizing the types of accidents and injuries at each identified hazardous location and applying the cost data to the accidents, a practical measure can be established for relative severity at each location.

Reordering of the hazardous location listing with priorities determined by severity--as measured by costs--will serve as a practical guide for scheduling investigating the most significant locations first.

Example listings of hazardous locations and their priorities are shown in Tables 2 through 4.

DOCUMENTATION

There needs to be complete documentation of data and logic leading to identifying hazardous locations. When the time comes to evaluate the results of implemented countermeasures, the analyst will need to know the background and considerations that led to the recommendations--questions related to:

- Location Parameters--what type of location is this?
- Accident Experience--what type and how many accidents have occurred at the hazardous location?
Table 2

Example Listing of Hazardous Sections

| HA OACR OUG OUE TECTIc NALYSIS FOR STATE HIGHWAY SUFF. SECTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RURAL 2-LANE | | | | | | | | | | | |
| DISTRICT | NO. | STATE | REF POST | SUB REF POST | LENGTH (EER FCMS) | POPULATION CODE | LANE CODE | NO. OF ACCIDENTS | ACCIDENTS PER MILLION VEH. MILES | CRITICAL | SEVERITY |
| 1 | C41 | 001.47 | 007.47 | .00 | 765 | 1 | 1 | 3 | 5.16 | 4.27 | 16.8 |
| 1 | C67 | 434.90 | 037.77 | .00 | 1700 | 1 | 1 | 3 | 5.01 | 4.26 | 15.6 |
| 1 | 060A | 001.00 | 001.19 | .00 | 467 | 1 | 1 | 3 | 4.97 | 4.61 | 24.7 |
| 1 | 081 | 008.44 | 010.67 | .00 | 2300 | 1 | 1 | 2 | 4.63 | 4.51 | 16.6 |
| 1 | C92 | 421.23 | 472.73 | .50 | 2220 | 1 | 1 | 6 | 4.93 | 3.77 | 155.0 |
| 1 | 5120 | 002.00 | 000.03 | .93 | 600 | 1 | 1 | 1 | 4.90 | 4.61 | 24.9 |
| 1 | 526 | 194.15 | 187.34 | .20 | 1000 | 1 | 1 | 20 | 4.63 | 2.96 | 94.9 |
| 1 | 067 | 011.51 | 017.25 | .00 | 607 | 1 | 1 | 4 | 4.82 | 4.03 | 69.6 |
| 1 | 526 | 187.34 | 193.66 | .00 | 618 | 1 | 1 | 4 | 4.70 | 3.49 | 377.5 |
| 1 | C65 | 293.26 | 293.51 | .00 | 1978 | 1 | 1 | 4 | 4.77 | 4.01 | 22.9 |
| 1 | C55 | 361.97 | 366.94 | .00 | 1445 | 1 | 1 | 4 | 4.62 | 4.00 | 23.3 |
| 1 | C64 | 041.22 | 052.05 | .00 | 322 | 1 | 1 | 1 | 4.53 | 4.18 | 159.2 |
| 1 | C29 | 000.00 | 007.04 | .00 | 1312 | 1 | 1 | 15 | 4.44 | 3.17 | 697.5 |
| 1 | C65 | 000.00 | 010.09 | .00 | 341 | 1 | 1 | 6 | 4.38 | 3.69 | 214.9 |
| 1 | 129 | 000.00 | 007.06 | .00 | 162 | 1 | 1 | 2 | 4.28 | 4.42 | 58.3 |
| 1 | 081 | 038.79 | 048.83 | .00 | 149 | 1 | 1 | 1 | 4.26 | 4.14 | 90.1 |
| 1 | 077 | 000.00 | 003.03 | .00 | 1071 | 1 | 1 | 5 | 4.27 | 3.78 | 164.7 |
| 1 | C30 | 236.26 | 232.41 | .15 | 1833 | 1 | 1 | 6 | 4.19 | 3.68 | 147.6 |
| 1 | C75 | 300.35 | 303.24 | .00 | 1591 | 1 | 1 | 24 | 4.13 | 2.63 | 854.0 |
| 1 | C75 | 009.90 | 010.56 | .00 | 2070 | 1 | 1 | 4 | 4.13 | 4.00 | 93.8 |

Table 3

Example Listing of Hazardous Intersections

| DANGEROUS INTERSECTION ACCIDENT RATINGS |
|---|---|---|---|---|---|---|
| URBAN 4-LANE CIV. | | | | | | |
| MAY | H.P. | MAY | H.P. | MAY | H.P. | MAY | H.P. |
| 036 | 25.63 | 073 | 109.51 | 2820 | 8.300 | 24 | 4.00 |
| 050 | 92.86 | 275 | 180.24 | 2826 | 7.250 | 19 | 3.84 |
| 064 | 72.50 | 133 | 1.50 | 2829 | 24.270 | 48 | 3.50 |
| 058 | 275 | 177.43 | 2822 | 5.335 | 10 | 5.13 | 4.27 |
| 068 | 126.41 | 283 | 21.10 | 3502 | 3.475 | 6 | 4.73 | 4.37 |
| 010 | 57.17 | 050 | 272.42 | 944 | 51.54 | 1000 | 15.800 | 22 | 5.81 | 3.68 |
| 038 | 10.66 | 064 | 77.27 | 2823 | 57.375 | 52 | 5.81 | 3.36 |
| 068 | 5.00 | 275 | 18.25 | 2822 | 23.480 | 31 | 3.61 | 3.92 |
Table 4
Example Listing by Accident Costs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>US 74</td>
<td>Lancaster</td>
<td>6</td>
<td>17</td>
<td>$74,820 $163,110</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>316.67 to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>318.16 (1.67 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.8 miles north of Lincoln</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 74</td>
<td>Lancaster</td>
<td>35</td>
<td>60</td>
<td>$110,430 $161,750</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>324.35 to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>324.66 (.32 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in Lincoln</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 77</td>
<td>Gage</td>
<td>35</td>
<td>61</td>
<td>$124,410 $138,990</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.27 to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24.08 (1.81 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in Beatrice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 34</td>
<td>Cass</td>
<td>26</td>
<td>35</td>
<td>$92,600 $117,660</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>379.36 to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>381.43 (2.07 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in Plattsmouth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 73</td>
<td>Richardson</td>
<td>19</td>
<td>25</td>
<td>$62,100 $116,580</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.13 to 4.61 (.48 miles),</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in Falls City</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 136</td>
<td>Gage</td>
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<td>11</td>
<td>$113,250 $108,120</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>187.34 to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>193.66 (6.28 miles),</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in filley</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>N-67</td>
<td>Nemaha</td>
<td>6</td>
<td>9</td>
<td>$60,150 $107,400</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27.22 to 33.37 (6.08 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>south edge of Peru</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 73</td>
<td>Otoe</td>
<td>23</td>
<td>24</td>
<td>$97,920 $103,500</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>59.44 to 60.12 (.68 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in nebraska City</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 6</td>
<td>Lancaster</td>
<td>3</td>
<td>6</td>
<td>$21,960 $89,970</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>319.86 to 320.71 (.84 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>northeast edge of Lincoln</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>US 6</td>
<td>Seward</td>
<td>6</td>
<td>9</td>
<td>$56,790 $87,210</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>293.51 to 294.15 (2.64 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in milford</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-15</td>
<td>Butler</td>
<td>9</td>
<td>8</td>
<td>$76,670 $81,930</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>92.54 to 97.81 (5.27 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>north edge of david City</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-15</td>
<td>Seward</td>
<td>18</td>
<td>18</td>
<td>$57,860 $71,160</td>
<td></td>
</tr>
<tr>
<td>from ref.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>66.46 to 67.52 (1.06 miles),</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in seward</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Identifying Selecting Evaluating Programming Evaluating Evacuating
HAZARDOUS ALTERNATIVE ALTERNATIVE AND IMPLEMENTED THE HIGHWAY LOCATIONS IMPROVEMENTS IMPROVEMENTS IMPLEMENTING IMPROVEMENTS SAFETY

The Manual of Traffic Engineering Studies, published by the Institute of Traffic Engineers, sets forth a basic approach for analyzing hazardous locations. This involves four basic steps:

- Prepare collision diagrams
- Summarize accident characteristics
- Conduct field observations
- Prescribe improvements

Suggested procedures to be followed are described in the following sections.

**Prepare Collision Diagrams**

Most accident reporting systems provide fairly comprehensive information on accident occurrence and related conditions -- information such as:

- location description
- general geometric layout of location
- time and date of each accident
- severity of accident
- pavement condition for each accident
- weather at each accident
- intended paths of vehicles involved
- intersection control devices

Graphical presentation of such information usually is more effective than statistical summaries. A simple collision diagram will facilitate analyses -- particularly at intersections. Strip maps or multi-page maps are necessary to illustrate accidents on long sections of highway.

The procedures for preparing collision diagrams are:

1. Obtain accident reports for all accidents that have occurred at the location during the immediate preceding period of at least one year -- preferably longer. If significant changes have occurred in the
characteristics of the location in recent years (construction, signals, channelization, etc.), do not include reports for accidents occurring prior to these changes.

2. Draw the location. This drawing need not be to scale but should be large enough to assure plenty of room to show the path of each vehicle involved. In most cases standard forms are available.

3. Sketch the intended movement of each vehicle involved in each accident on the diagram.

4. Note the basic characteristics of each accident by symbol. Suggested characteristics are:
   - severity
   - date, day of week and time of accident
   - weather or pavement conditions
   - light conditions

5. Note any peculiarities or driver comments.

An example collision diagram is shown in Figure 2.

**Summarize Accident Characteristics**

By summarizing factual data related to accidents, it frequently is possible to identify relationships between accidents and possible contributing factors. When data for all accidents at a particular location consistently show common characteristics of time of day, weather, type of accident, or other conditions, some of the mystery is removed and these indicators can be used to point the direction of further investigations.

The importance of good factual reporting is obvious. Unreliable summarized data can lead to erroneous conclusions. But reliable data, summarized in meaningful ways, can be one of the most valuable tools for evaluating hazardous locations.
The procedures for summarizing data are:

1. Use accident reports obtained under the same criteria set forth for collision diagrams.

2. For all accidents at the location, summarize the characteristics by categories such as:
   - time of day
   - road surface conditions
   - light conditions
   - weather conditions
   - pavement conditions
   - safety equipment
   - injury severity
   - collision type

3. For each identified characteristic, calculate the percentage of the total reported accidents where the particular characteristic was identified.

4. When a characteristic is evident in a large percentage of the accidents at a location compare the percentage with a systemwide average for similar accidents at similar locations. The characteristic likely is a significant factor at the location if its occurrence is much more frequent than the systemwide average (i.e., 80% of the accidents on wet pavement at this location vs. 40% average throughout the system).

Table 5 shows one method of summarizing accident characteristics.

<table>
<thead>
<tr>
<th>Type of Accident</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run-off Road</td>
<td></td>
</tr>
<tr>
<td>Overturned on Roadway</td>
<td></td>
</tr>
<tr>
<td>Two or More Motor Vehicles</td>
<td></td>
</tr>
<tr>
<td>Entering at angle</td>
<td></td>
</tr>
<tr>
<td>Right turn direction - both going straight</td>
<td></td>
</tr>
<tr>
<td>Same - one stopped</td>
<td></td>
</tr>
<tr>
<td>From opposite direction - both going straight</td>
<td></td>
</tr>
<tr>
<td>Pedestrian</td>
<td></td>
</tr>
<tr>
<td>Car going straight</td>
<td></td>
</tr>
<tr>
<td>Car turning right</td>
<td></td>
</tr>
<tr>
<td>Car turning left</td>
<td></td>
</tr>
<tr>
<td>Car hitting</td>
<td></td>
</tr>
<tr>
<td>Railroad Train</td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td></td>
</tr>
<tr>
<td>Animal</td>
<td></td>
</tr>
<tr>
<td>Fixed Object in Road</td>
<td></td>
</tr>
<tr>
<td>Fell from Moving Vehicle</td>
<td></td>
</tr>
<tr>
<td>Ice Road Surface</td>
<td></td>
</tr>
<tr>
<td>Road Surface icy or Snowy</td>
<td></td>
</tr>
<tr>
<td>Dawn or Dusk</td>
<td></td>
</tr>
<tr>
<td>Darkness</td>
<td></td>
</tr>
<tr>
<td>Darkness</td>
<td></td>
</tr>
<tr>
<td>Property Damage Only</td>
<td></td>
</tr>
</tbody>
</table>

Table 5 shows one method of summarizing accident characteristics.
Field Observations

It may be necessary to observe hazardous locations in the field if causes of accidents cannot be determined from diagrams and statistical summaries. Observations also may be needed to verify assumptions made in the office.

Procedures for field observation normally should include the following steps:

1. Review of existing available data -- accident reports, accident summaries, diagrams, traffic counts, violation summaries and other operational data.

2. Schedule the observations according to apparent significant characteristics -- nighttime, wet pavement, etc.

3. Select several good vantage points and observe drivers to identify unusual behavior and, if possible, determine the cause of the behavior.

4. Drive through the location several times from different directions -- with particular attention to how the driver might see the environment.

5. Inventories of unique features not included in existing records.

6. Discussions with persons residing or working near the locations -- for personal insights.

7. Document the findings and conclusions.

The I.T.E. Manual of Traffic Studies lists eleven questions that the analyst should consider during a field observation:

1. Are the accidents caused by physical conditions of the road or adjacent property, and can the conditions be eliminated or corrected?

2. Is a blind corner responsible? Can it be eliminated? If not, can adequate measures be taken to warn the motorists?

3. Are the existing signs, signals, and pavement markings doing the job for which they were intended? Is it possible they are, in any way, contributing causes of accidents rather than preventing them?

4. Is traffic properly channelized to minimize the occurrence of accidents?

5. Would accidents be prevented by the prohibition of any single traffic movement, such as a minor left-turn movement?

6. Can part of the traffic be diverted to other thoroughfares where the accident potentialities are not as great?

7. Are night accidents for out of proportion to daytime accidents, based on traffic volume, indicating need for special nighttime protection, such as street lighting, signal control or reflectorized signs or markings?

8. Do conditions show that additional traffic laws or selective enforcement are required?

9. Is there a need for supplemental studies of traffic movement, such as driver observance of existing control devices, speed studies of vehicles approaching the accident location and others?
10. Is parking in the area contributing to accidents? If so, perhaps reduction of the width of approach lanes or sight obstructions in advance of the intersection resulting from the parking are causing the accidents?

11. Are there adequate advance warning signs of route changes so that the proper lanes may be chosen by approaching motorists well in advance of the area, thus minimizing the need for lane changing near the accident location?

Prescribe Improvements

After identifying hazardous locations and the related circumstances that probably have contributed to accidents, the next step obviously is to determine what action would be most effective to correct, or at least improve the situation.

Unfortunately, this decision frequently is not as clear cut as it might appear. Often we jump to an apparent obvious conclusion without considering all alternatives -- or the ultimate effect that a particular action might precipitate.

Someday we may be able to feed a computer with data on all circumstances and conditions and receive back a 100 percent foolproof solution. But until that time comes, there is no substitute for careful, comprehensive and logical analysis by an experienced person. As the total safety management system becomes implemented, and we start receiving reliable feedback on the results of our actions, the decisions on improvements will become easier -- and our confidence will be increased.

In the meantime, we are not completely in the dark. There are some guides based on experience. Some may not pass a test of statistical validity -- but they reflect best current judgments and provide a starting point. Use them -- but do not accept them as gospel truth. Question the criteria -- but make certain your processes for evaluating implemented improvements (see Chapter Six) are effective so that you will have sound bases for revising criteria.

Table 6 lists most of the improvement types commonly selected. It is not all-inclusive, but can serve as an informal checklist. In Appendix A these improvement types are described in more detail, with comments as to appropriateness for particular applications and with observations as to past experience.

Several important items should be kept in mind during the process of selecting appropriate improvements:

1. Identify all practical improvements -- everything from a do-nothing alternative to an ultimate alternative such as complete reconstruction. We are not making a final decision (this will be discussed in Chapter Four). The principal objective is to make certain we do not overlook an alternative which may be the most practical and economically advisable solution.

2. Identify all practical combinations of improvements.

3. For each alternative, identify the potential effect of the improvement -- the numbers of accidents, the type of accidents, and the severity of the accident.

DOCUMENTATION

There needs to be complete documentation of data and logic leading to prescription of applicable improvements. When the time comes to evaluate the results of implemented improvements, the analysts will need to know the background and considerations that led to the recommendations -- questions related to:

- Problem Identification -- What method was used to identify the problem at the hazardous location, and how was the problem defined?
Table 6

Example Checklist of Potential Improvements

SECTIONS

• Eliminate parking
• Install delineators
• Add guardrail-embankments
• Add guardrail-fixed objects
• Remove fixed objects
• Flatten fill slopes
• Add painted or raised median
• Deslicking
• Resurfacing
• Widen traveled way
• Reconstruction

• Install or improve edge marking
• Install or improve warning and/or directional signs
• Install median barrier
• Breakaway sign and light standards
• Install lighting
• Shoulder stabilization
• Widen shoulders
• Eliminate median crossovers
• Add climbing lanes

CURVES

• Install delineators
• Add guardrail
• Resurfacing

• Install warning signs
• Reconstruct curve

BRIDGE/UNDERPASS

• Install delineators
• Install lighting
• Energy absorption devices

• Add guardrails
• Bridge widening

INTERSECTIONS

• Install or improve warning and/or directional signs
• Install minor leg stop control
• Install lighting
• Install pedestrian signals
• Improve signals
• Install new signals
• Install warning signals

• Install stop ahead signs
• Install yield sign
• Install all-way stop signs
• Install warning signals
• Curtail left-turn movements
• Provide for left-turn movements
• Deslicking
• Install rumble strips

• Accident Characteristics -- What accident data were available and how were they utilized?

• Selection of Applicable Improvements -- Which improvements or combinations of improvements were considered? Which were not considered applicable and why?

• Location Peculiarities -- Are there any peculiarities about the hazardous location that may cause the improvements to produce non-typical results?

For consistency, each agency should adopt a standard format for documentation—and documentation should be included as a part of any subsequent design report. An example documentation worksheet is shown in Appendix B.

COMPLEMENTARY TECHNIQUES

Recent innovation and research into analyzing the causes of accidents emphasize a broader base of experience for analyses. Some of these techniques might well be used complementary to the procedures outlined in the previous sections.

Four of these techniques are briefly described in this section.

• Multi-Disciplinary Investigation Team
• Conflict Analysis
• Accident Pattern Tables
• Fault Tree Analysis

Additional information on other suggested approaches can be found in the Research Report for NCHRP 17-2A.

Multi-Disciplinary Investigation Team

Several states have established a multi-disciplinary investigation team (MDIT)
to investigate traffic accidents in depth. These teams may include persons of several disciplines, such as:

- Psychiatrists
- Sociologists
- Automotive engineers
- Law enforcement officers
- Physicians
- Highway engineers
- Laymen

The team does not rely solely on conventional accident reports for information—rather they conduct intensive on-site investigations as soon as possible after the accidents occur. Each team uses basic investigative techniques such as identifying and following clues until the basic cause of an event leading to an accident has been determined.

A typical MDIT operation is described below:

1. Each multi-disciplinary team has a vehicle specially equipped with measuring and recording devices such as radios, cameras and recorders.

2. The team monitors the state police radio for accidents that (a) are within its range, (b) occur at known hazardous locations, or (c) fit desired characteristics, e.g., single vehicle run-off-the-road.

3. The team rushes to the scene and collects as much information as possible about what happened. This information includes pictures, measurements and eye witness accounts.

4. The information is carefully analyzed by all members of the team. The usual result is a report that describes the accident far more thoroughly than conventional accident reports, and identifies the probable causes or contributing circumstances, including any dangerous highway design or construction errors.

Conflicts Analysis

Traffic conflicts analysis can be helpful for identifying improvements at locations having several accidents which appear to be unrelated. The basic assumptions behind conflicts analysis are:

- Traffic conflicts are measures of traffic accident potential.
- Any traffic conflict is a potential accident.

For a typical intersection there are more than twenty defined patterns of traffic conflict. These conflicts are identified by the occurrence of evasive actions, such as braking or weaving that are forced on drivers by impending accident situations. Figure 3 shows typical examples of common conflicts.

The advantage of conflicts analysis is that detailed studies on intersections can be based on a large volume of objective data rather than on a few accident reports. The disadvantage of conflicts analysis is that there is no way to predict the relative severity or possible result of each conflict.

The procedure involves observing the intersection, counting the conflicts, classifying conflicts by type and recording the data. The information is summarized on a sheet, similar to that shown on Figure 4, and analyzed in terms of potential improvements. For further discussion, see the Research Report for this study.

Accident Pattern Tables

As an aid to prescribing appropriate improvements, some use has been made of a matrix table which relates predominant accident types to probable causes. Assumptions behind this approach are that:

- patterns of accident types are associated with probable causes of accidents, and
Figure 3. Typical Intersection Conflicts

- Stop-On-Amber Rear-End Conflict
- Right-Turn Conflict
- Weave Conflict
- Slow-For-Turn Rear-End Conflict
- Cross-Traffic Conflict
- Slow-For-Iracific-Conflict
- Rear-End Conflict

Example Documentation of Conflicts
probable causes of accidents can infer the need for specific improvements.

If accidents at a location have predominant patterns, for example, mostly rear-end collisions, a table of predominant patterns vs. probable causes will direct attention to applicable improvements. The detection of a predominant pattern may be made from a collision diagram, a summary of significant characteristics or from a review of the accident reports.

The methodology is readily adaptable to a computer -- but the results should be reviewed carefully by a highway safety analyst.

The approach shows considerable promise and can be very helpful. But the stage of development is such that agencies should not rely on this technique alone to identify improvements.

An example table of this type, developed and used by the Mississippi State Highway Department is shown in Table 7. A companion table relating probable causes to applicable improvements is shown in Table 8.

Fault Tree Analysis

The underlying logic of a fault tree analysis is that most accidents are the result of many previous events. A fault tree is basically a logic diagram tracing all events and combinations of events that can result in an accident. The events are simplified to eliminate duplications, and probability values are assigned to indicate their likelihood. Usually there are several possible pathways, each having its own probability.

The fault tree analysis assumes that:

- the cause and effect relationships of accidents follow a logical flow which can be documented; and

- each event in the logical flow of accident causation may be assigned a probability.

<table>
<thead>
<tr>
<th>Probable Cause of Accident</th>
<th>Type of Accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restricted Sight Distance</td>
<td></td>
</tr>
<tr>
<td>Poor Pavement Marking</td>
<td>X</td>
</tr>
<tr>
<td>Inadequate Signals</td>
<td>X</td>
</tr>
<tr>
<td>Inadequate Signs</td>
<td>X</td>
</tr>
<tr>
<td>Slippery Surface</td>
<td>X</td>
</tr>
<tr>
<td>Inadequate Signal Timing</td>
<td>X</td>
</tr>
<tr>
<td>Inadequate Signal Phasing</td>
<td></td>
</tr>
<tr>
<td>Improperly Located Driveways</td>
<td></td>
</tr>
<tr>
<td>Fixed Objects</td>
<td>X</td>
</tr>
<tr>
<td>Under Designed</td>
<td>X</td>
</tr>
</tbody>
</table>
The analyst wants to know the events that cause a particular accident occurrence. Sequences of events are traced backwards—that is, B caused A, but what caused B—until terminal events are reached. The events, gates and pathways are diagrammed in the form of a tree, hence the name.

Table 9 lists the symbols commonly used in fault tree analysis:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR</td>
<td>OR gate</td>
</tr>
<tr>
<td>AND</td>
<td>AND gate</td>
</tr>
<tr>
<td>INH</td>
<td>Inhibit</td>
</tr>
<tr>
<td>EXT</td>
<td>External</td>
</tr>
</tbody>
</table>

Procedures for developing a fault tree are:

1. Start with the final occurrence (or core resultant event—collision) and work backward. The events and gates between the occurrence and the basic events are identified and analyzed to determine if each event independently can lead to the occurrence or if several events must happen together.

2. Some events are basic, requiring no further development of cause. When all basic events are identified, the probabilities of accident causation can be established.

3. Identify the events immediately preceding the core event that are required to determine if any of them are basic.

4. Analyze each identified event to determine if any of them are basic. The next three steps are optional, based on the analyst's judgment.

5. Assign probabilities of events leading directly to the AND gates. The probabilities of events leading directly to the OR gates are usually derived from an accident investigation.

6. Determine the influence of potential countermeasures by decreasing the probabilities of critical events and recalculating the probabilities of certain events and recalculating the probabilities of critical events and recalculating the probabilities of certain events.

7. Continue identifying preceding events until all basic events have been covered. Determination of basic events will depend on how much detail the analyst feels is necessary. Proper balance will be determined as an analyst becomes more experienced with the technique.

Figure 5 shows a simple example of a fault tree with sequence of events and probabilities. The analyst works from the occurrence and works backward. Events preceding the occurrence can be identified and analyzed to determine if all events together independently can lead to the occurrence. If several events must happen together, the analyst must determine if any of them are basic. When all basic events are identified, the probabilities of accident causation can be established.

Some events are basic, requiring no further development of cause. When all basic events are identified, the probabilities of accident causation can be established. The analyst works from the occurrence and works backward. Events preceding the occurrence can be identified and analyzed to determine if all events together independently can lead to the occurrence. If several events must happen together, the analyst must determine if any of them are basic. When all basic events are identified, the probabilities of accident causation can be established.
<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangle Event</td>
<td></td>
<td>An effect of consequence event produced by other events.</td>
</tr>
<tr>
<td>Circle Event</td>
<td></td>
<td>A basic event requiring no further development of its cause.</td>
</tr>
<tr>
<td>Diamond Event</td>
<td></td>
<td>A terminal event not developed further due to lack of information or lack of significance.</td>
</tr>
<tr>
<td>House Event</td>
<td></td>
<td>A normal event that is usually expected in operation of the system.</td>
</tr>
<tr>
<td>AND Logic Gate</td>
<td></td>
<td>All inputs are required to produce an output event whose probability is equal to the product of the probabilities of the input events.</td>
</tr>
<tr>
<td>OR Logic Gate</td>
<td></td>
<td>Any input will produce an output event whose probability is equal to the sum of the probabilities of the input events.</td>
</tr>
</tbody>
</table>

Figure 6: Example Fault Tree Analysis

<table>
<thead>
<tr>
<th>Event</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCIDENT AREA ENTRANCE</td>
<td>0.001</td>
</tr>
<tr>
<td>DRIVER INTELLIGENCE IMPAIRMENT</td>
<td>0.006</td>
</tr>
<tr>
<td>DRIVER INTELLIGENCE IMPAIRMENT + Cognizance</td>
<td>0.008</td>
</tr>
<tr>
<td>VEHICLE HITS TREE</td>
<td>0.00026</td>
</tr>
<tr>
<td>DRIVER LEAVES ROADWAY</td>
<td>0.003</td>
</tr>
<tr>
<td>MECHANICAL VEHICLE</td>
<td>0.002</td>
</tr>
<tr>
<td>P = 0.02</td>
<td></td>
</tr>
<tr>
<td>P = 0.001</td>
<td></td>
</tr>
<tr>
<td>P = 0.006</td>
<td></td>
</tr>
<tr>
<td>P = 0.008</td>
<td></td>
</tr>
<tr>
<td>P = 0.00026</td>
<td></td>
</tr>
<tr>
<td>P = 0.003</td>
<td></td>
</tr>
<tr>
<td>P = 0.002</td>
<td></td>
</tr>
</tbody>
</table>
Having identified hazardous locations, the probable circumstances which have made the location hazardous, and alternative improvements to improve the situation, the next step is to evaluate these alternatives to determine the best specific action or combinations of actions to be undertaken.

This chapter will discuss procedures for the individual evaluations—the following chapter will discuss how to use the results of these evaluations for preparing and implementing programs.

Two basic tasks confront us:

1. To determine which of several improvements will be the "best buy" at particular locations; and
2. To establish some type of measurement of the relative "value" of individual proposed improvements at all locations.

The purpose of the first task is quite evident. The second task is necessary because it is unlikely that we can fund or physically effect all improvements immediately.

The program probably will be spread over a period of years and there is need to establish realistic priorities.

Evaluations will be based principally on economic analyses and will involve the following six steps:

2. Assigning values to accident reduction.
5. Analyzing improvement at each location.
6. Assigning program priorities.

ECONOMIC CONSIDERATIONS

There are numerous concepts and approaches for performing economic analyses. Often there is difference of opinion as to the most appropriate application for a particular situation. Alternative approaches were reviewed during the NCHRP 17-2A research project and are discussed in the research report.

It is generally agreed that analysis identifying annual benefits and annual costs is acceptable for safety improvement evaluations. Discussion will be limited here to this approach.

The assumptions behind this approach are:

- The relative merit of an improvement is measured by its net annual benefit or benefit/cost ratio.
- All costs can be reduced to an equivalent uniform annual cost.
- All benefits can be reduced to an equivalent uniform annual benefit.
- An improvement will be needed for its entire service life.
ESTIMATING ACCIDENT REDUCTION

The premise for proposing an improvement at a hazardous location is that there will be benefits resulting from accident reduction. The justification for any improvement, and its priority, is based on the ratio of the benefits and the costs of implementing the improvement. Therefore, the prediction of accident reduction becomes very critical in the process of evaluating improvements.

Various analytical procedures have been suggested for forecasting accident reduction. The most reliable approach is to use data based on actual experience before and after specific improvements. Unfortunately, many agencies do not as yet routinely develop these data. Data that have been developed by some agencies provide valuable indicators of probable results. But the state-of-the-art has not reached the point where these indicators are reliable for universal application. The very heart of the total safety management system set forth in this manual lies in rigorous analysis of actual results for better forecasting of future results.

In the meantime, those agencies not having access to better information can benefit from the experience of others. Tentative guides for predicting accident reduction through specific improvements can be found in Appendix A. Use them until you develop something better.

Data Requirements

Benefits eventually will be identified in dollar amounts related to reductions in fatalities, personal injuries and property damage—but initially the yardstick will be reduction in accident rate with consideration of types of accidents and their severity. Required input data for each location will include:

- Historical accident experience—accident rates, types of accidents and severity.
- Estimated future ADT—the growth or decline of traffic volumes.
Expected reduction in accident rate—by type of accident or by severity.

If an improvement is not implemented, it can be assumed the accident rate experience can be projected through a particular future time period with adjustments for changes in ADT. And the mixture of types of accidents and their severity usually will remain the same.

Use of Tables

The tables in Appendix A provide reasonable indicators (based on limited experience data) of potential accident reduction following implementation of particular improvements. The organization of the tables identify several possible combinations of conditions:

- Type of location (sections, curves, intersections, etc.)
- Type of improvement
- Urban and rural
- Two lanes or more than two lanes.

Expected accident reduction for any future year is calculated as:

\[
\text{Accidents Saved} = N \cdot P \left( \frac{\text{ADT - future year}}{\text{ADT - record period}} \right)
\]

Where: 
- \( N \) = the number of accidents in the period before the improvement project;
- \( P \) = the percent reduction selected from the table (expressed as a decimal).

It is emphasized that the values given in Appendix A should serve only as a starting point if an agency has not developed reliable forecast data of their own. Those agencies designing and implementing comprehensive safety management systems should make certain that the feedback portion of the system provides the type of information shown in Appendix A, with even more extensive breakdown of actual accident reductions by type and severity. The requirements for feedback and evaluation are discussed in greater detail in Chapter Six.

Assigning Values to Accident Reduction

Two methods commonly are used for assigning economic values to accident reductions:

1. costing by severity class, or
2. costing by type of accident.

Motorists pay for accidents in one or more of the following ways:

- Direct settlement paid to other persons.
- Payment as a result of judicial proceedings.
- Medical and property damage repair costs.
- Automobile insurance premiums.

Basic Accident Cost Data

The most reliable data on accident costs would be those which have been collected locally. Information from the Motor Vehicle Administration, local insurance companies, fleet operators and the Public Health Service will be more suitable than nationwide statistics. Two of the more commonly used nationwide studies are summarized below.

National Safety Council - 1972

The Safety Council includes wage loss, medical expense, insurance administrative costs and property damage in their estimates.
Severity Class | Cost Per Accident
---|---
Fatal | $82,000
Nonfatal disabling injury | $3,400
Property Damage (including minor injuries) | $480

National Highway Traffic Safety Administration - 1971

While NHTSA did not attempt to place a value on human life, it did include calculable costs associated with the loss of human life—wages lost, medical expense, legal fees, insurance payments, home and family care and property damage. About eight percent of total costs were assigned to “pain and suffering.”

Severity Class | Cost Per Accident
---|---
Fatality | $235,000
Nonfatal injury (average) | $11,200
Permanent total disability | $315,000
Permanent partial disability | $100,000
Non-permanent disability | $3,800
Property Damage Only | $500
Average (approx.) | $2,800

Accident cost data from the two sources above reflect different philosophies as to what cost elements are included. Basic cost data adopted by any agency must reflect concepts and judgments acceptable to that agency. Top management should be involved in these decisions.

Benefit Computations—Based on Reduced Accident Severity

When calculating accident reduction benefits on the basis of severity of accidents, the following steps are followed:

1. Select or develop average cost data for each of several classes of severity—i.e., fatalities, one or more classes of injuries, and property damage-only accidents.
2. Compute the expected accident reduction (numbers of accidents) by each severity class, for each year of the service life of the improvement.
3. Multiply the average costs for each severity class by accident reduction numbers for each year.
4. Compute the total of all classes for each year and calculate the total annual benefits.

Benefit Computations—By Types of Accidents

When benefits are computed on the basis of the types of accidents, the procedures are:

1. Select or develop average cost data by accident severity classes.
2. Establish categories of types of accidents (head on, side swipe, left turn, etc.) and determine the frequency of each severity class for each accident type.
3. Compute the average cost for each accident type:

\[
\text{Average accident cost} = \frac{(F_f)(C_f) + (F_i)(C_i) + (F_p)(C_p)}{F_f + F_i + F_p}
\]

Where:  
- \(F_f\) = Number of fatal accidents for this accident type.  
- \(F_i\) = Number of injury accidents for this accident type.  
- \(F_p\) = Number of property damage accidents for this accident type.  
- \(C_f\) = Average cost per fatal accident.  
- \(C_i\) = Average cost per injury accident.  
- \(C_p\) = Average cost per property damage accident.
4. Multiply the average accident cost for each accident type by the reduction of each accident type and sum all types to obtain a total dollar value for each year.

Either of the above techniques is acceptable. Costing by type of accident reduces the influence of the rare event, a fatal accident, yet reflects its importance through the types of collision. If it is difficult to obtain data relating accident severity to types of accidents, costing by severity class may be more practical.

ESTIMATING SECONDARY BENEFITS

The primary benefit to be expected from the implementation of an accident reduction improvement is a decrease in accident rate or severity, and the benefit analysis should focus on these factors. However, the possibility should not be overlooked that a safety improvement may also affect other road user and non-road user benefits. For example, a signal installation may reduce certain types of accidents while simultaneously increasing motorist delay; signal progression may reduce rear end collisions and lower auto emission levels; and street lighting has been shown to have a beneficial effect on both nighttime accidents and street crime.

Examples of secondary benefits might include:

- Reduced traffic congestion—which will not only decrease idling time and cost for vehicles but also reduce motorist delay.
- Improved roadway and roadside geometrics—which can minimize wear to vehicle components and also reduce fuel consumption.
- Higher speed of operation from realignment of a series of sharp horizontal curves.
- Smoother operation from implementation of a one-way street system with signal progression.
- Reduction in the need for vehicular "slow-downs" by improving the sight distance on the approach to a YIELD-controlled intersection.
- Reduction of the time and mileage for lost motorists by improving guide signing at an interchange.
- Elimination of motorist delay by prohibiting left-turn at selected locations.
- Reduction in street crime brought about by improved roadway lighting.
- More effective use of enforcement and other protective service personnel brought about by fewer accident-related duties.

Often these benefits will be negligible compared to the accident reduction benefits. But under some circumstances the secondary benefits will be significant and should be included in the analyses.

ESTIMATING IMPROVEMENT COSTS

The expected service life of each improvement and the cost of implementation are basic input for analysis.

Estimated Service Life

The service life is the period of time that the improvement can reasonably be expected to affect accident rates. Twenty years usually is the maximum time for major geometric changes of roadways or bridges. Examples of estimated service life used in California are:

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Service Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signals</td>
<td>15 years</td>
</tr>
<tr>
<td>Safety Lighting</td>
<td>15 years</td>
</tr>
<tr>
<td>Median Barriers</td>
<td>15 years</td>
</tr>
<tr>
<td>Flashing Beacons</td>
<td>10 years</td>
</tr>
</tbody>
</table>
Improvement (continued)

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Service Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guardrail</td>
<td>10 years</td>
</tr>
<tr>
<td>Pavement Grooving</td>
<td>10 years</td>
</tr>
<tr>
<td>Signing (major)</td>
<td>10 years</td>
</tr>
<tr>
<td>Signing (minor)</td>
<td>5 years</td>
</tr>
<tr>
<td>Raised Pavement Markers</td>
<td>5 years</td>
</tr>
<tr>
<td>Guide Markers</td>
<td>5 years</td>
</tr>
<tr>
<td>Painted Stripes</td>
<td>2 years</td>
</tr>
</tbody>
</table>

Both the costs and benefits of improvements should be calculated for the period of time designated as expected service life. The analysis period should not extend beyond the period of reliable forecast. Thus, the estimated service life should reflect the length of time that estimated accident reduction can reasonably be expected instead of the physical life of the improvement. For example, given a strong possibility of an intervening solution such as improved vehicle design, traffic diversion or highway reconstruction, the service lives of the alternatives should be adjusted to reflect the shorter planning horizon.

Improvement Costs

There are three basic parts of improvement costs:

- Initial costs—the investment prior to and during construction.
- Annual costs—the annual expense required to keep the improvements operating.
- Terminal value—the amount recoverable at the end of the service life.

The manner of estimating initial costs will vary with the complexity of the improvement. Routine installation of signals, signs and similar standard installations can be based on average costs from experience. More extensive improvements will require preliminary design and estimating of quantities as bases for cost estimates.

Many improvements require an annual expenditure for maintenance and operation. For example, a traffic signal will have annual costs for electrical power and equipment maintenance. Annual cost figures can be obtained by analyzing operating cost data. For some improvements, the annual cost will be zero or so small that it can be ignored in the economic analysis.

The terminal value is the difference between the monetary value at the end of the period of service and the future cost of removal, repair, transfer and/or sale. For a safety improvement, it may include signing that is usable at another location or salvageable guardrail. If a proposed improvement will have terminal value, it should be included in the analysis. However, most improvements have very little terminal value.
EQUIVALENT UNIFORM ANNUAL BENEFITS AND COSTS

In order to conduct meaningful economic analyses, there is need to convert the computed benefits and costs to equivalent uniform annual values—with appropriate consideration of interest rates and the cost of capital investment.

Formulas for these computations are presented below. It will be necessary to refer to standard interest/discount rate tables for the proper values of factors to be used—depending on the particular interest rate that is selected. Background on the concepts behind this approach can be found in numerous engineering economics texts.

Interest Rates

The economic analysis will include consideration of interest on the investments. Each agency should select an interest rate appropriate for its own use. There are no fixed criteria for interest rates. A wide range of values is shown in the table below as examples of interest rates used by eighteen agencies to evaluate highway safety improvements in 1973.

<table>
<thead>
<tr>
<th>Interest Rate</th>
<th>Agencies Using This Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>New York</td>
</tr>
<tr>
<td>8%</td>
<td>Ohio and Tennessee</td>
</tr>
<tr>
<td>7%</td>
<td>Georgia, Oklahoma and Utah</td>
</tr>
<tr>
<td>6%</td>
<td>Colorado, Massachusetts, North Carolina, Puerto Rico, West Virginia and Seattle</td>
</tr>
<tr>
<td>5%</td>
<td>Delaware, Minnesota, Missouri, Virginia and Wyoming</td>
</tr>
<tr>
<td>0%</td>
<td>California</td>
</tr>
</tbody>
</table>

A common approach is to use the interest rates associated with long-term borrowing for highway construction.

Equivalent Uniform Annual Benefits (EUAB)

When estimated benefits from accident reductions are expected to be reasonably uniform through each year of the lifespan of the improvement, the calculated annual benefit value may be used directly as the "equivalent uniform annual benefit."

Accident reduction usually will be related to projected traffic volumes—and if a significant increase in traffic is expected, the benefits will increase proportionally during the period. Simple averaging of the annual benefits will not give a proper basis for economic evaluation. It is necessary to establish an equivalent uniform annual benefit (EUAB) with consideration of the interest rate. The following formula should be used:

\[ EUAB = CR^1_n \sum (\text{each year's benefit}) (\text{each year's PW}_n) \]

Where:
- \( CR^1_n \) = Capital Recovery Factor for \( n \) years (service life of improvement) at interest rate \( i \).
- \( PW^1_n \) = Present Worth Factor for each year at interest rate \( i \).
- \( \sum \) = Summation of all years of service life.

The factors for capital recovery and present worth may be found in conventional interest tables.

Equivalent Uniform Annual Costs (EUAC)

Because the cost of an improvement consists of an initial investment, recurring annual costs and consideration of salvage value, it is necessary to establish an equivalent uniform annual cost (EUAC) during the life of the improvement. If the annual costs are uniform through the period, use the formula:

\[ EUAC = CR^1_n (I) - T (n^{th} \text{ year } SF^1_n) + K \]

If the annual costs vary from year to year, use the formula:

\[ EUAC = CR^1_n \left[I + \sum_{j=1}^{n} K_j PW^1_i\right] - T(SF^1_n) \]
Where: \( CR_n^i \) = Capital Recovery Factor for \( n \) years at an interest rate of \( i \).

\( PW_n^i \) = Present Worth Factor for each year at an interest rate of \( i \).

\( SF_n^i \) = Sinking Fund Factor for \( n \) years at an interest rate of \( i \).

Initial cost of improvement.

\( K \) = Constant annual cost.

\( T \) = Terminal value of improvement.

\( n \) = Service life of improvement.

\( \Sigma \) = Summation of all years of service life.

The values for capital recovery factor, present worth factor and series present worth factor can be found in conventional interest tables or calculated using the formulas in Table F-2 in Appendix F of the Research Report.

CRITERIA FOR SELECTION AND PRIORITIES

The values for the equivalent uniform annual benefits and costs computed for each improvement are used to establish indices for selecting improvements and establishing priorities.

The two indices are:

- NET ANNUAL BENEFITS -- the difference between equivalent uniform annual benefits and costs (EUAB - EUAC)
- BENEFIT/COST RATIO -- the ratio of the equivalent uniform annual benefits to costs (EUAB/EUAC)

The significance of these indices is quite evident. As long as the net annual benefit is a positive value, the improvement is a feasible investment. But if we have a choice between two or more improvements, the one with the largest net annual benefit should be selected.

Similarly, any benefit/cost ratio value of more than one indicates a feasible improvement. Each of these types of indices has an application for particular conditions and circumstances as will be described below.

Programming Objectives

Before selecting specific improvements and establishing priorities, there is need to clearly identify the safety program objectives of the agency. Two different approaches might be considered.

1. To select and implement safety improvements in ways that will ensure maximum total benefits from the investment at each location.

2. To select and implement safety improvements in ways that will ensure maximum total benefits from the investment of funds that are available.

The characteristics of programs developed by these two approaches may be quite different. For the first approach, those improvements having the highest net annual benefits at each location would always be selected. For the second approach, the set of improvements from all locations that provide the most benefit is the selection criteria.

Experience has shown that most relatively small, inexpensive improvements characteristically have higher benefit/cost ratios with only moderate net annual benefits. And conversely, the larger, more expensive improvements generally result in larger net annual benefits with lower benefit/cost ratios.

These inherent characteristics of improvements pose a problem for both basic approaches to programming.

- If we assure maximum net benefits at each location, we can expect that the average cost of individual improvements will be relatively high—and if funds are limited, we can implement improvements at far fewer locations.
- If we assure maximum benefits from available funds, we can expect many lower cost improvements—but some of these will not completely solve the problem, and will serve only as stopgap measures until more comprehensive solutions are implemented.
Each agency must face this question and establish appropriate objectives and policies as they see fit. Two general criteria should serve as guides.

1. If the safety program concepts are considered a continuing integral part of the highway planning function, every effort should be made to assure maximum benefits at each improvement location.

2. If the safety improvements are undertaken as a "one-shot" nonrecurring program, the philosophy of getting the maximum benefits from specific earmarked funds probably is acceptable.

The first approach is strongly recommended, and is the basis for subsequent guides and instructions in this manual.

Selecting Improvements at Each Location

The first step at each location is to analyze the relationships between possible improvements. We are faced with a choice of several alternatives—and the selection of one precludes the implementation of others. These are called "mutually exclusive" alternatives. An example might be a short section of rural highway with a high number of accidents attributable to substandard curvature and narrow roadway width. Logical alternatives might be:

- Minor widening and improvement of superelevation; or
- Reconstruct to straighten curves.

It is necessary to choose between these alternatives—select one or the other.

On the other hand, sometimes we will find that it is feasible to implement any or all of the suggested improvements. These are called "independent." An example of this situation would be an intersection with a bad record of left-turn and rear-end accidents—and the potential improvements were:

- Improve the signing
- Construct left-turn lanes
- Install signals

These improvements can be implemented independently or in various combinations. The practical combinations are shown below:

<table>
<thead>
<tr>
<th>Improve Signing</th>
<th>Left-Turn Lanes</th>
<th>Install Signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternate A</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Alternate B</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Alternate C</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Alternate D</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Alternate E</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Alternate F</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Alternate G</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To make a selection, the mutually exclusive alternatives and all practical combinations of independent alternatives are grouped. We then select one alternative or combination from this group. For example, consider a hazardous railroad crossing that presently has flashing lights. The mutually exclusive alternatives are:

- Gates
- Grade separation

The independent alternatives are:

- Safety lighting
- Advance warning signs

The groups of mutually exclusive improvements and practical combinations of independent improvements would be:

- Grade separation
- Gates
- Gates and safety lighting
- Gates and advance warning signs
- Gates, safety lighting and advance warning signs
- Safety lighting
- Advance warning signs
- Safety lighting and advance warning signs
We select one improvement from this group using net annual benefit analysis—the improvement with the most net benefit is selected.

**Ranking for Program Consideration**

Once we have identified the improvement, or combination of improvements which will assure the maximum net annual benefits at each location, the next step is to establish priorities for implementation of the improvements.

The list may be quite long—and it will be evident that accomplishment of the total program will require several years. It is convenient to establish a series of annual programs which may be related to specific annual budgetary allocations.

Several factors may influence decisions on selecting specific improvements for a particular year. Some of these may be non-economic considerations. But, to the extent practical, priorities should be based on relative economic merit of individual improvements. And, one of the generally accepted indices for this purpose is the computed benefit/cost ratio.

The benefit/cost ratio (EUAB/EUAC) should be computed for the selected improvement at each location—and the total list should be structured in descending order of benefit/cost ratios. The current annual program should include projects selected from the top of the list. The amount of available funds would determine the number of projects that can be selected for that year.

The ranking is not rigid. It is to be used as a guide. If an improvement is too expensive for the remaining funds, it should be by-passed. Improvement further down the ranking list should be examined to find one or sets of several that will fit the remaining budgeted funds. If many improvements are eligible for the program, it is advisable to use a computerized dynamic programming model.

Each year a new list should be developed. And again, the next year’s annual program should be selected from those improvements with the higher benefit/cost ratios.

**DOCUMENTATION**

There needs to be complete documentation of data and logic leading to the selection of eligible improvements. When the time comes to evaluate the results of implemented improvements, the analyst will need to know the background and considerations that led to the recommendations—questions related to:

- **Improvement parameters**—What are the estimated service lives of the applicable improvements? Estimated costs?
- **Improvement performance**—What is the estimated accident reduction of each applicable improvement?
- **Evaluation data**—What is the equivalent uniform annual cost of each improvement? Equivalent uniform annual benefit?
- **Evaluation results**—Which improvements were selected? What were their benefit/cost ratios? Which improvements were rejected? Why?

For consistency, each agency should adopt a standard format for documentation—and documentation should be included in any subsequent design report. Example documentation worksheets are shown in Appendix B.

**EXAMPLE EVALUATIONS**

Appendix B contains a complete example of the management system procedures and evaluations applied to a typical situation.

Although the data are hypothetical and shortened to simplify calculations, the steps, procedures and example forms reflect the concepts and approaches detailed in this manual—from the identification of hazardous locations to the evaluation of the safety program.
Only since the Federal government has stepped into the picture and established safety standards and provided financial incentives for safety programs have highway agencies been required to direct specific attention to safety.

In some ways this turn of events has been unfortunate—because it has placed highway safety considerations in a separate category of operations rather than an integral part of the basic objectives and policies of a highway agency. But at least our attention has been directed to assuring safe highway facilities—and administrative officials of each agency should now formally acknowledge the extent of commitment to highway safety within their overall programs.

Some states have statutes requiring that available highway funds be used first for maintenance—so as to assure protection of the investment in existing facilities—and only the remaining funds can be used for new construction and improvements. The same type of priorities might be applicable to assure protection of the motorists.

The point is that safety programs need not be financed only with specified, earmarked funds. A well conceived, total comprehensive safety program might well be integrated with overall highway program objectives without financial limitations. But if highway agencies are not ready to make this commitment, the practice of earmarking specific funds will at least assure a minimum safety program.

Formal policy statements should be developed by each agency to clarify the status of the safety program and to define its scope and responsibilities. An example policy statement is shown in Figure 6.

**PROGRAM COORDINATION**

It is evident that safety improvements cannot be programmed and implemented entirely independent of other highway programs—even when separate funding is provided. Careful planning and coordination is essential.
OBJECTIVE: The Department will adopt and implement a safety management system.

The objective of this system is improved highway safety through (1) identifying hazardous or potentially hazardous locations, (2) developing the best cost-effective improvements to correct these hazards, (3) assigning program priorities based on the benefit-cost ratio of each improvement, (4) programming, designing and constructing improvements by integrating these improvements into the regular work systems of the Department and (5) evaluating the effectiveness of individual improvements and the total safety program.

In developing and operating this system, the Department will extend full cooperation to other agencies of the state government, local governments and agencies of the Government of the United States.

SCOPE: This policy applies to the management and utilization of funds for highway safety improvements. High priority safety improvement projects evolving from the safety management system may be financed and implemented as an integral part of the regular highway construction program.

RESPONSIBILITY: The Safety Director will, within the limits of normally delegated authority and responsibility, maintain coordination with other state, federal and local agencies of government; prepare safety programs and coordinate funding assistance from the Federal Government; ensure coordination with other safety programs and assist the Management Systems Engineer in internal development coordination.

The Management Systems Engineer is responsible for developing the safety management system and for guiding system implementation, subject to normal lines of authority and responsibility.

After proposed safety improvements have been identified, the regular highway construction program should be reviewed to ascertain if any major improvements are planned at the locations of the proposed safety improvements.

If major work is not planned or if the proposed safety improvement will not be affected by reconstruction—proceed to implement the safety improvement as soon as possible.

If the safety improvement will be replaced or negated by reconstruction in a few years, the following options are open:

- Recompute the net annual benefits or the benefit/cost ratio for the improvement with a reduced service life. If the results are still significantly positive, go ahead with implementation.
- If the countermeasure cannot be economically justified with reduced service life, determine whether the reconstruction can be accelerated for earlier completion.
- If reconstruction cannot be accelerated sufficiently, reevaluate one or more lesser improvements to determine whether a smaller investment may be justified as a stopgap measure.

In some agencies, it will be necessary to coordinate safety improvement programs with other agency divisions—such as traffic engineering and maintenance—when these divisions have responsibilities for performing minor improvements and betterment work not included in the formal construction program. And certainly there is need for coordination with the design division to make certain the findings and conclusions relative to existing hazardous locations are considered when establishing design standards and procedures for new construction projects.

IMPLEMENTATION RESPONSIBILITIES

Various techniques and procedures can be used for implementing different types of improvements. When preparing programs, several questions need to be answered:
How will the work be performed?
Who will design the improvement?
Who will be responsible for work performance?

Safety improvements may be accomplished by contract or with direct labor by agency work forces. Large complex improvements usually should be performed by contract, while agency work forces often can effectively execute the smaller-type improvements. Each agency must analyze its own capabilities and the economics of the alternative approaches.

Some improvements may be so simple that little design effort is required—removing obstacles, pavement striping, installing routine signs and signals, etc. Other improvements may require considerable study and design effort—intersection design, grade separations, channelization, large signs, sophisticated signal systems, etc. Work by contract will require more extensive design and the specification documentation. There is need to identify the extent of design work and the level of expertise required—and assign specific design responsibilities to appropriate units within the agency or to outside consultants.

Depending on the type of work involved, different organizational units and levels within an agency may be called upon to supervise work performance—units such as:

- Construction Division
- Maintenance Division
- Traffic Engineering Division
- District Engineers

Specific responsibilities should be identified for directing and/or supervising the work of both contractors and agency employees for each proposed improvement.

PROGRAMMING AND BUDGETING PRACTICES

Programming and budgeting obviously are quite closely related. When a specific program is formulated and adopted, the budget must then reflect the funds needed to accomplish the program. Or, if a fixed budgeted amount is established, the program must reflect the work that can be accomplished with available funds. Some agencies now utilize performance budgeting techniques which combine the work program and budget in a single document.

Highway improvement programs normally provide two types of information—(1) the long-range goals and objectives for 10 years or more in the future, and (2) the specific projects to be constructed in the current fiscal period. Safety improvement programs should follow the same pattern. The total listing of proposed improvements for improved safety reflects long-range objectives. As many of the higher ranking projects as possible should be included in the specific programs and budgets for each year. But how do we know where the cut-off point will be each year? The basic objectives and policies adopted by the agency will influence this decision.

Funds for highway safety improvement programs may come from several sources, including:

- Outside funds (Federal or other) earmarked for safety improvements.
- Outside funds for general highway improvements.
- Local funds earmarked for safety improvements (either for matching outside funds or independently undertaking improvements).
- Local funds for general highway improvements.

Each agency should ascertain the amount of outside earmarked funds available and the requirements for proportionate participation (if any) with local earmarked funds. Top management then will have to decide how much (if any) of other local funds can be used specifically for safety improvements. But for the first time, because of the management system approach, top officials will have factual data to realistically evaluate the alternatives as to how the money should best be invested. Specific safety programs and budgets can then be formulated and documented along with breakdowns of sources of funds.
As specific improvements are more clearly identified and designed, and more precise cost estimates can be prepared, it may be necessary to make adjustments in the budget estimates.

SCHEDULING

Effective scheduling of individual projects is essential to accomplishing any highway improvement program—including implementing of safety improvements. It would be unrealistic to propose an annual program requiring considerable more funds than will be available—and it would be equally unrealistic to suggest a program larger than can be accomplished with available manpower.

Consideration must be given to time and manpower requirements for:

- Detailed planning and design
- Contracting formalities
- Obtaining special equipment and/or materials
- Constructing and/or installing improvements.

For some improvements, the requirements will be minimal. A simple work order may be sufficient to authorize the work, materials and equipment may be available in stock, and a few days work by agency crews may finish the job. But other improvements may require considerable lead time before implementation, with commitment of significant amounts of engineering, administrative and construction manpower.

Some agencies, with large numbers of projects under way, utilize various forms of computerized critical path scheduling techniques. At the other extreme, a simple bar graph can be used to document the schedule of development and implementation of each of a series of proposed improvements. In any case, it is essential that a realistic schedule be established with target dates for accomplishment of the various phases of project development.

Chapter Six

EVALUATING IMPLEMENTED IMPROVEMENTS

One of the principal weaknesses of post experience with highway safety programs has been lack of adequate follow-up and evaluation of the actual results of implemented improvements.

Accident prediction is not yet a precise art. Even the best of approaches usually involves some assumptions—and certainly there are many complex contributory factors which we do not understand. There is documentation of safety improvements that have failed to produce predicted benefits. Sometimes unexpected side effects of an improvement have actually worsened the situation.

We do not know all the answers—and until we increase our storehouse of knowledge on what really happens after implementing various safety improvements, we cannot have
complete confidence in our future judgments and actions. Orderly systems and procedures for regular evaluation of all implemented improvements are essential to effective management of highway safety programs.

DATA REQUIREMENTS

In previous chapters, emphasis was placed on the need for good documentation on all steps taken for identifying hazardous locations, selecting and evaluating alternative improvements, prescribing and implementing a particular improvement and predicting results. This information will be needed by the analyst when evaluating after-implementation results.

Specifically, the analyst will want to know:

- What type of improvement was installed?
- Where was it installed?
- When was it installed?
- Which agency installed the improvement?
- What was the implementation cost?
- What was the prior accident data?
- How was the problem diagnosed?
- Why was this improvement selected?
- What results were predicted?

Figure 7 illustrates a typical project file documentation. Figure 8 is an example summary form used by one agency as data documentation for computer input.
The purpose of implementing an improvement is to effect a significant accident reduction. Several techniques have been employed for evaluating results. Before and After Analysis: This analysis compares accident experience at a particular location before and after implementation to obtain statistically reliable data for evaluating a type of improvement. To group together the before and after accident experiences of all locations, a parallel control group analysis is used. This analysis compares accident experience at similar locations not receiving improvements with the trend in experience from "before" to "after." Basing or Compare Accident Experience of Several Locations: This analysis compares accident experience at similar locations and allows for a comparison of similar control locations. Before and after analyses have been used more extensively than the other techniques, and after analyses are described in this manual. Parallel or Control Group Analysis: This analysis compares accident experience at similar locations and allows for a comparison of similar control locations. Before and after analyses have been used more extensively than the other techniques, and after analyses are described in this manual. Parallel or Control Group Analysis: This analysis compares accident experience at similar locations and allows for a comparison of similar control locations. Before and after analyses have been used more extensively than the other techniques, and after analyses are described in this manual.
The basic data needed are:

- The improvement documentation—location, time, etc.
- Accident data—how many, what types, how severe.
- Traffic volumes.
- Any significant changes in the physical environment (other than the improvement) which may influence accident records—illumination, skid resistance, etc.

Before and after comparisons normally will be made in terms of accident rates—accidents per million vehicles or per million vehicle miles. The basis for measurement will be percent reduction of accident rate. Comparisons also may be made in terms of numbers of accidents, but adjustments must be made for both time periods and changes in traffic volumes for meaningful results.

Before and after data should reflect comparable time periods, preferably at least twelve months. When less than twelve months data are available following implementation, the before data should be selected from the same months as the after data. For example, if after data are based on a period from October to March, the before data should be based on experience for the same months of the preceding year—or for the average of those months for several preceding years.

After the time period has been identified and the basic data selected, the first step is to calculate the accident rates before and after—using the respective data on numbers of accidents and traffic volumes.

For intersections or spots:

\[
\text{Accidents per million vehicles} = \frac{\text{(No. of accidents)} \times 10^6}{\text{(No. of days)} \times \text{(ADT)}}
\]

For sections:

\[
\text{Accidents per million vehicle miles} = \frac{\text{(No. of accidents)} \times 10^6}{\text{(No. of days)} \times \text{(ADT)} \times \text{(Section Length)}}
\]

For each location, or for each group of locations with similar characteristics and improvements, the change in accident experience is calculated and identified as:

\[
\text{Percent Accident Reduction} = 100 \frac{(\text{Accident rate before}) - (\text{accident rate after})}{(\text{Accident rate before})}
\]

The procedures shown above should then be repeated to identify changes in accident experience by types of accidents and severity of accidents. This will permit evaluation of the overall effect of the improvement. For example, the total accident rate may not have been materially reduced, but a significant decrease in severity of accidents will result in measurable overall benefits. On the other hand, a reduction in accident rate may produce little benefit if, for some unforeseen circumstance, the severity of accidents shows a marked increase.

The original premise was that each improvement was economically justified. Using the actual findings on reduction of accidents by types and severity, along with updated data on accident costs and the costs of implementing improvements, we can now determine whether we made wise decisions. And more important, the findings will help us make better decisions next year.

SIGNIFICANCE OF RESULTS

Before we jump to a conclusion about the merits of a particular improvement, and its effectiveness in reducing accidents, we need to back-off and take a second look at our data to determine how much confidence we have in the findings.
There is a certain degree of chance in all happenings. Just because a coin comes up heads 7 times out of 10 flips, we would not have much confidence in predicting 70 heads out of 100 flips. We are reasonably sure it is going to even out about 50-50 in the long run. But if it happened that heads came up 70 out of the next 100 times the results would start to be significant—we would begin to believe the coin was unbalanced, or that something other than mere chance was controlling the happening.

The same thing applies to accident data. We would have little confidence in predicting great changes on the basis of one week's experience, or a month—or probably even three months. The more experience we observe, the greater will be our confidence.

Suppose two locations had the accident experience shown below for periods of one year before and one year after implementation of an improvement.

<table>
<thead>
<tr>
<th>Location</th>
<th>Before Accidents</th>
<th>After Accidents</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50</td>
<td>40</td>
<td>20%</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>4</td>
<td>20%</td>
</tr>
</tbody>
</table>

Even though both locations experienced the same percent reduction during the same period, we would have a great deal more confidence in the findings at location A than at location B.

A simple test can be employed to determine whether the results at a particular location (or group of locations) are truly statistically significant. The test assumes that the distribution of accidents at a location has the general characteristics of a Poisson distribution. This distribution is illustrated graphically by the curves in Figure 18, and relates the total number of accidents in the data period preceding the improvement to the percent reduction of accidents following implementation of the improvement.

The curves in Figure 9 are designed to assure a 95% level of confidence that the indicated accident reduction was significant. This means there is only a 5% probability...
that the reduction occurred merely by chance. A 95% level of confidence is considered generally acceptable. Similar curves for other levels of confidence are shown in the Research Report for NCHRP 17-2A.

The lower of the two curves reflects a liberal test of significance—the upper curve a more conservative test. Testing of results at a particular location involves the following steps:

1. Identify the number of accidents in the data time period before implementation (the time should be comparable to the after-implementation data time period).
2. Compute the percent accident reduction at the location (see instructions in previous section).
3. Adjust, if necessary, the number of before accidents:
   a. If the before time period is longer than the after time period (this is the usual case), adjust the number of before accidents, \( b' \), to reflect differences in traffic volumes and time periods:
   \[
   b' = \frac{b \times (\text{After ADT}) \times \text{Days in after period}}{(\text{Before ADT}) \times \text{Days in before period}}
   \]
   b. For intersections, use the sum of the ADT on each of the legs and divide by 2 to obtain average ADT.
   c. If the traffic volume changes during the before or after period, multiply each ADT by the number of days it was applicable.
   d. If the after time period is longer than the before time period, the number of before accidents, \( b \), need not be adjusted.
4. Refer to the curves in Figure 17 and locate the point of intersection of the number of accidents and the percent reduction.
5. If the intersection point is below the bottom curve, we are not sufficiently confident that the improvement actually caused that amount of accident reduction. The data are not considered significant as bases for future judgments.
6. If the intersection point is above the top curve, we are 95% certain that the accident reduction was attributable to the improvement. Data from these locations should be reliable for updating our standards, guides and criteria for future planning.

7. If the intersection point falls between the two curves, the significance of the results is uncertain. Continue to collect data from the location for an additional period of time and then re-evaluate the improvement.

EXAMPLE EVALUATION

Raised pavement markers were installed with existing lane lines on a four-mile hazardous section of freeway. The following data were obtained for two years before and one year following the installation of the improvements.

<table>
<thead>
<tr>
<th>Year</th>
<th>Accidents</th>
<th>Traffic Volume (ADT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before: 1971</td>
<td>48</td>
<td>52,000</td>
</tr>
<tr>
<td>1972</td>
<td>46</td>
<td>55,000</td>
</tr>
<tr>
<td>(Average)</td>
<td>(47)</td>
<td>(53,500)</td>
</tr>
<tr>
<td>After: 1973</td>
<td>33</td>
<td>58,500</td>
</tr>
</tbody>
</table>

The evaluation steps are:

1. Accident Rate Before = \( \frac{(47) \times (10^6)}{(365) \times (53,500) \times (4.0)} \) = 0.602 accidents/million vehicle miles
2. Accident Rate After = \( \frac{(33) \times (10^6)}{(365) \times (58,500) \times (4.0)} \) = 0.386 accidents/million vehicle miles
3. Percent Reduction = \( 100 \times \left( \frac{0.602 - 0.386}{0.602} \right) = 100 \times \left( \frac{0.216}{0.602} \right) = 35.9\% \)
4. Check the Poisson distribution curves to determine the significant percent reduction for 95% confidence with 47 accidents.
   - Lower curve (liberal test) = 24% reduction
   - Upper curve (conservative test) = 32% reduction
Because the actual reduction of accident rate (35.9%) exceeds the minimum requirements for both tests, the results are considered significant.

5. If data are available, conduct similar evaluations and testing of significance by types of accidents and severity of accidents.

Documentation

There is need for careful documentation of each step of the evaluation of implemented improvements. This information will be essential for evaluation of the overall program and for refinement of data for future forecasts—as described in the following chapter.

Specifically, the documentation should include:

- Before and After Periods -- What was the before period? The after period? This information will be useful to compare the results of a given type of improvement at similar locations.
- After Accident History -- How many accidents have occurred at this location since improvement implementation? What type? This information will be useful in measuring and analyzing the results of the improvement.
- Improvement Results—What were the results of the improvement? Was this a significant decrease? If not, why? Was the magnitude of the decrease as expected? If not, why? This information will be useful in refining the selection of applicable improvements and the prediction of accident reduction benefits.

With relatively small numbers of evaluations, the documentation can be prepared manually and filed with other improvement documents. In larger agencies, much of the evaluation and documentation is performed with computer programs. Table 10 is an example computer printout of a before and after analysis.
Table 10. Example Improvement Review Report

TRAFFIC & SAFETY DIVISION
* INDIVIDUAL COUNTERMEASURE REVIEW REPORT *

RESPONSIBLE AGENCY: STATE HIGHWAY DEPARTMENT
LOCATION: STATE HIGHWAY NUMBER 2 FROM MILEPOINT 140.50 TO 149.00
TYPE OF COUNTERMEASURE: 12004
DATE COUNTERMEASURE FULLY OPERATIONAL: APRIL 1, 1972

** CRASH EXPERIENCE **

<table>
<thead>
<tr>
<th></th>
<th><strong>ACCIDENTS</strong></th>
<th></th>
<th><strong>INJURIES</strong></th>
<th></th>
<th>* SEVERITY MEASURES *</th>
<th><em><strong>EXPOSURE</strong></em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TOTAL</td>
<td>PDO</td>
<td>FATAL</td>
<td>DISABLING</td>
<td>NON-DISABLING</td>
<td>TOTAL RSI</td>
</tr>
<tr>
<td>BEFORE</td>
<td>55</td>
<td>40</td>
<td>2</td>
<td>4</td>
<td>13</td>
<td>23</td>
</tr>
<tr>
<td>AFTER</td>
<td>39</td>
<td>26</td>
<td>1</td>
<td>3</td>
<td>14</td>
<td>23</td>
</tr>
<tr>
<td>PERCENT</td>
<td>29</td>
<td>35.</td>
<td>50</td>
<td>25</td>
<td>-8</td>
<td>-25</td>
</tr>
</tbody>
</table>

ESTIMATED PERCENT REDUCTION: 5
SIGNIFICANCE: REDUCTION WAS NOT SIGNIFICANT

RSI = Relative Severity Index, an expression of the relative severity based on the types of accidents, their respective severity mixes and accident cost figures such as National Safety Council.
Legislators and top officials will have a principal interest in the first evaluation above--effectiveness. They have made a commitment to the program, established objectives and allocated resources for safety improvements. They should expect an accounting of the results--both costs and benefits. And they should know what to expect from future investments.

Those persons charged with responsibility for executing the safety program should have a keen interest in the third evaluation above--criteria and procedures. The effectiveness of future programs is dependent on reliable data, realistic criteria and sound decisions. There is need continually to improve and refine the program management.

All levels of officials and management should have an awareness of changing conditions and of circumstances which might suggest changing the direction and scope of safety efforts.

Effectiveness

Resources have been invested in highway safety improvements. What did we get for our money?

Effectiveness is best measured in terms of:

- Increase or decrease in accident rates and accident severity at improved sites.
- Total reduction in cost of accident damage.
- Return on investment of improvement expenditures.

This type of information should be summarized from actual experience data and presented in graphical or tabular form.

Table 11 shows a tabular summary used by one agency to identify the overall costs and benefits of its traffic safety program. The information is broken down by type of improvement and covers periods one year before and one year after the improvements. The method of comparison used is a ratio of one year benefits to initial...
Table 11. Example Summary of First Year Benefit/Cost Ratios By Improvement Type

### 1969-70 F.Y. TRAFFIC SAFETY PROGRAM

(ONE YEAR BEFORE AND ONE YEAR AFTER)

<table>
<thead>
<tr>
<th>TYPE OF IMPROVEMENT</th>
<th>NO. OF PROJECTS</th>
<th>NO. OF ACCIDENTS Before F.Y.</th>
<th>NO. OF PEOPLE KILLED Before F.Y.</th>
<th>NO. OF PROJECTS</th>
<th>NO. OF ACCIDENTS After F.Y.</th>
<th>NO. OF PEOPLE KILLED After F.Y.</th>
<th>PERCENT REDUCTION</th>
<th>COST OF PROJECTS ($1000)</th>
<th>ACCIDENT COST SAVINGS ($1000)</th>
<th>BENEFIT COST RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEW SIGNALS (With or without channelization)</td>
<td>36</td>
<td>672</td>
<td>447</td>
<td>221</td>
<td>4</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>1.810</td>
<td>370</td>
</tr>
<tr>
<td>MODIFY SIGNALS (Mast Arms, larger signal heads, detectors, etc.)</td>
<td>56</td>
<td>1316</td>
<td>1078</td>
<td>435</td>
<td>5</td>
<td>5</td>
<td>N</td>
<td>N</td>
<td>1.310</td>
<td>130</td>
</tr>
<tr>
<td>LEFT-TURN CHANNELIZATION</td>
<td>41</td>
<td>319</td>
<td>207</td>
<td>107</td>
<td>5</td>
<td>6</td>
<td>N</td>
<td>N</td>
<td>1.040</td>
<td>310</td>
</tr>
<tr>
<td>SIGNING (Warning)</td>
<td>16</td>
<td>652</td>
<td>466</td>
<td>177</td>
<td>9</td>
<td>19</td>
<td>N</td>
<td>N</td>
<td>1.600</td>
<td>1,120</td>
</tr>
<tr>
<td>SAFETY LIGHTING (A)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N</td>
<td>N</td>
<td>4.6</td>
<td>-1.0</td>
</tr>
<tr>
<td>FLASHING BEACONS</td>
<td>19</td>
<td>127</td>
<td>58</td>
<td>55</td>
<td>14</td>
<td>16</td>
<td>N</td>
<td>N</td>
<td>90</td>
<td>1,270</td>
</tr>
<tr>
<td>WET PAVEMENT CORRECTION (Grooving or Resurface)</td>
<td>10</td>
<td>241</td>
<td>164</td>
<td>72</td>
<td>5</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>440</td>
<td>660</td>
</tr>
<tr>
<td>RECONSTRUCTION &amp; MISC. (Curve corrections, roadway realignments, sight distance improvements)</td>
<td>62</td>
<td>757</td>
<td>467</td>
<td>266</td>
<td>24</td>
<td>26</td>
<td>N</td>
<td>N</td>
<td>2,920</td>
<td>1,980</td>
</tr>
<tr>
<td>TOTAL PROGRAM</td>
<td>241</td>
<td>4285</td>
<td>2885</td>
<td>1334</td>
<td>66</td>
<td>89</td>
<td>N</td>
<td>N</td>
<td>7,774.6</td>
<td>5,800</td>
</tr>
</tbody>
</table>

(A) Dark Accidents  (B) Wet Accidents  N = Not significant at 10% level  + = Increase

MARCH 1973
investment costs. These ratios are intended to evaluate the relative merits of each phase of the highway safety program. However, they are indicative only of the rate of return on the initial investment regardless of ultimate cost-effectiveness.

Various other types of summaries can be prepared which will provide bases for official evaluation of the effectiveness of the program--items such as the origin and distribution of funds for safety improvements, comparison of actual results with forecast results, overall progress in reducing the number of identified hazardous locations on the system, the scope of work remaining and the reflection of safety program findings in new construction standards and procedures.

Objectives and Policies

The purpose of management reporting is to inform top-level management of the status of the highway safety program and to provide information significant to basic policy decisions.

Comprehensive highway safety programs are relatively new. Concepts, approaches and the role of the Federal Government are all subject to change as we gain experience. External changes such as an energy crisis may precipitate drastic changes in transportation modes, types of vehicles, speeds and in the characteristics of accidents. Increased attention to highway safety is here to stay, but the direction and administration of safety programs must be subject to periodic evaluation.

Those persons most closely associated with direct management and supervision of highway safety programs are in the best position to recognize changes as they occur and to identify desirable changes in basic objectives and policies. Recommendations should be developed and submitted to top management for appropriate changes in future program emphasis--and for legislation required to facilitate programs.

Criteria and Procedures

Various criteria and procedures are used throughout the total safety management system. In Chapter Six we discussed the need for regular evaluation of implemented improvements and the use of this actual experience data for improving analysis procedures, refining forecasts and updating cost information.

To assure continuing improvement and effectiveness of safety programs, operational managers regularly should raise the following questions:

Identifying hazardous locations

- Are all accidents being reported?
- Are the reports complete and accurate?
- Is additional information needed?
- Is data processing effective?
- Are some hazardous locations overlooked?
- Is the priority of the listing realistic?
- Is the cut-off point too high or too low?

Selecting alternative improvements

- Are the problems being identified correctly?
- Is there need for more information?
- Are all potential improvements being considered?
- Are combinations of improvements considered?
- Should alternative or supplementary analysis techniques be used?
- Is the potential improvement checklist up-to-date?

Evaluating alternative improvements

- Are the data on traffic volumes and forecasts reliable?
- Are the criteria reliable for forecasting accident reduction?
  By type of improvement?
  By type of accident?
  By severity?
- Are the data on accident costs realistic?
Refinement of Forecasts

The very heart of the safety management system lies in the ability to forecast reduction in numbers or severity of accidents as a result of implementing a particular improvement at a particular location under particular conditions. We have already established that (1) forecasting should be based on data from actual experience, (2) reliable data for forecasting currently may be quite limited, and (3) there is need continually to update and refine forecasting values.

When systems and procedures have been established for uniform and consistent reporting and processing of data, forecasting values can be based on an accumulation of data over a period of years and updated each year as new data becomes available. A recommended procedure, utilized by some agencies, is to use data from the most recent five-year period. Data from the fifth year are dropped when data from a new year are added to the data bank. Obviously, such a procedure is facilitated greatly with computer processing of data.

We are seeking realistic values for the estimated percent reduction in accident rates. In Chapter Six we discussed how to calculate "before" and "after" accident rates at a location—and how to compute percent reduction in accident rate. We also described a statistical test to determine if the results were significant or if the reduction might be attributable to chance—and we accepted those results for which we were at least 95% certain that the improvement actually caused the accident reduction.

Now we have a different problem. We have large amounts of data on the effect of the same improvement under similar conditions at many locations. We want to calculate a percent reduction value that best reflects the overall experience. But there may be a very wide range of percent values among the locations—and an average percent
reduction, alone, does not really tell the whole story. It is important to know the reliability of this "average" value, because there may be a choice of selection between two or more possible improvements, each having similar average values of accident reduction experience.

For example, assume two improvements, each of which has experienced an overall average reduction percent of 30%—but the average reflected a wide range of values at individual locations for one and a narrow range for the other. Based on a 95% level of confidence, the values for forecasting may be a 30% reduction plus or minus 15% in one case and a 30% reduction plus or minus 60% for the other. We can be reasonably certain in the first case that actual results will be in the range of 15% to 45% reduction of accidents. In the second case, however, the results might range from a 30% increase in accidents to a 90% decrease in accidents. These are called "expected ranges"—we have 95% confidence that the results will fall within these limits.

The steps for computing average accident rate reductions (AARR) and expected ranges (ER) are as follows:

1. Review each implemented location to eliminate all non-typical implementations. Break the improvement-type categories down into additional categories if clearcut differences are adequately represented and adequate data are available.

2. If the before time period is longer than the after time period, adjust the number of before accidents, \( B \), at each location to reflect differences in traffic volumes and time periods. The adjusted number of before accidents, \( B' \), is calculated:

\[
B' = B \frac{(After ADT) \times (Days in after period)}{(Before ADT) \times (Days in before period)}
\]

If the after time period is longer than the before time period, adjust the number of after accidents, \( A \), at each location to reflect differences in traffic volumes and time periods. Adjusted number of after accidents, \( A' \), is calculated:

\[
A' = A \frac{(Before ADT) \times (Days in before period)}{(After ADT) \times (Days in after period)}
\]

For intersections, use the sum of the AADT on each of the legs and divide by 2 to obtain average ADT.

If the traffic volume changes during the before or after period, multiply each ADT by the number of days it was applicable.

3. Calculate the percent average accident rate reduction, AARR:

\[
AARR = 100 \left( 1 - \frac{\sum A'}{\sum B} \right)
\]

\[
= 100 \left( 1 - \frac{\sum A}{\sum B'} \right)
\]

Where:
- \( A \) = Number of after accidents
- \( A' \) = Adjusted number of after accidents
- \( B \) = Number of before accidents
- \( B' \) = Adjusted number of before accidents
- \( \Sigma \) = Summation of all values

4. Calculate the expected range, ER, expressed as a percentage:

\[
ER = 200 \sqrt{\frac{n}{(n-1) \Sigma X^2}} \left( \Sigma Y^2 + \Sigma \frac{Y}{X} \Sigma X^2 - 2 \frac{Y}{X} \Sigma XY \right)
\]

Where:
- \( n \) = Number of implemented countermeasures
- \( \Sigma \) = Summation of all values

If the before period is longer than the after period:
- \( X \) = Adjusted number of before accidents = \( B' \)
- \( Y \) = Number of after accidents = \( A \)
If the after period is longer than the before period:

\[ X = \text{Number of before accidents} = B \]
\[ Y = \text{Adjusted number of after accidents} = A' \]

Example Computations

1. Four of the five locations where a particular improvement was installed are typical. Before period is two years and the after period is one year.

<table>
<thead>
<tr>
<th>Location</th>
<th>Before Accidents</th>
<th>ADT</th>
<th>After Accidents</th>
<th>ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
<td>2,000</td>
<td>4</td>
<td>2,100</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>2,000</td>
<td>4</td>
<td>2,000</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>4,500</td>
<td>6</td>
<td>4,000</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>1,250</td>
<td>3</td>
<td>1,300</td>
</tr>
<tr>
<td>Total</td>
<td>( \Sigma B = 58 )</td>
<td></td>
<td>( \Sigma A = 17 )</td>
<td></td>
</tr>
</tbody>
</table>

2. Adjust the number of before accidents:

\[
\text{Adjusted number of before accidents} (B') = \frac{B}{ADT}
\]

<table>
<thead>
<tr>
<th>Location</th>
<th>Adjusted number of before accidents (B')</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \frac{14}{2,000} = 7.35 )</td>
</tr>
<tr>
<td>2</td>
<td>( \frac{12}{2,000} = 6.00 )</td>
</tr>
<tr>
<td>3</td>
<td>( \frac{24}{4,500} = 10.67 )</td>
</tr>
<tr>
<td>4</td>
<td>( \frac{8}{1,250} = 4.16 )</td>
</tr>
<tr>
<td>( \Sigma B' = 28.18 )</td>
<td></td>
</tr>
</tbody>
</table>

3. Calculate the average accident rate reduction, AARR:

\[
\text{AARR} = 100 \left[ 1 - \frac{17}{28.18} \right] = 40\%
\]

4. Calculate the expected range, ER:

\[
\begin{align*}
\Sigma X^2 &= 221.18 \\
\Sigma Y^2 &= 77 \\
\Sigma XY &= 129.90 \\
\end{align*}
\]

\[
\text{ER} = 200 \sqrt{\frac{\frac{4}{3(28.18)^2} \left[ 77 + \left( \frac{17}{28.18} \right)^2 \right] - 2 \left( \frac{17}{28.18} \right) \left( 129.90 \right) \right]} \\
= 200 \sqrt{0.001285} \\
= 200 (0.358) = 72.6\%
\]

On the basis of this analysis, we can expect, with a 95% level of confidence, that future implementations of this type improvement will result in accident reduction within the range of 32.8% to 47.2% (40% ± 7.2%).

Forecasting by a Family of Curves

When there are variable alternatives within the improvement characteristics itself, forecasting of accident reduction can be refined by developing a family of curves reflecting the probable effect of the alternatives.
Forecasting accident reduction through bridge widening is an example of this situation. Three factors influencing the amount of accident reduction will be:

- The width of the existing bridge
- The width of the approach roadway
- The amount the bridge is widened

Data can be developed from actual experience and translated to a family of curves as illustrated in Figure 10. This will permit consideration of several alternative designs, in terms of costs and benefits, for a bridge widening improvement location. Similar families of curves can be developed for other improvements.

Figure 10. Example Family of Curves for Forecasting Accident Reduction (136)
<table>
<thead>
<tr>
<th>Type of Improvement</th>
<th>Urban or Rural</th>
<th>Number of Lanes</th>
<th>All Accidents</th>
<th>Fatal Injury Accidents</th>
<th>Property Damage Only Accidents</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eliminate parking</td>
<td>U</td>
<td>2 plus</td>
<td>32</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install/improve edge-marking</td>
<td>R</td>
<td>2</td>
<td>14</td>
<td>17a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install/improve warning signs</td>
<td>U</td>
<td>2 plus</td>
<td>20a</td>
<td>26a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install/improve warning signs</td>
<td>R</td>
<td>2</td>
<td>36</td>
<td>32a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install/improve warning signs</td>
<td>R</td>
<td>2 plus</td>
<td>18a</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install median barrier-cable</td>
<td>U</td>
<td>2 plus</td>
<td>-33a</td>
<td>4a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install median barrier-beam</td>
<td>U</td>
<td>2 plus</td>
<td>-20a</td>
<td>-22b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install median barrier-type</td>
<td>U</td>
<td>2 plus</td>
<td>-46a</td>
<td>-11a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install median barrier</td>
<td>R</td>
<td>4 plus</td>
<td>-53a</td>
<td>-61a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add painted/raised median</td>
<td>U</td>
<td>2 plus</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pavement resurfacing</td>
<td>U</td>
<td>2 plus</td>
<td>42</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pavement resurfacing</td>
<td>R</td>
<td>2</td>
<td>12</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pavement resurfacing</td>
<td>R</td>
<td>2 plus</td>
<td>44</td>
<td>59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder stabilization</td>
<td>R</td>
<td>2</td>
<td>38</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Widen shoulder, no dimensions</td>
<td>R</td>
<td>2</td>
<td>-2</td>
<td>7a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Widen traveled way, no dimensions</td>
<td>R</td>
<td>2</td>
<td>38</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Widen traveled way from 9 ft lanes</td>
<td>R</td>
<td>2</td>
<td>38</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Widen traveled way from 10 ft lanes</td>
<td>R</td>
<td>2</td>
<td>5a</td>
<td>-65b</td>
<td>Livestock accidents only</td>
<td></td>
</tr>
<tr>
<td>Livestock fencing</td>
<td>R</td>
<td>2 or more</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modernization to design standards</td>
<td>R</td>
<td>2</td>
<td>10</td>
<td>-6a</td>
<td>-60b</td>
<td></td>
</tr>
<tr>
<td>Modernization to design standards</td>
<td>R</td>
<td>2 plus</td>
<td>15b</td>
<td>22a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centerline striping at crsits</td>
<td>R</td>
<td>2</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal Curves</td>
<td>R</td>
<td>2 plus</td>
<td>26b</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install delineators</td>
<td>R</td>
<td>2 plus</td>
<td>46a</td>
<td>-10b</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>Install/improve warning signs</td>
<td>R</td>
<td>2</td>
<td>57</td>
<td>71</td>
<td>23a</td>
<td></td>
</tr>
<tr>
<td>Install/improve warning signs</td>
<td>R</td>
<td>2 plus</td>
<td>52</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reconstruct curve</td>
<td>R</td>
<td>2</td>
<td>88</td>
<td>89</td>
<td>96</td>
<td></td>
</tr>
</tbody>
</table>

** Minor street must be 33% or more of total intersection volume which must be less than 8,000 ADT.
### Table A-1 (continued)

Accident Reduction Forecast From Evaluation of Criteria

<table>
<thead>
<tr>
<th>Type of Improvement</th>
<th>Urban or Rural</th>
<th>Number of Lanes</th>
<th>All Accidents</th>
<th>Fatal Injury Accidents</th>
<th>Property Damage Only Accidents</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add pedestrian signals</td>
<td>U</td>
<td>2</td>
<td>13</td>
<td>0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Add pedestrian signals</td>
<td>U</td>
<td>2 plus</td>
<td>3a</td>
<td>0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Improve signals</td>
<td>U</td>
<td>2</td>
<td>31</td>
<td>33a</td>
<td>ypes of improvements</td>
<td></td>
</tr>
<tr>
<td>Improve signals</td>
<td>U</td>
<td>2 plus</td>
<td>-2</td>
<td>14b</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Improve signals</td>
<td>R</td>
<td>2 plus</td>
<td>42a</td>
<td>43b</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Improve signals</td>
<td>U</td>
<td>2 plus</td>
<td>-5</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Curb &amp; turning movement</td>
<td>U</td>
<td>2 plus</td>
<td>40</td>
<td>39</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Add left turn lane w/o signal</td>
<td>U</td>
<td>2</td>
<td>19a</td>
<td>80a</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Add left turn lane w/o signal</td>
<td>U</td>
<td>2 plus</td>
<td>6</td>
<td>54a</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Add left turn lane w/o signal</td>
<td>R</td>
<td>2 plus</td>
<td>46</td>
<td>58b</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Add left turn lane &amp; signal</td>
<td>U</td>
<td>2 plus</td>
<td>27</td>
<td>1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Add left turn lane &amp; signal</td>
<td>U</td>
<td>2 plus</td>
<td>43a</td>
<td>58b</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Add left turn lane &amp; signal</td>
<td>R</td>
<td>2 plus</td>
<td>-6</td>
<td>-1b</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Add left turn lane &amp; signal</td>
<td>R</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Overhead Lane</td>
<td>U</td>
<td>2 plus</td>
<td>51a</td>
<td>62</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Overhead Lane</td>
<td>R</td>
<td>2</td>
<td>33</td>
<td>5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Overhead Lane</td>
<td>U</td>
<td>2 plus</td>
<td>27</td>
<td>1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Overhead Lane</td>
<td>R</td>
<td>2 plus</td>
<td>46</td>
<td>76</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Install new traffic signals</td>
<td>U &amp; R</td>
<td>2 plus</td>
<td>29</td>
<td>50</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Deslacking</td>
<td>U</td>
<td>2 plus</td>
<td>20</td>
<td>15</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Rumble strips</td>
<td>R</td>
<td>2</td>
<td>27b</td>
<td>26b</td>
<td>24b</td>
<td></td>
</tr>
</tbody>
</table>

* 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%

The percentage range means that there is at least a 75% certainty that the true average percentage reduction is within the percentage given in the column, plus or minus the range given. For example, the entry 68 means that the range of 75 percent certainty lies between a reduction of 98 to 39%.

### Table A-2. Accident Reduction Forecasts Used By Mississippi State Highway Department

<table>
<thead>
<tr>
<th>Improvement Type</th>
<th>Front End</th>
<th>Rear End</th>
<th>Right Angle</th>
<th>Sidewalk</th>
<th>Left Turn</th>
<th>Right Turn</th>
<th>Fixed Object</th>
<th>Pedestrian</th>
<th>Right Accidents</th>
<th>Wet Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement Markings</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>Upgrade</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>20</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Overhead Warning</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Timing</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>100(E)</td>
<td></td>
</tr>
<tr>
<td>12’ Lens</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>800(E)</td>
<td></td>
</tr>
<tr>
<td>MUTCD (1)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>10,000(N)</td>
<td></td>
</tr>
<tr>
<td>Turn Phase</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td>200(E)</td>
<td></td>
</tr>
<tr>
<td>Opt. Program</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>2,000(E)</td>
<td></td>
</tr>
<tr>
<td>Actuate</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>1,500(E)</td>
<td></td>
</tr>
<tr>
<td>Pedestrian Phase</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Remove Signal</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Add Signal</td>
<td>(3) 80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>Deslacking</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,000</td>
<td></td>
</tr>
<tr>
<td>Sight Distance</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>5,000</td>
<td></td>
</tr>
<tr>
<td>Turn Bay</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5,000</td>
<td></td>
</tr>
<tr>
<td>Reconstruct</td>
<td>20</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Close Median Opening (5)</td>
<td>50 50</td>
<td>50 50</td>
<td>50 100</td>
<td>50 50</td>
<td>50 50</td>
<td>50 50</td>
<td>50 100</td>
<td>50 50</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Relocate Fixed Object</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5,000</td>
<td></td>
</tr>
<tr>
<td>Relocate Drives</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>2,000</td>
<td></td>
</tr>
</tbody>
</table>

(1) Includes Timing, 12’ Lens, Turn Phasing and Actuation
(2) Percent of Accidents Involved at Median Opening
(3) One Accident Increase Per 2000 VPD
(4) Upgrading Existing Equipment
(5) Replacing Existing With New Equipment

---

**A-4**
Table A-3. Accident Reduction Forecasts Used By California Division of Highways

<table>
<thead>
<tr>
<th>Type of Improvement</th>
<th>Average Accident Reduction (%)</th>
<th>Minimum Accident Experience (in years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Signals (with or without channelization and/or lighting)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-leg intersection</td>
<td>27%</td>
<td>5 last year</td>
</tr>
<tr>
<td>Offset leg intersection</td>
<td>27%</td>
<td>5 last year</td>
</tr>
<tr>
<td>3-leg intersection</td>
<td>27%</td>
<td>5 last year</td>
</tr>
<tr>
<td>Modified Signals</td>
<td>27%</td>
<td>5 last year</td>
</tr>
<tr>
<td>New Left-turn Channelization at Signalized Intersections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without left-turn phase</td>
<td>15%</td>
<td>3 per year</td>
</tr>
<tr>
<td>With left-turn phase</td>
<td>36%</td>
<td>5 per year</td>
</tr>
<tr>
<td>New Left-turn Channelization at non-signalized Intersections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With curbs and/or raised bars</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban area</td>
<td>70%</td>
<td>4 last year</td>
</tr>
<tr>
<td>Suburban area</td>
<td>65%</td>
<td>3 per year</td>
</tr>
<tr>
<td>Rural area</td>
<td>60%</td>
<td>2 per year</td>
</tr>
<tr>
<td>With painted channelization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban area</td>
<td>15%</td>
<td>3 last year</td>
</tr>
<tr>
<td>Suburban area</td>
<td>30%</td>
<td>2 per year</td>
</tr>
<tr>
<td>Rural area</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Flashing Beacons at Intersections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-leg red-yellow</td>
<td>50%</td>
<td>4 per year</td>
</tr>
<tr>
<td>3-leg red-yellow</td>
<td>50%</td>
<td>3 per year</td>
</tr>
<tr>
<td>4-way red</td>
<td>79%</td>
<td>4 per year</td>
</tr>
<tr>
<td>Flashing Beacons at Railroad Crossing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80%</td>
<td>2 per year</td>
<td></td>
</tr>
<tr>
<td>Advance Warning Flashers at Curves and Intersections</td>
<td>30%</td>
<td>3 per year</td>
</tr>
<tr>
<td>New Safety Lighting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>At Intersections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New</td>
<td>75% of night acc.</td>
<td>3 night acc., per year or 5 night acc. in two years</td>
</tr>
<tr>
<td>Upgrading</td>
<td>50% of night acc.</td>
<td></td>
</tr>
</tbody>
</table>

(1) Percentage of all accidents unless otherwise noted.
(2) These numbers may be reduced by the number of fatal accidents at the location under study.
APPENDIX B

EXAMPLE EVALUATIONS

The purpose of this Appendix is to supplement the guides and instructions in the Manual with example evaluations.

The example will start with a typical situation of accident data and follow through with each of the subsequent steps from identifying hazardous locations to evaluating implemented improvements.

All data are hypothetical and shortened to simplify calculations—both the computations and forms reflect typical application of the concepts and procedures set forth in the Manual.

IDENTIFYING HAZARDOUS LOCATIONS

Accident Data

Location: 5.5 mile section of rural two-lane highway
Traffic: 750 AADT -- constant during period
Accidents:

<table>
<thead>
<tr>
<th>DATE</th>
<th>LOCATION</th>
<th>SEVERITY</th>
<th>CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 10, 1973</td>
<td>0.20</td>
<td>PDO</td>
<td>Left turn, day, dry</td>
</tr>
<tr>
<td>Feb. 10, 1973</td>
<td>1.00</td>
<td>2 Fatalities</td>
<td>Head on, night, dry</td>
</tr>
<tr>
<td>Aug. 8, 1971</td>
<td>1.42</td>
<td>PDO</td>
<td>Lost control, day, wet</td>
</tr>
<tr>
<td>Mar. 8, 1973</td>
<td>1.43</td>
<td>1 Fatality</td>
<td>Head on, day, wet</td>
</tr>
<tr>
<td>June 6, 1973</td>
<td>1.44</td>
<td>3 Injuries</td>
<td>Sideswipe, night, wet</td>
</tr>
<tr>
<td>Aug. 10, 1972</td>
<td>1.44</td>
<td>PDO</td>
<td>Sideswipe, night, wet</td>
</tr>
<tr>
<td>Mar. 20, 1972</td>
<td>1.45</td>
<td>1 Injury</td>
<td>Lost control, night, dry</td>
</tr>
<tr>
<td>July 7, 1973</td>
<td>1.70</td>
<td>PDO</td>
<td>Rear end, night, wet</td>
</tr>
<tr>
<td>Sept. 2, 1971</td>
<td>1.80</td>
<td>PDO</td>
<td>Lost control, day, dry</td>
</tr>
<tr>
<td>Feb. 2, 1971</td>
<td>2.00</td>
<td>2 Injuries</td>
<td>Head on, night, dry</td>
</tr>
</tbody>
</table>
Statewide Rates

The established statewide average accident rates for rural two-lane roadways are:

Sections: 4.0 accidents per MVM
Spots or Intersections: 2.0 accidents per MV

Vehicle Exposure

For the section under study, the vehicle exposure (m) during the period was:

For the section:
\[ m = \frac{(750)(3\times365)(5.5)}{10^6} = 4.5 \text{ MVM} \]

For locations:
\[ m = \frac{(750)(3\times365)}{10^6} = 0.8 \text{ MV} \]

Critical Rates (Rate Quality Control Method)

For the section under study, the critical rates for identifying hazardous locations are:

\[ Rc = Ra + K\sqrt{\frac{Ra}{m}} - \frac{0.5}{m} \]

For the section:
\[ Rc = 4.0 + 1.5\sqrt{\frac{4.0}{4.517}} - \frac{0.5}{4.517} \]
\[ = 4.0 + 1.412 - 0.111 \]
\[ = 5.3 \text{ Acc./MVM} \]

For locations (0.1 mile lengths) within the section:
\[ Rc = 2.0 + 1.5\sqrt{\frac{2.0}{0.821}} - \frac{0.5}{0.821} \]
\[ = 2.0 + 2.341 - 0.609 \]
\[ = 3.7 \text{ Acc./MV} \]

Number of accidents per cluster:
\[ Nc = Rc\times m \]
\[ = (3.7)(0.821) \]
\[ = 3.0 \text{ accidents within 0.1 mile} \]

Observed Rates

During the study period, the observed accident rates were:

For the section:
\[ \text{Rate} = \frac{\text{number of accidents}}{m} \]
\[ = \frac{17}{4.5} \]
\[ = 3.8 \text{ Acc./MVM} \]

CONCLUSION - The observed rate is less than the computed critical rate of 5.3 Acc./MVM. The entire section is not identified as hazardous.

For locations:
The computed critical number of accidents for locations was 3.064 accidents within 0.1 mile. Reviewing the accident data shows that 5 accidents occurred between miles 1.42 and 1.45.

The observed rate for this location is:
\[ \text{Rate} = \frac{\text{number of accidents}}{m} \]
\[ = \frac{5}{0.821} \]
\[ = 6.1 \text{ Acc./MV} \]
CONCLUSION - The observed rate exceeds the computed critical rate of 3.7 Acc./MV. This location can be identified as hazardous.

Documentation

See Figure B-1.

SELECTING ALTERNATIVE IMPROVEMENTS

Review of accident data along with field investigation shows the location is a fairly sharp curve at the end of a long tangent. There is indication that the drivers were surprised. Most of the accidents occurred when the pavement was wet.

Probable Accident Cause Analysis

See Figure B-2 for example documentation of accident cause analysis.

Potential Improvements

The following improvements appear applicable to the conditions at this location.

- Improve the signing
- Resurfacing for improved traction
- Both signing and resurfacing
- Flatten the curve by reconstruction

Example documentation of these potential improvements is shown in Figure B-3.

<table>
<thead>
<tr>
<th>Year</th>
<th>1971</th>
<th>1972</th>
<th>1973</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>From (date)</td>
<td>1/1</td>
<td>1/1</td>
<td>1/1</td>
<td>1/1/71</td>
</tr>
<tr>
<td>To (date)</td>
<td>12/31/71</td>
<td>12/31/71</td>
<td>12/31/73</td>
<td>12/31/73</td>
</tr>
<tr>
<td>AADT</td>
<td>750</td>
<td>750</td>
<td>750</td>
<td>Ave = 750 mph</td>
</tr>
<tr>
<td>Exposure</td>
<td>223,750</td>
<td>223,750</td>
<td>223,750</td>
<td>821,250</td>
</tr>
<tr>
<td>Total accidents</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Fatal accidents</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No. fatalities</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Injury accidents</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>PDO accidents</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Accident rate</td>
<td>7.3</td>
<td>7.3</td>
<td>3.6</td>
<td>6.09 Acc/MV</td>
</tr>
</tbody>
</table>

SYSTEMWIDE AVE. RATE FOR CATEGORY: 2.0 Acc./MV

CRITICAL RATE FOR LOCATION: 3.73 Acc./MV

INDEX OF SEVERITY: 3.732

COMMENTS:

Figure B-1. Hazardous Location Identification Worksheet
For the Hazardous Curve on State Highway 99.
PROBABLE ACCIDENT CAUSE ANALYSIS WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 99 from milepost 1.40 to 1.50

COLLISION DIAGRAM: □ Attached □ Not drawn

ACCIDENT CHARACTERISTICS:

<table>
<thead>
<tr>
<th>Type of Accident</th>
<th>Fatal</th>
<th>Injury</th>
<th>P.D.O.</th>
<th>Total</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head on</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>20%</td>
</tr>
<tr>
<td>Rear end</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Right angle</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Side swipe</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>40%</td>
</tr>
<tr>
<td>Fixed object</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Overturned</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Lost control</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>40%</td>
</tr>
</tbody>
</table>

Total: 2 Accidents

Percent: 20% fatal, 40% injury, 40% P.D.O., 100% total

CONDITIONS:

<table>
<thead>
<tr>
<th>Time of day</th>
<th>6:00 am - Noon</th>
<th>6:00 pm - Midnight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light conditions</td>
<td>Noon - 6:00 pm</td>
<td>Midnight - 6:00 am</td>
</tr>
<tr>
<td>Surface conditions</td>
<td>Dry 1</td>
<td>Wet 4</td>
</tr>
<tr>
<td></td>
<td>Snow or ice</td>
<td></td>
</tr>
<tr>
<td>Weather</td>
<td>Cloudy 1</td>
<td>Clear 1</td>
</tr>
<tr>
<td></td>
<td>Rain 4</td>
<td>Snow</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

OTHER:

PROBABLE CONTRIBUTORY CAUSES:
Drivers appear to be surprised by the sharp curves. The curve does not meet current minimum design standards. The surface is smooth and slippery, especially when wet.

Figure B-2. Probable Accident Cause Analysis Worksheet
For the Hazardous Curve on State Highway 99.

POTENTIAL IMPROVEMENT IDENTIFICATION WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 99 from milepost 1.40 to 1.50

APPLICABLE IMPROVEMENTS:

<table>
<thead>
<tr>
<th>IMPROVEMENT</th>
<th>EXPECTED RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>101 -- Curve signing</td>
<td>40% reduction of all accidents</td>
</tr>
<tr>
<td>102 -- Resurfacing curve</td>
<td>20% reduction of all accidents</td>
</tr>
<tr>
<td>103 -- Signing and resurfacing</td>
<td>50% reduction of all accidents</td>
</tr>
<tr>
<td>104 -- Reconstruction of curve</td>
<td>90% reduction of all accidents</td>
</tr>
</tbody>
</table>

SPECIAL COMMENTS:

Figure B-3. Potential Improvement Identification Worksheet
For the Hazardous Curve on State Highway 99.
EVALUATING ALTERNATIVE IMPROVEMENTS

Estimated Accident Reduction

Based on data from "before and after" experience, it is estimated that implementation of the improvements will result in the following percent reduction in accident rates.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signing</td>
<td>40%</td>
</tr>
<tr>
<td>Resurfacing</td>
<td>20%</td>
</tr>
<tr>
<td>Signing and Resurfacing</td>
<td>50%</td>
</tr>
<tr>
<td>Curve Reconstruction</td>
<td>90%</td>
</tr>
</tbody>
</table>

The annual accident reduction (numbers of accidents) attributable to each improvement should then be:

Annual accident reduction = m(Ra)(R%)  
where m = vehicle exposure per year (0.274MV)  
Ra = current accident rate (6.090 acc/MV)  
R% = expected percent reduction in accident rate

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Annual Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signing</td>
<td>0.67 acc./yr.</td>
</tr>
<tr>
<td>Resurfacing</td>
<td>0.33 acc./yr.</td>
</tr>
<tr>
<td>Signing and Resurfacing</td>
<td>0.83 acc./yr.</td>
</tr>
<tr>
<td>Curve Reconstruction</td>
<td>1.50 acc./yr.</td>
</tr>
</tbody>
</table>

Accident Costs

Use National Highway Traffic Safety Administration accident costs:

<table>
<thead>
<tr>
<th>Severity Class</th>
<th>Average Cost Per Accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>$235,000</td>
</tr>
<tr>
<td>Injury</td>
<td>11,200</td>
</tr>
<tr>
<td>PDO</td>
<td>500</td>
</tr>
<tr>
<td>AVE</td>
<td>2,800</td>
</tr>
</tbody>
</table>

Equivalent Uniform Annual Benefits

Because the AADT is expected to remain constant, the equivalent uniform annual benefit will be the same as the average annual benefit.

Benefits will be based on an average cost of $2,800 per accident.

EUAB = (annual accident reduction)($2,800)

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signing</td>
<td>$1,875</td>
</tr>
<tr>
<td>Resurfacing</td>
<td>925</td>
</tr>
<tr>
<td>Signing and Resurfacing</td>
<td>2,325</td>
</tr>
<tr>
<td>Curve reconstruction</td>
<td>4,200</td>
</tr>
</tbody>
</table>

Equivalent Uniform Annual Cost

Using an interest rate of 10% and values from the interest tables shown in Table B-1, the equivalent uniform annual cost is calculated as follows:

EUAC = CRF(I) - T(n IyearSFF) + (K)

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signing</td>
<td>$1,875</td>
</tr>
<tr>
<td>Resurfacing</td>
<td>925</td>
</tr>
<tr>
<td>Signing and Resurfacing</td>
<td>2,325</td>
</tr>
<tr>
<td>Curve reconstruction</td>
<td>4,200</td>
</tr>
</tbody>
</table>
### Table B-1
Interest Factors for \( i = 10\% \)

<table>
<thead>
<tr>
<th>n</th>
<th>( n )</th>
<th>( (1+i)^n )</th>
<th>( i )</th>
<th>( \frac{1}{(1+i)^n} )</th>
<th>( \frac{n}{(1+i)^n} )</th>
<th>( \sum_{k=0}^{n-1} \frac{k}{(1+i)^n} )</th>
<th>( \sum_{k=0}^{n-1} \frac{k^2}{(1+i)^n} )</th>
<th>( (1+i)^n )</th>
<th>( (1+i)^n )</th>
<th>( (1+i)^n )</th>
<th>( (1+i)^n )</th>
<th>( (1+i)^n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00000</td>
<td>0.09090</td>
<td>1.00000</td>
<td>0.90909</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
</tr>
<tr>
<td>2</td>
<td>1.21000</td>
<td>0.18182</td>
<td>2.42101</td>
<td>0.18182</td>
<td>0.36364</td>
<td>0.72727</td>
<td>1.21000</td>
<td>0.18182</td>
<td>0.36364</td>
<td>0.72727</td>
<td>1.21000</td>
<td>0.18182</td>
</tr>
<tr>
<td>3</td>
<td>1.33100</td>
<td>0.27273</td>
<td>2.83421</td>
<td>0.27273</td>
<td>0.54546</td>
<td>1.09091</td>
<td>1.33100</td>
<td>0.27273</td>
<td>0.54546</td>
<td>1.09091</td>
<td>1.33100</td>
<td>0.27273</td>
</tr>
<tr>
<td>4</td>
<td>1.46410</td>
<td>0.36364</td>
<td>3.29511</td>
<td>0.36364</td>
<td>0.72727</td>
<td>1.46410</td>
<td>0.36364</td>
<td>0.72727</td>
<td>1.46410</td>
<td>0.36364</td>
<td>1.46410</td>
<td>0.36364</td>
</tr>
<tr>
<td>5</td>
<td>1.61051</td>
<td>0.45455</td>
<td>3.75561</td>
<td>0.45455</td>
<td>0.90909</td>
<td>1.61051</td>
<td>0.45455</td>
<td>0.90909</td>
<td>1.61051</td>
<td>0.45455</td>
<td>1.61051</td>
<td>0.45455</td>
</tr>
<tr>
<td>6</td>
<td>1.77156</td>
<td>0.54546</td>
<td>4.21661</td>
<td>0.54546</td>
<td>1.09091</td>
<td>1.77156</td>
<td>0.54546</td>
<td>1.09091</td>
<td>1.77156</td>
<td>0.54546</td>
<td>1.77156</td>
<td>0.54546</td>
</tr>
<tr>
<td>7</td>
<td>1.94527</td>
<td>0.63637</td>
<td>4.67711</td>
<td>0.63637</td>
<td>1.27273</td>
<td>1.94527</td>
<td>0.63637</td>
<td>1.27273</td>
<td>1.94527</td>
<td>0.63637</td>
<td>1.94527</td>
<td>0.63637</td>
</tr>
<tr>
<td>8</td>
<td>2.12939</td>
<td>0.72727</td>
<td>5.1374</td>
<td>0.72727</td>
<td>1.45455</td>
<td>2.12939</td>
<td>0.72727</td>
<td>1.45455</td>
<td>2.12939</td>
<td>0.72727</td>
<td>2.12939</td>
<td>0.72727</td>
</tr>
<tr>
<td>9</td>
<td>2.32574</td>
<td>0.81818</td>
<td>5.59731</td>
<td>0.81818</td>
<td>1.63636</td>
<td>2.32574</td>
<td>0.81818</td>
<td>1.63636</td>
<td>2.32574</td>
<td>0.81818</td>
<td>2.32574</td>
<td>0.81818</td>
</tr>
<tr>
<td>10</td>
<td>2.53231</td>
<td>0.90909</td>
<td>6.05641</td>
<td>0.90909</td>
<td>1.81819</td>
<td>2.53231</td>
<td>0.90909</td>
<td>1.81819</td>
<td>2.53231</td>
<td>0.90909</td>
<td>2.53231</td>
<td>0.90909</td>
</tr>
</tbody>
</table>

---

**Where:**

- **CRF** = Capital Recovery Factor for \( n \) years at 10% interest
- **SFF** = Sinking Fund Factor for \( n \) years at 10% interest
- \( I \) = Initial Cost
- \( K \) = Annual cost (constant)
- \( T \) = Terminal value
- \( n \) = Service Life

The values for CRF are found in the table of interest rates, Figure B-4. In this example, the SFF is not used because it is not expected the improvements will have terminal values.

**Improvement Evaluation Indexes**

<table>
<thead>
<tr>
<th>Improvement</th>
<th>EUAC</th>
<th>Benefit/Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signing</td>
<td>0.187(1,000) + 100 = $ 285</td>
<td>6.57</td>
</tr>
<tr>
<td>Resurfacing</td>
<td>0.187(7,500) = 1,400</td>
<td>0.66</td>
</tr>
<tr>
<td>Signing and resurfacing</td>
<td>0.187(8,000) + 100 = 1,595</td>
<td>1.46</td>
</tr>
<tr>
<td>Curve reconstruction</td>
<td>0.117(40,000) = 4,680</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Signing will provide the highest net annual benefit. Neither resurfacing or curve reconstruction are economically feasible.
The evaluation of each improvement should be documented. Figure B-4 shows an example documentation form for the curve signing. Figure B-5 summarizes the evaluation of all considered improvements.

**PROGRAMMING AND IMPLEMENTING IMPROVEMENTS**

After the evaluations are completed and a particular improvement, or combination of improvements, has been selected at each location, the next step is to list all selected improvements in descending order of benefit/cost ratio. Projects will be selected from the top of this list to be included in the current year's program.

Figure B-6 illustrates how the curve signing improvement might rate with other contemplated improvements.

**EVALUATING IMPLEMENTED IMPROVEMENTS**

Figure B-7 illustrates a procedure for analyzing "before and after" accident data at a particular location—and for evaluating the effect of the implemented improvement and the validity of the findings.

**EVALUATING THE HIGHWAY SAFETY PROGRAM**

Figure B-8 is an example format for evaluating and documenting the effectiveness of the overall highway safety program.

---

### Improvement Analysis Worksheet

#### Location:
State Highway 99 from milepost 1.40 to 1.50

#### Improvement Code: 101

#### Improvement Description: Curve Signing

<table>
<thead>
<tr>
<th>Estimated Service Life</th>
<th>5 yrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current 1974 AADT</td>
<td>750</td>
</tr>
<tr>
<td>Estimated 1975 AADT</td>
<td>700</td>
</tr>
</tbody>
</table>

**Estimated Accident Reduction:**

<table>
<thead>
<tr>
<th>By Types:</th>
<th>By Severity:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left turn</td>
<td>%</td>
</tr>
<tr>
<td>Head on</td>
<td>%</td>
</tr>
<tr>
<td>Rear end</td>
<td>%</td>
</tr>
<tr>
<td>Right angle</td>
<td>%</td>
</tr>
<tr>
<td>Slide wipe</td>
<td>%</td>
</tr>
<tr>
<td>Fixed object</td>
<td>%</td>
</tr>
<tr>
<td>Lost control</td>
<td>%</td>
</tr>
<tr>
<td>Skidding</td>
<td>% Fatal</td>
</tr>
<tr>
<td>Wet pavement</td>
<td>% Injuries</td>
</tr>
<tr>
<td>Night</td>
<td>% PDO</td>
</tr>
<tr>
<td>RR crossing</td>
<td>% Total</td>
</tr>
<tr>
<td>Total</td>
<td>% All Accidents</td>
</tr>
<tr>
<td></td>
<td>% All Accidents</td>
</tr>
</tbody>
</table>

**Equivalent Uniform Annual Benefits:**

- From accident reduction: $18.65
- From secondary benefits: $18.65
- Total: $37.30

**Estimated Costs:**

- Initial Implementation: $1,000
- Annual operation and maintenance: $100
- Terminal value: $0
- Equivalent uniform annual cost: $37.30

**Net Annual Benefit:** $1,500

**Benefit/Cost Ratio:** 5.11

**Special Comments:**

---

**Documentation**

Highway Safety Program Documentation Record

Prepared by [Name]

Date: 11/10/74

Location Identification Code: 3033 - 1.45

---

**Figure B-4. Improvement Analysis Worksheet**
For Improvement #101—Curve Signing.
**Improvement Evaluation Worksheet**

*One for each hazardous location*

**Location:** State Highway 99 from milepost 1.40 to
milepost 1.50

**Summary of Evaluations:**

<table>
<thead>
<tr>
<th>Code</th>
<th>101</th>
<th>102</th>
<th>103</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Curve Sign</td>
<td>Resurfacing Curve</td>
<td>Signing, reflectors, and painting curves</td>
</tr>
<tr>
<td>Initial cost</td>
<td>$1,000</td>
<td>$7,500</td>
<td>$10,000</td>
</tr>
<tr>
<td>Annual cost</td>
<td>$100</td>
<td>$0</td>
<td>$200</td>
</tr>
<tr>
<td>Salvage value</td>
<td>$0</td>
<td>$0</td>
<td>$1,000</td>
</tr>
<tr>
<td>Service life</td>
<td>8 yrs</td>
<td>7 yrs</td>
<td>7 yrs</td>
</tr>
<tr>
<td>Equiv. uniform cost</td>
<td>$365</td>
<td>$1,400</td>
<td>$2,350</td>
</tr>
<tr>
<td>Equiv. uniform benefits</td>
<td>$1,865</td>
<td>$1,865</td>
<td>$3,750</td>
</tr>
<tr>
<td>Net annual benefits</td>
<td>$1,500</td>
<td>$450</td>
<td>$1,375</td>
</tr>
<tr>
<td>Benefit/cost ratio</td>
<td>5.11</td>
<td>1.33</td>
<td>1.53</td>
</tr>
</tbody>
</table>

**Rejected Improvements (and explanation):**

**Eligible Improvements and Ranking:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5099-1.45</td>
<td>SH 99 -- milepost 1.40 - 1.50</td>
<td>101</td>
<td>Curve signing</td>
</tr>
<tr>
<td>5099-6.75</td>
<td>SH 99 -- RR crossing @ M.P. 6.77</td>
<td>109</td>
<td>Flashing lights &amp; gates</td>
</tr>
</tbody>
</table>

**Comments:** Figure B-5. Improvement Evaluation Worksheet
For the Hazardous Curve on State Highway 99.

---

**Program Priority Listing Worksheet**

*Year 1975*

<table>
<thead>
<tr>
<th>Location</th>
<th>Improvement</th>
<th>Estimated Cost</th>
<th>B/C Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>5099-1.45</td>
<td>SH 99 -- milepost 1.40 - 1.50</td>
<td>$1,000</td>
<td>5.11</td>
</tr>
<tr>
<td>5099-6.75</td>
<td>SH 99 -- RR crossing @ M.P. 6.77</td>
<td>$15,000</td>
<td>1.43</td>
</tr>
</tbody>
</table>

**Comments:**

Figure B-6. Improvements Selected at Hazardous Locations
Entered on the 1975 Program Priority Listing Worksheet.
<table>
<thead>
<tr>
<th>Phase Of Program</th>
<th>Before Accident</th>
<th>Percent Reduction (+ Indicates Increases)</th>
<th>Number Of Projects</th>
<th>Total Costs (000)</th>
<th>Acc. Cost (000)</th>
<th>Benefit Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Killed Accidents</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Fatal</td>
<td>Injury</td>
<td>PDO</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Initial</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>WET PAVEMENT GROOVING</td>
<td>9</td>
<td>3</td>
<td>87.5</td>
<td>66.7</td>
<td>91.4</td>
<td>30.0</td>
</tr>
<tr>
<td>ROADSIDE OBJECT REMOVAL</td>
<td>2</td>
<td>2</td>
<td>50.0</td>
<td>50.0</td>
<td>20.0</td>
<td>21.7</td>
</tr>
<tr>
<td>CURVE SIGNING</td>
<td>1</td>
<td>1</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>75.0</td>
</tr>
<tr>
<td>TOTAL PROGRAM</td>
<td>11</td>
<td>6</td>
<td>91.8</td>
<td>66.7</td>
<td>73.3</td>
<td>31.9</td>
</tr>
</tbody>
</table>

Figure 8-8. Evaluation of the 1976 Highway Safety Program

Date: JAN 15, 1977

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34 Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., $5.00
35 Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., $5.00
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