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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **162**

METHODS FOR EVALUATING HIGHWAY SAFETY IMPROVEMENTS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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METHODS FOR EVALUATING HIGHWAY SAFETY IMPROVEMENTS

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
TRANSPORTATION ADMINISTRATION
HIGHWAY SAFETY

TRANSPORTATION RESEARCH BOARD
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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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FOREWORD

By Staff
Transportation Research Board

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.

CONTENTS

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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. Laughland, Planning and Safety Engineer, Roy Jorgensen Associates; Dr. Lonnie E. Haefner, 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., reearch 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.

METHODS FOR EVALUATING HIGHWAY SAFETY IMPROVEMENTS

SUMMARY

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.

CHAPTER TWO

FINDINGS

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:

REPORTING AGENCY	SAMPLE SIZE	PERCENTAGE OF LOCATIONS NOT REPORTED	PERCENTAGE OF LOCATIONS REPORTED WITHIN 0.01 MILE
State Police	95	3	38
Sheriffs Office	3	0	33
City Police	203	18	75

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 agenices. 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 1

ACCIDENT COST STUDIES DATA

		COSTS (DOLLARS)							
		PER ACCIDENT				PER VEHICLE			
STUDY CONDUCTED BY	YEAR	FATAL	NONFATAL INJURY	PROPERTY DAMAGE ONLY	AVG.	FATAL	NON-FATAL INJURY	PROPERTY DAMAGE ONLY	AVG.
Massachusetts	1953	5,200	860	200	380	—	—	—	—
Utah	1955	3,690	1,280	300	500	—	—	—	—
Illinois	1959	9,865	1,600	195	380	5,060	820	100	196
California	1964	9,000	2,300	700	1,400	—	—	—	—
(Rural)		(9,700)	(2,600)	(800)	(1,800)	—	—	—	—
(Urban)		(7,700)	(2,100)	(600)	(1,200)	—	—	—	—
Washington, D.C.	1966	91,650 *	1,675 *	370 *	1,035 *	47,000	860	190	530
National Highway Traffic Safety Administration	1971	235,000	11,200	500	2,800	—	—	—	—
National Safety Council	1972	82,000	3,400	480	—	—	—	—	—

* Value estimated by assuming 1.95 vehicles per accident.

TABLE 2

COST FACTORS USED IN ACCIDENT COST STUDIES

	USED IN STUDY CONDUTED BY:						
FACTOR	MASS.	UTAH	ILL.	CALIF.	WASH., D.C.	NHTSA	NSC
Property damage	×	×	×	×	×	×	×
Injury costs	×	×	×	×	×	×	×
Worktime lost	×	×	×	×	×	×	×
Loss of use of vehicle	×	×	×	×	×	×	×
Legal costs	×	×	×	×	×	×	×
Damage awards	×	×	×	×	×	×	×
Unreported accidents	—	—	×	×	×	×	×
Potential loss of future earnings	—	—	—	—	×	×	×
Funeral expenses	—	—	—	—	×	×	×
Pain and suffering	—	—	—	—	—	×	—
Insurance payments	—	—	—	—	—	×	—
Insurance administrative costs	—	—	—	—	—	—	×

ALTERNATIVE	EQUIVALENT UNIFORM ANNUAL COST	ANNUAL ACCIDENT REDUCTION	ANNUAL DOLLAR BENEFITS		NET ANNUAL BENEFIT	
			CALIFORNIA STUDY COSTS	NHTSA STUDY COSTS	CALIFORNIA STUDY COSTS	NHTSA STUDY COSTS
A	5,000	4	5,600	11,200	600	6,200
B	10,500	8	11,200	22,400	700	11,900
C	15,000	10	14,000	28,000	−1,000	13,000
D	20,500	15	21,000	42,000	500	21,500

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.

TABLE 3

LISTING OF CANDIDATE PROJECTS

LOCATION	ALTER-NATIVE	INITIAL COST	EQUIVALENT UNIFORM ANNUAL COST	EQUIVALENT UNIFORM ANNUAL BENEFIT	NET ANNUAL BENEFIT	BENEFIT/ COST RATIO
A	1	$1,000	$228	$ 800	$572	3.51
A	2	2,000	456	700	244	1.54
A	3	2,500	570	1,170	600	2.05
B	1	2,000	456	750	294	1.64
B	2	4,000	912	1,750	838	1.92
C	1	1,000	228	700	472	3.07
C	2	2,000	456	900	444	1.97
C	3	3,000	684	1,000	316	1.46
D	1	1,000	228	800	572	3.51
D	2	5,000	1,040	2,000	960	1.54
E	1	500	114	500	386	4.39
E	2	4,000	912	1,600	688	1.75
F	1	1,500	342	1,200	858	3.51
F	2	3,000	682	1,100	418	1.61

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 clear-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 data base 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:

* The length of the list is determined by number of locations that can be analyzed. See discussion in Chapter Two of the Users' Guide.

* 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

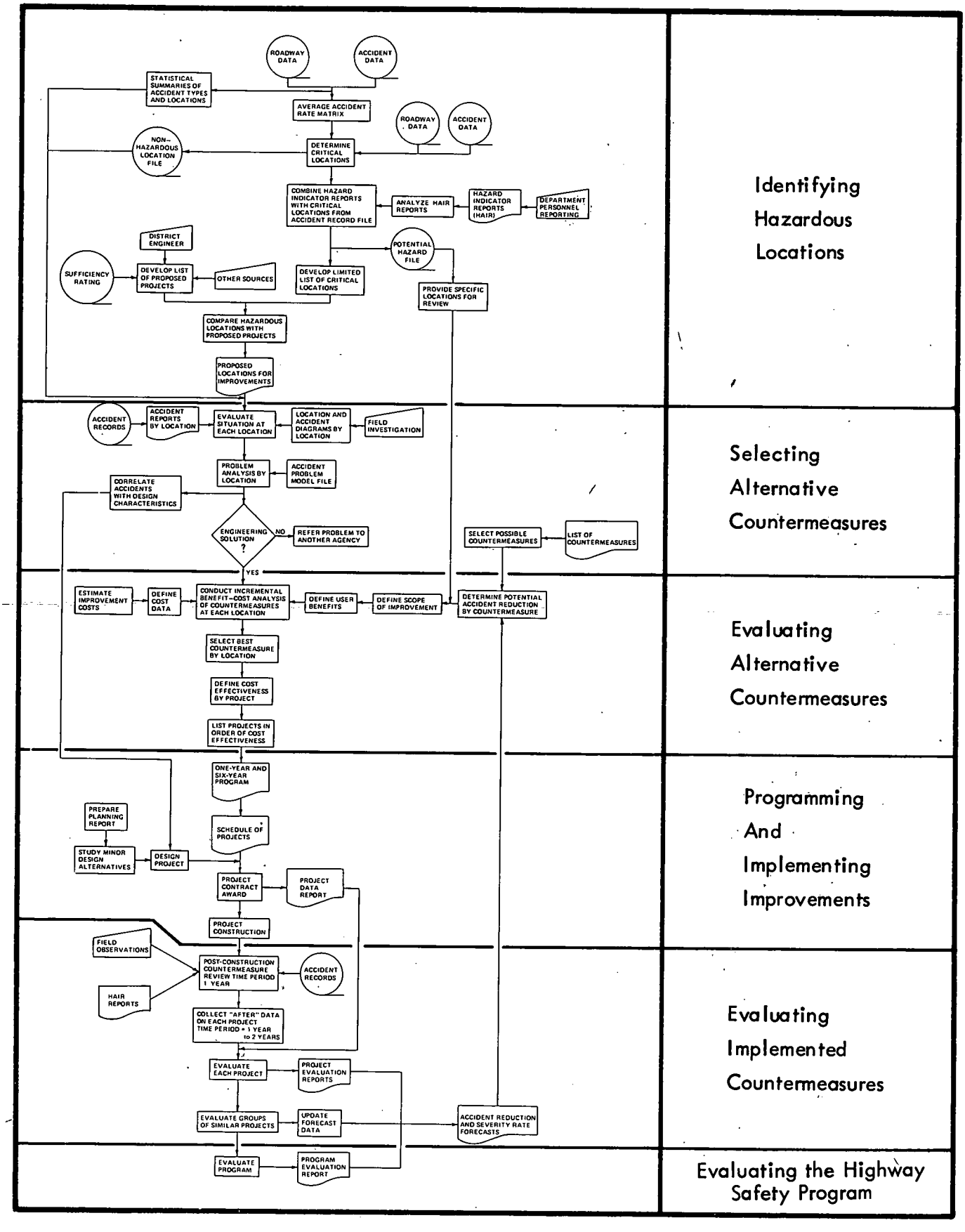


Figure 1. Nebraska's Highway Safety System Divided into the Six Basic Components of the Model System.

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 useable 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.
3. Benefit/cost ratio.

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 commitment.

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 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.

Appendix A

BASIC CONCEPT OF STATISTICS AND PROBABILITY

Experience and research has indicated that traffic accidents are comparatively rare events. Uncertainty usually surrounds their occurrence. Because of this, meaningful analyses of accidents depend in part on the use of statistical techniques. Although the analyst may use these techniques in rote fashion, an understanding of basic statistical concepts will reduce the likelihood of misapplication and permit the extension of the techniques described in the manual to more advanced problems.

The concepts discussed in this appendix are:

- Probability
- Distributions
- Data parameters
  - Sample mean
  - Sample variance
- Population parameters
- Hypothesis
- Error types
- Degrees of freedom
- Regression to the mean

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 minus P is the probability that the event will <u>not</u> 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.

<u>Example</u>

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

Accident Type		Number of Accidents
Rear End	(R)	47
Left Turn	(L)	42
Sideswipe	(S)	34
Head On	(N)	19
Pedestrian	(P)	4

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:

$$\text{Probability (Rear End)} = P(R) = \frac{R}{R + \text{all other accidents}}$$

$$= \frac{R}{R + L + S + N + P} = 47/146$$

$$= 0.32$$

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

$$P(R) + P(L) + P(S) + P(N) + P(P) = 0.32 + 0.29 + 0.23 + 0.13 + 0.03 = 1$$

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

$$P(\text{not } R) = 1 - P(R)$$

$$= 0.68$$

Under certain circumstances, probabilities may be added or multiplied. The probability that the next accident is either rear end <u>or</u> left turn is P (R) + P(L) = 0.61. The probability that the next two independent accidents will <u>both</u> be rear end is P (R) x P (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.

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.

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.

<u>Sample Mean</u>

The sample mean is the most useful measure of central tendency. For a set of n data values, x_i, the sample mean $\bar{x}$ is calculated as follows:

$$\bar{x} = \frac{1}{n}(x_1 + x_2 + x_3 + \ldots\ldots + x_n)$$

$$= \frac{1}{n}\sum x_i$$

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

$$\bar{x} = \sum x_i \; P(x_i)$$

<u>Sample Variance</u>

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:

$$s^2 = \frac{(\sum x_i^2) - n\bar{x}^2}{n - 1}$$

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

$$s^2 = \sum (x_i - \bar{x})^2 \; P(X_i)$$

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 #1 and #2 in Figure A-1 are both 8 but the variances are 1 and 8.75, respectively. The variance of distribution #1 is calculated:

$$s^2 = (6-8)^2(4/64) + (7-8)^2(16/64) + (9-8)^2(16/64) + (10-8)^2(4/64) = 1$$

The variance of distribtuion #2 is calculated:

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

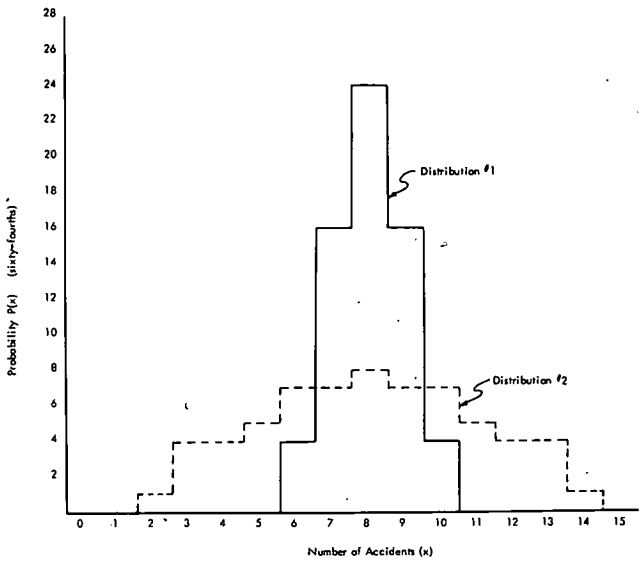


Figure A-1. Distribution Having the Same Means and Different Variances

POPULATION PARAMETERS

The objective of taking a sample of data and analyzing it is to determine some information about the nature of the variable 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 = μ (Greek "mu")
Population variance = σ^2 (Greek "sigma")

Without examining the entire population, it is impossible to know the correct values of μ and σ^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.

HYPOTHESES

Many of the statistical tests which are performed as part of an accident analysis rely implicitly on some type of hypothesis. In most cases, two hypotheses are considered:

1. Null Hypothesis, H_o - a statement of an assumed condition.
2. Alternative Hypothesis, H_1 - a statement of a different condition, which is accepted if H_o is found to be incorrect.

On the basis of a statistical test, either H_o or H_1 will be accepted. In a typical case, a hypothesis used in a test to determine if the mean annual number of run-off-the-road accidents per mile on rural Interstate highways is 4.2 would be:

H_o: $\mu = 4.2$

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.

ERROR TYPES

The general procedure in statistical analysis is to form a hypothesis, about the true mean, μ, 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 α (Greek "alpha"), the probability of making a type II error is referred to by the symbol β (Greek "beta"). It is, of course, desirable to have α and β be as small as possible. In most cases, the analyst has the opportunity of selecting a value of α, which is also called the level of significance. Typical values for α 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 α. 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 million vehicles during different sampling periods will fluctuate about the true average rate for that location. If a sample is taken, there is a certain low probability that the accident rate considered will be extreme in the high (or low) direction, that is, to deviate to a great degree from the mean. If the sample does yield an extreme rate and if another sample is examined at a later time, the laws of chance say that the second rate will be nearer to the true mean. When the two rates are compared, the accident rate will have tended toward the mean. Thus, whether the location is "treated" or not, the accident rate could be lower in the second "after" period. It is possible to erroneously identify a "reduction" as being a result of the treatment rather than the result of the chance phenomenon. Such an error could result in less than optimal expenditures of funds in future projects. Therefore, each measured reduction must be tested for statistical significance.

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 #376 and NCHRP Synthesis of Highway Practice #14.

Skid Testing

This procedure is designed to identify those locations that are slippery under either wet or dry conditions.

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.

Discussion

Within the past ten years, several agencies have defined the basic properties of tires and pavement which influence wet pavement friction. Basically, obtaining the necessary friction depends largely on displacing water from the tire tread imprint. The problem is to move water, some of it as far as 4", in only 0.02 seconds at 22 mph (0.01 seconds at 45 mph). The surface texture of the aggregates in contact with the tires affords the most assistance.

The initial skid resistance and deceleration speed gradient on asphalt concrete depends mainly on the shapes 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.

Hazard Indicator Reporting

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 ruts are examples.

4) Potential Hazard -- a physical feature which may be hazardous because it is fixed, protrudes, 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 decision and make vehicles less controllable. They also may contribute to vehicle damage. For those 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).

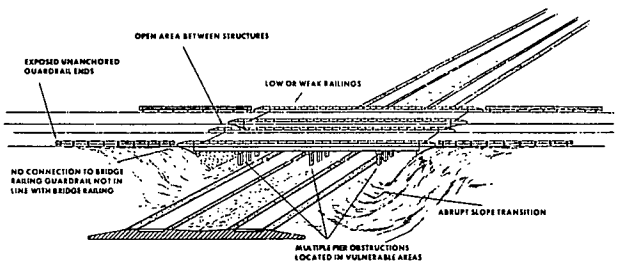


Figure B-1
Typical Potential Hazards

- 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 remediable 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 1/100 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.

a. Procedure

The procedure for using hazard indicator reporting to identify hazardous locations is as follows:

1. Complete the hazard indicator report whenever any of the four types of hazards are identified.

2. Submit the completed reports to the district maintenance foreman.

b. Processing

Observed minor accident reports are combined with the accident record file after they have been edited and checked against the file for duplication.

Observed near accident reports and the evidence of a dangerous incident reports are processed as described below.

1. Summarize the number of events and event indicators reported by type and reporting unit. This summarization should be continued on a monthly basis until reporting has become relatively uniform and seasonal trends have been identified. This may take 2 to 3 years.

2. Identify (1) intersections, (2) roadway sections of one-half mile or longer lengths, or (3) sections defined by two intersections which are having significant numbers of accidents. It is recommended that "significant numbers" be defined as follows:

- Check for a minimum number of events--for example, three. This number should be adjusted according to the length of the final list.

- Calculate the rate of events per million vehicle miles.

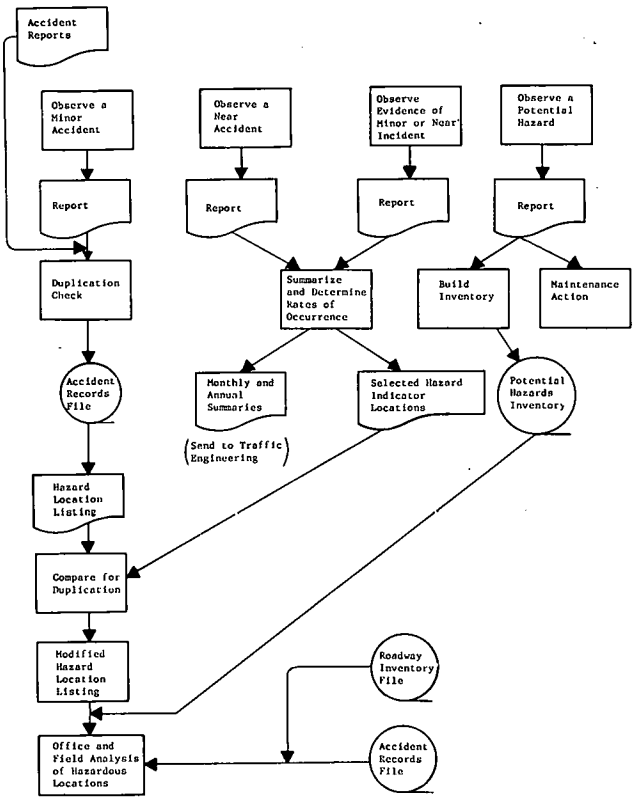
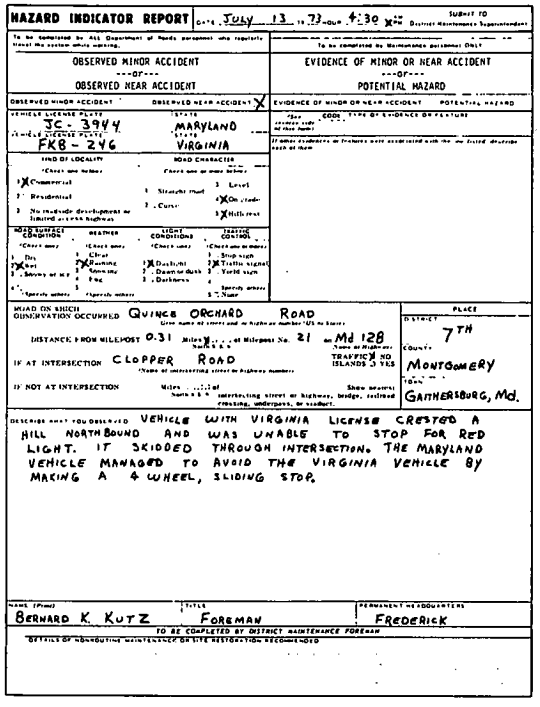


Figure B-2.
Information Flow for Hazard Reporting (Nebraska)

c. Example

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



HAZARD INDICATOR REPORT — DATE JULY 13, 1973 — HOUR 4:30 X PM — SUBMIT TO District Maintenance Superintendent

To be completed by All Department of Roads personnel who regularly travel the system while working.

OBSERVED MINOR ACCIDENT --OR-- OBSERVED NEAR ACCIDENT

To be completed by Maintenance personnel ONLY

EVIDENCE OF MINOR OR NEAR ACCIDENT --OR-- POTENTIAL HAZARD

OBSERVED MINOR ACCIDENT — OBSERVED NEAR ACCIDENT X

EVIDENCE OF MINOR OR NEAR ACCIDENT — POTENTIAL HAZARD

VEHICLE LICENSE PLATE: JC-3944 — STATE: MARYLAND

VEHICLE LICENSE PLATE: FKB-246 — STATE: VIRGINIA

KIND OF LOCALITY (Check one or more below): 1. X Commercial; 2. Residential; 3. No roadside development or limited access highway

ROAD CHARACTER (Check one or more below): 1. Straight road; 2. Curve; 3. Level; 4. X On grade; 5. X Hillcrest

ROAD SURFACE CONDITION (Check one): 1. Dry; 2. X Wet; 3. Snowy or ice; 4. Fog; 5. (Specify others)

WEATHER (Check one): 1. Clear; 2. X Raining; 3. Snowing; 4. Fog; 5. (Specify others)

LIGHT CONDITIONS (Check one): 1. X Daylight; 2. Dawn or dusk; 3. Darkness; 4. (Specify others)

TRAFFIC CONTROL (Check one or more): 1. Stop sign; 2. X Traffic signal; 3. Yield sign; 4. (Specify others); 5. Water

ROAD ON WHICH OBSERVATION OCCURRED: QUINCE ORCHARD ROAD (Give name of street and or highway number (US or State))

DISTANCE FROM MILEPOST 0.31 Miles X North S E W of Milepost No. 21 on Md 128 (Name of Highway)

IF AT INTERSECTION: CLOPPER ROAD (Name of intersecting street or highway number) — TRAFFIC X NO ISLANDS ☐ YES

IF NOT AT INTERSECTION: Miles ..... North S E W of ..... Show nearest intersecting street or highway, bridge, railroad crossing, underpass, or viaduct.

PLACE: DISTRICT 7TH; COUNTY MONTGOMERY; TOWN GAITHERSBURG, Md.

DESCRIBE WHAT YOU OBSERVED: VEHICLE WITH VIRGINIA LICENSE CRESTED A HILL NORTHBOUND AND WAS UNABLE TO STOP FOR RED LIGHT. IT SKIDDED THROUGH INTERSECTION. THE MARYLAND VEHICLE MANAGED TO AVOID THE VIRGINIA VEHICLE BY MAKING A 4 WHEEL, SLIDING STOP.

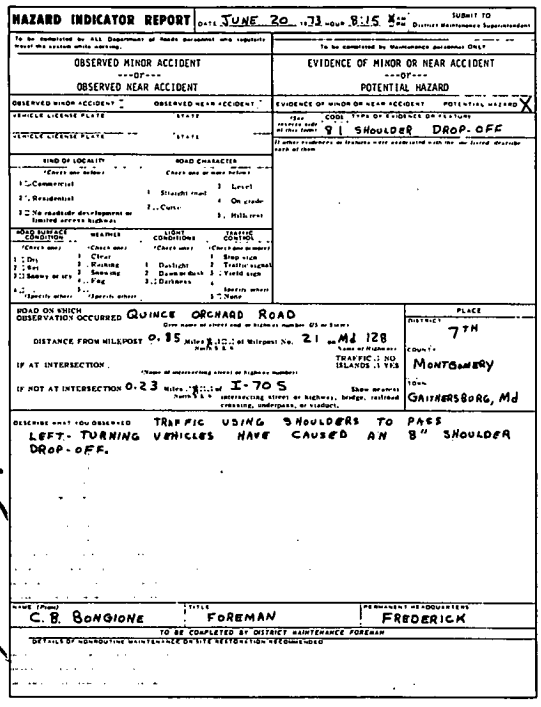
NAME (Print): BERNARD K. KUTZ — TITLE: FOREMAN — PERMANENT HEADQUARTERS: FREDERICK

TO BE COMPLETED BY DISTRICT MAINTENANCE FOREMAN

DETAILS OF NONROUTINE MAINTENANCE OR SITE RESTORATION RECOMMENDED

Figure B-3
Hazard Indicator Report

B-9



HAZARD INDICATOR REPORT — DATE JUNE 20, 1973 — HOUR 8:15 X AM — SUBMIT TO District Maintenance Superintendent

To be completed by All Department of Roads personnel who regularly travel the system while working.

OBSERVED MINOR ACCIDENT --OR-- OBSERVED NEAR ACCIDENT

To be completed by Maintenance personnel ONLY

EVIDENCE OF MINOR OR NEAR ACCIDENT --OR-- POTENTIAL HAZARD

OBSERVED MINOR ACCIDENT — OBSERVED NEAR ACCIDENT

EVIDENCE OF MINOR OR NEAR ACCIDENT — POTENTIAL HAZARD X

VEHICLE LICENSE PLATE — STATE

TYPE OF EVIDENCE OR FEATURE: 91 SHOULDER DROP-OFF

KIND OF LOCALITY (Check one or more below): 1. Commercial; 2. Residential; 3. No roadside development or limited access highway

ROAD CHARACTER (Check one or more below): 1. Straight road; 2. Curve; 3. Level; 4. On grade; 5. Hillcrest

ROAD SURFACE CONDITION (Check one): 1. Dry; 2. Wet; 3. Snowy or ice; 4. Fog; 5. (Specify others)

WEATHER (Check one): 1. Clear; 2. Raining; 3. Snowing; 4. Fog; 5. (Specify others)

LIGHT CONDITIONS (Check one): 1. Daylight; 2. Dawn or dusk; 3. Darkness; 4. (Specify others)

TRAFFIC CONTROL (Check one or more): 1. Stop sign; 2. Traffic signal; 3. Yield sign; 4. (Specify others); 5. Water

ROAD ON WHICH OBSERVATION OCCURRED: QUINCE ORCHARD ROAD (Give name of street and or highway number (US or State))

DISTANCE FROM MILEPOST 0.85 Miles X North S E W of Milepost No. 21 on Md 128 (Name of Highway)

IF AT INTERSECTION: (Name of intersecting street or highway number) — TRAFFIC ☐ NO ISLANDS ☐ YES

IF NOT AT INTERSECTION: 0.23 Miles X North S E W of I-70S — Show nearest intersecting street or highway, bridge, railroad crossing, underpass, or viaduct.

PLACE: DISTRICT 7TH; COUNTY MONTGOMERY; TOWN GAITHERSBURG, Md

DESCRIBE WHAT YOU OBSERVED: TRAFFIC USING SHOULDERS TO PASS LEFT-TURNING VEHICLES HAVE CAUSED AN 8" SHOULDER DROP-OFF.

NAME (Print): C. B. BONGIONE — TITLE: FOREMAN — PERMANENT HEADQUARTERS: FREDERICK

TO BE COMPLETED BY DISTRICT MAINTENANCE FOREMAN

DETAILS OF NONROUTINE MAINTENANCE OR SITE RESTORATION RECOMMENDED

We tried to develop this several years ago.

Figure B-4.
Hazard Indicator Report

B-10

Correlation of Geometrics and Accidents

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 oxides 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.

B-11

a. Procedure

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

1. Describe roadway geometrics 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 from NCHRP Report #47 is shown in Figure B-5.

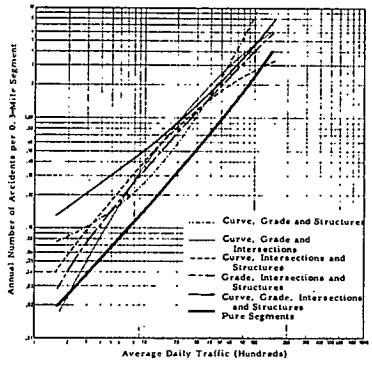


Figure B-5
Accident Rate vs. Geometrics

B-12

Accident Risk Factor

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, (R), which is a function of hazard exposure, consequences of the hazardous event and the probability of the hazardous event producing or leading to some adverse consequence.

R = (C) (E) (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.

E = 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, post 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 consequences. 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.

Table B-1. Ratings For Risk Calculation (52)

FACTOR	CLASSIFICATION	RATING
1. Consequences (Most probable result of the potential accident) C	Catastrophe; numerous fatalities; damage over $1,000,000; major disruption of activities	100
	Multiple fatalities; damage $100,000 to $1,000,000	50
	Fatality, damage $100,000 to $500,000	25
	Extremely serious injury (amputation, permanent disability); damage $1,000 to $100,000	15
	Disabling injury; damage up to $1,000	5
	Minor cuts, bruises, bumps; minor damage	1
2. Exposure (The frequency of occurrence of the hazard-event) E	Hazard-event occurs:	
	Continuously (or many times daily)	10
	Frequently (approximately once daily)	6
	Occasionally (from once per week to once per month)	3
	Unusually (from once per month to once per year)	2
	Rarely (it has been known to occur)	1
	Remotely possible (not known to have occurred)	0.5
3. Probability (Likelihood that accident sequence will follow to completion) P	Complete accident sequence:	
	Is the most likely and expected result if the hazard-event takes place	10
	Is quite possible, not unusual, has an even 50/50 chance	6
	Would be an unusual sequence or coincidence	3
	Would be a remotely possible coincidence	1
	Has never happened after many years of exposure, but is conceivably possible	0.5
	Practically impossible sequence (has never happened)	0.1
4. Cost factor (Estimated dollar cost of proposed corrective action) CF	Over $50,000	10
	$25,000 to $50,000	6
	$10,000 to $25,000	4
	$1,000 to $10,000	3
	$100 to $1,000	2
	$25.00 to $100	1
	Under $25.00	0.5
5. Degree of correction (Degree to which hazard will be reduced) DC	Hazard positively eliminated, 100%	1
	Hazard reduced at least 75%	2
	Hazard reduced by 50% to 75%	3
	Hazard reduced by 25% to 50%	4
	Slight effect on hazard (less than 25%)	6

a. Procedure

The procedure for using the accident risk factor to identify hazardous locations is:

1. Determine the Consequences Factor (C) from Figure B-1 for each location.
2. Determine the Exposure Factor (E) from Figure B-1 for each location.
3. Determine the Probability Factor (P) from Figure B-1 for each location.
4. Calculate the Risk Factor (R) for each location.

   R = (C)(E)(P)

5. The locations with the highest risk factors are the hazardous locations.

Formula Methods

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 assumption 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 calculations. 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 ($R^2 = 0.703$) predicting the total number of multiple vehicle accidents per mile over a period of four years of daylight, excluding bad weather, with the formula

$$Y = 2.834 - 172.655A + 610.139B + 1720.888C - 962.097D + 45.588E$$

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:

Exposure = (Average 24-hour automobile volume)(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 Dimmick formula, also known as the BPR formula. (6)

$$A_5 = 1.28 \left[\frac{V^{0.170} + T^{0.151}}{P_c^{0.171}} \right] + K$$

Where:

A_5 = 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 #50 (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.

Field Observation

Field observation is always applicable on 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.

a. 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.

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. Observe 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.

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 #1 is the offending vehicle and vehicle #2 is the offended vehicle.

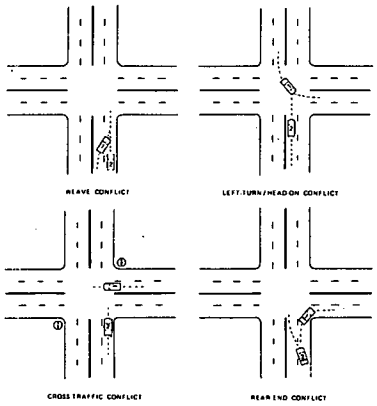


Figure B-6.
Common Types of Conflicts

Much of the basic work in conflict analysis was done by Perkins and Harris (124) of the General Motors Research Laboratories and Baker (8) of U.S. Department of Transportation. A detailed description of the analyses by Perkins and Harris is included in Highway Research Record #225. Detailed procedures are available in General Motors Research Publication #895, GMR Traffic Conflicts Techniques - Procedures Manual. Baker's analysis is in Highway Research Record #384.

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.

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.

Based on the 3M studies, there appear to be "relatively safe" speeds--which are adopted by 85 percent of the drivers. The mixing of the judgments of hundreds or thousands of drivers apparently produces a "reasonable" or "prudent" speed that is the best trade-off between the advantages and disadvantages of fast speeds. If this is true, high-accident locations might be identified by looking at vehicle speeds.

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

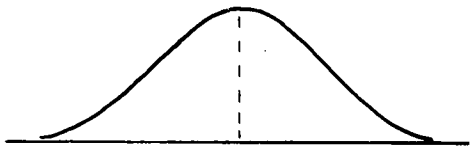


Figure B-7
Random Distribution

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 B-8.

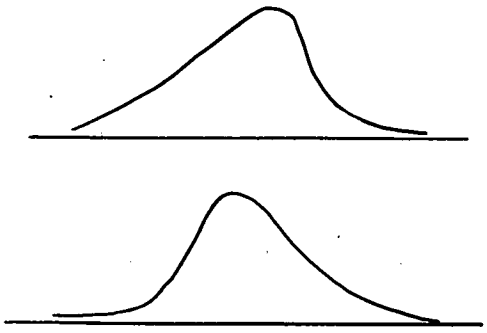


Figure B-8
Skewed Distribution

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 slower), 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 phenomena 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 (77), 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.

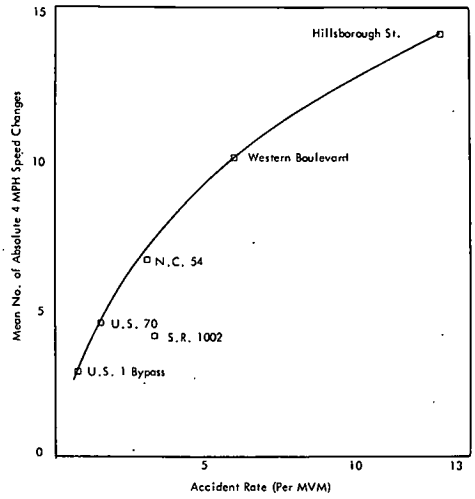


Figure B-9
Accident Rate vs. Speed Changes

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 #51 (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:

Reaction Time (sec)	Minimum Headway (ft)	Coefficient of Correlation (R)	R^2
0.50	44	0.64	0.414
0.75	66	0.62	0.383
1.00	88	0.59	0.345
1.25	110	0.63	0.395
2.00	150	0.60	0.358

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.

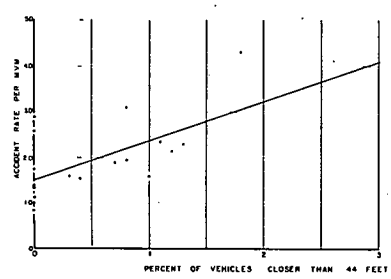


Figure B-10
Accident Rate vs. Headway

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.

APPENDIX C
STATISTICAL TESTS FOR SIGNIFICANT ACCIDENT CHARACTERISTICS

The recommended statistical tests for significant accident characteristics are:

Binomial Test - Normal Approximation -- the number the accidents at the study site is large ($>$ 50) and the number of a given type of accident at the study site is greater than 5.

Poisson Distribution Test -- the number of accidents at the study site is small ($<$ 50) or the number of a given type of accident at the study site is less than 5.

Chi-Square Distribution Test -- The data available to the investigator is of suspect quality.

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.

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_o: An accident characteristic at a particular site is identical to that at a larger group of reference sites.
   H_1: An accident characteristics at a particular site is greater than (or less than) that.....
2. Select a level of confidence (0.95 is recommended).
3. Determine a value for Z from the table below:

Level of Confidence	Z
0.995	2.576
0.990	2.326
0.980	2.056
0.975	1.960
0.950	1.645
0.900	1.282
0.800	0.842

4. Calculate z

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

Where:

$\overline{X}$ = 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_o, must be rejected at the selected level of confidence.

a. Example

At a hazardous location, eighteen of the sixty accidents occurred on wet pavement.

Pavement Condition	Study Site Accidents	Study Site Percent	Similar Locations Statewide Accidents	Similar Locations Statewide Percent
Wet	18	30	400	20
Other	42	70	1,600	80
	60		2,000	

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_o: percent of wet pavement accidents at the study site is identical to the percent of wet pavement accidents at similar statewide locations
   H_1: percent of wet pavement accidents ..... is greater than
2. Level of Confidence = 95% = 0.950
3. Z = 1.645
4. $z = \dfrac{30 - 20}{\sqrt{\dfrac{(20)(80)}{60}} \quad \sqrt{\dfrac{2,000 - 60}{2,000 - 1}}} = 1.96$
5. Since z is greater than Z, 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.
   $m = nP$
   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).
   $$P(<K) = P(O) + P(1) + P(2) + \ldots + P(K-1)$$
   $$= \frac{e^{-m}\, m^{O}}{O!} + \frac{e^{-m}\, m^{1}}{1!} + \ldots + \frac{e^{-m}\, m^{K-1}}{(K-1)!}$$
   Where:
   K = number of the given type of accidents at the location under study
   e = base of natural logarithms = 2.7182 . . .
   ! = factorial (K x K-1 x K-2 . . . 3 x 2 x 1) (O! = 1)
   P(<K) can also be found in the Poisson cumulative distribution table (Figure C-1) by letting X = K-1.
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.

a. Example

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

Pavement Condition	Study Site Accidents	Study Site Percent	Similar Locations Statewide Accidents	Similar Locations Statewide Percent
Wet	5	42	400	20
Other	7	58	1,600	80
	12		2,000	

Because the total number of accidents is less than 50, use the Poisson Distribution Test.

1. m = (0.20)(12) = 2.4
2. P (< 5) = P(o) + P(1) + P(2) + P(3) + P(4)
   $$= \frac{e^{-2.4}\, 2.4^{o}}{o!} + \frac{e^{-2.4}\, 2.4^{1}}{1!} + \frac{e^{-2.4}\, 2.4^{2}}{2!} + \frac{e^{-2.4}\, 2.4^{3}}{3!} + \frac{e^{-2.4}\, 2.4^{4}}{4!}$$
   $$= 0.091 + 0.217 + 0.262 + 0.209 + 0.125$$
   $$= 0.904$$
3. P (> 5) = 1 - .904 = .096
4. Since the probability is less than 0.1 that five or more wet pavement accidents occur, when similar locations statewide have an average of 2.4, it would be concluded that this site differs significantly from the other locations.

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 X_a^2 from the table below.

Level of Confidence	X_a^2
0.995	7.879
0.990	6.635
0.975	5.024
0.950	3.841
0.900	2.706
0.800	1.642

3. Calculate X^2
   For study locations where Fe is fewer than 100 accidents,
   $$X^2 = \sum \frac{(|Fo-Fe| - \frac{1}{2})^2}{Fe}$$
   For study locations where Fe is greater than 100 accidents,
   $$X^2 = \sum \frac{(Fo - Fe)^2}{Fe}$$
   Where:
   Fo = the observed number of a given type of accident at the location under study
   Fe = nP = 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 X^2 to X_a^2

If X^2 is greater than X^2_a, the number of a given type of accident is unusually high for the level of confidence.

a. Example

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

Pavement Condition	Study Site: Accidents	Study Site: Percent	Similar Locations Statewide: Accidents	Similar Locations Statewide: Percent
Wet	10	33	400	20
Other	20	67	1,600	80
	30		2,000	

1. Level of Confidence = 0.95 (95 out of 100)
2. $X^2_a = 3.841$
3. Calculate X^2

Fe(wet) = (0.2)(30) = 6
Fe(other)= (0.8)(30) = 24

Fo(wet) = 10
Fo(other)= 20

$$X^2 = \frac{(|10-6| - \frac{1}{2})^2}{6} + \frac{(|20-24| - \frac{1}{2})^2}{24}$$

$$= 2.04 + 0.51 = 2.55$$

4. X^2 is less than X^2_a. Therefore, the 10 wet pavement accidents at the location under study are not significantly unusual.

Table C-1. Poisson Cumulative Distribution

m	X: 0	1	2	3	4	5	6	7	8	9	10
0.02	0.980	1.000									
0.04	0.961	0.999	1.000								
0.06	0.942	0.998	1.000								
0.08	0.923	0.997	1.000								
0.10	0.905	0.995	1.000								
0.15	0.861	0.990	0.999	1.000							
0.20	0.819	0.982	0.999	1.000							
0.25	0.779	0.974	0.998	1.000							
0.30	0.741	0.963	0.996	1.000							
0.35	0.705	0.951	0.994	1.000							
0.40	0.670	0.938	0.992	0.999	1.000						
0.45	0.638	0.925	0.989	0.999	1.000						
0.50	0.607	0.910	0.986	0.998	1.000						
0.55	0.577	0.894	0.982	0.998	1.000						
0.60	0.549	0.878	0.977	0.997	1.000						
0.65	0.522	0.861	0.972	0.996	0.999	1.000					
0.70	0.497	0.844	0.966	0.994	0.999	1.000					
0.75	0.472	0.827	0.959	0.993	0.999	1.000					
0.80	0.449	0.809	0.953	0.991	0.999	1.000					
0.85	0.427	0.791	0.945	0.989	0.998	1.000					
0.90	0.407	0.772	0.937	0.987	0.998	1.000					
0.95	0.387	0.754	0.929	0.984	0.997	1.000					
1.00	0.368	0.736	0.920	0.981	0.996	0.999	1.000				
1.1	0.333	0.699	0.900	0.974	0.995	0.999	1.000				
1.2	0.301	0.663	0.879	0.966	0.992	0.998	1.000				
1.3	0.273	0.627	0.857	0.957	0.989	0.998	1.000				
1.4	0.247	0.592	0.833	0.946	0.986	0.997	0.999	1.000			
1.5	0.223	0.558	0.809	0.934	0.981	0.996	0.999	1.000			
1.6	0.202	0.525	0.783	0.921	0.976	0.994	0.999	1.000			
1.7	0.183	0.493	0.757	0.907	0.970	0.992	0.998	1.000			
1.8	0.165	0.463	0.731	0.891	0.964	0.990	0.997	0.999	1.000		
1.9	0.150	0.434	0.704	0.875	0.956	0.987	0.997	0.999	1.000		
2.0	0.135	0.406	0.667	0.857	0.947	0.983	0.995	0.999	1.000		
2.2	0.111	0.355	0.623	0.819	0.928	0.975	0.993	0.998	1.000		
2.4	0.091	0.308	0.570	0.779	0.904	0.964	0.988	0.997	0.999	1.000	
2.6	0.074	0.267	0.518	0.736	0.877	0.951	0.983	0.995	0.999	1.000	
2.8	0.061	0.231	0.469	0.692	0.848	0.935	0.976	0.992	0.998	0.999	1.000
3.0	0.050	0.199	0.423	0.647	0.815	0.916	0.966	0.988	0.996	0.999	1.000

Table C-1 (Continued). Poisson Cumulative Distribution

m	X: 0	1	2	3	4	5	6	7	8	9	10
3.2	0.041	0.171	0.380	0.603	0.781	0.895	0.955	0.983	0.994	0.998	1.000
3.4	0.033	0.147	0.340	0.558	0.744	0.871	0.942	0.977	0.992	0.997	0.999
3.6	0.027	0.126	0.303	0.515	0.706	0.844	0.927	0.969	0.988	0.996	0.999
3.8	0.022	0.107	0.269	0.473	0.668	0.816	0.909	0.960	0.984	0.994	0.998
4.0	0.018	0.092	0.238	0.433	0.629	0.785	0.889	0.949	0.979	0.992	0.997
4.2	0.015	0.078	0.210	0.395	0.590	0.753	0.867	0.936	0.972	0.989	0.996
4.4	0.012	0.066	0.185	0.359	0.551	0.720	0.844	0.921	0.964	0.985	0.994
4.6	0.010	0.056	0.163	0.326	0.513	0.686	0.818	0.905	0.955	0.980	0.992
4.8	0.008	0.048	0.143	0.294	0.476	0.651	0.791	0.887	0.944	0.975	0.990
5.0	0.007	0.040	0.125	0.265	0.440	0.616	0.762	0.867	0.932	0.968	0.986
5.2	0.006	0.034	0.109	0.238	0.406	0.581	0.732	0.845	0.918	0.960	0.982
5.4	0.005	0.029	0.095	0.213	0.373	0.546	0.702	0.822	0.903	0.951	0.977
5.6	0.004	0.024	0.082	0.191	0.342	0.512	0.670	0.797	0.886	0.941	0.972
5.8	0.003	0.021	0.072	0.170	0.313	0.478	0.638	0.771	0.867	0.929	0.965
6.0	0.002	0.017	0.062	0.151	0.285	0.446	0.606	0.744	0.847	0.916	0.957
6.2	0.002	0.015	0.054	0.134	0.259	0.414	0.574	0.716	0.826	0.902	0.949
6.4	0.002	0.012	0.046	0.119	0.235	0.384	0.542	0.687	0.803	0.886	0.939
6.6	0.001	0.010	0.040	0.105	0.213	0.355	0.511	0.658	0.780	0.869	0.927
6.8	0.001	0.009	0.034	0.093	0.192	0.327	0.480	0.628	0.755	0.850	0.915
7.0	0.001	0.007	0.030	0.082	0.173	0.301	0.450	0.599	0.729	0.830	0.901
7.2	0.001	0.006	0.025	0.072	0.156	0.276	0.420	0.569	0.703	0.810	0.887
7.4	0.001	0.005	0.022	0.063	0.140	0.253	0.392	0.539	0.676	0.788	0.871
7.6	0.001	0.004	0.019	0.055	0.125	0.231	0.365	0.510	0.648	0.765	0.854
7.8	0.000	0.004	0.016	0.048	0.112	0.210	0.338	0.481	0.620	0.741	0.835
8.0	0.000	0.003	0.014	0.042	0.100	0.191	0.313	0.453	0.593	0.717	0.816
8.5	0.000	0.002	0.009	0.030	0.074	0.150	0.256	0.386	0.523	0.653	0.763
9.0	0.000	0.001	0.006	0.021	0.055	0.116	0.207	0.324	0.456	0.587	0.706
9.5	0.000	0.001	0.004	0.015	0.040	0.089	0.165	0.269	0.392	0.522	0.645
10.0	0.000	0.000	0.003	0.010	0.029	0.067	0.130	0.220	0.333	0.458	0.583
10.5	0.000	0.000	0.002	0.007	0.021	0.050	0.102	0.179	0.279	0.397	0.521
11.0	0.000	0.000	0.001	0.005	0.015	0.038	0.079	0.143	0.232	0.341	0.460
11.5	0.000	0.000	0.001	0.003	0.011	0.028	0.060	0.114	0.191	0.289	0.402
12.0	0.000	0.000	0.001	0.002	0.008	0.020	0.046	0.090	0.155	0.242	0.347
12.5	0.000	0.000	0.000	0.002	0.005	0.015	0.035	0.070	0.125	0.201	0.297
13.0	0.000	0.000	0.000	0.001	0.004	0.011	0.026	0.054	0.100	0.166	0.252
13.5	0.000	0.000	0.000	0.001	0.003	0.008	0.019	0.041	0.079	0.135	0.211
14.0	0.000	0.000	0.000	0.000	0.002	0.006	0.014	0.032	0.062	0.109	0.176
14.5	0.000	0.000	0.000	0.000	0.001	0.004	0.010	0.024	0.048	0.088	0.145
15.0	0.000	0.000	0.000	0.000	0.001	0.003	0.008	0.018	0.037	0.070	0.118

Table C-1 (Continued). Poisson Cumulative Distribution

m	X: 11	12	13	14	15	16	17	18	19	20
3.2	1.000									
3.4	1.000									
3.6	1.000									
3.8	0.999	1.000								
4.0	0.999	1.000								
4.2	0.999	1.000								
4.4	0.998	0.999	1.000							
4.6	0.997	0.999	1.000							
4.8	0.996	0.999	1.000							
5.0	0.995	0.998	0.999	1.000						
5.2	0.993	0.997	0.999	1.000						
5.4	0.990	0.996	0.999	1.000						
5.6	0.988	0.995	0.998	0.999	1.000					
5.8	0.984	0.993	0.997	0.999	1.000					
6.0	0.980	0.991	0.996	0.999	0.999	1.000				
6.2	0.975	0.989	0.995	0.998	0.999	1.000				
6.4	0.969	0.986	0.994	0.997	0.999	1.000				
6.6	0.963	0.982	0.992	0.997	0.999	0.999	1.000			
6.8	0.955	0.978	0.990	0.996	0.998	0.999	1.000			
7.0	0.947	0.973	0.987	0.994	0.998	0.999	1.000			
7.2	0.937	0.967	0.984	0.993	0.997	0.999	0.999	1.000		
7.4	0.926	0.961	0.980	0.991	0.996	0.998	0.999	1.000		
7.6	0.915	0.954	0.976	0.989	0.995	0.998	0.999	1.000		
7.8	0.902	0.945	0.971	0.986	0.993	0.997	0.999	1.000		
8.0	0.888	0.936	0.966	0.983	0.992	0.996	0.998	0.998	1.000	1.000
8.5	0.849	0.909	0.949	0.973	0.986	0.993	0.997	0.999	0.999	1.000
9.0	0.803	0.876	0.926	0.959	0.978	0.989	0.995	0.998	0.999	1.000
9.5	0.752	0.836	0.898	0.940	0.967	0.982	0.991	0.996	0.998	0.999
10.0	0.697	0.792	0.864	0.917	0.951	0.973	0.986	0.993	0.997	0.998
10.5	0.639	0.742	0.825	0.888	0.932	0.960	0.978	0.988	0.994	0.997
11.0	0.579	0.689	0.781	0.854	0.907	0.944	0.968	0.982	0.991	0.995
11.5	0.520	0.633	0.733	0.815	0.878	0.924	0.954	0.974	0.986	0.992
12.0	0.462	0.576	0.682	0.772	0.844	0.899	0.937	0.963	0.979	0.988
12.5	0.406	0.519	0.628	0.725	0.806	0.869	0.916	0.948	0.969	0.983
13.0	0.353	0.463	0.573	0.675	0.764	0.835	0.890	0.930	0.957	0.975
13.5	0.304	0.409	0.518	0.623	0.718	0.798	0.861	0.908	0.942	0.965
14.0	0.260	0.358	0.464	0.570	0.669	0.756	0.827	0.883	0.923	0.952
14.5	0.220	0.311	0.413	0.518	0.619	0.711	0.790	0.853	0.901	0.936
15.0	0.185	0.268	0.363	0.466	0.568	0.664	0.749	0.819	0.875	0.917

Table C-1 (Continued). Poisson Cumulative Distribution

m	X									
	21	22	23	24	25	26	27	28	29	30
9.5	1.000									
10.0	0.999	1.000								
10.5	0.999	0.999	1.000							
11.0	0.998	0.999	1.000							
11.5	0.996	0.998	0.999	1.000						
12.0	0.994	0.997	0.999	0.999	1.000					
12.5	0.991	0.995	0.998	0.999	0.999	1.000				
13.0	0.986	0.992	0.996	0.998	0.999	1.000				
13.5	0.980	0.989	0.994	0.997	0.998	0.999	1.000			
14.0	0.971	0.983	0.991	0.995	0.997	0.999	0.999	1.000		
14.5	0.960	0.976	0.986	0.992	0.996	0.998	0.999	1.000		
15.0	0.947	0.967	0.981	0.989	0.994	0.997	0.998	0.999	1.000	1.000

Appendix D

COMPLEMENTARY METHODS OF PRESCRIBING IMPROVEMENTS

The analysis of hazardous locations to prescribe improvements is greatly influenced by the skill and experience of the analyst. To supplement this skill and experience, several researchers have attempted to develop methods to complement the analyst's skill and experience. These methods are in the development 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. Likewise, the assumptions for each method should be considered tentative until proven.

The complementary methods discussed on the following pages are:

- Near-Miss Scale of Danger -- The weighing of near-misses according to their closeness to the critical avoidance time.
- Branching Analysis -- The placing of contributing circumstances in their correct relationships.
- Behavioral Sequence Model -- A chain of events is developed for each participant contributing to the accident.
- True Critical Point -- An analysis of the driver's processes of controlling the vehicle.
- Operations Analysis -- The analysis of the required driver operations to gain an understanding of the driver's actions.

Near-Miss Scale of Danger

The application of a scale of danger for near-misses should allow better comparisons of accident potential at different locations.

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

The tentative assumptions behind the near-miss scale of danger are:

- Those near-misses that come closest to the minimum avoidance time should identify the factors creating traffic accidents at the location.
- The measures designed to counter those near-misses closest to their minimum avoidance times should do the most to reduce the number of accidents at that location.

To make near-miss or conflicts measurements more precise, Hayward (76) developed estimates of "minimum avoidance times" which he called "time measured to collision" (TMTC). The criticality of each near-miss depends on the closeness to the TMTC. The scale of danger can be used to distinguish dangerous near-misses from other less serious traffic events.

Based on a theoretical TMTC and empirical values obtained from a test intersection, Hayward recommends that traffic events with TMTC's of one second or less should be designated as near-misses.

a. Procedure

The procedure for using a near-miss scale of danger to prescribe applicable improvements is the same as conflicts analysis except that only those conflicts that approach the minimum time to collision are counted.

Branching Analysis

Branching analysis helps to place the contributing circumstances in perspective and affords 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 (151) 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.

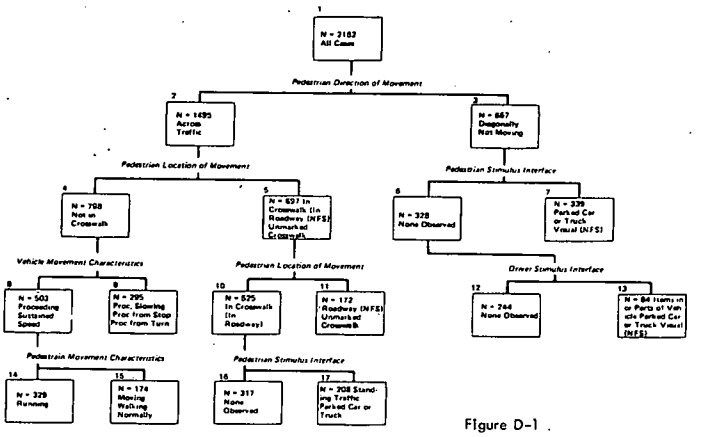


Figure D-1
Branching Analysis Example

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 actions
- 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.

a. Procedure

Using the categories as a guide, the procedure for this method is to examine the chain or sequence of events leading to a collision. Working backward from the collision, a sequence of events is constructed in terms general enough to apply to all accidents at the location. The analyst determines how to break the chain and avoid the collision.

b. Example

The basic behavioral sequence functions leading to a pedestrian-vehicle accident are shown in Figure D-2: (151)

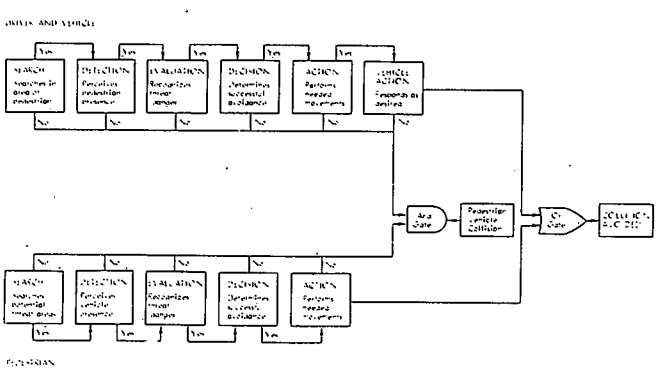


Figure D-2
Behavioral Sequence Model

This basic model was expanded in Figure D-3 to include the factors that influence the driver and vehicle as well as the pedestrian and the environment.

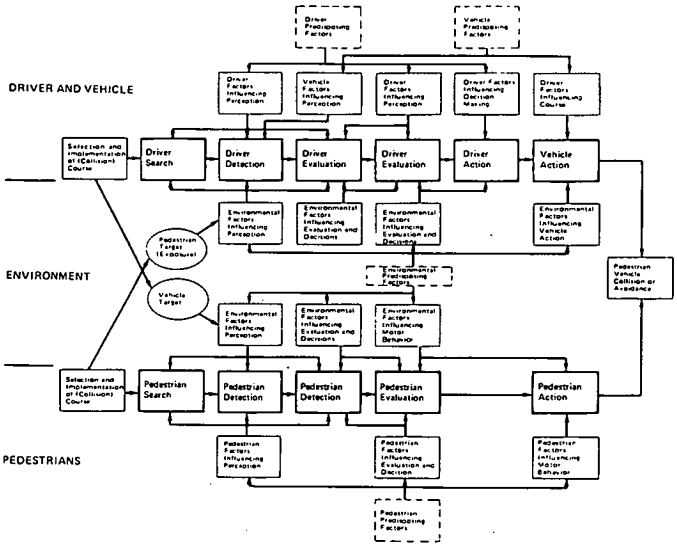


Figure D-3
Expanded Behavioral Sequence Model

D-7

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 D-5.

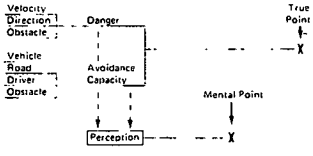


Figure D-5
True Critical and Mental Point Model

How well the driver's mental point coincides with the true point is of great importance. No accident occurs when the mental point is placed before the true point. However, when the mental point is placed past the true point, an accident may or may not occur. The deciding factor is the "action point."

The action point is the point selected by the driver as to when he actually will apply the avoidance force. He does not place his action point at exactly the same spot as his mental point. In other words, he does not decide to act only when he believes he has reached the exact point of no return; he acts prior to that point.

The action point results when the driver modifies his mental point by his desired margin for error. The relationships among these three points are shown in Figure D-6.

True Critical Point

This method is useful in helping the analyst to understand the driver's processes of controlling the vehicle and to choose improvements that will make these processes more effective.

The assumptions behind the true critical point method are:

- Mistakes made by drivers in judging the point-of-no-return underlie avoidable accidents.
- Mistakes result from imperfections in the perception process.
- Drivers allow margins for errors to reduce the consequences of a mistake.

There are no specific data requirements. As the analyst develops quantitative questions, studies may be conducted to determine the required values.

This approach was developed by the 3M Company and documented in their report, The Price of Not Walking (23). The following is a paraphase of the 3M study conclusions:

In his control process, the driver must have some comprehension of both the danger and his avoidance capacity if he is to apply the avoidance force before the true critical point. True critical point as defined by 3M is "That point in space or time which is the last instant that the avoidance force is, by physical laws, able to alter the danger force so as to prevent an accident"--that is, the point of no return. A model of the true critical point is shown in Figure D-4.

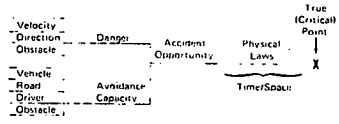


Figure D-4
True Critical Point Model

D-8

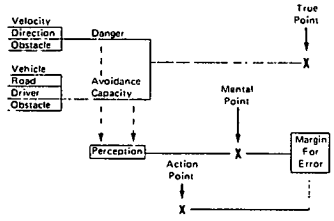


Figure D-6
Action Point Model

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.

D-11

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

Results	Odds
Decisions at one per 10 events	20 per mile
Errors at one per 40 decisions	1 every two miles
Near collisions at one per 250 errors	1 every 500 miles
Collisions at one per 122 near collisions	1 every 61,000 miles
Injuries at one per 7 collisions	1 every 430,000 miles
Fatalities at one per 250 collisions	1 every 16,000,000 miles

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.

D-13

Road Structure	Environment
Continuous	**Outside the Vehicle**
Width of pavement	Sun glare
Curb and shoulder	Trees
Lane markings	Darkness
Surface roughness	Rain or snow
	Fog, haze or smoke
Discreet	Wet road
Horizontal curves	Snow or ice on road
Vertical curves	Sand or gravel on road
Surface hazards	Moving vehicles
Traffic signs and signals	
Intersecting roads	**Inside the Vehicle**
Guardrail and posts	Passenger
Obstructions (visual)	Vehicle instruments
Parked vehicles	Sounds (vehicle, voices, radio)
Traffic signs	Temperature
Abutments	Humidity
Advertising signs	Control motions and forces
Pedestrians	Motion and inertial forces
Animals	Air conditioning
Bicyclists	

A driver makes decisions only on the events he observes or anticipates. If he fails to observe or anticipate a crucial event, he may make one or more errors of judgment leading to the possibility of an accident. Also, a multitude of events occurring simultaneously may confuse him and cause errors of judgment.

Most incorrect actions produced by errors of judgment are not serious and do not produce dangerous results. However, once in a while a series of events will cause an incorrect action that leads to a collision or near collision with the possibility of injuries or fatalities.

D-12

Appendix E

ALTERNATIVE METHODS OF ESTIMATING ACCIDENT REDUCTION BENEFITS OF IMPROVEMENTS

Accident reduction benefit can be estimated in terms of:

- Numbers-of-accidents methods
  - + Reduced numbers of accidents
  - + Reduction to an average number of accidents
  - + Percentage reduction in numbers of accidents
- Accident rate methods
  - + Reduction to an average accident rate
  - + Percentage reduction in accident rate
    - - For all accidents
    - - By accident type
- Severity rate methods
  - + Reduction to an average severity rate
    - - All above average severity classes
    - - All significantly high severity classes
  - + Percentage reduction in severity rate
    - - For all accidents
    - - By accident type

The number-of-accidents 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.

Ca = average cost of an average accident
Cf = average cost of a fatal accident
Ci = average cost of an injury accident
Cp = average cost of a property-damage-only accident
L = section length in miles
Pa = average percentage for a severity class
Paf = systemwide average percent of accidents that are fatal, expressed as a decimal
Pai = systemwide average percent of accidents that are injuries, expressed as a decimal
Pap = systemwide average percent of accidents that are property damage only, expressed as a decimal
Pc = critical percentage for a severity class
Pf = percent of accidents as the location that are fatal
Pi = percent of accidents at the location that are injury, expressed as a decimal
Pp = percent of accidents at the location that are property damage only, expressed as a decimal
Ptf = percent of accidents of that type that are fatal, expressed as a decimal
Pti = percent of accidents of that type that are injuries, expressed as a decimal
Ptp = percent of accidents of that type that are property damage only, expressed as a decimal

Ra. = systemwide accident rate for the type of location under study (Acc/MV or Acc/MVM)
Rf = future accident rate (Acc/MV or Acc/MVM)
Rfi = future accident rate for each type (Acc/Mv or Acc/MVM)
RSI = relative severity index
R% = expected accident rate reduction percentage, expressed as as a decimal
R%i = expected accident rate reduction percentage for each accident type, expressed as a decimal
Sf% = expected fatal severity rate reduction percentage, expressed as a decimal
Si% = expected injury severity rate reduction percentage, expressed as a decimal
Sp% = expected property-damage-only severity rate reduction percentage, expressed as a decimal
Vf = future traffic volume in vehicles per day (VPD)
Z = 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 types of 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.

a. 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, Rf, 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 <u>each year</u> of the service life of the improvement.

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

$$\text{Annual Accident Reduction} = \frac{365\,(Vf)\,(Rf-Ra)\,(L)}{10^6} \quad \Big\}\ \text{for sections}$$

b. Example

The following is an example of estimating accident reduction by assuming reduction to an average accident rate:

1. Using California's statewide average rates shown below, the average accidents per million vehicle miles for a rural 4-lane expressway with ADT = 58,000 is 3.0 Acc/MVM. Note that Figure E-1 shows that this rate has been demonstrated to change with ADT.

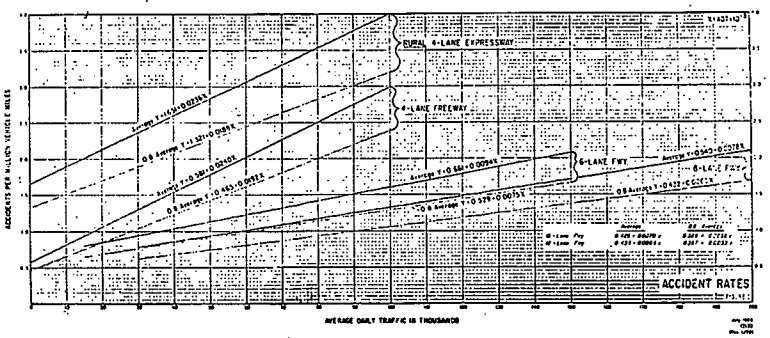


Figure E-1
Accident Rate vs. ADT

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.

Year	Rate
5 years ago	4.4 Acc/MVM
4 years ago	4.2
3 years ago	4.6
2 years ago	5.0
Last year	4.8
5 year average	4.6 = Rf

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.

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

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 locations 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:

- past 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 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.

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

$$\text{Annual Accident Reduction} = \frac{365\,(Rf)(Vf)(R\%)}{10^6} \quad \Big\}\ \text{For spot locations}$$

$$\text{Annual Accident Reduction} = \frac{365\,(Rf)(Vf)(R\%)(L)}{10^6} \quad \Big\}\ \text{For sections}$$

b. Example

The following is an example of estimating accident reduction using the rate of percentage reduction in accident rate for all accident types.

1. The expected accident rate reduction, R%, is 0.40.

2. Average accident rate for past 5 years is 5.5 Acc/MV. Use an Rf of 5.5 Acc/MV.

3. Reductions for each of the 5 years of improvement's service life are:

Year After Implementation	Future Accident Rate Rf	Future Traffic Volume Vf	Expected Accident Rate Reduction R%	Estimated Accident Reduction
1	5.5 Acc/MV	5,000VPD	40%	4.0 Acc
2	5.5	5,250	40	4.2
3	5.5	5,500	40	4.4
4	5.5	5,750	40	4.6
5	5.5	6,000	40	4.8

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 Users' Manual for a discussion of these methods.)

2. For each type of accident, estimate future accident rates, Rfi, 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 <u>each year</u> of the service life of the improvement.

$$\text{Annual Accident Reduction} = \sum \frac{365\,(Rfi)(Vf)(R\%i)}{10^6} \quad \Big\} \text{ For spot locations}$$

$$\text{Annual Accident Reduction} = \sum \frac{365\,(Rfi)(Vf)(R\%i)(L)}{10^6} \quad \Big\} \text{ For sections}$$

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.

1. Estimate accident rate reduction by type.

Accident Type	Estimated Accident Rate Reduction
Head on	0%
Rear end	10%
Right Angle	10%
Side Swipe	20%
Left Turn	10%
Right Turn	20%
Others	0%

2. Estimate future accident rates assuming no improvement. For simplicity, use the average rates at the location for the past 4 years.

Accident Type	Future Accident Rate
Head on	0.2 Acc/MV
Rear end	0.8
Right Angle	1.9
Side Swipe	0.7
Left Turn	2.3
Right Turn	1.4
Others	0.3
Total	7.6

3. Estimate the accident reductions for each of the 3 years of the improvement's service life:

Year After Implementation	Accident Type	Future Accident Rate (Rfi)	Future Traffic Volume (Vf)	Expected Accident Rate Reduction (R%i)	Estimated Accident Reduction Type	Estimated Accident Reduction Year
1	Rear End	0.8 Acc/MV	8,000VPD	0.10	0.2	
	Right Angle	1.9	8,000	0.10	0.6	
	Side Swipe	0.7	8,000	0.20	0.4	
	Left Turn	2.3	8,000	0.10	0.7	
	Right Turn	1.4	8,000	0.20	0.8	
						2.7
2	Rear End	0.8	8,400	0.10	0.2	
	Right Angle	1.9	8,400	0.10	0.6	
	Side Swipe	0.7	8,400	0.20	0.4	
	Left Turn	2.3	8,400	0.10	0.7	
	Right Turn	1.4	8,400	0.20	0.9	
						2.8
3	Rear End	0.8	8,800	0.10	0.3	
	Right Angle	1.9	8,800	0.10	0.6	
	Side Swipe	0.7	8,800	0.20	0.4	
	Left Turn	2.3	8,800	0.10	0.7	
	Right Turn	1.4	8,800	0.20	0.9	
						2.9

SEVERITY RATE METHODS

<u>Reduction to an Average Severity Rate</u>

When it is not possible to forecast the reductions in severity rates due to improvements, but average severity rates <u>are</u> 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 systemwide 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, Rf, 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, Vf.

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.

$$\text{Annual Accident Reduction} = \frac{365\,(Vf)(Rf)}{10^6}\left[(Pf-Paf)+(Pi-Pai)+(Pp-Pap)\right] \quad \text{For spot locations}$$

$$\text{Annual Accident Reduction} = \frac{365\,(Vf)(Rf)(L)}{10^6}\left[(Pf-Paf)+(Pi-Pai)+(Pp-Pap)\right] \quad \text{For sections}$$

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.

Severity Class	Percentage
Fatal	3.0 (Paf = 0.30)
Injury	22.0 (Pai = 0.22)
Property Damage Only	75.0 (Pap = 0.75)

2. Calculate the percentage of accident types at the study location by severity class.

Severity Class	Percentage	Pf
Fatal	6.0 (Pf = 0.06)	0.06
Injury	43.0 (Pi = 0.43)	0.43
Property Damage Only	51.0 (Pp = 0.51)	0.51

3. Estimate future accident rates assuming no improvements. Use the average rates at the location for the past 5 years.

Year	Rate
5 years ago	6.1 Acc/MV
4 years ago	6.3
3 years ago	6.5
2 years ago	6.7
Last year	6.9
5 year average	6.5 = R_f

4. Forecast future traffic volumes.

Year	Volume
1	5,800 VPD
2	5,700
3	5,600
4	5,500

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

Year	Reduction
1	$\frac{(365)(5,800)(6.5)}{10^6}\left[(0.06-0.03)+(0.43-0.22)\right] = 3.3$ Acc
2	$\frac{(365)(5,700)(6.5)}{10^6}\left[(0.06-0.03)+(0.43-0.22)\right] = 3.2$ Acc

3	$\frac{(365)(5,600)(6.5)}{10^6}\left[(0.06-0.03)+(0.43-0.22)\right] = 3.2$ Acc
4	$\frac{(365)(5,500)(6.5)}{10^6}\left[(0.06-0.03)+(0.43-0.22)\right] = 3.1$ Acc

c. Procedure--Reduction of all Significantly High Severity Classes

Estimates of accident reduction using the reduction to an average severity rate method for all significantly high 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 accidents by severity class at the location under study.
3. Estimate the potential future accident rate, Rf, 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.
4. Determine future traffic volumes, Vf.
5. Select a level of confidence that the severity class is significantly high. (See Appendix A for a discussion on level of confidence and level of significance.)
6. Determine a value of Z for that level of confidence.

Level of Confidence	Z
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

7. Calculate the critical percentage, Pc, for each severity class for each year of the improvement's service life.

$$Pc = Pa + Z\,\frac{1,000}{19.105}\sqrt{\frac{Pa}{(Vf)(Rf)}} + \frac{(5)\,(10^5)}{(Vf)(Rf)(3.65)}$$

8. If the percentage of accidents in a severity class is larger than the critical percentage, Pc, it is significantly high. Include the reduction of that percentage to the average percentage in the accident reduction.
9. Calculate the expected accident reduction for each year of the service life of the improvement. Include only those severity classes that are significantly higher than average.

$$\text{Annual Fatal Accident Reduction} = \frac{365(Vf)(Rf)}{10^6}\,(Pf-Paf)$$

$$\text{Annual Injury Accident Reduction} = \frac{365(Vf)(Rf)}{10^6}\,(Pi-Pai)$$

$$\text{Annual Property Damage Only Accident Reduction} = \frac{365(Vf)(Rf)}{10^6}\,(Pp-Pap)$$

For spot locations

$$\text{Annual Fatal Accident Reduction} = \frac{365(Vf)(Rf)(L)}{10^6}\,(Pf-Paf)$$

$$\text{Annual Injury Accident Reduction} = \frac{365(Vf)(Rf)(L)}{10^6}\,(Pe-Pae)$$

$$\text{Annual Property Damage Only Accident Reduction} = \frac{365(Vf)(Rf)(L)}{10^6}\,(Pp-Pap)$$

For sections

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

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:

Severity Class	Percentage
Fatal	3.5 = Paf
Injury	28.5 = Pai
Property Damage Only	68.0 = Pap

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

Severity Class	Percentage
Fatal	7.0 = Pf
Injury	53.0 = Pi
Property Damage Only	40.0 = Pp

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.
6. Z = 1.282.
7. Calculate Critical Percentages for each year of service life.

Severity Class	Critical Percentage (Pc)
Fatal	$3.5 + \frac{(1.282)(1,000)}{19.105}\sqrt{\frac{3.5}{(1,000)(5.2)} + \frac{500,000}{(1,000)(5.2)(365)}} = 5.5\%$
Injury	$28.5 + \frac{(1.282)(1,000)}{19.105}\sqrt{\frac{28.5}{(1,000)(5.2)} + \frac{500,000}{(1,000)(5.2)(365)}} = 33.7\%$
Property Damage Only	$68.0 + \frac{(1.282)(1,000)}{19.105}\sqrt{\frac{68.0}{(1,000)(5.2)} + \frac{500,000}{(1,000)(5.2)(365)}} = 75.9\%$

Because the traffic volume and accident rate remain constant, the critical percentages calculated above remain constant.

8. Fatal Accident and injury accident percentages are significantly high.
9. Annual Reductions for this 0.3 mile section:

Severity Class	Estimated Annual Accident Reduction
Fatal	$\frac{(365)(1,000)(5.2)(0.3)}{10^6}(0.07 - 0.035) = 0.02$ Acc
Injury	$\frac{(365)(1,000)(5.2)(0.3)}{10^6}(0.53 - 0.285) = 0.14$ Acc

Because the traffic volume and accident rate remain constant, the accident reduction will be the same for all 15 years of the improvement's service life, namely 0.02 fatal accidents and 0.14 injury accidents per year.

The fatal accident reduction is very small. But when multiplied by the NHTSA and NSC fatal accident cost, the annual benefits are $4,700 and $1,640, respectively. The use of fractions to express accidents may appear absurd. However, it is done in lieu of trying to assign a whole accident arbitrarily to one year out of many. For example, an average of 0.02 fatal accidents per year is the same as 1 fatal accident every 50 years. To which year would this fatal accident be assigned? If it is assigned to the 25th year, it falls outside the service life of the improvement. So, it is easier to deal with averages and fractions.

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 assumption 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 relationships should be used.

6. Calculate the estimates of severity cost reduction for each year of the service life of the improvement, and sum these estimated costs.

$$\text{Annual Severity Cost Reduction} = \frac{365(Rf)(Vf)}{10^6}\left[(Pf)(Sf\%)+(Pi)(Si\%)+(Pp)(Sp\%)\right] \quad \text{For spot locations}$$

$$\text{Annual Severity Cost Reduction} = \frac{365(Rf)(Vf)(L)}{10^6}\left[(Pf)(Sf\%)+(Pi)(Si\%)+(Pp)(Sp\%)(Cp)\right] \quad \text{For sections}$$

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.

b. Example

The following is an example of estimating severity reduction using the percentage reduction of severity costs for all accident types.

1. The expected accident rate reductions by severity class are:

Severity Class	Expected Reductions
Fatal	60% (Sf% = 0.60)
Injury	20% (Si% = 0.20)
Property Damage Only	5% (Sp% = 0.05)

2. Use NHTSA cost estimates.

Severity Class	Average Cost
Fatal	$235,000 = Cf
Injury	11,200 = Ci
PDO	500 = Cp
All	2,800 = Ca

3. Determine the percent of accident by severity class.

Severity Class	Percent
Fatal	2% (Pf = 0.02)
Injury	58% (Pi = 0.58)
Property Damage Only	40% (Pp = 0.40)

4. Estimate future traffic volume.

Year After Implementation	Traffic Volume
1	5,000
2	5,500
3	6,000

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

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

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

Year After Implementation		Estimated Severity Cost Reduction
1	=	$\frac{365(5.5)(5{,}000)}{10^6}\left[(0.02)(0.60)(235{,}000) + (0.58)(0.20)(11{,}200) + (0.40)(0.05)(500)\right] = \$41{,}440$
2	=	$\frac{365(5.5)(5{,}500)}{10^6}\left[(0.02)(0.60)(235{,}000) + (0.58)(0.20)(11{,}200) + (0.40)(0.05)(00)\right] = \$45{,}640$
3	=	$\frac{365(5.5)(6{,}000)}{10^6}\left[(0.02)(0.60)(235{,}000) + (0.58)(0.20)(11{,}200) + (0.40)(0.05)(500)\right] = \$49{,}840$

Total Estimated Severity Cost Reduction = $136,920

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

$$\text{Annual Severity Cost Reduction} = \sum \frac{365(Rf)(Vf)}{10^6}\left[(Ptf)(Sf\%)(Cf)+(Pti)(Si\%)(Ci)+(Ptp)(Sp\%)(Cp)\right] \text{ For spot locations}$$

$$\text{Annual Severity Cost Reduction} = \sum \frac{365(Rf)(Vf)(L)}{10^6}\left[(Ptf)(Sf\%)(Cf)+(Pti)(Si\%)(Ci)+(Ptp)(Sp\%)(Cp)\right] \text{ For sections}$$

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:

Accident Type	Accident Severity Reduction Percentages		
	Fatal	Injury	PDO
Head on	90%	60%	15%
Rear end	40	30	10
Right angle	80	40	20
Others	10	10	40

7. Estimate percent reduction in severity cost.

$$(100)\ \frac{\text{Estimated Severity Cost Reduction}}{\text{Projected Severity Cost with no Improvements}} = \frac{\$136{,}920}{\$377{,}470}(100) = 36\%$$

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. Obtain the percentage of accidents by severity class for each accident type.
4. Estimate future traffic volumes, 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.

2. Use NHTSA cost estimates.

Severity Class	Average Cost
Fatal	$235,000 = Cf
Injury	11,200 = Ci
PDO	500 = Cp
All	2,800 = Ca

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

Accident Type	Percentages of Accidents by Severity Class			Percentage of All Accidents
	Fatal	Injury	PDO	
Head on	3%	77%	20%	20
Rear end	1	64	35	50
Right angle	2	53	45	20
Others	1	44	55	10
Total	2	62	36	

4. Estimate future traffic volumes.

Year After Implementation	Traffic Volume
1	7,500
2	8,000
3	8,500

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

$$\frac{365\,(5.5)(7{,}500 + 8{,}000 + 8{,}500)}{10^6}\left[(0.02)(235{,}000)+(0.62)(11{,}200) +(0.36)(500)\right] = \$569{,}680$$

6. The estimate of severity cost reduction for the three year after period is:

Accident Type

Head on $= \frac{365(0.2)(5.5)(24,000)}{10^6}\left[(0.03)(0.90)(235,000)+(0.77)(0.60)(11,200)+(0.20)(0.15)(500)\right]$

$= \$117,720$

Rear end $= \frac{365(0.5)(5.5)(24,000)}{10^6}\left[(0.01)(0.40)(235,000)+(0.64)(0.30)(11,200)+(0.35)(0.10)(500)\right]$

$= \$74,870$

Right Angle $= \frac{365(0.2)(5.5)(24,000)}{10^6}\left[(0.02)(0.80)(235,000)+(0.53)(0.40)(11,200)+(0.45)(0.20)(500)\right]$

$= \$59,540$

Others $= \frac{365(0.1)(5.5)(24,000)}{10^6}\left[(0.01)(0.10)(235,000)+(0.44)(0.10)(11,200)+(0.55)(0.40)(500)\right]$

$= \$4,037$

Total estimated severity cost reduction = $256,167

7. Estimate percent reduction in severity cost.

$$(100)\frac{\text{Estimated Severity Cost Reduction}}{\text{Projected Severity Cost with no Improvement}} = \frac{\$256,167}{\$569,680}(100)$$

$$= 45\%$$

The projected accident reduction would have been 31%.

g. 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.

Table E-1
Relative Severity Index Values

TYPE OF ACCIDENT	N.H.T.S.A.				N.S.C.			
	URBAN		RURAL		URBAN		RURAL	
	$ Cost	R.S.I.	$ Cost	R.S.I.	$ Cost	R.S.I.	$ Cost	R.S.I.
MULTI-VEHICLE								
At Intersection								
1. Entering at angle	4,010	13.4	19,179	63.9	1,813	4.1	6,119	13.9
2.a. From same direction--both going straight	2,890	9.6	5,051	16.8	1,459	3.3	2,337	5.3
2.b. Same--one turn, one straight	2,241	7.5	4,742	15.8	1,204	2.7	2,213	5.0
2.c. Same--one stopped	3,740	12.5	4,855	16.2	1,793	4.1	2,259	5.1
2.d. Same--all others	1,717	5.7	3,305	11.0	998	2.3	1.640	3.7
3.a. From opposite direction--both moving	3,128	10.4	16,104	53.7	1,553	3.5	5,289	12.0
3.b. Same--one left turn, one straight	5,040	16.8	15,022	50.1	2,123	4.8	5,074	11.5
3.c. Same--all others	2,605	8.7	3,669	12.2	1,347	3.1	1,785	4.1
Non-Intersection								
1. Going opposite direction	3,547	11.8	19,820	66.1	1,589	3.6	6,163	14.0
2. Going same direction	3,049	10.2	9,472	31.6	1,482	3.4	3,538	8.0
3.a. One car parked	1,371	4.6	2,127	7.1	855	1.9	1,169	2.7
3.b. One car stopped in traffic	3,838	12.8	8,349	27.8	1,865	4.2	3,213	7.3
4.a. One car entering parked position	1,705	5.7	300	1.0	993	2.3	440	1.0
4.b. One car leaving parked position	953	3.2	2,191	7.3	697	1.6	1,195	2.7
5.a. One car entering alley or driveway	3,048	10.2	8,110	27.0	1,492	3.4	3,146	7.2
5.b. One car leaving alley or driveway	1,958	6.5	4,811	16.0	1,047	2.4	2,088	4.7
6. All others	1,632	5.4	5,646	18.8	964	2.2	2,569	5.8
PEDESTRIAN	17,656	58.9	74,145	247.2	6,228	14.2	20,838	47.4
RAILROAD TRAIN	31,113	103.7	61,618	205.4	8,976	20.4	17,097	38.9
BICYCLE	12,192	40.6	36,199	120.7	4,837	11.0	11,295	25.7
ANIMAL	3,452	11.5	1,659	5.5	1,680	3.8	936	2.1
FIXED OBJECT	5,191	17.3	8,980	29.9	2,185	5.0	3,256	7.4
OTHER OBJECT	2,958	9.9	5,852	19.5	1,486	3.4	2,247	5.1
OVERTURNED ON ROADWAY	8,340	27.8	10,684	35.6	3,603	8.2	3,927	8.9
RAN OFF ROADWAY	7,476	24.9	12,675	42.3	2,863	6.5	4,463	10.1

Appendix F

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[1]
    - Benefit/cost ratio[2]
    - Rate of Return
    - Payback period

[1] Alternatives are independent if the selection of one alternative does not preclude the selection of any of the other alternatives at the same time.

[2] Recommended in Users' Manual

  + Methods for evaluating mutually exclusive alternatives[3]
    - Net annual benefit[2]
    - Net present worth
    - Incremental benefit/cost ratio

- Evaluation methods based on cost effectiveness. These methods 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[1]
    - Cost/effectiveness ratio
  + Methods for evaluating mutually exclusive alternatives[3]
    - Incremental cost/effectiveness

[1] Alternatives are independent if the selection of one alternative does not preclude the selection of any of the other alternatives at the same time.

[2] Recommended in Users' Manual

[3] Alternatives are mutually exclusive if the selection of one alternative precludes the selection of any of the other alternatives at the same time.

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^i_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	=	Interest/discount rate
I	=	Initial cost
IB/IC	=	Incremental Benefit/Cost Ratio
IC/IE	=	Incremental 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
n	=	Service life
NAB	=	Net Annual Benefit
NPW	=	Net Present Worth
P	=	Annual percent increase in cost
PW^i_n	=	Present Worth Factor* for nth 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^i_n	=	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.

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.

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)

a. Procedure

The Equivalent Uniform Annual Cost, EUAC, of an improvement is calculated in the following manner:

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:
   If the annual costs, K, are assumed to remain constant over the service life of the improvement

$$EUAC = (I)\,CR^i_n + K - (T)\,SF^i_n$$

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

$$EUAC = CR^i_n\,(I) + \sum_{m=1}^{n} (K_m)\,PW^i_m) - (T)\,SF^i_n$$

where K_m is the annual cost (e.g., maintenance, operation) which is incurred in year m, and PW^i_m 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.

b. 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%.

$$\begin{aligned} EUAC &= (I)\,CR^i_n + K - (T)\,SF^i_n \\ &= (I)\,CR^{10\%}_{12} + K - (T)\,SF^{10\%}_{12} \\ &= (40{,}000)(0.014676) + 750 - (1000)(0.04676) \\ &= 5871 + 750 - 47 \\ &= \$6574/yr. \end{aligned}$$

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.

a. 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 = Annual Benefit

If the benefits vary from year to year,

$$EUAB = CR_n^i \sum_{m=1}^{n} B_m \; PW_m^i$$

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.

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

a. 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 an improvement,

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

If the annual costs vary from year to year over the service life of the improvement,

$$PWOC = I - T \cdot PW_n^i + \sum_{i=1}^{n} K_i \cdot PW_i^i$$

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,

$$PWOC = I - T\ (PW^i_n) + K\ (SPW^i_n)$$

$$= 40,000 - 2,500\ (0.3855) + 1000\ (6.1446)$$

$$= 45,180$$

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

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,

$$PWOB = B\ (SPW^i_n)$$

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

$$PWOB = \sum_{m=1}^{n} B_m\ PW^i_m$$

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:

$$PWOB = B\ (SPW^{10}_{10})$$

$$= 5,000\ (6.1446)$$

$$= \$30,720$$

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 F-1.
Basic Data for Examples

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

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.

a. 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, [1] EUAB (see procedure on page F-8) or as Present Worth of Benefits, [1] PWOB (see procedure on page F-12).
5. Express costs as Equivalent Uniform Annual Costs, [1] EUAC (see procedure on page F-6) or as Present Worth of Costs, [1] PWOC (see procedure on page F-10).
6. Calculate the benefit/cost ratio, B/C, of each improvement:

$$B/C = \frac{EUAB}{EUAC} = \frac{PWOB}{PWOC}$$

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.

b. 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.

[1] See additional assumption required if improvements have different service lives.

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

Improvement	EUAB
A	80,000
B	55,000
C	25,000
D	40,000

5. Calculate the EUAC for each improvement:

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

For improvement A:

$$EUAC = (200,000)\, CR_{20}^{10\%} + 4000 - (20,000)\, SF_{20}^{10\%}$$

$$= (200,000)\,(0.11746) + 4000 - (20,000)(0.01746)$$

$$= \$27,143$$

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

B EUAC = (100,000)(0.13147) + 2000 - (10,000)(0.03147)= $14,833

C EUAC = (50,000)(0.16275) + 1000 = $ 9,137

D EUAC = (75,000)(0.16275) = $12,206

6. Calculate the benefit cost ratio for each improvement:

Improvement	Benefit/Cost Ratio
A	80,000/27,143 = 2.95
B	55,000/14,833 = 3.71
C	25,000/ 9,137 = 2.74
D	40,000/12,206 = 3.28

7. 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 internal rate of return method are:

- initial cost
- annual cost
- terminal value
- service life
- annual benefits.

a. 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.

$$0 = I - (B-K)\, SPW_n^i - T\ PW_n^i$$

The calculation of a rate-of-return must be done by trial and error. The time and effort required by the trial and error procedure is the major disadvantage of this method. However, many data processing facilities have computer programs to calculate the internal rate-of-return.

For improvements that have no terminal value or have a perpetual service life, the rate-of-return may be solved using the equation given below.

$$\frac{B-K}{I} = Cr_n^i$$

The symbol i is the rate of return.

This formula can also be used to identify a starting point in the iterative process required when an improvement does have a terminal value.

4. Order the improvements by magnitude of the rate-of-return, largest to smallest.

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 costs
- 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

$$I = K_1 \; PW_1^i + K_2 \; PW_2^i + \ldots . \; K_p \; PW_p^i$$

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 steps 1-3.

4. Calculate the payback period:

Payback Period of A:

$\$ 200,000 = (80,000-4,000)(0.909)+(80,000-4,000)(0.826) + (80,000-4,000+20,000)(0.751) = 203,956$

Improvement A will repay its cost in just under 3 years.

Payback Period of B:

$\$100,000 = (55,000-2,000)(0.909)+(55,000-2,000+10,000)(0.826) = \$100,215$

Improvement B will repay its cost in slightly under 2 years.

Payback Period of C:

$\$50,000 = (25,000-1,000)(0.909)+(25,000-1,000)(0.826) = \$41,640$ in 2 years

$\$50,000 = (25,000-1,000)(0.909)+(25,000-1,000)(0.826) +(25,000-1,000)(0.751) = 59,664$ in 3 years

Improvement C will repay its cost in 2½ years.

Payback Period of D:

$\$75,000 = (40,000)(0.909)+(40,000)(0.826) = 69,400$

Improvement D will repay its cost in a little over 2 years.

5. Improvement B is Best

Improvement	Rank
B	Best
D	Second Best
C	Third Best
A	Fourth Best

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.

a. Procedure

Steps for using cost/effectiveness to rank independent improvements are:

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.

b. 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.

3. Calculate equivalent uniform annual costs.

Improvement		EUAC
A	=	$27,150
B	=	$14,850
C	=	$ 9,150
D	=	$12,100

4. Use number of accidents as the unit of effectiveness.

5. Estimate the average annual benefits:

Improvement	Average Annual Accident Reduction Benefit
A	32 accidents
B	22
C	10
D	16

6. Calculate the Cost/Effectiveness.

Improvement	Cost Effectiveness
A	27,150 / 32 = $848 per accident reduced
B	14,850 / 22 = 675 per accident reduced
C	9,150 / 10 = 915 per accident reduced
D	12,200 / 16 = 762 per accident reduced

7. The array for those improvements is: B, D, A, C.

METHODS 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.

The data requirements of the net annual benefit method are:

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

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

b. Example

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

Improvement	EUAB
A	80,000
B	55,000
C	25,000
D	40,000

5. Calculate the EUAC of each improvement.

Improvement		EUAC
A	=	$27,143
B	=	$14,833
C	=	$ 9,137
D	=	$12,206

6. Calculate the NAB of each improvement.

Improvement	NAB
A	80,000 - 27,143 = $52,857
B	55,000 - 14,833 = $40,167
C	25,000 - 9,137 = $15,863
D	40,000 - 12,206 = $27,794

7. Select improvement A among those mutually exclusive alternatives because it has the highest net annual benefits.

Net Present Worth

This method, also known as "Net Present Value," selected the same improvements as the net annual benefit method or the incremental benefit/cost ratio. 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 present worth.

If the improvements have different service lives, it may be assumed that each improvement can be re-applied at the end of its service life.

The data requirements of the net present worth 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.

a. Procedure

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 present worth of benefits. (See procedure on page F-12)
6. Calculate the net present worth, NPW, of each improvement.
   NPW = PWOB - PWOC
7. Select the improvement with the greatest net present worth.

b. Example

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 60-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.

4. Calculate Present Worth of Costs.

Improvement	Present Worth of Costs
A	200,000 - 20,000 (0.149) + 200,000 (0.149) -20,000 (0.021) + 200,000 (0.021) -20,000 (0.003) + 4,000(9.967) = $270,400

Improvement	Present Worth of Costs
B	100,000 - 10,000 (0.240) + 100,000 (0.240) -10,000 (0.057) + 100,000 (0.057) -10,000 (0.014) + 100,000 (0.014) -10,000 (0.003) + 2,000 (9.967) = $147,900
C	50,000 + 50,000 (0.386) + 50,000 (0.149) +50,000 (0.057) + 50,000 (0.022) +50,000 (0.009) + 50,000 (0.003) + 1,000 (9.967) = $91,250
D	75,000 + 75,000 (0.386) + 75,000 (0.149) +75,000 (0.057) + 75,000 (0.022) + 75,000(0.009) +75,000 (0.003) = $121,950

5. Calculate Present Worth of Benefits.

Improvement	Present Worth of Benefits
A	(80,000) (9.967) = 797,350
B	(55,000) (9.967) = 548,200
C	(25,000) (9.967) = 249,200
D	(40,000) (9.967) = 398,700

6. Calculate Net Present Worth.

Improvement	Net Present Worth
A	797,350 - 270,400 = 526,950
B	548,200 - 147,900 = 400,300
C	249,200 - 91,250 = 157,950
D	398,700 - 121,950 = 276,750

7. Select improvement A because it has the largest 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.

If the alternative improvements have different service lives and equivalent uniform annual benefits and costs are used, it may be assumed that when 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.

Again, if the improvements have different service lives but present worths of benefits and costs are used it is assumed that each improvement can be re-applied. at the end of its service life.

The data requirements of the incremental benefit/cost ratio method are:

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

One of the most common errors in economic analysis is the use of the benefit/cost ratio, B/C, where the incremental benefit/cost ratio, IB/IC, should be used. One of the principal reasons for this incorrect usage is a misunderstanding of the differences between the two methods.

The B/C ratio is the average return for each dollar invested. For example, a B/C ratio of 1.4 means that on the average $1.40 is returned in benefits for each dollar invested. The law of diminishing returns tells us that as more money is invested, the return for each additional dollar may begin to decline. For example, the return on the first $10,000 of a $30,000 three-stage project may be $16,000, the return on the second $10,000 may be $14,000 and the return on the third $10,000 may be $12,000. The B/C ratio of this project is 1.4. If overall benefit-cost ratio were used, the project would be carried through to completion regardless of returns for different stages of expenditure. However, if spending were stopped after the first $10,000, the B/C ratio would be 1.6. For the greatest economic return, the second $10,000 should be spent on this project only if there were no projects where the $10,000 could be invested to obtain a return greater than 1.4. Likewise, the third $10,000 should be

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, tha 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, K, T and n 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)

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.

$$IB/IC = \frac{B_i - B_b}{C_i - C_b}$$

Where: B_i = Benefits of improvement under consideration
B_b = Benefits of the best lower cost improvement
C_i = Cost of improvement under consideration
C_b = 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)

Present Worth of Benefits (PWOB)

(See procedure on page F - 12)

Equivalent Uniform Annual Benefits (EUAB)

(See procedure on page F -8)

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

$$B/C = \frac{\text{Present Worth of Benefits}}{\text{Present Worth of Costs}}$$

$$= \frac{\text{Equivalent Uniform Annual Benefits}}{\text{Equivalent Uniform Annual Costs}}$$

Only those improvements with a B/C ratio greater than 1 will be included in further analysis.

6. List the improvements with a B/C ratio 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 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.

Improvement		EUAC	EUAB
A	=	$27,143	$80,000
B	=	14,832	55,000
C	=	9,138	15,000
D	=	12,206	40,000

5. Calculate the benefit/cost ratio.

Improvement	Benefit/Cost Ratio
A	80,000/27,143 = 2.95
B	55,000/14,832 = 3.71
C	15,000/9,138 = 2.74
D	40,000/12,206 = 3.28

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

Improvements	EUAC	EUAB
C	9,138	25,000
D	12,206	40,000
B	14,832	55,000
A	17,143	80,000

7. Calculate the incremental benefit/cost ratio of D to C.

$$IB/IC = \frac{40,000 - 25,000}{12,206 - 9,138} = \frac{15,000}{3,068} = 4.89$$

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.

8. Calculate the incremental ratio of B to D.

$$IB/IC = \frac{55,000 - 40,000}{14,832 - 12,206} = \frac{15,000}{2,626} = 5.71$$

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

Calculate the incremental ratio of A to B.

$$IB/IC = \frac{80,000 - 55,000}{27,143 - 14,832} = \frac{25,000}{12,311} = 2.03$$

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

9. 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. (168)

The assumption behind incremental cost/effectiveness is that the relative merit of an improvement is measured by the ratio of the increase 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.

a. 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.

7. Calculate the incremental cost/effectiveness, IC/IE, for the improvement with the second lowest cost compared to the improvement with the lowest cost.

$$IC/IE = \frac{C_2 - C_1}{E_2 - E_1}$$

Where: C_1 = Costs of lowest cost improvement
C_2 = Costs of next lowest cost improvement
E_1 = Benefits of lowest cost improvement
E_2 = Benefits of second lowest cost improvement.

8. The IC/IE indicates the cost per unit of effectiveness reduction from acceptance of the next highest cost alternative. The analyst must judge whether the additional cost is justified.

If the analyst judges the cost per unit of additional effectiveness to be justifiable, the second lowest cost improvement is better than the lowest cost improvement and becomes the best lower cost improvement.

If the analyst judges the cost per unit of additional effectiveness not to be justifiable, the lowest cost improvement is the best lower cost improvement.

9. Continue, in order of increasing costs, to calculate the incremental cost/effectiveness, IC/IE, for each improvement compared to the best lower cost improvement.

$$IC/IE = \frac{C_i - C_b}{E_i - E_b}$$

Where: C_i = Cost of improvement under consideration
C_b = Cost of best lower cost improvement
E_i = Benefits of improvement under consideration
E_b = Benefits of best lower cost improvement

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.

	Improvement			
	A	B	C	D
Initial Cost, I	$500	$5,000	$10,000	$50,000
Annual Cost, K	0	500	500	1,000
Terminal Value, T	100	0	1,000	1,000
Service Life, n	10	5	25	15

Interest Rate, i = 10%

3. Calculate equivalent uniform annual costs.

Improvement		EUAC
A	=	0.163 (500)-(100)(0.063)+0 = $75
B	=	0.264 (5,000)-0 +(500) = $1,820
C	=	0.110 (10,000)-(1,000)(0.0102)+(500) = $1,592
D	=	0.131 (50,000)+(1,000)(0.0315)+(1,000) = $7,542

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

5.

Improvement	Estimated Annual Accident Reduction
A	3
B	10
C	25
D	30

6. List improvements in order of increasing equivalent uniform annual cost.

Improvement	EUAC
A	$ 75
C	1,592
B	1,820
D	7,542

7. Compare C to A.

$$IC/IE = \frac{1,592 - 75}{25 - 3} = \frac{1,517}{22}$$

= $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.

$$IC/IE = \frac{1,820 - 1,592}{10 - 25} = \frac{228}{-15}$$

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

10. Compare D to C.

$$IC/IE = \frac{7,542 - 1,592}{30 - 25} = \frac{5,950}{5}$$

= $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[1] Mathematical Tables From Handbook of Chemistry and Physics[1] or CRC Mathematical Tables From Handbook of Chemistry and Physics[1].

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

Compound Amount Factor (CAF)

- Amount at Compound Interest
- 1 divided by Present Worth Factor
- For $i = 0$, CAF = 1, For all other values of i, CAF = $(1 + i)^n$

Present Worth Factor (PWF)

- Present Value
- 1 divided by Compound Amount Factor
- For $i = 0$, PWF = 1, For all other values of i, PWF = $\frac{1}{(1 + i)^n}$

Series Compound Amount Factor (SCAF)

- Amount of Annuity
- 1 divided by Sinking Fund Factor
- For $i = 0$, SCAF = n. For all other values of i, SCAF = $\frac{(1 + i)^n - 1}{i(1 + i)^n}$

Capital Recovery Factor (CRF)

- Annuity whose Present Value is 1
- 1 divided by Series Present Worth Factor
- For $i = 0$, CRF = $\frac{1}{n}$. For all other values of i, CRF = $\frac{i(1 + i)}{(1 + i)^n - 1}$

Sinking Fund Factor (SFF)

- 1 divided by Series Compound Amount Factor
- For $i = 0$, SFF = $\frac{1}{n}$. For all other values of i, SFF = $\frac{i}{(1 + i)^n - 1}$

Series Present Worth Factor (SPWF)

- Present Value of Annuity
- 1 divided by Capital Recovery Factor
- For $i = 0$, SPWF = n. For all other values of i, SPWF = $\frac{(1 + i)^n - 1}{i(1 + i)^n}$

1 Published by Chemical Rubber Publishing Co., Cleveland, Ohio

Table F-3

Interest Factors for i = 10%

Number of Periods (n)	SINGLE PAYMENT: Compound Amount Factor (CAF) $(1+i)^n$	SINGLE PAYMENT: Present Worth Factor (PWF) $\frac{1}{(1+i)^n}$	UNIFORM SERIES OF PAYMENTS: Sinking Fund Factor (SFF) $\frac{i}{(1+i)^n - 1}$	UNIFORM SERIES OF PAYMENTS: Compound Amount Factor (SCAF) $\frac{(1+i)^n - 1}{i}$	UNIFORM SERIES OF PAYMENTS: Present Worth Factor SPWF) $\frac{(1+i)^n - 1}{i(1+i)^n}$	UNIFORM SERIES OF PAYMENTS: Capital Recovery Factor (CRF) $\frac{i(1+i)^n}{(1+i)^n - 1}$	Number of periods (n)
1	1.10000	0.90909	1.00000	1.00000	0.90909	1.10000	1
2	1.21000	0.82645	0.47619	2.10000	1.73554	0.57619	2
3	1.33100	0.75131	0.30211	3.31000	2.48685	0.40211	3
4	1.46410	0.68301	0.21547	4.64100	3.16987	0.31547	4
5	1.61051	0.62092	0.16380	6.10510	3.79079	0.26380	5
6	1.77156	0.56447	0.12961	7.71561	4.35526	0.22961	6
7	1.94872	0.51316	0.10541	9.48717	4.86842	0.20541	7
8	2.14359	0.46651	0.08744	11.43589	5.33493	0.18744	8
9	2.35795	0.42410	0.07364	13.57948	5.75902	0.17364	9
10	2.59374	0.38554	0.06275	15.93742	6.14457	0.16275	10
11	2.85312	0.35049	0.05396	18.53117	6.49506	0.15396	11
12	3.13843	0.31863	0.04676	21.38428	6.81369	0.04676	12
13	3.45227	0.28966	0.04078	24.52271	7.10336	0.14078	13
14	3.79750	0.26333	0.03575	27.97498	7.36669	0.13575	14
15	4.17725	0.23939	0.03147	31.77248	7.60608	0.13147	15
16	4.59497	0.21763	0.02782	35.94973	7.82371	0.12782	16
17	5.05447	0.19784	0.02466	40.54470	8.02155	0.12466	17
18	5.55992	0.17986	0.02193	45.59917	8.20141	0.12193	18
19	6.11591	0.16351	0.01955	51.15908	8.36492	0.11955	19
20	6.72750	0.14864	0.01746	57.27499	8.51356	0.11746	20
21	7.40025	0.13513	0.01562	64.00249	8.64869	0.11562	21
22	8.14027	0.12285	0.01401	71.40274	8.77154	0.11401	22
23	8.95430	0.11168	0.01257	79.54301	8.88322	0.11257	23
24	9.84973	0.10153	0.01130	88.49731	8.98474	0.11130	24
25	10.83470	0.09230	0.01017	98.34704	9.07704	0.11017	25
26	11.91817	0.08391	0.00916	109.18175	9.16095	0.10916	26
27	13.10999	0.07628	0.00826	121.09992	9.23722	0.10826	27
28	14.42099	0.06934	0.00745	134.20991	9.30657	0.10745	28
29	15.86309	0.06304	0.00673	148.63091	9.36951	0.10673	29
30	17.44940	0.05731	0.00608	164.49399	9.42691	0.10608	30
35	28.10243	0.03558	0.00369	271.02431	9.64416	0.10369	35
40	45.25925	0.02209	0.00226	442.59246	9.77905	0.10226	40
45	72.89047	0.01372	0.00139	718.90466	9.86281	0.10139	45
50	117.39082	0.00852	0.00086	1163.90822	9.91481	0.10086	50
60	304.48154	0.00328	0.00033	3004.81540	9.96716	0.10033	60

APPENDIX G
SENSITIVITY AND RISK ANALYSIS

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 effect 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 analyst 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 I, 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.

	Alternative		
	No Change	1	2
Initial Cost (I)	0	$315,000	$650,000
Annual Maintenance (K)	20,000	24,000	30,000
Terminal Value (T)	0	10,000	30,000
Accidents/yr			
Fatal	2	1	0
Injury	30	26	20
PDO	70	60	60

The costs for I, 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.

Alternative	EUAC
No change	20,000
1	75,780
2	135,930

The incremental benefit cost ratios for the base conditions described above are showing in line A of Table G-1. I can be seen that both Alternatives 1 and 2 are worthwhile, but the incremental analysis (1 vs. 2) indicates that Alternative 2 is better than Alternative 1.

Table G-1
Sensitivity of the Incremental Benefit/Cost Ratio

Condition	1 vs. No Change	2 vs. No Change	2 vs. 1	Choice
A. Base Conditions	1.25	1.19	1.13	2
B. Decrease n from 8 to 7 years	1.14	1.08	1.03	2
C. Increase i from 7% to 8%	1.21	1.15	1.09	2
D. Increase I and K by 15%	1.04	1.01	0.98	1
E. All Terminal Values = $0	1.23	1.16	1.10	2
F. No PDO Accident Reduction	1.11	1.12	1.19	2
G. No injury accident reduction	1.04	0.93	0.83	1
H. No fatal accident reduction	0.36	0.33	0.30	No Change
I. PDO accident cost = $600/acc	1.22	1.17	1.13	2
J. Injury accident cost = $1,500/acc	1.15	1.06	0.98	1
K. Fatal accident cost = $40,000/acc	1.07	1.02	0.96	1
L. Fatal accident cost = $30,000/acc	0.90	0.84	0.80	No Change

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 B of Table G-1 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 ten years, for example, Alternative 2 would improve its ratio with respect to both the no change alternative and Alternative 1.

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.

Sensitivity to Construction and Maintenance Costs

In some cases it is possible that construction and maintenance costs may be estimated inaccurately. If the base conditions are assumed, with the exception that construction and maintenance costs for Alternatives 1 and 2 are increased by 15 percent, the EUAC for these alternatives will increase. The terminal values are assumed to remain the same. Line D of Table G-1 indicates that as a result of this change, Alternatives 1 and 2 still have favorable B/C ratios with respect to the no change condition, but that using an incremental comparison, 1 is better than 2. With a 15 percent decrease in construction and maintenance costs, Alternative 2 is again the best.

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 one percent in the interest rate. Using incremental benefit/cost analysis, Alternative 2 remains the best proposal.

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.

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/accident also favors Alternative 1, while with a cost of $30,000 per fatal accident neither alternative is justified.

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.

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 items 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 $\pm$ 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
   $\sum$ = Summation for all possible values of the data

   Since P is unitless, E will be in the same units as X. If X represents possible values of the initial cost in dollars, E will also be expressed in dollars.

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

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 1 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.

Table G-2

Expected Values of Each Data Item at Site X

	No. Change			Countermeasure 1			Countermeasure 2		
Factor	Value	Probability	Expected Value	Value	Probability	Expected Value	Value	Probability	Expected Value
Initial Cost, I									
Best judgment value	$0	1.00		$412,[illegible]	0.30		$650,000	0.60	
Best judgment value -10%	-	0.00	$0	283,500	0.30	$311,850	585,000	0.20	$650,000
Best judgment value +10%	-	0.00		346,500	0.20		715,000	0.20	
Annual Cost, K									
Best judgment value	$20,000	0.80		$24,000	0.40		$30,000	0.50	
Best judgment value - 15%	17,000	0.10	$20,000	20,400	0.30	$24,000	25,500	0.30	$29,550
Best judgment value + 15%	23,000	0.10		27,600	0.30		34,500	0.20	
Terminal Value, t									
Value #1	$ 50	1.00		$0	0.10		$0	0.00	
Value #2	10,000	0.00	$0	10,000	0.80	$10,000	10,000	0.11	
Value #3	20,000	0.00		20,000	0.10		20,000	0.10	
Value #4	30,000	0.00		30,000	0.00		30,000	0.80	
Fatal Accidents per Year									
Value #1	0 Acc.	0.00		0 Acc.	0.20		0 Acc.	0.60	
Value #2	1	0.10		1	0.60		1	0.30	
Value #3	2	0.85	1.95 Acc.	2	0.20	1.00 Acc.	2	0.10	0.50 Acc.
Value #4	3	0.05		3	0.00		3	0.00	
Injury Accidents per Year									
Value #1	15 Acc.	0.00		15 Acc.	0.00		15 Acc.	0.10	
Value #2	20	0.00		20	0.20		20	0.80	
Value #3	25	0.70	29.5 Acc.	25	0.50	25.5 Acc.	25	0.10	20.0 Acc.
Value #4	30	0.20		30	0.30		30	0.00	
Value #5	35	0.10		35	0.00		35	0.00	
PDO Accidents per Year									
Value #1	50 Acc.	0.00		50 Acc.	0.10		50 Acc.	0.30	
Value #2	60	0.10		60	0.70		60	0.60	
Value #3	70	0.80	70 Acc.	70	0.20	61 Acc.	70	0.10	53 Acc.
Value #4	80	0.10		80	0.00		80	0.00	
Service Life, n									
Value #1	6 years	0.00		6 years	0.20		6 years	0.10	
Value #2	8	1.00	8 years	8	0.60	8 years	8	0.50	8.6 years
Value #3	10	0.00		10	0.20		10	0.40	
Interest Rate, i									
Value #1	6%	0.00		6%	0.10		6%	0.10	
Value #2	7	1.00	7%	7	0.80	7%	7	0.60	7.2%
Value #3	8	0.00		8	0.10		8	0.30	

2. The expected value of a particular data item is calculated. For the initial cost of Alternative 1,

$$E(I_1) = \sum (P)(I)$$
$$= (0.3)(\$283,500) + (0.2)(346,500) + (0.5)(\$315,000)$$
$$= \$311,850$$

   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.

Condition	B/C ratio
No change vs. 1	1.21
No change vs. 2	1.00
1 vs. 2	0.78

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 (1.27×10^{-4}). 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 possiblities, 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)

Appendix H

ALABAMA'S HIGHWAY SAFETY BUDGET MAXIMIZATION SYSTEM

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 alternate. 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".[1] 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 L 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.

[1] First introduced by Richard Bellman. (11)

Form BM 172
June 1973

Page ___ of ___

HIGH ACCIDENT LOCATION INVESTIGATION FORM

(1) Location: _____ Urban ( ) Rural ( )

(2) Time Period of Accident History (Years): _____

(3) Date: _____ (4) Investigators: _____

Number of Causes (5) Roadway Environment Causes	(6) No. Accid.	Severity During Accident History (7) No. Fat.	(8) No. Non Fat. Inj.	(9) No. Pro. Dam.
1.				
2.				
3.				
4.				

Number of Alternatives (10) Alternatives (Description)	(11. Cost	(12. Life	(13. Maint. Cost/Yr.	(14. Effect on Cause 1.	2.	3.	4.
1.							
2.							
3.							

Figure H-1. Form BM 172 Used as Input

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 (9,8), CSEF (20,11 ), B (8)
      READ (5,10) IOP1, IOP2, IOP2, IOP3, IOP4, (TITL (I), I=19)
   10 FORMAT (4I1, 19A4)
      READ (5, 11) CFAT, CINJ, CPDO, RURB, RRUR
   11 FORMAT (8F10.0)
      WRITE (6,15) (TITL(I), I=1,19)
   15 FORMAT (20X,19A4)
      WRITE (6,16) IOP1, IOP2, IOP3, IOP4
   16 FORMAT (/' OPTION 1 2 3 4'/ 9 X, 4I4)
      WRITE (6, 17) RURB. RRUR
   17 FORMAT (/' INJ/FAT RATIO URBAN=',F5.1,', RURAL= ',F5.2)
      WRITE (6,18) CFAT, CINJ, CPDO
   18 FORMAT (' NEG UTILITY FATALITY= ',F7.0, ' INJURY=',F6.0,' PRP
      DM=' 2,F5.0/////)
C     THE ABOVE READS AND PRINTS THE BASIC PARAMETERS CONSTANT
C          FOR THE ENTIRE PROGRAM.
C     BELOW IS THE INPUT WHICH IS EXECUTED FOR EACH ACCIDENT
      LOCATION.
      N=0
    1 READ (5,20) NO1, (XLOC (I),I=1,16), ILOC,TIME,NMO,NYR,NCAU
      N=N=1
   20 FORMAT (I4, 16A4, 2XI1, F4.0,I2,I2,I1)
      IF(NO1) 98,99,98
   98 CONTINUE
      IF (IOP2) 122,123,122
  122 WRITE (6,121) NO1, (XLOC(I),I=1,16)
  121 FORMAT (        3X, I4, 2X, 16A4)
      READ (5,30) NO 2,((SEV(I,J), J-1,4), I=1,NCAU),ALT
      NALT=ALT/10.+.1
      NJ = 3 + NCAU
      DO145  I = 1,NALT
      READ (5,50)NO3,*SCEF(I,J), J=1,NJ)
  145 CONTINUE
      GO TO 1
  123 CONTINUE
      IF (IOP3.EQ.0) GO TO 1123
      NCK = N/2
      NCK = 2*NCK
      IF (N.EQ.NCK) GO TO 1125
 1123 WRITE (6,22)
   22 FORMAT (1H1)
      WRITE (6,1127)
```

```
1127  FORMAT (//' REF NO')
      GO TO 1128
1125  WRITE (6, 125)
 125  FORMAT ( ///// ' REF  NO ')
1128  CONTINUE
      IF (NCAU.EQ.1)  GO TO 129
       WRITE (6,21) NO1, (XLOC(I), I=1, 16), TIME, NMO, NYR. NCAU
 21    FORMAT (3X,I4,8X,16A4,//9X, 'ACCIDENT HISTORY ' F4.2,
     2' YEARS.  MONTH ', I
     12,', YEAR ', I2, ',  ' , I1, ' CAUSES. ' )
      GO TO 130
 129  WRITE (6,29)  NO1, (XLOC (I), I=1,16), TIME, NMO, NYR, NCAU
 29   FORMAT (3X,I4, 8X, 16A4,//9X, ' ACCIDENT HISTORY ', F4.2,
      2' YEARS.  MONTH ' , I
      12, ', YEAR ', I2, ' , ', I1, ' CAUSE. ')
 130  CONTINUE
C     ROUTINE FOR ASSISTING RURAL OR URBAN RATIOS BELOW.
      IF (ILOC-1)  24,23,24
 23   WRITE (6,25)
 25   FORMAT ('     AREA CONSIDERED URBAN.')
      R =RURB
      GO  TO  28
 24   WRITE (6, 26)
 26   FORMAT ('     AREA CONSIDERED RURAL. ')
      R = RRUR
 28   CONTINUE
C     SECOND CARD INPUT FOR EACH CRITICAL LOCATION (SEVERITIES).
      READ *%,30)NO2,((SEV(I,J),J=1,4), I = 1,NCAU),ALT
 30   FORMAT (I4,38F2.0)
      NALT = ALT/ 10.+.1
C     ROUTINE TO CHECK CARD SEQUENCE CODE.
      IF (NO1-NO2)  35,36,35
 35   WRITE (6,37)NO1,NO2
 37   FORMAT ('  SEQUENCE/CODE  NO.  ERROR.  CHECK  ', I5, ' AND', I5,
     2' ** PROCESSING CONTINUES ')
 36   CONTINUE
C     OUTPUT OF SEVERITIES AND TOTALS.
      WRITE  (6,42)
 42   FORMAT (/ ' ROADWAY CAUSE   TACC  NFAT  NINJ  NPRO')
      TOT1=0
      TOT2=0
      TOT3=0
      TOT4=0
      DO 42  I = 1,NCAU
      WRITE  (6,40)  I, (SEV(I,J),J=1,4)
 40   FORMAT  (1X,I7,F12.0,3F6.0)
      CHECK = SEV(I,2)+ SEV*I,3) + SEV(I,4)
      IF (ABS*SEV*I,1)-CHECK)-.1)  72,69,69
```

H-5

```
 69   WRITE  (6,68)  I
 68   FORMAT  (' ERROR IN NUMBER COUNT IN SEVERITY, CAUSE', I3/,
     2'  ***PROCESSING CONTINUES, TOTAL IS IGNORED. ')
 72   CONTINUE
      TOT1=TOT1+  SEV(I,1)
      TOT2=TOT2 + SEV(I,2)
      TOT3=TOT3 + SEV(I,3)
      TOT4=TOT4 + SEV(I,4)
 41   CONTINUE
      WRITE(6,43)  TOT1,TOT2,TOT3,TOT4
 43   FORMAT('  TOTALS', F12.0,3F6.0)
      INPUT NEXT SET OF NATL CARDS, ONE FOR EACH ALTERNATIVE.
      NJ=3+NCAU
      DO 45  I = 1, NALT
      READ  *5,50)NO3, *CSEF*I,J),  J=1, NJ)
 50   FORMAT *I4,F7.0,F2.0,F5.0,8F3.2)
      IF(NO3-NO1) 51,52,51
 51   WRITE*6,37)  NO1,  NO3
 52   CONTINUE
 45   CONTINUE
C     OUTPUT OF ALTERNATIVE INFORMATION.
      WRITE (6,58)(I, I=1, NCAU)
 58   FORMAT( / ' ALTERNATIVE  COST  LIFE  MAIN COST  EFFECT ON...',
     1815)
C     NUMBER COUNT CHECK OF SEVERITIES.
      DO  70  I=1, NALT
      WRITE(6,71)  I, (CSEF(I,J), J=1, NJ)
 71   FORMAT(I7,F13.2,F8.0,F9.2,F24.2,7F5.2)
 70   CONTINUE
C     COMPUTATION OF B(I), THE ITH ALTERNATIVE BENEFIT.
      Q=(CFAT + R * CINJ)  /(1.+R)
      DO  75  I=1, NALT
      B(I)  = 0.
      DO  76  J=1, NCAU
      JEFT = J +3
      B(I) = B (I) + Q*(SEV*J,2)+SEV(J,3))*CSEF(I,JEFT))+CPDO*SEV(J,4)*
     1CSEF(I,JEFT)
 76   CONTINUE
 75   CONTINUE
C     CALCULATION OF COST/BENEFITS AND OUTPUT.
      WRITE (6,80)
 80   FORMAT( /5X,' COST/BENEFIT ANALYSIS'//' ALTERNATIVE    COST
     2 BENEFIT        COST/BENEFIT')
      DO  90  I=1, NALT
      B(I)=B(I)*CSEF*I,2)/TIME
      CSBN=CSEF(I,1)/B(I)
      WRITE(6,91)I,CSEF (I,1),B(I), CSBN
 91   FORMAT (I7,F14.2,F14.2,F14.2,F18.4)
 90   CONTINUE
```

H-6

```
      IF(IOP3.EQ.1) GO TO 980
      WRITE (6,94)
 94   FORMAT (   /'   COST/BENEFIT ANALYSIS, MAINTENANCE INCLUDED'/)
      WRITE (6,95)
 95   FORMAT( ' ALTERNATIVE   MAINTENANCE  TOTAL COST   COST/BENEF
     1IT')
      DO 97  I=1, NALT
      XMAIN=CSEF(I,2)*CSEF(I,3)
      CBNM=(CSEF(I,1)+XMAIN)/B(I)
      TMCST=CSEF(I,1)+XMAIN
      WRITE (6,96) I,XMAIN,TMCST,CBNM
 96   FORMAT (I7,F23.2,F14.2,F16.4)
 97   CONTINUE
 980  CONTINUE
      IF (IOP1) 105,106,105
 105  XNO1=NO1
      WRITE(7,107) NALT,(CSEF(I,1), I=1,NALT),XNO1
 107  FORMAT(I3,7F10.0/F10.0,/,8F10.0)
      WRITE(7,107)NALT,(B(I),I=1,NALT),XNO1
 106  CONTINUE
      GO TO 1
 99   CALL EXIT
      STOP
      END
```

H-7

DYNAMIC PROGRAMMING MODULE (DPM)

```
C     THIS MAIN PROGRAM IS THE OPTIMIZATION ROUTINE FOR THE
C     DYNAMIC PROGRAMMING ALGORITHM.  IT CALCULATES AND OUT-
C     PUTS THE OPTIMAL DECISION AND OPTIMAL RETURN FOR ALL
C     INPUT STATES OR BUDGETS.

      DIMENSION ORET (50,301),ODEC(50,301), NIN(50), NDE(51),
     *NOD(50,301),C(50,31), R(31) ,CO(30),RO(30),CX(50,31),RX(31),XNO1(50
     1)
 1    CONTINUE
      IST=0
      VRET=0.0
      READ(5,4) NSTG,NBJ,XINC,K1,K2,XNO2
 4    FORMAT (2I4,F6.0,2I4,F10.0)
      IF (NSTG)2,999,2
 2    CONTINUE
      DO 5  I=1,NSTG
 5    NIN(I)=301
 3    FORMAT (20I4)
      WRITE (6,101)
      DO 15 I=1,NSTG
      C(I,1)=0.
      READ(5 ,100) NDEC,(CX(I,IC),IC=1,NDEC),XNO1(I)
      NDE(I)=NDEC
      DO 301  IC=NDEC
      ICP1=IC+1
      C(I,ICP1)=CX(I,IC)
 301  CONTINUE
 15   CONTINUE
      WRITE (6,200) XNO2
 200  FORMAT(8X,'DPM RUN CODE ",F6.0//)
      WRITE(6,201)NSTG,NBJ,XINC,K1,K2
 201  FORMAT(4X,'STAGES---MAXIMUM---INCREMENT---LLIMIT---ULIMIT',/,
     1I9,I9,F12.2,2I9,//,'-----STAGE---INPUTS---DECISIONS')
      DO 203 I=1,NSTG
      WRITE(6,202)I,NIN(I),NDE(I)
 202  FORMAT (I9,I8,I10)
 203  CONTINUE
      WRITE(6,101)
      WRITE(6,200) XNO2
      WRITE (6,204)
 204  FORMAT (1H,' STAGE  DECISION  COST  RETURN  REF NO  CST/BEN
     1')
      IPAP=0
      NSP1=NSTG+1
      NDE(NSP1)=0
      DO 10 I=1,NSTG
      R(1)=0.
```

H-8

```
      READ(5,100) NDEC,(RX(IC),IC=1,NDEC),XNO1(I)
      DO 302  IC=1,NDEC
      ICP1=IC+1
      R(ICP1)=RX(IC)
302   CONTINUE
      NDEC=NDE(I)+1
      DO 206 IC=1,NDEC
      IX=IC=1
      RECB=R(IC)
      IF (R(IC).EQ.0.0) RECB=1
      CBEN=C(I,IC)/RECB
      WRITE(6,205)I,IX,C(I,IC),$(IC),XN01(I)   ,CBEN
205   FORMAT(I6,I9,F11.0,F11.0,F11.0,F7.0,F10.4)
206   CONTINUE
      IPAP =IPAP+NDEC
      IPI=I+1
      IPC=IPAP+NDE(IP1)
      IF(IPC.LT.50) GO TO 303
      WRITE(6,101)
      WRITE(6,200)  XN02
      WRITE(6,204)
      IPAP=0
303   CONTINUE
101   FORMAT(I3,7F10.0/8F10.0/8F10.0)
      NINP=NIN(I)
      DO 20 J=1,NINP
      CALL XING(I,J,XIN,XINC)
      DUM=-1000000000000.*NBJ
      NDEC=NDE(I)+1
      DO 30 K=1,NDEC
      CALL XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
      IF(KICK)901,901,902
902   GO TO 30
901   CONTINUE
      CALL RET (I,XIN,TDEC,VRET,R,K)
      IF(I-1)7,7,8
 7    TEST=VRET
      GO TO 11
 8    TEST=VRET+ORET(I-1,IST)
      GO TO 11
 11   IF(NBJ* (DUM-TEST))13,12,12
 13   DUM=TEST
      ODEC(I,J)=TDEC
      ORET(I,J)=DUM
      NOD(I,J)=K
 12   GO TO 29
 29   CONTINUE
 30   CONTINUE
 20   CONTINUE
 10   CONTINUE
```



```
      NINP=NIN(NSTG)
      NOPC=40/NSTG
      KKK=NOPC
      ICORO=0
      ICORO=0
      DO 40 M=K1,NINP,K2
      ICORO=ICORO+1
      J=M
      XIN=(J-1)*XINC
      IF(KKK.NE.NOPC)  GO TO 67
      WRITE(6,101)
      WRITE(6,200) XN02
      WRITE(6,16)
16    FORMAT(' ',      5X,'BUDGET  LOCATION ' , 4X, ' ALT-NUM',
     *5X,'COST',5X,'RETURN')
      KKK=0
67    KKK=KKK+1
      WRITE(6,18) XIN
18    FORMAT('0',1X,F12.2)
      CO(ICORO)=XIN
      DO 45 L=1,NSTG
      I=NSTG+1-L
      CALL XING(I,J,XIN,IXNC)
      TDEC=ODEC(I,J)
      KK=(NOD(I,J)-1)
      NO1=XNO1(I)
      WRITE(6,17)  I,NO1,KK,ODEC(I,J),ORET(I,J)
17    FORMAT(' ' , 12X,I3,1X,I4,6X,I4,F12.0,F12.0,F10.4)
      K=NOD(I,J)
      CALL XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
      J=IST
45    CONTINUE
      RO(ICORO)=ORET(NSTG,M)
40    CONTINUE
      IIX=30
      WRITE(7,100)  IIX,(CO(I),I= 1,30),XNO2
      WRITE(7,100)  IIX,(RO(I),I=1,30),XNO2
      WRITE (6,101)
101   FORMAT (' 1 ')
      GO TO 1
999   CALL EXIT
      STOP
      END
```



```
C
C        THIS SUBROUTINE INCREMENTS THE STATE VARIABLE OR BUDGET
C        FIGURE BY THE APPROPRIATE AMOUNT.
C
      SUBROUTINE XING(I,J,XIN,XINC)
      XIN=(J-1)*XINC
      RETURN
      END
```



```
C
C        THIS SUBROUTINE CALCULATES THE OUTPUT STATE NUMBER
C        RESULTING FROM THE INPUT XIN AND SAFETY MEASURE K.  IT
C        ALSO DETERMINES THE COST OF A PARTICULAR SAFETY MEASURE
C        CORRESPONDING TO STAGE I.
C
      SUBROUTINE XOUT(I,IST,XIN,K,TDEC,KICK,XINC,C)
      DIMENSION C(50,31)
      TDEC=C(I,K)
      OUT=XIN-TDEC
      IF (OUT) 10,20,20
 10   KICK=1
      GO TO 30
 20   KICK=0
      IST=(OUT/XINC) + 1.5
 30   RETURN
      END
```

```
THIS SUBROUTINE DETERMINES THE RETURN ASSOCIATED WITH
SAFETY MEASURE K.

SUBROUTINE RET (I,XIN,TDEC,VRET,R,K)
DIMENSION R(31)
VRET=R(K)
RETURN
END
```


Table H-1. Alternatives Selected at Locations 101 to 125 for Budgets of $200,000 to $3,000,000 in Increments

Location	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
101	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
102	-	C	C	C	C	C	C	C	C	C	C	C	C	C	C
103	A	-	-	-	C	-	C	C	C	C	C	C	C	C	C
104	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
105	-	-	-	-	B	-	C	C	C	C	C	C	C	C	C
106	A	A	A	A	B	A	B	B	B	B	B	B	B	B	B
107	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
108	B	C	C	C	C	C	C	C	C	C	C	C	C	C	C
109	A	-	-	-	A	-	A	C	C	A	C	C	C	C	C
110	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C
111	-	A	A	A	A	A	A	A	A	A	C	A	C	C	C
112	B	B	B	B	B	B	B	B	B	B	B	B	B	B	A
113	A	A	B	B	B	B	B	B	B	B	B	B	B	B	B
114	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
115	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
116	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
117	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
118	-	A	A	A	A	A	A	A	A	A	A	A	A	A	A
119	-	-	-	-	A	-	A	A	A	A	A	A	A	A	A
120	-	-	-	-	-	-	A	A	A	-	A	A	A	A	A
121	-	B	B	B	B	B	B	B	B	B	B	B	B	B	B
122	-	A	B	B	B	B	B	B	B	B	B	B	B	B	B
123	-	B	B	B	B	B	B	B	B	B	B	B	B	B	B
124	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
125	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B

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 from 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 users' manual. The other two methods are discussed below.

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.

a. Procedure

Steps for using a comparative parallel study to measure improvement effect 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:

$$\% \text{ Change} = \frac{Ai - Ac}{Ac} \times 100$$

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 effect.

Section	Miles	Accidents During Test Period	Accidents Per Mile*
Implementation (Edge Marked)	61	126	2.07
Control (Not Edge Marked)	55	167	3.04

*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.

a. 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:

$$Ri = Bi\ (Ac/Bc)$$

Where:

Ri = Anticipated experience at the Implementation site(s) if the improvement has not been implemented.

Bi = 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:

$$\% \text{ Change} = \frac{Ei - Ri}{Ri} \times 100.$$

Where:

Ei = 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:

Section	Miles	Before Edge Marking No.	Before Edge Marking Per Mile	After Edge Marking No.	After Edge Marking Per Mile
Implementation (edge marked)	61	123	2.02	126	2.07
Control (not edge marked)	55	132	2.40	167	3.04

$$Ri = 2.02\ (3.04/2.40) = 2.56$$

$$\%\ \text{Change} = \frac{2.07 - 2.56}{2.56} = -19\%$$

Using the number of before accidents, 123, and Figures J-1, J-2 and J-3, and Figure 9 of the Users' Manual, the 19% reduction is significant at the 90% level using the Poisson Comparison of Means Test and at the 95% level using the Poisson Distribution Test.

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 problems 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.

a. 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.

b. Example

Mississippi has developed performance standards for several types of improvements as shown on Table I-1.

Table I-1

Performance Standards for Improvement Type

Improvement Type		Accident Reductions (Percent)									
		Head-On	Rear-End	Right Angle	Sideswipe	Left Turn	Right Turn	Fixed Object	Pedestrian	Night Accident	Wet Pavement
Pavement Markings				10	20	10	10		10	10	
Signs	Upgrade	20	10						10		20
	Overhead Lane		10		20						
	Overhead Warning		20	20		20	20				
Signals	Timing		10	10		10	10		10		
	12" Lens		10								
	MUTCD (1)		20	20	10	20	20			20	
	Turn Phase		10			50					
	Opt. Program	20	10	10		10					
	Actuate		10	10	20	10	20				
	Pedestrian Phase								60		
	Remove Signal		90								
	Add Signal		(3)	80							
Roadway	Deslick										50
	Sight Distance	20		20		20	20				
	Turn Bay		20								
	Reconstruct	20	10								
Misc.	Close Median Opening (2)	100	50	100	50	100					
	Relocate Fixed Objects							60			
	Lighting									50	
	Relocate Drives	20	20	10	10	10	10				

(1)--Includes Timing, 12" Lens, Turn Phasing and Actuation
(2)--Percent of Accidents Involved at Median Opening
(3)--One Accident Increase Per 2000 VPD
(E)--Upgrading Existing Equipment
(N)--Replacing Existing With New Equipment

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.

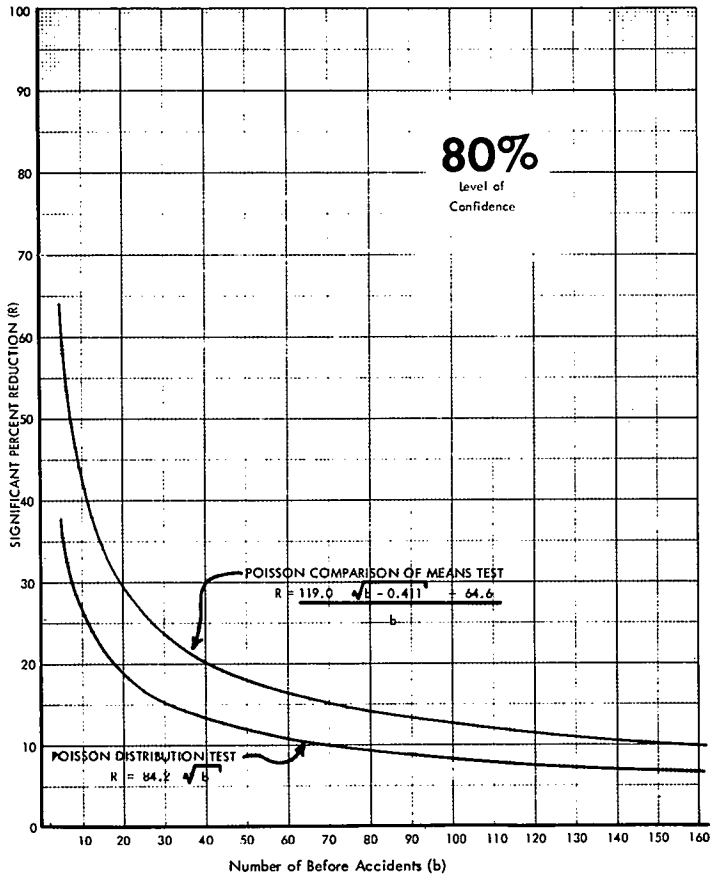


Figure J-1. Poisson Tests for Significance at 80% Level of Confidence

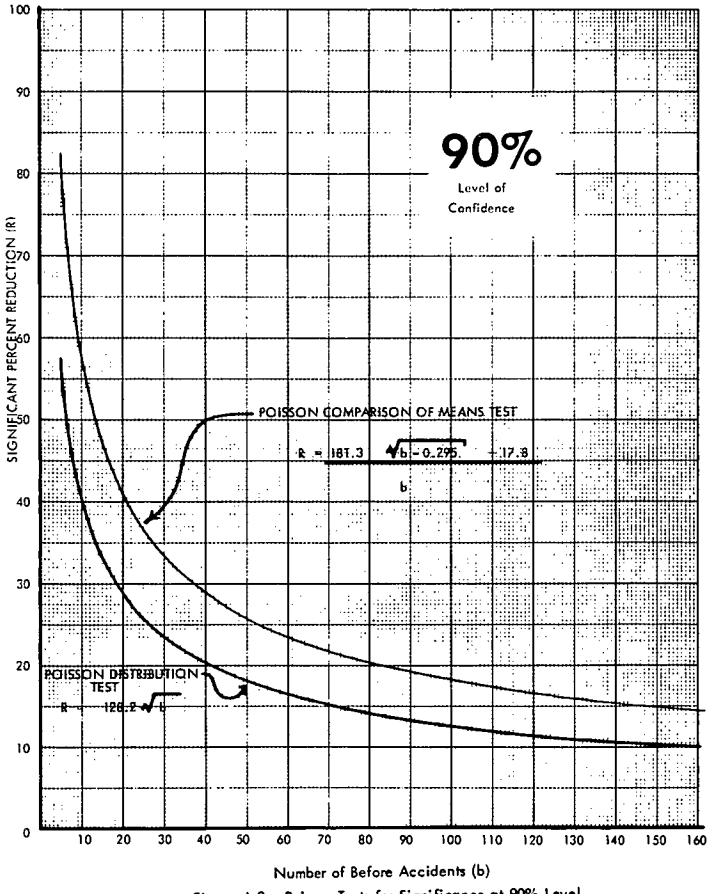


Figure J-2. Poisson Tests for Significance at 90% Level of Confidence

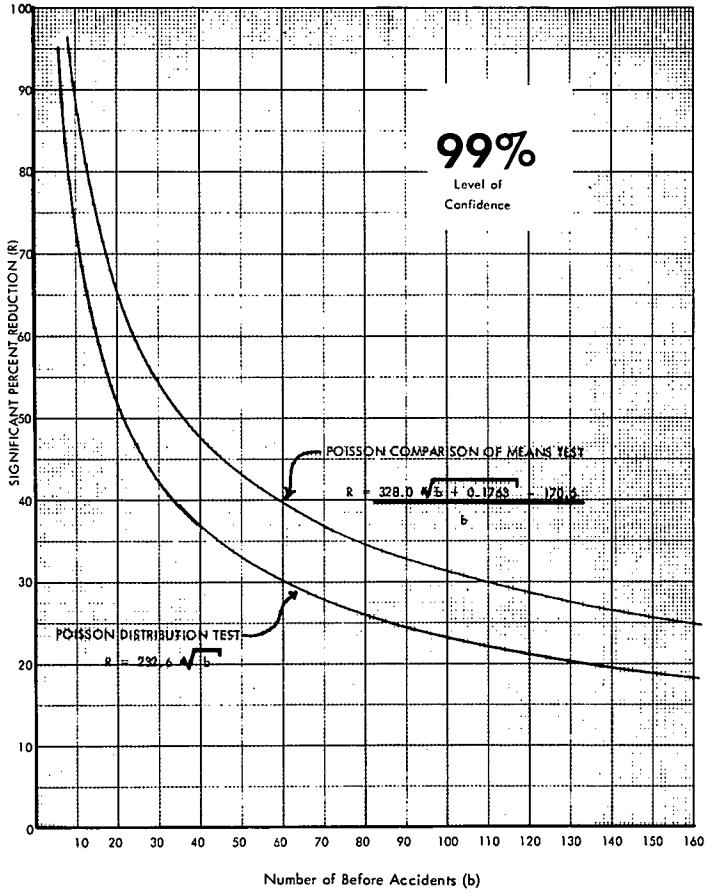


Figure J-3. Poisson Tests for Significance at 99% Level of Confidence

Appendix K

ALTERNATIVE METHODS OF EVALUATING COMPLETED HIGHWAY SAFETY PROGRAMS

The evaluations of completed highway safety programs provide top management 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 cost
- annual benefits
- interest rate
- implementation date.

a. 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.

   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.
3. Determine the actual annual operating cost of each improvement.
4. Determine the actual annual benefits of each improvement.
5. Select an interest rate, i.
6. Calculate the Present Worth of Benefits, PWOB, and the Present Worth of Costs, PWOC, of each group of improvements.

PWOB = (m-1 year CAF)(Σ year 1 benefits) + (m-2 year CAF)(Σ year 2 benefits) +...+(1 year CAF)(Σ year m-1 benefits) + (Σ year m benefits)

PWOC = (m year CAF)(Σ initial construction costs) + (m-1 year CAF) (Σ year 1 operating costs) +....+(1 year CAF)(Σ year m-1 operating costs) + (Σ year m operating costs)

Where: m = number of years since implementation
Σ = summation of all improvements
CAF = compound amount factor for interest rate i (the value for CAF may be found in interest tables or calculated by the formulas in Figure F-2.)

7. Calculate the benefit/cost ratio, B/C, of each group of improvements.

$$B/C = \frac{PWOB}{PWOC}$$

b. Example

The following is an example of using the benefit/cost ratios to evaluate one phase of three years' programs.

1-4. Develop the basic data.

Phase of 1970 Program	Initial Construction Costs	OPERATING COSTS 1971	1972	1973	BENEFITS 1971	1972	1973
Lighting	$ 40,000	$1,000	$1,000	$1,000	$20,000	$20,000	$20,000
Signing	5,000	500	400	500	5,000	6,000	7,000
De-slicking	100,000	0	0	0	40,000	45,000	50,000

5. Use an interest rate i = 10%
   (Interest factors for 10% are given in Figure F-3 on Page F-46.)

6. Calculate PWOB and PWOC.
   m = 3

   Lighting PWOB = (20,000)(1.210) + (20,000)(1.100) + 20,000
   = $66,200

   Signing PWOB = (5,000)(1.210) + (6,000)(1.100) + 7,000
   = $19,650

   De-slicking PWOB = (40,000)(1.210) + (45,000)(1.100) + 50,000
   = $147,900

   Lighting PWOC = (40,000)(1.331) + (1,000)(1.210) + (1,000)(1.100) + 1,000
   = $56,550

   Signing PWOC = (5,000)(1.331) + (500)(1.210) + (400)(1.100) + 500
   = $8,200

   De-slicking PWOC = (100,000)(1.331)
   = $133,100

7. Calculate B/C:

Lighting B/C $= \frac{66,200}{56,550} = 1.17$

Signing B/C $= \frac{19,650}{8,200} = 2.40$

De-slicking B/C $= \frac{147,900}{133,100} = 1.11$

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.

3. Determine the actual annual operating cost of each improvement.

4. Select a unit of effectiveness.

5. Determine the actual annual benefits, B, in the desired units of effectiveness of each improvement.

6. Select an interest rate, i.

7. Calculate the present worth of costs, PWOC, of each group of improvements.

PWOC = (m year CAF)(Σ initial construction costs) + (m-1 year CAF) (Σ year 1 annual costs) +...+(1 year CAF)(Σ year m-1 annual costs) + (Σ year m costs)

Where: m = Number of year since implementation
Σ = Summation of all improvements
CAF = Compound Amount Factor for interest rate, i. (The value for CAF may be found in interest tables or calculated by the formulas in Figure F-2.

8. Calculate the average annual benefit, $\bar{B}$, in the desired units of effectiveness, for each year's program.

$$\bar{B} = \frac{\sum B}{m}$$

Where: B = Annual benefit of a year's program in the desired units of effectiveness
m = Number of years implemented
$\sum$ = Summation of all year since implementation

9. Calculate the cost/effectiveness array:

$$C/E = \frac{SF_m^i \text{ (PWOC)}}{\sum \bar{B}}$$

Where: $\bar{B}$ = the average annual benefit of a year's program in the desired units of effectiveness
PWOC = Present worth of cost of a group of improvements
$\sum$ = Summation of all years' programs included in the group of improvements
SF_m^i = Sinking fund factor for m years and interest rate i. (The value for SFF 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:

1-5. Determine the basic data.

Phase of 1970 Program	Initial Construction Costs	OPERATING COSTS 1971	1972	1973	BENEFITS (ACCIDENTS)* 1971	1972	1973
Lighting	40,000	$1,000	$1,000	$1,000	8	8	8
Signing	5,000	500	400	500	2	2	3
De-slicking	100,000	0	0	0	15	15	18

*Unit of effectiveness = accidents reduced

6. Interest rate, i = 10%.

7. Calculate the present worth of costs, PWOC.
m = 3

Lighting PWOC = (40,000)(1.331) + (1,000)(1.210) + (1,000)(1.100) + 1,000
= $56,550

Signing PWOC = (5,000)(1.331) + (500)(1.210) + (400)(1.100) + 500
= $8,200

De-slicking PWOC = (100,000)(1.331)
= $133,100

8. Calculate the average annual benefits, $\bar{B}$.

Program Phase	$\bar{B}$		
Lighting	(8+8+8)/3	=	8.00 Accidents
Signing	(2+2+3)/3	=	2.33 Accidents
De-slicking	(15+15+18)/3	=	16.00 Accidents

9. Calculate the cost/effectiveness array:

Program Phase	C/E		
Lighting	(0.302)(56,550)/8.00	=	$2,135 per accident
Signing	(0.302)(8,200)/2.33	=	$1,061 per accident
De-slicking	(0.302)(133,100)/16.00	=	$2,512 per accident

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
Typical Improvements

Location-Alternative	Improvement Description	Service Life (years)	Initial Cost (dollars)	Annual Cost (dollars)	Terminal Value (dollars)	Equivalent Uniform Annual Benefit (dollars)	Equivalent Uniform Annual Cost* (dollars)
101-A	Roadway Signs	6	600	20	0	2,110	120
101-B	Delineators, Bridge Paint	6	2,300	125	0	8,450	510
101-C	Alt. A and Alt. B	6	2,900	145	0	10,560	630
101-D	Guardrail	20	19,100	150	0	12,670	1,105
101-E	Alt. A, Alt. B and Alt. D	18	22,000	295	0	15,840	1,515
102-A	Redesign Intersection	20	10,800	50	0	1,640	590
102-B	Install left turn lane	10	12,700	400	0	4,095	1,670
102-C	Alt. A and Alt. B	20	23,500	450	0	5,735	1,625
103-A	Roadway Signs	6	2,000	50	0	465	385
103-B	Pavement Markings	4	5,000	50	0	1,235	1,300
103-C	Alt. A and Alt. B	5	7,000	100	0	1,700	1,500
104-A	Roadway Signs	6	200	20	0	300	55
104-B	Left turn lane pavement markings	3	800	25	0	3,600	290
104-C	Alt. A and Alt. B	4	1,000	45	0	3,900	295
105-A	Install right turn lane	10	15,000	200	0	145	1,700
105-B	Pave shoulders 4' each side	10	20,000	50	0	2,110	2,050
105-C	Alt. A and Alt. B	10	35,000	250	0	2,255	3,750
106-A	Roadway Signs	6	450	30	0	875	105
106-B	Replace Bridge Structure	20	90,000	200	0	5,240	4,700
107-A	Roadway Signs	6	600	20	0	110	120
107-B	Delineators and raised pavement markers	6	1,650	40	0	650	315
107-C	Alt. A and Alt. B	6	2,250	60	0	760	435
108-A	Roadway Signs	6	210	20	0	290	55
108-B	Delineators with edgeline paint	6	390	20	0	1,455	85
108-C	Alt. A and Alt. B	6	600	40	0	1,745	140
109-A	Channelize intersection	20	2,000	50	0	160	150
109-B	Install turn lanes	10	28,000	400	0	970	3,200
109-C	Alt. A and Alt. B	12	30,000	450	0	1,130	2,950
110-A	Roadway Signs	6	300	20	0	1,610	70
110-B	Alt. A and channelization island	15	1,100	40	0	2,150	115
110-C	Grade change for 1 mile	20	300,000	600	0	7,520	15,600
111-A	Widening of roadway to provide deceleration and left turn lanes	5	15,000	800	0	12,115	3,800

*Using a 0% Interest Rate

Table L-1 (Cont'd.)

Location-Alternative	Improvement Description	Service Life (years)	Initial Cost (dollars)	Annual Cost (dollars)	Terminal Value (dollars)	Equivalent Uniform Annual Benefit (dollars)	Equivalent Uniform Annual Cost* (dollars)
112-A	Installing oversized stop signs	6	25	5	0	1,545	10
112-B	Installing oversized stop signs and flasher beacon	12	2,000	325	0	4,090	490
113-A	Install flasher beacon	10	2,000	250	0	2,255	450
113-B	Install flasher beacon and channelize intersection	15	10,000	600	0	1,385	1,265
113-C	Construct grade separation	20	1,500,000	3,000	0	5,640	75,300
114-A	Install flasher beacon	10	2,000	250	0	6,810	450
115-A	Delineators	5	1,500	200	0	1,365	500
115-B	Pavement markers	5	1,500	200	0	1,365	500
115-C	Alt. A and Alt. B	5	3,000	400	0	2,730	1,000
116-A	Widening pavement of deceleration and acceleration lanes	20	20,000	500	0	8,765	1,500
117-A	Upgrading traffic signal	15	700	300	0	3,510	345
118-A	Upgrading traffic signal	15	24,000	1,200	0	6,805	2,800
119-A	Reconst. 0.25 mi. of Ala. 17	20	40,000	1,000	0	2,315	3,000
120-A	Reconstruct 1.00 mile	15	150,000	2,500	0	3,385	12,500
121-A	Resurface with plant mix. shoulder work	5	8,000	300	0	1,585	1,900
121-B	Flatten curve on new const. Lengthen drainage structures.	20	30,000	500	0	3,960	2,000
122-A	Install Guardrail	10	3,300	100	0	580	430
122-B	Construct wider bridge	20	89,600	50	0	11,405	4,530
123-A	Install guardrail	10	3,300	100	0	455	430
123-B	Install wider bridge	20	64,600	50	0	8,910	3,280
124-A	Install left turn lanes at co. rd. intersection with restriction on parking at same	10	1,500	100	0	9,310	150
125-A	Build up low shoulders and install delineators in two crossovers	10	850	25	0	820	110
125-B	Repave roadway and buildup low shoulders from M.P. 371.80-372.15	10	4,650	100	0	6,140	565
126-A	Install 3-way flasher and stop bars on county road	3	730	100	0	1,130	345
127-A	Repave roadway from M.P. 35.50 to 35.90	4	8,700	150	0	1,585	2,325
127-B	Realign roadway to match bridge in place from M.P. 35.50 - 35.90	20	80,000	150	0	10,490	4,150

*Using a 0% Interest Rate

Table L-1 (Cont'd.)

Location-Alternative	Improvement Description	Service Life (years)	Initial Cost (dollars)	Annual Cost (dollars)	Terminal Value (dollars)	Equivalent Uniform Annual Benefit (dollars)	Equivalent Uniform Annual Cost* (dollars)
128-A	Increase superelevation in curves with pavement and repave both lanes including shoulders	10	12,575	100	0	13,140	1,360
129-A	Install rumble strips on co. rd. #41	2	195	50	0	5,735	150
130-A	Install guardrail at bridge ends	10	1,980	25	0	110	225
130-B	Place leveling course at bridge ends and replace roadway from M.P. 74.50 - 75.20	10	32,600	50	0	325	3,310
131-A	Install 2 guide signs "Airport Road," W2-2, R1-1 & 3-way stop bars	2	335	25	0	5,735	195
132-A	Widen section on Ala. 79 to provide a left turn lane	10	20,000	750	0	6,750	2,750
133-A	Lengthen left turn, deceleration, and acceleration lanes; channelize Alton Road approach and median crossover, upgrade existing flasher.	10	15,000	750	0	18,765	2,250
134-A	Larger signal heads, stop bars	10	400	0	0	4,300	40
134-B	Widen bridge to standards	20	2,000,000	0	0	2,550	100,000
134-C	Alt. A and B	20	2,000,400	0	0	6,340	100,020
135-A	Flashing beacon	10	400	0	0	3,275	40
135-B	Rebuild Curve, add superelevation	10	2,000	0	0	7,100	200
136-A	Improve signing	10	200	0	0	1,860	20
136-B	Repaint transition, signing	5	300	0	0	2,590	60
136-C	Flashing beacon before signals	10	500	0	0	2,990	50
137-A	Channelize	10	3,000	100	0	2,420	400
137-B	Signalize-3 phase	10	9,000	300	0	7,735	1,200
137-C	Alt. A and Alt. B	10	12,000	400	0	10,155	1,600
138-A	Improve pavement marking for night driving	10	2,000	0	0	39,555	200
138-B	Decrease number of crossovers	10	5,000	0	0	27,480	500
138-C	Signalize several crossovers	10	16,000	0	0	54,865	1,600
138-D	Widen left turn lanes	10	50,000	0	0	31,060	5,000
138-E	Alt. A, B, C and D	10	73,000	0	0	137,100	7,300
139-A	Widen pavement and superelevation	15	15,000	0	0	2,395	1,000
139-B	Rebuild to straighten curves	15	30,000	0	0	3,590	12,000
140-A	Install flashing beacon	10	500	0	0	1,780	50
140-B	Curbing to allow only parallel parking	10	1,000	0	0	1,855	100
140-C	Alt. A and B	10	1,500	0	0	3,635	150

*Using a 0% Interest Rate

Table L-1 (Cont'd.)

Location-Alternative	Improvement Description	Service Life (years)	Initial Cost (dollars)	Annual Cost (dollars)	Terminal Value (dollars)	Equivalent Uniform Annual Benefit (dollars)	Equivalent Uniform Annual Cost* (dollars)
141-A	Widen roadway	10	2,000	0	0	360	200
141-B	Add turn lanes	10	4,000	0	0	1,386	400
142-A	Widen pavement and add add turn lanes	10	2,000	0	0	4,170	200
143-A	4 lane highway (27 mi.)	20	10,000,000	40,500	0	46,370	540,500
144-A	Place warning signs and cut trees	3	500	0	0	355	165
144-B	Alt. A plus left turn bay (east bound)	20	5,000	0	0	540	250
144-C	Reconstruction of 1 mile	20	250,000	0	0	970	12,500
145-A	Construct wider road	20	2,500,000	0	0	31,515	125,000
146-A	Upgrade signs & markings	4	3,000	750	0	2,865	1,500
146-B	Reconstruct intersection	20	35,000	1,250	0	4,000	3,000
146-C	Route relocation	20	2,300,000	0	0	6,875	115,000
147-A	Install signals to convert bridge to onoway traffic	10	20,000	500	0	2,280	2,500
148-A	Replace narrow bridge	20	43,000	0	0	2,780	2,150
149-A	Warning signs and shoulder delineation	4	1,000	0	0	2,140	250
149-B	Reconstruct one mile road	20	250,000	0	0	3,420	12,500
150-A	Widen shoulders	3	8,000	500	0	70	3,165
150-B	Reconstruct 2 miles roadway	20	150,000	1,200	0	215	8,700
151-A	Widen shoulders	3	10,000	500	0	70	3,835
151-B	Reconstruct 2 miles of roadway	20	200,000	1,200	0	215	11,200
152-A	Resurface	5	70,000	200	0	2,320	14,200
153-A	Extend drainage and widen shoulders	5	11,000	700	0	1,275	2,900
153-B	Reconstruct 0.3 mile roadway	20	24,000	1,500	0	2,915	2,700
154-A	Widen shoulders	5	4,500	500	0	765	1,400

*Using 0% Interest Rate

Table L-1 (Cont'd.)

Location-Alternative	Improvement Description	Service Life (years)	Initial Cost (dollars)	Annual Cost (dollars)	Terminal Value (dollars)	Equivalent Uniform Annual Benefit (dollars)	Equivalent Uniform Annual Cost* (dollars)
154-B	Reconstruct 0.3 mile roadway	20	15,000	1,500	0	2,405	2,250
155-A	Resurface (5 miles)	4	50,000	500	0	7,640	13,000
155-B	Rebuild to four-lane (5 miles)	20	2,500,000	5,000	0	11,060	130,000
156-A	Channelize intersection	10	15,000	200	0	970	1,700
156-B	Build turn lanes	10	30,000	400	0	1,655	3,400
156-C	Alt. A and Alt. B	10	45,000	500	0	1,845	5,000
157-A	Relocate county road	20	15,000	25	0	1,270	775
157-B	Regrade sharp vertical curve	5	30,000	100	0	2,250	6,100
157-C	Rebuild to 4-lane divided hwy.	20	3,000,000	850	0	3,105	150,850
158-A	Build turn lanes	5	30,000	200	0	2,555	6,200
158-B	Upgrade to 4-lane divided hwy.	20	3,000,000	850	0	3,725	150,850
159-A	Resurface pavement (5 miles)	5	100,000	500	0	2,510	20,500
159-B	Build speed change lanes	20	150,000	300	0	2,015	7,800
159-C	Alt. A and Alt. B	20	250,000	800	0	2,525	13,300
160-A	Resurface (5 miles)	4	50,000	500	0	1,310	13,000
160-B	Rebuild to 4-lanes	20	1,500,000	5,000	0	5,530	80,000
161-A	Build turn lanes	5	30,000	200	0	4,435	6,200
161-B	Regrade .5 mile section	5	80,000	400	0	3,830	16,400
161-C	Rebuild to 4-lane (5 miles)	20	3,000,000	850	0	5,425	150,850
162-A	Widen roads to provide turn lanes	20	400,000	3,000	0	23,895	23,000
163-A	Upgrade signs & markings	3	1,000	100	0	1,730	435
163-B	Extend climbing lane	15	50,000	200	0	5,020	3,535
164-A	Install guardrail	3	3,600	100	0	270	1,300
164-B	Widen bridge	20	18,000	250	0	2,015	1,150
164-C	Alt. A and Alt. B	20	21,600	350	0	2,085	1,430
165-A	Update signals, cantilever arm with guardrail protection	20	28,000	0	0	2,910	1,400
166-A	Restripe 3 mile segment	2	1,200	200	0	4,055	800
167-A	Install flasing signal and update signing	8	2,500	100	0	1,455	410
167-B	Redesign intersection	20	5,000	100	0	2,330	350
168-A	Delineate bridge & approaches	8	300	100	0	855	140
169-A	Update signing, delineate approach to bridge	2	300	100	0	180	250
169-B	Delineate bridge	2	750	150	0	2,050	1,175

*Using a 0% Interest Rate

Table L-1 (Cont'd.)

Location-Alternative	Improvement Description	Service Life (years)	Initial Cost (dollars)	Annual Cost (dollars)	Terminal Value (dollars)	Equivalent Uniform Annual Benefit (dollars)	Equivalent Uniform Annual Cost* (dollars)
170-A	Improve signing & install turn lanes	8	5,000	50	0	2,070	675
170-B	Resurface approx. 6.1 miles	7	106,000	100	0	5,070	15,245
170 C	Alt. A and Alt. B	8	111,000	150	0	7,090	14,025
171-A	Improve signing, delineate bridge & approaches	5	700	150	0	2,090	290
172-A	Install rumble strips on Blake Bottom Road	4	200	50	0	3,000	100
173-A	Install guardrail on north and south side of roadway widen shoulders for recovery area	20	6,350	100	0	4,510	420
174-A	Install a 3-Way flasher at intersection and place stop ahead signs on Co. Rd. #74	10	775	25	0	2,680	105
175-A	Lower grade on east bound lane to level of west bound lane	20	17,600	100	0	6,770	980
176-A	Install left turn lane on east and west bound lanes	10	1,500	50	0	3,540	200
177-A	Install 4-way flasher	10	720	20	0	530	90
178-A	Flatten horizontal curve and lower vertical curves	15	300,000	5,000	0	11,705	25,000
179-A	Removal of existing median from Dugan Ave. to 1000' west of Heflin Ave. to provide a two-way left turn lane	10	50,000	2,000	0	16,255	7,000
180-A	Widen bridge culvert 6' on each end to full shoulder width	15	20,000	500	0	1,800	1,835

*Using a 0% Interest Rate

APPENDIX M

CANVASS OF USERS

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

Agencies Canvassed

error added twice

1 Alabama State Highway Department
2 Alabama Highway Safety Coordinator
3 Alaska Department of Highways
4 Arizona Highway Department
5 Arkansas State Highway Department
Austin, Texas
Australian Commonwealth Bureau of Roads
6 California Department of Public Works*
Chicago, Illinois
7 Colorado Department of Highways
Colorado Coordinator of Highway Safety
8 Connecticut Department of Transportation
9 Delaware Department of Highways and Transportation
District of Columbia Department of Highways and Traffic
10 Florida Department of Transportation*
Florida Governor's Highway Safety Commission
11 Georgia Department of Transportation
12 Hawaii Department of Transportation
13 Idaho Department of Highways
14 Illinois Department of Transportation
Illinois State Toll Highway Authority
15 Indiana State Highway Commission
Indiana Toll Road Commission
16 Iowa State Highway Commission
Japan Public Highway Corporation
17 Kansas State Highway Commission
Kansas Turnpike Authority
18 Kentucky Department of Highways
London, England
Los Angeles, California
19 Louisiana Department of Highways
Louisiana Highway Safety Commission
20 Maine State Highway Commission
Maine Turnpike Authority
21 Maryland Department of Transportation*
22 Massachusetts Department of Public Works*
Massachusetts Turnpike Authority
23 Michigan Department of State Highways*
Michigan Office of Highway Safety Planning
24 Minnesota Department of Highways
Minnesota Department of Public Safety
Minnesota Mining and Manufacturing Company
25 Mississippi State Highway Department
26 Missouri State Highway Commission
Missouri Division of Highway Safety
27 Montana Department of Highways
28 Nebraska Department of Roads
29 Nevada Department of Highways
30 New Hampshire Department of Public Works and Highways
31 New Jersey Department of Transportation
New Jersey Expressway Authority
New Jersey Highway Authority
New Jersey Turnpike Authority
32 New Mexico State Highway Commission
33 New York Department of Transportation*
New York Department of Motor Vehicles
New York State Thruway Authority
34 North Carolina State Highway Commission*
North Carolina Governor's Highway Safety Program
35 North Dakota State Highway Department
36 Ohio Department of Highways*
Ohio Turnpike Commission
37 Oklahoma Department of Highways
Oklahoma Turnpike Authority
Oakland County (Michigan) Traffic Improvement Association
38 Oregon Department of Transportation
39 Pennsylvania Department of Transportation
Pennsylvania Turnpike Commission
Phoenix, Arizona
Portland, Oregon
Puerto Rico Highway Authority
40 Rhode Island Department of Transportation
San Francisco, California
Seattle, Washington
41 South Carolina State Highway Department
42 South Dakota Department of Highways
St. Louis County, Missouri
43 Tennessee Department of Transportation*
Tennessee Highway Safety Coordinator
44 Texas Highway Department
Texas Traffic Safety Administrator
Toronto, Canada
45 Utah Department of Highways
46 Vermont Department of Highways
47 Virginia Department of Highways*
Virginia Highway Safety Division
48 Washington Department of Highways
49 West Virginia Department of Highways
50 Wisconsin Department of Transportation
Wisconsin Highway Safety Coordinator
51 Wyoming Highway Department

*Agencies canvassed by previous research team

ROY JORGENSEN ASSOCIATES, INC.

Engineering and Management Consultants

February 27, 1973

POST OFFICE BOX 575
GAITHERSBURG, MARYLAND 20760

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 HRB 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.

You may recall our previous study entitled "Evaluation of Criteria for Safety Improvements on the Highway," which we completed in 1966 for the Bureau of Public Roads. The results of Project 17-2A will represent refinement of this earlier effort.

We are confident that since the BPR Study, highway agencies have developed innovations in highway safety improvement evaluation techniques. The guidelines we develop will be based, in part, on a synthesis of current practice of highway agencies.

As a step in obtaining all of the detailed information required to conduct this study, we are enclosing a questionnaire oriented toward gaining knowledge concerning recent developments in methods for evaluating highway safety improvements.

While some portions of the questionnaire may duplicate the canvas made by the previous research agency working on this project, most of the questions are unique. Therefore, it is respectfully requested that you have the questionnaire completed by the person, or persons, in your organization most familiar with your highway safety improvement program.

The questionnaire has been structured to minimize time required for completion. Therefore, it will be appreciated if the requested data can be transmitted to us by April 2nd.

Any further personal observations or comments which may be of assistance to us in this endeavor will be received with appreciation.

Sincerely yours,

Questionnaire Cover Letter To Agencies
Canvassed by Previous Research Team

M-3

ROY JORGENSEN ASSOCIATES, INC.

Engineering and Management Consultants

February 27, 1973

POST OFFICE BOX 575
GAITHERSBURG, MARYLAND 20760

Dear

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The questionnaire has been structured to minimize time required for completion. Therefore, it will be appreciated if the requested data can be transmitted to us by April 2nd.

Any further personal observations or comments which may be of assistance to us in this endeavor will be received with appreciation.

Sincerely yours,

Questionnaire Cover Letter To Agencies Not
Canvassed by Previous Research Team

M-4

SUMMARY OF CANVASS

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.

M-5

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

- Oklahoma--"Manual for the Application of Statistical Techniques for Use in Accident Control," Dunlop Association; and "Application of Statistical Quality Control Techniques to Analysis of Highway Accident Data," Norden.

M-6

- Idaho--"Significance Testing for Accident Reduction," S. K. Dietz.
- Michigan--"A System Analysis of Accident Data," 1969.

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.

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 out-dated 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

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? _____

Number of Years	Number of States Responding
1, 2	21
3	14
4	—
5	5

IS THERE A MINIMUM VOLUME OF DATA? _____

If yes, describe: _____

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? _____

Twenty-eight agencies do not use statistical tests. Fourteen agencies do. 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?_____

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.

M-11

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 forms 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 log--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.

M-12

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 tools and check those being used.

		Used	Not Used
1.	Traffic counts	41	0
2.	Short counts by movement	36	5
3.	Conflict counts	16	25
4.	Photographic study	30	11
5.	Night investigation	28	13
6.	Skid testing	33	8
7.	Driving the location	41	0
8.	Physiological testing such as galvanic skin response	0	41
9.	Psychological response measurements	0	41
10.	Other	0	

M-13

IN WHAT FORMAT ARE THE RESULTS OF FIELD INVESTIGATIONS PRESENTED? AND TO WHOM? ATTACH A SAMPLE COMPLETED FORM.

Type of Format	Number of States
Standard Form	7
Memorandum (letters)	5
Technical report	21
No format	6

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.

		Used	Not Used
1.	Collision diagram	41	0
2.	Accident Profiles (analysis of the actual distribution of accident types.)	25	16

M - 14

		Used	Not Used
3.	Detection of specific significant accident characteristics such as:		
	a. time of day	39	2
	b. weather	39	2
	c. road surface conditions	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.

		Used	Not Used
1.	Common sense	41	0
2.	Probability models including trees	0	41
3.	Deterministic modeling	0	41
4.	Other		

M - 15

Other responses

Other responses included economic studies (2), judgment factors and compliance with Federal requirements.

HAVE YOU DEVELOPED ANY STATISTICAL MODELS FOR DETERMINING THE POTENTIAL EFFECTIVENESS OF PROPOSED SAFETY PROBLEM SOLUTIONS? _____

If yes, describe _____

Typical response

Yes - 5
No - 36

HOW DO YOU DEVELOP COSTS FOR POTENTIAL SOLUTIONS?

		Used	Not Used
1.	Average cost table, for example, needs study costs?	15	25
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		

M - 17

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 Responses

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, how are these reviews utilized? 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).

M - 16

HOW ARE BENEFITS (ACCIDENT AND SEVERITY REDUCTION AND OTHER USERS' BENEFITS) DETERMINED?

		Used	Not Used
1.	NHTSA Tables	5	35
2.	National Safety Council	25	15
3.	NCHRP Research Tables	6	34
4.	In-house accident cost studies	15	25
5.	Other? Describe _____		

HOW ARE FUTURE ACCIDENT OCCURRENCE RATES ESTIMATED?

		Used	Not Used
1.	Percent reduction of accident rate	19	21
2.	Percent reduction in severity	15	25
3.	Percent reduction of total number	20	20
4.	Other? Describe: _____		

WHAT IS THE SOURCE OF THE DATA FOR THESE ESTIMATES?

Source	Number of Agencies
Previous experience	19
Jorgensen - Westat Report	6
Other published reports	2
In-house	1

DO YOU USE A RATING OR INDEX TO DESCRIBE THE SEVERITY OF ACCIDENTS? _____

If yes, describe _____

Typical response

Yes - 24
No - 17

M - 18

Rating Used	Number of Agencies
Safety Council	5
Severity Index	8
TAD or other numerical ratings	4
B/C	1
Other	6

WHAT METHOD OF EVALUATION IS USED?

	Used	Not Used
1. Present worth	4	37
2. Rate of return	7	34
3. Benefit - cost ratio	32	9
4. Incremental Benefit-cost ratio	1	40
5. Total benefit	10	31
6. Other? Describe _____		

IF THE EVALUATION INVOLVES AN INTEREST/DISCOUNT RATE, WHAT RATE IS USED? _____ %
DOES THE EVALUATOR THINK THIS IS:

0	much too high?
1	slightly high?
12	about right?
1	slightly low?
0	much too low?

The actual range was 0% to 10% with 12 states falling between 5-7%.

M - 19

IS ANY INFLATION RATE APPLIED TO THE VALUE OF FUTURE BENEFITS? _____
If yes, what rate _____ %

Typical Response

No

Exceptions

Four states apply inflation rates ranging from 5.0% to 7.36%.

DESCRIBE RECENT TRENDS IN YOUR AGENCY'S HIGHWAY SAFETY IMPROVEMENT FUNDING.

Typical Response

Funding levels are increasing in most states.

WHAT IS THE AVERAGE ELAPSED TIME BETWEEN THE DECISION TO CONSTRUCT A SPECIFIC HIGHWAY SAFETY IMPROVEMENT AND THE COMPLETION OF CONSTRUCTION OF THAT IMPROVEMENT?

Elapsed time	Number of Agencies
Less than one year	4
One to four years	20
6 years	1
Varies	12

M - 20

DO YOU MAKE ANY POST-IMPLEMENTATION REVIEWS?

Typical responses

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.

M - 21

WHAT TYPE OF POST-IMPLEMENTATION REVIEW DO YOU USE?

	Used	Not Used
1. Field observations	22	8
2. Accident reports	30	0
3. Conflict Analysis	6	24
4. Other, describe		
Traffic volumes		

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 RECENT REFINEMENTS IN SAFETY PROBLEM SOLVING TECHNIQUES.

Refinements listed are:

- Accident profile analysis

M - 22

- Safety Index for wet pavements
- Conflict Analysis
- Personnel adjustments
- On-site field investigations
- Video-tape equipment.

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.

Appendix N

FIELD TESTING OF USERS' MANUAL

Experienced, potential users were asked to review and test the Users' Manual as follows:

1. A procedural review was made by the individual most likely to be using the manual to analyze highway safety improvements. This review contains four sample problems to be worked by the reviewer.
2. A management review was made by middle- and top-level management to determine the adaptability of the system and system components to operations in the reviewing department.
3. A management review was made by the analyst who made the procedural review. This review was similar to the middle- and top-level management review.

The procedural review consisted of solving four sample problems using sample data and the Users' Manual.

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

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 Burnham, Jr.	Georgia Department of Transportation
Eugene D. Brenning	Illinois Department of Transportation
Donald F. Petty	Indiana State Highway Commission
Thomas Hicks	Maryland Department of Transportation
K. C. Townley	Missouri State Highway Commission
Dennis Oelschlager	Nebraska Department of Roads
Walter F. Mead	New Hampshire Department of Public Works and Highways
George J. Collins	New Jersey Department of Transportation
Duane Bentz	North Dakota Highway Department
Robert Janecko	Pennsylvania Department of Transportation
W. G. Van Gelder	City of Seattle, Washington
James F. Bauman	City of St. Louis, Missouri
Richard F. Daykin	St. Louis County, Missouri
Ken F. Kobetsky	West Virginia Department of Highways

ROY JORGENSEN ASSOCIATES, INC.

Engineering and Management Consultants

POST OFFICE BOX 575
GAITHERSBURG, MARYLAND 20760

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. BERGSTRALH
Vice President

Figure N-1. Letter to Agencies Responding to Initial Canvass

ROY JORGENSEN ASSOCIATES, INC.

Engineering and Management Consultants

POST OFFICE BOX 575
GAITHERSBURG, MARYLAND 20760

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 HRB 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.

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. BERGSTRALH
Vice President

Figure N-2. Letter to Agencies Not Responding to Initial Canvass

ROY JORGENSEN ASSOCIATES, INC.

Engineering and Management Consultants

POST OFFICE BOX 575
GAITHERSBURG, MARYLAND 20760

Dear

Thank you and the Department of Transportation for accepting our invitation to participate in the field testing of our NCHRP 17-2A Users' Manual for Evaluating Highway Safety Improvements.

The design of the field testing procedures is almost completed. We intend to mail them to you with the next couple of weeks. The field test of the manual will consist of three tasks:

1) A management review by middle and top level management,

2) A procedural review by the individual most likely to be using the manual to analyze highway safety improvements,

3) A management review by the same individual who performs task number two.

The management review is intended to determine the adaptability of the system and system components to operations in your department. The procedural review consists of solving four sample problems using sample data and the Users Manual. The management review by the analyst is similar to the middle and top level management review but intended to determine the perspective of the user.

Sincerely,

JOHN C. LAUGHLAND
Principal Investigator
NCHRP 17-2A

Figure N-3. Letter to Agencies Accepting Invitation to Participate

ROY JORGENSEN ASSOCIATES, INC.

Engineering and Management Consultants

POST OFFICE BOX 575
GAITHERSBURG, MARYLAND 20760

Dear

As promised we are enclosing the draft copies of a users' manual containing a Management System for Evaluating Highway Safety Improvements and a set of materials for testing the manual in an operating highway department. Part A of the material is a management review. Part B of the material is a procedural review which contains the sample problems and an analyst's review.

If you can make practical applications of the methods in the manual in the near future the results of these applications would be greatly valued and possibly incorporated in our research report.

In addition to the field testing, we would appreciate receiving data on some highway safety improvements you have made. These data will be used to review our examples. Therefore, we would like you to complete the Example Highway Safety Improvement Form with as many projects as you have data available.

Please return the completed reviews and example forms at your earliest convenience but no later than March 1, 1974. If you have any questions, please call Dean Clough or John Laughland, collect, at (301) 948-8190.

Sincerely,

DEAN R. CLOUGH
Project Manager
NCHRP 17-2A

Enclosures: 2 Users' Manual
2 Management Reviews
1 Procedural Review
1 Highway Safety Improvement Form

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.

Basic Data

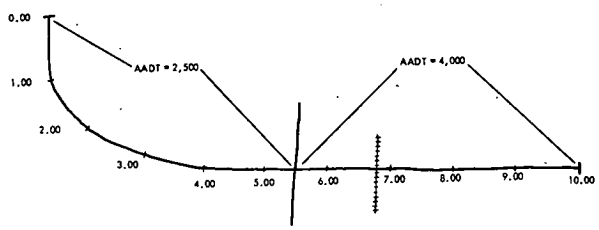

Figure N-5. State Highway 1

Table N-1. Average Accident Cost

SEVERITY	COST
Fatal	$200,000
Injury	10,000
PDO	500
Average	3,000

Table N-2. Systemwide Average Accident Rate

CLASSIFICATION	AVERAGE ACCIDENT RATE
Rural 2-Lane State Highway	2.0 Acc/MV
Rural 4-Lane State Highway	1.8
Rural State Highway RR Crossings	1.9 Acc/MV

Table N-3. Potential Improvement Data.

IMPROVEMENTS	COST INITIAL	COST ANNUAL	SERVICE LIFE	TERMINAL VALUE	ACCIDENT REDUCTION
101 - Curve Signing	$ 1,000	$ 100	5 yrs.	$ 0	40 percent of all accidents
102 - Resurfacing Curves	7,500	0	8 yrs.	0	50 percent of all skidding and wet pavement accidents
103 - Signing, Resurfacing and Painting Curve	10,000	200	7 yrs.	1,000	80 percent of all skidding wet pavement and night accidents
104 - Signing and Speed Reduction	1,500	100	5 yrs.	0	30% of rural intersection accidents
105 - Channelization	12,000	150	10 yrs.	0	60% of all intersection accidents
106 - Traffic Signals	8,000	500	10 yrs.	1,000	75% of turning and associated accidents
107 - Grade Separation	500,000	1,500	50 yrs.	0	95% of all intersection accidents
108 - Flashing Lights	10,000	1,000	10 yrs.	500	40% of RR crossing accidents
109 - Flashing Lights and Gates	15,000	1,000	10 yrs.	1,000	70% of RR crossing accidents
110 - Railroad Grade Separation	300,000	1,000	50 yrs.	0	100% of RR crossing accidents
111 - Removal of Fixed Object	2,000	0	Perpetual	0	100% of fixed object accidents
112 - Guardrail Placement Around Fixed Object	1,000	50	10 yrs.	0	80% reduction in fixed object accident severity
113 - Guardrail Placement At Bridge	5,000	100	10 yrs.	0	50% reduction in severity
114 - Bridge Widening	50,000	0	25 yrs.	0	40% reduction of accidents

N-7

N-8

Table N-4. Accidents Occurring on State Highway 1

DATE	LOCATION	SEVERITY	CHARACTERISTICS
Jan. 4	4.48	PDO	Rear end, night, dry
Jan. 13	6.76	1 Injury	Lost control, night, wet
Jan. 16	7.80	PDO	Sideswipe, night, dry
Feb. 2	2.00	2 Injuries	Head on, night, dry
Feb. 7	2.50	PDO	Hit abutment, day, dry
Feb. 12	5.50	2 Fatalities	Left turn, day, dry
Mar. 8	1.43	1 Fatality	Head on, day, wet
April 1	5.52	1 Injury	Right angle, day, wet
May 12	6.75	3 Injuries	Rear end, day, wet
May 15	3.75	PDO	Left turn, day, wet
May 15	8.10	2 Injuries	Head on, dry, day
June 6	1.44	3 Injuries	Sideswipe, night, wet
June 25	6.77	PDO	Rear end, night, dry
July 7	1.70	PDO	Rear end, night, wet
July 26	6.78	1 Fatality	Train-car, day, dry
Aug. 8	1.42	PDO	Lost control, day, wet
Aug. 10	1.44	PDO	Sideswipe, night, wet
Aug. 29	6.79	1 Fatality	Train-car, night, wet
Sept. 2	1.80	PDO	Lost control, day, dry
Sept. 15	9.80	PDO	Rear end, night, wet
Oct. 17	9.52	3 Fatalities	Hit Abutment, night, wet
Nov. 1	3.25	PDO	Sideswipe, day, dry
Nov. 22	9.50	1 Injury	Hit Abutment, night, wet
Dec. 10	0.20	PDO	Left turn, day, dry
Dec. 22	8.70	1 Fatality	Lost control, night, dry, DWI

N-9

Table N-5. Accidents Occurring on State Highway 1 Arranged by Location

DATE	LOCATION	SEVERITY	CHARACTERISTICS
Dec. 10	0.20	PDO	Left turn, day, dry
Aug. 8	1.42	PDO	Lost control, day, wet
Mar. 8	1.43	1 Fatality	Head on, day, wet
June 6	1.44	3 Injuries	Sideswipe, night, wet
Aug. 10	1.44	PDO	Sideswipe, night, wet
July 7	1.70	PDO	Rear end, night, wet
Sept. 2	1.80	PDO	Lost control, day, dry
Feb. 2	2.00	2 Injuries	Head on, night, dry
Feb. 7	2.50	PDO	Hit abutment, day, dry
Nov. 1	3.25	PDO	Sideswipe, day, dry
May 15	3.75	PDO	Left turn, day, wet
Jan. 4	4.48	PDO	Rear end, night, dry
Feb. 12	5.50	2 Fatalities	Left turn, day, dry
April 1	5.52	1 Injury	Right angle, day, wet
May 12	6.75	3 Injuries	Rear end, day, wet
Jan. 13	6.76	1 Injury	Lost control, night, wet
June 25	6.77	PDO	Rear end, night, dry
July 26	6.78	1 Fatality	Train-car, day, dry
Aug. 29	6.79	1 Fatality	Train-car, night, wet
Jan. 16	7.80	PDO	Sideswipe, night, dry
May 15	8.10	2 Injuries	Head on, day, dry
Dec. 22	8.70	1 Fatality	Lost control, night, dry, DWI
Nov. 22	9.50	1 Injury	Hit abutment, night, wet
Oct. 17	9.52	3 Fatalities	Hit abutment, night, wet
Sept. 15	9.80	PDO	Rear end, night, wet

N-10

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%. (Three worksheets are attached. Xerox additional copies as needed.)

1-7 Complete the attached Improvement Evaluation Worksheet (Form 105) for the hazardous location identified in Question 1-3.

Highway Safety Program
Documentation Record
FORM 101

Location Identification Code
Date 3-13-1974
Prepared by ARC

HAZARDOUS LOCATION IDENTIFICATION WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 1 from 1.42 to 1.44

Intersection ☐ Spot ☒ Section ☐ Section length

CATEGORY: Rural ☐ Urban ☐ 2-lane ☒ 4-lane Undivided ☐ Divided ☐ Freeway ☐

DESCRIPTION: Sketch on back of sheet ☐ No sketch or collision diagram drawn ☒ See collision diagram ☐

ACCIDENT EXPERIENCE:

Year						Total
From (date)	Jan. 1					Jan. 1
To (date)	Dec. 31					Dec. 31
AADT	2,500					Ave= 2,500
Exposure	912,500					912,500
Total accidents	4					4
Fatal accidents	1					1
No. fatalities	1					1
Injury accidents	1					1
PDO accidents	2					2
Accident rate	4.4					4.4 acc/MV

SYSTEMWIDE AVE. RATE FOR CATEGORY: 2.0 Acc/MV

CRITICAL RATE FOR LOCATION: 3.89 Acc/MV

INDEX OF SEVERITY:

COMMENTS:

N-11

N-12

Highway Safety Program
Documentation Record
FORM 101

Location Identification Code
Date 3-13-74
Prepared by ARC

HAZARDOUS LOCATION IDENTIFICATION WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 1 from 6.75 to 6.79

Intersection ☐ Spot ☒ Section ☐ Section length

CATEGORY: Rural ☐ Urban ☐ 2-lane ☒ 4-lane Undivided ☐ Divided ☐ Freeway ☐

DESCRIPTION: Sketch on back of sheet ☐ No sketch or collision diagram drawn ☐ See collision diagram ☐

ACCIDENT EXPERIENCE:

Year						Total
From (date)	Jan. 1					Jan. 1
To (date)	Dec. 31					Dec. 31
AADT	4,000					Ave= 4,000
Exposure	1,440,000					1,440,000
Total accidents	5					5
Fatal accidents	2					2
No. fatalities	2					2
Injury accidents	2					2
PDO accidents	1					1
Accident rate	3.4					3.4 Acc/MV

SYSTEMWIDE AVE. RATE FOR CATEGORY: 1.9 Acc/MV

CRITICAL RATE FOR LOCATION: 3.59 Acc/MV

INDEX OF SEVERITY:

COMMENTS: RR crossing at 6.77 with crossbuck only

N-13

Highway Safety Program
Documentation Record
FORM 102

Location Identification Code
Date 3-13-74
Prepared by ARC

PROBABLE ACCIDENT CAUSE ANALYSIS WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 1 from 6.75 to 6.79

COLLISION DIAGRAM: ☐ Attached ☐ Not drawn

ACCIDENT CHARACTERISTICS:

No. of Accidents

Type of Accident	Fatal	Injury	P.D.O.	Total	Percent
Head on					%
Rear end	0	1	1	2	40 %
Right angle					%
Side swipe					%
Fixed object					%
Overturned					%
Train-car	2	0	0	2	40 %
Lost control	0	1	0	1	20 %
Total	2	2	1	5	100%
Percent	%	%	%	100%	

CONDITIONS:

No. of accidents

Time of day - 6:00 am - Noon ____ 6:00 pm - Midnight ____ Noon - 6:00 pm ____ Midnight - 6:00 am ____

Light conditions - Day 2 Night 3

Surface conditions - Dry 2 Wet 3 Snow or ice ____

Weather - Cloudy ____ Clear ____ Rain ____ Snow ____ Other ____

Other -

PROBABLE CONTRIBUTORY CAUSES: Drivers are unable to see the train in time to stop safely.

N-14

Highway Safety Program
Documentation Record
FORM 103

Location Identification Code
Date 3-13-74
Prepared by ARC

POTENTIAL IMPROVEMENT IDENTIFICATION WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 1 from 6.75 to 6.79

APPLICABLE IMPROVEMENTS:

IMPROVEMENT	EXPECTED RESULTS
108 -- Flashing lights Mutually exclusive	40% reduction of railroad crossing accidents
109 -- Flashing lights and gates Mutually exclusive	70% reduction of railroad crossing accidents
110 -- Railroad Grade Separation Mutually exclusive	100% reduction of RR. crossing accidents

SPECIAL COMMENTS:

N-15

Highway Safety Program
Documentation Record
FORM 104

Location Identification Code
Date 3-13-74
Prepared by ARC

IMPROVEMENT ANALYSIS WORKSHEET
(One for each potential improvement)

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 4000 EST. 19 ___ AADT ___

☒ Constant
☐ Increasing by ___ % annually
☐ Increasing by ___ VPD annually

ESTIMATED ACCIDENT REDUCTION:

By Types:				By Severity:	
Left turn	%	Skidding	%	Fatal	%
Head on	%	Wet pavement	%	Injuries	%
Rear end	%	Night	%	PDO	%
Right angle	%	RR crossing	40 %	Total	%
Side swipe	%		%		
Fixed object	%		%	All Accidents	
Lost control	%		%	%	

EQUIVALENT UNIFORM ANNUAL BENEFITS:

From accident reduction $ 6,000
From secondard benefits $ —
Total $ 6,000

ESTIMATED COSTS:

Initial implementation $ 10,000
Annual operation and maintenance $ 1,000
Terminal value $ 500
Equivalent uniform annual cost $ 2,465

NET ANNUAL BENEFIT $ 3,535 BENEFIT/COST RATIO 2.43

SPECIAL COMMENTS:

N-16

Highway Safety Program
Documentation Record
FORM 104

Location Identification Code
Date 3-13-74
Prepared by ARC

IMPROVEMENT ANALYSIS WORKSHEET
(One for each potential improvement)

LOCATION: State Highway 1 from 6.75 to 6.79

IMPROVEMENT CODE: 109
IMPROVEMENT DESCRIPTION: Flashing lights and gates

ESTIMATED SERVICE LIFE 10 YRS.
CURRENT 1973 AADT 4,000 EST. 19 ___ AADT ___

☒ Constant
☐ Increasing by ___ % annually
☐ Increasing by ___ VPD annually

ESTIMATED ACCIDENT REDUCTION:

By Types:				By Severity:	
Left turn	%	Skidding	%	Fatal	%
Head on	%	Wet pavement	%	Injuries	%
Rear end	%	Night	%	PDO	%
Right angle	%	RR crossing	70 %	Total	%
Side swipe	%		%		
Fixed object	%		%	All Accidents	
Lost control	%		%	%	

EQUIVALENT UNIFORM ANNUAL BENEFITS:

From accident reduction $ 10,500
From secondard benefits $ —
Total $ 10,500

ESTIMATED COSTS:

Initial implementation $ 15,000
Annual operation and maintenance $ 1,000
Terminal value $ 1,000
Equivalent uniform annual cost $ 3,166

NET ANNUAL BENEFIT $ 7,334 BENEFIT/COST RATIO 3.32

SPECIAL COMMENTS:

N-17

Highway Safety Program
Documentation Record
FORM 104

Location Identification Code
Date 3-13-74
Prepared by ARC

IMPROVEMENT ANALYSIS WORKSHEET
(One for each potential improvement)

LOCATION: State Highway 1 from 6.75 to 6.79

IMPROVEMENT CODE: 110
IMPROVEMENT DESCRIPTION: RR Grade Separation

ESTIMATED SERVICE LIFE 50 YRS.
CURRENT 1973 AADT 4,000 EST. 19 ___ AADT ___

☐ Constant
☐ Increasing by ___ % annually
☐ Increasing by ___ VPD annually

ESTIMATED ACCIDENT REDUCTION:

By Types:				By Severity:	
Left turn	%	Skidding	%	Fatal	%
Head on	%	Wet pavement	%	Injuries	%
Rear end	%	Night	%	PDO	%
Right angle	%	RR crossing	100 %	Total	%
Side swipe	%		%		
Fixed object	%		%	All Accidents	
Lost control	%		%	%	

EQUIVALENT UNIFORM ANNUAL BENEFITS:

From accident reduction $ 15,000
From secondard benefits $ —
Total $ 15,000

ESTIMATED COSTS:

Initial implementation $ 300,000
Annual operation and maintenance $ 1,000
Terminal value $ 0
Equivalent uniform annual cost $ 25,600

NET ANNUAL BENEFIT $ -10,600 BENEFIT/COST RATIO 0.59

SPECIAL COMMENTS:

N-18

Highway Safety Program
Documentation Record
FORM 105

Location Identification Code
Date 3-13-74
Prepared by ABC

IMPROVEMENT EVALUATION WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 1 from 6.75 to 6.79

SUMMARY OF EVALUATIONS:

Code	108	109	110		
Description	Flashing lights	Flashing lights & gates	RR grade separation		
Initial cost	$ 10,000	$ 15,000	$ 300,000	$	$
Annual cost	$ 1,000	$ 1,000	$ 1,000	$	$
Salvage value	$ 500	$ 1,000	$ 0	$	$
Service life	10 yrs	10 yrs	50 yrs	yrs	yrs
Equiv. uniform cost	$ 2,465	$ 3,166	$ 25,600	$	$
Equiv. uniform benefits	$ 6,000	$ 10,500	$ 15,000	$	$
Net annual benefits	$ 3,535	$ 7,334	$ -10,600	$	$
Benefit/cost ratio	2.43	3.32	0.59		

REJECTED IMPROVEMENTS (and explanation): Improvement #110 is not economically justified.

ELIGIBLE IMPROVEMENTS AND RANKING:

Code	Description	B/C Ratio
109	Flashing lights and gates	3.32

COMMENTS:

N-19

PROBLEM 2

Data: AADT = 4,000 increasing at 5% per year
Interest rate = 0%

A TYPICAL YEAR'S ACCIDENTS

LOCATION	SEVERITY	CHARACTERISTICS	APPLICABLE IMPROVEMENT
Intersection	1 injury	Left turn, day, dry	Channelization
	PDO	Left turn, day, wet	Traffic Signals
	2 injuries	Left turn, night, dry	Grade Separation
	PDO	Rear end, night, dry	
	PDO	Rear end, day, dry	

2-1 Complete an Improvement Analysis Worksheet (Form 104) for each of the applicable improvements described above.

2-2 Complete an Improvement Evaluation Worksheet (Form 105) for the intersection described above.

N-20

Highway Safety Program
Documentation Record
FORM 104

Location Identification Code
Date 3-13-74
Prepared by ABC

IMPROVEMENT ANALYSIS WORKSHEET
(One for each potential improvement)

LOCATION: Problem #2

IMPROVEMENT CODE: 105
IMPROVEMENT DESCRIPTION: Channelization

ESTIMATED SERVICE LIFE 10 YRS.
CURRENT 19 74 AADT 4,000 EST. 19 ___ AADT _____
☐ Constant
☒ Increasing by 5 % annually
☐ Increasing by ___ VPD annually

ESTIMATED ACCIDENT REDUCTION:

By Types:				By Severity:	
Left turn	___%	Skidding	___%	Fatal	___%
Head on	___%	Wet pavement	___%	Injuries	___%
Rear end	___%	Night	___%	PDO	___%
Right angle	___%	RR crossing	___%	Total	___%
Side swipe	___%		___%		
Fixed object	___%		___%	All Accidents	
Lost control	___%		___%	60 %	

EQUIVALENT UNIFORM ANNUAL BENEFITS:
From accident reduction $ 11,320
From secondard benefits $ —
Total $ 11,320

ESTIMATED COSTS:
Initial implementation $ 12,000
Annual operation and maintenance $ 100
Terminal value $ 0
Equivalent uniform annual cost $ 1,300

NET ANNUAL BENEFIT $ 10,020 BENEFIT/COST RATIO 8.71

SPECIAL COMMENTS:

N-21

Highway Safety Program
Documentation Record
FORM 104

Location Identification Code
Date 3-13-74
Prepared by ABC

IMPROVEMENT ANALYSIS WORKSHEET
(One for each potential improvement)

LOCATION: Problem #2

IMPROVEMENT CODE: 106
IMPROVEMENT DESCRIPTION: Traffic signals

ESTIMATED SERVICE LIFE 10 YRS.
CURRENT 19 74 AADT 4,000 EST. 19 ___ AADT _____
☐ Constant
☒ Increasing by 5 % annually
☐ Increasing by ___ VPD annually

ESTIMATED ACCIDENT REDUCTION:

By Types:				By Severity:	
Left turn	___%	Skidding	___%	Fatal	___%
Head on	___%	Wet pavement	___%	Injuries	___%
Rear end	___%	Night	___%	PDO	___%
Right angle	___%	RR crossing	___%	Total	___%
Side swipe	___%	Turning	75 %		
Fixed object	___%		___%	All Accidents	
Lost control	___%		___%	___%	

EQUIVALENT UNIFORM ANNUAL BENEFITS:
From accident reduction $ 14,152
From secondard benefits $ —
Total $ 14,152

ESTIMATED COSTS:
Initial implementation $ 8,000
Annual operation and maintenance $ 500
Terminal value $ 1,000
Equivalent uniform annual cost $ 1,200

NET ANNUAL BENEFIT $ 12,952 BENEFIT/COST RATIO 11.79

SPECIAL COMMENTS:

N-22

Highway Safety Program
Documentation Record
FORM 104

Location Identification Code
Date 3-13-74
Prepared by ARC

IMPROVEMENT ANALYSIS WORKSHEET
(One for each potential improvement)

LOCATION: Problem #2

IMPROVEMENT CODE: 107
IMPROVEMENT DESCRIPTION: Grade separation

ESTIMATED SERVICE LIFE 50 YRS.
CURRENT 19 74 AADT 4,000 EST. 19 ___ AADT ___

☐ Constant
☒ Increasing by 5 % annually
☐ Increasing by ___ VPD annually

ESTIMATED ACCIDENT REDUCTION:

By Types:				By Severity:	
Left turn	%	Skidding	%	Fatal	%
Head on	%	Wet pavement	%	Injuries	%
Rear end	%	Night	%	PDO	%
Right angle	%	RR crossing	%	Total	%
Side swipe	%		%		
Fixed object	%		%	All Accidents	
Lost control	%		%	95 %	

EQUIVALENT UNIFORM ANNUAL BENEFITS:

From accident reduction $ 59,660
From secondard benefits $ —
Total $ 59,660

ESTIMATED COSTS:

Initial implementation $ 500,000
Annual operation and maintenance $ 1,500
Terminal value $ 0
Equivalent uniform annual cost $ 11,500

NET ANNUAL BENEFIT $ 48,160 BENEFIT/COST RATIO 5.19

SPECIAL COMMENTS:

N-23

Highway Safety Program
Documentation Record
FORM 105

Location Identification Code
Date 3-13-74
Prepared by ARC

IMPROVEMENT EVALUATION WORKSHEET
(One for each hazardous location)

LOCATION: Problem #2

SUMMARY OF EVALUATIONS:

Code	105	106	107		
Description	Channelization	Traffic signals	Grade separation		
Initial cost	$ 12,000	$ 8,000	$ 500,000	$	$
Annual cost	$ 100	$ 500	$ 1,500	$	$
Salvage value	$ 0	$ 1,000	$ 0	$	$
Service life	10 yrs	10 yrs	50 yrs	yrs	yrs
Equiv. uniform cost	$ 1,300	$ 1,200	$ 11,500	$	$
Equiv. uniform benefits	$ 11,320	$ 14,152	$ 59,660	$	$
Net annual benefits	$ 10,020	$ 12,952	$ 48,160	$	$
Benefit/cost ratio	8.71	11.79	5.19		

REJECTED IMPROVEMENTS (and explanation):

ELIGIBLE IMPROVEMENTS AND RANKING:

Code	Description	B/C Ratio
107	Grade separation	5.19

COMMENTS:

N-24

PROBLEM 3

3-1 What are the accident rates and accident rate reductions for the 5 improvements listed below? *

IMPROVEMENTS	BEFORE AADT	BEFORE ACCIDENTS	BEFORE RATE	AFTER AADT	AFTER ACCIDENTS	AFTER RATE	REDUCTION RATE	REDUCTION PERCENT
A	2,000	8	10.96	2,100	4	5.22	5.74	52.4 %
B	3,000	10	9.13	3,000	6	5.48	3.65	39.8%
C	4,000	15	10.27	3,500	13	10.18	0.09	0.9%
D	5,000	15	8.22	5,500	5	2.49	5.73	59.7%
E	10,000	35	9.59	10,500	15	3.91	5.68	59.2%

3-2 Which of these reductions are significant using the following tests?

TEST	IMPROVEMENTS WITH SIGNIFICANT REDUCTIONS
Poisson Distribution	D & E
Poisson Comparison of Means	D & E

* ASSUME BEFORE & AFTER PERIODS ARE BOTH 1 YEAR

N-25

PROBLEM 4

4-1 What is your forecast of an improvement cost and accident reduction for an improvement type based on the data below?

COUNTERMEASURE TYPE-LOCATION	INITIAL COST	FIRST YEAR'S ANNUAL COST	ACCIDENT RATE 1 YEAR BEFORE	ACCIDENT RATE 1 YEAR AFTER	1 YEAR AFTER AADT
A-1	$15,000	$500	10.2 Acc/MV	6.2 Acc/MV	6,000
A-2	12,500	500	8.8	5.2	8,000
A-3	14,000	500	9.4	5.7	2,000
B-1	50,000	0	10.0	4.0	4,000
B-2	60,000	0	9.0	3.0	4,000
C-1	1,800	100	9.0	6.0	3,000
C-2	2,000	100	9.6	6.2	4,000
C-3	2,100	150	8.8	6.2	5,000
C-4	2,000	150	9.6	5.8	4,000
C-5	2,800	100	10.5	6.5	2,000

COUNTERMEASURE TYPE	FORECAST OF ACCIDENT RATE REDUCTION PERCENT	CONFIDENCE INTERVAL
A	40.0 %	
B	63.2 %	
C	33.2 %	

* ASSUME BEFORE AADT = AFTER AADT

N-26

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.

	TIME TO COMPLETE PROBLEM		
	Shortest	Longest	Average
PROBLEM 1	15 minutes	10 hours	4.8 hours
PROBLEM 2	30 minutes	4 hours	2.4 hours
PROBLEM 3	10 minutes	1 hour	45 minutes
PROBLEM 4	1 hour	5 hours	2.7 hours

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.

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.

2. DID YOU HAVE ANY DIFFICULTY FINDING INTEREST TABLES?
_____ IF SO, EXPLAIN.

Only one user had difficulty finding interest tables.

3. IS THERE A STATISTICS TEXT OR HANDBOOK IN YOUR OFFICE?
_____ IF SO, CITE THE TITLE AND AUTHOR.

Fifty percent of the reviewers indicated lack of statistics text. This finding justifies the brief explanation of statistical concepts provided and charts of statistical distributions.
Text in use by the other reviewers are:

- Statistics with Applications to Highway Traffic Analyses by Eno Foundation
- Handbook of Statistical Tables
- Basic Statistics for Business and Economics by Smith and Leabe
- Quantitative Analysis for Business Decisions by Biernan, Bonini, Fouraker and Juedicke
- An Outline of Statistical Methods by Arkinard and Colton
- Elementary Statistics by Paul Noel
- Calculus and Analytic Geometry by Stein

4. IS THERE AN ECONOMICS TEXT IN YOUR OFFICE? _____
IF SO, CITE THE TITLE AND AUTHOR.

Only two reviewers indicated they had no economics text.

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.

D. ANALYST QUALIFICATIONS

Characteristics of the reviewing analysts are as follows:

- College graduates -- all but one was an engineer. He had a BBA with emphasis on economics and math.
- Experience range -- 2 to 28 years.
- Average experience -- 10 years.
- Professional registration -- 4 out of 9 were professional engineers, 3 were engineers-in-training.

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?_____ IF NOT, EXPLAIN.

Unanimous yes with one qualification indicating the description is quite general.

a. ARE THE COMPONENTS OF THE MANAGEMENT SYSTEM LOGICAL? _____ IF NOT, EXPLAIN.

Unanimous yes with one qualification, "The third item should be superflous 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.

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 Bureaus 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.

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 fatals, respectively.

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? _____ 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

1. 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 analyst.

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 fatals to injuries to PDO 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 fatals and 1 injury per crash; P.D. is enormous. An improvement increases number of accidents to 10 but with no fatals, 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.

Pennsylvania

I personally believe that intricate statistical methods for accident data, 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.

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 are enough options. Three reviewers thought it was too rigid.

2. WHICH ACCIDENT COSTS -- NHTSA or NSC -- DO YOU PREFER TO USE?_____ WHY?

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 fatals 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.

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 "noes" and the rest want to wait and see.

5. IF YOU ARE SATISIFED 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.

7. DO YOU FEEL THE MANUAL IS TOO TECHNICAL? _____
TOO GENERAL? _____
EXPLAIN AND CITE EXAMPLES.

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 utilitzation 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.

Appendix O

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:

Improvement	Accident Rate Reduction
Realignment	50%
Superelevation	50%
Reconstruction	25%
Combinations and Miscellaneous	25%

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)

$$\text{Estimated Accident Reduction} = \frac{(0.50)(4.0)(365)(6,500)}{10^6}$$

$$= 2.75 \text{ Accidents Per Year}$$

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.

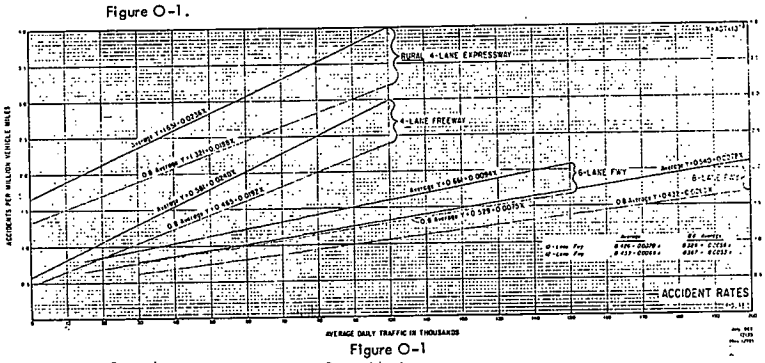

Figure O-1
Statewide Averages

Example

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

$$\text{Estimated Accident Reduction} = \frac{(4.8 - 2.3)(365)(22{,}000)}{10^6}$$

$$= 20.1 \text{ Accidents Per Year}$$

Appendix P

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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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 influences 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.

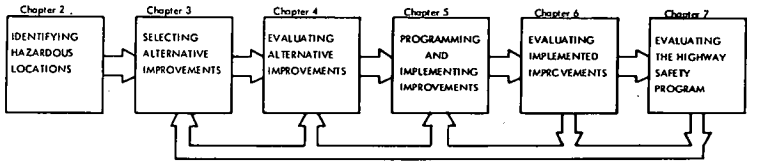


Figure 1
Model System

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 that data to be used and determine the reliability of reported information on items such as:

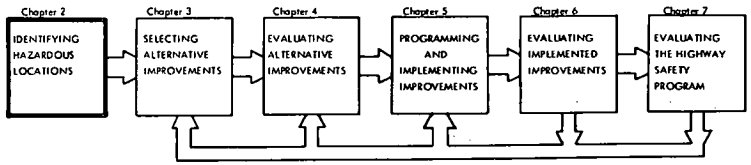
- The location of the accident
- The type of accident
- Severity of accident
- Traffic volume

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	Rural
2 lane	2 lane
4 or more lane undivided	4 or more lane undivided
4 or more lane divided	4 or more lane divided
Freeway	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.

Basic Data Requirements	Number of Accidents Method	Accident Rate Method	Number-Rate Method	Rate-Quality Control Method
Time period	X	X	X	X
Accident locations	X	X	X	X
Section lengths		X	X	X
Traffic volumes		X	X	X
Average accident rates		X	X	X
Categories of highways			X	X

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.

Criteria	Number of Accidents Method	Accident Rate Method	Number-Rate Method	Rate-Quality Control Method
Sections:				
Accidents per mile			X	
Accidents per MVM		X	X	X
Intersections and Spots:				
Number of accidents	X		X	
Accidents per MV		X	X	X

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.

$$\text{Rate/MVM} = \frac{(\text{no. of accidents on section})(10^6)}{(\text{ADT})(\text{no. of days})(\text{section length})}$$

4. Calculate the actual accident rate for each intersection or spot during the study period.

$$\text{Rate/MV} = \frac{(\text{no. of accidents at intersection or spot})(10^6)}{(\text{ADT at location})(\text{no. of days})}$$

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.

$$\text{Av. accidents per mile} = \frac{\sum \text{(number of accidents)}}{\sum \text{(miles of category)}}$$

$$\text{Av. accidents per MVM} = \frac{\sum \text{(number of accidents)}(10^6)}{\sum \text{(section ADT)(no. of days)(section length)}}$$

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.

$$\text{Av. accidents per location} = \frac{\text{total number of accidents}}{\text{total number of locations}}$$

$$\text{Av. accidents per MV} = \frac{\text{(total number of accidents)}(10^6)}{\sum \text{(location ADT)(no. of days)}}$$

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.

Table 1

Example Accident Rate Report

STATE ROUTE NO	WSP SECTION	COUNTY NO.	DISTRICT NO.	STATE ROUTE SEQUENCE	STATE ROUTE MILEPOST	URBAN/RURAL	BEGINNING OF SECTION	SECTION LENGTH (Miles)	AVERAGE DAILY TRAFFIC VOLUME	1971 ACCIDENT DATA: NO. OF PROPERTY DAMAGE ACCIDENTS	NO. OF INJURY ACCIDENTS	NO. OF FATAL ACCIDENTS	TOTAL NUMBER OF ACCIDENTS	NO. OF PERSONS INJURED	NO. OF FATALITIES	AMOUNT OF PROPERTY DAMAGE (Hundreds $)	ECONOMIC LOSS TO HWY. USER (Hundreds $)	FATALITY RATE	ACCIDENT RATE	Multi Year Average: FATALITY RATE	ACCIDENT RATE	NO. YEARS
304	1	18	3	00	1.23	U	6TH STREET	.38	1250	19	11		30	15	1	1	346		173.0		173.0	1
003	2	18	3	00	35.18	U	CALLOW AVENUE	.09	12000	18	2		20	2		1	47		50.7		43.9	4
509	1	27	3	00	.00	U	SR 5	.65	13750	116	45		161	59		8	1365		49.4		49.4	1
901	1	17	1	00	11.31	U	LEARY WAY	.39	2600	10	8		18	10		1	231		46.6		24.5	4
009	3	31	1	00	29.43	R	SR 9	.12	1600	2	1		3	1			23		42.8		30.4	2
305	1	18	3	00	.00	R	WINSLOW FERRY DOCKS	.22	3450	9	2		11	3		1	70		39.7		19.2	4
104	1	18	3	00	24.45	R	EDMONDS FERRY DOCK	.17	2550	3	3		6	4		1	93		37.9		28.8	4
101	2	14	3	00	83.75	U	H ST VIA WISK/HERON	.62	13600	85	20		105	23		4	533		35.7	14.5	30.0	2
167	1	27	3	00	.00	U	SR 410 IN SUMNER	.54	3300	16	7		23	10		1	231		35.4		35.4	1
164	1	17	1	00	14.52	R	SR 169-PORTER ENUMCLW	.11	6500	14	5		9	6		1	139		34.5		28.4	4
195	1	38	6	00	22.30	R	SR 270 IN PULLMAN	.07	12500	7	4		11	6		1	139		34.4		30.4	4
500	2	06	4	00	19.15	U	3RD AVE IN CAMAS	.14	6100	8	2		10	2		1	46		32.1		17.3	4
161	2	27	3	00	27.71	U	SR 162 IN PUYALLUP	.18	11450	18	6		24	7		1	162		31.9	33.2	28.8	4
009	1	29	1	00	55.75	R	STATE STREET	.14	1850	1	2		3	4			92		31.7		69.4	4
162	1	27	3	00	.00	U	SR 161 IN PUYALLUP	.19	7700	13	3		16	4		1	93		30.0		24.5	4
507	1	21	4	00	1.31	U	MAIN STREET	.21	14000	25	7		32	11		1	254		29.8		31.2	4
539	1	37	1	00	10.77	R	TROMP ROAD	.03	6200	2			2						29.5		37.3	2
304	1	18	3	00	.95	U	SR 303 WARREN AVE RT	.28	14450	26	16		42	25	3	3	578	18.0	28.4		35.5	4
432	1	08	4	00	1.76	U	SR 433	.12	12850	11	5		16	8	1	1	185		28.4		33.8	4
900	1	17	7	00	9.90	U	SR 167 IN RENTON	.45	9700	30	14		44	24	2	2	554		27.6		18.0	4
009	2	31	1	00	15.76	U	SR 204 W LAKE STEVENS	.26	7700	9	11		20	25		1	577		27.4	44.1	23.8	1
206	1	32	6	00	7.07	R	FOOTHILLS ROAD	8.32	120	6	4		10	7	2	1	162		26.5		27.4	4
022	1	03	5	00	35.74	R	SR 221 E OF PROSSER	.69	1800	8	3	1	12	3		3	938	441.2	26.2	105.9	13.0	4
306	1	18	3	00	1.61	U	TRENTON AVENUE	.49	640	1	2		3				69		25.2		11.4	4
022	2	39	5	00	3.06	U	SR 220 IN TOPPENISH	.34	3200	10			10						24.6		13.5	4
409	1	35	4	00	3.65	R	COLUMBIA STREET	.27	2475	4	2		6	4			92		24.5	59.0	13.9	4
303	2	18	3	50	1.46	U	SR 303	.54	4150	13	6		20	10	1	1	618	122.3	24.5		11.8	2
002	2	32	6	35	286.93	U	SR 9C	.47	3690	109	44	1	153	62		6	1432		24.2		22.9	4
014	1	20	4	00	63.48	R	SKAMANIA COUNTY LINE	.04	2825		1		1	3			69		24.2		6.7	4
104	1	18	3	00	15.54	R	SR 3	.65	2300		1		1	2			46		23.8		12.3	2
173	1	09	2	00	10.62	R	CRANES RD BREWSTER BR	.19	1210	1	1		2	3			69		23.8		13.9	4
020	1	29	1	00	5.13	R	FAIRHAVEN AVE	.16	5800	6	2		8	5		1	116		23.6		23.6	1
513	1	17	1	00	6.92	U	35TH NE AT LAKE CITY	.20	8750	13	2		15	2		1	47		23.5		14.4	4
202	1	17	1	00	21.72	R	FALL CITY ROAD	.11	4250	2	2		4	4		1	92		23.4		22.3	2
101	1	14	3	00	83.07	U	SR 105 IN ABERDEEN	.05	21300	4	5		9	5		1	116		23.2		17.0	2
011	1	37	1	00	22.55	U	HOLLY STREET	.98	7650	45	17	1	63	35	1	3	1195	30.5	23.0	10.1	24.3	4

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:

$$Rc = Ra + K\sqrt{\frac{Ra}{m}} - \frac{0.5}{m}$$

Where: Rc = Critical accident rate
(For sections - accidents per MVM)
(For intersections or spots - accidents per MV)
Ra = 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 95% level of confidence is desirable. Example values of K for various levels of confidence are shown below.

Level of Confidence	K
0.995	2.576
0.95	1.645
0.90	1.282

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, Rc, by the formula:

$$Rc = Ra + K\sqrt{\frac{Ra}{m}} - \frac{.05}{m}$$

Where: Ra = 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 counter-measures, 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

HAZARDOUS SECTION ANALYSIS FOR STATE HIGHWAY SUFF. SECTIONS

RURAL 2-LANE

DISTRICT NO.	HWY NO.	START REF POST	END REF POST	LENGTH	ADT (24HR)	POPULATION CODE	LANE CODE	NO. OF ACCIDENTS	ACCIDENTS PER MILLION VEH. MILES	CRITICAL RATE	SEVERITY RATE
1	C41	085.47	087.47	2.00	795	1	1	3	5.16	4.27	16.5
1	C52	436.80	437.75	.95	1700	1	1	3	5.08	4.26	75.6
1	866A	000.00	001.19	1.19	463	1	1	1	4.97	4.81	247.2
1	081	010.44	010.92	.48	2300	1	1	2	4.56	4.51	16.8
1	C92	421.23	422.73	1.50	2220	1	1	6	4.93	3.77	255.8
1	S13D	000.00	000.93	.93	600	1	1	1	4.90	4.81	29.9
1	136	179.15	187.34	8.18	1800	1	1	26	4.83	2.96	976.1
1	067	013.51	017.25	3.74	607	1	1	4	4.82	4.03	69.6
1	136	187.34	193.66	6.28	818	1	1	9	4.79	3.49	377.5
1	C05	293.26	293.51	.29	1978	1	1	1	4.77	4.81	29.9
1	C34	365.97	366.38	.41	1445	1	1	1	4.62	4.80	42.3
1	C64	047.22	052.85	5.63	322	1	1	3	4.53	4.18	159.2
1	C79	000.00	007.04	7.04	1312	1	1	15	4.44	3.17	657.6
1	C05	000.00	010.99	10.99	341	1	1	6	4.38	3.69	214.9
1	129	000.00	007.89	7.89	162	1	1	2	4.28	4.42	58.3
1	041	038.79	048.83	10.04	192	1	1	3	4.26	4.14	90.1
1	077	000.00	003.03	3.03	1071	1	1	5	4.22	3.78	165.7
1	136	230.26	232.41	2.15	1823	1	1	6	4.19	3.66	197.1
1	C34	300.35	310.34	9.99	1591	1	1	24	4.13	2.93	854.0
1	C75	009.90	010.54	.64	2070	1	1	2	4.13	4.40	93.8

23

Table 3
Example Listing of Hazardous Intersections

DANGEROUS INTERSECTION ACCIDENT RATINGS
(1972)

URBAN 4-LANE DIV.

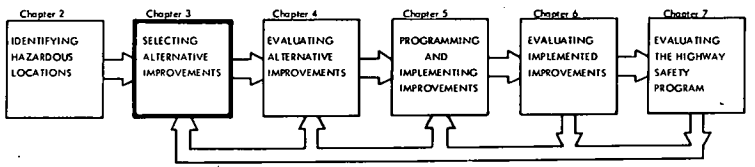
HWAY	M.P.	HWAY	M.P.	HWAY	M.P.	HWAY	M.P.	INTERSECTION NUMBER	TOTAL VEH PER DAY	NO. OF ACCIDENTS	RATE	CRITICAL RATE
036	25.63	073	109.51					2820	8,300	18	5.94	4.00
050	91.86	275	180.26					2826	9,250	19	5.62	3.94
064	72.50	133	1.50					2829	24,520	46	5.14	3.50
038		275	177.91					2822	5,335	10	5.13	4.27
006	126.41	283	21.10					3302	3,475	6	4.73	4.57
010	57.17	030	272.92	044	51.54			1005	15,800	22	3.81	3.68
038	10.66	064	77.22					2823	37,375	52	3.81	3.36
085	5.00	275	184.25					2832	23,480	31	3.61	3.52

24

For consistency, each agency should adopt a standard format for documentation--and documentation should be included in any subsequent design report. An example documentation worksheet is shown in Appendix B.

Table 4
Example Listing by Accident Costs

Locations	County	Accidents 1971	Accidents 1972	Relative Severity 1971	Relative Severity 1972
US 34 from ref. 316.47 to 318.14 (1.67 miles), 2.8 miles north of Lincoln	Lancaster	6	17	$ 74,820	$ 163,110
US 34 from ref. 324.35 to 324.66 (.32 miles), in Lincoln	Lancaster	35	40	$ 116,430	$ 141,750
US 77 from ref. 22.27 to 24.08 (1.81 miles), in Beatrice	Gage	35	41	$ 124,410	$ 138,990
US 34 from ref. 379.36 to 381.43 (2.07 miles), in Plattsmouth	Cass	26	35	$ 92,400	$ 117,660
US 73 from ref. 4.13 to 4.61 (.48 miles), in Falls City	Richardson	19	25	$ 62,100	$ 116,580
US 136 from ref. 187.34 to 193.66 (6.28 miles), in Filley	Gage	9	11	$ 113,250	$ 108,120
N-67 from ref. 27.22 to 33.37 (6.08 miles), south edge of Peru	Nemaha	6	9	$ 60,150	$ 107,490
US 73 from ref. 59.44 to 60.12 (.68 miles), in Nebraska City	Otoe	23	24	$ 97,920	$ 103,590
US 6 from ref. 319.86 to 320.71 (.84 miles), northeast edge of Lincoln	Lancaster	3	6	$ 21,960	$ 89,970
US 6 from ref. 293.51 to 296.15 (2.63 miles), in Milford	Seward	6	9	$ 56,790	$ 87,210
N-15 from ref. 92.68 to 97.81 (5.13 miles), north edge of David City	Butler	9	8	$ 74,670	$ 81,930
N-15 from ref. 66.46 to 67.52 (1.06 miles), in Seward	Seward	18	18	$ 57,960	$ 71,160



Chapter Three

SELECTING ALTERNATIVE IMPROVEMENTS

The procedures described in Chapter Two will result in a listing of hazardous locations throughout the system. Identification has been based primarily on actual accident experience. Each location has had an abnormally high accident rate -- and after checking them out, we are reasonably sure there is more to the circumstance than mere chance.

The next step is to investigate the locations to determine probable causes and to prescribe improvements which will correct conditions. There is no assurance that a cause will be found in all cases. And when a cause is found, chances are that there will be several alternative improvements to be considered.

The purpose of this chapter is to set forth some orderly systematic procedures for investigating the hazardous locations and for identifying possible solutions.

In recent years there has been considerable research into methods for analyzing causes of accidents. Many techniques are documented in the Research Report for NCHRP 17-2A. It would be inappropriate to attempt to include all suggested techniques in this manual. A basic accepted approach is presented -- along with several supplementary or alternative techniques that might be applied.

THE BASIC APPROACH

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 for 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.

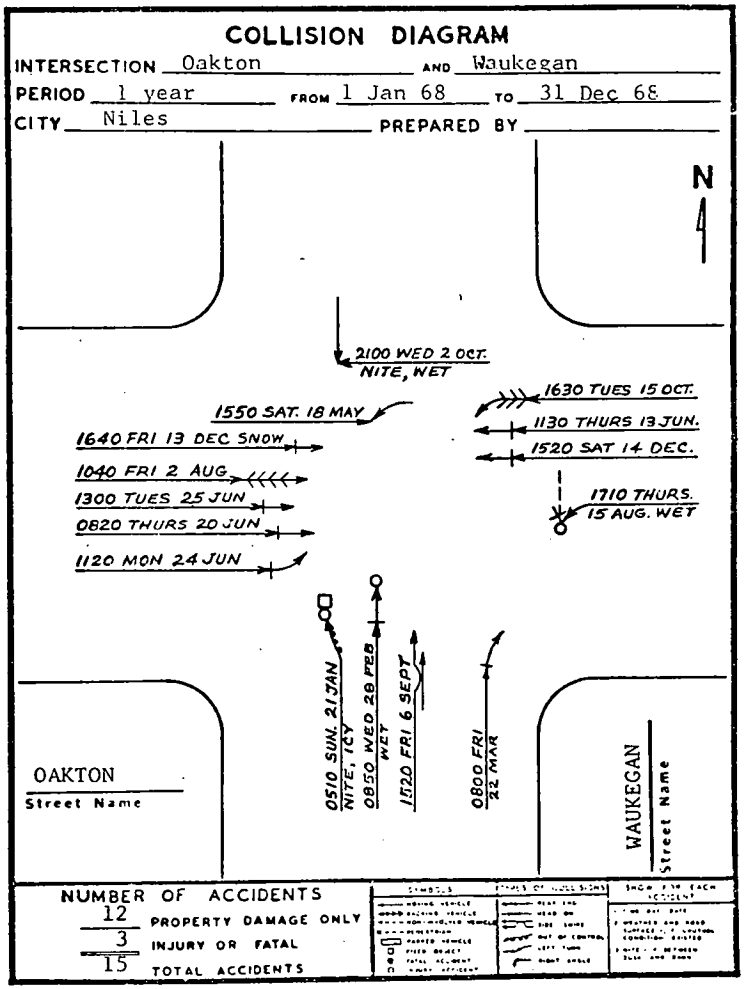


Figure 2. Example Collision Diagram

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 5
Example Summary of Accident Characteristics

Type of Accident	Year									
	No.	%	No.	%	No.	%	No.	%	No.	%
Ran off Road										
Overturned on Roadway										
Two or More Motor Vehicles										
Entering at angle										
From same direction - both going straight										
Same--one turning; one going straight										
Same -- one stopped										
From opposite direction -- both going straight										
Pedestrian										
Car going straight										
Car turning right										
Car turning left										
Car backing										
Railroad Train										
Bicyclist										
Animal										
Fixed Object in Road										
Fell From Moving Vehicle										
Wet Road Surface										
Road Surface Icy or Snowy										
Dawn or Dusk										
Darkness										
Fatalities										
Injuries										
Property Damage Only										

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 far 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 ran-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.

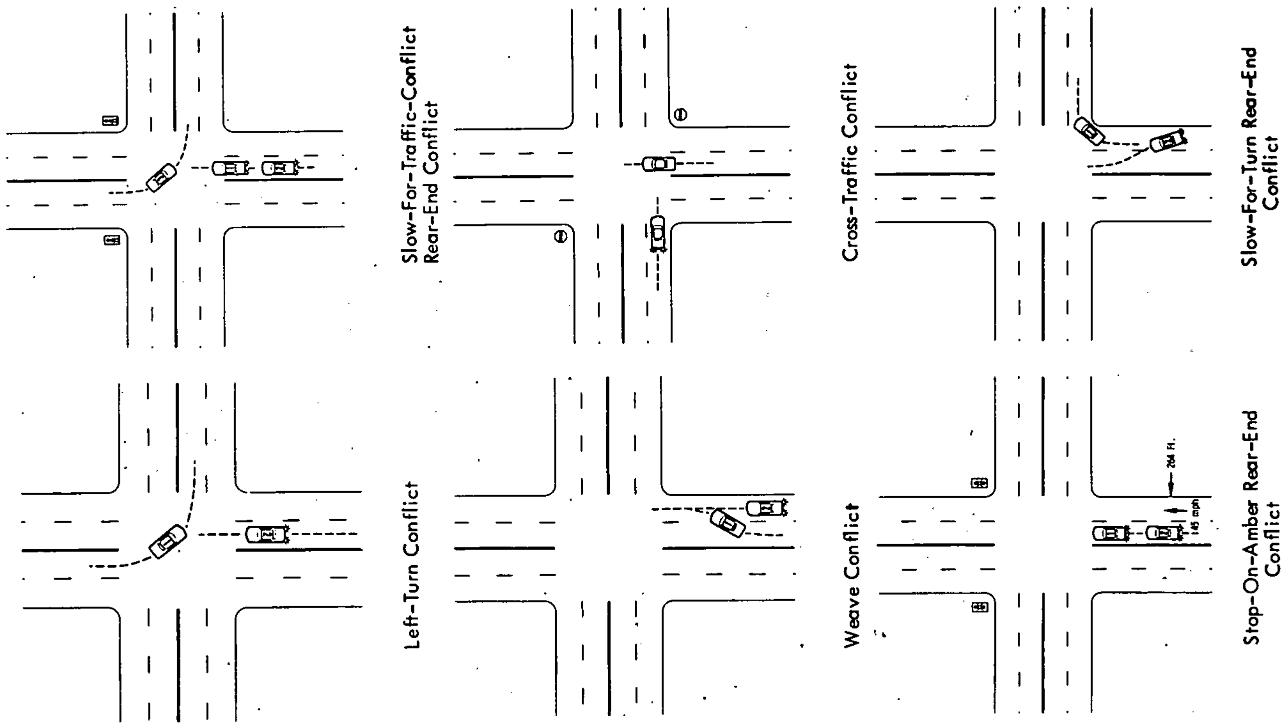
The advantage of conflicts analysis is that detailed studies on intersections can be based on a large volume of objective data rather than on a few accident reports. The disadvantage of conflicts analysis is that there is no way to predict the relative severity or possible result of each conflict.

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



Left-Turn Conflict

Slow-For-Traffic-Conflict Rear-End Conflict

Weave Conflict

Cross-Traffic Conflict

Stop-On-Amber Rear-End Conflict

Slow-For-Turn Rear-End Conflict

Figure 3. Typical Intersection Conflicts

	COUNT START TIME (MILITARY)	WEAVE		LEFT-TURN FROM WRONG LANE		RIGHT-TURN FROM WRONG LANE		TURN INTO WRONG LANE		OPPOSING LEFT-TURN		THRU CROSS-TRAFFIC LEFT TO RIGHT		THRU CROSS-TRAFFIC RIGHT TO LEFT		LEFT-TURN CROSS-TRAFFIC FROM LEFT		LEFT-TURN CROSS-TRAFFIC FROM RIGHT		RIGHT-TURN CROSS-TRAFFIC		REAR END CONFLICTS												SINGLE VEHICLE PEDESTRIAN CONFLICTS	WEAVE-PEDESTRIAN CONFLICTS	
		NO. VEHS.	NO. CONFS.	NO. VEHS.	NO. CONFS.	NO. VEHS.	NO. CONFS.	NO. VEHS.	NO. CONFS.	NO. VEHS.	NO. CONFS.	NO. VEHS.	NO. CONFS.	NO. VEHS.	NO. CONFS.	NO. VEHS.	NO. CONFS.	NO. VEHS.	NO. CONFS.	NO. VEHS.	NO. CONFS.	STOP ON AMBER	SLOW FOR LEFT-TURN	SLOW FOR RIGHT-TURN	PREVIOUS TRAFFIC CONFLICT	SHOPPING ENT. BEYOND INTERSECTION	SLOW TRUCK	CONGESTION IN INTERSECTION	CLEAR INTERSECTION	STALLED VEHICLE	TRAFFIC BACK-UP	PEDESTRIAN	MERGING BEYOND INTERSECTION			
	8 9 10 11	12 13	14 15	16 17	18 19	20 21	22 23	24 25	26 27	28 29	30 31	32 33	34 35	36 37	38 39	40 41	42 43	44 45	46 47	48 49	50 51	52 53	54 55	56 57	58 59	60 61	62 63	64 65	66 67	68 69	70 71	72 73	74 75	76 77	78 79	80
1	0630	1	1			4	2	3	3											1	1	3	3	1				1				4				
2																																				
3	0650			3	3			4	2	4	2			1	1	2	1					2														
4																																				
5	0710	3	2	2	1			6	5													1	3		2		2				10	6			2	
6																																				
7	0730					1	1	3	3			1	1					2	1	4	3	6							1							
8																																				
9	1530	2	2					2	1	3	1											1		1												
10																																				
11	1550			4	3			3	3													4	15			1							2			
12																																				
13	1610	3	2					1	1							1	1					6	4													
14																																				
15	1630					6	4	1	1	1	1									1	1	7	6							1				6		

(Fill In) PROJECT NO. 3-5 1 0 1

(Check One) PERIOD 6
BEFORE 4 ☒
AFTER 5 ☐

(Fill In) INTERSECTION APPROACH NO. 7 1

TRAFFIC CONFLICTS DATA SHEET "C"

CONFLICT COUNTS

INTERSECTION NAME: CLOPPER & QUINCE ORCHARD RDS
RECORDED BY: J. K. REDDING, JR.
COMMENTS: SCHOOL CHILDREN HAVE DIFFICULTY CROSSING CLOPPER ROAD IN THE MORNING.

Figure 4. 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 7

Example Table of Predominant Accident Types vs. Probable Causes

Probable Cause of Accident	Type of Accident									
	Head-on Collision	Rear-End Collision	Right Angle Collision	Sideswipe	Left Turn Collision	Right Turn Collision	Hit Fixed Object	Hit Pedestrian	Wet Weather Ratio	Night Time Ratio
Restricted Sight Distance	X		X		X	X		X		
Poor Pavement Marking	X			X					X	X
Inadequate Signals		X	X		X	X		X		
Inadequate Signs		X		X						
Slippery Surface		X							X	
Inadequate Signal Timing		X	X		X	X				
Inadequate Signal Phasing					X	X		X		
Improperly Located Driveways				X						
Fixed Objects							X			
Under Designed			X	X	X	X				

Table 8

Example Table of Probable Causes vs. Applicable Improvements

1. Restricted Sight Distance
   - 1.1. Removal of obstructions such as brush, weeds, trees
   - 1.2. Removal or adjustments of poles, signs, embankments, etc.
   - 1.3. Reduction of grades where necessary
   - 1.4 Establishment of No Passing Zones
   - 1.5 Removal of parking near intersections
2. Poorly or Unmarked Pavement
   - 2.1. Provide normal application of pavement marking in accordance with MUTCD
   - 2.2 Provide Stop Bars where needed
   - 2.3 Provide raised pavement markers where required
   - 2.4 Replace markings in poor condition
3. Inadequate Signals
   - 3.1 Upgrade signal in accordance with MUTCD
   - 3.2 Provide louvers where necessary
   - 3.3 Provide visors where required
   - 3.4 Provide back plates where warranted
   - 3.5 Provide adequate location for each approach
   - 3.6 Provide adequate number for each approach
4. Inadequate Signing
   - 4.1. Upgrade signs in accordance with MUTCD
   - 4.2. Removal of unwarranted signs
   - 4.3 Provide advance warning signs where applicable
   - 4.4 Replace worn out signs
   - 4.5 Adjust improperly placed signs that may distract driver attention
5. Slick Surface
   - 5.1 Groove existing pavement
   - 5.2 Overlay existing pavement
   - 5.3 Provide adequate drainage
   - 5.4 Provide Slippery When Wet signs
6. Inadequate Signal Timing
   - 6.1 Adjust amber in accordance with MUTCD
   - 6.2 Adjust phases to provide ample time for movements to take place
   - 6.3 Provide actuaction where warranted
7. Inadequate Signal Phasing
   - 7.1 Provide left or right turn phases if warranted
   - 7.2 Remove left or right turn phases if not warranted
8. Improperly located driveways
   - 8.1 Removal or adjustment of drives
   - 8.2 Provide curbs to control off street parking and driveways
9. Fixed Objects
   - 9.1 Removal or adjusting obstacles within 30' of pavement
   - 9.2 Provide break-away feature to obstructions that can't be moved
   - 9.3 Protection to fixed objects that cannot be otherwise treated
   - 9.4 Provide crash attenuators to fixed objects that cannot be otherwise treated
   - 9.5 Removal of curbs from exit gores
10. Inadequate Lighting
    - 10.1 Provide lighting of intersection where night time ratios of accidents are high
11. Under Designed
    - 11.1 Widen lanes where necessary
    - 11.2 Add lanes where necessary
    - 11.3 Add or lengthen turn bays where necessary
    - 11.4 Provide right turn lanes where necessary
    - 11.5 Provide traffic divisional islands to separate opposing traffic
    - 11.6 Provide traffic channelization and direction-ing for motorists
    - 11.7 Provide pedestrian safety islands where warranted
    - 11.8 Adjustment or replacement of improperly designed island

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.

Procedures for developing a fault tree are:

1. Start with the final occurrence or consequent event--the collision.
2. Identify the events immediately preceding the occurrence and determine if these events must happen together or can lead independently to the occurrence.
3. Analyze each identified event to determine if any of them are basic, requiring no further development of cause.
4. Continue identifying preceding events until all basic events have been covered. Determinations 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.

   Note: The next three steps are optional, based on availability of probabilities of basic events.

5. Assign probabilities to each basic event.
6. Calculate probabilities of events produced by other events by (1) adding probabilities of events leading directly to an "OR" gate and (2) multiplying probabilities of events leading directly to an "AND" gate.
7. Determine the influence of potential countermeasures by decreasing the probabilities of certain events and recalculating subsequent other probabilities.

Figure 5 shows a simple example of a fault tree with sequence of events and probabilities. The analysis starts with the collision and works backward. Events preceding the collision are identified and analyzed to determine if each event independently can lead to the occurrence, or if several events must happen together. Some events are basic, requiring no further development of cause. When all basic events are identified, the probabilities of accident causation can be established.

Table 9

Symbols Used in Fault Tree Analysis

Name	Symbol	Definition
Rectangle Event		An effect of consequence event produced by other events.
Circle Event		A basic event requiring no further development of its cause.
Diamond Event		A terminal event not developed further due to lack of information or lack of significance.
House Event		A normal event that is usually expected in operation of the system.
AND Logic Gate		All inputs are required to produce an output event whose probability is equal to the product of the probabilities of the input events.
OR Logic Gate		Any input will produce an output event whose probability is equal to the sum of the probabilities of the input events.

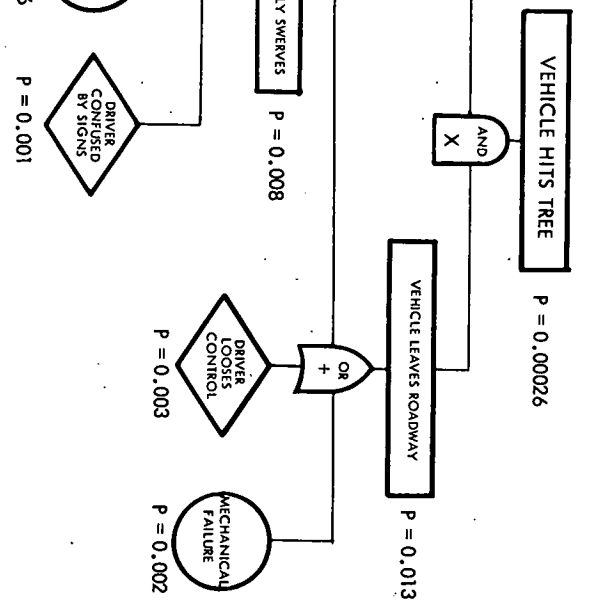
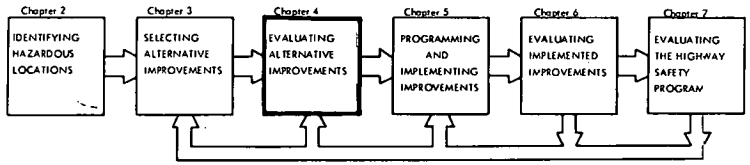


Figure 5. Example Fault Tree Analysis



Chapter Four

EVALUATING ALTERNATIVE IMPROVEMENTS

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:

1. Estimating accident reduction.
2. Assigning values to accident reduction.
3. Estimating secondary benefits.
4. Estimating improvement costs.
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.

Information needed for analyses includes:

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

There have been expressions of skepticism about the need for precise formal economic analysis on the basis of practical considerations that:

1. Much of the basic input data reflects very rough estimates or assumptions for which there may be wide variations in judgments and opinions.

2. Currently there are many uncertainties as to future basic travel characteristics—modes of travel, types of vehicles, speeds, vehicle safety features, --significant changes in any one of these might negate decisions based on the orderly world of theoretical economics.

3. Basic decisions on policy and programs by politically oriented agencies quite often are based on motives and factors other than objective evaluations.

To some extent this skepticism is valid. The ultimate findings and conclusions may have some inaccuracies--and the ground rules may be changed in a few years--and those who make the ultimate decisions may largely ignore our recommendations. But we can no longer, in good conscience, plan by the "seat of our pants." And until something better comes along, the conventional economic analysis provides our best tool for planning and decision making.

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	$103,000
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:

$$\text{Average accident cost} = \frac{(Ff)(Cf) + (Fi)(Ci) + (Fp)(Cp)}{Ff + Fi + Fp}$$

Where: Ff = Number of fatal accidents for this accident type.
Fi = Number of injury accidents for this accident type.
Fp = Number of property damage accidents for this accident type.
Cf = Average cost per fatal accident.
Ci = Average cost per injury accident.
Cp = 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:

Improvement	Service Life
Signals	15 years
Safety Lighting	15 years
Median Barriers	15 years
Flashing Beacons	10 years

Improvement (continued)	Service Life
Guardrail	10 years
Pavement Grooving	10 years
Signing (major)	10 years
Signing (minor)	5 years
Raised Pavement Markers	5 years
Guide Markers	5 years
Painted Stripes	2 years

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 useable 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.

Interest Rate	Agencies Using This Rate
10%	New York
8%	Ohio and Tennessee
7%	Georgia, Oklahoma and Utah
6%	Colorado, Massachusetts, North Carolina, Puerto Rico, West Virginia and Seattle
5%	Delaware, Minnesota, Missouri, Virginia and Wyoming
0%	California

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:

$$EUAB = CR^i_n \sum (\text{each year's benefit})\ (\text{each year's } PW^i_n)$$

Where: CR^i_n = Capital Recovery Factor for n years (service life of improvement) at interest rate i.
PW^i_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:

$$EUAC = CR^i_n (I) - T\,(n^{th} \text{ year } SF^i_n) + K$$

If the annual costs vary from year to year, use the formula:

$$EUAC = CR^i_n \left[I + \sum_{j=i}^{n} K_j PW^i_j \right] - T(SF^i_n)$$

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.

I = Initial cost of improvement.
K = Constant annual cost.
T = Terminal value of improvement.
n = Service life of improvement.
Σ = 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 <u>each</u> 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 <u>available funds</u>, 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:

	Improve Signing	Left-Turn Lanes	Install Signals
Alternate A	X		
Alternate B		X	
Alternate C			X
Alternate D	X	X	
Alternate E	X		X
Alternate F		X	X
Alternate G	X	X	X

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:

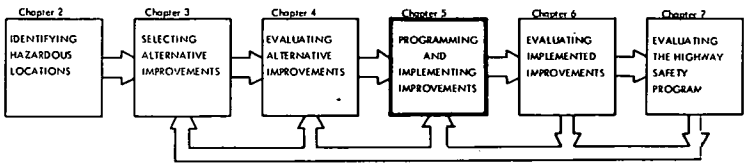
- Improvement parameters--What are the estimated service lives of the applicable improvements? Estimated costs?
- Improvement performance--What is the estimated accident reduction of each applicable improvement?
- Evaluation data--What is the equivalent uniform annual cost of each improvement? Equivalent 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.



Chapter Five

PROGRAMMING AND IMPLEMENTING IMPROVEMENTS

Completion of the analyses described in the preceding chapter will provide a list of safety-oriented improvements of highway facilities. We are reasonably sure that we have chosen the best improvements--and that each is economically sound and desirable. And the economic analysis establishes a logical and realistic priority basis for programming and actually implementing the improvements.

But there is need to place the highway safety improvement program in proper perspective--and to establish policies and procedures effectively to implement the program. Normally, this will involve top-level management decisions.

BASIC OBJECTIVES AND POLICIES

Most highway agencies operate on the basis of some established objectives and policies, written or unwritten, which define their purpose, goals and general framework of management. Quite often, safety is included as one of the criteria governing the design, construction and maintenance of highway facilities. But seldom has there been a

singular effort directed solely at assuring safety in highway facilities. 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.

Figure 6. Example Safety Management System Policy Statement

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

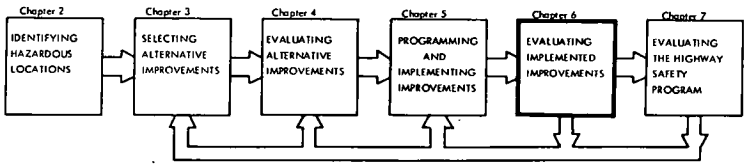
Effective scheduling of individual projects is essential to accomplishing any highway improvement program--including implementing of safety improvements. It would be unrealistic to propose an annual program requiring considerable more funds than will be available--and it would be equally unrealistic 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 past 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.

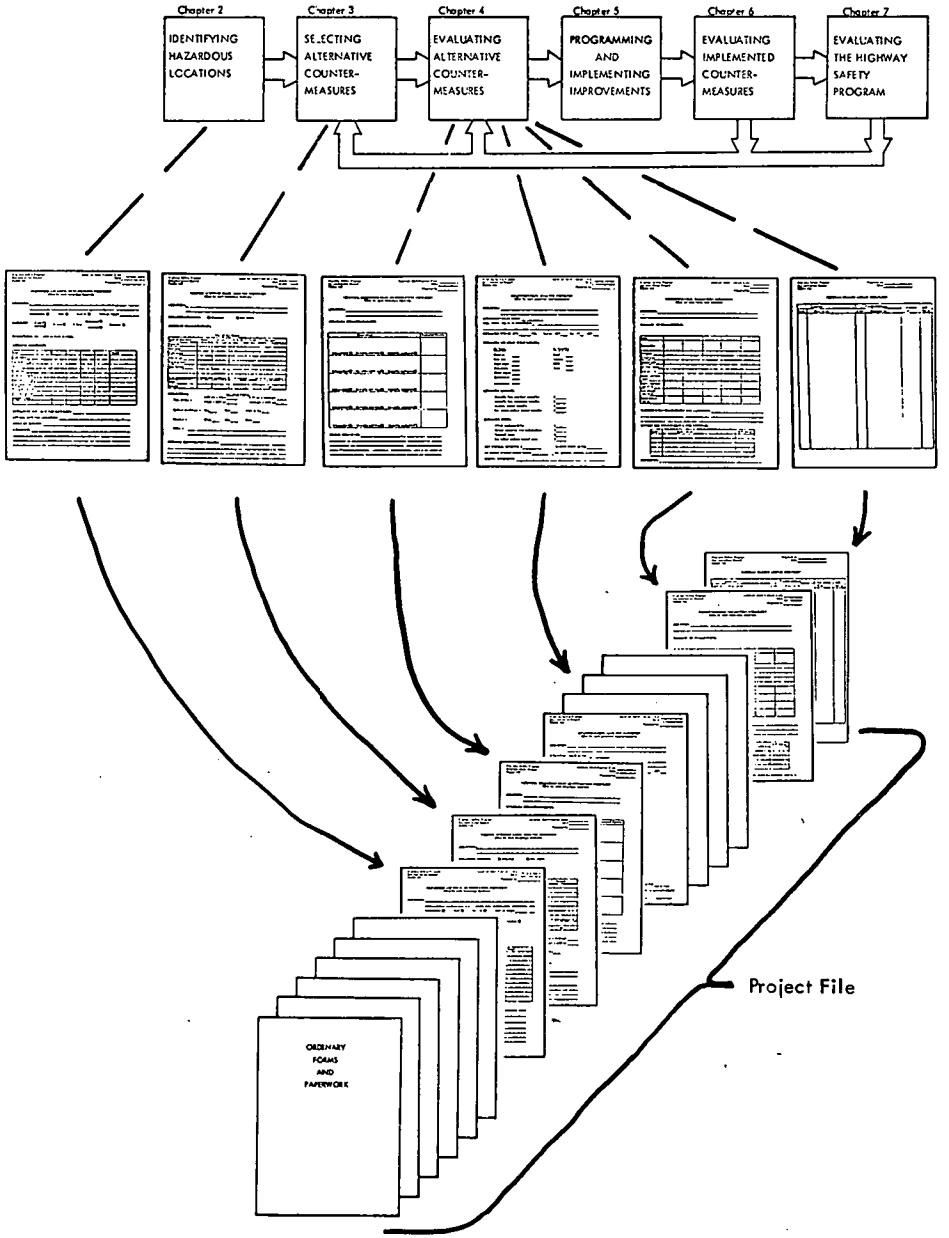


Figure 7. Basic Documentation of the Process

BASIS FOR COMPARISON

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 improvement implementation. To obtain statistically reliable data for evaluating a type of improvement, the before and after accident experiences at several locations may be grouped together.
- Parallel or Control Group Analysis: This analysis compares accident experience at the improved location with accident experience at similar locations not receiving improvements. Comparisons are made with the experience at these "control group" locations during the "after" period or with the trend in experience from "before" to "after."
- Performance Standard Analysis: This analysis compares improvement performance with standard performance for that improvement--and is applicable only when performance standards have been established.

Before and after analyses have been used more extensively than the other techniques, probably because of the difficulty of finding truly similar control locations. The before and after analysis is described in this manual. The other two methods are discussed in the NCHRP 17-2A Research Report.

EVALUATION PROCEDURES

Before and after studies may be conducted at a single location or at several locations with similar characteristics where the same improvement has been implemented. A regular program should be established for reviewing all implemented improvements every three months during the first year, and annually thereafter.

COUNTERMEASURE NUMBER (Assigned by Traffic & Safety) 1–5

COUNTERMEASURE LOCATION OR AREA OF INFLUENCE

Type of Location at Which Countermeasure Applied 6

1–State Highway	4–Vehicle Design	7–Drivers	0–Others
2–City Street	5–Emergency Facilities	8–Schools	
3–County Road	6–Courts	9–	

Specific Location or Area of Influence (Select Corresponding Method of Describing Location for Codes 1–3 above.)

(1) State Highway Number 7
From Milepoint 10
To Milepoint 15

(2) City Number 7
Highway Number (For State Highways in Urban Areas – City Code 18) 10
From Node or At Node for Intersection 13
Milepoint of Node – For Highways 17
To Node 22
Milepoint of Node – For Highways 26

(3) County Number 7
Township 9
Range 11
From Node or At Node for Intersection 13
To Node 15

(4) _____

Location: Statewide–1, City–2, County–3 in Column 7
City Number or County Number in Columns 8–10. 7

DIRECTION OF TRAVEL FOR WHICH COUNTERMEASURE IS APPLICABLE

Roadway Section – Both Directions – 1; One Direction – 2 31
If for one direction, indicate direction of travel 32
Intersection – All Approaches – 1; Specific Approaches – 2 33
If for Specific Approaches, indicate direction of Approaches – N-1, NE-2, E-3, SE-4, S-5, SW-6, W-7, NW-8 34 35 36 37

TIME LIMITS

Last day in before period or day before field preparation began
Month 38
Day 40
Year 42

First day of after period or first day that countermeasure is fully operational
Month 44
Day 46
Year 48

Last day that countermeasure was operational
Month 50
Day 52
Year 54

TYPE OF COUNTERMEASURE _____ 56–60

RESPONSIBLE AGENCY 61

COST OF IMPROVEMENT (Round to $100's) $ 62 , 66 , 0 0

ESTIMATED PERCENT REDUCTION IN ACCIDENTS 67

Figure 8. Data Documentation for Computer Input

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:

$$\text{Accidents per million vehicles} = \frac{(\text{No. of accidents})\ (10^6)}{(\text{No. of days})\ (\text{ADT})}$$

For sections:

$$\text{Accidents per million vehicle miles} = \frac{(\text{No. of accidents})\ (10^6)}{(\text{No. of days})\ (\text{ADT})\ (\text{Section Length})}$$

For each location, or for each group of locations with similar characteristics and improvements, the change in accident experience is calculated and identified as:

$$\text{Percent Accident Reduction} = 100 \left[\frac{(\text{Accident rate before}) - (\text{accident rate after})}{(\text{Accident rate before})} \right]$$

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.

Location	Before Accidents	After Accidents	% Reduction
A	50	40	20%
B	5	4	20%

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

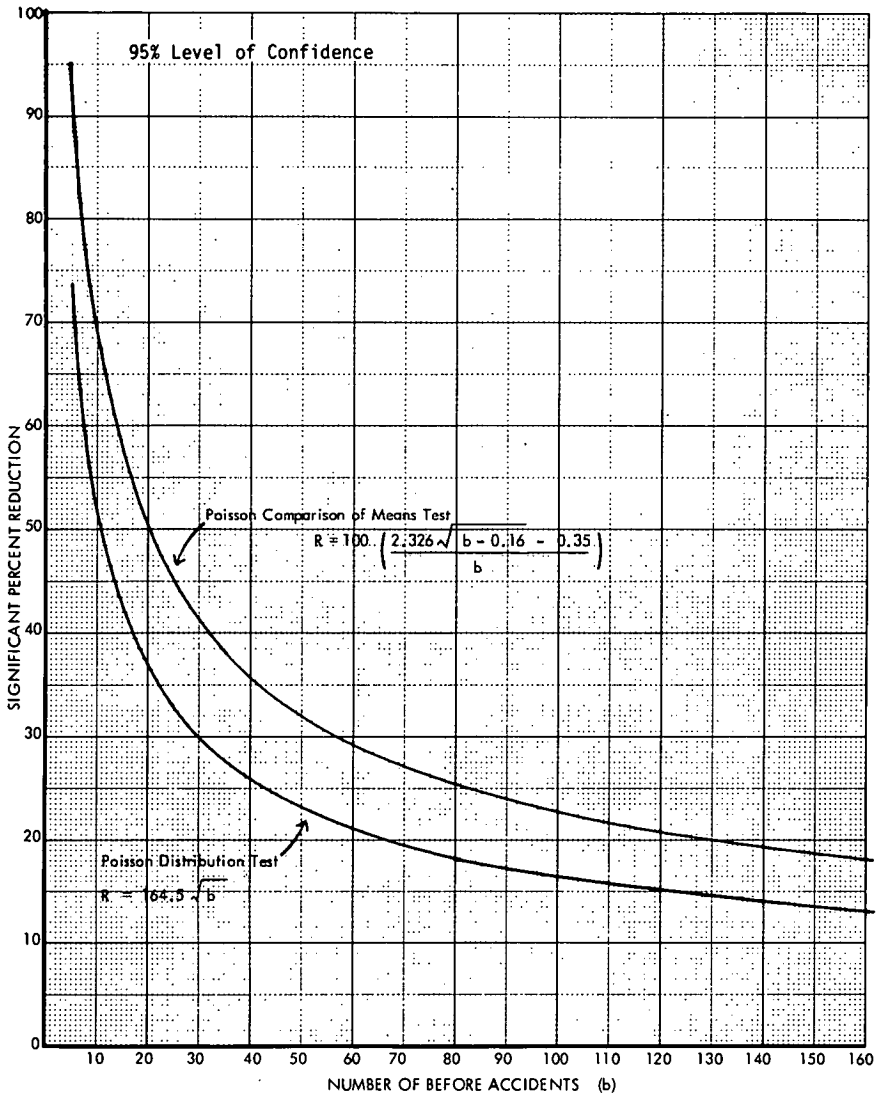


Figure 9. Poisson Tests For Significance

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:
   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:

$$B' = B \frac{\text{(After ADT) (Days in after period)}}{\text{(Before ADT) (Days in before period)}}$$

   For intersections, use the sum of the ADT 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.
   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.

		Accidents	Traffic Volume (ADT)
Before:	1971	48	52,000
	1972	46	55,000
	(Average)	(47)	(53,500)
After:	1973	33	58,500

The evaluation steps are:

1. Accident Rate Before $= \dfrac{(47)\,(10^6)}{(365)\,(53{,}500)\,(4.0)}$

   $= 0.602$ accidents/million vehicle miles

2. Accident Rate After $= \dfrac{(33)\,(10^6)}{(365)\,(58{,}500)\,(4.0)}$

   $= 0.386$ accidents/million vehicle miles

3. Percent Reduction $= 100\left[\dfrac{(0.602) - (0.386)}{(0.602)}\right] = 100\left[\dfrac{0.216}{0.602}\right]$

   $= 35.9\%$

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

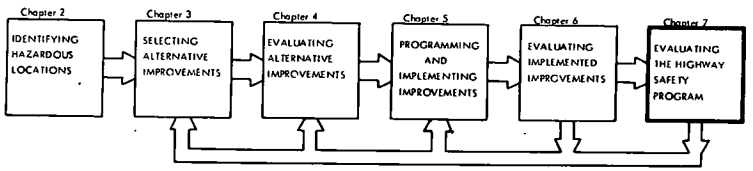
** CRASH EXPERIENCE **

	ACCIDENTS		**********	**********	INJURIES	**********	**********	* SEVERITY MEASURES *		***EXPOSURE***	
	TOTAL	PDO	FATAL	DISABLING	NON-DISABLING	POSSIBLE	TOTAL	TOTAL RSI	AVG RSI	NO. DAYS	ADT
BEFORE	55	40	2	4	13	4	23	103,910	1,649	365	2,663
AFTER	39	26	1	3	14	5	23	74,890	1,664	365	3,008
PERCENT REDUCTION	29	35	50	25	-8	-25	0	27	0		

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.



Chapter Seven

EVALUATING THE HIGHWAY SAFETY PROGRAM

Previously we discussed the need for a highway agency clearly to establish basic objectives and policies for its highway safety program. Subsequently, a management system framework was defined to facilitate accomplishment of objectives.

Periodically there is need to evaluate the total safety program in terms of:

- Effectiveness--Are we getting results consistent with the defined objectives? Is there evidence of positive benefits? Are the expenditures economically justified?

- Appropriateness of Objectives--Are current objectives appropriate? Have conditions changed or is there any indication of trends which would point to redirection of effort?

- Criteria and Procedures--Based on experience, should changes be made in criteria and procedures for planning and implementing programs? Are the values used for forecasting still valid? Are the basic data on costs and benefits realistic? Is accident reporting of adequate quality and precision?

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)

TYPE OF IMPROVEMENT	NO. OF PRO-JECTS	NO. OF ACCIDENTS (Before / After) Total	PDO	Injury	Fatal	NO. OF PEOPLE KILLED	PERCENT REDUCTION Total	PDO	Injury	Fatal	Killed	COST OF PROJECTS ($1000)	ACCIDENT COST SAVINGS ($1000)	BENEFIT COST RATIO (1 Year)
NEW SIGNALS (With or without channelization)	36	672	447	221	4	5				N	N	1,810	370	.20
		538	380	155	3	3	20	15	30	25	40			
MODIFY SIGNALS (Mast Arms, larger signal heads, detectors, etc.)	56	1516	1076	435	5	5		N		N	N	1,310	130	.10
		1412	1057	348	7	7	7	2	22	+ 40	+ 40			
LEFT-TURN CHANNELIZATION	41	319	207	107	5	8				N	N	1,040	310	.30
		249	163	83	3	3	22	22	22	40	63			
SIGNING (Warning)	16	652	466	177	9	19						160	1,120	7.00
		472	384	87	1	1	28	18	51	89	95			
SAFETY LIGHTING (A)	1	1	0	1	0	0	N	N				4.6	−1.0	−.22
		2	1	1	0	0	+100	+100	0	0	0			
FLASHING BEACONS	19	127	58	55	14	19		N	N			90	1,270	14.11
		99	51	47	1	1	22	12	15	93	95			
WET PAVEMENT CORRECTION (Grooving or Resurface) (B)	10	241	164	72	5	7				N		440	660	1.50
		73	55	17	1	1	70	67	76	80	86			
RECONSTRUCTION & MISC. (Curve corrections, roadway realignments, sight distance improvements)	62	757	467	266	24	26		N				2,920	1,980	.68
		654	428	221	5	5	14	8	17	79	81			
TOTAL PROGRAM	241	4285	2885	1334	66	89						7,774.6	5,800	.75
		3499	2519	959	21	21	18	13	28	68	76			

(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 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?

- Are the cost estimates reliable for implementing improvements?
- Are the estimates of improvement service life realistic?
- Is the interest rate appropriate for economic analysis?
- Are the analysis providing valid comparisons of costs and benefits?
- Are the priority indicators realistic?

Programming and implementing improvements

- Are all available earmarked safety funds being utilized?
- Is the safety program adequately coordinated with other agency improvement programs?
- Is there any overlap of responsibility for planning and implementing safety improvements
- Are various improvements being implemented in the most economical manner? By contractors? By agency work forces?
- Is the scheduling process effective? Are there problems with manpower utilization and meeting target dates?
- Should there be changes in the approach to funding safety improvements?

Evaluating implemented improvements

- Is all necessary information being documented accurately?
- Are the data on post-implementation accidents reported adequately?
- Are the tests adequate to assure that the results are significant?
- Do we have a reasonable level of confidence that the results were primarily attributable to the improvements?
- Are the actual benefits and costs at each location reasonably close to our predictions? If not, why?
- Is there reasonable consistency in the results from one location to another?

Evaluating the highway safety program

- Are the benefits identified with highway safety improvements sufficient to justify the investments in the program?
- Are there particular types of investments that are more productive than others?

- What is the total scope of the problem? Are we making progress?
- Is there need to adjust the levels of funding or to redirect emphasis?
- Is top management getting the information they need for policy decisions?
- Based on experience, is there need to update standards, guides and criteria for planning safety improvements?
- Can improvements be made in the safety management system procedures?

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 accident 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:

$$B' = B \frac{\text{(After ADT)(Days in after period)}}{\text{(Before ADT)(Days in before period)}}$$

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:

$$A' = A \frac{\text{(Before ADT)(Days in before period)}}{\text{(After ADT)(Days in after period)}}$$

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:

$$AARR = 100\left[1 - \frac{\Sigma A'}{\Sigma B}\right] \quad \text{or,}$$

$$= 100\left[1 - \frac{\Sigma A}{\Sigma B'}\right]$$

Where: A = Number of after accidents
A' = Adjusted number of after accidents
B = Number of before accidents
B' = Adjusted number of before accidents
Σ = Summation of all values

4. Calculate the expected range, ER, expressed as a percentage:

$$ER = 200\sqrt{\frac{n}{(n-1)(\Sigma X)^2}\left[\Sigma Y^2 + \left(\frac{\Sigma Y}{\Sigma X}\right)^2 \Sigma X^2 - 2\frac{Y}{X}\,\Sigma XY\right]}$$

Where: n = Number of implemented countermeasures
Σ = 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 = Number of before accidents = B

Y = 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.

	Before		After	
Location	Accidents	ADT	Accidents	ADT
1	14	2,000	4	2,100
2	12	2,000	4	2,000
3	24	4,500	6	4,000
4	8	1,250	3	1,300
Total	$\Sigma B = 58$		$\Sigma A = 17$	

2. Adjust the number of before accidents:

Location	Adjusted number of before accidents (B')		
1	$14 \frac{(2,100)(365)}{(2,000)(730)}$	=	7.35
2	$12 \frac{(2,000)(365)}{(2,000)(730)}$	=	6.00
3	$24 \frac{(4,000)(365)}{(4,500)(730)}$	=	10.67
4	$8 \frac{(1,300)(365)}{(1,250)(730)}$	=	4.16
			$\Sigma B' = 28.18$

3. Calculate the average accident rate reduction, AARR:

$$AARR = 100 \left[1 - \frac{17}{28.18}\right] = 40\%$$

4. Calculate the expected range, ER:

Location	Adjusted Before Squared	After Squared	Adjusted Before X After
1	54.02	16	29.40
2	36.00	16	24.00
3	113.85	36	64.02
4	17.31	9	12.48
Total	$\Sigma X^2 = 221.18$	$\Sigma Y^2 = 77$	$\Sigma XY = 129.90$

$n = 4$

$\Sigma X = \Sigma B' = 28.18$

$\Sigma Y = \Sigma A = 17$

$$ER = 200 \sqrt{\frac{4}{3(28.18)^2} \left[77 + \left(\frac{17}{28.18}\right)^2 221.18 - 2\left(\frac{17}{28.18}\right)(129.90)\right]}$$

$$= 200 \sqrt{.001285}$$

$$= 200\ (0.358) = \pm\ 7.2\%$$

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% $\pm$ 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.

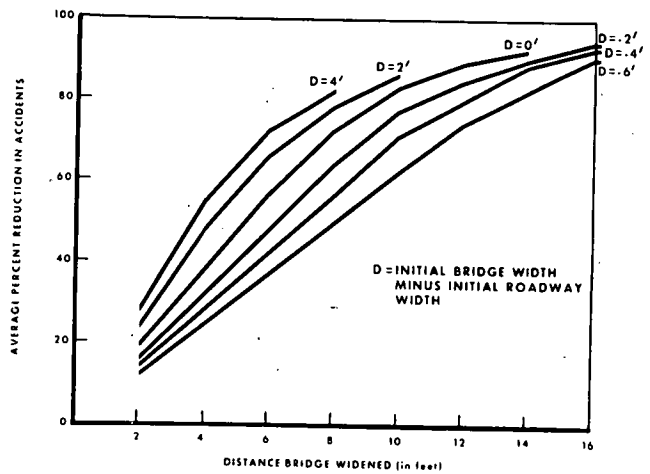


Figure 10. Example Family of Curves for Forecasting Accident Reduction (136)

APPENDIX A

GUIDES FOR SELECTING IMPROVEMENTS AND FORECASTING ACCIDENT REDUCTION

This appendix is directed principally to those agencies which have not accumulated sufficient accident experience data base of their own for guiding identification of potential improvements and forecasting probable results.

The information herein is not intended as a comprehensive authoritative source document. The state-of-the-art currently has not reached that point. The general guides for selecting improvements and forecasting results reflect the findings and conclusions of several agencies and research undertakings--in most instances based on rather limited data. The information may be helpful as a starting point--but each agency should develop its own data based on its own experience.

The forecasts in Table A-1 were developed in 1965 and published in 1966 in Evaluation of Criteria For Safety Improvements on The Highway by Jorgensen and Westat. This report should be reviewed before extensive use of the forecasts in Table A-1.

The forecasts in Table A-2 are currently used by the Mississippi State Highway Department in conjunction with Tables 7 and 8.

The forecasts in Table A-3 are currently used by the California Division of Highways.

Table A-1

Accident Reduction Forecasts from Evaluation of Criteria

Type of Improvement	Urban or Rural	Number of Lanes	Accident Reduction, Percent* All Accidents	Fatal Injury Accidents	Property Damage Only Accidents	Comments
Sections						
Eliminate parking	U	2 plus	32	3	-	
Install/improve edge marking	R	2	14	17a	-	
Install/improve warning signs	U	2	14	14a	-	
Install/improve warning signs	U	2 plus	20a	26a	-	
Install/improve warning signs	R	2	36	32a	-	
Install/improve warning signs	R	2 plus	18a	3	-	
Install median barrier-cable	-	2 plus	-33a	4a	-	
Install median barrier-beam	-	2 plus	-20a	-22a	-	
Install median barrier-type	-	2 plus	-44a	-11a	-	
Install median barrier	-	4 plus	-53b	-61a	-	
Add painted/raised median	U	2 plus	12	-	-	
Pavement resurfacing	U	2 plus	42	46	-	Depends on number of wet pavement accidents and total number per mile. See Ref.,p. 182.
Pavement resurfacing	R	2	12	21	-	
Pavement resurfacing	R	2 plus	44	59	-	
Shoulder stabilization	R	2	38	46	-	
Widen shoulder, no dimensions	R	2	-2	7a	-	
Widen traveled way, no dimensions	R	2	38	30	-	
Widen traveled way from 9 ft lanes	R	2	38	16	-	
Widen traveled way from 10 ft lanes	R	2	5a	-65b	-37a	
Livestock fencing	R	2 or more	90	-	-	Livestock accidents only
Modernization to design standards	R	2	10	-6a	-40b	
Modernization to design standards	R	2 plus	15b	22a	-	
Centerline striping at crests	R	2	64	-	-	
Horizontal Curves						
Install delineators	R	2	2b	16	-	See Ref.,p. 48.
Install delineators	R	2 plus	46a	-10b	61	
Install/improve warning signs	R	2	57	71	23a	
Install/improve warning signs	R	2 plus	52	40	-	
Reconstruct curve	R	2	88	89	96	

Table A-1 (continued)

Accident Reduction Forecast From Evaluation of Criteria

Type of Improvement	Urban or Rural	Number of Lanes	Accident Reduction, Percent* All Accidents	Fatal Injury Accidents	Property Damage Only Accidents	Comments
Install warning signs and delineators	U	2 plus	20	-27a	-	
Install warning signs and delineators	R	2	22a	41a	-	
Bridge/Underpass						
Install delineators	R	2	47	-8b	-	
Install delineators	R	2 plus	53a	62	89	
Intersections						
Install/improve directional/ warning signs	R	2	37	19	-	
Install/improve directional/ warning signs	R	2 plus	9	-7	-	
Install/improve directional/ warning signs	U	2	29	51a	-	
Install/improve directional/ warning signs	U	2 plus	41	47a	26a	
Install/improve directional/ warning signs	R	2	61	43b	-	T-intersection
Install/improve directional/ warning signs	R	2 plus	65	67	-	
Stop ahead sign	R	2	47	96	-	
Install yield sign	U	2	59a	80	-	
Install yield sign	U	2 plus	-46	-	-	
Install minor leg stop control	U	2	48	71	-	
Install minor leg stop control	U	2 plus	38a	18a	22	
Install minor leg stop control	R	2	65	89	-	
Install all-way stop signs**	U	2	68a	67a	-	
Install warning signals	U	2 plus	-27b	73a	-	
Install warning signals	R	2	56a	29a	-	
Install warning signals	R	2 plus	21b	-	-	T-intersection

** Minor street must be 35% 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

Type of Improvement	Urban or Rural	Number of Lanes	Accident Reduction, Percent* All Accidents	Fatal Injury Accidents	Property Damage Only Accidents	Comments
Add pedestrian signals	U	2	13	56a	-	
Add pedestrian signals	U	2 plus	3a	42a	-	
Improve signals	U	2	31	35a	-	Changes to improve driver's response to signal-vision, attention, etc.
Improve signals	U	2 plus	-2	10b	-	
Improve signals	R	2 plus	42a	45b		
Improve signals	U	2 plus	-	57	-	T-intersection
Curtail turning movement	U	2 plus	40	39	-	
Add left turn lane w/o signal	U	2	19a	80a	-	
Add left turn lane w/o signal	U	2 plus	6	54a	18a	
Add left turn lane w/o signal	R	2 plus	-6	-1b	-	
Add left turn lane w/o signal	U	2	79	79	-	T-intersection
Add left turn lane w/o signal	U	2 plus	51a	62	-	
Add left turn lane w/o signal	R	2	33	5	-15	Y-intersection
Add left turn lane & signal	U	2 plus	27	1	-7b	
Add left turn lane & signal	R	2 plus	43a	58a	-	
Add left turn lane & signal	R	2	-	-	-	T-intersection
Add left turn lane & signal	R	2 plus	-42a	-28b	-	
Add left turn signal w/o turn lane	U	2	-	-	-	
Add left turn signal w/o turn lane	U	2 plus	39	57	-	
Add left turn lane, signal & illumination	U	2 plus	46	76	-	
Install new traffic signals	U & R	2 plus	29	50	-	Proven hazardous intersections, 60% right angle and left turn accidents
Deslicking	U	2 plus	20	15	-	
Rumble strips	R	2	27b	26b	24b	

* The symbols in the percentage reduction columns have the following meaning:

No symbol	Good estimate	0-30%
a	Rough estimate	30-70%
b	Very rough estimate	70-150%
-	No estimate made	over 150%

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 38%.

Table A-2. Accident Reduction Forecasts Used By Mississippi State Highway Department

Improvement Type		Accident Reductions (Percent) Head-On	Rear-End	Right Angle	Sideswipe	Left Turn	Right Turn	Fixed Object	Pedestrian	Night Accident	Wet Pavement	Estimated Cost Of Improvement
Pavement Markings				10	20	10	10		10	10		$ 500
Signs	Upgrade	20	10						10		20	500
	Overhead Lane		10		20							400
	Overhead Warning		20	20		20	20					400
Signals	Timing		10	10		10	10		10			100(E)
	12" Lens		10									800(E)
	MUTCD (1)		20	20	10	20	20			20		10,000(N)
	Turn Phase		10			50						200(E)
	Opt. Program	20	10	10		10						2,000(E)
	Actuate		10	10	20	10	20					1,500(E)
	Pedestrian Phase								60			300
	Remove Signal		90									400
	Add Signal		(3)	80								10,000
Roadway	Deslick										50	3,000
	Sight Distance	20		20		20	20					
	Turn Bay		20									5,000
	Reconstruct	20	10									50,000
Misc.	Close Median Opening (2)	100	50	100	50	100						1,000
	Relocate Fixed Objects							60				1,000
	Lighting									50		5,000
	Relocate Drives	20	20	10	10	10	10					2,000

(1)--Includes Timing, 12" Lens, Turn Phasing and Actuation
(2)--Percent of Accidents Involved at Median Opening
(3)--One Accident Increase Per 2000 VPD
(E)--Upgrading Existing Equipment
(N)--Replacing Existing With New Equipment

Table A-3. Accident Reduction Forecasts Used By California Division of Highways

Type of Improvement	Average Accident Reduction (1)	Minimum Accident Experience (2)
New Signals (with or without channelization and/or lighting)		
4-leg intersection	27%	5 last year
Offset leg intersection	27%	
3-leg intersection	27%	
Modified Signals	27%	5 last year
New Left-turn Channelization at Signalized Intersections		
Without left-turn phase	15%	5 last year or 4 per year
With left-turn phase	36%	5 per year
New Left-turn Channelization at non-signalized Intersections		
With curbs and/or raised bars		
Urban area	70%	4 last year or 3 per year
Suburban area	65%	
Rural area	60%	
With painted channelization		
Urban area	15%	3 last year or 2 per year
Suburban area	30%	
Rural area	50%	
Flashing Beacons at Intersections		
4-leg red-yellow	50%	4 per year or 6 in two years
3-leg red-yellow	50%	3 per year or 5 in two years
4-way red	75%	4 per year or 6 in two years
Flashing Beacons at Railroad Crossing	80%	2 per year or 3 in two years
Advance Warning Flashers at Curves and Intersections	30%	3 per year or 5 in two years
New Safety Lighting		
At intersections		
New	75% of night acc.	3 night acc. per year or 5 night acc. in two years
Upgrading	50% of night acc.	
New Safety Lighting (continued)		
At RR crossing	60% of night acc.	2 night acc. per year or 3 night acc. in two years
At bridge approach	50% of night acc.	4 night acc. per year or 6 night acc.
At underpass	10% of night acc.	3 night acc. per year or 5 night acc. in two years
Delineation		
Double yellow median lines	5%	5 per year
Right edge lines	2% or 25% of ran-off-road accidents	5 per year
Reflectorized raised pavement markers	5%	5 per year or 3 night acc. per year
No passing stripes	65% or 85% of passing acc.	5 per year or 2 passing acc. per year
Reflectorized guide markers		
At horizontal curves	30%	1 night acc. per year or 2 night acc. in two years
At bridge approaches	40%	
Protective Guardrail		
At bridge rail ends	50%	1 per year or 2 in two years
At embankment curves	50%	ADT < 5000, 2 per year ADT > 5000, 3 per year
Inside curves	30%	
Outside curves	65%	
Signing		
Curve warning arrows	20%	2 per year
Advance curve warning with advisory speed	20%	3 per year
4-way stop	70%	5 accidents susceptible to correction
Advisory speed sign	36%	2 per year
Special curve warning	75%	6 with 2 susceptible to correction
Miscellaneous		
Realignment	50%	--
Superelevation	50%	--
Reconstruction (combinations and miscellaneous)	25%	--

(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
Date Period: 3 years -- 1971, 1972 and 1973.
Traffic: 750 AADT -- constant during period
Accidents:

DATE	LOCATION	SEVERITY	CHARACTERISTICS
Dec. 10, 1973	0.20	PDO	Left turn, day, dry
Feb. 10, 1973	1.00	2 Fatalities	Head on, night, dry
Aug. 8, 1971	1.42	PDO	Lost control, day, wet
Mar. 8, 1973	1.43	1 Fatality	Head on, day, wet
June 6, 1973	1.44	3 Injuries	Sideswipe, night, wet
Aug. 10, 1972	1.44	PDO	Sideswipe, night, wet
Mar. 20, 1972	1.45	1 Injury	Lost control, night, dry
July 7, 1973	1.70	PDO	Rear end, night, wet
Sept. 2, 1971	1.80	PDO	Lost control, day, dry
Feb. 2, 1971	2.00	2 Injuries	Head on, night, dry

DATE	LOCATION	SEVERITY	CHARACTERISTICS
Feb. 7, 1971	2.50	PDO	Hit abutment, day, dry
Nov. 1, 1971	3.25	PDO	Sideswipe, day, dry
May 15, 1972	3.75	PDO	Left turn, day, wet
Nov. 22, 1973	4.00	1 Injury	Hit tree, day, dry
Jan. 4, 1972	4.48	PDO	Read end, night, dry
Feb. 12, 1972	5.50	2 Fatalities	Left turn, day, dry

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:

$$m = \frac{(750)(3x365)(5.5)}{10^6} = 4.5 \text{ MVM}$$

For locations:

$$m = \frac{(750)(3x365)}{10^6} = 0.8 \text{ MV}$$

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:

$$Nc = (Rc)(m)$$

$$= (3.7)(.821)$$

$$= 3.0 \text{ accidents within 0.1 mile}$$

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.

Highway Safety Program
Documentation Record
FORM 101

Location Identification Code 5099-1.45
Date 5/10/74
Prepared by DRC

HAZARDOUS LOCATION IDENTIFICATION WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 99 from milepost 1.40 to 1.50

Intersection ☐ Spot ☒ Section ☐ Section length _____

CATEGORY: Rural ☒ Urban ☐ 2-lane ☒ 4-lane Undivided ☐ Divided ☐ Freeway ☐

DESCRIPTION: Sketch on back of sheet ☐ See collision diagram ☐
No sketch or collision diagram drawn ☒

ACCIDENT EXPERIENCE:

Year	1971	'72	'73			Total
From (date)	1/1	1/1	1/1			1/1/71
To (date)	12/31	12/31	12/31			12/31/73
AADT	750	750	750			Ave= 750 veh.
Exposure	273,750	273,750	273,750			821.25
Total accidents	2	2	1			5
Fatal accidents	0	0	1			1
No. fatalities	0	0	1			1
Injury accidents	1	1	0			2
PDO accidents	1	1	0			2
Accident rate	7.3	7.3	3.6			6.09 acc/mv

SYSTEMWIDE AVE. RATE FOR CATEGORY: 2.0 Acc/MV

CRITICAL RATE FOR LOCATION: 3.732 Acc/MV

INDEX OF SEVERITY: _____

COMMENTS: _____

Figure B-1. Hazardous Location Identification Worksheet For the Hazardous Curve on State Highway 99.

Highway Safety Program
Documentation Record
FORM 102

Location Identification Code 5099 - 1.45
Date 5/10/74
Prepared by DRC

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:

No. of Accidents

Type of Accident	Fatal	Injury	P.D.O.	Total	Percent
Head on	1	0	0	1	20 %
Rear end	0	0	0	0	— %
Right angle	0	0	0	0	— %
Side swipe	0	1	1	2	40 %
Fixed object	0	0	0	0	— %
Overturned	0	0	0	0	— %
Lost control	0	1	1	2	40 %
					%
Total	1	2	2	5	100%
Percent	20 %	40 %	40 %	100%	

CONDITIONS:

No. of accidents

Time of day - 6:00 am - Noon ____ 6:00 pm - Midnight ____
Noon - 6:00 pm ____ Midnight - 6:00 am ____

Light conditions - Day 2 Night 3

Surface conditions - Dry 1 Wet 4 Snow or ice ____

Weather - Cloudy ____ Clear 1 Rain 4 Snow ____ Other ____

Other - ____

PROBABLE CONTRIBUTORY CAUSES: Drivers appear to be surprised by the sharp curve. 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.

Highway Safety Program
Documentation Record
FORM 103

Location Identification Code 5099 - 1.45
Date 5/10/74
Prepared by DRC

POTENTIAL IMPROVEMENT IDENTIFICATION WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 99 from milepost 1.40 to 1.50

APPLICABLE IMPROVEMENTS:

IMPROVEMENT	EXPECTED RESULTS
101 -- Curve signing	40 % reduction of all accidents
102 -- Resurfacing curve	20% reduction of all accidents
103 -- Signing and resurfacing curve	50 % reduction of all accidents
104 -- Reconstruction of curve	90 % reduction of all accidents

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.

Signing	40%
Resurfacing	20%
Signing and Resurfacing	50%
Curve Reconstruction	90%

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

Signing	(0.274)(6.090)(0.40)	= 0.67 acc./yr.
Resurfacing	(0.274)(6.090)(0.20)	= 0.33 acc./yr.
Signing & Resurfacing	(0.274)(6.090)(0.50)	= 0.83 acc./yr.
Curve Reconstruction	(0.274)(6.090)(0.90)	= 1.50 acc./yr.

Accident Costs

Use National Highway Traffic Safety Administration accident costs:

Severity Class	Average Cost Per Accident
Fatal	$235,000
Injury	11,200
PDO	500
AVE	2,800

Improvement Costs

The estimated cost and service life of each improvement is:

Improvement	Initial Cost	Annual Cost	Service Life
Signing	$ 1,000	$100	8 years
Resurfacing	7,500	--	8 years
Signing and resurfacing	8,000	100	8 years
Curve reconstruction	40,000	--	20 years

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)

Improvement		EUAB
Signing	(0.67)(2,800) =	$1,875
Resurfacing	(0.33)(2,800) =	925
Signing and resurfacing	(0.83)(2,800) =	2,325
Curve reconstruction	(1.50)(2,800) =	4,200

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:

$$EUAC = CRF(I)-T(n^{th}\text{year}SFF)+(K)$$

Table B-1

Interest Factors for i = 10%

Number of Periods (n)	SINGLE PAYMENT: Compound Amount Factor (CAF) $(1+i)^n$	SINGLE PAYMENT: Present Worth Factor (PWF) $\frac{1}{(1+i)^n}$	UNIFORM SERIES OF PAYMENTS: Sinking Fund Factor (SFF) $\frac{i}{(1+i)^n-1}$	UNIFORM SERIES OF PAYMENTS: Compound Amount Factor (SCAF) $\frac{(1+i)^n-1}{i}$	UNIFORM SERIES OF PAYMENTS: Present Worth Factor SPWF) $\frac{(1+i)^n-1}{i(1+i)^n}$	UNIFORM SERIES OF PAYMENTS: Capital Recovery Factor (CRF) $\frac{i(1+i)^n}{(1+i)^n-1}$	Number of periods (n)
1	1.10000	0.90909	1.00000	1.00000	0.90909	1.10000	1
2	1.21000	0.82645	0.47619	2.10000	1.73554	0.57619	2
3	1.33100	0.75131	0.30211	3.31000	2.48685	0.40211	3
4	1.46410	0.68301	0.21547	4.64100	3.16987	0.31547	4
5	1.61051	0.62092	0.16380	6.10510	3.79079	0.26380	5
6	1.77156	0.56447	0.12961	7.71561	4.35526	0.22961	6
7	1.94872	0.51316	0.10541	9.48717	4.86842	0.20541	7
8	2.14359	0.46651	0.08744	11.43589	5.33493	0.18744	8
9	2.35795	0.42410	0.07364	13.57948	5.75902	0.17364	9
10	2.59374	0.38554	0.06275	15.93742	6.14457	0.16275	10
11	2.85312	0.35049	0.05396	18.53117	6.49506	0.15396	11
12	3.13843	0.31863	0.04676	21.38428	6.81369	0.04676	12
13	3.45227	0.28966	0.04078	24.52271	7.10336	0.14078	13
14	3.79750	0.26333	0.03575	27.97498	7.36669	0.13575	14
15	4.17725	0.23939	0.03147	31.77248	7.60608	0.13147	15
16	4.59497	0.21763	0.02782	35.94973	7.82371	0.12782	16
17	5.05447	0.19784	0.02466	40.54470	8.02155	0.12466	17
18	5.55992	0.17986	0.02193	45.59917	8.20141	0.12193	18
19	6.11591	0.16351	0.01955	51.15908	8.36492	0.11955	19
20	6.72750	0.14864	0.01746	57.27499	8.51356	0.11746	20
21	7.40025	0.13513	0.01562	64.00249	8.64869	0.11562	21
22	8.14027	0.12285	0.01401	71.40274	8.77154	0.11401	22
23	8.95430	0.11168	0.01257	79.54301	8.88322	0.11257	23
24	9.84973	0.10153	0.01130	88.49731	8.98474	0.11130	24
25	10.83470	0.09230	0.01017	98.34704	9.07704	0.11017	25
26	11.91817	0.08391	0.00916	109.18175	9.16095	0.10916	26
27	13.10999	0.07628	0.00826	121.09992	9.23722	0.10826	27
28	14.42099	0.06934	0.00745	134.20991	9.30657	0.10745	28
29	15.86309	0.06304	0.00673	148.63091	9.36951	0.10673	29
30	17.44940	0.05731	0.00608	164.49399	9.42691	0.10608	30
35	28.10243	0.03558	0.00369	271.02431	9.64416	0.10369	35
40	45.25925	0.02209	0.00226	442.59246	9.77905	0.10226	40
45	72.89047	0.01372	0.00139	718.90466	9.86281	0.10139	45
50	117.39082	0.00852	0.00086	1163.90822	9.91481	0.10086	50
60	304.48154	0.00328	0.00033	3034.81540	9.96716	0.10033	60

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	EUAC
Signing	0.187(1,000) + 100 = $ 285
Resurfacing	0.187(7,500) = 1,400
Signing and resurfacing	0.187(8,000) + 100 = 1,595
Curve reconstruction	0.117(40,000) = 4,680

Improvement Evaluation Indexes

Improvement	Net Annual Benefit (EUAB) - (EUAC)	Benefit/Cost Ratio (EUAB)/(EUAC)
Signing	$1,590	6.57
Resurfacing	475	0.66
Signing and resurfacing	730	1.46
Curve reconstruction	480	0.90

Signing will provide the highest net annual benefit. Neither resurfacing or curve reconstruction are economically feasible.

Documentation

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.

Highway Safety Program
Documentation Record
FORM 104

Location Identification Code 3099 - 1.45
Date 5 / 10 / 74
Prepared by DRC

IMPROVEMENT ANALYSIS WORKSHEET
(One for each potential improvement)

LOCATION: State Highway 99 from milepost 1.40 to 1.50

IMPROVEMENT CODE: 101
IMPROVEMENT DESCRIPTION: Curve signing

ESTIMATED SERVICE LIFE 5 YRS.
CURRENT 1974 AADT 750 EST. 1975 AADT 750

- [x] Constant
- [ ] Increasing by ____ % annually
- [ ] Increasing by ____ VPD annually

ESTIMATED ACCIDENT REDUCTION:

By Types:				By Severity:	
Left turn	___%	Skidding	___%	Fatal	___%
Head on	___%	Wet pavement	___%	Injuries	___%
Rear end	___%	Night	___%	PDO	___%
Right angle	___%	RR crossing	___%	Total	___%
Side swipe	___%		___%		
Fixed object	___%		___%	All Accidents	
Lost control	___%		___%	40 %	

EQUIVALENT UNIFORM ANNUAL BENEFITS:

From accident reduction	$ 1,865
From secondard benefits	$ —
Total	$ 1,865

ESTIMATED COSTS:

Initial implementation	$ 1,000
Annual operation and maintenance	$ 100
Terminal value	$ 0
Equivalent uniform annual cost	$ 365

NET ANNUAL BENEFIT $ 1,500 BENEFIT/COST RATIO 5.11

SPECIAL COMMENTS: _____

Figure B-4. Improvement Analysis Worksheet For Improvement #101--Curve Signing.

Highway Safety Program
Documentation Record
FORM 105

Location Identification Code S099-1.45
Date 5/10/1974
Prepared by DRC

IMPROVEMENT EVALUATION WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 99 from milepost 1.40 to milepost 1.50

SUMMARY OF EVALUATIONS:

Code	101	102	103		
Description	Curve signing	Resurfacing curve	Signing, resurfacing and painting curve		
Initial cost	$ 1,000	$ 7,500	$ 10,000	$	$
Annual cost	$ 100	$ 0	$ 200	$	$
Salvage value	$ 0	$ 0	$ 1,000	$	$
Service life	5 yrs	8 yrs	7 yrs	yrs	yrs
Equiv. uniform cost	$ 365	$ 1,400	$ 2,350	$	$
Equiv. uniform benefits	$ 1,865	$ 1,865	$ 3,735	$	$
Net annual benefits	$ 1,500	$ 465	$ 1,375	$	$
Benefit/cost ratio	5.11	1.33	1.59		

REJECTED IMPROVEMENTS (and explanation): _____

ELIGIBLE IMPROVEMENTS AND RANKING:

Code	Description	B/C Ratio

COMMENTS: _____

Figure B-5. Improvement Evaluation Worksheet For the Hazardous Curve on State Highway 99.

Highway Safety Program
Documentation Record
FORM 106

Prepared by DRC
Date 5/11/1974

PROGRAM PRIORITY LISTING WORKSHEET
Year 1975

Location		Improvement		Estimated Cost	B/C Ratio
Code	Description	Code	Description		
S099-1.45	SH 99 -- milepost 1.40 - 1.50	101	Curve signing	$1,000	5.11
S099-6.75	SH 99 -- RR crossing @ M.P. 6.77	109	Flashing lights & gates	$15,000	1.49

Figure B-6. Improvements Selected at Hazardous Locations Entered on the 1975 Program Priority Listing Worksheet.

1976 HIGHWAY SAFETY PROGRAM EVALUATION

Phase Of Program	Before Accident / After Accident: Killed	Number of Accidents: Fatal	Injury	PDO	Total	Percent Reduction (+ Indicates Increases): Killed	Accidents: Fatal	Injury	PDO	Total	Number Of Projects	Total Costs: Initial (000)	Oper. (000)	Acc. Cost Savings (000)	Benefit / Cost Ratio
WET PAVEMENT GROOVING	8	3	58	20	81	87.5	66.7	91.4	30.0	75.3	10	$265	$10	$1708	0.56
	1	1	5	14	20										
ROADSIDE OBJECT REMOVAL	2	2	15	23	40	50.0	50.0	20.0	21.7	25.0	20	$60	$0	$28	0.42
	1	1	12	17	30										
CURVE SIGNING	1	1	2	4	7	100.0	100.0	+50.0	75.0	42.9	4	$4	$0.4	$8.4	1.75
	0	0	3	1	4										
												$	$	$	
												$	$	$	
												$	$	$	
												$	$	$	
												$	$	$	
TOTAL PROGRAM	11	6	75	47	128	81.8	66.7	73.3	31.9	57.8	34	$329	$10.4	$207.2	0.56
	2	2	20	32	54										

FORM 108

Date: JAN 15, 1977

Figure B-8. Evaluation of the 1976 Highway Safety Program

B-18

Highway Safety Program Documentation Record
FORM 107

Location Identification Code 5099 - 1.45
Date 10/5/1976
Prepared by DRC

IMPROVEMENT EFFECT WORKSHEET
(One for each hazardous location)

LOCATION: State Highway 99 from milepost 1.40 to 1.50

IMPROVEMENT: 101 -- Curve Signing

DATE IMPLEMENTED: 9/10/75 SOURCE OF FUNDING: 100% State

INITIAL COST: $ 1,025 ANNUAL COST: $ 100

BEFORE ACCIDENT EXPERIENCE: See Hazardous Location Identification Worksheet (Form 101)

AFTER ACCIDENT EXPERIENCE:

Year	1975	1976				Total
From (date)	10/1	1/1				10/1/75
To (date)	12/31	9/30				9/30/76
AADT	750	750				Ave= 750
Exposure	0.063 MV	0.205 MV				0.274 MV
Total accidents	0	1				1
Fatal accidents	0	0				0
No. fatalities	0	0				0
Injury accidents	0	1				1
PDO accidents	0	0				0
Accident rate	0.0	4.88				3.65 Acc/MV

BEFORE ACCIDENT RATE: 6.09 Acc/MV AFTER ACCIDENT RATE: 3.65 Acc/MV

PERCENT ACCIDENT REDUCTION: $100 \left[\frac{6.09 - 3.65}{6.09}\right] = 40$ %

ADJUSTED NUMBER OF BEFORE ACCIDENTS: 5 $\left[\frac{(750)(365)}{(750)(1095)}\right] = 1.67$ Acc

SIGNIFICANT ACCIDENT REDUCTION AT 95 % LEVEL OF CONFIDENCE:
☐ POISSON DISTRIBUTION TEST ☐ POISSON COMPARISON OF MEANS TEST

COMMENTS The graphs for significant accident reduction do not allow for less than 5 before accidents. However, it is obvious that a 40% reduction is not significant.

Figure B-7. Improvement Effect Worksheet

B-17

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Rep. No. Title

—* A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80

1 Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80

2 An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80

2A Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00

3 Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60

4 Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20

5 Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00

6 Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p. $3.20

7 Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80

8 Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00

9 Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60

10 Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80

11 Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80

12 Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00

13 Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80

14 Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00

15 Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00

16 Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60

17 Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $6.00

18 Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80

19 Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20

* Highway Research Board Special Report 80.

Rep. No. Title

20 Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20

21 Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40

22 Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60

23 Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40

24 Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20

25 Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00

26 Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60

27 Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00

28 Surveillance Methods and Ways and Means of Communicating with Drivers (Proj. 3-2), 66 p., $2.60

29 Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00

30 Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60

31 A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $2.00

32 Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., $5.00

33 Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $3.60

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

36 Highway Guardrails—A Review of Current Practice (Proj. 15-1), 33 p., $1.60

37 Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), 80 p., $3.60

38 Evaluation of Pavement Joint and Crack Sealing Materials and Practices (Proj. 9-3), 40 p., $2.00

39 Factors Involved in the Design of Asphaltic Pavement Surfaces (Proj. 1-8), 112 p., $5.00

40 Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., $2.00

41 Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., $3.60

42 Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., $5.60

43 Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., $2.00

44 Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $1.40

45 Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40

46 Effects of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $4.60

47 Accident Rates as Related to Design Elements of Rural Highways (Proj. 2-3), 173 p., $6.40

48 Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20

49 National Survey of Transportation Attitudes and Behavior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20

Rep. No. *Title*

50 Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $5.20

51 Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00

52 Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., $3.80

53 Multiple Use of Lands Within Highway Rights-of-Way (Proj. 7-6), 68 p., $3.20

54 Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., $2.60

55 Research Needs in Highway Transportation (Proj. 20-2), 66 p., $2.80

56 Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., $6.40

57 Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., $3.20

58 Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., $3.60

59 Standard Measurements for Satellite Road Test Program (Proj. 1-6), 78 p., $3.20

60 Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2) 148 p., $6.00

61 Evaluation of Studded Tires—Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., $3.00

62 Urban Travel Patterns for Hospitals, Universities, Office Buildings, and Capitols (Proj. 7-1), 144 p., $5.60

63 Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., $4.00

64 Motorists' Needs and Services on Interstate Highways (Proj. 7-7), 88 p., $3.60

65 One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., $1.40

66 Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., $2.80

67 Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), 45 p., $2.20

68 Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 3-10), 38 p., $2.00

69 Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (Proj. 10-2A), 58 p., $2.80

70 Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., $3.00

71 Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., $2.80

72 Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., $2.20

73 Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5/1), 55 p., $2.80

74 Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., $2.80

74A Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., $8.00

74B Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., $4.00

75 Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., $3.60

Rep. No. *Title*

76 Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2)), 37 p., $2.00

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80 Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., $5.20

81 Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., $5.60

82 National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., $4.00

83 Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., $2.80

84 Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., $2.40

85 Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., $1.80

86 Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., $3.20

87 Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., $2.00

88 Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., $2.00

89 Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., $3.20

90 Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., $4.00

91 Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research (Proj. 16-1), 70 p., $3.20

92 Valuation and Condemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., $2.60

93 Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., $6.20

94 Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., $1.80

95 Highway Fog (Proj. 5-6), 48 p., $2.40

96 Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., $5.40

97 Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., $2.60

98 Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), 98 p. $5.00

99 Visual Requirements in Night Driving (Proj. 5-3), 38 p., $2.60

100 Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., $3.40

101 Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks (Proj. 6-9), 70 p., $3.60

102 Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), 114 p., $5.40

103 Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., $5.00

104 Rules of Compensability and Valuation Evidence for Highway Land Acquisition (Proj. 11-1), 77 p., $4.40

Rep. No.	Title
105	Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., $5.00
106	Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., $3.40
107	New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., $2.40
108	Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), 75 p., $4.00
109	Elastomeric Bearing Research (Proj. 12-9), 53 p., $3.00
110	Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., $4.40
111	Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., $5.20
112	Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., $2.60
113	Optimizing Flow on Existing Street Networks (Proj. 3-14), 414 p., $15.60
114	Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., $2.60
115	Guardrail Performance and Design (Proj. 15-1(2)), 70 p., $3.60
116	Structural Analysis and Design of Pipe Culverts (Proj. 15-3), 155 p., $6.40
117	Highway Noise—A Design Guide for Highway Engineers (Proj. 3-7), 79 p., $4.60
118	Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), 96 p., $5.20
119	Control of Highway Advertising Signs—Some Legal Problems (Proj. 11-3(1)), 72 p., $3.60
120	Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), 90 p., $4.80
121	Protection of Highway Utility (Proj. 8-5), 115 p., $5.60
122	Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., $13.60
123	Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12), 239 p., $9.60
124	Improved Criteria for Traffic Signal Systems in Urban Networks (Proj. 3-5), 86 p., $4.80
125	Optimization of Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5A), 86 p., $4.40
126	Divergencies in Right-of-Way Valuation (Proj. 11-4), 57 p., $3.00
127	Snow Removal and Ice Control Techniques at Interchanges (Proj. 6-10), 90 p., $5.20
128	Evaluation of AASHO Interim Guides for Design of Pavement Structures (Proj. 1-11), 111 p., $5.60
129	Guardrail Crash Test Evaluation—New Concepts and End Designs (Proj. 15-1(2)), 89 p., $4.80
130	Roadway Delineation Systems (Proj. 5-7), 349 p., $14.00
131	Performance Budgeting System for Highway Maintenance Management (Proj. 19-2(4)), 213 p., $8.40
132	Relationships Between Physiographic Units and Highway Design Factors (Proj. 1-3(1)), 161 p., $7.20
133	Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects (Proj. 7-8), 127 p., $5.60
134	Damages Due to Drainage, Runoff, Blasting, and Slides (Proj. 11-1(8)), 23 p., $2.80
135	Promising Replacements for Conventional Aggregates for Highway Use (Proj. 4-10), 53 p., $3.60
136	Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds (Proj. 15-4), 85 p., $4.60
137	Roadside Development—Evaluation of Research (Proj. 16-2), 78 p., $4.20
138	Instrumentation for Measurement of Moisture—Literature Review and Recommended Research (Proj. 21-1), 60 p., $4.00
139	Flexible Pavement Design and Management—Systems Formulation (Proj. 1-10), 64 p., $4.40
140	Flexible Pavement Design and Management—Materials Characterization (Proj. 1-10), 118 p., $5.60
141	Changes in Legal Vehicle Weights and Dimensions—Some Economic Effects on Highways (Proj. 19-3), 184 p., $8.40
142	Valuation of Air Space (Proj. 11-5), 48 p., $4.00
143	Bus Use of Highways—State of the Art (Proj. 8-10), 406 p., $16.00
144	Highway Noise—A Field Evaluation of Traffic Noise Reduction Measures (Proj. 3-7), 80 p., $4.40
145	Improving Traffic Operations and Safety at Exit Gore Areas (Proj. 3-17) 120 p., $6.00
146	Alternative Multimodal Passenger Transportation Systems—Comparative Economic Analysis (Proj. 8-9), 68 p., $4.00
147	Fatigue Strength of Steel Beams with Welded Stiffeners and Attachments (Proj. 12-7), 85 p., $4.80
148	Roadside Safety Improvement Programs on Freeways—A Cost-Effectiveness Priority Approach (Proj. 20-7), 64 p., $4.00
149	Bridge Rail Design—Factors, Trends, and Guidelines (Proj. 12-8), 49 p., $4.00
150	Effect of Curb Geometry and Location on Vehicle Behavior (Proj. 20-7), 88 p., $4.80
151	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques (Proj. 1-12(2)), 100 p., $6.00
152	Warrants for Highway Lighting (Proj. 5-8), 117 p., $6.40
153	Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances (Proj. 22-2), 19 p., $3.20
154	Determining Pavement Skid-Resistance Requirements at Intersections and Braking Sites (Proj. 1-12), 64 p., $4.40
155	Bus Use of Highways—Planning and Design Guidelines (Proj. 8-10), 161 p., $7.60
156	Transportation Decision-Making—A Guide to Social and Environmental Considerations (Proj. 8-8(3)), 135 p., $7.20
157	Crash Cushions of Waste Materials (Proj. 20-7), 73 p., $4.80
158	Selection of Safe Roadside Cross Sections (Proj. 20–7), 57 p., $4.40
159	Weaving Areas—Design and Analysis (Proj. 3-15), 119 p., $6.40

Rep. No.	Title
160	Flexible Pavement Design and Management—Systems Approach Implementation (Proj. 1-10A), 54 p., $4.00
161	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities (Proj. 14-2), 55 p., $4.40
162	Methods for Evaluating Highway Safety Improvements (Proj. 17-2A), 150 p., $7.40

Synthesis of Highway Practice

No.	Title
1	Traffic Control for Freeway Maintenance (Proj. 20-5, Topic 1), 47 p., $2.20
2	Bridge Approach Design and Construction Practices (Proj. 20-5, Topic 2), 30 p., $2.00
3	Traffic-Safe and Hydraulically Efficient Drainage Practice (Proj. 20-5, Topic 4), 38 p., $2.20
4	Concrete Bridge Deck Durability (Proj. 20-5, Topic 3), 28 p., $2.20
5	Scour at Bridge Waterways (Proj. 20-5, Topic 5), 37 p., $2.40
6	Principles of Project Scheduling and Monitoring (Proj. 20-5, Topic 6), 43 p., $2.40
7	Motorist Aid Systems (Proj. 20-5, Topic 3-01), 28 p., $2.40
8	Construction of Embankments (Proj. 20-5, Topic 9), 38 p., $2.40
9	Pavement Rehabilitation—Materials and Techniques (Proj. 20-5, Topic 8), 41 p., $2.80
10	Recruiting, Training, and Retaining Maintenance and Equipment Personnel (Proj. 20-5, Topic 10), 35 p., $2.80
11	Development of Management Capability (Proj. 20-5, Topic 12), 50 p., $3.20
12	Telecommunications Systems for Highway Administration and Operations (Proj. 20-5, Topic 3-03), 29 p., $2.80
13	Radio Spectrum Frequency Management (Proj. 20-5, Topic 3-03), 32 p., $2.80
14	Skid Resistance (Proj. 20-5, Topic 7), 66 p., $4.00
15	Statewide Transportation Planning—Needs and Requirements (Proj. 20-5, Topic 3-02), 41 p., $3.60
16	Continuously Reinforced Concrete Pavement (Proj. 20-5, Topic 3-08), 23 p., $2.80
17	Pavement Traffic Marking—Materials and Application Affecting Serviceability (Proj. 20-5, Topic 3-05), 44 p., $3.60
18	Erosion Control on Highway Construction (Proj. 20-5, Topic 4-01), 52 p., $4.00
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