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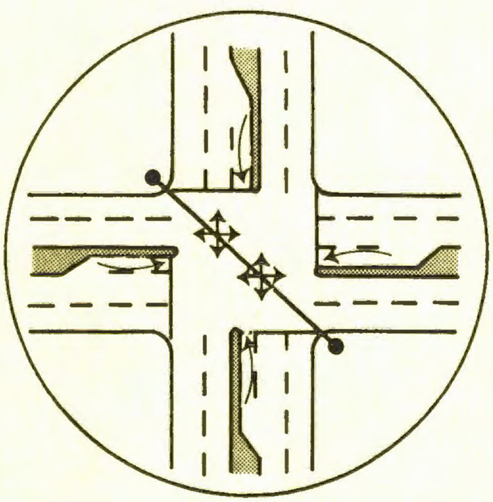
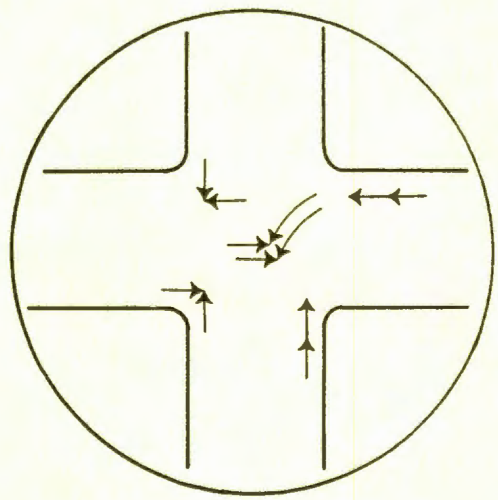
Procedural Guide





FOREWORD

This Procedural Guide contains detailed guidelines for the planning, conduct, and use of safety engineering studies at identified hazardous locations. The Guide should be beneficial to highway engineers and other professionals involved in highway safety and/or traffic operations.

The objectives of this guide are to describe how to:

1. Plan an effective highway safety engineering investigation of an identified hazardous location.

2. Perform a highway safety engineering investigation of an identified hazardous location, using appropriate procedures and techniques.

3. Select the most appropriate procedures and techniques required for safety engineering studies, considering agency size and type.

4. Identify safety deficiencies and feasible countermeasures necessary to alleviate the hazardous situations.

5. Select a safety project based on safety objectives.

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

Milton P. Criswell
Director
Office of Development

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"HIGHWAY SAFETY ENGINEERING STUDIES"

INTRODUCTION

The "Highway Safety Engineering Studies" Procedural Guide contains detailed guidelines for the planning, conduct, and use of safety engineering studies at identified hazardous locations. It is intended for use by those who are responsible for organizing and conducting engineering procedures and for analyzing the procedure findings.

The guide contains the necessary procedures to perform the engineering study processes and subprocesses within the Highway Safety Improvement Program described in the Federal-Aid Highway Program Manual (FHPM) 8-2-3.

I. HISTORY OF THE HIGHWAY SAFETY IMPROVEMENT PROGRAM

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

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

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

With these objectives in mind, the Federal-Aid Highway Program Manual (FHPM) 6-8-2-1, "Highway Safety Improvement Program," was developed and issued. Under this FHPM, a systematic process for organizing a highway safety improvement program was prescribed. FHPM 6-8-2-1 was superceded by FHPM 8-2-3, "Highway Safety Improvement Program," in 1979.

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

II. FRAMEWORK OF THE HIGHWAY SAFETY IMPROVEMENT PROGRAM

The structure of the Highway Safety Improvement Program (HSIP) is described in FHPM 8-2-3. It consists of three components: planning, implementation, and evaluation. Each component is comprised of one or a series of processes and subprocesses which are designed to produce specified outputs which, in turn, serve as input to subsequent HSIP activities.

The HSIP at the process level is illustrated in Figure 1, which exemplifies the inter-relationship among the six processes. Four processes are defined in the Planning Component, and the Implementation Component and Evaluation Component each contain one process. The arrows indicate flow of data and information in the HSIP.

The subprocess level of the HSIP is shown in Figure 2, where 14 specific subprocesses are defined. The necessary sequence of subprocesses is also illustrated within each process. For example, in Process 3 ("Conduct Engineering Studies"), the collection and analysis of data (Subprocess 1) should be performed before accident countermeasures are developed (Subprocess 2). Projects can be finalized or developed for each highway location (in Subprocess 3) only after the first two subprocesses are completed. The final listing of safety improvement projects is then used as the input into Process 4 ("Establish Project Priorities).

This guide contains detailed descriptions of Process 3 of the Planning Component - "Conduct Engineering Studies".

III. HIGHWAY SAFETY TERMINOLOGY

The structure of the Highway Safety Improvement Program (HSIP) was established in FHPM 8-2-3 in terms of components, processes, subprocesses, and procedures. These terms are defined as follows:

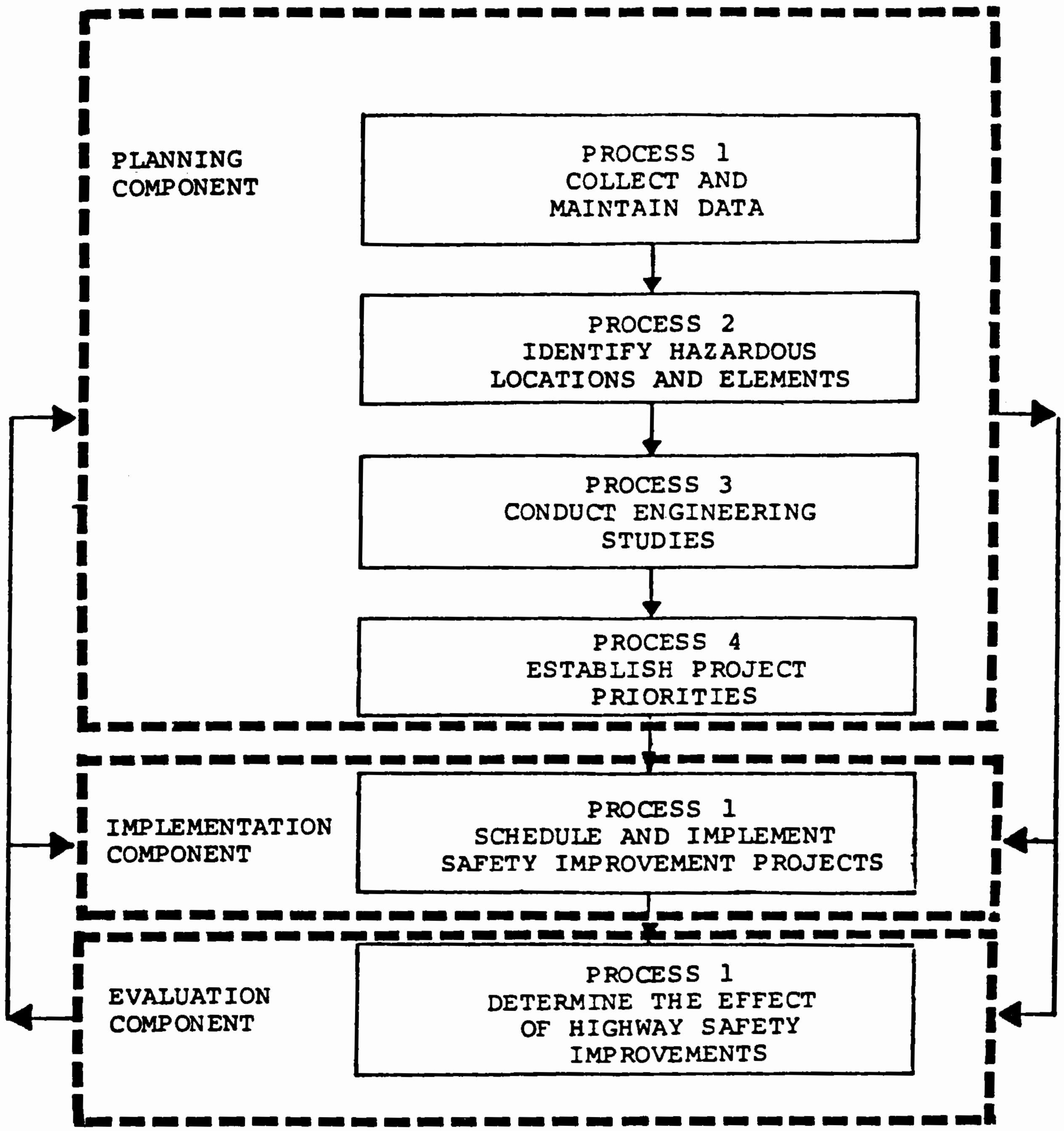


Figure 1. Highway Safety Improvement Program at the process level.

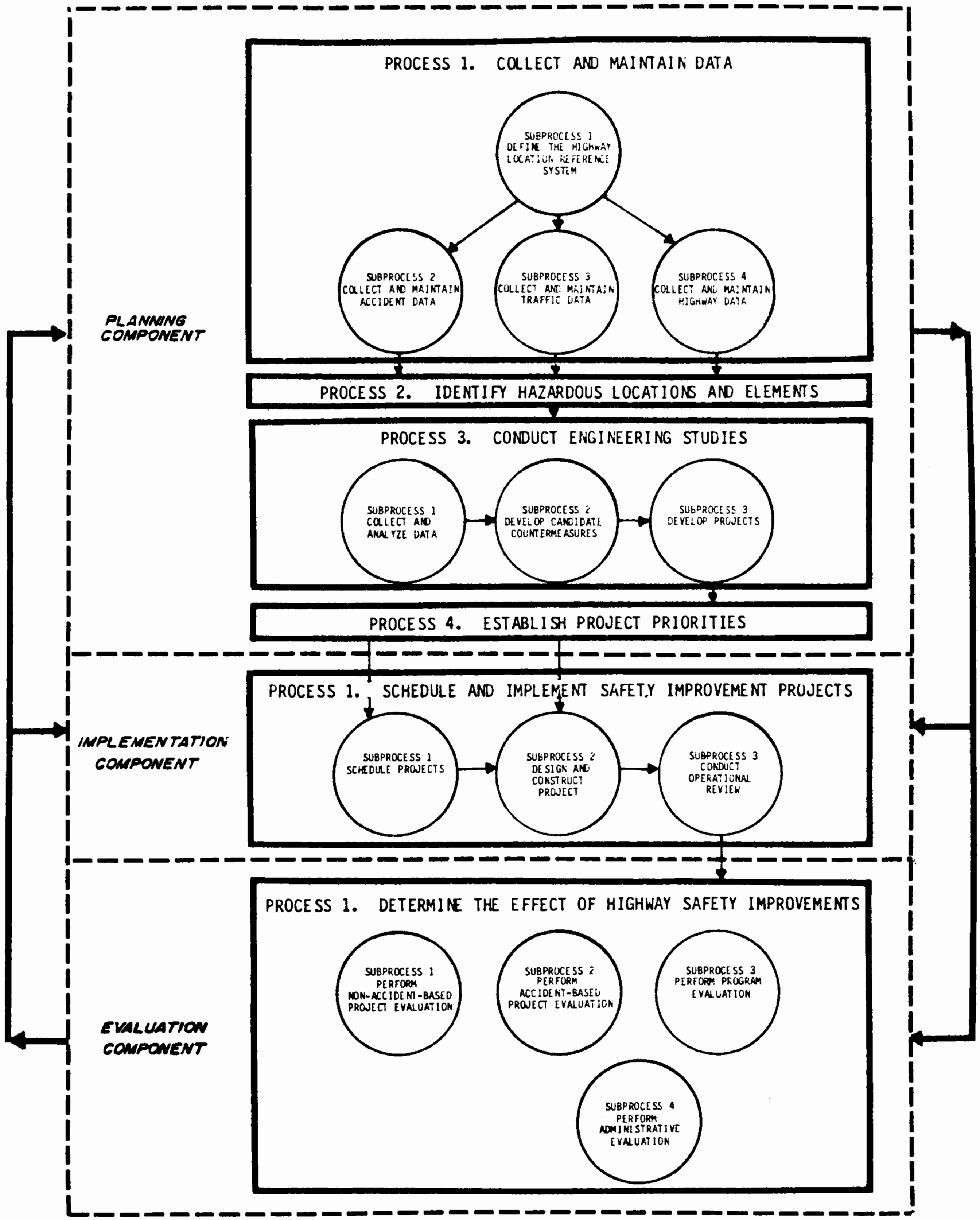


Figure 2. Highway Safety Improvement Program subprocesses.

- Components - refer to the three general phases of the HSIP: (1) Planning, (2) Implementation, and (3) Evaluation.

- Processes - refer to the sequential elements within each component. For instance, the four processes within the planning component include: (1) Collect and Maintain Data, (2) Identify Hazardous Locations, (3) Conduct Engineering Studies, and (4) Establish Priorities for Safety Improvements.

- Subprocesses - refer to specific activities which are contained within processes. For example, under Process 3 of the Planning Component ("Conduct Engineering Studies"), the three subprocesses are: (1) Collect and Analyze Data, (2) Develop Candidate Countermeasures, and (3) Develop Projects.

- Activities - refer to the steps used to relate the procedures to the subprocesses. For example, the accident procedures are contained in Activity 1 - "Perform Accident Procedure" of Subprocess 1 - "Collect and Analyze Data".

- Procedures - refer to the possible ways in which each of the processes or subprocesses may be attained. For instance, the procedures for Subprocess 1 (Collect and Analyze Data) of Process 3 ("Conduct Engineering Studies") are: (1) Accident-Based Procedures, (2) Traffic-Based Procedures, (3) Environment-Based Procedures, and (4) Special Study Procedures.

- Techniques - refer to the feasible means to perform the selected study procedures. For example, to perform a traffic-based procedure such as a "Volume Study," alternate techniques could include: (1) mechanical methods (permanent or portable), (2) manual methods, (3) photographic techniques, and (4) the moving-vehicle estimation method.

A listing of procedures and techniques under each subprocess was developed based on:

- Widely accepted practices currently in use by various highway agencies.

- Techniques developed and/or used by one or more highway agencies which may offer a useful method under certain conditions.

- New or untested concepts reported in the literature which may offer worthwhile alternatives to existing procedures and deserve further testing for possible future use.

Within the text of the procedural guide, the procedures are categorized by safety, traffic, environmental and other related variables. A brief description of these categories is given below.

- Accident-Based Procedures

Traffic accidents provide the major indication of a safety problem at a location. By definition, a distinct relationship exists between traffic accidents and the specific hazardousness of a location. Accident-based engineering studies are used to define this relationship and identify the safety deficiencies of the location. The five accident-based procedures are:

  - Procedure 1 - Accident Summary by Type.
  - Procedure 2 - Accident Summary by Severity.
  - Procedure 3 - Accident Summary by Contributing Circumstances.
  - Procedure 4 - Accident Summary by Environmental Conditions.
  - Procedure 5 - Accident Summary by Time of Day.

- Field Review Procedures

This procedure provides for the review of site conditions in the field environment. It assists in defining safety deficiencies and possible causes of accident patterns. The field review procedure is:

  - Procedure 6 - Safety Performance Study.

- Traffic-Based Procedures

Traffic operations-based studies conducted at identified hazardous locations can provide essential information to assist in the selection of the most appropriate safety improvements at each location. The nine traffic operations-based procedures are:

  - Procedure 7 - Volume Study.
  - Procedure 8 - Spot Speed Study.
  - Procedure 9 - Travel Time and Delay Study.
  - Procedure 10 - Roadway and Intersection Capacity Study.
  - Procedure 11 - Traffic Conflict Study.
  - Procedure 12 - Gap Study.
  - Procedure 13 - Traffic Lane Occupancy Study.
  - Procedure 14 - Queue Length Study.

- Environmental-Based Procedures

Environmental-based engineering studies include the collection and analysis of all information related to the physical features of the roadway for specific spots, sections, and elements. The five environmental-based procedures are:

  - Procedure 15 - Roadway Inventory Study.
  - Procedure 16 - Sight Distance Study.

- Procedure 17 - Skid Resistance Study.
- Procedure 18 - Highway Lighting Study.
- Procedure 19 - Weather-Related Study.

- Special Study Procedures

  There are several engineering studies which may be required in special situations and are not classified as either accident-based, traffic-based, or environmental-based. These studies are:

  - Procedure 20 - School Crossing Study.
  - Procedure 21 - Rail- Highway Crossing Study.
  - Procedure 22 - Traffic Control Device Study.
  - Procedure 23 - Bicycle and Pedestrian Study.

The following terms are used throughout the Procedural Guide and an understanding of their meaning is essential.

- Safety Problem - the result of a failure in the roadway-driver-vehicle system as evidenced by abnormal accident experiences, trends or patterns.

- Possible Accident Cause - specific elements of the roadway-driver-vehicle system related to a specific safety problem which can be identified on the basis of past experience, predominant accident trends and patterns, etc.

- Probable Accident Cause - factors which have been shown through field study procedures to be deficient and therefore may be a contributing cause of the safety problem. Countermeasures should attempt to alleviate or minimize these causes.

Specific categories of highway safety improvements are discussed throughout the guide. Highway safety improvements may be arranged in the following hierarchy.

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

- Project - The implementation of one or more countermeasures to reduce identified or potential safety deficiencies at a location (spot or section) on the highway or its environs. A project may also consist of the implementation of an identical countermeasure or set of countermeasures implemented at similar locations. Examples include: (1) the installation of an open-graded friction course on a section of highway which is experiencing a disproportionately high number of wet-weather accidents; (2) the same project applied to a number of similar highway sections which are experiencing high numbers of wet-weather accidents; and (3) shoulder stabilization, edgelining, and fixed-object removal along a section of rural highway which is experiencing abnormally high run-off-road accidents and severity.

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

IV. DETAILS OF SUBPROCESSES, PROCEDURES, AND TECHNIQUES

Introduction

Within the planning component of the Highway Safety Improvement Program (HSIP), a major effort is expended within Process 3, "Conduct Engineering Studies." This process involves the selection of safety measures at identified hazardous locations. Based on the project selected, safety improvements can then be implemented and evaluated.

The effectiveness of a safety project depends on the proper selection of the project for a particular location. The major objective in the selection process is to recommend improvements which are most appropriate to reduce accidents and accident potential. To meet this objective, the specific safety problems should be correctly defined. This will permit the most feasible safety-related countermeasures to be recommended. From this list of candidate countermeasures, economic analysis procedures should be used to aid in the selection of the most desirable project.

Safety Engineering Investigation Model

After a location is identified as hazardous, the selection of a safety project requires an organized plan (model) to allow for an effective assessment of the hazardous conditions. Such a plan (model) is displayed in Figure 3. It outlines the basic activities within Process 3 of the Planning Component of the HSIP. The following three subprocesses are contained within Process 3 ("Conduct Engineering Studies"):

- Subprocess 1 - Collect and Analyze Data

This subprocess consists of the activities for identifying the safety problem and specific safety deficiencies. These activities are:

- Activity 1 - Perform Accident Study Procedures.
- Activity 2 - Field Review Location.
- Activity 3 - Select Appropriate Traffic, Environment, and Special Study Procedures.

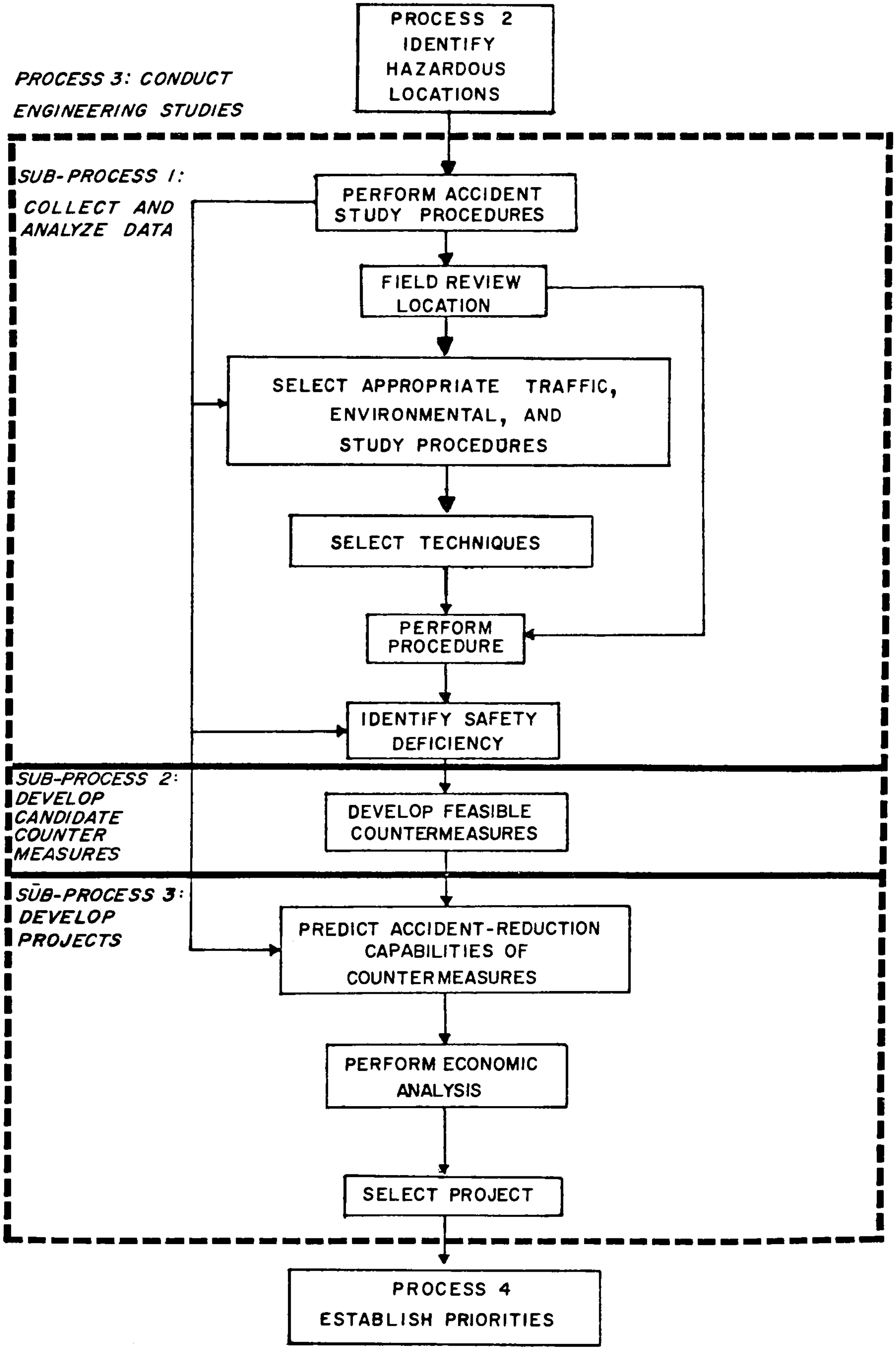


Figure 3. Engineering investigation model.

- Activity 4 - Select Techniques.
- Activity 5 - Perform Procedures.
- Activity 6 - Identify Safety Deficiencies.

Involved in this subprocess is the performance of the accident, traffic, environment, and special-based studies used to identify the safety problem. This subprocess will allow for (1) selecting and performing the appropriate study procedures used in identifying the safety deficiencies, (2) analyzing the procedure findings individually and collectively, and (3) identifying the safety deficiencies. Based on these identified safety deficiencies, appropriate safety-related countermeasures can be developed (in Subprocess 2).

- Subprocess 2 - Develop Candidate Countermeasures

This subprocess serves to develop a list of feasible safety-related countermeasures for a location based on the findings of Subprocess 1. It contains:

- Activity 7 - Develop Feasible Countermeasures.

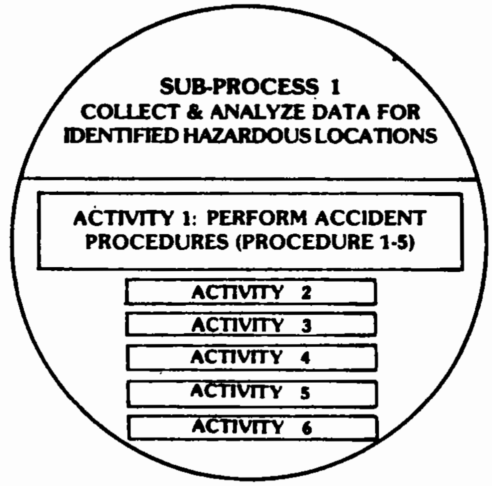
Input into this subprocess is received from documented research, past experiences and other sources. This subprocess includes: (1) the review of safety deficiencies at a site and (2) the development of a list of feasible countermeasures. This list will be used to develop a safety project (in Subprocess 3).

- Subprocess 3 - Develop Projects

This subprocess is comprised of the activities necessary for analyzing the alternative countermeasures and selecting a single project for a location. They are:

- Activity 8 - Predict Accident-Reduction Capabilities of Countermeasures.
- Activity 9 - Perform Economic Analysis.
- Activity 10 - Select Project.

Within this subprocess, estimates are made of the accident-reduction capabilities of a countermeasure for use in the economic analysis. Alternate procedures for conducting economic analyses are also provided. This subprocess will allow for (1) predicting accident reduction capabilities of the feasible countermeasures, (2) performing economic analysis of the countermeasures, and (3) selecting a single project for a site. This output will be used in Process 4 of the Planning Component to select and plan for the implementation of projects.



Subprocess 1 - Collect And Analyze Data

ACTIVITY 1 Perform Accident Study Procedures

Purpose

The purpose of this activity is to collect and analyze accident information at hazardous locations and to use these data to identify safety problems and possible safety deficiencies.

Overview

The primary measure of safety at a highway location is traffic accidents. Once a highway location has been selected for a safety study, data should be collected and analyzed to identify and describe accident characteristics of the location. From these characteristics, countermeasures to alleviate the safety-related deficiencies can be more readily identified. Analyses of accident data will aid in the identification of safety problems and possible safety deficiencies.

To identify safety problems at a location, the following five accident analysis procedures will be described starting on page 37. They are:

- Procedure 1 - Accident Summary by Type.
- Procedure 2 - Accident Summary by Severity.
- Procedure 3 - Accident Summary by Contributing Circumstances.
- Procedure 4 - Accident Summary by Environmental Conditions.
- Procedure 5 - Accident Summary by Time of Day.

Prior to conducting the accident analysis procedures, preparation of the data is necessary. The following guidelines are suggested for preparing the data for accident analysis purposes.

● Periods of Data Collection

The time period to be used for the collection of accident data should consist of a minimum of one full year. Collection of data for a 12-month period reduces the effect of seasonal conditions as well as the various holiday or vacation times which tend to influence traffic conditions. Based on several studies, however, collection of data for a 3-year period is recommended to increase the reliability of the information and to provide a long enough sample to clearly define accident patterns. With the use of a 3-year study period, it is expected that the "chance" occurrence of accidents in a pattern will be minimized. Use of a time period longer than 3 years may not be cost effective, and it increases the probability that time-related changes in traffic patterns will be reflected in the accidents. Thus, in general, a 3-year time period is suggested.

In selecting the study period, the following criteria should be considered:

1. Care should be taken to insure that changes in the roadway characteristics (i.e., number of lanes, paving, etc.) are accounted for when evaluating the accident activity.

2. The accident data should represent current information since such factors as traffic volumes, pavement conditions, and other site-related data may vary with time.

In defining the study period length, it is necessary that the safety engineer be familiar with the history of the location. This will allow the engineer to better identify any uncharacteristic accident tendencies resulting from physical changes of the site.

● Methods of Data Collection

The data required for performing the accident study procedures are primarily obtained from the accident report form. It is prepared at the scene of the accident by the investigating officer. From this report, information is obtained concerning the day, date, location, environmental conditions, driver's intent and actions at the site, and other data which may provide useful clues for reconstructing the accident. In addition, a pictorial representation or diagram of the accident is usually provided on the accident form. A sample accident report form is displayed in Figure 4.

In using accident data for study purposes, several possible deficiencies should be noted. First, not all accidents are reported. Most states have minimum dollar values for accident reporting. In addition, many accidents do not even receive a police investigation. Second, the accident data on the report may be biased by the investigating officer. However, these deficiencies do not override the overall usefulness of the accident data in safety studies.

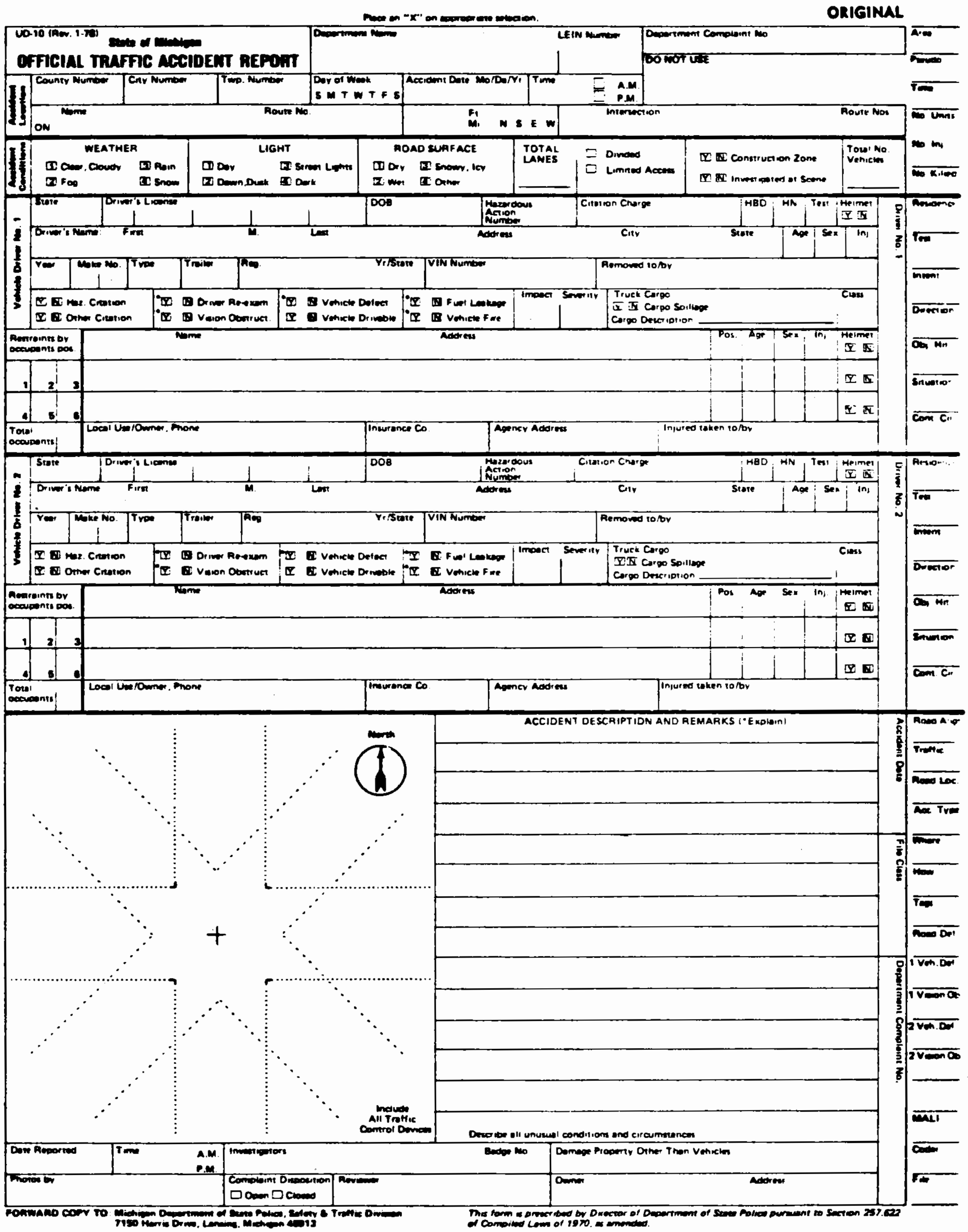


Figure 4. Accident reporting form - Michigan.

The retrieval of accident data can be conducted with one of two methods -- computer techniques or a manual search of data files.

Computer Techniques

With this method, specific accident information is obtained from a computer file. The accident data typically consist of information coded directly from the standard traffic accident report. This information may include:

- Locational data (main roadway, reference roadway, distance and direction, etc.).
- Time-related occurrence data (day, date and hour).
- Accident severity data.
- Roadway and environmental condition information present at the time of the accident (roadway surface, geometrics, traffic control, weather, light conditions, and other descriptive information).
- Vehicle and driver action data (vehicle type, intent, direction of specific vehicle, hazardous action, contributing circumstances, etc.).
- Accident type (related by description of vehicle movements).

Advantages:

1. Permits a large accumulation of data in a limited space.
2. Permits flexibility in data analysis techniques.
3. Promotes efficiency in the data analysis process.
4. Allows a large number of locations to be studied in a relatively short amount of time.

Disadvantages:

1. Requires trained computer personnel to operate the system.
2. Equipment costs can be high.
3. May require extensive training to operate computer system for specific accident analyses.

Limitations to the use of computer systems are the availability of hardware (equipment), software (programs), and funds necessary to operate the system. Initial costs of a computer system are high. Many small agencies are unable to purchase such systems (even with available Federal monies to assist in the funding of computer systems for highway safety uses). In addition, the limited amount of information input on a system for some agencies may not make a computer a cost-effective alternative.

An alternative to purchasing a system consists of sharing an existing computer system. This could be achieved within an agency (inter-departmentally), by a group of agencies, or by an individual agency sharing the use of its facilities with other agencies. Shared facilities are commonly used on statewide accident data systems. Other background information on the use of computerized accident record systems is provided in Table 1.

Manual Search of Accident Record Files

This method is usually applicable to agencies with small accident files (500 accident reports per year). The accident record files are usually located in the offices of the police agency having jurisdiction of the area in which the accident location exists. The accident records are usually filed by one of the following methods:

- By date of accident occurrence.
- Alphabetically by roadway name or numerically by route number on which accident occurred.
- By intersection (proceeding sequentially along the major roadway and alphabetically between roadways).
- By intersection and by roadway link alphabetically.

A manual accident search requires that a technician examine the files and separate the required accident reports from the total file. After the reports are collected, they are individually reviewed by a technician or engineer and summarized. For large accident files, this method results in a considerable expenditure of manpower and time.

Advantages:

1. Allows a personal review of each accident report.
2. Provides detailed information which may not be easily coded for computer analysis, such as the data contained in the narrative and descriptive (diagram) part of the report.

Disadvantages:

1. Requires considerable manpower and time requirements.
2. Provides limited data analysis capabilities.
3. Accuracy is limited by the availability of the reports.

The manual retrieval of accident data is limited by the time requirements for data searching and the availability of personnel and capabilities of the filing system. Further information on this technique is displayed in Table 1.

Table 1. Primary considerations for accident data collection.

Consideration / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Computer Techniques	. Obtains summary of accidents by accident type and analysis from computer file search and using computer programs	. Computer . Summary sheets	. Engineer or trained computer technician to operate computer system	. Searching, printing, and analysis time per site - approx. 1-2 hours	. Computer $1,000-*	. Defined location . Accident reports or data on a statewide basis . Data analysis programs . Roadway inventory	. Locational accident summary . Threshold value by accident type (based on locations with similar characteristics)	. Accident summaries . Accident analysis data . Accident type "threshold" values
2. Manual Search Methods	. Obtains summary of accidents by accident type from physical search of available accident files and manual recording of data	. Summary sheets	. Technician to search accident files . Technician to compile data . Trained technician or engineer to analyze data	. Searching time dependent on period of study . Search time typically 1/2-2 days per site . Data analysis time (limited to pattern assessment) approx. 1 hours per site	. None	. Defined location . Accident reports or data on a systemwide basis . Roadway inventory	. Locational accident summaries	. Accident summaries . Accident pattern assessment

*Computer system costs can be extremely high dependent on computer system obtained and sharing of costs.

● Selection of Data Collection Technique

In selecting the appropriate data collection method for accident records, it is necessary to review the management concerns involved in the use of each technique. The management concerns for accident data collection include: time requirements, manpower requirements, and equipment requirements. Table 2 displays the utility of the data collection methods in relation to the management concerns. Based on these concerns, Table 3 provides recommendations on the use of these techniques based on the expected number of accident reports compiled per year.

The conduct of this activity is based on the availability of accident data. However, in some situations, accident data are unavailable (or very little data exists) for an identified hazardous location. For these cases, traffic conflicts (described in Activity 3) can be used to supplement accident data and obtain a diagnosis of possible safety problems. The data obtained from the conflicts procedure may be assumed to represent the accident potential at a site.

Another means which can be used to supplement available accident data is to conduct a site investigation. From a review of certain roadway and roadside characteristics, significant input to the safety analysis can be obtained. These characteristics may include:

- Skid marks on pavement.
- Tire tracks or excessive wearing of roadway shoulder material.
- Damaged guardrail, bushes, etc.
- Broken glass, chrome strips and other vehicle debris.
- Collision marks on trees.
- Bent or damaged sign posts, delineation markers, etc.

● Accident Summary Methods

Once the accident data is retrieved, summaries should be prepared. The summary data can be presented in the following forms:

1. Manual summary sheets.
2. Collision diagrams.
   - Manual.
   - Automated.
3. Statistically-related programs.

Manual Summary Sheet

One method of summarizing accident data is the use of the manual summary sheet shown in Figure 5. This summary is prepared by a trained technician or engineer who reviews the individual accident reports and registers a mark by the specific characteristic defined in the accident report. These marks are summarized and percentages (of total accidents) are calculated for each location per year. This type of summary is easy to perform but can be time consuming. A deficiency is that the character-

Table 2. Technique utility for accident data collection methods.

Technique / Management Concerns	Computer Methods	Manual Search
.Time Requirements	.Minimal	.For large data system (>1000 accident reports per year), data collection will be time consuming; .Smaller systems (<1000 accident reports per year) will require less data collection effort;
.Manpower Requirements	.If self-owned system, computer programmers are required; .If shared system, costs are paid to operating agency for their personnel use	.Available technicians to search files
.Equipment Requirements	.Available computer facilities	.Minimal

Table 3. Recommended accident data collection techniques.

Technique / No. of Accident Reports/Year	Computer Methods	Manual Search
<500		●
500-1000	●	●
>1000	●	

Location: ____________________

Type of accident	1977		1978		1979	
	No.	%	No.	%	No.	%
Left turn head-on						
Rear-ends						
Angle						
Pedestrian						
Sideswipes						
Run-off-road						
Fixed object						
Head-on						
Wet conditions						
Dry conditions						
Day Conditions						
Dusk or night conditions						
Fatal accident (No. persons)						
Injury accident (No. persons)						
Property damage accident						

Figure 5. Manual summary of accident characteristics.

istics are usually defined on a total location basis. For instance, left-turn accidents at a signalized intersection may only present a problem on one of the approach legs; however, the information obtained from the summary sheet will fail to identify the approach upon which the left-turn accident problem exists. In reviewing data from the summary sheet, further locational data is required to obtain a proper assessment of accident patterns; i.e., a breakdown of the data by approach leg or direction of travel.

Collision Diagrams

The collision diagram provides a graphical representation of individual accidents [1,2]. They are extremely useful in providing a pictorial summary of the accident events. Basic information found in each collision diagram includes:

- Specific location.
- Type of accident.
- Hour and date.
- Weather and road characteristics.
- Driver action and impact data.
- Severity.

Collision diagrams are usually prepared for a 1-year period (January through December). However, for low-accident locations (locations with five or less accidents per year) diagrams can be prepared for multi-year periods.

Collision diagrams are schematic and are not intended to show exact vehicle paths. The steps for manually preparing collision diagrams are:

1. Obtain report forms for accidents that have occurred at the location during the study period. If significant changes have recently occurred at the location (i.e., geometric changes, signals, etc.), make separate before and after diagrams. Any pattern changes that appear will, thus, reflect changing geometric or traffic conditions.

2. Draw the path of all vehicles involved in each accident. This drawing need not be to scale but should be large enough to show the path of each vehicle involved.

3. Note the basic characteristics of each accident by symbol. Suggested characteristics are:

    a. Severity.
    b. Date, day of week and time of accident.
    c. Environmental conditions.
    d. Vehicle paths.

Collision diagrams are used extensively as a graphic representation of the accident summaries and may include all of the information covered by the five accident-based procedures. In addition, these schematic drawings provide locational information that is not provided by statistical summaries. Therefore, collision diagrams often yield more effective information to the engineer than do statistical summaries. A typical collision diagram is shown in Figure 6.

Computerized Collision Diagrams

In recent years, computerized collision diagrams [3] have given the engineer and technician a method for the quick and easy production of accident information, as shown in Figure 7. Accident types are plotted on the proper intersection legs and may be color coded by severity. Collision diagrams may quickly be produced in any size, depending on the need. Any available sample size of accident data may be used, and traditional symbols for accident types may be employed. Computer costs of producing this type of diagram is in the range of $2 - $10 depending on the amount of information to be printed. This approach requires a system with computer plotting capabilities.

Standard Statistical Programs

These programs [4,5,6,7] provide cross tabulations, histograms, and other statistical applications to assist in the summary and analysis of the data. Sample outputs from several of these programs are shown in Figure 8. A sample list of available computerized statistical programs include: DART (Data Analysis and Reporting Techniques), SPSS (Statistical Package for the Social Sciences), MIDAS, (Michigan Interactive Data Analysis System), and OSIRIS IV (Organized Set of Integrated Routines for the Investigation of Social Science Data) and SAS (Statistical Analysis System). A description of their capabilities is given in Table 4.

The selection of a statistical package for analysis of accident data is beyond the scope of this manual. However, it should be noted that all computer programs require the input of the accident data into a computer file for analysis.

● Accident Analysis Alternatives

The accident study procedures involve the development of summaries of the accident data at a site by various characteristics (detailed in Table 5). These summaries are used to detect abnormal accident trends or patterns and to distinguish between "correctable" and "non-correctable" accident situations. These characteristics will be used to identify the safety problem at a hazardous location. These problems will be further studied for the development of appropriate safety improvements.

In the study of accidents at a site, there may be a substantial number of accidents which do not fall into a specific accident category or

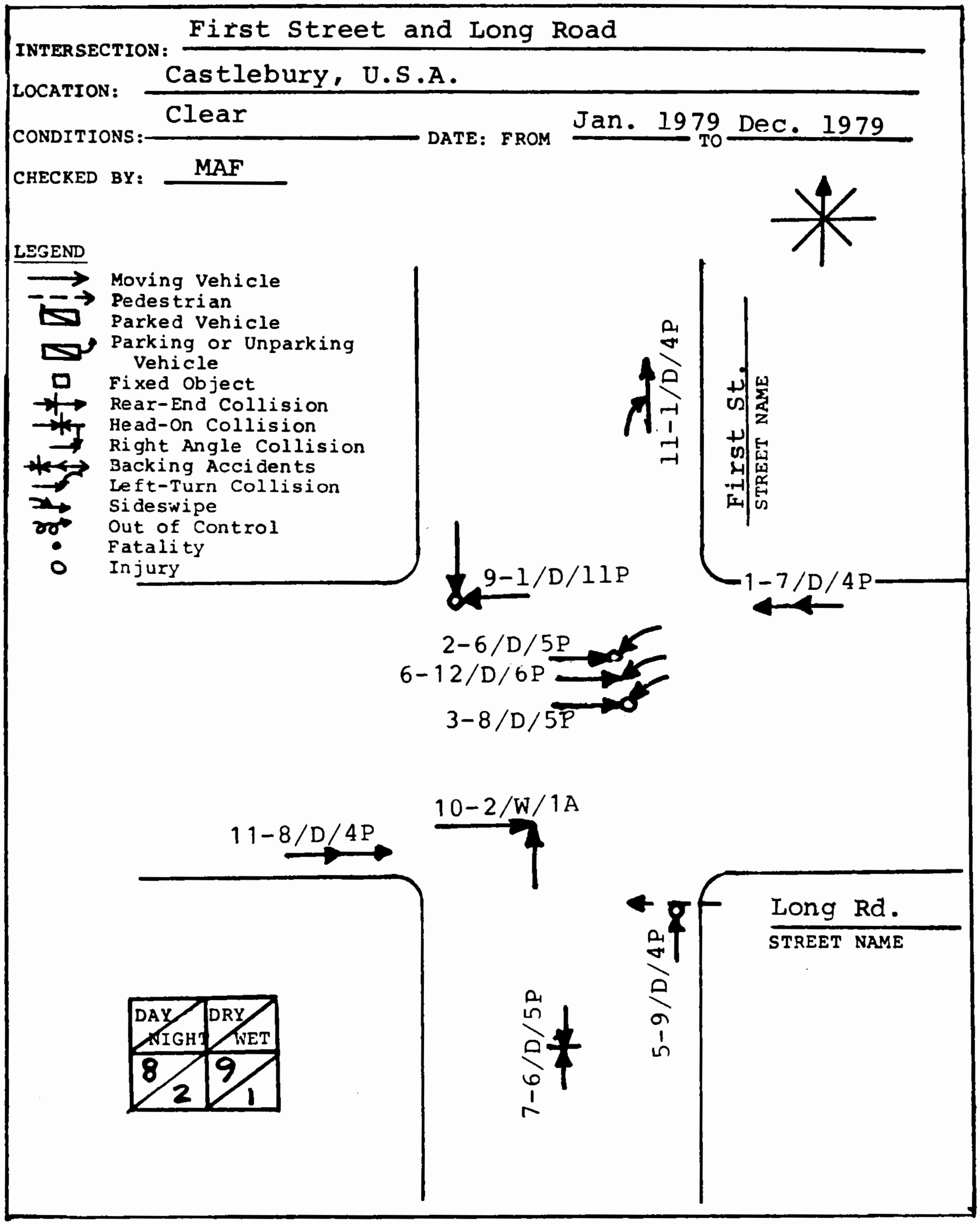


Figure 6. Collision diagram form.

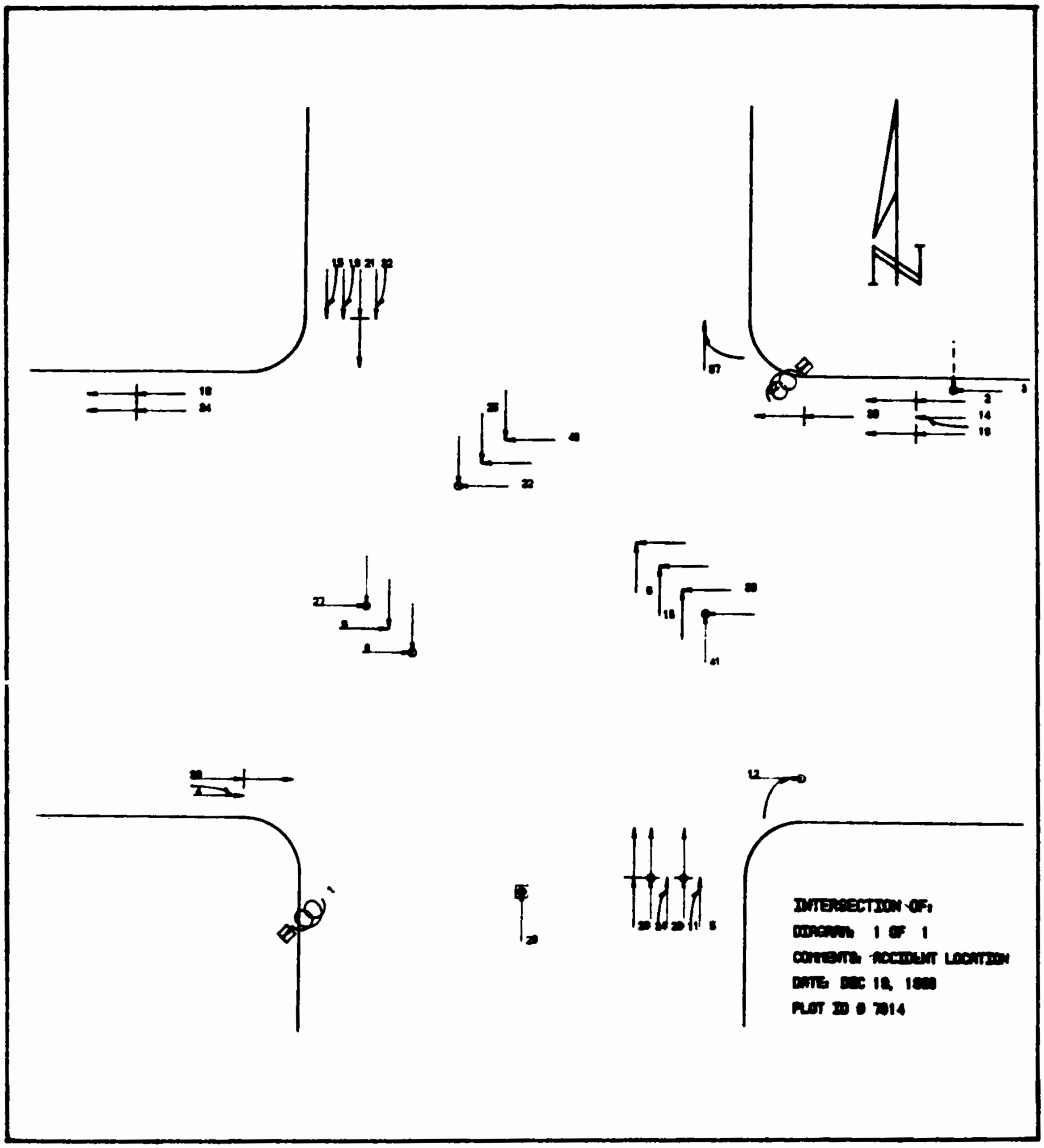


Figure 7. Computerized collision diagram.

VAR004 DAY OF THE WEEK

CATEGORY LABEL	CODE	ABSOLUTE FREQ	RELATIVE FREQ (PCT)	ADJUSTED FREQ (PCT)	CUM FREQ (PCT)
SUNDAY	1.	1	2.4	2.4	2.4
MONDAY	2.	4	9.5	9.5	11.9
TUESDAY	3.	5	11.9	11.9	23.8
WEDNESDAY	4.	9	21.4	21.4	45.2
THURSDAY	5.	7	16.7	16.7	61.9
FRIDAY	6.	7	16.7	16.7	78.6
SATURDAY	7.	9	21.4	21.4	100.0
	TOTAL	42	100.0	100.0	

VAR004 DAY OF THE WEEK

```
  CODE
       I
   1.  ****** (        1)
       I  SUNDAY
       I
       I
   2.  ******************** (        4)
       I  MONDAY
       I
       I
   3.  ************************* (        5)
       I  TUESDAY
       I
       I
   4.  ********************************************* (        9)
       I  WEDNESDAY
       I
       I
   5.  *********************************** (        7)
       I  THURSDAY
       I
       I
   6.  *********************************** (        7)
       I  FRIDAY
       I
       I
   7.  ********************************************* (        9)
       I  SATURDAY
       I
       I.........I.........I.........I.........I.........I
       0         2         4         6         8        10
       FREQUENCY
```

Figure 8. Sample statistical program outputs.

Table 4. Description of sample list of available statistical computer packages.

Program Package	Description	Capabilities	Availability
DART (Data Analysis and Reporting Techniques)	Statistical package designed to assist in the selection, analysis, and evaluation of accident data	Sort, rank, duplicate and search options; transform data values; perform statistical analyses (systemwide capabilities)	Available through National Highway Traffic Safety Administration (NHTSA) at a minimal cost to a State
SPSS (Statistical Package for the Social Sciences)	Package of computer programs designed for analysis of social science data	Sort, rank, duplicate and search options; perform statistical analyses	Available as a package throughout the U.S. by SPSS, Inc., Chicago, Illinois
MIDAS (Michigan Interactive Data Analysis System)	Package of computer programs designed for statistical analysis of data	Sort, rank, duplicate and search options; perform statistical analyses	Available in sections of Michigan
OSIRIS IV (Organized Set of Integrated Routines for Investigation of Social Science Data)	Package designed for the data management and statistical analyses for situations in the social sciences	Sort, search, duplicate, display, edit, copy, and rank data; transform data values; perform statistical analyses	Available through University of Michigan Institute of Social Research
SAS (Statistical Analysis System)	Package of computer programs designed for statistical analysis of research data	Storage, retrieval, data modification, report writing, statistical analyses, and file handling	Available as a package throughout the U.S. by the SAS Institute, Raleigh, N.C.

Table 5. Typical accident characteristic categories.

Description	Categories
Summary by Type	1. Left-turn, head-on 2. Right-angle 3. Rear-end 4. Sideswipe 5. Pedestrian-related 6. Run-off-road 7. Fixed object 8. Head-on 9. Parked vehicle 10. Other
Summary by Severity	1. Fatal 2. Personal Injury - incapacitating - nonincapacitating - possible injury 3. Property Damage
Summary by Contributing Circumstances	1. Driving under the influence of alcohol or drugs 2. Reckless or careless driving 3. Ill, fatigued or inattention 4. Failure to comply with license restrictions 5. Obscurred vision 6. Defective equipment 7. Lost control due to shifting load, wind, or vacuum
Summary by Environmental Conditions	1. Weather (clear, cloudy, rain, fog, snow) 2. Ambient light (light, dark, dawn, dusk, street lights) 3. Roadway surface (dry wet, snowy, icy)
Summary by Time of Day	1. 12:00 midnight - 1:00 A.M. 2. 1:00 A.M. - 2:00 A.M. 3. 2:00 A.M. - 3:00 A.M. 4. 3:00 A.M. - 4:00 A.M. . . . 24. 11:00 P.M. - 12:00 Midnight

pattern and which cannot be corrected by cost-effective means (e.g., excessive costs in relation to benefits derived, accidents resulting from reckless driving). Much of this information can be derived from data on the "contributing circumstances" section of the police report. In addition, random or "chance" accidents may occur and be identified by the lack of a pattern of specific accident types. These accidents comprise the "non-correctable" type accidents. After careful investigation to assure that the accidents are indeed non-correctable, they may be excluded from further analysis.

The other types of accidents may be correctable through various implementable countermeasures. Based on the accident patterns and available traffic and environmental data, probable causes of accidents can be determined.

When summarizing accident data for analysis purposes, several criteria should be adhered to:

1. Accident data should be reviewed with respect to the direction the vehicles were traveling. For analysis purposes, accident characteristics should be segregated by direction of travel. Review of accidents on an overall study area basis may result in misconceptions of the safety problem, particularly where a single approach may have a high or low percentage of the recorded intersection accidents.

2. Accident data should be reviewed with respect to location. Accidents occurring within the intersection area should be separated from those occurring outside the area of influence of the intersection. For this purpose, a definition of the study area should be made prior to analysis. In addition, similar accident types occurring in differing situations should be separated. For example, left-turn accidents into a driveway should not be included with left-turn accidents at the intersection.

For accident analysis purposes, two approaches to identify an accident pattern are available. They include: (1) expected value analysis and (2) cluster analysis.

Expected Value Analysis

The most accurate means of identifying an accident pattern would be through the determination of an expected value for a specific accident characteristic. This method is a systematic mathematical procedure for identifying all abnormal accident characteristics. To utilize this approach, accident data for similar sites (geometrics, volumes, traffic control, etc.) are obtained and the average number of a specific accident type determined. This average can be used as an "expected" value for the specific accident characteristic. Locations having accident numbers higher than the expected values relate an "overrepresentation" of the specific accident characteristic and require further investigation.

To account for variability or fluctuations in the data between sites, the use of the variance of the accident frequency is made to establish a range for an expected value. Assuming that accidents are normally distributed, the expected range can be defined as follows:

$$AV = \bar{X} \pm Ks$$

Where:

AV = expected range of accident frequency

$\bar{X}$ = average accident frequency (accidents/number of sites)

K = selected level of confidence that a site will have a specific accident frequency

s = standard deviation of accident frequencies

The average and standard deviation values may be obtained directly from the accident statistics using the following formulas:

$$\bar{X} = \frac{\Sigma fX}{n}$$

and

$$s = \sqrt{\frac{\Sigma f(X-\bar{X})^2}{n-1}}$$

Where:

$\bar{X}$ = average accident frequency

f = number of sites with a given frequency of a selected accident type

X = accident frequency at a site

n = total number of sites

s = standard deviation of accident frequencies

The "K" value is based on the desired level of confidence that a site will have accident characteristics within a certain range. Values of "K" and their respective confidence levels are shown below.

K	Confidence Level (%)
1.00	68.3
1.96	95.0
3.00	99.7

The expected range values for any given location with similar characteristics will increase as the confidence level increases. Figure 9 displays this relationship.

The above values define a range of expected values between ($\bar{X} \pm Ks$). This type of analysis is used in identifying an accident pattern by selecting the level of confidence that a site will have certain accident characteristics. If the accidents characteristics of the site are greater than the defined level, a significant pattern is denoted.

Cluster Analysis

In this approach, the identification of a particular accident characteristic is defined by an observed "cluster" or grouping of a specific accident characteristic at a site. A cluster is normally identified by an abnormal occurrence of a specific characteristic in relation to other accident types occurring at a site. For instance, at a signalized intersection with two left-turn accidents, three rear-end collisions, and five right-angle accidents, right-angle accidents could be defined as a pattern due to their abnormal occurrence in relation to the other accidents at the site. Similarly, on a roadway link where two head-on collisions and six "run-off-the-road" accidents occurred, the "run-off-the-road" accidents would be identified as a pattern.

The frequency of accidents required to define a pattern will vary considerably depending on the volume of traffic at the site. Accident rates (utilizing an exposure factor) have been used with success to identify some accident characteristics. However, on an overall basis, rates may yield erroneous results when assessing certain specific accident characteristics. The use of the total intersection volume to calculate a left-turn accident rate will exhibit inconsistencies between sites due to the fluctuations in left-turn volumes. Because the collection of left-turn related volumes on a daily basis is not economically feasible, accident frequencies have been used as the primary factor in accident pattern assessment for such instances.

Accident frequencies used to define accident patterns also differ between locations within different agencies. For instance, on a State level, the occurrence of three right-angle accidents at a particular intersection may not be considered a safety problem. However, within a small city or village, a similar frequency would represent a safety problem. The primary difference in these cases would be the occurrence of other accident characteristics at a site.

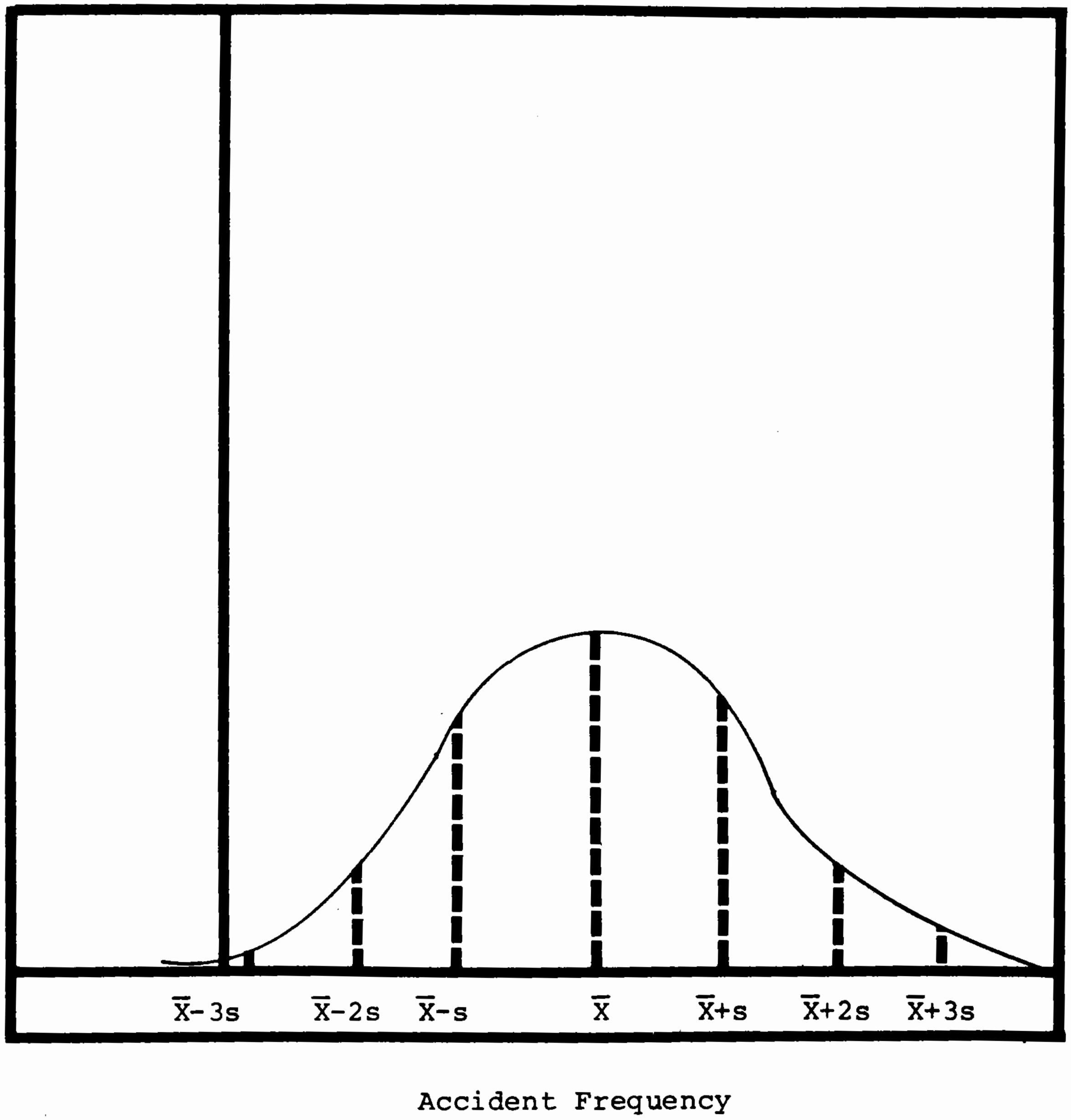


Figure 9. Relationship of confidence level in a normal distribution.

The above factors relate the difficulty in attempting to assign a discrete accident number for determining accident patterns. Rather, pattern identification using eye inspection methods and engineering judgment are desirable in this approach.

Findings

Possible accident causes need to be defined once the accident patterns are identified. This will assure the selection of appropriate countermeasures to relieve the hazardous situation.

Table 6 is used to provide the preliminary list of possible accident causes. It is developed based on specific accident patterns [8,9,10] at a site. For instance, if a pattern of pedestrian-vehicle collisions occurred at an intersection, possible causes, from Table 6, could be:

- Inadequate pavement markings.
- Inadequate channelization.
- Improper signal phasing.
- Restricted sight distance.
- Inadequate pedestrian signals.
- Inadequate roadway lighting.
- Inadequate gaps at unsignalized intersection.
- Excessive vehicle speed.

Field conditions, as noted on the police accident report or computerized accident form, may be used to refine the list of possible causes.

The list of possible causes developed within this activity is used as input into the further activities (Activities 2-6) within the model. It will serve as the basis for the selection of appropriate safety-related countermeasures to alleviate the hazardous condition(s).

It should be noted that this list may not be conclusive or exhaustive. Other situations may result in possible causes not found in this list. However, Table 6 does provide a general review of possible accident causes as a function of accident patterns.

Inputs and Outputs of Activity

- Inputs
  - Identified hazardous location.
  - Accident files.
- Outputs
  - Summary of accident characteristics.
  - Identified accident patterns.
  - List of possible accident causes.

Table 6. Accident trend or pattern evaluation.

Accident Pattern or Trend	Possible Causes
I. <u>Intersection</u>	
A. Left-Turn Head-On Collision	1. Large volume of left-turns. 2. Restricted sight distance. 3. Too short amber phase. 4. Absence of special left-turning phase. 5. Excessive speed on approaches.
B. Rear-End Collisions at Unsignalized Intersections	1. Drivers not aware of intersection. 2. Slippery surface. 3. Large volume of turning vehicles. 4. Inadequate roadway lighting. 5. Excessive speed on approaches. 6. Lack of adequate gaps. 7. Crossing pedestrians.
C. Rear-End Collisions at Signalized Intersections	1. Slippery surface. 2. Large number of turning vehicles. 3. Poor visibility of signals. 4. Inadequate signal timing. 5. Unwarranted signal. 6. Inadequate roadway lighting. 7. Excessive speed on approaches. 8. Crossing pedestrians.
D. Right-Angle Collision at Signalized Intersections	1. Restricted sight distances. 2. Excessive speed on approaches.

Table 6. Accident trend or pattern evaluation (continued).

Accident Pattern or Trend	Possible Causes
D. Right-Angle Collisions at Signalized Intersections (cont.)	3. Poor visibility of signals. 4. Inadequate signal timing. 5. Inadequate roadway lighting. 6. Inadequate advance intersection warning signs. 7. Large total intersection volume.
E. Right-Angle Collisions at Unsignalized Intersections	1. Restricted sight distance. 2. Large total intersection volume. 3. Excessive speed on approaches. 4. Inadequate roadway lighting. 5. Inadequate intersection warning signs. 6. Inadequate traffic control devices.
F. Pedestrian/Vehicle Collision	1. Restricted sight distance. 2. Inadequate protection for pedestrians. 3. School crossing data. 4. Inadequate signals. 5. Improper signal phasing. 6. Driver had inadequate warning of frequent midblock crossings. 7. Inadequate pavement markings. 8. Inadequate gaps at unsignalized intersections. 9. Inadequate roadway lighting. 10. Excessive vehicle speed.

Table 6. Accident trend or pattern evaluation (continued).

Accident Pattern or Trend	Possible Causes
II. Link	
A. Run-Off-Roadway Collisions	1. Slippery surface. 2. Roadway design inadequate for traffic conditions. 3. Poor delineation. 4. Inadequate roadway lighting. 5. Inadequate shoulder. 6. Improper channelization. 7. Inadequate pavement maintenance. 8. Poor visibility. 9. Excessive speed on approaches.
B. Fixed-Object Accidents	1. Obstructions in or too close to roadway. 2. Inadequate roadway lighting. 3. Inadequate pavement marking. 4. Inadequate signs, delineators, and guardrails. 5. Inadequate roadway design. 6. Slippery surface. 7. Excessive vehicle speed.
C. Parked Vehicle Accidents	1. Improper pavement markings. 2. Improper parking clearance at driveways. 3. Angle parking. 4. Excessive vehicle speed.

Table 6. Accident trend or pattern evaluation (continued).

Accident Pattern or Trend	Possible Causes
C. Parked Vehicle Accidents (Cont.)	5. Illegal parking. 6. Improper parking. 7. Large parking turnover.
D. Sideswipe or Head-On Collision	1. Inadequate roadway designs. 2. Improper road maintenance. 3. Inadequate shoulders. 4. Excessive vehicle speed. 5. Inadequate pavement markings. 6. Inadequate channelization. 7. Inadequate signing.
E. Driveway-Related Collisions	1. Left-turning vehicles. 2. Improperly located driveways. 3. Right-turning vehicles. 4. Large volume of through traffic. 5. Restricted sight distance. 6. Inadequate roadway lighting. 7. Excessive speeds on approaches.
F. Train-Vehicle Accidents	1. Restricted sight distance. 2. Poor visibility. 3. Excessive vehicle speeds on approaches. 4. Improper traffic signal pre-emption timing. 5. Slippery surface.

Table 6. Accident trend or pattern evaluation (continued).

Accident Pattern or Trend	Possible Causes
F. Train-Vehicle Accidents (Cont.)	6. Improper pre-emption timing of RR signals or gates. 7. Rough crossing surface. 8. Sharp crossing angle.
III. <u>Environment-Related</u> A. Wet Pavement Accidents	1. Slippery surface. 2. Inadequate drainage. 3. Inadequate pavement markings.
B. Night Accidents	1. Poor visibility or lighting. 2. Poor sign quality. 3. Inadequate channelization or delineation.

ACCIDENT-BASED PROCEDURES

Accident-based procedures include the study and analysis of the accident characteristics of a site. Characteristics such as accident type, severity, contributing circumstances, environmental conditions, and time-related data are examined in this section. These characteristics are reviewed for each site to identify safety problems and their possible causes. The study results provide the initial basis for the selection of safety improvements to alleviate or reduce the identified safety problems.

Within Activity 1, the following procedures are described:

- Procedure 1 - Accident Summary by Type.
- Procedure 2 - Accident Summary by Severity.
- Procedure 3 - Accident Summary by Contributing Circumstances.
- Procedure 4 - Accident Summary by Environmental Conditions.
- Procedure 5 - Accident Summary by Time Period.

A detailed description of these procedures are given below.

PROCEDURE 1 Accident Summary By Type

Purpose

An "accident summary by type" procedure is conducted to identify the safety problem and possible safety deficiencies based on the accident patterns occurring at the location. The occurrence of patterns is typically classified by a specific accident type, such as:

- Left-turn, head-on.
- Right-angle.
- Rear-end.
- Sideswipes.
- Pedestrian-related.
- Run-off-road.
- Fixed object.
- Head-on.
- Parked vehicle.
- Bicycle-related.
- Others.

Application

The "accident summary by type" procedure identifies patterns of accident occurrences based on the specific accident type and location of the accidents at a site. Following the identification of accident patterns, the results are used to suggest possible causes of the accident patterns using information shown in Table 6.

The "accident summary by type" study serves as the major indicator of the possible causes of the safety problem(s) at a specific site. It also identifies such factors as: direction of travel of the involved vehicles, intended movements of the involved vehicles, and the number of involved vehicles. Review of these factors are commonly used to assist in defining the possible causes of accident patterns.

Input from the other accident procedures are used to verify, add, or delete possible accident causes from the list produced by this accident procedure. The output is used in the field review activities of the safety engineering investigation model.

The "accident summary by type" data is further used in identifying countermeasures capable of reducing or alleviating the specific safety problem(s) at a site. For example, a pattern of left-turn accidents at a signalized intersection may require one of the following countermeasures for reducing the left-turn accident problem:

- Construction of an exclusive left-turn lane.
- Inclusion of a left-turn phase in the signal phasing plan.
- Re-timing of the signal.

Finally, based on the "accident summary by type" data and the accident reduction capabilities of a countermeasure, an economic analysis can be performed to select the appropriate safety project.

PROCEDURE 2 Accident Summary By Severity

Purpose

An "accident summary by severity" procedure is conducted to assist in identifying safety deficiencies and in selecting countermeasures utilizing the severity characteristics of the individual accidents. Severity classifications generally used include the following (given with typical severity codes):

- Fatality (K).

- Personal injury.

    - Incapacitating injury (A).
    - Non-incapacitating injury (B).
    - Possible injury (C).

- Property damage (O).

Application

The severity characteristics at a location can, in some cases, identify possible causes of safety problems. However, the principal use of severity data is to provide a weighted scale (based on the severity of individual accidents) to increase the effect of the more "severe" accidents or accident types in the analysis. Since the reduction of the more severe accidents produce greater benefits, the findings of this procedure would assist the analyst in placing a greater priority on reducing specific accident types or patterns with a high severity factor.

This summary is used with the "Accident Summary By Type" findings to provide background information on the severity characteristics of the accident situation. Since the severity of an accident is commonly associated with the travel speed of the vehicles, this relationship (through the use of personal injury (PI) accidents/property damage (PD) accident ratios) may define possible speed-related causes of accidents. For instance, a pattern of personal injury (Type-A) rear-end accidents on an approach may be related to excessive travel speeds through the area. Similarly, the review of patterns of personal injury or fatality accidents at a site can produce input into further data needs (studies) for selection of an appropriate countermeasure(s).

In addition, an accident type summary utilizing accident severity characteristics can be used to define "expected" values for each accident type. The data can be used to determine whether a "weighted" specific accident type is "overrepresented" or "critical". In utilizing the severity information for such purposes, several methods of defining the severity characteristics are available.

The simplest method for defining the severity of a specific accident is by using the most severe characteristic. For instance, if a fatality occurred, the accident would be labelled a <u>"fatality"</u> regardless of the number of personal injuries or the amount of property damage. Similarly, a <u>"personal injury"</u> accident would be identified by the occurrence of at least one personal injury. A <u>"property damage"</u> accident is limited to those events in which no fatality or personal injury resulted, although property damage to a vehicle(s) or other property occurred. This method is widely used since it can be applied directly to the accident type and other information for use in identifying patterns or possible accident causes. A weighting scale may be used to provide comparisons of the severity characteristics at or between sites. One typical weighting scale [1] is given as:

- Fatality = 12.
- Personal injury = 3.
- Property damage only = 1.

A disadvantage of using this scale is the sharp difference between a "property damage only" accident and a "fatality" accident. This difference can have disproportionate effects in the priority value. For example, a single fatality accident will have equal weight to 12 "property damage only" accidents. In this sense, one fatal accident can bias the data significantly. To reduce this effect, a lower weighting for fatality accidents may be used, for example, an 8 or 9. The lower weighting may be particularly useful for locations in which fatality accidents are extremely rare compared with other accidents at the site.

An alternate weighting method utilizes individual accident costs. These costs include items associated with loss as a result of the accident, including losses incurred in productivity, insurance losses, etc. Accident costs based on average nationwide figures are available from the National Safety Council (NSC). These values are updated annually. The most recent accident cost (1979) values by the NSC are:

- Fatality - $160,000.
- Injury (non-disabling) - $6,200.
- Property damage only (including minor injury) - $870.

These values are applied to each accident on the basis of the number of fatalities and injuries. The "property damage only" factor is applied only to accidents in which no fatalities or personal injuries occurred. An example of the accident cost for an accident involving two fatalities and three personal injuries would be:

$$\text{Accident Cost} = 2(\$160,000) + 3(\$6,200)$$
$$= \$320,000 + \$18,600 = \$338,600$$

The National Highway Traffic Safety Administration (NHTSA) has also developed accident costs. These costs are significantly greater than the NSC costs; however, the NHTSA method of computing these costs include several items not included in the NSC figures. NHTSA has not updated their cost figures in recent years.

Other cost scales have been developed by individual states. In many cases, they may be more accurate than the nationwide statistics for use in a specific region. If available, the individual states figures should be used.

The accident cost method is advantageous in that it displays the accident information in a form readily adaptable for use in the economic analysis of countermeasures. In addition, it serves to provide a more meaningful value to users of the data. A major disadvantage of this method, however, is the difference in accident costs between a fatality and a property damage accident. This difference may result in an unwarranted emphasis being placed on a fatal accident which may have been a "chance" occurrence. The cost ratio of fatality to property damage accidents is nearly 200 to 1 for the NSC values.

The "Accident Summary By Severity" study procedure, used with accident summary by type information, can provide valuable input for identifying possible causes of safety problems. As an independent procedure, it can be used to identify patterns of severe-type accident events. However, its major use in safety applications is in selecting countermeasures. By providing emphasis on the more "severe" accident events, a greater benefit can be realized by the alleviation or reduction of these accident events.

PROCEDURE 3 Accident Summary By Contributing Circumstances

Purpose

This accident study procedure is designed to identify possible accident causes based on the "contributing circumstances" noted by the investigating police officer at the scene of the accident. "Contributing circumstances" are categorized by (1) human (driver) factors, (2) environmental factors, and (3) vehicle-related factors.

Application

The "contributing circumstances" summary information can be used with other accident summaries to provide background data on possible causes of accidents. It is typically used with the "accident summary by type" data to develop a preliminary list of possible accident causes. This list is used to verify, add, or delete possible causes developed by the "accident summary by type" procedure. In addition, the contributing circumstances information can be used to separate "correctable" and "noncorrectable" accidents for use in identifying accident patterns. In separating the accidents by these classifications, careful investigation should be made to assure that the accidents are indeed "non-correctable".

Information on contributing circumstances is based on an evaluation by the investigating officer at the scene of an accident. It is determined from comments of the involved drivers, a review of field conditions at the time of the accident, distinguishing characteristics made at the accident site (alcohol blood-level tests, skid marks, etc.), and the experience and knowledge of traffic safety principles of the reporting officer.

"Contributing circumstances" information is included on the police accident report. The following list displays the contributing factors which are commonly used by police agencies to identify contributing circumstances. The relationship of these circumstances as "correctable" or "non-correctable" is also shown. "Correctable" type circumstances are those which could be alleviated by means of a feasible safety-related countermeasure specific to the study site. "Non-correctable" circumstances are of a random nature and are not specifically amenable to correction by a cost-effective countermeasure.

Contributing Circumstances

● Driver-Related

- Unsafe speed (C).
- Failed to yield right-of-way (C).
- Following too close (C).
- Improper passing (C).
- Disregard traffic controls (C).
- Turning improperly (C).
- Alcohol involvement (C)(N).
- Drug involvement (C)(N).
- Sick, (N).
- Fell asleep (C)(N).
- Lost consciousness (N).
- Driver inattention (C)(N).
- Distraction (C)(N).
- Physical disability (N).
- Other.
- None detected.
- Not stated.

● Vehicle-Related

- Brakes defective (N).
- Headlights defective (N).
- Other lighting defects (N).
- Steering failure (N).
- Tire failure/inadequate (N).
- Tow hitch defective (N).
- Over or improper load(N).
- Oversized load on veh.(N)
- Other.
- None detected.

● Environment-Related

- Animal's action (N).
- Glare (C)(N).
- View obstructed/limited (C).
- Debris in roadway (C).
- Improper/non-working traffic controls (C).
- Shoulders defective (C).
- Holes/deep ruts/ bumps(C).
- Road under construction/ maintenance (C).
- Improperly parked vehicle(s) (C).
- Fixed object(s) (C).
- Slippery surface (C).
- Water ponding (C).
- None detected.
- Not stated.

LEGEND:

(C) - correctable
(N) - non-correctable

Where accident type patterns (as defined in Procedure 1) are defined, contributing circumstances data are used in identifying or verifying the possible causes of accidents.

It should be noted that the contributing circumstances information is prepared by the investigating officer at the scene of the accident and may contain several circumstances per accident. This information may identify specific conditions which may not be included in the collision diagrams or other summaries. In this respect, the contributing circumstances data are a very useful tool. However, the data should not be considered conclusive since it is based on the opinions and judgement of the investigating officer.

PROCEDURE 4 Accident Summary By Environmental Conditions

Purpose

This study procedure identifies possible causes of safety deficiencies related to the condition of the roadway environment existing at the time of the accident. Typical classifications used in the accident analysis include:

- Lighting conditions (daylight, dusk, dawn, dark).
- Roadway surface condition (dry, wet, snowy/icy, unknown).

Application

In highway safety studies, accidents are summarized by environmental conditions to identify possible causes of safety problems. Using accident data, a summary of the environmental characteristics for all accidents at a study location can be obtained. These are compared to average or expected values for similar sites or areas to determine whether the occurrence of a specific environmental characteristic is greater or less than the expected value at the site.

The average or expected values can be obtained from an average for several sites for all roadway accidents in an area. Many State agencies can supply this information. Since these values are used as a general guideline for defining an uncharacteristic condition, it is advantageous for the selected comparison sites to represent a variety of locational situations to obtain a more representative expected value.

Where sufficient accident data to obtain average or expected values are unavailable, the use of a general guideline or value might be considered. Generalized values can be obtained by reviewing the environment-related characteristics, such as:

- Nighttime (dark condition) accidents ratio (r_n).

$$r_n = \frac{\text{(dusk + dawn + dark) accidents}}{\text{total accidents}}$$

- Wet pavement condition accidents ratio (r_w).

$$r_w = \frac{\text{"wet pavement" accidents}}{\text{total accidents}}$$

A comparison of traffic volumes during the dawn, dusk, and nighttime periods (typically 7:00 p.m. - 7:00 a.m.) to total daily traffic volumes can be used to obtain an expected ratio of "dark condition" accidents to total accidents.

For "wet condition" accidents, several weather agencies within a State can supply a "wet pavement exposure rate" (defined as the ratio of hours of exposure to wet-pavement conditions to the total number of hours in a study period). This ratio can be used as a generalized expected value. Alternative means to obtain "wet-pavement conditions" ratios may include:

- Use of general rainfall (or sunshine) index ratios (as supplied from local weather agencies or almanacs).

- Use of estimated ratios based on past experiences (values generally range from 10-30 percent depending on area's rainfall characteristics).

Comparing the environment-related accident data at a site to expected values will define whether the specific environment characteristic was "critical" to the accident activity at a location. When these conditions represent critical conditions (such as a high percentage of nighttime, wet weather, or wet roadway accidents), they may identify an accident pattern of wet weather or nighttime accidents. Applied to individual accident patterns, the expected values can be used to identify possible accident causes. It should also be noted that information on environmental conditions present at the time of the accident can assist in the separation of "correctable" and "non-correctable" accidents. For instance, accidents occurring under snowy-icy weather conditions may sometimes relate a "non-correctable" situation, if their occurrences are determined to be highly infrequent.

PROCEDURE 5 Accident Summary By Time Period

Purpose

This study procedure is conducted to assist in identifying safety deficiencies by defining the time period patterns of the accident events. To assist in this procedure, accidents can be classified by:

- Time of day.
- Day of week.
- Month of year.

Application

This procedure primarily identifies the time period of occurrence of the accident activity at a location. It is used to identify not only the over-representative occurrence of accidents during a specific time period but also defines the study periods required for the performance of other study procedures (i.e., operations-based and environment-based) used to identify the safety deficiencies. Summaries of the accident data are developed and compared to expected values to identify the periods of overrepresented accident occurrences.

To develop expected values for accidents by time of day, a ratio of the volume data (hourly) to the total volume may be used. This can also be done similarly for day of week and month of year periods if the data are available. Where the volume information is unavailable for these time periods, generalized criteria can be used. These criteria can be developed based on local information or can be obtained from such sources as the Transportation and Traffic Engineering Handbook (1976). A sample of accident occurrence by time of day is shown in Figure 10.

Comparison of the study data to "expected" values will serve to define the "overrepresented" time-related accident events. Information relating possible accident causes can also be defined. For example, an overrepresentative amount of accidents occurring during the peak hours may indicate congestion-related causes.

These overrepresented conditions will define the periods for study of the specific accident types occurring during that period.

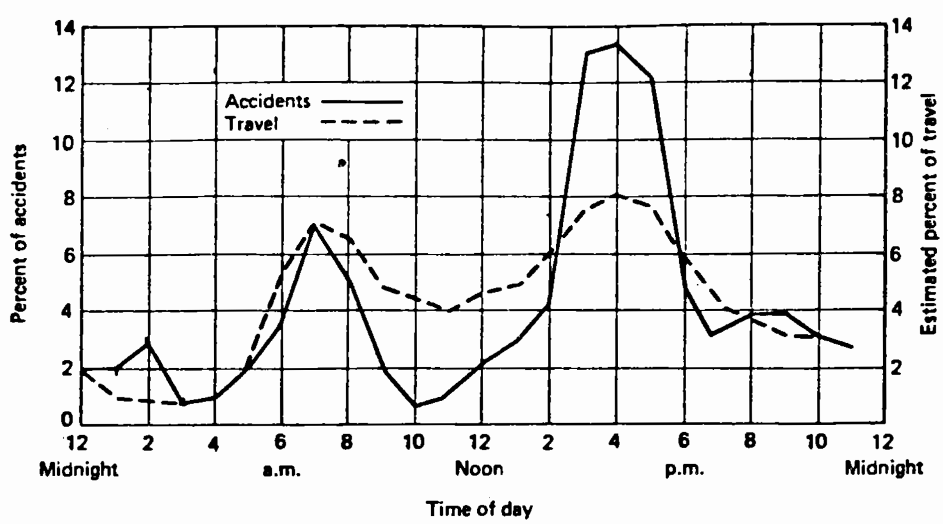


Figure 4.29. Distributions of travel accidents and travel by time of day. [Source: Gilbert T. Satterly, Jr., and Donald E. Cleveland, *Traffic Control and Roadway Elements —Their Relationship to Highway Safety* (Washington, D.C.: Highway Users Federation for Safety and Mobility, 1969), p. 6.]

Figure 10. Accident by time of day characteristics.

● Example

To illustrate the use of the accident-based procedures in an actual field situation, the following example is provided. For the intersection of Block Street and Dove Road, accident summary sheets and collision diagrams are displayed in Figures 11-14.

● Procedure 1 - Accident Summary By Type

Reviewing these summaries and evaluating the data for accident patterns by the cluster analysis method, the following patterns are noted as being overrepresented.

1. Northbound left-turn accidents at the intersection (1975-5, 1976-3, 1977-9).
2. Right-angle collisions at driveway west of the intersection (1975-4, 1976-3, 1977-10).
3. Right-angle accidents in the intersection area (1975-3, 1976-5, 1977-10).

Based on these patterns, the following possible causes are obtained from Table 6:

Accident Pattern	Possible Causes
Left-turn head-on collision	● Large volume of left turns. ● Restricted sight distance. ● Too short amber phase. ● Absence of special left-turning phase. ● Excessive speed on approaches.
Right-angle collisions (driveway-related)	● Left-turning vehicles. ● Improperly located driveways. ● Right turning vehicles. ● Large volume of through traffic. ● Restricted sight distance. ● Inadequate roadway lighting. ● Excessive speed on approaches.
Right-angle collisions at signalized intersections	● Restricted sight distances. ● Inadequate roadway lighting. ● Inadequate advance intersection warning signs. ● Poor visibility of signal indication. ● Excessive speed on approaches. ● Inadequate signal timing. ● Large total intersection volume.

Location: Block Street at Dove Road

Type of accident	1977		1978		1979	
	No.	%	No.	%	No.	%
Left turn head-on	7	23.3	9	22.0	11	18.6
Rear-ends	8	26.7	11	25.8	12	20.3
Angle	8	26.7	14	34.2	24	40.7
Pedestrian	1	3.3	1	2.4	0	-
Sideswipes	6	20.0	4	9.8	10	16.9
Run-off-road			1	2.4	0	-
Fixed object			1	2.4	2	3.5
Head-on					0	-
Wet conditions	9	30.0	16	39.0	20	33.9
Dry conditions	21	70.0	25	61.0	39	66.1
Day Conditions	24	80.0	28	68.3	48	81.4
Dusk or night conditions	6	20.0	13	31.7	11	18.6
Fatal accident (No. persons)	0	-	0	-	0	-
Injury accident (No. persons)	5	16.7	9	22.0	16	27.1
Property damage accident	25	83.3	32	78.0	43	72.9

Figure 11. Manual accident summaries (example).

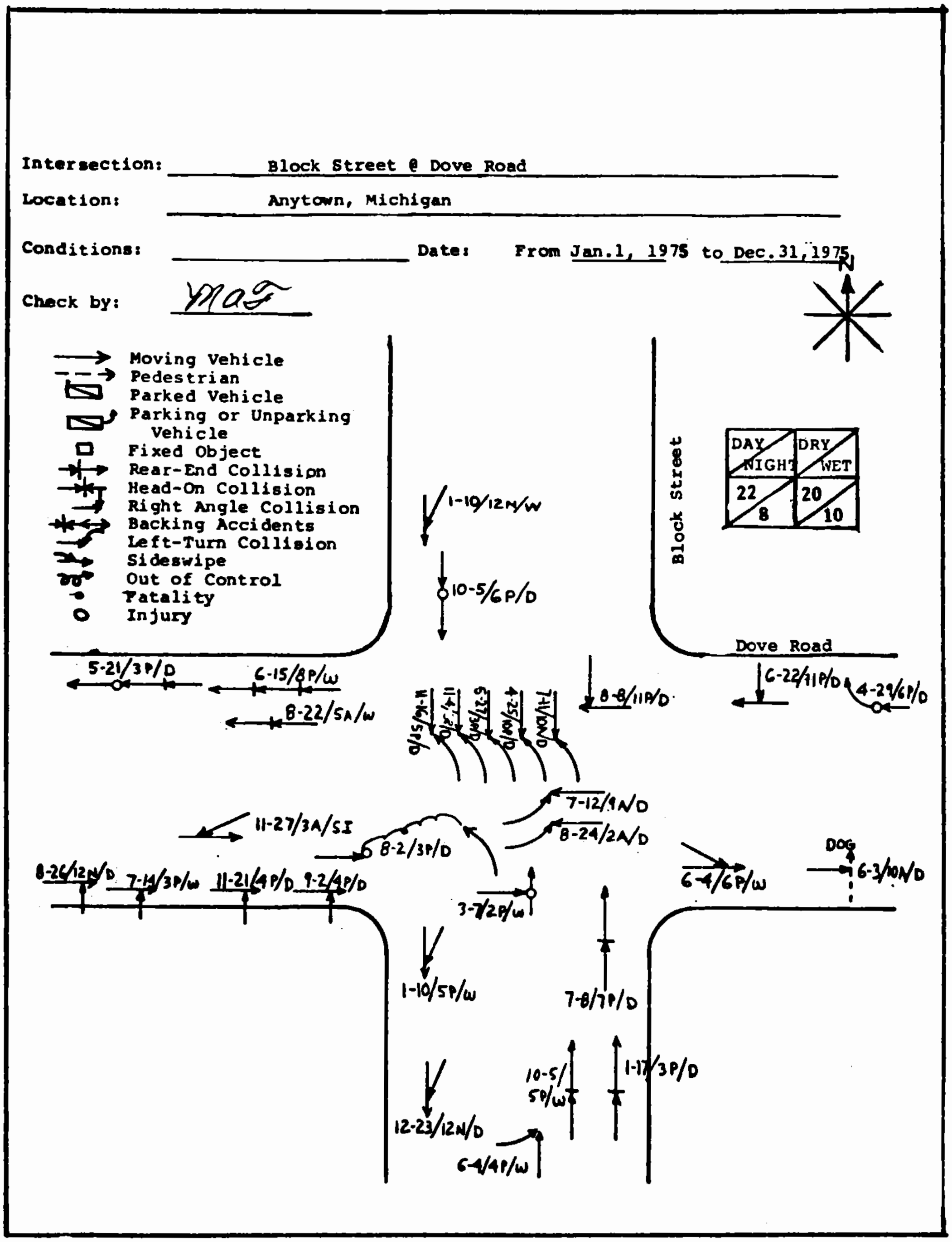


Figure 12. Collision diagram (example) - 1975.

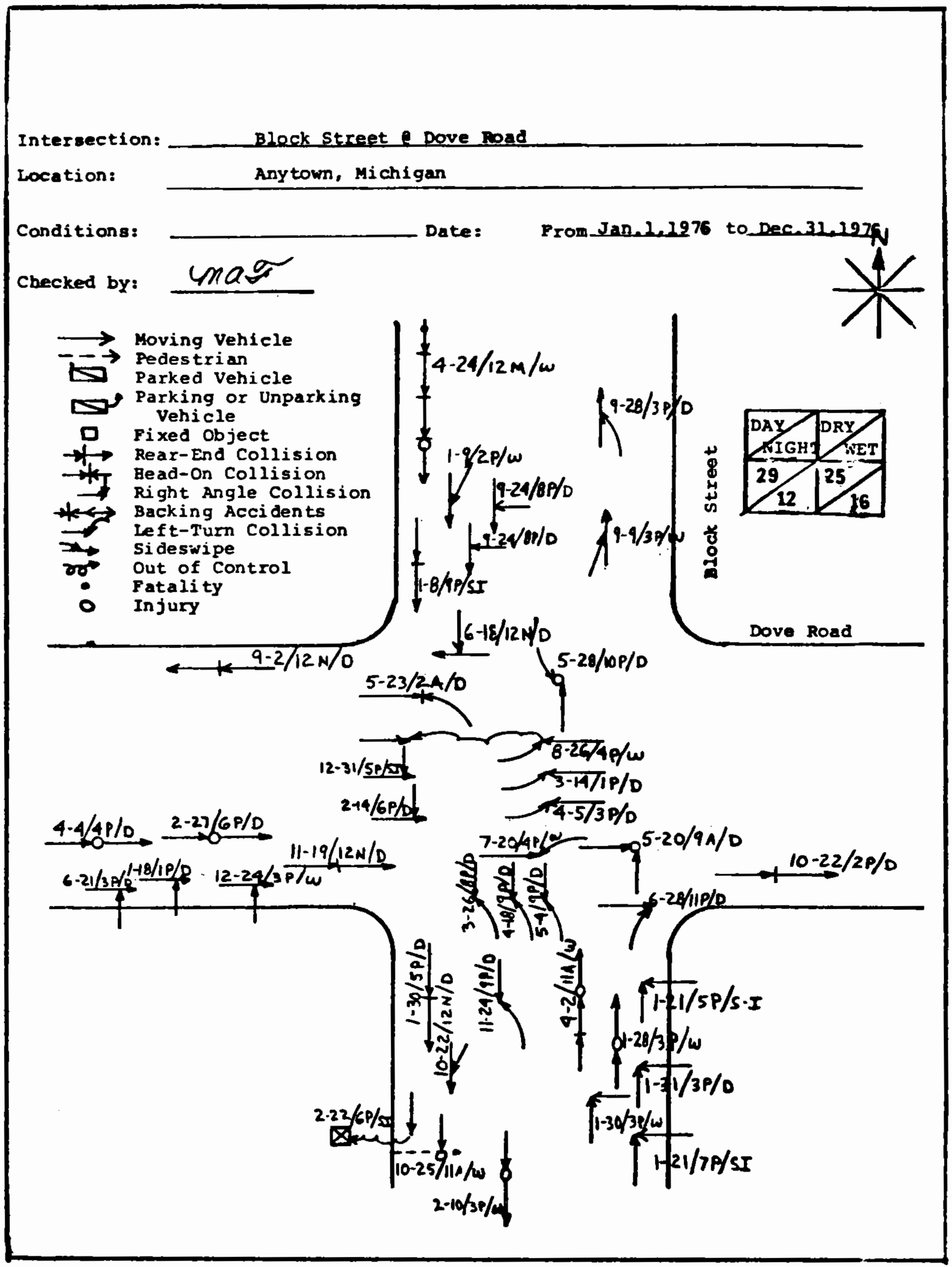


Figure 13, Collision diagram (example) - 1976.

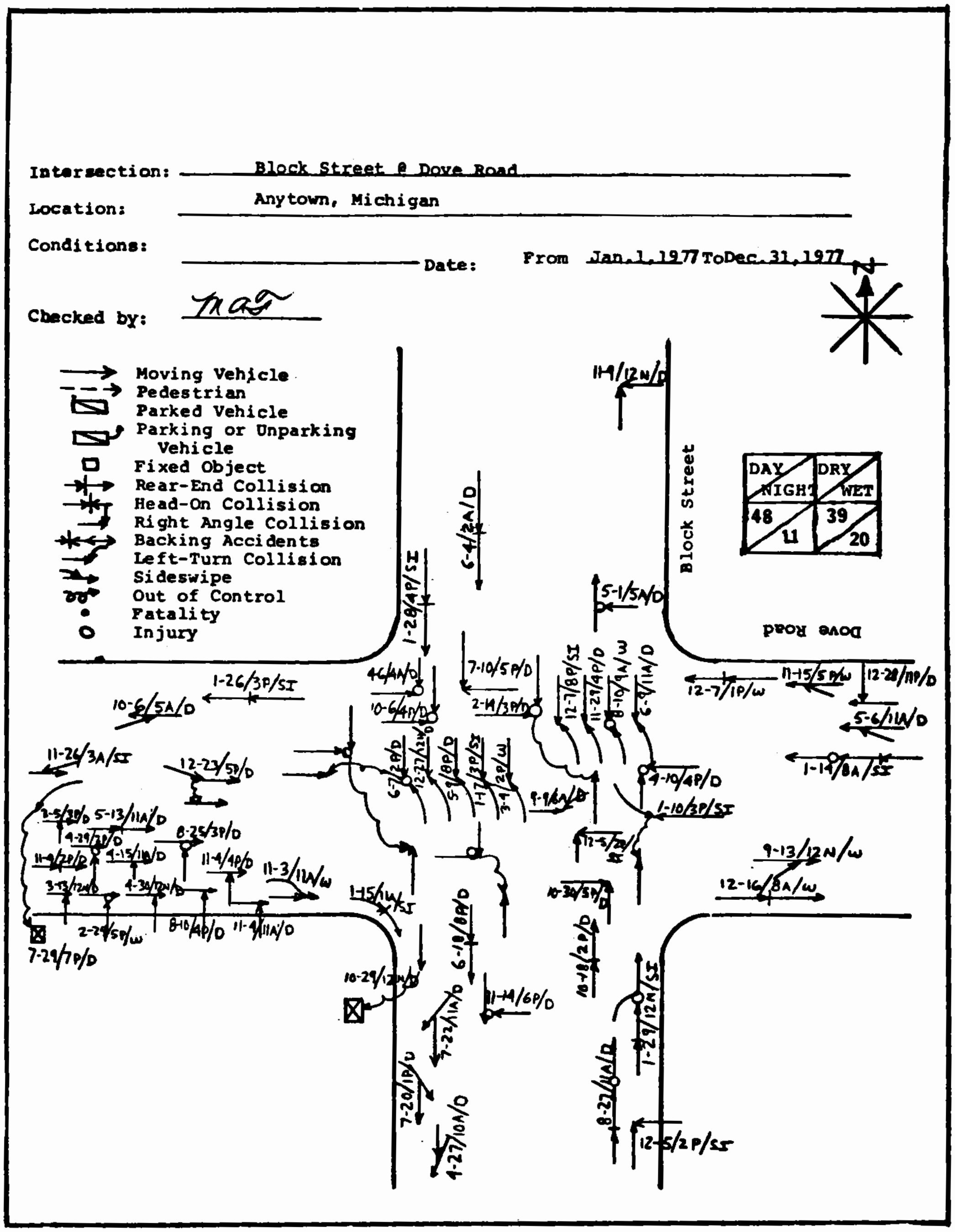


Figure 14. Collision diagram (example) - 1977.

● Procedure 2 - Accident Summary By Severity

A review of accident severity data shows the following characteristics:

Accident Pattern	1975	1976	1977
N.B. Left-Turns	5 P.D.	3 P.D.	2 P.I. 7 P.D.
Right-angle (driveway-related)	4 P.D.	3 P.D.	3 P.I. 7 P.D.
Right-angle at intersection	1 P.I. 2 P.D.	1 P.I. 4 P.D.	7 P.I. 3 P.D.

P.D. = Property Damage P.I. = Personal Injury

A review of the P.I./P.D. ratios for the accident patterns shows:

. NB left-turns - 2 P.I./15 P.D. = 0.133
. Right-angle (driveway-related) - 3 P.I./14 P.D. = 0.214
. Right-angle at intersection - 9 P.I./9 P.D. = 1.00

Review of these ratios identifies a possible severity pattern for the right-angle accidents at the intersection. This accident type should include a study of speed characteristics as a possible cause.

Using the severity weighting plan described in the Traffic and Transportation Engineering Handbook [1] (i.e., Fatality = 12, Personal Injury = 3, and Property Damage = 1), the weighted accident values are:

Accident Pattern	1975	1976	1977	Total
NB left-turn	5	3	13	21
Right-angle (driveway-related)	4	3	16	23
Right-angle at intersection	5	7	24	36

Utilizing the alternate weighting plan developed using NSC (1979) accident costs and assuming that each personal injury accident resulted in a single nondisabling injury, the following accident costs were computed:

Accident Pattern	1975	1976	1977	Total
NB Left-Turn	$4,350	$2,610	$18,490	$25,450
Right-angle (drive-way related)	$3,480	$2,610	$24,690	$30,780
Right-angle at intersection	$7,940	$9,680	$46,010	$63,630

A comparison of the "TOTAL" value by either plan reveals that priority in the study of safety problems and the selection of countermeasures should be given to the "right-angle at intersection" accidents.

- <u>Procedure 3 - Accident Summary By Contributing Circumstances</u>

A review of contributing circumstances data taken from the individual accident reports revealed the following characteristics:

- <u>Northbound Left-Turns</u>

  - Failed to yield right-of-way (12).
  - Disregard traffic controls (8).
  - Slippery surface (1).

- <u>Right-Angle Accidents West of Intersection (Driveway-Related)</u>

  - Failed to yield right-of-way (15).
  - View obstructed/limited (6).

- <u>Right-Angle Accidents at Intersection</u>

  - Unsafe speed (4).
  - Failed to yield right-of-way (9).
  - Disregard traffic controls (13).
  - Driver inattention (6).

The number following each "contributing circumstance" lists the frequency in which each specific circumstance was related to the individual accident patterns. Changes to the list developed by the "accident summary by type" procedure are given below.

Change	Possible Cause and Affected Accident Pattern	Reason
Addition	"Slippery surface" - LEFT-TURN HEAD-ON COLLISION	Noted as contributing circumstances.
Deletion	"Excessive speed on approaches" - LEFT-TURN HEAD-ON COLLISION	Contributing circumstances data related accident problem to be caused by left-turn traffic "waiting" in queue.
Deletion	"Inadequate intersection warning signs" - RIGHT-ANGLE COLLISIONS (DRIVEWAY-RELATED)	Contributing circumstances data related accident problem to drivers exiting driveway.
Deletion	"Excessive speed on approaches" RIGHT-ANGLE COLLISIONS (DRIVEWAY-RELATED)	Contributing circumstances data related accident problem to drivers exiting driveway.

- Procedure 4 - Accident Summary By Environmental Conditions

A table of the environmental characteristics is shown below:

Accident Type	1975	1976	1977
Wet/Total Acci.	9/30 (30.0%)	16/41 (39.0%)	20/59 (33.9%)
Dusk and Night/ Total Acci.	6/30 (20.0%)	13/41 (31.7%)	11/59 (18.6%)

For comparison purposes, the three study years are combined and summarized as follows:

Accident Type	Total Accidents (1975-1977)
Wet/Total Accidents	45/130 (34.6%)
Dark and Night/Total Accidents	30/130 (23.1%)

Assuming the City's average values for the "wet/total accidents" and "dusk, dawn, and night/total accidents" ratios were 25.4 percent and 29.5 percent, respectively, the following evaluation is performed:

"Wet/Total Accidents" = 34.6% > 25.4%
"Dusk, Dawn and Night/Total Accidents = 23.1% < 29.6%

The result of this comparison suggests a pattern of "wet pavement accidents." The "dusk and nighttime accidents" are not considered critical. This pattern suggests the following accident causes for the wet pavement conditions, obtained from Table 6.

Accident Pattern	Possible Cause
Wet-weather related accidents	. Slippery surface. . Inadequate drainage. . Inadequate pavement markings.

● Procedure 5 - Accident Summary By Time Period

Summaries of time-related data by time of day for the defined accident patterns reveal:

Accident Description	1975	1976	1977	Total (%)
NB Left-turn head-on collisions	1(10-11a) 1(3- 4p) 1(4- 5p) 1(5- 6p) 1(10-11p)	1(8- 9p) 2(9-10p)	1(8-10a) 1(11-12n) 1(12n- 1p) 2(2- 3p) 1(3- 4p) 1(4- 5p) 2(8- 9p)	3(9a-12n)-17.6% 3(12n- 3p)-17.6% 5(3p- 6p)-29.6% 3(6p- 9p)-17.6% 3(9p-12m)-17.6%
Right-angle collisions (Driveway-Related)	1(12n- 1p) 1(3- 4p) 2(4- 5p)	1(1- 2p) 2(3- 4p)	2(11a-12n) 2(12n-1p) 1(2p- 3p) 2(3 - 4p) 2(4 - 5p) 1(5 - 6p)	2(9a-12n)-11.8% 5(12n- 3p)-29.4% 10(3 - 6p)-58.8%

Accident Description	1975	1976	1977	Total (%)
Right-angle accidents at the intersection	1(2- 3p) 1(3- 4p) 1(11p-12m)	1(9-10a) 1(12n- 1p) 1(5- 6p) 1(6- 7p) 1(10-11p)	1(3 - 4a) 1(2 - 3p) 2(3 - 4p) 3(4 - 5p) 3(5 - 6p)	1(3a- 6a)- 5.5% 1(9a-12n)- 5.5% 3(12n- 3p)-16.6% 10(3 - 6p)-55.8% 1(6 - 9p)- 5.5% 2(9p-12m)-11.1%

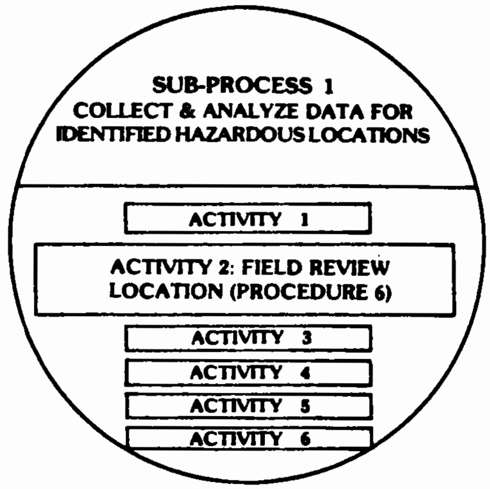
a = a.m.   p = p.m.   n = noon   m = midnight

Comparing the last column values to the values in Figure 10, the following critical time periods for the specific accident occurrences were identified.

- Northbound Left-Turn
  - (9:00 a.m. - 12:00 noon)
  - (6:00 p.m. - 9:00 p.m.)
  - (9:00 p.m. - 12:00 mid.)
- Right-Angle Collisions (Driveway-Related)
  - (12:00 noon - 3:00 p.m.)
  - (3:00 p.m. - 6:00 p.m.)
- Right-Angle Accidents at Intersection
  - (3:00 p.m. - 6:00 p.m.)
  - (9:00 p.m. - 12:00 mid.)

Similar comparisons can be made with the day of week and time of year data.

The accident characteristics occurring during these periods may determine the possible accident causes to be studied in later activities. They also identify the periods for study of the site. For example, it is noted that an overrepresented number of right-angle accidents occurred during the 9:00 p.m. - 12:00 midnight period. A review of field conditions during this time period may be necessary. In addition, the occurrence of these accident types under a nighttime condition may identify "inadequate lighting or delineation" as a possible accident cause.



ACTIVITY 2 Field Review Location

Purpose

Following the performance of the accident procedures, it is necessary that a field review of the study location be performed. This review will serve several purposes. They are:

1. To verify site data used in performing the accident procedures.

2. To verify the presence of locational deficiencies suspected, based on the accident patterns.

3. To identify, verify, or delete possible accident causes from the list obtained by the accident procedures.

4. To observe the physical features of the site.

5. To observe traffic operations.

Overview

The field review activity is an important step in analyzing safety problems at a site. Within this activity, preliminary review of the site is made and the physical environment and traffic operations are observed. From these observations, the list of possible accident causes as derived from the accident procedures can be revised. This list of possible accident causes will be used to determine further data needs to identify the safety deficiencies.

Prior to performing the field review, available site data (such as the accident summaries, notes made in previous reviews of the location, and condition diagrams) are reviewed. Information on accident patterns and their possible causes are used as guidelines in the field review.

The structured evaluation of the field conditions consists primarily of a checklist of questions (Figure 15) covering potential areas of deficiencies. These areas are divided into two categories: operational and physical. Items which are typically covered include (but may not be limited to):

- <u>OPERATIONAL</u>
  - Sight restrictions for drivers.
  - Driver response to signs, signals, or other traffic control devices.
  - Vehicle speeds.
  - Violation of parking or other traffic regulations.
  - Driver confusion.
  - Vehicle delay.
  - Traffic conflicts.
  - Pedestrian conflicts.
  - Traffic flow deficiencies.

- <u>PHYSICAL</u>
  - Sight obstruction.
  - Roadway geometrics (alignment).
  - Roadway characteristics (curve radii, street width, number of lanes).
  - Pedestrian crosswalks.
  - Traffic signs, signals, and other traffic control devices.
  - Parking conditions.
  - Speed limits.
  - Street lighting.
  - Pavement condition.

An alternate checklist is presented in the Institute of Traffic Engineer's <u>Manual of Traffic Engineering Studies</u> [9]. The manual includes a series of questions that should be considered during a field observation. This list is not as comprehensive as the previous list, but it does list many deficiencies which typically occur at a hazardous location.

The use of a trained traffic engineer or technician is recommended for the field review activity. This person should, as a minimum, be familiar with standard design practices [1,2], traffic control device manuals [3], roadway lighting manuals [4], and other standard traffic and transportation engineering references [5,6,7,8]. Where personnel are available, a team review is recommended.

FIELD OBSERVATION REPORT

LOCATION: ______________________________ CONTROL: __________

DATE: ______________________________ TIME: __________

OPERATIONAL CHECKLIST:	NO	YES
1. Do obstructions block the drivers view of opposing or conflicting vehicles?	____	____
2. Do drivers respond incorrectly to signals, signs or other traffic control devices?	____	____
3. Do drivers have trouble finding the correct path through the location?	____	____
4. Are vehicle speeds too high?	____	____
5. Are vehicle speeds too low?	____	____
6. Are there violations of parking or other traffic regulations?	____	____
7. Are drivers confused about routes, street names, or other guidance information?	____	____
8. Is vehicle delay causing a safety problem?	____	____
9. Are there traffic flow deficiencies or traffic conflict patterns associated with turning movements?	____	____
10. Is the volume of through traffic causing problems?	____	____
11. Is the volume of turning traffic causing problems?	____	____
12. Do pedestrian movements through the location cause conflicts?	____	____
13. Do bicyclist movements through the location cause conflicts?	____	____
14. Are there other traffic flow deficiencies or traffic conflict patterns?	____	____
15. Does the lack of or inadequate lighting cause safety problems?	____	____
16. Do the presence of existing driveways contribute to accidents or erratic movements?	____	____
17. Are pavement conditions causing drivers to react in an erratic fashion?	____	____
18. Do approach grades cause safety problems?	____	____

Figure 15. Checklist of field review questions.

PHYSICAL CHECKLIST:	NO	YES
1. Can sight obstructions be removed or decreased?	____	____
2. Are the street alignment or widths inadequate?	____	____
3. Are curb radii too small?	____	____
4. Should pedestrian crosswalks be relocated?	____	____
5. Repainted?	____	____
6. Are signs inadequate as to usefulness, message, size conformity and placement? (see MUTCD)	____	____
7. Are signals inadequate as to placement, conformity, number of signal heads, or timing? (see MUTCD)	____	____
8. Are pavement markings inadequate as to their clearness or location?	____	____
9. Is channelization (islands or paint markings) inadequate for reducing conflict areas?	____	____
10. Separating traffic flows?	____	____
11. Defining movements?	____	____
12. Does the legal parking layout affect sight distance?	____	____
13. Through or turning vehicle paths?	____	____
14. Traffic flow?	____	____
15. Do speed limits appear to be unsafe?	____	____
16. Is the number of lanes insufficient?	____	____
17. Is roadway lighting inadequate?	____	____
18. Are driveways inadequately designed?	____	____
19. Located?	____	____
20. Does the pavement condition (potholes, washboard, or slippery surface) contribute to accidents?	____	____
21. Are approach grades too steep?	____	____

COMMENTS:

Operational--"O" and item number
Physical--"P" and item number

____
____
____

Figure 15. Checklist of field review questions. (continued).

Findings

The typical output for this activity is an evaluation of the operational and physical elements of the hazardous location. Using the checklist of questions (as displayed in Figure 15), the direct output consists of "responses" ("YES", "NO", and comments) to the series of questions. These responses are then used to verify the findings obtained by the accident procedures and to identify further accident causes or potential safety hazards at the study location.

The accident procedure results were used to highlight specific operational and roadway characteristics for evaluation within this procedure. The accident summary results were used to develop a list of possible accident causes or safety deficiencies. From the findings produced by this activity, the list is made more specific; i.e., possible causes are applied to the particular location and deleted, adjusted, or added depending on the actual field findings. In addition, other safety deficiencies are noted.

The final list of possible causes developed by the accident and field review findings are further analyzed in the traffic, environment, and special study procedures identified in Activity 3.

Inputs and Outputs of Activity

- Inputs
  - Hazardous location.
  - Accident procedure findings.
  - Preliminary list of possible accident causes.
- Outputs
  - Review of physical characteristics of study location.
  - Review of operational characteristics of study location.
  - Film record of location (if photographic techniques are used.)
  - List of possible accident causes.

Procedure Description

In providing a structured review of the location, an organized procedure is developed to perform the field review activity. Procedure 6 - "Safety Performance Study" [10] has been devised to achieve this objective.

FIELD REVIEW PROCEDURE

PROCEDURE 6 Safety Performance Review

Purpose

A safety performance study is an organized program designed to provide systematic field observations and inspections of highway facilities and traffic. The study results are used to detect deficiencies in the operational or environmental conditions at a location. This study provides a review of a hazardous location or situation "in the field" and serves to verify or supplement the findings of the accident procedures.

Application

This procedure should be performed at all identified hazardous locations to supplement the accident procedures. It will assure that the summaries produced by these procedures are consistent with existing field conditions.

In this procedure, a review of the site conditions and the traffic operations is made. The review of field conditions (site survey), as the driver experiences it, involves physically driving through the location. It also involves the structured review of the location to identify hazards and problems. The findings obtained from the accident procedures will assist in performing this step.

- Performance Guidelines

It is more favorable to use two people (at least one experienced engineer, if available) to conduct the drive through. One person is used to observe and drive and the other person is used to observe and record. A tape recorder may be the easiest means of recording the general observations and comments obtained during this step. Completion of the data form shown in Figure 15 is necessary for specific observations, although it may be more convenient to complete the form at a later time, based on the taped information. During the site survey, it is also desirable to check the accuracy and completeness of any condition diagrams prepared or obtained for the study area.

When driving through the location, all approaches to the study area should be reviewed. This survey should be conducted to include sufficient distances in advance of the study area to observe the total area of influence.

For effective results, the study area should initially be driven at normal travel speeds to experience the location as motorists would. The follow-up trips should then be driven slowly to permit recording of the data and observation of the physical characteristics of the site. For these observations, the field review checklist should be utilized. It may also be advantageous for the observer to walk the study area to review the physical characteristics. At this time, it would also be extremely valuable to obtain a film record of the site for future reference purposes. A final task during the site survey would be to look for good locations from which to observe the traffic operations within the study area.

This portion of the study procedure can be performed under any traffic conditions, whereas the traffic operations review requires observation under specific traffic conditions. However, for certain situations such as assessing the effectiveness of reflectorized materials or highway lighting, review under nighttime conditions may be necessary. Although it is more efficient to perform the safety performance study during a single survey period, it may be necessary, particularly for high volume or high information load locations, to perform the site survey separate from the traffic operational review.

The review of traffic operations at the study location is typically performed following the site survey. A single observer is normally used. The observer should be experienced in safety and traffic operations. The use of an engineer is recommended. However, a highly trained technician may serve a similar purpose. Where the complexity of the situation warrants, a multi-disciplinary team may be used. The observer(s) should be stationed at selected vantage points within the study area to view the field operations. These vantage points should be situated such that the presence of an observer would not significantly influence the motorist behavior in the area.

Using the checklist of operational items, the observer should review the site. Particular attention should be given to operational characteristics noted as being "possible accident causes" based on the accident procedures. The checklist is completed and appropriate comments recorded.

The traffic operations review should normally be carried out during the most adverse operational conditions, or as defined from the accident summary by time of day procedure. For instance, in urban areas, traffic problems are typically acute during the morning or evening peak periods.

The length of the review periods are based upon the amount of data necessary to adequately identify the deficiency. Table 7 displays recommended minimum survey periods for a location as a function of highway type and the element(s) to be specifically observed. Where several elements are to be observed at one time, the study period should, at a minimum, correspond to the longest specified period for an individual element. Dependent upon the information load and the location's characteristics, a longer overall study period may be needed to permit observation of all pertinent factors at the location.

Alternate Techniques

Several techniques are available for performing a safety performance study. They include:

1. Manual (field) method.

Table 7. Recommended field review survey periods.

	Highway Type				Time and Condition					Time Min/Mile		
	Freeway	Multilane Divided	Multilane Undivided	Two Lane	Any	Rain	Night	Any Peak	Night-Rain	20 or Less	25-55	60 or More
A. ROADWAY ELEMENTS												
ELEMENT 1-PAVEMENT SURFACE												
A-RIDING QUALITIES	x	x	x	x	x					x		
B-SURFACE DRAINAGE	x	x	x	x		x				x		
C-FRICTION QUALITY	x	x	x	x	x					x		
D-SHOULDERS	x	x	x	x	x					x		
E-ROADSIDE INTERFERENCE		x	x	x								x
ELEMENT 2-MEDIANS												
A-BARRIERS	x	x			x						x	
B-GLARE SCREEN	x	x					x				x	
C-CONDITION OF A&B	x	x			x						x	
D-STRIPED MEDIAN			x						x		x	
E-CROSSOVERS		x					x				x	
ELEMENT 3-INTERCHANGES												
A-SPEED CHANGE LANES	x	x			x							x
B-ADEQUACY OF RAMPS	x	x						x				x
ELEMENT 4-INTERSECTIONS												
A-CHANNELIZATION		x	x	x						x		
B-TURNING LANES		x	x	x				x				x
C-SIGNT DISTANCE		x	x	x	x						x	
D-TURNING RADII		x	x	x	x						x	
B. TRAFFIC CONTROL DEVICES												
ELEMENT 1-SIGNALIZATION		x	x	x				x				x
ELEMENT 2-SIGNING												
A-SUFFICIENT SIGNS	x	x	x	x	x							x
B-TOO MANY SIGNS	x	x	x	x	x							x
C-LOCATION OF SIGNS	x	x	x	x	x							x
D-CONDITION OF SIGNS	x	x	x	x	x							x
E-ILLUMINATED SIGNS	x	x	x	x					x			x
F-LEGEND	x	x	x	x					x			x
G-ADVANCED GUIDE SIGNS	x	x			x							x
H-LANE ASSIGNMENTS	x	x			x							x
I-GORE SIGNING	x				x							x
J-EXIT NUMBERS	x				x							x
K-LANE DROPS	x	x	x		x							x
L-EXIT SPEEDS	x				x							x
M-REGULATORY SIGNS	x	x	x	x	x							x
N-STREET NAME SIGNS			x	x			x			x		
ELEMENT 3-STRIPING AND MARKING												
A-CENTER AND EDGE STRIPE	x	x	x	x					x			x
B-GORE AREAS	x								x			x
C-RAISED PAVEMENT MARKER	x	x	x	x					x			x
ELEMENT 4-DELINEATORS	x	x							x			x
ELEMENT 5-MILEPOST MARKERS	x	x	x	x	x							x
ELEMENT 6-LIGHTING	x	x	x									x
A-ADDITIONAL LIGHTING	x	x	x									x
C-TRAFFIC REGULATIONS ELEMENT	x	x	x	x	x							

2. Photographic techniques.
   - Ground method.
   - Aerial surveillance.

Primary considerations for these techniques are defined in Table 8.

● Manual (Field) Method

This method is the most widely used technique. Although most States use this study procedure on a demand or spot review basis, several States use the field method to provide continuous monitoring of a location or situation. This method consists of the on-site visual observation or inspection of the traffic operations and roadway facilities by trained personnel. These conditions are observed and, if possible, the cause of any unusual or erratic behavior is determined. In addition, any unique features at the location are noted. If possible, discussions with people living or working near the location (to obtain input from daily users) are initiated. After these steps have been completed, the observations based on the checklist of field-related questions are recorded and comments provided where necessary. This list of observations is further used to identify and verify possible accident causes.

Advantages:

1. Permits the review of the total scope of the study location.
2. Permits the close-up review of certain physical deficiencies.
3. Requires minimal equipment needs.

Disadvantages:

1. No permanent photographic record of the field conditions.
2. Study results may contain human biases.

This method is favored in most safety review situations due to the flexibility in observing the study location from all approaches, thereby permitting a review of a greater number of situations. However, as the location becomes more complex (higher volumes, greater number of movement types and conflicts), the advantages of this method lessen considerably as the reviewer has too much data to "interpret" or review. For high volume and complex situations, use of extra personnel or the use of the photographic techniques may be more appropriate.

● Photographic Methods

These methods have also been used in safety performance studies. Photographic methods provide a permanent record of the site conditions. Two typical filming methods are available - the ground method and aerial surveillance. Both approaches have the capacity of using either a time-lapse or a continuous-filming process.

The ground level method allows observation of the highway facilities and traffic operations using camera equipment situated near the study

Table 8. Primary considerations for Safety Performance Study techniques.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Field Method	. Observe highway facilities and traffic flow in the field environment	. Pencils . Data forms	. Traffic engineer or highly trained technician to observe location	. Observation time (as provided in Table 7)	. None	. Identified hazardous location . Accident studies . Past field reports . Past records of location . Citizen input	. Observation or inspection of all operational and physical site data	. Identification of possible operational and physical (environment) site deficiencies
2. Photographic Technique - Ground Method	. Observe highway facilities and traffic operations under field conditions in an office environment	. Camera equipment . Film screen . Data forms	. Camera technician to set up and remove camera(s) . Technician to spot check camera (for longer observation periods) . Traffic engineer or highly trained technicians to observe location	. Camera set up and removal time ranges from 1-3 hours per camera dependent on travel time involved . Observation time (see Table 7)	. Camera equipment $500-$2,000	. Identified hazardous location . Accident studies . Past field reports . Past records of location . Citizen input	. Observation from film or operational and physical site data item (excludes those physical items outside adequate camera range) . Other traffic data (gap, volume, etc.)	. Identification of possible operational and some physical (environment) site deficiencies
- Aerial Surveillance	. Observe highway facilities and traffic flow under field operations in an office environment	. Airplane or helicopter availability . Camera equipment . Pencils . Data forms . Film screen	. Pilot . Camera technician to set up and check camera . Traffic engineer or highly trained technician to review film data (operations)	. Air time . Observation time as provided in Table 7	. Subcontract filming rates $150 per site	. Identified hazardous location . Accident studies . Past field reports . Past records of location . Citizen input	. Identification of operational and physical (environment) site data	. Identification of possible operational and physical (environment) site deficiencies

area. The equipment is typically situated at a height greater than 10 feet to permit the coverage of a wide area. It also reduces the chance of vandalism of the equipment. To permit the review of the field conditions from a number of approaches, the use of additional cameras may be necessary. Typically, however, a single camera is used. For link or corridor analysis, a series of cameras located at key locations within the study area will be required.

Prior to setup of the camera, the study area is driven from different approaches to view the roadway environment as the driver sees it and to review the physical roadway environs using the checklist of questions. In addition, any unique features of the location are noted. If possible, discussions with people living or working near the location are made. This will help to familiarize the observer with the characteristics of the location.

In setting up the camera, a vantage point is selected to obtain a wide area of coverage. This area of coverage should include the expected area of traffic activity at the location. For intersections, it should include, at a minimum, a view of all approaches to the intersection. If possible, it should encompass a distance of approximately 200 feet along each approach leg. Along links, a view of the entire study link should be made. This may require several cameras. These areas are illustrated in Figure 16.

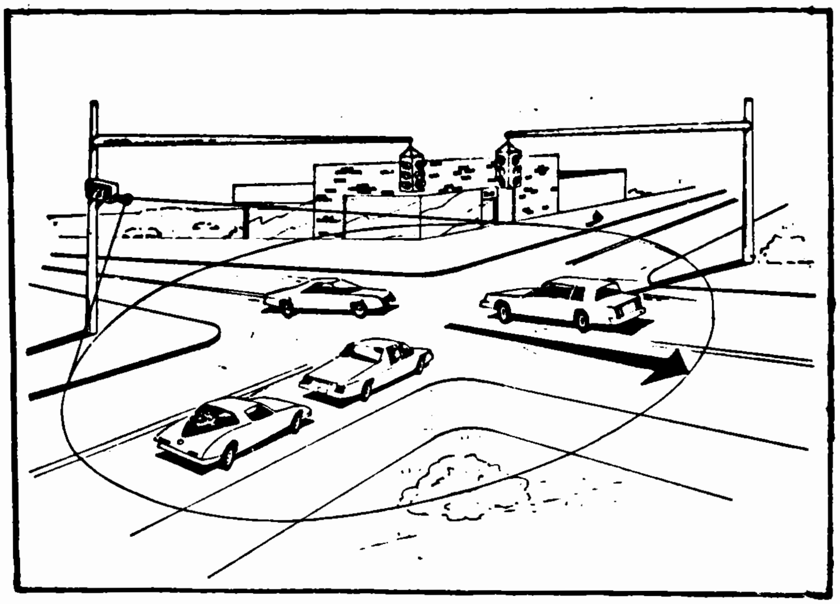
Filming of the location is performed using either time-lapse or continuous-film (videolog) photography. With time-lapse equipment, photographs are shot at specific time intervals (e.g., every 0.5 sec.) while continous photography permits continous filming of the location. Both methods produce favorable outputs. However, the time-lapse equipment allows a greater filming period per film roll. Detailed descriptions of the time-lapse and continous film methods are provided in Appendix D.

The film is reviewed in a manner similar to the field method. The checklists of questions are used to evaluate the field operations and conditions while the film is shown on the screen. The review process requires a trained engineer familiar not only with traffic engineering and safety principles but also with photography principles such as distortion, camera angle of view, etc. Where more than a single camera is used at one site, conditions are evaluated with the simultaneous viewing of both film records. From the information obtained from the field survey and film record, the further identification and verification of possible accident causes (as determined in Activity 1) can be made.

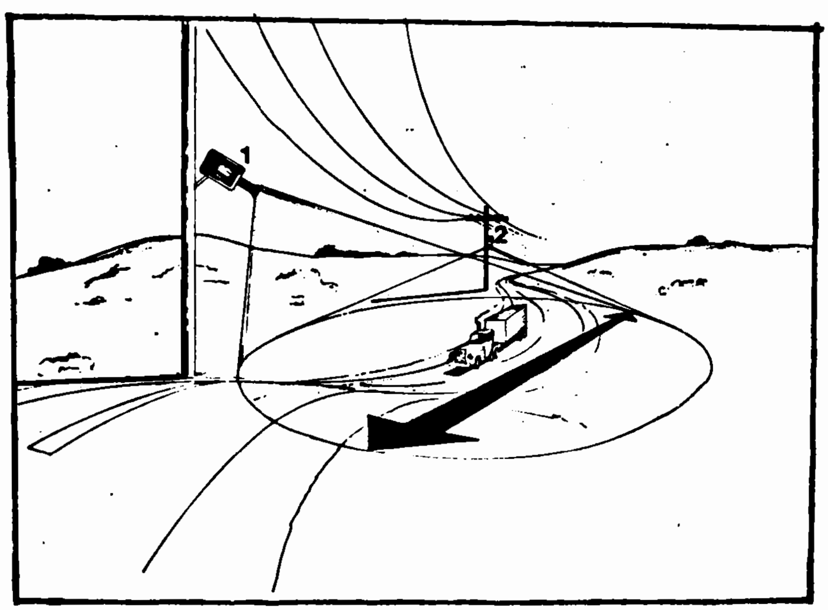
Advantages:

1. Provides a pictorial record of the location under operating conditions.

2. Permits the review of the film by a team of engineers, when necessary, without site visits.



A. Intersection



B. Link

Figure 16. Filming method.

3. Allows data to be obtained for other traffic variables such as volume, gap, and speed data.

4. Allows field information to be obtained over an extended period of time.

Disadvantages:

1. Equipment costs are considerable.

2. Physical characteristics may not be shown clearly due to distortions, lack of lighting, poor weather conditions, etc.

3. Requires additional lighting to perform nighttime studies.

4. Camera field of view may tend to distort traffic activities.

Aerial surveillance is an alternate photographic technique which requires filming the study area from an overhead location using an airplane or helicopter. The study area is filmed during the entire study period to obtain the traffic operations review of the location. In conjunction with the filming activities (but not necessarily the same day), a field review of the roadway environment is made. For both portions of the study, the checklist of questions should be used. In the field portion of this technique, review of traffic operations can also be performed as a check of the aerial data.

In viewing the film record, overhead filming will typically allow for a greater perspective and coverage of the study area than by the ground level method. The review, however, will require that the observer be familiar with the use and analysis of film records. The information obtained by aerial photography may provide a more accurate review of traffic movement at the location than ground methods, since the total study area can be more easily reviewed. However, relating traffic movement to a specific physical characteristic from overhead (signing, signal phase operation) is difficult.

Advantages:

1. Provides a pictorial record of the location.

2. Provides a wide area of coverage and perspective of the location.

3. Can provide a continuous review along a segment or corridor.

4. Can obtain data on other traffic variables.

5. Permits the review of the film by a team of engineers, when necessary.

Disadvantages:

1. Equipment needs and costs are high.

2. Requires additional field review to obtain evaluation of physical elements.

3. Difficult to use for nighttime studies.

4. Can be difficult to interpret causes of operational deficiencies.

5. Effectiveness and clarity of film is highly dependent on weather and light conditions.

This technique is advantageous for long segment lengths or corridor analysis. Filming of the location is costly and a field review for evaluation of the physical elements is still required. For field situations in which additional traffic stream data (e.g., volume, speed, gap, etc.) can be obtained in conjunction with the operational review, this technique could be advantageous.

Selection Of Technique

In selecting the appropriate technique for performing safety performance studies, the primary management concerns are the time, manpower, and equipment resources required for each technique and the comprehensiveness of the review phase of each information type; i.e., physical and operational items. Table 9 displays the utility of each technique as they relate to the specific management concern.

In selecting an appropriate technique, Table 10 is used to suggest a preferred technique for a given situation. Where more than one technique is feasible, the information in Table 9 would be used to select the best technique. To assist in the selection process, several guidelines are provided. They are:

1. The manual method should be used in safety performance studies at spot locations or short segment lengths. This is primarily due to the technique's low personnel and equipment needs.

2. Where situations are complex (with a greater number of conflicting movements) and a team review of the field situation is used, the ground level photographic technique may be favored.

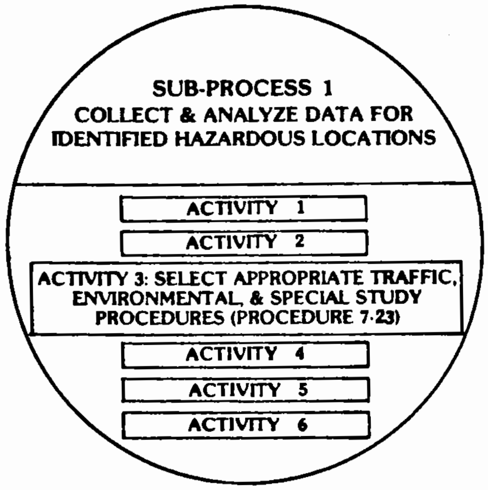
3. Aerial surveillance is favored for corridor-type analysis. Due to the length of the study area for this type of analysis, review by other means is difficult. The aerial method allows one to film a greater perspective of the field area. For this reason, this technique is also favored at complex freeway interchanges.

Table 9. Technique utility of Safety Performance Study.

Technique / Management Concern	Field Method	Photographic Technique: Ground Level Method	Photographic Technique: Aerial Surveillance
Manpower requirements	• Traffic engineer or trained technician for field review	• Traffic engineer to view film and field review physical characteristics • Trained technician for camera set-up	• Traffic engineer to view film • Trained technician or traffic engineer for field review of physical characteristics
Equipment requirements	• Minimal	• Camera equipment	• Airplane or helicopter availability • Camera equipment
Time requirements	• Usually limited to two hours or less (due to human limitations)	• Able to use over extended period of time	• Limited by flying time of airplane or helicopter
Comprehensiveness of information - OPERATION-RELATED	• Provides detailed review	• Provides detailed review (limited by camera perspective)	• Provides general review
- PHYSICAL ROADWAY ELEMENTS	• Provides detailed review	• Requires separate field review	• Requires separate field review

Table 10. Favorable Safety Performance Study techniques.

Technique / Situation	Field Method	Photographic Technique: Ground Method	Photographic Technique: Aerial Surveillance
Intersection or spot location	X	X	
Roadway segment or link	X	X	
Corridor			X
Interchange	X	X	X



ACTIVITY 3 Select Appropriate Traffic, Environmental, And Special Study Procedures

Purpose

The purpose of this activity is to select the traffic, environmental, and special study procedures needed to verify and define the safety deficiencies at a hazardous location.

Overview

To properly select appropriate safety improvements for a location, an accurate definition of the safety deficiencies is necessary. In this way, unsatisfactory conditions can be described and appropriate countermeasures developed to resolve or alleviate the safety problems.

To accurately define the safety deficiencies at a site so that appropriate safety improvements can be developed, the following considerations should be included:

- Probable accident cause.
- Field conditions relating the probable cause.
- A measure (extent) of the problems where feasible.

These considerations can be defined using the procedures described within this Guide. For example, information on the probable cause of accidents is obtained primarily from the accident-based procedures (Procedures 1-5) and verified by field review (Procedure 6), traffic-based

(Procedure 7-14), environmental-based, (Procedure 15-19), and special study procedures (Procedure 20-23). The field conditions which identify the probable accident cause and the measure of the safety problem are provided by the traffic, environmental, and special study procedures.

To appropriately define these considerations, it is necessary that the proper information be obtained to describe them. This requires that procedures be selected which will result in the collection of the necessary data and production of the desired findings. These procedures include:

- <u>Traffic-Based Procedures</u>

  - Procedure 7 - Volume Study
  - Procedure 8 - Spot Speed Study
  - Procedure 9 - Travel Time and Delay Study
  - Procedure 10 - Roadway and Intersection Capacity Study
  - Procedure 11 - Traffic Conflict Study
  - Procedure 12 - Gap Study
  - Procedure 13 - Traffic Lane Occupancy Study
  - Procedure 14 - Queue Length Study

- <u>Environment-Based Procedures</u>

  - Procedure 15 - Roadway Inventory Study
  - Procedure 16 - Sight Distance Study
  - Procedure 17 - Skid Resistance Study
  - Procedure 18 - Highway Lighting Study
  - Procedure 19 - Weather-Related Study

- <u>Special Study Procedures</u>

  - Procedure 20 - School Crossing Study
  - Procedure 21 - Railroad Crossing Study
  - Procedure 22 - Traffic Control Device Study
  - Procedure 23 - Bicycle or Pedestrian Study

Before selecting the appropriate procedures, additional data needed to define the safety deficiencies must be identified. Based on the observed accident patterns and possible causes, the data needs can be identified by Table 11. This table displays the relationship between accident pattern, possible accident causes, data needs, and study procedures. Following the sequence of the table, the accident pattern and possible cause information are used to identify the data needs.

Once all data needs are defined, a search of available records or files is made to collect currently available data. This information may be used as representative of the site conditions and, thus, eliminate further need for collecting this particular data through an independent

Table 11. Determination of selected procedures.

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Left-turn head-on collisions	Large volume of left-turns	Volume data Vehicle conflicts Roadway inventory Signal timing and phasing Travel time and delay data	Volume Study Traffic Conflict Study Roadway Inventory Study Capacity Study Travel Time and Delay Study
	Restricted sight distance	Roadway inventory Sight distance characteristics Speed characteristics	Roadway Inventory Study Sight Distance Study Spot Speed Study
	Too short amber phase	Speed characteristics Volume data Roadway inventory Signal timing and phasing	Spot Speed Study Volume Study Roadway Inventory Study Capacity Study
	Absence of special left-turning phase	Volume data Roadway inventory Signal timing and phasing Delay data	Volume Study Roadway Inventory Study Capacity Study Travel Time and Delay Study
	Excessive speed on approaches	Speed characteristics	Spot Speed Study
Rear-end collisions at unsignalized intersections	Drivers not aware of intersection	Roadway inventory Sight distance characteristics Speed characteristics	Roadway Inventory Study Sight Distance Study Spot Speed Study
	Slippery surface	Pavement skid resistance characteristics Conflicts resulting from slippery surface	Skid Resistance Study Weather-Related Study Traffic Conflict Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Rear-end collisions at unsignalized intersections	Large number of turning vehicles	Volume data Roadway inventory Conflict data	Volume Study Roadway Inventory Study Traffic Conflict Study
	Inadequate roadway lighting	Roadway inventory Volume data Data on existing lighting	Roadway Inventory Study Volume Study Highway Lighting Study
	Excessive speed on approaches	Speed characteristics	Spot Speed Study
	Lack of adequate gaps	Roadway inventory Volume data Gap data	Roadway Inventory Study Volume Study Gap Study
	Crossing pedestrians	Pedestrian volumes Pedestrian/vehicle conflicts Signal inventory	Volume Study Pedestrian Study Roadway Inventory Study
Rear-end collisions at signalized intersections	Slippery surface	Pavement skid resistance characteristics Conflicts resulting from slippery surface	Skid Resistance Study Weather-Related Study Traffic Conflict Study
	Large number of turning vehicles	Volume data Roadway inventory Conflict data Travel time and delay data	Volume Study Roadway Inventory Study Traffic Conflict Study Delay Study
	Poor visibility of signals	Roadway inventory Signal review Traffic conflicts	Roadway Inventory Study Traffic Control Device Study Traffic Conflict Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Rear-end collisions at signalized intersections	Inadequate signal timing	Roadway inventory Signal timing plans Volume data Travel time and delay data	Roadway Inventory Study Intersection Capacity Study Travel Time and Delay Study
	Unwarranted signal	Roadway inventory Volume data	Roadway Inventory Study Volume Study
	Inadequate roadway lighting	Roadway inventory Volume data Data on existing lighting	Roadway Inventory Study Volume Study Highway Lighting Study
	Excessive speed on approaches	Speed characteristics	Spot Speed Study
	Crossing pedestrians	Pedestrian volumes Pedestrian/vehicle conflicts Signal inventory	Volume Study Pedestrian Study Roadway Inventory Study
Right-angle collisions at signalized intersections	Restricted sight distance	Roadway inventory Sight distance characteristics Travel speed information	Roadway Inventory Study Sight Distance Study Spot Speed Study
	Excessive speed on approaches	Speed characteristics	Spot Speed Study
	Poor visibility of signals	Roadway inventory Signal review Traffic conflicts	Roadway Inventory Study Traffic Control Device Study Traffic Conflict Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Right-angle collisions at signalized intersections	Inadequate signal timing	Roadway inventory Signal timing plans Volume data Delay data	Roadway Inventory Study Volume Study Intersection Capacity Study Travel Time and Delay Study
	Inadequate roadway lighting	Roadway inventory Volume data Data on existing lighting	Highway Lighting Study Roadway Inventory Study Volume Study
	Intersection advance warning signs	Roadway inventory Speed characteristics Traffic conflicts	Roadway Inventory Study Spot Speed Study Traffic Conflict Study
	Large total intersection volume	Volume data Roadway inventory	Volume Study Intersection Capacity Study
Right-angle collisions at unsignalized intersections	Restricted sight distance	Roadway inventory Sight distance characteristics Speed characteristics	Roadway Inventory Study Sight Distance Study Spot Speed Study
	Large total intersection volume	Volume data Roadway inventory Delay data	Volume Study Intersection Capacity Study Traffic Control Device Study Travel Time and Delay Study
	Excessive speed on approaches	Speed characteristics	Spot Speed Study
	Inadequate roadway lighting	Roadway inventory Volume data Data on existing lighting	Roadway Inventory Study Volume Study Highway Lighting Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Right-angle collisions at unsignalized intersections	Intersection advance warning signs	Roadway inventory Speed characteristics Traffic conflicts	Roadway Inventory Study Spot Speed Study Traffic Conflict Study
	Inadequate traffic control devices	Roadway inventory Volume data Traffic control device adherence	Roadway Inventory Study Volume Study Traffic Control Device Study
Pedestrian-vehicle collisions	Restricted sight distance	Roadway inventory Speed characteristics Sight distance characteristics	Roadway Inventory Study Spot Speed Study Sight Distance Study
	Inadequate protection for pedestrians	Pedestrian volumes Safe crossing gaps Roadway inventory Speed characteristics	Volume Study Gap Study School Crossing Study Roadway Inventory Study Spot Speed Study
	School crossing area	Pedestrian volumes Safe crossing gaps Roadway inventory Speed characteristics	Volume Study Gap Study School Crossing Study Roadway Inventory Study Spot Speed Study
	Inadequate signals	Pedestrian volumes Pedestrian/vehicle conflicts Roadway inventory	Volume Study Pedestrian Study Roadway Inventory Study
	Inadequate signal phasing	Pedestrian volumes Vehicle volumes Roadway inventory Pedestrian/vehicle conflicts	Volume Study Roadway Inventory Study Pedestrian Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Pedestrian-vehicle collisions	Driver had inadequate warning of frequent mid-block crossings	Pedestrian/vehicle conflict Speed characteristics Pedestrian volumes Roadway inventory	Pedestrian Study Spot Speed Study Volume Study Roadway Inventory Study
	Inadequate pavement markings	Roadway inventory Traffic conflicts	Roadway Inventory Study Traffic Control Device Study Traffic Conflict Study
	Inadequate gaps at unsignalized intersections	Roadway inventory Volume data Gap data Speed characteristics Pedestrian/vehicle conflicts	Roadway Inventory Study Volume Study Gap Study Spot Speed Study Pedestrian Study
	Inadequate roadway lighting	Roadway inventory Volume data Data on existing lighting	Roadway Inventory Study Volume Study Highway Lighting Study
	Excessive vehicle speed	Speed characteristics	Spot Speed Study
Run-off-road collisions	Slippery pavement	Skid resistance characteristics Conflicts resulting from slippery surface	Skid Resistance Study Weather-Related Study Traffic Conflict Study
	Roadway design inadequate for traffic conditions	Roadway inventory Speed characteristics Sight distance characteristics	Roadway Inventory Study Spot Speed Study Sight Distance Study
	Poor delineation	Roadway inventory Erratic maneuvers	Roadway Inventory Study Traffic Conflict Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Run-off-road collisions	Inadequate roadway lighting	Roadway inventory Volume data Data on existing lighting	Roadway Inventory Study Volume Study Highway Lighting Study
	Inadequate shoulder	Roadway inventory Erratic maneuvers	Roadway Inventory Study Traffic Conflict Study
	Improper channelization	Roadway inventory Erratic maneuvers	Roadway Inventory Study Traffic Conflict Study
	Inadequate pavement maintenance	Pavement roughness characteristics	Roadway Serviceability Study
	Poor visibility	Fog data	Weather-Related Study
	Excessive speed along roadway	Speed characteristics	Spot Speed Study
Fixed-object collisions	Obstructions in or too close to roadway	Roadway inventory Erratic maneuvers	Roadway Inventory Study
	Inadequate roadway lighting	Roadway inventory Volume data Data on existing lighting	Roadway Inventory Study Volume Study Highway Lighting Study
	Inadequate pavement marking	Roadway inventory Erratic maneuvers	Roadway Inventory Study Traffic Control Device Study Traffic Conflict Study
	Inadequate signs, delineators and guardrails	Roadway inventory Erratic maneuvers	Roadway Inventory Study Traffic Conflict Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Fixed-object collisions	Inadequate roadway design	Roadway inventory Speed characteristics Sight distance characteristics	Roadway Inventory Study Spot Speed Study Sight Distance Study
	Slippery surface	Skid resistance characteristics Conflicts resulting from slippery surface	Skid Resistance Study Weather-Related Study Traffic Conflict Study
	Excessive vehicle speed	Speed characteristics	Spot Speed Study
Collisions with parked or parking vehicles	Improper pavement marking	Roadway inventory	Roadway Inventory Study Traffic Control Device Study
	Improper parking clearance at driveways	Roadway inventory	Roadway Inventory Study
	Angle parking	Roadway inventory Traffic conflicts	Roadway Inventory Study Traffic Conflict Study
	Excessive vehicle speed	Speed characteristics	Spot Speed Study
	Illegal parking	Roadway inventory	Roadway Inventory Study
	Improper parking	Roadway inventory	Roadway Inventory Study
	Large parking turnover	Roadway inventory Traffic conflicts	Roadway Inventory Study Traffic Conflict Study
Sideswipe or head-on collisions	Inadequate roadway design	Roadway inventory Speed characteristics Sight distance characteristics	Roadway Inventory Study Spot Speed Study Sight Distance Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Sideswipe or head-on collisions	Improper road maintenance	Pavement roughness characteristics	Roadway Serviceability Study
	Inadequate shoulders	Roadway inventory Traffic conflicts	Roadway Inventory Study Traffic Conflict Study
	Excessive vehicle speed	Speed characteristics	Spot Speed Study
	Inadequate pavement marking	Roadway inventory Traffic conflicts	Roadway Inventory Study Traffic Conflict Study Traffic Control Device Study
	Inadequate channelization	Roadway inventory Traffic conflicts	Roadway Inventory Study Traffic Conflict Study
	Inadequate signing	Roadway inventory Traffic conflicts	Roadway Inventory Study Traffic Conflict Study
Driveway-related collisions	Left-turning vehicles	Volume data Traffic conflicts Roadway inventory	Volume Study Traffic Conflict Study Roadway Inventory Study
	Improperly located driveway	Roadway inventory Volume data Traffic conflicts	Roadway Inventory Study Volume Study Traffic Conflict Study
	Right-turning vehicles	Volume data Roadway inventory Traffic conflicts	Volume Study Roadway Inventory Study Traffic Conflict Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Driveway-related collisions	Large volume of through traffic	Volume data Speed data Gap data Travel time and delay data Roadway inventory	Volume study Spot Speed Study Gap Study Travel Time and Delay Study Roadway Inventory Study
	Restricted sight distance	Roadway inventory Speed characteristics Sight distance characteristics	Roadway Inventory Study Spot Speed Study Sight Distance Study
	Inadequate roadway lighting	Roadway inventory Volume data Data on existing lighting	Roadway Inventory Study Volume Study Highway Lighting Study
	Excessive speeds on approaches	Speed characteristics	Spot Speed Study
Train-vehicle accidents	Restricted sight distance	Roadway inventory Speed characteristics Sight distance characteristics Railroad data	Roadway Inventory Study Weather-Related Study Highway Lighting Study
	Poor visibility	Roadway inventory Fog data Lighting data	Roadway Inventory Study Weather-Related Study Highway Lighting Study
	Excessive speeds on approaches	Speed characteristics	Spot Speed Study
	Improper traffic signal pre-emption timing	Roadway inventory	Roadway Inventory Study Volume Study Railroad Crossing Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Train-vehicle accidents	Inadequate pavement markings	Roadway inventory	Roadway Inventory Study Railroad Crossing Study Traffic Control Device Study
	Slippery surface	Skid resistance characteristics Conflicts related to slippery surface	Skid Resistance Study Weather-Related Study
	Improper pre-emption timing of RR signals or gates	Speed data Sight distance characteristics Roadway inventory Railroad data	Spot Speed Study Sight Distance Study Roadway Inventory Study Railroad Crossing Study
	Rough crossing surface	Roadway inventory Traffic conflicts	Roadway Inventory Study Traffic Conflict Study
	Sharp crossing angle	Roadway inventory Speed data Sight distance characteristics Railroad data	Roadway Inventory Study Spot Speed Study Sight Distance Study Railroad Crossing Study
Wet pavement accidents	Slippery pavement	Skid resistance characteristics Conflicts resulting from slipprey surface	Skid Resistance Study Weather-Related Study
	Inadequate drainage; Inadequate pavement markings	Field review notes Roadway inventory data Traffic conflict data	Safety Performance Study Roadway Inventory Study Traffic Conflict Study

Table 11. Determination of selected procedures (Continued).

Accident Pattern	Possible Causes	Data Needs	Procedures to be Performed
Night accidents	Poor visibility or lighting	Roadway inventory Volume data Data on existing lighting Traffic conflicts	Roadway Inventory Study Volume Study Highway Lighting Study Traffic Conflict Study
	Poor sign quality; Inadequate channelization or delineation	Field review notes Roadway inventory data Traffic conflict data	Safety Performance Study Roadway Inventory Study Traffic Conflict Study

study. Care should be taken that this data be representative of current conditions. The use of inappropriate data can result in an improper definition of a safety problem.

To assist in assuring the accuracy of the data, the following guidelines can be used.

1. Where recent physical or operational changes in the study area have been made of a type that might have an impact in the traffic characteristics under review, data taken prior and during implementation of these changes should not be used.

2. Data obtained prior to the accident review periods should not be used.

Once the data has been determined to be representative of current conditions, it should be checked against the list of required data needs identified from Table 11. This step will avoid duplication of effort in obtaining the data needs through an independent study.

When the finalized list of data needs has been determined, the procedures to obtain the data can be selected. Table 11 is again used to assist in the selection process. It lists the traffic-based, environment-based, and special study procedures for the collection of specific data needs. This table, however, should not be deemed conclusive. Field situations may result in some changes in the list of procedures. However,the table does provide useful guidelines.

A search of the table for the respective situation at a site will reveal the procedures available to obtain the required data. For example, where volume data are required, the use of volume study procedures will be designated. Another example would be where information on the average queue length at a signalized intersection for waiting left-turn vehicles is desired. In this case, the queue length study procedure should be performed. Appendix C displays the list of procedures and the various data which can be obtained from them.

It should be noted that within a procedure, a significant amount of data from other procedures are used. For example, in performing the sight distance procedure, spot speed information typically obtained from a spot speed study procedure is used. Also, information from the roadway inventory study procedure may be used.

Findings

Based on the input of the previous activities, further data needs and the selection of the traffic, environmental and special study procedures will be made. These procedures will identify the necessary data and be used to define the safety deficiencies at a site. With this data, the selection of appropriate safety improvements can be accomplished.

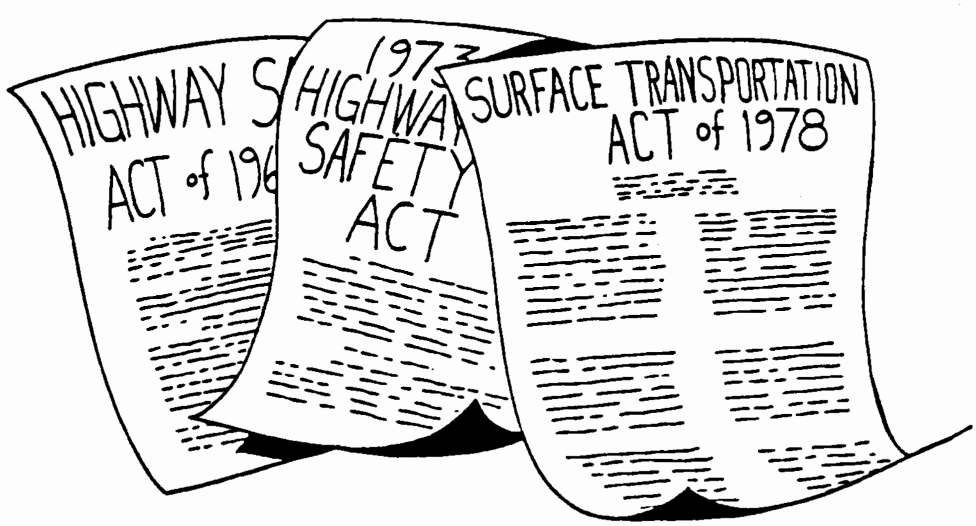
Inputs and Outputs of Activity

- Inputs
  - Identified accident patterns and possible causes.
  - Available traffic and roadway data.

- Outputs
  - List of data needs to define safety deficiencies.
  - Recommended procedures to obtain data.

Description of Procedures

As an output of this activity, recommendations on traffic-based, environment-based, and special study procedures to assist in selecting safety-related countermeasures are provided. In the following sections of this guide, the detailed descriptions of these procedures are provided.



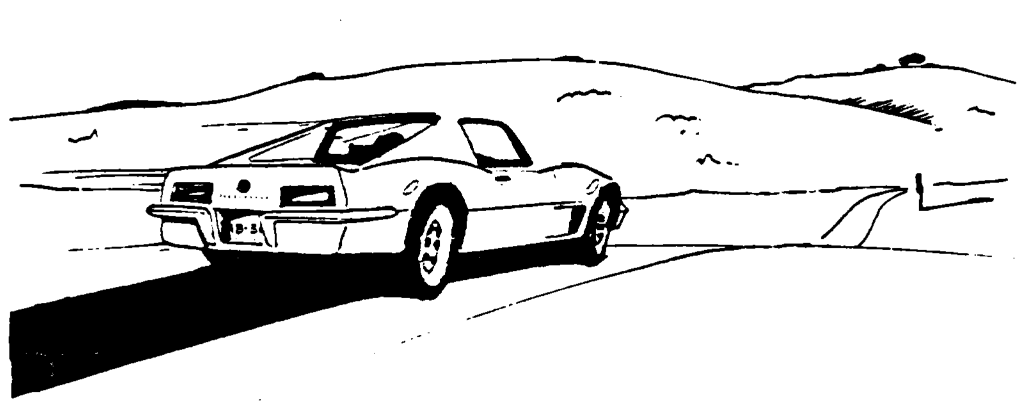
TRAFFIC-BASED PROCEDURES

Traffic-based procedures entail the study of the traffic characteristics of a facility. This includes such basic traffic data as speed and volume, and the more operational-related data, such as occupancy and capacity characteristics. Not all traffic-based procedures are included in a study of a hazardous site or condition. They are performed based on the possible accident causes obtained from the accident and field review procedures. The findings from the traffic-based studies identify and quantify the traffic characteristics of the study area. By identifying these characteristics, a more specific definition of the safety deficiency can be determined and hence greater reliability in the selection of safety-related countermeasures may be obtained.

Since clearly defined relationships between many traffic characteristics and safety do not exist, the results of these procedures are used in conjunction with the accident findings to provide a more accurate identification of the safety deficiencies. The findings are also used in the economic analysis of countermeasures to assist in developing the specific benefits or disbenefits of each countermeasure. In addition, the findings may be used in the Evaluation Component of the Highway Safety Improvement Program (HSIP) as a measure of the "before" characteristics for an implemented countermeasure.

Within Activity 3, the following procedures are described:

- Procedure 7 - Volume Study.
- Procedure 8 - Spot Speed Study.
- Procedure 9 - Travel Time and Delay Study.
- Procedure 10 - Roadway and Intersection Capacity Study.
- Procedure 11 - Traffic Conflict Study.
- Procedure 12 - Gap Study.
- Procedure 13 - Traffic Lane Occupancy Study.
- Procedure 14 - Queue Length Study.



PROCEDURE 7 Volume Study

Purpose

Traffic volume studies are conducted to determine the number and movement of vehicles and/or pedestrians within, through, or at selected points in an area. The resultant traffic volumes are used to identify an exposure factor for estimating accident rates.

Application

Within highway safety applications, various forms of volume information are used as input in highway safety studies. These forms consist of the following information types. By time period:

Annual total traffic volumes relate the estimated or actual volume at the location for a full (365-day) year. This information is used for:

- Computing accident rates on an annual basis.
- Measuring and establishing trends in traffic volume.
- Relating annual travel in vehicle miles as economic justification for countermeasures (economic analyses) or as comparison data for evaluating "measures of effectiveness" (project evaluation).

AADT (average annual daily traffic) or ADT (average daily traffic) represents a daily or 24-hour traffic volume at a location. Specifically it is used in:

- Measuring the present traffic demand for service.
- Evaluating traffic variables in other procedures.
- Relating daily travel in vehicle miles as economic justification for countermeasures (economic analyses) or as comparison data for evaluating "measures of effectiveness" (project evaluation).

Hourly volumes represent volumes during a specific 1-hour time period. They are used to:

- Review time-specific data required in other traffic-based procedures; such as, delay and travel-time studies, traffic conflict studies, gap studies, etc.

Peak hour volumes represent hourly traffic volumes during the highest, or peak, travel periods at a location. This data can be used for:

- Determining safety-related deficiencies in highway capacity (highway capacity analysis).

- Reviewing time-specific data required in other traffic-based procedures used to select countermeasures.

- Planning and designing safety improvements; such as, geometric changes, traffic operation and regulatory programs, and enforcement measures.

Short-term volumes are obtained for intervals of less than 1 hr. The short-term count data (1-,5-,6-,10-min., etc. intervals) are typically used for:

- Estimating volumes for longer time periods.

- Analyzing maximum rates of flow and variations within peak hours for use in other traffic-based procedures.

- Determining traffic characteristics by peak hour volumes.

By location, volume count information is normally obtained at an intersection or at a midblock location.

Intersectional volume counts determine: (1) total traffic entering the intersection from all legs, (2) total traffic executing each of the possible turning movements, (3) total traffic by time periods, and (4) classification of vehicles by type. This information is used for:

- Analyzing accident data (to help establish remedial measures).

- Evaluating traffic variables related to intersection operation such as delay data, capacity information, etc.

- Designing intersection improvements.

- Justification of intersection improvements.

Midblock volume counts are used to determine: (1) total traffic from each direction, (2) total traffic by time periods, and (3) classification of vehicle by type. This information has uses similar to those described above for intersectional volume data.

Other types of volume data or information can also prove useful for various applications.

Classification volumes give the type of vehicle, number of axles, weight, and dimensions and are used for:

- Adjusting machine volume counts.
- Analyzing accident data by type of vehicle.
- Analyzing roadway capacity by determining the effect of commercial vehicles.
- Designing roadway facilities with respect to minimum turning paths, clearances, grades, etc.
- Justifying and planning roadway improvements.

Pedestrian volume counts are used for:

- Analyzing pedestrian accidents.
- Determining the volume of pedestrians along a walkway or at a crossing.
- Evaluating the adequacy of pedestrian control and protection facilities; i.e., pedestrian barriers, pedestrian signal timings, etc.
- Assessing further pedestrian travel trends.
- Justifying and planning pedestrian improvements.

In specifying the need for volume data, all count information is identified by: (1) a time period and (2) a location. These factors are determined by the planned use of the data. Other volume data such as classification or pedestrian volumes are obtained, when necessary. In many cases, the use of short term volume counts and expansion factors can significantly reduce the effort involved in a volume study by allowing use of a short count period to project an estimate of the required volume data.

- Use of Volume Data

In highway safety analysis, volume data is principally used as a means to describe the exposure, either vehicular or pedestrian or both, at a hazardous location. For this application, the volume information is related to another traffic variable to aid in defining the study area's characteristics. For example, in describing vehicle delay at an intersection, the collection of intersection approach volume data will allow a description of the delay characteristics on a "per-vehicle," "per-approach," or "total-intersection" basis. In identifying the level of service of a facility, the volume data are compared to a computed value for the capacity of the facility in order to estimate the facility's ability to service the traffic demand.

Volume information is also used in the economic analysis and evaluation of safety-related countermeasures by providing a common measure to compare similar data items. For instance, in an economic analysis of alternatives, the use of volume data to compare the total benefits or disbenefits of an alternative is beneficial. Similarly, in selecting projects for implementation agencywide, volume considerations can result in a different implementation order (as related by the effects of the benefit/disbenefit data). The use of volume information in the Evaluation Component of the HSIP is in describing various "measures of effectiveness" in rate-related terms.

In general, the uses of the volume information will dictate the specific form of volume data to be collected. For example, in assessing the hazardousness of a location (Process 2 of the Planning Component of the HSIP), annual total traffic volumes are used to develop an accident rate factor. The following table summarizes the specific time-related volume information required within Process 3, "Conduct Engineering Studies", of the HSIP.

Table 12. Volume information needs by purpose.

PURPOSE	VOLUME INFORMATION
1. Collecting and analyzing data (Subprocess 1 - Process 3 - Planning Component).	● Hourly volumes. ● Peak hour volumes. ● Short-term counts.
2. Developing projects (Subprocess 3 - Process 3 - Planning Component).	● Annual total traffic volumes. ● AADT or ADT.

The planned use of the volume information, as specified by the procedures within Process 3 of the HSIP, will further define the exact volume information to be collected. For example, where it is required to obtain the level of service of a facility during the peak hours, peak-hour volumes would be collected. Similarly, for use in conflict studies, it would be necessary to obtain volume information simultaneously with the recording of the conflict data.

● Performance Guidelines

Typically, the time frame for collecting the volume information will be based on the time patterns of the accident summaries. Where the accident procedures indicate patterns of accident activity during a specific period of the day, this period will generally be used as the basis for the performance of other procedures used to identify the probable accident causes. Similarly, the volume information would also be collected during this time frame.

General guidelines for the collection of volume data are:

1. The location of the count should be well defined for the study purpose. If an intersection area is defined as the study location, then the count data should comprise only that traffic which passes through or utilizes the intersection. Care should be taken that counts do not include traffic which may use driveways located near the intersection and fail to pass through the intersection. For midblock (or link) situation, similar criteria should be used to avoid influencing the volume data with additional traffic.

2. In central business districts or suburban areas, counts should generally be taken between noon Monday and noon Friday since this period has been shown to be most representative of typical traffic conditions.

3. Except for special cases in which the accident activity warrants, counting periods should not coincide with atypicial activities or conditions which may result in the collection of non-representative count data. These activities or conditions could include holidays, sporting events, unusual weather, transit or mass transportation strikes, or temporary street closures.

4. For counts at special traffic generator facilities, the count periods may differ from the usual period and should coincide with the peak operation periods of the traffic generator.

- <u>Use of Expansion Factors</u>

When volume information is required for a time period greater than that originally collected, volume expansion factors can be used. Expansion factors [30-32] are typically developed using a systematic volume monitoring system consisting of a number of control stations.

For short-count periods (5,6,10 or 12 min.), expansion to an hourly count is a function of the numerical relationship of the count period length to an hour. For example, to expand a 5-min. count to an hourly volume a multiplier of 60 min. divided by 5-min. = 12 would be applied to the sampled count. Control stations could also be used for such short-count expansions provided that such disaggregate data is collected.

<u>Study Techniques</u>

Several techniques are available for collecting volume data. They include the use of:

- Mechanical counters.
- Manual counts.

- Photographic Methods.
- Moving Vehicle Methods.

Information on primary considerations for these techniques are given in Table 13.

- Mechanical Counters

Mechanical counters are most often used to record traffic volumes where counts of a long duration (24 hours or longer) are required. Two methods of mechanical counting are typically used: permanent (fixed) counters and portable counters. Permanent counters are used for continuous count data and differ mainly in the vehicle detection technique used. Types of permanent counters include:

- Pressure devices.
- Pushbutton devices.
- Photoelectric devices.
- Radar devices.
- Magnetic devices.
- Induction loop devices.
- Ultrasonic devices.
- Infrared devices.
- Radio frequency devices.

Permanent counters [1-9] are generally used for a continuous system-wide program of counting or vehicle detection and are not readily adaptable for use in highway safety analysis except at those locations where permanent counters exist. The installed equipment consists of the detection device (installed in-ground, above-roadway, etc.) and a recorder connected to the detection device and located at a safe distance from the road (to prevent any disruptions to traffic or to alleviate any effect as a fixed object). The volume data can be output in various formats, including printed tape, graphical charts or computer tape, and is either stored on-site or is relayed to a central processing station.

Advantages:

1. Has a relatively low cost per hour of counting.
2. Provides extensive time coverage.
3. May be able to obtain other traffic variables, if necessary (i.e., speed, gap, occupancy, etc.).
4. Can combine volume data with other information to provide immediate input to traffic controls.
5. Provides a high service life, if maintained.

Disadvantages include:

1. Unable to obtain axle or classification counts with some equipment.

Table 13. Primary considerations for Volume Study techniques.

Consideration / Procedure	Function	Equipment Requirements	Manpower Requirements	Time Requirements
A. Mechanical Counters				
1. Permanent	Records continuous count data at fixed locations	.Counting device (normally installed at individual locations as part of a systemwide program) .Recording device .Miscellaneous maintenance equipment	.After installation of counters, an experienced technician is necessary for maintenance purposes	.Installation time per counter ranges (from 4-8 hrs. .Data recording or analysis time is minimal
2. Portable	Records short-term, periodic counts at a flexible list of locations	.Traffic counter (junior, period, or senior) .Pneumatic road tubing, cable sensors or tape-switch .Installation equipment (hammer, nails, and pieces, etc.) .Miscellaneous maintenance equipment	.Two technicians to install counters (one person to install counter, other person to alert traffic to their presence) .A technician or engineer to record or adjust counts .An experienced technician for equipment maintenance purposes	.Installation time ranges from 15 minutes - one hour per counter dependent on travel time, number of counters installed, and maintenance of counter .Data recording time is minor (approx. 15 minutes per 24 hr. count)
B. Manual Counts	Records short-term volume data with the use of field observers	.Counting board or hand counter .Pencils .Data sheets .Calculator	.Dependent on volume of traffic and tally equipment used .Manpower requirements range from one to four technicians .Technician or engineer to sum or adjust counts	.Time spent in obtaining data varies with period of count .Minimal recording time (typically performed in-field)
C. Moving Vehicle Method	Records directional volume data (and speed and travel-time data) along roadway segments while traversing the roadway section	.Vehicle .Counting board or hand counter .Time recording device or analyzer .Pencils .Data sheets .Calculator	.A driver (technician) .A minimum of one recorder (dependent on traffic volumes and availability of time recording devices) .Engineer to compute volume and other data	.A minimum of six test runs per direction is recommended .Duration of test runs is dependent on length of test section and time of day (peak or off-peak period) .Data analysis requires approximately one half hour per section
D. Photographic Techniques	Records volume data (and other stream flow data characteristics) from photographic records	.Camera .Time-lapse mechanism .Airplane availability (dependent on technique used) .Counting board or hand tally .Calculator	.A person experienced in photographic set-up procedures .A technician to check equipment during operation .A trained technician or engineer to view and record data .With aerial photography pilot and experienced engineer to calculate data is required	.Camera set-up time is approximately one-half hour .Technician check of equipment varies with distance of location from office (ranges approximately from 15 minutes to an hour) .Data review and analysis time is related to period of actual count

Table 13. Primary considerations for Volume Study techniques (continued).

Consideration / Procedure	Associated Costs	Data Input	Data Obtained	Data Output
A. Mechanical Counters				
1. Permanent	Counter and installation (dependent on type selected) - $1000-$18,000	Specific location	Continuous volume count, speed, and other traffic data	Volume, speed, and other related traffic data
2. Portable	Initial cost of counter, tubing, hammer, nails, etc. - $850 - $2000	Specific location	Specific volume count data (in some cases, speed and other related traffic data)	Volume data
B. Manual Counts	Initial cost of counting boards ranges from $125 (single counter) to $450 (four counter board)	Specific location	Specific volume count data	Volume data
C. Moving Vehicle Method	Initial cost of recording device or traffic analyzer (dependent on capabilities) and miscellaneous maintenance equipment - $1000 - $3000	Specific location	Travel time, opposing traffic, overtaking traffic, and passed traffic data	Travel time, travel speed, and volume data
D. Photographic Techniques	Initial cost of camera equipment (dependent on quality) - $500 - $2000	Specific location	Speed, volume, vehicle classification, spacing between vehicles, and vehicle movement (turn) patterns	Speed, volume, and other traffic data

2. Has high initial installation costs.
3. Can require high maintenance costs.
4. Can result in excessive disruption of traffic during maintenance activities.
5. Can be highly susceptible to vandalism.
6. Can be difficult to detect malfunctions where unit continues to operate.

Chief limitations to the use of permanent-type counters for safety studies are the high initial installation costs (approx. $2,000 - $18,000) and their permanent nature. However, the permanence of these counters makes them effective for use as control stations at either midblock or intersection locations or as part of a data collection system for other data needs, such as timing actuated signal controls; evaluating speed, gap, and other traffic variables; setting vehicular merging patterns; and serving various other research purposes. At a control station, these counters can be used for developing volume expansion factors on a daily, weekly, monthly, or annual basis and for obtaining AADT, ADT, or annual total traffic volumes. The selection of this method for most volume data collection is limited to locations where permanent count equipment or stations currently exist.

Portable counters [2,3,4,10-17] are typically used for short-term, periodic counts. Several types of portable counters are used and include a recording counter (normally called a senior counter) and a nonrecording (junior) counter. The counters are typically battery operated and use rubber hoses (road tubes) placed across the specified portion of the roadway as detectors. These detectors transmit traffic count information to the counter through air impulses. Other type counters are solid-state and utilize either tapeswitch [15,16,18] or electrical cable [15,16] to transmit electric impulses relating the traffic information to the recorders. The count information is recorded either on a visual register (non-recording), a graphic chart, or a printed or punched tape (recording). To obtain pedestrian volume data, a similar technique is used; however, the detection device is typically a pad placed across the sidewalk to provide an electrical feedback to the recording device.

Due to the portable nature of these counters, they are readily adaptable to the study of most locations whether at an intersection or along a roadway segment, and can be installed with relatively short notice. In positioning the device at a location, it is necessary that a nearby object be utilized as an anchor for the counter to prevent theft and minimize vandalism. It is also necessary that the detection device be situated within the roadway properly in order to gather the required information types. Examples displaying the positioning of these devices for certain information types is shown in Figure 17.

Advantages:

1. Has relatively low cost per hour of counting.

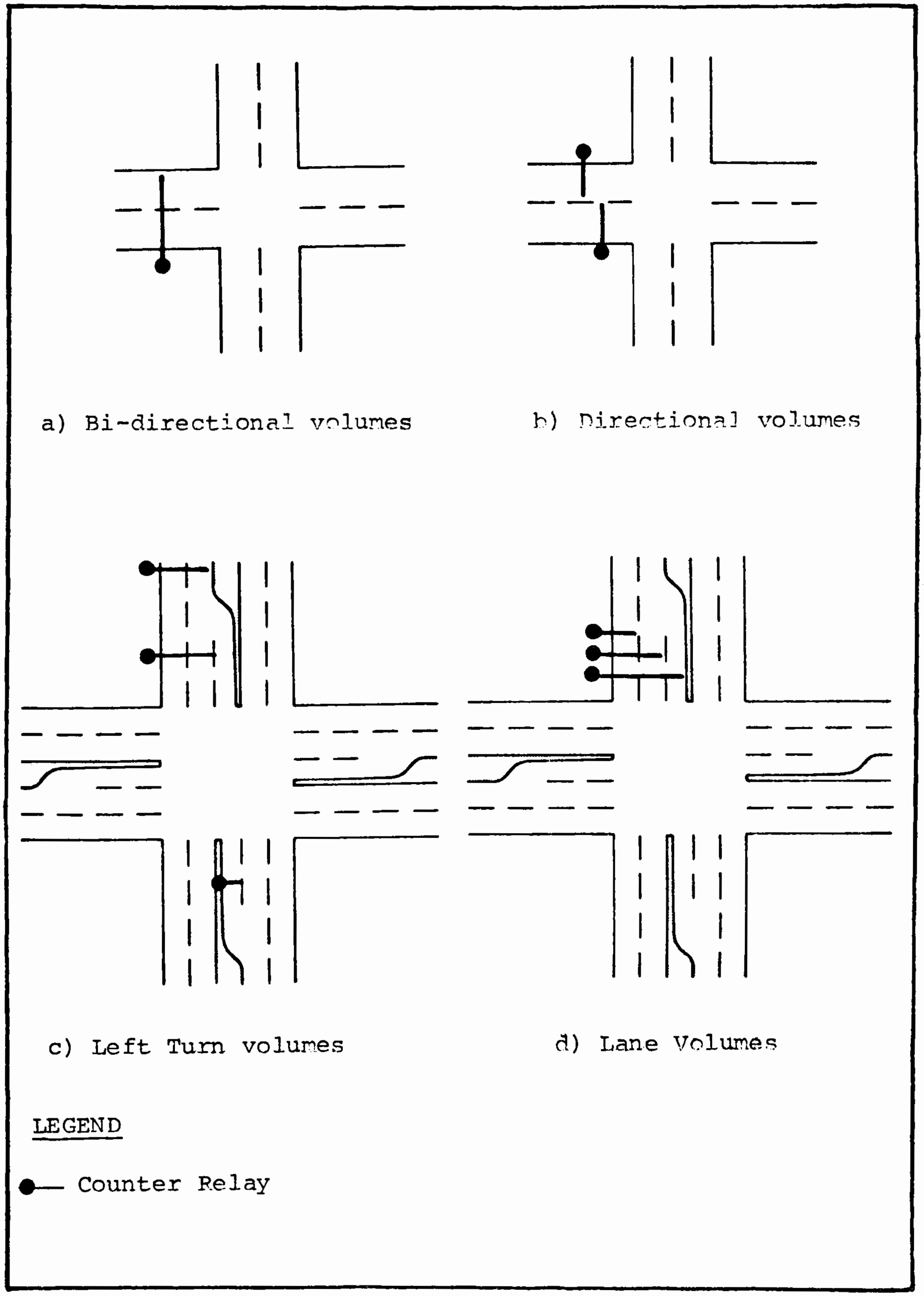


Figure 17. Field placement of portable traffic counters for specific information types.

2. Can provide extensive time coverage.
3. Able to obtain specific lane use information.
4. Permits flexibility in use of the counters.
5. Provides a high service life.
6. Easy to maintain.

Disadvantages are:

1. Unable to obtain vehicle classification data for some type of counters.
2. Is highly susceptible to vandalism.
3. Requires periodic checks to assure its continuous operation.
4. Unable to detect turning movements unless a separate turn lane exists.
5. Limits use primarily to paved roadways.
6. Provides a limited count period if battery is not maintained.

The use of portable counters is limited by the roadway (or sidewalk) surface and weather conditions. The need to provide a stable surface to attach the detection device restricts the use of portable counting devices on most unpaved roadway surfaces. Also, cold or winter weather conditions affect the use of portable counters by increasing the possibilities of breaking or cracking of the detection device (tubing, cable, or tapeswitch). In addition, wet surface conditions can reduce the adhesive qualities of the cable or tapeswitch connections, thereby causing the detection devices to loosen and result in inaccurate or lost data.

The use of portable counters are effective at most intersections or midblock locations for time periods ranging from 10 to 15 min, to a 24-hour or longer period. Longer periods are limited by battery life and the need for a regular check of its operation. Portable counters are also effective as control stations to be used for developing volume expansion factors on a 10- to 15-min., hourly, or 24-hour basis.

● Manual Volume Counts

Manual volume counts [2,3,4,10] are most often used to obtain traffic volume counts which cannot be easily collected by mechanical counters, such as: turning movements, vehicle classification data, occupancy studies, and pedestrian counts. This method involves the use of observers to manually record the volume data. Volume data are recorded using a tally board, hand counter, or tally marks made on the data sheet. These data are then summarized and transcribed onto data sheets.

Traffic count data taken manually are usually limited to a 2-hour period due to the human limitations involved in long counting periods and high personnel costs. Additionally, longer counting periods may lead to inaccuracies in the data. Also, nighttime counts are discouraged. For certain uses (vehicle classification counts and longer pedestrian counts), longer time periods may be necessary. When periods greater than 2 hours are used, shifts in personnel are recommended.

Personnel requirements for manual counts differ depending on the volume of traffic to be counted. General recommendations for personnel requirements include:

- Low to medium volume midblock location (one observer).
- High volume midblock location (one observer per direction).
- Low volume intersection (one observer).
- Medium volume intersection (one observer per two approaches).
- High volume intersection (one observer per approach).

Manual counts permit the accumulation of data for a variety of situations and conditions. Counts typically range from a 1-min. count to a two-hour total. The comprehensive data collection capabilities of the manual counting method make it desirable for conducting volume studies typically used for highway safety analysis purposes.

Advantages:

1. Generally maintains a high level of accuracy.
2. Able to obtain turning movements and classification data.
3. Can obtain a general field review of area while counting.
4. Able to accurately record pedestrian data.
5. Has minimal equipment needs.
6. Provides flexibility in its usage.

Disadvantages:

1. Can result in relatively high costs for long periods due to personnel needs.

2. Limits the length of the counting periods due to human limitations and manpower availability.

● <u>Photographic Techniques</u>

Photographic techniques can be used to obtain volume data at a specific location or along a section of roadway. This technique normally is used in the study of traffic variables such as speed, gaps, conflicts, etc. This method films (photographs) the study site and uses an observer to extract the filmed data from the pictorial record of the study site in a controlled (office) environment.

Two photographic methods are typically used: time-lapse and continuous-film photography. Time-lapse photography methods [19,20] use a motion-picture-type camera equipped with a time-lapse mechanism and a frame-numbering device. The camera is set up to provide a clear view of the study area to be counted, typically requiring a high vantage point. The camera is actuated to take pictures at distinct intervals of time (typically 0.5 - 3.0 sec.), thereby permitting a substantially longer filming time per roll of film than by continuous filming methods. The camera operates throughout the film length (e.g., 3,600 frames or 30 minutes of filming at a 0.5 second filming interval). For longer time periods, periodic checks of the film by a technician will be required.

Review of the film data requires personnel experienced in data extraction by photographic methods.

Continuous-strip photography [20,21] is similar to the time-lapse method. The data extraction methods are also similar.

With both filming modes, filming can be performed from a vantage point near the study area or by an aerial method. In the first method, data extraction is performed as described above. The aerial method [22-25] is more complicated. It requires the assembling of the film prints on a board in their filming sequence. Vehicle accumulations along the highway section during each flight run are summarized. Assuming that no change in vehicle accumulations occurred during the flight, the vehicle accumulation can be assumed to represent the volume of traffic along the roadway during each flight run. Converting this count to a specific time period involves either the use of additional flight run data or volume/time-of-day relationships for a similar type highway facility. This method provides an accurate estimate of volume data.

In both cases, volume data can be obtained for short-term (hourly) or longer period counts. The aerial method, however, is limited by the flying time and the availability of data for comparable sites. Volume expansion factors can increase the usage of the count data obtained by photographic techniques.

Advantages:

1. Able to obtain data for other traffic variables, e.g., vehicle speeds, delay time, etc.
2. Provides a permanent record of the study area.
3. Can obtain highly accurate data.
4. Able to obtain classification and pedestrian data.

Disadvantages:

1. May require a time-consuming analysis of data.
2. Can result in relatively high costs due to personnel and equipment needs.
3. Requires regular maintenance of equipment to minimize malfunctioning of equipment.
4. Requires favorable lighting and weather conditions.

The effective application of photographic techniques to obtain volume data is supplemental input during the collection of other traffic variables at either intersection or midblock locations. In many ways, the film data are similar to the manual count method; however, the film technique requires substantial equipment needs.

- <u>Moving Vehicle Method</u>

The moving vehicle method [26-29] can also be used to obtain traffic volume data along a section of roadway. This method is normally used in studying the travel time characteristics of a roadway section but can provide an estimate of the traffic volume. It is usually conducted along uniform two-way sections of roadway. The data collected should include: travel time (obtained by a stop watch or other time measuring devices), the opposing traffic (obtained from a manual count of vehicles moving in the opposite direction of the test car), the overtaking traffic volume (obtained from a manual count of vehicles moving in the same direction and overtaking the test car) and passed traffic (obtained from a manual count of vehicles moving in the same direction and passed by the test car). These data are recorded during each test run along the roadway.

For reliable results, a minimum of six test runs in each direction should be made. The estimated volume (V_i) is:

$$V_i = \frac{60}{T_i+T_j} (M_j+O_i-P_i)$$

where:

V_i = volume per hour, direction i (for volume in other direction(s), subscripts will be changed).
M_j = opposing traffic count of vehicles while test car was traveling in the opposite (j) direction.
O_i = number of vehicles overtaking the test car while traveling in direction i.
P_i = number of vehicles passed by the test car while traveling in direction i.
T_i = travel time when traveling in direction i (in minutes).
T_j = travel time when traveling in direction j (in minutes).

The results are averaged to produce an estimate of the volumes on an hourly basis.

Advantages:

1. Able to concurrently obtain travel time and operating speed data.
2. Requires minimal equipment.

Disadvantages are:

1. Provides an <u>estimate</u> of volume data.
2. Results in <u>high personnel</u> costs.
3. Limits results to roadway segments.

Volume data obtained by this method are limited to an hourly traffic volume estimate along a roadway segment.

<u>Selection of Volume Techniques</u>

In selecting a technique for performing a volume study, it is necessary to define the management concerns related to each technique. These concerns include the time, manpower, and equipment requirements as well as the information capabilities and the accuracy of the collected data. Based on these management concerns, Table 14 displays the utility of each technique. These characteristics are dependent on and vary with each particular agency based on its individual resources. In addition, the availability or non-availability of volume expansion factors may also make one technique more appropriate for an agency.

Table 15 lists the volume techniques to be used by an agency based on the volume information to be collected. Where several techniques are acceptable, a review of the management concerns, as well as a consideration of the particular characteristics of the area to be counted should be made to aid in the selection of the appropriate technique. For example, in obtaining pedestrian and vehicular volume information at an intersection during the evening peak hour, several techniques are feasible. In this case, manual volume counting techniques would probably be used since it is the only technique that permits collection of both types of data. However, if portable counters were available and vehicle volumes were significant, portable counters could be used for the vehicle volumes and manual methods for the pedestrian volumes. To further assist in selecting the appropriate technique for such situations, some general guidelines are provided.

1. The use of mechanical counting equipment is preferred where only volume levels are required. This is due primarily to the low cost per hour of counting and high reliability (when maintained on a regular basis).

2. Permanent counters, because of their high initial cost and relative immobility, are not readily adaptable for most situations. They are usually used as part of a systemwide data collection network or for collection of additional traffic variables at a specific location as part of a traffic flow program.

3. For count information where special volume information is necessary, manual counts are advantageous due to the accuracy of the

Table 14. Technique utility for Volume Study.

Technique / Management Concern	Mechanical: Permanent	Mechanical: Portable	Manual	Moving Vehicle Method	Photographic Techniques
1. Time Requirements	. Continuous long-term counting	. Flexible counting periods (limited by battery life)	. Usually limited to a period of 2 hours or less	. Short-term (1 hour or less)	. Short-term in nature (several days max.)
2. Manpower Requirements	. Technician level	. Technician level	. Technician level	. Technician level	. Technician level
3. Equipment Requirements	. Permanent detector installation	. Portable counter	. Minimal	. Vehicle availability	. Camera equipment . Airplane availability (aerial)
4. Information Needs - Intersection Volumes	. Typically by approach	. Typically by approach	. By lane use or specific movement	. Not practical	. By lane use or specific movement
- Mid-Block Volumes	. By direction (where installed)	. By direction	. By direction	. By direction	. By direction
- Pedestrian Volumes	. Not practical for highway safety applications	. Not practical for highway safety applications	. Provides an accurate record	. Not applicable	. Reasonable for use when studying pedestrian behavior characteristics
- Classification studies	. Not all equipment applicable	. Not all equipment applicable	. Provides an accurate record	. Provides an estimate	. Can provide an accurate record
5. Level of Accuracy	. Accurate	. Accurate	. Highly accurate	. Estimate	. Estimate

Table 15. Favorable Volume Study techniques.

Technique / Information Type	Mechanical		Manual	Moving Vehicle Method	Photo-graphic Technique
	Permanent	Portable			
.Annual Total Traffic	X				
.AADT or ADT	X	X			
.Peak Hour					
- Mid-Block	X	X	X	X	X
- Intersection	X	X	X		X
.Short Term					
- Mid-Block	X	X	X		X
- Intersection	X	X	X		X
.Classification Counts			X		X
.Pedestrian Volumes			X		X

method. Such counts include classification counts, pedestrian volumes, etc.

4. The conduct of short-term counts by manual or other methods should be encouraged when expansion factors are available to generate count information for a longer time period.

5. The moving vehicle method should only be used when the measurement of delay and travel-time characteristics are made. Similarly, photographic techniques should only be used where other traffic variables, such as speed, gap, occupancy, etc., are being measured at the same time.

Findings

The tabulation and output of traffic volume data uses data sheets displaying the specific information type obtained. Examples of these sheets are shown in the Appendix for intersection counts, midblock counts, classification counts, and pedestrian counts (pages I-1 to I-4).

Analysis of traffic volumes, vehicle classification, and the directional distribution of vehicles is sometimes useful in explaining sudden variations in accident frequencies or conditions. However, the major use of volume data will be in defining the magnitude of a condition as defined in other safety-related studies.

PROCEDURE 8 Spot Speed Study

Purpose

Spot speed studies are used to determine the speed distribution of a traffic stream at a spot location.

Application

A number of characteristics are commonly determined in spot speed studies. They include:

- Median Speed (50th percentile) - The middle value in a speed distribution pattern, i.e., one-half of the observed values are higher than the median and one-half are lower.

- Modal Speed - The speed (or range of speeds) at which the greatest frequency of observations occurs.

- 85th Percentile Speed - The speed within a distribution at or below which 85 percent of the vehicles travel and above which 15 percent travel.

- Skewness - The tendency of a speed distribution to favor a particular speed range. It is used to identify the overall speed tendencies of a speed study sample.

- Pace - The 10 mile per hour range in speeds containing the highest number of recorded observations. The pace is used in identifying the range of speeds for the sample.

- Need for Spot Speed Study

The spot speed study may be performed because of information from (1) the accident procedures, (2) the field review, (3) complaints made by citizens or (4) other conditions which warrant a review of the "safe approach or travel speed" of the traffic. Typical accident patterns and possible causes indicating the need for a spot speed study are shown in Table 16:

Table 16. Accident patterns relating a need for a Spot Speed Study.

Situation	Pattern	Possible Cause
Signalized Intersection	● Right-angle accidents ● Left-turn accidents ● Rear-end accidents	● Short amber phase or high travel speed. ● Short amber phase or high travel speed. ● Long amber phase.
Unsignalized Intersection	● Right-angle accidents ● Left-turn accidents	● Insufficient sight distance or high travel speed.
Curve section of roadway	● Head-on, run-off-road, or fixed object accident.	● High travel speed.
Any location	● High severity characteristics.	● High travel speed.

- Use of Spot Speed Characteristics

Spot speed studies are useful for:

- Determining and justifying the need for countermeasures, such as the posting of advisory speed indicators at curves.

- Relating to other traffic variables such as capacity information.

- Evaluating locations or studying sites to determine the effect of changes in traffic control or conditions.

Period of Data Collection

The study period for performing a spot speed study is dictated by the "time of day" accident patterns at the site. For example, if a pattern of accidents is indicated during a specific time period, this period should be used for performance of the spot speed study.

It is important that studies be performed in favorable weather and typical traffic conditions, except where special studies dictate the performance of a study under special conditions.

Sample Size Determination

Prior to performing a spot speed study, it is necessary to determine the sample size required to depict the existing conditions accurately.

The minimum sample size [1] is determined by the following formula:

$$N = (SK/E)^2$$

Where:

N = minimum sample size

S = sample standard deviation (mph or kph)

K = constant relating to the desired confidence level

E = permitted error in the speed estimate (mph or kph)

If the standard deviation, S, has not been determined prior to the study, an estimated value should be used. Table 17 contains sample standard deviations, classified by highway area and type, which are based on past research and experience [1].

If the specific field conditions of the study area are not included in the below table, the "Rounded Value" may be used.

Table 17. Standard deviations of spot speed for sample size determination.

Highway Area	Highway Type	MPH	KPH
Rural	Two-lane	5.3	8.5
Rural	Four-lane	4.2	6.8
Intermediate	Two-lane	5.3	8.5
Intermediate	Four-lane	5.3	8.5
Urban	Two-lane	4.8	7.7
Urban	Four-lane	4.9	7.9
Rounded Value		5.0	8.0

Generally, a confidence level of 95.0% (K = 1.96) is used for most traffic engineering purposes. For special cases, a greater confidence level may be required. Commonly used confidence levels and their respective "K" values are:

Confidence Level (%)	K
68.3	1.00
90.0	1.64
95.0	1.96
99.0	2.58
99.7	3.00

The permitted error, E, generally ranges from ± 1.0 mph (1.5 kph) to ± 5.0 mph (8.0 kph). The selected "permitted error" is based on the importance of the accuracy of the results. A low permitted error should be used for safety studies.

A general rule-of-thumb for sample size determination is to use a minimum sample of 100 vehicles.

● Example

A spot speed study is to be performed at an isolated curve to determine driver conformance to the posted speed limit. The study is warranted because a pattern of run-off-road accidents has been identified. The minimum sample size was computed using the previously defined criteria:

S = 5.3 mph (8.5 kph)

K = 1.96 (confidence level of 95.0 percent)

E = ± 1.0 mph (1.6 kph)

English

$$N = \left[\frac{5.3 \times 1.96}{1.0}\right]^2 = 108;$$

Metric

$$N = \left[\frac{8.5 \times 1.96}{1.6}\right]^2 = 108$$

● Performance Guidelines

To depict an unbiased and accurate estimate of spot speed data at a location, several general rules should be followed:

1. Equipment should be concealed from the approaching driver;
2. The observer or the data recorder should be as inconspicuous as possible;
3. Onlookers should be avoided;
4. An adequate sample should be obtained:
5. The lead vehicle in a queue should preferably be sampled to obtain a more representative sample of free flowing vehicles;
6. Select trucks for speed observation in proportion to their presence in the traffic stream; and
7. Avoid sampling a large proportion of high and low speed vehicles.

Speed Study Techniques

Four principal methods of data collection are available to obtain spot speed data. They include:

- Doppler Meter.
- Stop watch method.
- Electric or electronic methods.
- Photographic techniques.

Primary considerations for these techniques are given in Table 18.

● Doppler Meter

Meters based on the Doppler principle [2,3,4] utilize reflected electro-magnetic or sound waves to detect vehicle speeds. Two meter types are typically used: radar and sonic. The radar meter [2,3] is usually operated by trained personnel in accordance with the manufacturer's specifications and procedures. It can be operated from a mobile battery pack or plugged into a vehicle power source (cigarette lighter, etc.). Prior to recording data, a tuning fork is used to calibrate the meter.

In operating the meter, the observer is situated in an inconspicuous manner on the side of the road. The operator directs the meter at the desired vehicle, attempting to keep the angle between the vehicle's direction of travel and the line of sight of the meter as small as possible. This practice minimizes the error in the meter reading. The meter dis-

Table 18. Primary considerations for Spot Speed Study techniques.

Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Stop Watch Methods	.Manually records time for vehicle to traverse a specified distance	.Stop Watch .Dependent on method used; -flashing lights, or -enoscope, or -speed watch .Pneumatic tubing or electrical cable	.One observer (technician) per direction	.Dependent on required sample size and traffic volume at study location	.Stop watch $30-$200 .Speed watch $150-$300 .Enoscope $100	.Defined location .Accident summary data .Travel course length	.Time (seconds) to traverse course length	.Travel (spot) speed at study location
2. Electric or Electronic Methods	.Mechanically records time for vehicle to travel a short specified distance	.Relay device (road tubing, tapeswitch, etc) .Recording device (meter)	.One observer (technician) per direction .Technician to set up equipment	.15-30 minutes per site to set up equipment .Recording time dependent on sample size required and traffic at specific location	.Meters and miscellaneous equipment range from $200-$2000	.Defined location .Travel course length .Accident summary data	.Time (seconds) to traverse course length	.Travel (spot) speed at study location
3. Photographic Techniques	.Manually records or computes time for a vehicle to traverse a specified section of roadway using photographic techniques	.Camera .Airplane (if aerial means used)	.Technician to set up camera .Pilot (if aerial means used) .Technician to check camera during operation .Technician or engineer to review, record, or compute data	.Camera set up time - 30-60 minutes per camera .Technician equipment check varies with distance of location from office .Data review and analysis time dependent on study period	.Camera equipment $500 - $2000	.Defined location .Travel course length .Accident summary data	.Time (seconds) to traverse course length	.Travel (spot) speed at study location
4. Meters Using Dopper Principle	.Provides spot speeds using radar techniques	.Radar gun	.Technician to operate radar meter	.Dependent on sample size and traffic volume in study area (time is usually less than with other techniques)	.Radar gun $500-$1500	.Defined location .Accident summary data	.Spot speed at location	.Spot speed at location

plays the speed of the vehicle, which is then recorded on a data sheet (shown in the Appendix, page I-5). This process is continued until the minimum sample size is obtained.

The ultrasonic meter method [3,4] utilizes an overhead, transmitter-receiver. The meter is directed toward approaching traffic and records the sound wave reflections. In many cases the data are relayed (via telephone lines or other transmission equipment) to a central location, where they are recorded on data sheets.

Advantages:

1. Set-up and operation is simple for radar method.
2. Can produce reliable results.
3. Equipment has high service life.
4. Typically permits sampling of high percentage of vehicles in a relatively short amount of time.

Disadvantages:

1. Experienced or FCC certified data collectors are required.
2. Difficult to distinguish a single vehicle being observed in heavy and/or multi-lane traffic.
3. For sonic meter, equipment is costly.
4. For sonic meter, renting or buying of a data transmission means is required.

The radar meter is the most widely used method of obtaining speed data. It is appropriate for most situations because of its low cost, ease of use, and the capability to obtain a large sample in a relatively short amount of time. Sonic meters are infrequently used due to the lack of available equipment.

● Stop Watch Method

The stop watch method [2-7] estimates vehicle speed from the measured time required for a vehicle to travel over a defined distance. In this method, a measured course is laid out at the study location. Recommended course lengths are dependent on the estimated travel speeds along the roadway. Typical course lengths are given in Table 19.

In some cases, the course length is laid out in lengths such as 100 feet, 100 meters, etc. For time measurement and accuracy purposes, these distances should be set, so that the minimum time to traverse the course will not be less than 1.5 seconds. A 2.0-2.5 second target value is preferred.

Table 19. Recommended course lengths for Spot Speed Studies using stop watch methods.

Estimated Average Speed of Traffic Stream		Course Length	
mph	kph	ft.	m
<25	<40	88	25
25-40	40-65	176	50
>40	>65	264	75

Source: Transportation and Traffic Engineering Handbook

Pavement markings or identifiable reference points are used to define the course limits. These markings or points should be easily visible by the observer from his vantage point .

Techniques available to assist in timing vehicles include:

- An observer method.
- The use of an enoscope.
- The use of flashing lights.

In the observer technique, an observer is positioned midway between the reference markings. As the front wheels of a vehicle cross the reference marks, the observer actuates a stop watch. The watch is stopped the instant the vehicle passes the second reference point. The stop watch reading is then recorded on a data sheet.

Using an enoscope*, the observer is situated at one end of the course. The enoscope, placed at the other end, provides a flash of light as the vehicle passes the reference point. A stop watch is used to record the elapsed time. The stop watch reading is then recorded on a data sheet.

* An enoscope is an L-shaped box, opened at both ends, with a mirror set at a 45° angle to the arms of the device, permitting a flash of light to be emitted as a vehicle passes the device.

In the <u>flashing lights</u> technique, a detection and switch device, such as pneumatic road tubing, tapeswitches, or electrical conduit is positioned at one end of the course. The device is connected to a set of flashing lights. As a vehicle passes the reference point, the lights are actuated. The observer stationed at the other reference point measures the starting and ending times. The stop watch reading is then recorded onto a data sheet.

The readings obtained by these techniques are recorded onto a data sheet similar to the one shown in the Appendix (page I-6).

Advantages:

1. Requires minimal set-up time.
2. Has low or no maintenance costs.
3. Equipment costs can be low.
4. Operation is simple.

Disadvantages:

1. May result in timing inaccuracies due to inappropriate vantage points.
2. Human bias may affect timing of vehicles.
3. Visibility of relay or recording devices along the roadside may result in atypical driving patterns.

The stop watch methods are appropriate for most situations. Prior to the use of radar meters, such methods were commonly employed for spot speed studies. Where equipment resources are minimal, these methods provide a reliable measurement of spot speeds.

● <u>Electric and Electronic Methods</u>

The electric and electronic methods [3,4,7-11] utilize detection and relay devices such as: pneumatic road tubes, tapeswitch, magnetic tapes, etc., positioned within the roadway and interfaced to electric or electronic recording devices. In most of these methods, vehicle travel times over a measured course are used to define the spot speed. The course length may be as short as 6 to 15 feet, depending on the expected travel speeds. The course is bounded by switch devices installed on the roadway, which transmit the vehicle travel times to a recording device or recording meter located along the side of the road.

Techniques for measuring the travel time include:

- Pen graphic recorder.
- Speed watch.
- Electrically operated meter.
- Electronic meter.

- Mobile traffic data collection system.
- Electronic decade meter.
- Magnetic loop detectors.

The pen graphic recorder utilizes either pneumatic road tubes or tapeswitches positioned at the beginning and end points of the travel course. As a vehicle passes the starting point, indicator marks are automatically recorded on a chart (moving at a constant speed) for each axle on the vehicle. When the vehicle passes the end point, another set of indicator marks is generated by the same pen. The speed of the vehicle is determined by the distance between the two sets of marks.

In the speed watch method, the timing of a vehicle is obtained automatically.* The speed watch is connected to roadway detection and switch devices located at the beginning and end of the course. As a vehicle passes the starting point, the speed watch is actuated. The watch is automatically stopped as the vehicle passes the end point. The reading on the speed watch is recorded onto a data sheet by an observer who also resets the device.

The electric and electronic decade meters are similar to the speed watch. Pneumatic road tubes actuate the electric meters while tapeswitches are used in relaying information to the electronic decade meter. Calibrated speed readings are recorded from these devices.

Mobile traffic data collection systems and magnetic loop detectors are similar in that both are able to obtain speed data by measuring the time it takes a vehicle to pass a predefined loop length. Such information is relayed to a roadside recording device where it is recorded on magnetic tape or on printed or punched tape. These methods can also be used to obtain other traffic variables, such as: volume, space headway, and time headway.

Advantages:

1. Reduces human error and bias.
2. Can be simple to operate.
3. Produces reliable measurements.
4. Collects a large number of measurements in a relatively short amount of time.

Disadvantages:

1. Detection devices located on the roadway may influence driver behavior.

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* A speed watch is a calibrated timing unit operated by road tube or electrical impulses.

2. Requires frequent calibration of devices due to weather changes.
3. Equipment costs may be considerable.

These techniques are more accurate than the stop watch method. The lack of equipment usually limits their use, however. Where equipment is available, this technique is appropriate for most highway locations.

● Photographic Techniques

Photographic techniques [12] utilize distance and time relationships to obtain speed information. Means of performing photographic surveys include time-lapse and continuous film photography. Steps for these techniques are similar to those described in Procedure 7 - "Volume Study". Advantages, disadvantages, and limitations are also similar. This technique is generally limited to use where other traffic variables are being studied.

Selection of Techniques

In selecting techniques for performing a spot speed study, it is necessary to consider the management concerns. These concerns include: equipment, time, and manpower requirements, the data collection capabilities, and the accuracy of each technique. Table 20 displays the utility of each spot speed study technique as a function of these management concerns.

General guidelines to use in selecting a technique are:

1. For most highway safety applications, the use of a radar meter is preferred. Costs of a radar meter ($500- $1500) can be moderately higher than some of the other techniques. The flexibility, ease of use, and overall efficiency of the radar meter make it a desirable technique.

2. Where radar equipment is unavailable, stop watch methods are acceptable.

3. If greater accuracy is desired, the electric or electronic methods are required. Where available, magnetic loop detectors produce highly reliable results.

4. Photographic techniques are discouraged except where other traffic variables are to be measured.

Findings

The tabulation and output of the spot speed data are usually presented on data sheets as shown in the Appendix (pages I-5 to I-6).

Table 20. Technique utility for Spot Speed Study.

Technique / Management Contern	Stop Watch Method	Electric or Electronic Methods	Photographic Techniques	Doppler Principle Methods
.Time Requirements	.Requires short equipment set up and data collection effort .Requires substantial data manipulation effort	.Requires substantial equipment set up effort .Uses short data collection effort .Uses short data manipulation effort	.Requires substantial equipment set up effort .Uses short data collection effort .Requires substantial data extraction effort .Requires substantial data manipulation effort	.Uses short data collection and manipulation effort
.Equipment Requirements	.Stop watch .Other needs minimal	.Detection devices .Electric or electronic meters	.Photographic equipment	.Radar meter
.Manpower Requirements	.Technician level	.Technician level	.Technician level	.Technician level
.Data Collection Capabilities	.Indirectly obtains speed data	.Most methods directly obtain speed data	.Indirectly obtain speed and other traffic variables	.Directly obtains speed data
.Level of Accuracy	.Accurate	.Highly accurate (dependent on maintenance of equipment)	.Accuracy limited by vantage point of camera	.Accurate for most purposes

In the stop watch methods, several of the electric and electronic methods, and photographic techniques, the data obtained are typically in the form of the travel time data required to pass over a defined course length. In this form, the data must be transformed into speed information by dividing the recorded travel time into the course length.

● Use Of Findings

In cases where high travel speeds are noted as a "possible accident cause", the speed characteristics are directly compared to the speed limits and conditions at the study site. Where travel speeds are determined to be higher than is reasonably safe for field conditions, a reduction in travel speeds, a change in geometrics or field conditions, or advance warning of vulnerable conditions are feasible alternatives. Where insufficient sight distance exists, the sight obstruction may be removed, or approach speeds reduced.

Finally, spot speed data can also be used to compare the effectiveness of an improvement using speed as a measure of effectiveness in a before/after study. Evaluation studies are covered in detail in the Evaluation Component of the HSIP.

● Example

The following example is for a spot speed study conducted with the stop watch method over a course length of 176 feet (52.8 m). From the data shown in Figure 18, the following characteristics were calculated.

Median speed - (50th percentile) - Obtained by manually counting the vehicle groups to depict the speed at which fifty percent (or 54 vehicles) of the vehicles travel at a higher rate. In this case, the median speed is 37.5 mph.

Modal Speed - Obtained by manually counting and selecting the vehicle speed group with the greatest number of observations. In this case, the modal speed would be 40.0 mph (25 observations).

85th percentile speed - Obtained by manually counting the vehicle groups to depict the speed at which 15 percent (or 16 vehicles) of the vehicles travel at or higher. In this case, the 85th percentile speed is 42.8 mph.

Skewness - Obtained by dividing $2(S_{93} - S_{50})$ by $(S_{93} - S_7)$.

$$\frac{2(46.1 - 37.5)}{(46.1 - 31.5)} = \frac{17.2}{14.6} = 1.18$$

A skewness of 1.0 indicates symmetry of the speeds about the mean speed. A value below 1.0 shows skewness towards the lower speeds,

SPOT SPEED STUDY
FIELD SHEET

Date 8/25/80 Location RUSSELL ROAD Direction NB

Time 10-11 AM Weather CLEAR Road Surface Condition DRY

SECONDS	mph for 88 ft	mph for 176 ft		PASSENGER VEHICLES		BUSES		TRUCKS		TOTAL
					No veh		No veh		No veh	
1	60.0	120.0								
1-1/5	50.0	100.0								
1-2/5	42.8	85.7								
1-3/5	37.5	75.5								
1-4/5	33.3	66.6								
2	30.0	60.0		||	2					
2-1/5	27.2	54.5								
2-2/5	25.0	50.0		|||	3					
2-3/5	23.0	46.1		𝍸	5			/	/	
2-4/5	21.4	42.8		𝍸 𝍸 |||	13					
3	20.0	40.0		𝍸 𝍸 𝍸 𝍸 𝍸	25					
3-1/5	18.7	37.5		𝍸 𝍸 𝍸 𝍸 |	21					
3-2/5	17.6	35.2		𝍸 |||	8					
3-3/5	16.6	33.3		𝍸 𝍸 𝍸 ||	17			/	/	
3-4/5	15.7	31.5		𝍸 |||	8					
4	15.0	30.0		|||	3					
4-1/5	14.2	28.9								
4-2/5	13.6	27.2		|	1					
13	4.6	9.2								
14	4.2	8.5								
15	4.0	8.0								
			TOTAL VEHICLES		106				2	108

Figure 18. Spot speed study data-example.

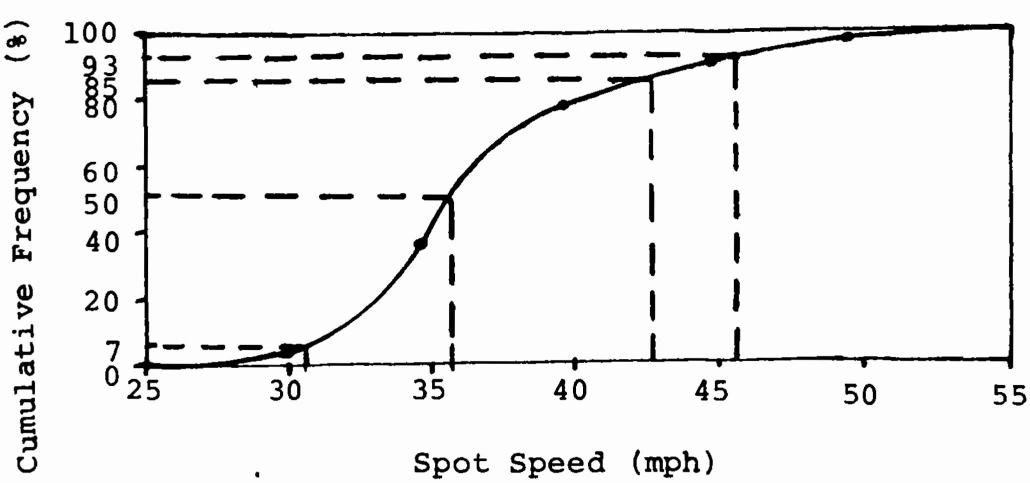


Figure 19. Graphical summary of spot speed data.

indicating a greater tendency of lower travel speeds along the study section. A higher value indicates higher travel speeds. In the example noted above, the distribution shows skewness towards the higher speed ranges which indicates more free flowing uncongested conditions.

Pace - Obtained by manually counting the vehicles in each speed group to represent the greatest number of observations within a 10 mph range. In the example, the pace occurs in approximately the 33-43 mph range with 84 of 108 observations in this range. It indicates a narrow range of travel speeds by the sample traffic which is a favorable safety condition. A wide range usually indicates more hazardous conditions, caused by differences in travel speeds between vehicles.

The spot speed findings can be obtained using a graphical approach as shown in Figure 19. This plot visually displays the speed distribution pattern of the traffic. On one axis, the range of spot speeds is displayed. The other axis records the cumulative frequency of observations within the defined speed ranges. The key spot speed characteristics can be obtained from, and are shown on the graph. The data reveal a narrow distribution of speeds along the study area.

Another speed characteristic often used by traffic engineers is speed variance. The variance is obtained by squaring the standard deviation of the speeds. For optimum safety conditions, the variance should be less than 1.0. It has been shown by several researchers that accident involvements increase significantly when large deviations from the mean speed occur.

PROCEDURE 9 Travel Time And Delay Study

Travel time and delay studies are normally grouped into two areas:

- Link studies.
- Intersection studies.

Each study serves a unique purpose and has differing criteria regarding its performance. This section will discuss these studies.

• Link Studies

Purpose

Link travel time and delay studies are used to obtain data on the amount of time it takes to traverse a specified section of roadway and the amount, cause, location, duration, and frequency of delays occurring during the trip. Travel time and delay characteristics are indicators of the level of service of a facility. They can be used as a relative measure of efficiency of traffic flow.

Application

● Need For Link Study

This study may be used where accident patterns reveal the occurrence of traffic congestion, i.e., rear-end, right-angle, or left-turn accidents along a roadway. Other means of identification may be from field reviews or complaints. These patterns occur typically during high traffic volume periods and are typically minor in severity.

● Use Of Travel Time and Delay Study Data

These studies are useful for:

- Identifying and defining sources of congestion for use in developing appropriate countermeasures to remedy the congestion.
- Calculating delay costs used in economic analysis or for improvement justification purposes.
- Evaluating the effectiveness of various traffic improvements, such as determining the effectiveness of a change in parking conditions.

● Period of Data Collection

Link studies are typically performed during peak volume hours (weekday) to obtain delay characteristics while traffic is operating under the heaviest traffic conditions. The actual time period is established from the accident summary by time data. In some cases, a comparison of delay characteristics for peak and off-peak conditions may be desirable.

These studies should be performed under favorable weather conditions to obtain a sample of typical operating conditions. In addition, for "before-and-after" evaluation studies, it is necessary that similar traffic conditions exist during both periods of data collection.

● Sample Size Determination

The sample size[3] or number of test runs for link studies is based on the study purpose, the permitted error, and the desired confidence level in the accuracy of the data. Ranges of permitted error in the estimate of the mean travel speed are related to the study purpose, as shown in Figure 21.

The required minimum sample size is given on the charts in Figure 20 for confidence levels of 95.0 and 99.7 percent. Typically, a 95.0 percent confidence level is desirable for most traffic engineering studies.

Average Range in Travel Speed	Minimum Sample Size for Specified Permitted Error				
(mph)	±1.0 mph	±2.0 mph	±3.0 mph	±4.0 mph	±5.0 mph
1.0	2	2	2	2	2
2.0	3	2	2	2	2
3.0	5	3	2	2	2
4.0	6	3	2	2	2
5.0	8	4	3	2	2
6.0	10	5	3	3	2
7.0	12	6	3	3	3
8.0	15	6	4	3	3
9.0	18	7	5	3	3
10.0	21	8	5	4	3
11.0	23	9	6	4	3
12.0	27	10	6	5	4
13.0	32	11	7	5	4
14.0	34	12	8	6	4
15.0	37	14	8	6	5
kph	±2.0 kph	±3.5 kph	±5.0 kph	±6.5 kph	+8.0 kph
2.0	2	2	2	2	2
4.0	3	2	2	2	2
6.0	5	3	2	2	2
8.0	6	3	3	2	2
10.0	8	4	3	3	2
12.0	10	5	4	3	3
14.0	12	6	4	3	3
16.0	15	7	5	4	3
18.0	18	9	6	4	3
20.0	21	9	6	5	4
22.0	23	11	7	5	4
24.0	27	13	8	6	5

Confidence Level of 95.0 Percent.

Average Range in Travel Speed	Minimum Sample Size for Specified Permitted Error				
(mph)	±1.0 mph	±2.0 mph	±3.0 mph	±4.0 mph	±5.0 mph
1.0	4	2	2	2	2
2.0	6	4	3	2	2
3.0	10	5	4	3	3
4.0	13	6	4	4	3
5.0	18	8	5	4	4
6.0	23	10	6	5	4
7.0	28	12	7	6	5
8.0	34	13	8	6	5
9.0	40	15	10	7	6
10.0	47	18	11	8	6
11.0	52	20	12	9	7
12.0	61	23	13	10	8
13.0	74	25	15	11	8
14.0	79	28	17	12	9
15.0	85	31	18	12	10
kph	±2.0 kph	±3.5 kph	±5.0 kph	±6.5 kph	±8.0 kph
2.0	4	3	2	2	2
4.0	6	4	3	3	2
6.0	10	5	4	3	3
8.0	13	7	5	4	4
10.0	18	9	6	5	4
12.0	23	11	8	6	5
14.0	28	13	9	7	6
16.0	34	16	10	8	6
18.0	40	19	12	9	7
20.0	47	21	13	10	8
22.0	52	24	15	11	9
24.0	61	30	17	12	10

Confidence Level of 99.7 Percent.

Source: "Sample Size Determination for Travel Time and Delay Studies", J.C. Oppenlander, Traffic Engineering, September 1976.

Figure 20. Sample size determination - link study.

Table 21. Ranges of permitted error by study purpose.

Study Purpose	Permitted Error
. Transportation planning and highway needs studies	3.0 to 5.0 mph (5.0 to 8.0 kph)
. Traffic operation, trend analysis, and economic evaluations	2.0 to 4.0 mph (3.5 to 6.5 kph)
. Before-and-after studies	1.0 to 3.0 mph (2.0 to 5.0 kph)

Source: Manual of Traffic Engineering Studies, Institute of Traffic Engineers, (1976).

A sample size should be determined for each direction of travel and for each set of traffic and environmental conditions.

In using these tables, the following steps should be performed:

1. Determine the permitted error based on the specific survey purpose. Although the above table provides a range of values, the selection of the specific permitted error is based on the significance of the study. The more critical the study results, the lower the permitted error. This decision is made by the engineer-in-charge.

2. Estimate the average travel speed (mph or kph) for the test route.

3. Select a confidence level.

4. Using Figure 20 for the selected confidence level and the previously defined information determine the minimum sample size.

● Example

It is desired to study the travel time characteristics along a six-mile section of arterial roadway. The study is to be used to review the traffic operations at a site where a pattern of congestion-related accidents have been identified. Following is the procedure that should be used to determine the sample size.

1. Based on the study purpose (evaluation of traffic operations), the permitted error is 2.0 to 4.0 mph (3.5 to 6.5 kph). As a consequence of the critical nature of this study, a permitted error of 2.0 mph (3.5 kph) should be selected.

2. An average range of travel speeds for the study is assumed to be 5.0 mph (8.0 kph). It was obtained from an estimate of an earlier study.

4. Using Figure 20, the required minimum sample size is determined to be four test runs or observations per direction.

● Definition of Study Area

For roadway segments, study sections usually start and end at intersections. The test section should both begin and end at a centerline. At roadway segments not outlined by intersections, the starting and ending points should be well marked or delineated.

Delay and Travel Time Study Techniques

Several techniques are available to perform a link study. They include:

- Test car techniques.
- Moving vehicle method.
- License plate method.
- Observer methods.
- Photographic methods.
- Interview method.

Primary considerations of these techniques are shown in Table 22.

● Test Car Techniques

Test-car techniques[4-9] use the results of a test vehicle driven over the study section for a series of runs or trips. One of several driving patterns may be used. They include:

- Floating car.
- Average car.
- Maximum car.

In the "floating car method", the driver "floats" with traffic, i.e., the driver attempts to pass as many vehicles as pass the test vehicle. The "average car" method uses a driving speed which is estimated as the average vehicle speed within the test section. In the "maximum car" tech-

Table 22. Primary considerations for Travel Time and Delay Study techniques.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Test Car Techniques	. Obtains travel time and delay data by physically driving test section and recording information	. Vehicle . Traffic analyzer or stop watches (2) . Data sheets	. Driver (technician) . Technician to record data . Trained technician or engineer to compute delay characteristics	. Time for single test run dependent on route length and delay . Minimum of 12 test runs per direction . 1 hour to to reduce data	. Stop watches $25-$200 . Traffic analyzer $1,500-$5,000	. Defined location (accident summary data) . Required sample size . Study period	. Travel time . Location, amount and cause of delay	. Travel time and delay characteristics (stopped time, fixed delay, etc.)
2. License Plate	. Obtains travel time data by recording license plate numbers at test route ends	. Stop watches (one per direction per station) . Computer (if available)	. Two technicians per direction per location (one to observe, the other to record . Technician to reduce travel speed or average travel data	. Dependent on test route length . Minimum of 50 license plate matchings per direction . Several hours to reduce data	. Stop watches $25-$200	. Defined location . Test section length . Required sample size	. Recorded time passage of vehicle at a specific station(s)	. Overall travel time . Overall travel speed
3. Photographic Methods	. Obtains travel time data (and possibly delay information) using filmed records of the test section	. Camera equipment . Data sheets	. Trained technician to set up camera . Technician to periodically check camera or change film . Trained technician or engineer to view and record film records	. Camera filming time dependent on sample size and roadway volume . Viewing time-dependent on study period . Minimum of 50 license plate matchings or 12 test runs of data per direction . Several hours to reduce data	. Camera equipment - $500 $2,000 . Airplane rental dependent on test time	. Defined location . Test section length . Required sample size . Study period	. Recorded time passage of vehicle at a specific station(s) . Possibly specific delay information	. Overall travel time . Overall travel speed . Possibly delay information

Table 22. Primary considerations for Travel Time and Delay Study techniques (continued).

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
4. Graphic Pen Recorder Method	. Obtains travel time data by registering time-related input on graphical chart	. Graphic pen recorder . Road tubes . Data sheets	. Technician to set up recorder . Technician(s) to operate keys and aid in identifying vehicles . Trained technicians to record data from charts . Trained technicians to reduce data	. Data collection period dependent on sample size required and approach volumes . Several hours to reduce data	Graphic pen recorder - $300-$1,500	. Defined location . Test section length . Required sample size . Study period	. Travel time over test section	. Overall travel time
5. Interview Method	. Obtains travel time and general delay information from daily users of test section	. Data summary sheets	. Technician to interview users of the route . Technician to reduce data	. Approx. 2 hours to arrange data collection . 1 hour to reduce data . Minimum of 50 vehicles per direction	. None	. Defined location . Sample group . Required sample size . Study period	. Travel time . General list of delay points	. Overall travel time . General delay information
6. Observer Method	. Obtains travel time and delay information by observing vehicles in the field	. Stop watches (2 per station per direction)	. Technician per station . Trained technician or engineer to adjust data	. Time for single observation of vehicle dependent on length of test section . Minimum of 12 observed vehicles per direction . 1 hour to adjust data	. Stop watches $25-$200	. Defined location . Route length . Required sample size . Study period	. Travel time . Specific delay information (location, amount, and causes of delay)	. Travel time and delay characteristics
7. Delay Meter	. Obtains stopped time delay data at intersections by vehicle detection and accumulation relationship	. Delay meter . Detection equipment . Data sheets . Volume counter	. Technician to install delay measuring euqipment . Technician to record data . Technician to adjust data	. Data collection period dependent on sample size and approach volume . Data analysis time minimal	Delay meter and equipment $300-$2,000	. Defined location . Required sample size . Study period	. Vehicle seconds of delay . Approach volume count	. Stopped time delay characteristics for an approach

Table 22. Primary considerations for Travel Time and Delay Study techniques (continued).

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
8. Sampling Method	. Obtains estimated travel time and stopped time delay characteristics for intersections using sampling and approximation methods	. Tally board . Stop watch . Data sheets . Volume counter	. Technician to record approach or exiting volume . Technician to record stopped vehicles in approach . Technician to adjust data	. Data collection period dependent on sample size and approach volume . Typically minimal time expenditures . Data analysis time minimal	. Tally board (single - $150) . Volume counter - $600-$1,500	. Defined location . Required sample size . Study period	. Approach or exiting traffic volume . Number of stopped vehicles (instantaneous density)	. Estimated approach time and delay characteristics
9. Moving Vehicle Method	. Obtains volume, travel time, and delay information for roadway sections by physically driving test section	. Vehicle . Stop watches (2) . Counting board . Data sheets	. Driver (technician) . Technician to record delay information . Technician to record pther information . Trained technician or engineer to adjust data	. Dependent on test section length and volume of traffic . Minimum of 6 test runs per direction . Minimal time to adjust data	. Stop watches $25-$200 . Counting boards (single - $150)	. Defined location . Route length . Major expected delay points . Required sample size . Study period	. Travel time . Volume data . Location, amount and causes of delay	• Travel time and delay characteristics • Volume data

nique, the driver operates the test vehicle at the posted speed limit, unless impeded by traffic conditions. Each driving method produces similar findings.

Several means of recording data are available. The most common method uses stop watches. Two watches are used. The first watch is started at the beginning of the test run and used to record the elapsed time at various control points along the route. The second watch is used to measure the length of individual stopped time delays. The time, location, and causes of these delays are recorded on data sheets similar to those shown in the Appendix (page I-7).

Another means of recording delay data is with the use of automatic recording devices[10]. These devices are able to graphically record on roll tape or magnetic cassette a log of the relationship of the vehicle speed and delay with regard to time. Most of these devices are able to record not only the duration of stopped time (time that a vehicle is actually standing still, due to any factor), but also fluctuations in speed. However, an additional observer is needed to record the causes of delay and to relate the delays to the tape information. The tape or cassette data can be transferred onto data sheets or analyzed using standard computer programs.

Advantages:

1. Obtains data based on the experiences of a vehicle in the traffic stream.
2. Relatively simple to perform.
3. Able to obtain information on both travel time and delay characteristics.
4. Equipment needs can be minimal.
5. Data are usually reliable.

Disadvantages:

1. Can result in considerable time requirements.
2. Personnel costs may be high.

This technique permits collection of travel time, stopped time delay, and other delay information. It also allows a review of the field situation during the test run periods.

● Moving Vehicle Method

The moving vehicle method[4-9] requires test runs of the study section similar to the test car techniques. Information recorded on these runs includes the travel time, volume of opposing traffic, volume of overtaking traffic (estimated) and travel speeds. A further description of this technique is given in Procedure 7 - "Volume Study."

An additional observer in the vehicle can be used to obtain specific delay information. This technique differs from the test car techniques in that additional information is obtained during the test runs to assist in estimating traffic volumes along the test section.

Advantages:

1. Provides data based on the experiences of a vehicle in the actual traffic stream.
2. Able to provide an estimate of traffic volumes in the study section during each test run.
3. Relatively simple to perform.
4. Able to obtain both travel time and delay characteristics.
5. Equipment needs are minimal.

Disadvantages:

1. Can result in considerable time requirements.
2. Personnel costs may be high.

This technique provides a reliable measurement of travel time and delay information. The technique requires added personnel where delay information is to be obtained.

● <u>License Plate Method</u>

The license plate method[4,5,6,13] utilizes observers posted at the beginning, end, and other strategic points of the test section. Observers record the direction of travel, the last three digits of the license plate number of the sample vehicles, and the stop watch time at which the sample vehicle passes the observation point. The data are recorded onto speed data sheets as shown in the Appendix (page I-8). Attempts should be made to record as great a sample as possible.

In analyzing the field data, the zone of origin is assumed to be the station where the vehicle was first observed. The travel route and time is traced by the vehicle's successive appearances at a series of recording stations. The zone of destination is assumed to be the station where the vehicle was last observed. The data are combined and adjusted to provide information on the total travel time.

With this method, accuracy in the recording of the time data is a major concern. It is necessary that all timing devices are coordinated at the beginning of the study period. This coordination can be achieved by having all observers meet prior to the study to set their watches simultaneously. All watches are stopped when the observers meet following the completion of the study. At this time, adjustment for slower or faster watches can be made.

Advantages:

1. Can obtain a large sample in a short amount of time.
2. Equipment needs are minimal.
3. Data collection method is easy to perform.

Disadvantages:

1. Requires a large number of personnel to obtain data.
2. Data reduction can be time-consuming.
3. Obtains primarily travel time information.
4. Travel time information is approximate.
5. A large number of personal errors in recording license numbers can occur.

This technique is appropriate for link studies where the overall travel time information is the prime objective. Where detailed delay information is required, high personnel costs will result.

● Observer Methods

These methods[4,5,6,14,15] use observers to trace sample vehicles over the defined test section and to record travel time and delay information. Several stop watches are used to obtain the travel time and delay information. The information recorded and the recording procedures are similar to the stop watch methods described in the test-car techniques. For each observation point, a minimum of two observers are required in order to time the vehicles, note specific sources of delay and record the necessary data.

This method requires the availability of suitable observation posts to observe the vehicles along the test section. Observation posts may consist of windows in buildings or roof tops.

Advantages:

1. Permits viewing and recording of delay causes under actual field conditions.
2. Results are reliable.
3. Simple to perform.
4. Equipment needs are minimal.

Disadvantages:

1. Requires that observation posts are available.
2. May require substantial time requirements.
3. Accuracy may be limited by test section length.
4. Personnel costs may be high.

This method is favorable for obtaining data on short test sections as it can provide reliable information within the visual range of the observer.

● <u>Photographic Methods</u>

The photographic methods[5,6,16] utilize camera equipment located at the beginning and end points of the test route and at selected locations within the test route. The film is reviewed in an office environment in a manner similar to the license plate technique. Vehicles are timed using either time-lapse photography or external timing sources and recorded onto field sheets similar to the license plate technique. Operational characteristics of the photographic technique are provided in Procedure 7 - "Volume Study."

Advantages:

1. Provides a pictorial record of the test section.
2. Permits a detailed review of conditions under a controlled environment.
3. Able to obtain data on other traffic variables.
4. Able to obtain a large data sample.
5. Obtains an unbiased sample.

Disadvantages:

1. Requires considerable data collection and extraction time.
2. Equipment and time costs may be high.
3. Requires favorable lighting and weather conditions.

This technique requires substantial coordination in timing during the filming and viewing activities to achieve a high level of accuracy. Due to the data manipulation requirements, this technique has limited use for roadway studies.

● <u>Interview Method</u>

This method [5] involves interviewing selected individuals to determine the travel time and delays they experienced for specific trips. Individuals selected for the interviews are usually located at residences or places of employment located nearby who use the study section for their trips. The individuals are requested to record their travel time along the test section on a particular day. These data are collected, reviewed, and averaged to obtain an estimate of the travel time.

Advantages:

1. Has low overall cost.
2. Obtains large volume of data with relatively little effort.
3. Obtains input from daily users of the study area.

Disadvantages:

1. Results may not be reliable.
2. Requires cooperation from involved individuals.

Selection of Technique

Various methods are available to perform these techniques. To select the appropriate technique, the management concerns need to be determined and reviewed. They include the data collection capabilities, the level of accuracy, and the manpower, equipment, and time requirements of each technique. Table 23 displays the utility of each technique in relation to these management concerns. Table 24 displays available techniques used to perform the procedures as a function of the information obtained. Based on these tables, a favorable study technique can be selected.

For roadway studies where travel time data is desired, the license plate method is favorable. It permits the collection of a large sample of information in a reasonable amount of time. This method also has minimal equipment requirements. However, where delay characteristics are required, the test car techniques are most favorable. They permit the collection of data at the delay points. For short test sections within visual range of an observer, the observer methods may be used with reliable results.

Findings

The tabulation and output of the travel time and delay characteristics can be displayed in various formats. A sample output is shown in Figure 21. The information obtained for this graph is derived by computing the average travel speed along a section of roadway. The travel speed for a single vehicle run can be obtained from the following equation.

$$S = \frac{60D}{T}$$

Where:

S = travel speed (mph or kph)
D = length of study route or section (mile or km)
T = travel time (min)

The mean travel speed is computed as follows:

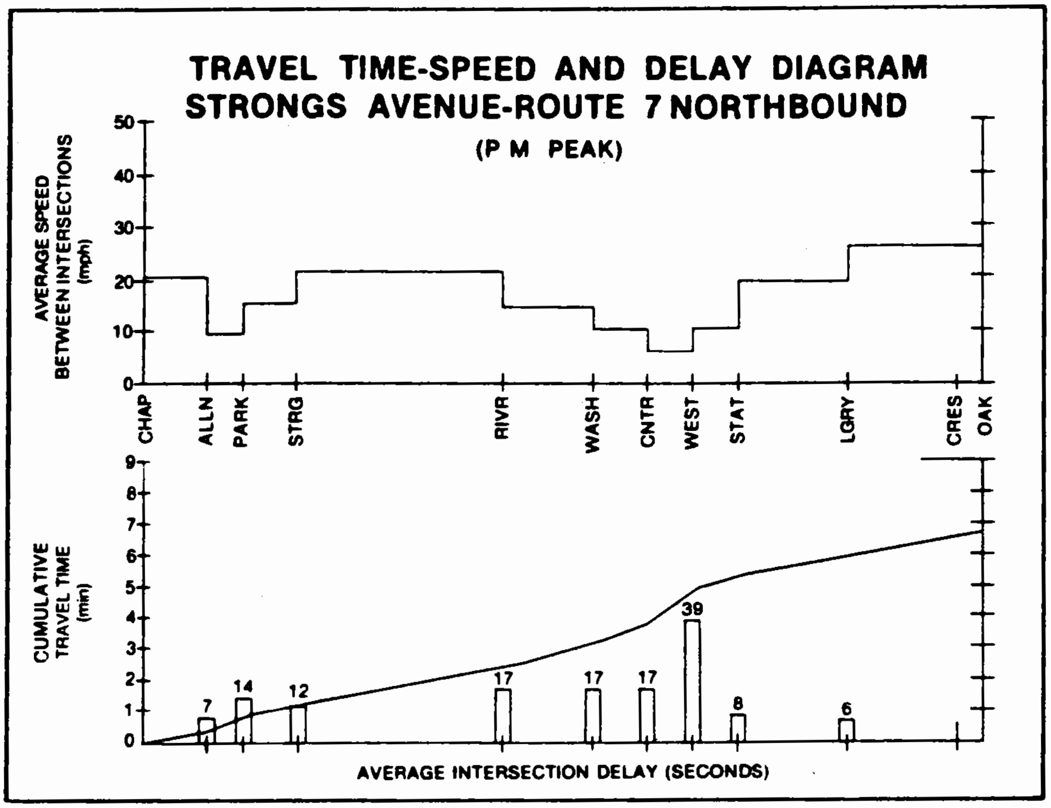
$$S = \frac{60ND}{T}$$

Table 23. Technique utility for Travel Time and Delay Study.

Technique / Management Concern	Test Car Techniques	License Plate Method	Photo-graphic Methods	Graphic Pen Recorders	Interview Method	Observer Method	Use of Delay Meters	Sampling Methods	Moving Vehicle Method
1. Data Collected	. Travel time and delay data for intersec-tions and roadways	. Travel time data for in-tersections and roadways	. Travel time and delay data for in-tersections and roadways	. Travel time data for inter-sections	. Travel time and delay data for road-ways	. Travel time and delay data for road-ways and intersec-tions	. Delay data for intersec-tions	. Travel time or delay data for in-tersections	. Travel time data for roadways
2. Level of Accuracy	. High	. Sufficient for most purposes	. High	. Sufficient for most purposes	. Approx.	. High	. Sufficient for most purposes	. Sufficient for most purposes	. Sufficient for most purposes
3. Equipment Requirements	. Vehicle . Other needs, minimal	. Minimal	. Camera equipment . Other needs, minimal	. Graphic pen re-corder . Other needs, minimal	. Minimal	. Minimal	. Delay meter & set up . Other needs, minimal	. Minimal	. Vehicle . Other needs, minimal
4. Manpower Requirements	. Technician level	. Technician level	. Technician level	. Technician level	. Technicain level . Sample group	. Technician level	. Technician level	. Technician level	. Technician level
5. Time Requirements	. High	. Moderate	. High	. Moderate	. Low	. Moderate	. Moderate	. Low	. High

Table 24. Favorable Travel Time and Delay Study techniques.

Technique / Information Needs	Test Car Techniques	License Plate Method	Photo-graphic Methods	Graphic Pen Recorders	Interview Methods	Observer Methods	Use of Delay Meters	Sampling Methods	Moving Vehicle Method
.Roadway									
-Travel Time	X	X	X		X	X			X
-Delay	X		X			X			
-Both	X		X			X			
.Intersection									
-Travel Time	X	X	X	X		X		X	
-Delay			X			X	X	X	
-Both			X			X		X	



Source: Manual of Traffic Engineering Studies, ITE, (1976)

Figure 21. Sample Travel Time and Delay Study output.

LEVELS OF SERVICE FOR URBAN AND SUBURBAN ARTERIAL STREETS

LEVEL OF SERVICE	*TRAFFIC FLOW CONDITIONS (TYPICAL APPROXIMATIONS, NOT RIGID CRITERIA)* *Description*	*Average Overall Travel Speed (mph)*	*Load Factor*	*Likely Peak-Hour Factor*	*Service Volume/ Capacity Ratio*
A	Free flow (relatively)	$\gtrsim 30$	0.0	$\lesssim 0.70$	$\lesssim 0.60$ (0.80)
B	Stable flow (slight delay)	$\gtrsim 25$	$\lesssim 0.1$	$\lesssim 0.80$	$\lesssim 0.70$ (0.85)
C	Stable flow (acceptable delay)	$\gtrsim 20$	$\lesssim 0.3$	$\lesssim 0.85$	$\lesssim 0.80$ (0.90)
D	Approaching unstable flow (tolerable delay)	$\gtrsim 15$	$\lesssim 0.7$	$\lesssim 0.90$	$\lesssim 0.90$ (0.95)
E	Unstable flow (congestion: intolerable delay)	Approx. 15	$\lesssim 1.0$ (0.85 typical)	$\lesssim 0.095$	$\lesssim 1.00$
F	Forced flow (jammed)	<15	(Not meaningful)	(Not meaningful)	(Not meaningful)

(Source: *Highway Capacity Manual*, HRB SR 87, 1965, Table 10-13)

Figure 22. Highway capacity chart - example.

Where:

S = mean travel speed (mph or kph)
D = length of study route or section (mile or km)
T = sum of travel time for all test runs or observations (min)
N = number of test runs or observations

The travel time data are obtained directly from the study data.

● Use Of Findings

The travel time and delay information is also used to determine the operating level of service along a facility. An average overall travel speed, obtained from the above formula, is compared to the traffic flow conditions for a facility to determine an operating level of service. For example, assuming the average travel time over a three-mile length of arterial roadway during the evening peak period (4:00-6:00 p.m.) was 7.42 minutes, the average travel speed would be:

$$\frac{3.00 \text{ miles}}{7.42 \text{ minutes}} \times \frac{60 \text{ minutes}}{\text{hour}} = 24.3 \text{ mph}$$

Using the table shown in Figure 22, It is determined that the roadway operates at a level of service "B" - "C" during this time period.

The travel time and delay findings may also be used in the selection and evaluation of safety-related countermeasures. In selecting feasible countermeasures, delay data may be used in an economic analysis to derive delay costs at a site. Delay costs include: the time cost to an individual (resulting from "lost" time which could have been used in a productive manner), and the vehicle operating costs. These cost figures can be obtained from various references on roadway economics, including those listed below.

1. Economic Analysis for Highways by R. Winfrey.

2. "Running Costs of Motor Vehicles as Affected by Road Design and Traffic", Paul J. Claffey, NCHRP 111.

The calculated delay costs are included in the economic analysis as a "disbenefit"; however, an anticipated improvement (reduction) in delay will result in a "benefit" being derived from a proposed project. Delay costs may also be included in formulas used in the scheduling or planning of improvements.

Finally, the use of the travel time and delay data for evaluation of countermeasures involves the measurement of these characteristics "before" and "after" implementation of the countermeasures. Differences in "before" and "after" data can be tested for significance.

● Intersection Studies

Purpose

Intersection delay studies are used to obtain delay data at an intersection. The delay characteristics can be used as a relative measure of the efficiency of traffic flow.

Application

● Need For Intersection Study

The need for a delay study in highway safety applications is primarily determined by the occurrence of accident patterns identifying traffic congestion, i.e., rear-end, right-angle, or left-turn accidents near major intersection points. Other means of identification may come from field review findings or local complaints describing congested conditions at a site. These patterns occur typically during high traffic volume periods. These accidents often result in minor severity, generally consisting of "property damage only" accidents.

● Use of Intersection Delay Data

Information obtained from these studies are useful for:

- Identifying and defining sources of congestion for use in developing appropriate countermeasures.
- Calculating delay costs used in economic analysis for improvement justification purposes.
- Evaluating the effectiveness of various traffic improvements, such as determining the effectiveness of a change in signal timing.
- Providing a congestion index to be used in comparing different roadways for use in programming safety projects.

● Period of Data Collection

Intersection delay studies are typically performed during peak traffic volume hours (weekday) to obtain delay characteristics while traffic is operating under the severest conditions. The actual time period is established from the accident summary by time data. In some cases, a comparison of delay characteristics for peak and off-peak conditions may be desirable.

These studies should be performed under favorable weather conditions to obtain a sample of typical operating conditions. In addition, for "before-and-after" evaluation studies, it is necessary that similar traffic conditions exist during both periods of data collection.

- Sample Size Determination

For intersection delay studies, critical factors used to determine the required minimum sample size [4] include an estimate of stopped traffic, the permitted error, and the confidence level of the results. The required minimum sample size is determined from the following formula:

$$N = \frac{(1-p)X^2}{pd^2}$$

Where:

N = minimum sample size.

p = proportion of vehicles that are required to stop on the intersection approach.

X^2 = Chi-square value for the desired confidence level.

d = permitted error in the proportion estimate of stopping traffic.

Data on the proportion of stopped vehicles at an approach can be obtained in a number of ways as described below.

1. Past data for an approach may be used.

2. A sample field test of approximately 100 vehicles per approach may be obtained.

3. At signalized intersections, the ratio of the red time to the cycle length may be used.

The chi-square (X^2) value is obtained as a function of the confidence in the accuracy of the data. Typically, a 95 percent confidence level is acceptable for most traffic engineering situations. Chi-Square values and the respective confidence level are:

Chi-Square (X^2)	Confidence Level (%)
2.71	90.0
3.84	95.0
5.02	97.5
6.63	99.0
7.88	99.5

The permitted error is based on the reliability of the "p" value. A smaller value is used to assure greater reliability in the results.

- Example

A traffic engineer wishes to evaluate the effect of an existing traffic control on the south leg of an intersection. A sample field test was performed, and a "p" value of 0.70 for the approach was obtained. Selecting a confidence level of 95.0 percent and a permitted error of 0.10 (10 percent), the following values are obtained:

$p = 0.70$
$X^2 = 3.84$
$d = 0.10$

The minimum required sample size on this approach is:

$$N = \frac{(1.0 - 0.7)3.84}{0.7(0.10)^2} = 164 \text{ vehicles}$$

- Definition of Study Area

At intersections, the study area should extend far enough away from the center of the intersection so as to include all vehicles stopped or delayed as a result of the intersection operation or "bottleneck". A preliminary review of the site will assist in identifying this point. The end point of the study area should be situated following the major delay point or cause of delay. As a minimum, this point should be set immediately after the stop lines. A more appropriate end point would be the far side of the intersection.

Delay Study Techniques

To perform an intersection delay study, four alternate procedures [1,2] are available. They are:

- Point sample method.
- Input-output method.
- Path trace method.

● Modeling.

The point sample method[1,2,5] is based on the periodic sampling of the number of stopped or queued vehicles at an approach. In this method, an observer is stationed near or at the study approach. The number of vehicles stopped (or in the queue) on the intersection approach at successive intervals (such as every 15 seconds) are counted. At the same time a volume count of the approach traffic during the same time period is conducted. The length of sampling interval is selected such that repetitive sampling in the same interval of the signal cycle is avoided. For example, sampling at a 60-second cycle length location should use intervals of 25 second lengths rather than ten or fifteen seconds to avoid this effect. From the sampled count data and the volume data, an estimation of the vehicle-seconds of stopped time delay can be determined.

This method is self-correcting since each count interval is independent of the other intervals. If sampling intervals are designed properly, the results will not be influenced by the signal indication, thereby permiting accurate results. A major disadvantage is the possibility of inaccuracies in the sampling results where a high volume of sampled vehicles occurs, which may lead to biased results.

The input and output method[1,2,5] is similar to the point sample method except that vehicles are observed at the beginning (input) and end (output) of the intersection area. For the sampling procedure, the number of vehicles occupying an intersection approach at successive time intervals are recorded during the study period. Each successive count represents the instantaneous density (number of vehicles occupying the length of the intersection approach per time interval) of the approach. During the study period, the number of vehicles leaving the intersection approach is also counted. This count represents the approach volume. The combination of the instantaneous density information and the traffic volume permits the estimation of the average travel time.

This procedure, based on sampling techniques, permits the accumulation of a large amount of data in a relatively short amount of time. However, inaccuracies with this procedure may result from vehicles entering or leaving the study area between the input and output points.

The path trace method [1,2,5,6,7] is based on a sample of individual vehicles using the study approach. Data on each sample vehicle is recorded over the period of time the vehicle is within the study area. The information recorded can include total travel time, stopped time, time in queue, acceleration/deceleration characteristics, or other factors. The major drawback to this method is the amount of time required to obtain the required minimum sample size.

Modeling techniques [1,2] utilize mathematical relationships. Sample data are obtained, tested, and calibrated to develop a model. The results are based on theoretical distributions. The method is time consuming and requires substantial effort in altering the variables for each set of intersection conditions. This procedure is primarily limited to research purposes.

Techniques for performing these procedures include: sampling methods, photographic methods, observer methods, test-car techniques, license plate methods, mechanical recorder methods, and delay meter methods. Primary considerations of these techniques are included in Table 22.

● Sampling Methods

Sampling methods[1,2,5,11,12] use observers to sample vehicles both on an approach and leaving the intersection area. The observer counts the number of vehicles occupying or stopped at the approach in successive time intervals for a defined period. To obtain delay characteristics, the approach volume during the study period is counted. For travel time information, the volume of traffic leaving the intersection area is counted during the study period.

These volumes or totals are used to obtain specific delay data, such as: average travel time, total delay, average delay per approach vehicle, average delay per stopped vehicle, and the percent of vehicles stopped, as shown on the data sheet on the Appendix (page I-9). This method has been shown to provide reliable estimates of the delay characteristics at an intersection.

Advantages:

1. Simple to perform.
2. Obtains a large amount of data in a limited amount of time.
3. Results are reliable.
4. Equipment and manpower requirements are minimal.
5. Data manipulation is simple.

Disadvantages:

1. Delay and travel time represent averaged results.
2. Large volumes of stopped vehicles along an approach may limit the accuracy of the results.

This technique has been found to be highly effective in performing intersection delay studies. Its overall low cost, due to minimal time and equipment needs, makes this technique favorable.

● Photographic Methods

The photographic methods (described in the link studies section) can be used to obtain intersection delay information. Once the intersection is filmed, data can be extracted by a sampling or a license plate method.

Further information on this method is provided in Procedure 7 - "Volume Study."

● Observer Method

The observer method (described in the link studies section) is favorable in that it can easily trace a selected vehicle's path at and through the intersection. By recording traffic volume data, a single vehicles' delay may be used to represent the total queue volume for that period.

● Test-Car Techniques

The test-car techniques (described in link studies section) may also be used. However, the method is cumbersome to perform on an intersection basis and results in significantly greater time expenditures than other available methods.

● License Plate Method

The license plate method (described in link studies section) can be used to obtain intersection delay information. It usually requires a substantial amount of personnel to record the license plates at high volume approaches. In addition, timing of the vehicle delay may be approximate since it is difficult to record the delay time for a single vehicle in much less than minute or half-minute intervals.

● Mechanical Recording Method

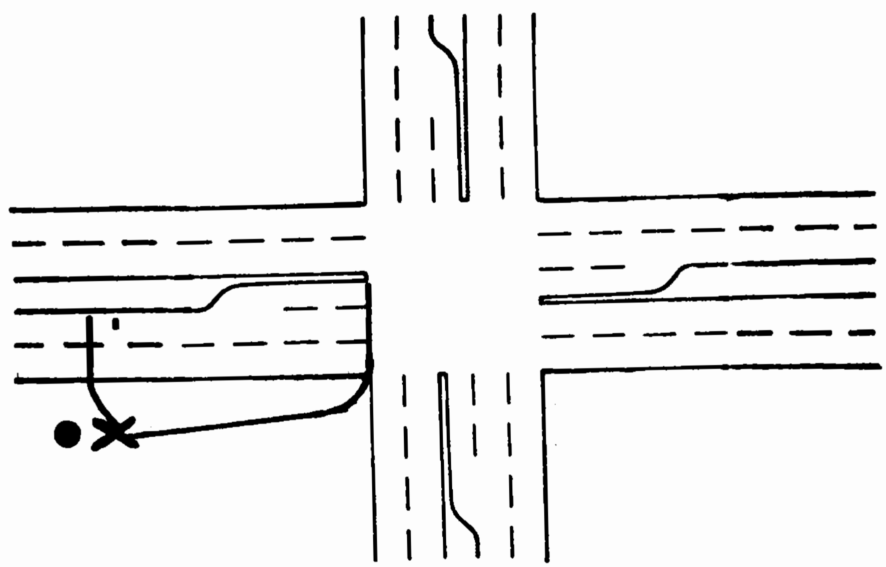
The mechanical recording method [5,6] is useful for intersection delay studies. This method uses road tubes or tapeswitches to transmit vehicle data to a recorder. A typical setup is shown in Figure 23. As the vehicle passes the initial study point, a mark is made on the recording tape. After passing the end point of the study area, another mark is recorded. The recording paper automatically advances in a time-related fashion. The indicator marks on the recording tape are then reviewed to obtain the travel time data. This method may require an observer to be stationed at the recorder to mark off those vehicles which do not pass completely through the test section.

Advantages:

1. Provides an accurate record of vehicle passage times.
2. Device is easy to operate.

Disadvantages:

1. Obtains only travel time information.
2. At intersection area, vehicle stopped on road tube or tapeswitch can produce inaccurate results.



LEGEND

● Observer
— Relay Device
X Mechanical Recording Device

Figure 23. Mechanical recording equipment set-ups.

3. Requires additional personnel to monitor data sheets (to obtain data on only those vehicles passing through the test section).
4. Data analysis can be time consuming.

This technique can provide highly accurate travel time data.

- Delay Meter Method

The delay meter method [5,6] permits the accumulation of vehicle-seconds of stopped time at intersections. Vehicles within a defined zone are counted and the amount of stopped time is measured using a delay meter, which is activated by an observer.

Advantages:

1. Simple to perform.
2. Time requirements are low.

Disadvantages:

1. Accuracy may be biased by observer actuating the delay meter.
2. Information is obtained only on the amount of stopped time delay.
3. Equipment and setup can be costly.

This technique is limited by the availability of the equipment. Since most agencies do not have access to this type of equipment, it is not often used.

Selection of Technique

Various techniques are available to perform these alternate procedures. To select the appropriate technique, the management concerns involved in the procedures need to be reviewed. The management concerns include the data collection capabilities, the level of accuracy, and the manpower, equipment, and time requirements of each technique. Table 23 displays the utility of each technique in relation to these management concerns. Table 24 displays available techniques used to perform the procedures as a function of the information obtained. Based on these tables, a favorable technique can be selected.

For intersection studies, the use of the sampling method is most favorable. The method typically requires a shorter time expenditure to obtain the minimum required sample and compute the findings. Other techniques require either substantial data collection or data analysis procedures. Where a record of the field situation is warranted, photographic techniques, utilizing the sampling method for data extraction, have proven effective.

Findings

For intersection delay and travel time studies, the output can be presented in a format similar to that shown in the bottom portion of Figure 21.

Results of an intersection delay study are usually given by calculating the following statistics for an intersection approach:

1. Total stopped-time delay in vehicle-seconds.
2. Average stopped-time delay per stopped vehicle in seconds.
3. Average stopped-time delay per approach vehicle.
4. Percentage of vehicles stopped.
5. Overall travel time.

● Use Of Findings

The effective use of intersection delay findings for determining the operating level of service at an intersection has not been defined at this time. While attempts have been made to compare the average delay per vehicle to the operating level of service, its effectiveness has not been proven. As a general guideline, average delay (stopped delay) per approach vehicle of 10 seconds or less at signal controlled intersections signifies efficient operation. Average delay values between 10 and 25 are typical and satisfactory while delay values of over 25 seconds indicate that some improvements might relieve the less than satisfactory flow conditions. For four-way stop locations, the improvement might take the form of traffic signal control.

The travel time and delay findings are used in the selection and evaluation of safety-related countermeasures. In selecting feasible countermeasures, delay data are used in the economic analysis to derive delay costs. Delay costs include: the time cost to an individual (resulting from "lost" time which could have been used in a productive manner) and the vehicle operating costs. These figures can be obtained from various references on roadway economics including:

1. <u>Economic Analysis for Highways</u> by R. Winfrey.

2. "Running Costs of Motor Vehicles as Affected by Road Design and Traffic", Paul J. Claffey, NCHRP 111.

The calculated delay costs are included in the economic analysis as a "disbenefit"; however, an anticipated improvement (reduction) in delay will result in a "benefit" being derived from the proposed improvement. Delay costs may also be included in formulas used in the scheduling or planning of improvements.

INTERSECTION DELAY STUDY
FIELD SHEET

Location MICHIGAN AVE. @ MILITARY AVE. Approach WEST Movement EB
Date 3/1/80 Weather CLEAR Study No. 1 Observer MAF

Time (minute starting at)	Total Number of Vehicles Stopped in the Approach at Time:				
	+0 sec	+15 sec	+30 sec	+45 sec	Exit Volume (V)
7:30 AM	0	5	12	21	40
7:31	28	3	4	8	75
7:32	11	18	2	5	52
7:33	7	3	11	28	43
7:34	40	16	4	1	71
7:35	0	5	16	19	63
7:36	26	7	2	11	63
7:37	31	14	2	6	58
7:38	16	38	14	4	71
7:39	3	8	22	33	60
Subtotal	162	117	89	136	
Total Density=N	504				596

AVERAGE TRAVEL TIME $(T) = \frac{N\,t}{V}$

$$(T) = \frac{504(15)}{596} = 12.68 \text{ seconds}$$

Figure 24. Sampling techniques - travel time data.

INTERSECTION DELAY STUDY
FIELD SHEET

Location MICHIGAN AVENUE @ MILITARY Approach WEST Movement EB
Date 3/1/80 Weather CLEAR Study No. 1 Observer MAF

Time (minute starting at)	Total Number of Vehicles Stopped in the Approach at Time:				Approach Volume	
	+0 sec	+15 sec	+30 sec	+45 sec	Number Stopped	Number Not Stopping
7:30 AM	0	4	11	19	22	18
7:31	28	0	0	6	30	45
7:32	9	18	0	2	20	32
7:33	0	0	8	24	24	19
7:34	39	14	2	0	39	32
7:35	0	4	16	19	22	41
7:36	26	6	0	9	23	40
7:37	31	12	2	6	38	20
7:38	15	38	14	0	39	32
7:39	0	6	22	33	35	25
Subtotal	148	102	75	118	292	304
Total	443				596	

Total Delay = Total Number Stopped x Sampling Interval

$= 443 \times 15 = 6645$ veh-sec

Average Delay per Stopped Vehicle $= \frac{\text{Total Delay}}{\text{Number of Stopped Vehicles}} = \frac{6645}{292} = 22.76$ sec

Average Delay per Approach Vehicle $= \frac{\text{Total Delay}}{\text{Approach Volume}} = \frac{6645}{596} = 11.15$ sec

Percent of Vehicles Stopped $= \frac{\text{Number of Stopped Vehicles}}{\text{Approach Volume}} = \frac{292}{596} = 0.49$ percent

Figure 25. Sampling techniques - delay data.

Finally, the use of the travel time and delay data for evaluation of countermeasures involves the measurement of characteristics "before" and "after" implementation of the countermeasures. Differences in "before" and "after" data are tested for significance.

● Example

An example of the sampling techniques used in determining intersection delay is given Figures 24 and 25 for obtaining the delay characteristics and the travel time data, respectively. Sample calculations are shown at the bottom of the data sheets. The example indicates an average delay per stopped vehicle of 22.8 seconds and an average delay per approach vehicle of 11.2 seconds. The sample size is equal to the total approach volume (596 vehicles). Using the general guidelines, this example does not indicate unusual delays.

PROCEDURE 10 Roadway And Intersection Capacity Study

Purpose

Highway capacity studies measure the ability (supply) of a highway facility to accomodate or service traffic volumes (demand).

Application

"Capacity" is defined as the maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or a roadway in one direction (or in both directions for a two-lane or three-lane highway) during a given time period under prevailing roadway and traffic conditions [1]. A comparison of actual traffic volumes to the computed capacity value is used to define the level of service of the facility.

The relationship between the level of service and safety of highway facilities have not been fully established through research. Until research is undertaken to develop precise relationships, it is not possible to directly use the results of a capacity analysis to infer that countermeasures that improve capacity will have a beneficial effect on safety. Nevertheless, capacity studies provide valuable information for many traffic safety engineering investigations.

For most roadway conditions, six levels of service are defined. They are:

Level of Service	Description
A	free flow
B	stable flow (upper speed range)
C	stable flow
D	approaching unstable flow
E	unstable flow
F	forced flow

Generally, levels of service "A", "B", or "C" are the most desirable conditions. They represent a stable traffic flow.

- Need For Capacity Study

The need for a highway capacity study is triggered by the occurrence of congestion related accidents (pattern of rear ends, right-angle, left-turn accidents during peak traffic periods), field observation of congestion or insufficient capacity conditions, and complaints by local citizens.

- Use of Capacity Study

The information obtained from a highway capacity study is used for:

- Planning and justifying safety countermeasures.
- Selecting a safety project.
- Evaluating the successful implementation of a safety project.

For example, assume two countermeasures are being considered for reducing accident frequency at a location. Also, assume countermeasure No. 1 will result in level of service "B" operation, as opposed to level of service "E", which is the existing condition at the location. Furthermore, countermeasure No. 2 is expected to have little effect on capacity. Based on capacity objectives, countermeasure No. 1 would likely be selected since it improves the operation of the location.

- Period Of Data Collection

Two types of data are typically collected for a capacity study. They are: roadway inventory information and volume data. The data differ by the techniques used to assess the roadway capacity.

The collection of roadway inventory data can be performed under varying traffic conditions. Traffic volume measurements, however, are normally obtained during peak traffic flow periods. Typical peak periods occur on weekdays (from Monday P.M. through Friday A.M.).

Alternate Techniques

Several techniques to determine capacity are available. Analysis methods include:

- *Highway Capacity Manual* (1965) charts.

- Northwestern University Signalized Intersection Capacity charts and nomographs by Jack E. Leisch.

- Interim Materials on Highway Capacity (TRB Circular No. 212).

- Critical movement analysis technique.

- Cycle sampling method.

Primary considerations of these techniques are identified in Table 25.

- Highway Capacity Manual

The 1965 Highway Capacity Manual (HCM) [1] provides the most complete and authoritative reference on capacity. It utilizes the following factors to determine the capacity of a facility.

- Roadway Factors
  - Approach width (urban)
  - Lane width (rural)
  - Lateral clearance
  - Shoulders
  - Auxiliary lanes
  - Surface conditions
  - Alignment
  - Grades

- Traffic Factors
  - Trucks
  - Buses
  - Lane distribution
  - Variations of traffic flow (load factors, peak hour factors)
  - Traffic interruptions (traffic signal, railroad crossing, etc.)
  - Turning traffic influence

In general, capacity computations involve the determination of an "unadjusted" capacity for a given set of standard conditions. This value is then adjusted by a series of multiplier factors to reflect the prevailing roadway, environment, and traffic conditions.

The support data for these computations are given in the HCM for different situations including:

- Freeway sections.
- Weaving sections.
- Ramp junctions.
- Signalized intersections.
- Urban and suburban arterials.
- Downtown (CBD) streets.
- Rural highways.

Based on empirical relationships, service volume or level of service characteristics can be defined through the use of charts, tables or formulas. Additional details of these formulas and charts are provided in the Highway Capacity Manual (1965).

Table 25. Primary considerations for Highway Capacity Study techniques.

Consideration / Technique	Function	Equipment Requirements	Time Requirements	Manpower Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Highway Capacity Manual	. Obtains capacity data for freeways, weave and merge sections, arterial streets, downtown streets, rural highways, and major intersections using table, charts, and formulas	. Highway Capacity Manual . Data sheets	. Approx. 15-45 minutes per site	. Trained technician or engineer to perform analysis	. HCM manual-$10	. Defined location . Roadway and roadside inventory . Signal timing (for signalized locations) . Volume measurements . Study period	. Available or design capacity	Service volumes and operating level of service of facility
2. Capacity Nomographs	. Obtains capacity of signalized intersections using charts derived from HCM data	. Set of charts . Data sheets	. Approx. 10-30 minutes per site	. Trained technician or engineer to perform analysis	. None	. Defined location . Roadway inventory . Signal timing (for signalized locations) . Volume measurements . Study period	. Available or design capacity	. Serivce volumes and operating level of service of facility
3. Interim Materials	. Obtains capacity of freeways, ramps, weaving sections, and unsignalized intersections using charts and formulas	. TRB Circular 212 . Data sheets	. Approx. 30-60 minutes per site	. Engineer to perform analysis	. TRB Circular 212 - $6	. Defined location . Roadway and roadside inventory . Signal timing (for signalized locations) . Volume measurements . Study period	. Available or design capacity	. Operating service volumes and level of service
4. Critical Lane	. Obtains level of service of signalized intersections using additive procedures based on sum of conflicting movement	. Data sheets	. Approx. 10-20 minutes per site	. Trained technician or engineer to perform analysis	. None	. Defined location . Roadway inventory . Volume measurements obtained during peak hour . Study period	. Critical lane summation	. Estimate of operating level of service
5. Cycle Sampling	. Obtains a measure of level of service of measuring percentage of fully loaded cycles	. Data sheets	. Approx. 20-80 minutes per site	. Technician to collect data . Technician to adjust data	. None	. Defined location . Cycle length . Study period	. Number of fully loaded cycles	Estimate of level of service

Advantages:

1. Is nationally accepted.
2. Provides capacity and level of service information for a wide range of highway situations.
3. Relationships are defined in simple terms and calculations are easy to perform.

Disadvantages:

1. Some of the analyses contain inconsistencies.
2. May require considerable analysis to obtain level of service information for intersections.

A basic limitation of this method is the time required to perform intersection analysis. Several steps, i.e., reading graphs and charts and using various formulae, are required to obtain a capacity value. However, this is only a minor limitation and does not reduce the overall effectiveness and applicability of this method to most highway situations.

- Northwestern University Capacity Charts

The Northwestern signalized intersection capacity charts and nomographs [2,3] utilize the *Highway Capacity Manual* data for intersection capacity. The nomographs are designed to simplify and reduce the work that otherwise would be required by the long-hand computational approach of the *Manual*. Data input requirements are similar to the HCM method.

The various adjustment factors, e.g., truck percentages, left-turn and right-turn percentages, etc., are incorporated into a nomograph so that for any known condition, intersection capacities can be obtained directly without reference to the *Manual*. The resultant output from these charts, for all practical purposes, are similar to those produced by the *Manual*.

Advantages:

1. Provide results similar to those obtained with the *Highway Capacity Manual (1965).*
2. Simple to perform.
3. Requires limited calculations.

Disadvantages:

1. Graphical readings may produce slight inaccuracies.
2. Limited to signalized intersection analysis.

These nomographs are currently used by many agencies throughout the U.S. and are most appropriate for intersection applications.

● Interim Materials Guide

A considerable number of studies related to highway capacity have been completed since the 1965 HCM was published. To supplement current Manual procedures, a set of Interim Materials on Highway Capacity [4] was recently published by the Transportation Research Board. It is currently under a two-year trial and evaluation period to be completed by January, 1982. The Interim Materials provide updated procedures in the following areas:

- Signalized intersections - critical movement analysis.
- Unsignalized intersections - two-way stop and yield sign locations.
- Weaving analysis.
- Freeway capacity.
- Pedestrian analysis.
- Transit analysis.

The procedure developed for unsignalized intersection capacity is only applicable to intersections with two-way stop signs or to locations where yield signs are posted. The first step of the procedure involves calculating the maximum flow available for each minor approach. Comparison of these values to the existing demand yields an estimate of the level of service and the anticipated delay. The procedure includes adjustment factors for conditions such as: the effects of main roadway traffic waiting to make left-turns; lane configuration on the minor approach; and shared lane movements, i.e., right and through vehicles using the same lane.

The sections of the Interim Materials that address weaving analysis and freeway capacity procedures are major supplements to the 1965 Manual techniques. The Interim Materials specifically deal with the following freeway components.

- Basic Freeway Segments.
- Weaving Areas.
- Ramp Junctions.

The Interim Materials for freeway capacity analysis are organized into the following parts:

1. Basic Characteristics - The basic factors and items which affect the basic factors are presented along with equations, graphs, and other supporting materials.

2. Computational Procedures - A step-by-step procedure is given for conducting the analysis.

3. Sample Problems - Examples of the methodology are presented for a variety of applications.

The procedure for determining the capacity of freeway segments in the Interim Materials is similar to the technique outlined previously for the HCM; however, new charts, correction factors, and level of service ranges are given to reflect changes in roadway, vehicle, and driver characteristics. The section on weaving analysis was derived from the results of recent research investigations. Two procedures are available. They are more complicated than in the HCM. However, the procedures have tended to reduce inconsistencies in the weaving procedures, such as the definition of the quality of flow and level of service.

● Critical Movement Analysis

The critical movement analysis technique (TRB 212) [4,5,6] provides a quick and efficient method of estimating the intersection level of service. The method utilizes input relating to intersection geometric layout, traffic volumes and traffic signal phasing for computing a total intersection critical volume. In this technique, critical movements are determined and summed for each signal phase. These volumes are compared to the level of service criteria as shown in Table 26 to determine the operating level of service.

Table 26. Critical volume and level of service relationships.

Level of Service	Description	Critical Volumes		
		2-Phase	3-Phase	Multi-Phase
A	Free	900	855	825
B	Stable (upper speed range)	1,050	1,000	965
C	Stable	1,200	1,140	1,100
D	Unstable	1,275	1,200	1,175
E	Capacity	1,500	1,425	1,375

Source: TRB Circular No. 212

Initially, observed traffic volumes are distributed to the available traffic lanes. This is achieved by placing traffic in its expected travel path using lane use factors. For instance, if 1,000 vehicles are observed on a two lane approach during the peak hour, the lane distribution would be:

1,000 x 0.55 = 550 vehicles in one lane
1,000 - 550 = 450 vehicles in the other lane

The lane carrying 550 vehicles is identified as the critical volume for that approach. Traffic would be assigned using similar factors for approaches with more than two lanes. If the volume had been recorded separately for each approach lane, then the actual volumes would be used instead of the estimated lane utilization factors.

From signal phasing patterns, critical movements are then determined. By summing conflicting movements using the highest volume lane for each specific movement, a volume associated with each critical movement or phase is computed. The critical movements are then summed to produce a critical volume. The level of service is determined by comparing the critical volume to the service volume ranges shown in Table 26.

This technique is currently being used by a number of agencies, and has been used primarily for planning purposes. It should be noted that more detailed methodologies, incorporating truck, lane width, and other equivalency factors have been introduced to improve the accuracy of the results.

Advantages:

1. Provides an estimate of the total intersection level of service.
2. Effects of design and operational changes can be evaluated.
3. Uses simple and quick computations.

Disadvantages:

1. Requires knowledge of lane utilization for accurate results.
2. Use of design factors can result in lengthy computations.
3. Requires knowledge of the operation of the adjacent intersection and roadways.
4. Levels of service criteria used are questionable dependent on the number and extent of the various adjustment factors.

Application of this technique is restricted to signalized intersections, where its use is highly recommended. However, where the computed level of service by this method approaches a critical point (level of service D, E, or F), the HCM or nomograph technique should be used to provide a more detailed evaluation of the individual intersection approaches.

● Cycle Sampling Method

The cycle sampling method is based on a measurement of the number of fully loaded signal phases resulting from a continuous traffic demand on an approach. The number of fully loaded phases is compared with the available number of cycles during the observation period to determine a load factor. Levels of service related to the load factor are shown below. These values were obtained from the 1965 HCM.

Level of Service	Load Factor
A	0.0
B	0.1
C	0.3
D	0.7
E	1.0

This technique is performed in the field during the peak period. The results are used to assess a peak hour level of service based on the sample counting period. Since this technique is a sampling technique, it may be feasible to count as little as 15 continuous minutes of operation per approach. However, the sample period should include the peak period within the hour to limit the influence of lower volumes on the critical peak periods.

Advantages:

1. Provides a quick estimate of the intersection level of service.
2. Requires a limited data collection period.
3. Requires minimal data analysis.

Disadvantages:

1. Results may be biased by the sample obtained.
2. Provides an estimate for operating level of service.
3. Load factor may not relate to actual level of service.

This method is used at signalized intersections. The use of the load factor as a measure of the level of service may lead to inaccuracies in the data findings. The load factor represents the percent of fully utilized green phases within the peak hour. A load factor of 1.0, representing 100 percent of green phases being fully loaded may not, however, represent unstable flow conditions. Rather, full utilization of green phase may represent a stable flow if the demand rate is equal to the service rate. This method is useful as an approximate method for determining the level of service. It is not extremely useful for highway safety applications.

Selection Of Alternate Techniques

The selection of the appropriate highway capacity analysis technique is dependent on the management concerns of the procedure. For capacity procedures, these concerns include the specific application of the procedure, the level of accuracy of the results, and the time, equipment, and manpower requirements of each technique. Table 27 displays the utility of each technique in relation to these management concerns. Based on the

Table 27. Technique utility for Highway Capacity Studies.

Technique / Management Concerns	Highway Capacity Manual	Capacity Nomo-graphs	Critical Movement Analysis	Cycle Sampling	TRB 212 - Interim Materials
. Level of Application	. Freeways, weaving and ramp junctions, urban and suburban arterials CBD (downtown) streets, rural highways, signalized intersections	. Signalized intersections	. Signalized intersections	. Signalized intersections	. Freeway, weaving and ramp junctions, unsignalized intersections, pedestrian walkways and signalized intersection (critical movement analysis)
. Level of Accuracy	. Detailed analysis of situations	. Detailed analysis by approach	. Detailed analysis by total intersection	. Approximate analysis by approach	. Detailed analysis of situations
. Time Requirements	. Require table look up and calculations	. Permits simple table look up	. Requires calculations and some table look up	. Requires single simple calculations	. Requires table look up and calculations
. Equipment Requirements	. Highway capacity manual	. Set of nomographs	. Minimal	. Minimal	. Interim Guide
. Manpower Equipment	. Engineer level	. Engineer level	. Engineer level	. Technician level	. Engineer level

Table 28. Favorable Highway Capacity Study techniques.

Technique / Application	Highway Capacity Manual	Capacity Nomographs	Critical Lane Analysis	Cycle Sampling	Interim Materials
. Freeways	X				X
. Weave and Ramp Junctions	X				X
. Urban and Suburban Arterials	X				
. CBD (Downtown) Streets	X	X	X		
. Rural Highways	X				
. Major Intersection		X	X	X	
. Unsignalized Intersections					X

specific needs of the procedure, Table 28 provides a list of available techniques to determine the capacity of a roadway or intersection.

Table 28 is used to identify alternate techniques available to perform the capacity procedure. Where several techniques are appropriate for a situation, a review of the management concerns shown in Table 27 is made to select an appropriate technique.

General guidelines used in selecting a technique include the following:

1. The Highway Capacity Manual (HCM) and Interim Materials, due to their wide range of applications and overall reliability in their findings are favorable for use in most situations.

2. Where analysis of signalized intersections is required, the nomograph method may be favorable. It uses the HCM data and combines several tables used in the HCM method onto a nomograph, allowing for a more efficient technique.

3. The critical movement technique is a useful method for signalized intersections where the overall intersection operation is being evaluated. Critical movement analysis has not been used significantly throughout the U.S. Recent attempts to encourage its use (through workshop sessions and classes) have tended to provide more widespread use of this technique.

4. The cycle sampling method is favorable as a guideline for capacity evaluation of existing signalized intersections. It is not intended for planning or design purposes.

Findings

Highway capacity results can be summarized in the form of tables comparing the existing use of the facility to the design capacity of the facility. A sample table is shown in the Appendix (page I-10). For special use lanes, i.e., left-turn lanes, right-turn lanes, capacity analysis is normally conducted as a separate item.

● Use Of Findings

Findings from a highway capacity study provide a measure of the level of service for a facility. Using the Highway Capacity Manual, the Northwestern nomographs, or the Interim Materials Guide, the findings will produce a "service volume" (available capacity for a defined level of service) of the facility for a given level of service. Level of service "E", denoting maximum capacity is commonly used. The observed volumes for the site are then compared to the service volume to develop a volume/capacity (V/C) ratio. Values of the V/C ratio for specific levels of service are:

V/C Ratio	Level of Service
0.0	A
0.1	B
0.3	C
0.7	D
1.0	E

These ratios are used to describe the level of service and to suggest the need for improvement. Level of service "D" and "E" will typcially warrant an improvement.

The findings from the critical lane analysis and cycle sampling methods result in a direct measurement of the level of service. The critical lane technique describes the overall intersection operation while the cycle sampling method assesses the level of service by intersection approach.

The results of the highway capacity procedure relates the traffic handling capabilities of a facility, and can be used to provide input on congestion-related safety deficiencies. Its primary use, however, is as input in the selection of countermeasures.

● Example 1 - CRITICAL MOVEMENT ANALYSIS

An example of this technique is given below for a three-phase intersection during the evening peak hour, as shown in Figure 26. It is assumed that the volumes are based on observed data. Since observed lane volumes are used, lane use factors are unnecessary.

By phase and lane use, the respective critical volumes are:

PHASE 1 - Southbound through - 280
- Southbound right - 210
- Northbound through - 340
- Northbound right - 130

PHASE 2 - Southbound left-turn - 130
- Northbound left-turn - 150

PHASE 3 - Eastbound through and left-turn - 400
- Eastbound through and right-turn - 320
- Westbound through and left-turn - 300
- Westbound through and right-turn - 325

The critical volume of each phase represent the highest volume for conflicting movements. As such, the following critical volumes are defined:

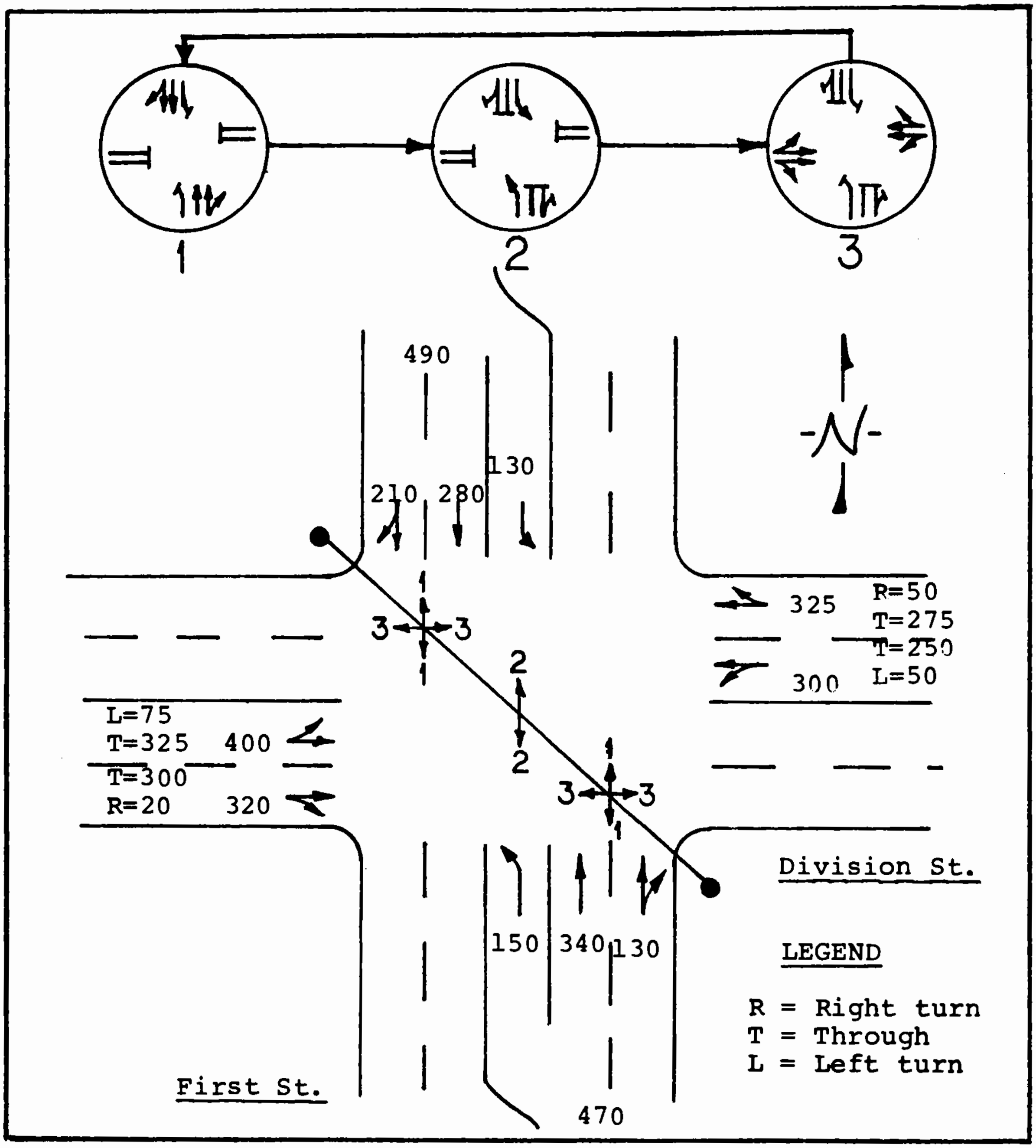


Figure 26. Critical movement technique - example diagram.

PHASE 1 (no conflicting movements) - Northbound through volume = 340 vehicles

PHASE 2 (no conflicting movements) - Northbound left-turn volume = 150 vehicles

PHASE 3 (conflicting movement between left-turn traffic and opposing through and right-turn traffic) - Eastbound left-turn and westbound through and right-turn = 75 + 325 = 400 vehicles

or,

- Westbound left-turn and eastbound through and right-turn = 50 + 325 = 375 vehicles.

PHASE 3 (critical volume) = 400 vehicles

Summarizing these volumes, the total critical volume is:

PHASE 1 - 340 vehicles
PHASE 2 - 150 vehicles
PHASE 3 - 400 vehicles
890 vehicles

From the previous table for a three-phase signal, this intersection operates at level of service "B".

● Example 2 - HIGHWAY CAPACITY MANUAL

Assume conditions for a signalized intersection as given below. The cycle length during the evening peak hour is 80 seconds with a phase timing plan of:

$\emptyset_1$ = (G/C) = 0.40 (40%)
$\emptyset_2$ (G/C) = 0.10 (10%)
$\emptyset_3$ (G/C) = 0.35 (35%)
amber phases (total) = 0.15 (15%)

Other factors are:

- lane width = 12 feet
- 2 thru lanes and one-left turn lane per approach.
- area = central business district
- metropolitan area = over 1,000,000 population
- peak hour factor (assumed) = 0.85
- separate left-turn lanes for 1st. Street
- 1st. Street right-turns = 10%
- Division Street left-turns = 5%
- Trucks and through buses = 4%
- No parking in area.

Compute the service volumes and V/C ratio of the north approach.

In computing the capacity, the chart (taken from HCM) shown in Figure 27 is used for an urban intersection approach on a two-way street with no parking.

NORTH APPROACH

Approach width (exclusive of left-turn lane) = 24'

Service Volume (through and right-turn) L.O.S. "E" =

$\frac{\text{2100 veh.}}{\text{hr. of green}}$ x (peak hour factor adjustment) X

(location within metro area-CBD factor) X

(adjustment for right-turns - 10%) X

(adjustment for left-turns - 0%) X

(adjustment for trucks and through buses) X

(G/C ratio for approach)

$= \frac{\text{2,100 veh.}}{\text{hr. of green}} \times 1.14 \times 1.00 \times 1.00 \times 1.10 \times 1.01 \times 0.40$

= 2,100 veh. x 0.51 = 1071 vehicles

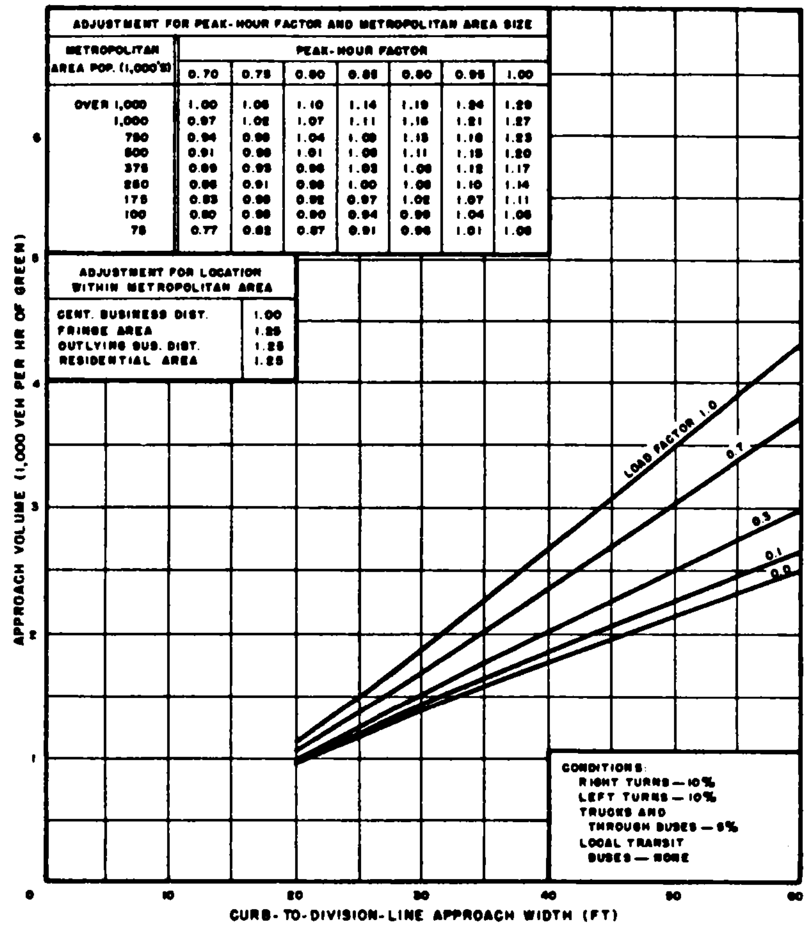
The observed through and right-turn volume during the peak hour is 490 vehicles.

The V/C ratio is: $\frac{490}{1071} = 0.46$

This represents a level of service "C" condition representing a stable flow.

For the separate left-turn with signal control, the capacity is defined by:

$$C = L \times G/C \times \frac{W}{10[1+0.8(N-1)][1-0.01(T-5)]}$$



Source: Highway Capacity Manual, HRB SR 87

Figure 27. HCM chart-example.

Where:

C = capacity

L = turn lane volume per hour of green time per 10 foot width (from HCM table)

G/C = "green time to cycle length" ratio of the separate lane

W = width of turn lane, ft.

N = number of turn lanes

T = truck percentage

$$\text{Capacity} = 1200 \times 0.10 \times \frac{12}{10[1+0.8(1-1)][1-0.01(4-5)]}$$

$$= 1200 \times 0.10 \times 1.19 = 143 \text{ vehicles}$$

The observed left-turn lane volume is 130 vehicles. The V/C ratio is:

$$\frac{130}{143} = 0.91$$

This represents a level of service "D" operation, indicating an unstable flow.

PROCEDURE 11 Traffic Conflict Study

Purpose

Traffic conflict studies are used in the diagnosis of safety and operational problems at a highway location. Traffic conflict counts can supplement routine field inspections of high-accident locations or they can be conducted at suspected hazardous sites.

Application

A traffic conflict occurs when a driver takes evasive action such as braking or weaving to avoid a collision. The collection, summarization, and analysis of conflict data comprises a traffic conflict study. Many safety engineers believe traffic conflicts to be an indicator of the accident potential at a site. However, defined relationships between conflicts and accidents have not yet been clearly established.

The traffic conflict technique (TCT) was originally developed by the General Motors Research Laboratories in 1967 [1,2]. The technique was designed to be a systematic method of observing and measuring accident potential at intersections. Since then, it has been modified and used by various U.S. highway agencies, particularly in the States of Ohio, Virginia, Kentucky, and Washington [3,4,5,6]. Various other countries including England, Sweden, and Canada have developed and utilized their versions of the traffic conflict technique [6,7,8,9]. Time lapse photography and video-taping is commonly used in these countries for collecting conflict data.

A traffic conflict study may involve identifying conflict categories by type, as well as determining conflict frequencies, rates, and severities (nearness to an accident). The conflicts are recorded and analyzed to provide input to meet the study purposes. In addition, a diagram may be prepared to graphically display the data.

● Use of Traffic Conflict Study

A traffic conflict study is useful for several purposes. In some cases, detailed accident information is unavailable, and in these cases, conflict data can serve as a replacement for these records to diagnose safety deficiencies.

Conflict studies can also be conducted to assist in the selection of safety-related countermeasures. For this application, traffic conflicts can provide valuable information in the study of hazardous locations, particularly at urban, signalized intersections where a significant number of conflicting movements normally occur in or near the intersection area. Countermeasures may be developed or selected to alleviate certain noticeable conflict types.

In the Evaluation Component of the Highway Safety Improvement Process, traffic conflicts can be used as a "measure of effectiveness" for a project. Their use in this way is favorable for intersections containing significant traffic volumes and a variety of conflicting traffic movements.

● Traffic Conflict Definitions

The TCT procedure discussed herein is based on NCHRP Report 219 [10], as completed by Midwest Research Institute (1980). Definitions of specific conflict types pertinent to most conflict studies are as follows:

● Left-Turn, Same-Direction Conflict

A left-turn, same-direction conflict occurs when the first vehicle slows to make a left-turn, thus placing a second, following vehicle in danger of rear-end collision. The second vehicle brakes or swerves, then continues through the intersection (see Fig. H-3 of Figure 28.)

● <u>Right-Turn, Same-Direction Conflict</u>

A right-turn, same-direction confict occurs when the first vehicle slows to make a right-turn, thus placing a second, following vehicle in danger of a rear-end collision. The second vehicle brakes or swerves, then continues through the intersection (see Fig. H-4 of Figure 28.)

● <u>Slow-Vehicle, Same-Direction Conflict</u>

A slow-vehicle, same-direction conflict occurs when the first vehicle slows while approaching or passing through an intersection, thus placing a second, following vehicle in danger of a rear-end collision. The second vehicle brakes or swerves, then continues through the intersection (see Fig. H-5 of Figure 28).

The reason for the vehicle's slowness may not be evident, but it could simply be a precautionary action, or a result of congestion or some other cause beyond the intersection.

● <u>Opposing Left-Turn Conflict</u>

An opposing left-turn conflict occurs when an oncoming vehicle makes a left-turn, thus placing a second vehicle, going in the other direction, in danger of a head-on or broadside collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Fig. H-6 of Figure 28).

By convention, in this and the following conflict situations, the conflicting vehicle is presumed to have the right-of-way, and this right-of-way is threatened by some other road user. Situations such as a "conflicted" vehicle placed in danger of a collision because it is running a red light, for example, are not treated as traffic conflicts.

● <u>Right-Turn, Cross-Traffic-From-Right Conflict</u>

A right-turn, cross-traffic-from-right conflict occurs when a vehicle approaching from the right makes a right-turn, thus placing a second vehicle in jeopardy of a broadside or rear-end collision. The second vehicle brakes or swerves, then continues through the intersection (see Fig. H-7 of Figure 28 for the direction of the two vehicles).

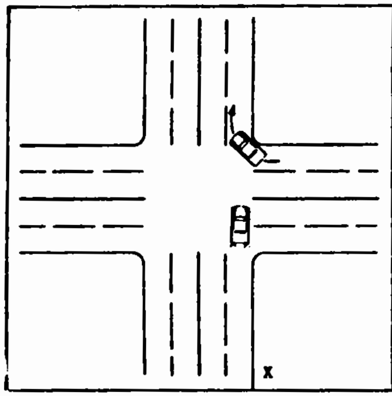


Figure H-7. Right-turn, cross-traffic-from-right conflict.

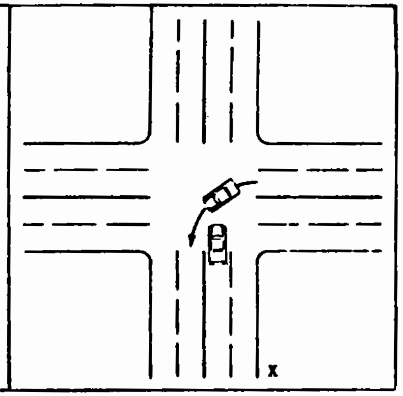


Figure H-8. Left-turn, cross-traffic-from-right conflict.

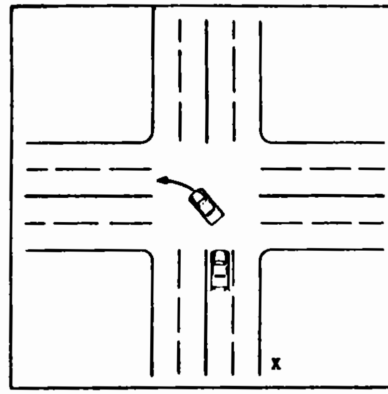


Figure H-3. Left-turn, same-direction conflict.

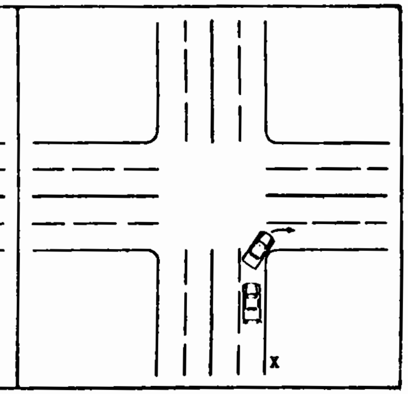


Figure H-4. Right-turn, same-direction conflict.

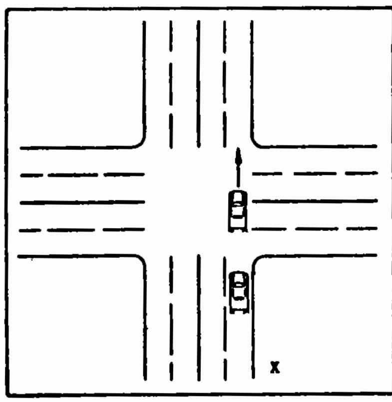


Figure H-5. Slow-vehicle, same-direction conflict.

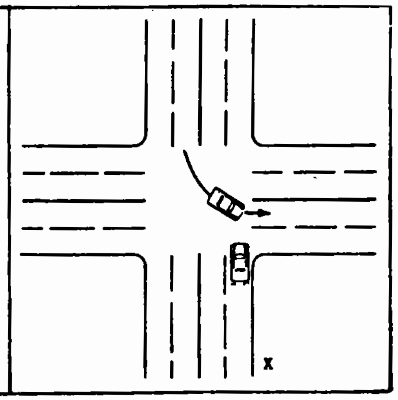


Figure H-6. Opposing left-turn conflict.

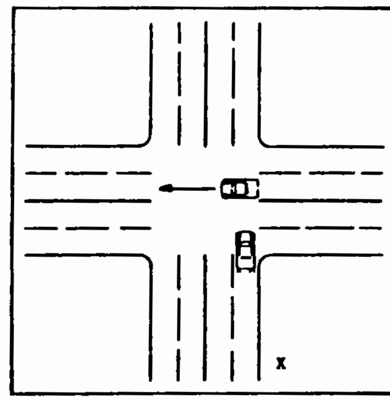


Figure H-9. Thru, cross-traffic-from-right conflict.

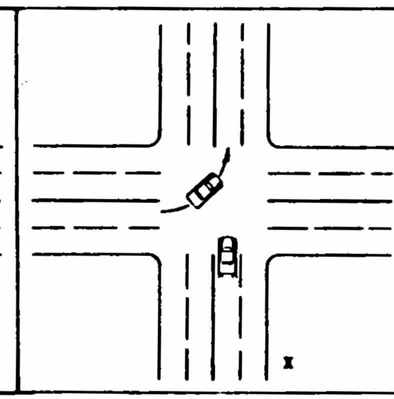


Figure H-10. Left-turn, cross-traffic-from-left conflict.

*Source: "Application of Traffic Conflict Analysis at Intersections", Glauz, W.D. and Migletz, D.J., NCHRP 219, February 1980.

Figure 28. Conflict types.

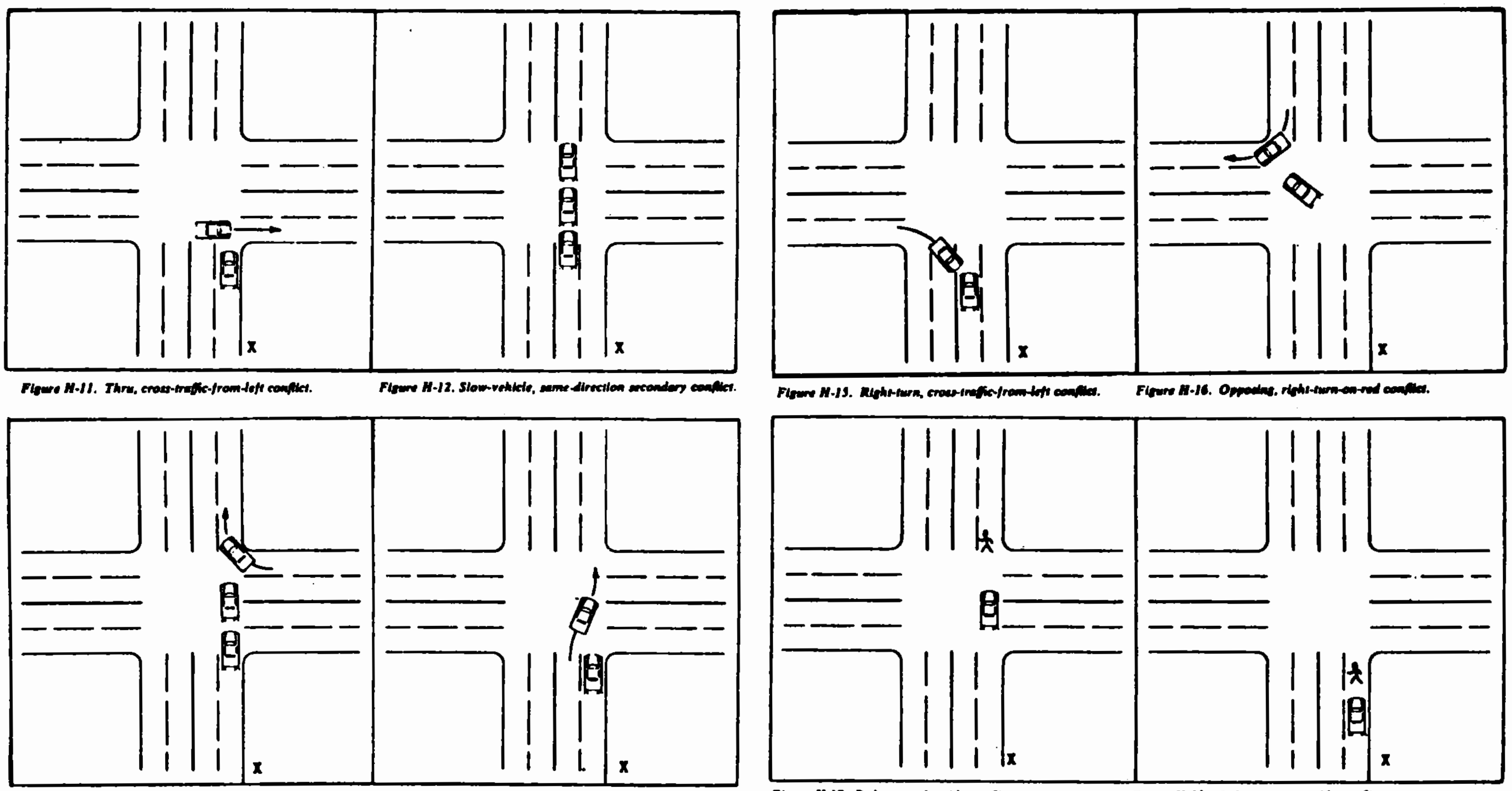


Figure H-11. Thru, cross-traffic-from-left conflict.

Figure H-12. Slow-vehicle, same-direction secondary conflict.

Figure H-15. Right-turn, cross-traffic-from-left conflict.

Figure H-16. Opposing, right-turn-on-red conflict.

Figure H-13. Right-turn, cross-traffic-from-right secondary conflict.

Figure H-14. Lane-change conflict.

Figure H-17. Pedestrian, far-side conflict.

Figure H-18. Pedestrian, near-side conflict.

*Source: "Application of Traffic Conflict Analysis at Intersections", Glauz, W.D. and Migletz, D.J., NCHRP 219, February 1980.

Figure 28. Conflict types (continued).

● Left-Turn, Cross-Traffic-From-Right Conflict

A left-turn, cross-traffic-from-right conflict occurs when a vehicle approaching from the right makes a left-turn, thus placing a second vehicle in danger of a broadside collision. The second vehicle brakes or swerves, then continues through the intersection (see Fig. H-8 of Figure 28).

● Thru, Cross-Traffic-From-Right Conflict

A thru, cross-traffic-from-right conflict occurs when a vehicle approaching from the right crosses in front of a second vehicle, thus placing it in danger of a broadside collision. The second vehicle brakes or swerves, then continues through the intersection (see Fig. H-9 of Figure 28).

● Left-Turn, Cross-Traffic-From-Left Conflict

A left-turn, cross-traffic-from-left conflict occurs when a vehicle approaching from the left makes a left-turn, thus placing a second vehicle in danger of a broadside or rear-end collision. The second vehicle brakes or swerves, then continues through the intersection (see Fig. H-10 of Figure 28).

● Thru, Cross-Traffic-From-Left Conflict

A thru, cross-traffic-from-left conflict occurs when a vehicle approaching from the left crosses in front of a second vehicle, thus placing it in danger of a broadside collision. The second vehicle brakes or swerves, then continues through the intersection (see Fig. H-11 of Figure 28).

● Secondary Conflicts

In the foregoing nine conflict situations, when the second vehicle makes an evasive maneuver, it may place yet another road user (a third vehicle) in danger of a collision. This type of event is called a "secondary conflict". Nearly always, the second conflict will look much like a slow-vehicle, same-direction conflict (or a lane-change conflict, which has not yet been described). The difference is that, in a secondary conflict, the conflicted vehicle is responding to a vehicle that, itself, is in a conflict situation (see examples in Figs. H-12 and H-13 of Figure 28).

By convention, more than one secondary conflict for any initial conflict is not counted. Even if a line of cars stops because the first one turns left, it is counted as a single secondary conflict.

● Other Types of Traffic Conflicts

Under certain special conditions, one may be asked to watch for and record other types of traffic conflicts. One such conflict is the "lane-change conflict", which occurs when a vehicle changes from one lane to another, thus placing a second, following vehicle in the new lane in danger of a rear-end or sideswipe collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Fig. H-14 of Figure 28). However, if the lane change is made by a vehicle because it is in danger, itself, of a rear-end collision with another vehicle, the following vehicle in the new lane is said to be faced not with a lane-change conflict situation, but with a secondary conflict situation.

Another unusual conflict is the "right-turn, cross-traffic-left" conflict. It occurs when a vehicle approaching from the left makes a right-turn across the center of the roadway and into an opposing lane, thus, placing a vehicle in that lane in danger of a head-on collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Fig. H-15 of Figure 28). This conflict is sometimes observed when the cross street is narrow, or when large trucks or buses make right-turns. The first vehicle must cross the center line for a conflict to exist.

An "opposing right-turn-on-red" conflict can only occur at a signalized intersection with a protected left-turn phase. Such a conflict occurs when an oncoming vehicle makes a right-turn-on-red during the protected left-turn phase, thus, placing a left-turning, conflicted vehicle (which has the right-of-way) in danger of a broadside or rear-end collision. The conflicted vehicle brakes or swerves, then continues through the intersection (see Fig. H-16 of Figure 28).

There can also be "pedestrian" conflicts, which occur when a pedestrian (the road user causing the conflict) crosses in front of a vehicle that has the right-of-way, thus, creating a possible collision situation. Any such crossing on the near side or far side of the intersection (see Figs. H-17 and H-18 of Figure 28) is liable to be a conflict situation. However, the pedestrian movements on the right and left sides of the intersection are not considered to create conflict situations if the movements have the right-of-way, such as during a "walk" phase.

In addition, a special type of study exists for conflicts termed "erratic maneuvers". A study of erratic maneuvers [11] records any sudden, unexpected movement by a vehicle which could result in an accident. It differs from a true conflict in that it usually involves only one vehicle commiting an unsafe movement independent of other vehicles. An example would be a vehicle crossing the centerline of a two lane roadway in a curve section. Other vehicles are not present to produce a conflict, however, this situation can be extremely hazardous to oncoming traffic.

● Data Collection Requirements

Prior to performing the conflicts procedure, it is necessary that the observers understand and be familiar with the specific conflict types, which will reduce misinterpretation of data and result in greater accuracy. To insure repeatability of the data between observers, they should discuss among themselves the conflict types and their use in field situations.

Observers should be trained in the traffic conflict technique prior to data collection. Training requires the supervision of a person experienced in the performance of the traffic conflicts technique. A period of one to two weeks is normally required for most training purposes. An important part of the training is the actual observation of conflicts at field sites.

Other data will also be obtained to effectively use the traffic conflict data. These include traffic volume and roadway inventory data.

● Period of Data Collection

For most safety applications, data collection requires a minimum of three days of observation. For low volume sites, however, a longer period may be necessary. A single day may be used where it can be assumed that the collected data will be repeatable on similar days.

Conflict data is collected on typical weekdays, unless indicated otherwise based on accident data. It is desirable to collect data during the peak or higher volume hours to limit data collection efforts and to diagnose safety problems under the anticipated peak conflict conditions. The conflict data should be collected under favorable weather conditions to eliminate any influence of the weather on the results of the study. The accident data may, however, dictate other periods of study.

It is also preferable that data be collected during each of the various peak periods during a day to allow identification of conflict patterns throughout the day.

Traffic Conflict Technique

● Survey Requirements

A general purpose form for collecting traffic conflict data at intersections is shown in the Appendix (page I-11), as developed in NCHRP 219 [10]. Information on the day, date, and observer should be completed prior to the field work. The actual beginning and ending count times should be recorded in the left column of the form. Data should normally be collected in 20-minute intervals. A mechanical count board may also help in recording all traffic conflict types.

Generally, a two-man survey team is used. The trained survey personnel observe the same intersection approach leg at the same time. One person observes and records the conflict information while the other person records volume data. Where specific traffic movement by lane is not required, portable counters can be used to reduce manpower requirements. In many situations, manual counting of traffic volumes is necessary.

The survey team is stationed approximately 100-300 feet (35-100 m) from the intersection in order to observe a specific approach. The distance is dependent on the anticipated queue backup during the sampling (survey) periods. It is necessary to be situated so as to be able to accurately observe all the vehicles and recognize activation of brake lights and weave movements.

When the survey begins, the observers record the volume and conflict information on the data sheets. Severe conflicts and special or unusual types of events should also be recorded on the data form. The data may include "erratic maneuvers" which are similar to traffic conflicts but are single vehicle events.

Time-lapse photography can be used to study conflict situations. Photographic means are particularly appropriate when studying erratic maneuvers, low volume locations, expected low conflict situations, and other situations which could require excessive time expenditures if manually observed. Further details of the conflicts counting procedure and minimum data requirements can be found in NCHRP Report No. 219 [10]. The major considerations of the traffic conflicts technique is shown in Table 29.

Findings

After traffic conflict data are collected and summarized, they must be properly analyzed to help determine specific locational problems that may exist. One way to display conflict data for further analysis purposes is with a Conflict Diagram, an example of which is shown in Figure 29. The diagram is prepared in much the same way as a collision diagram. One arrow per conflict type is shown with the number of routine and/or moderate conflicts per hour.

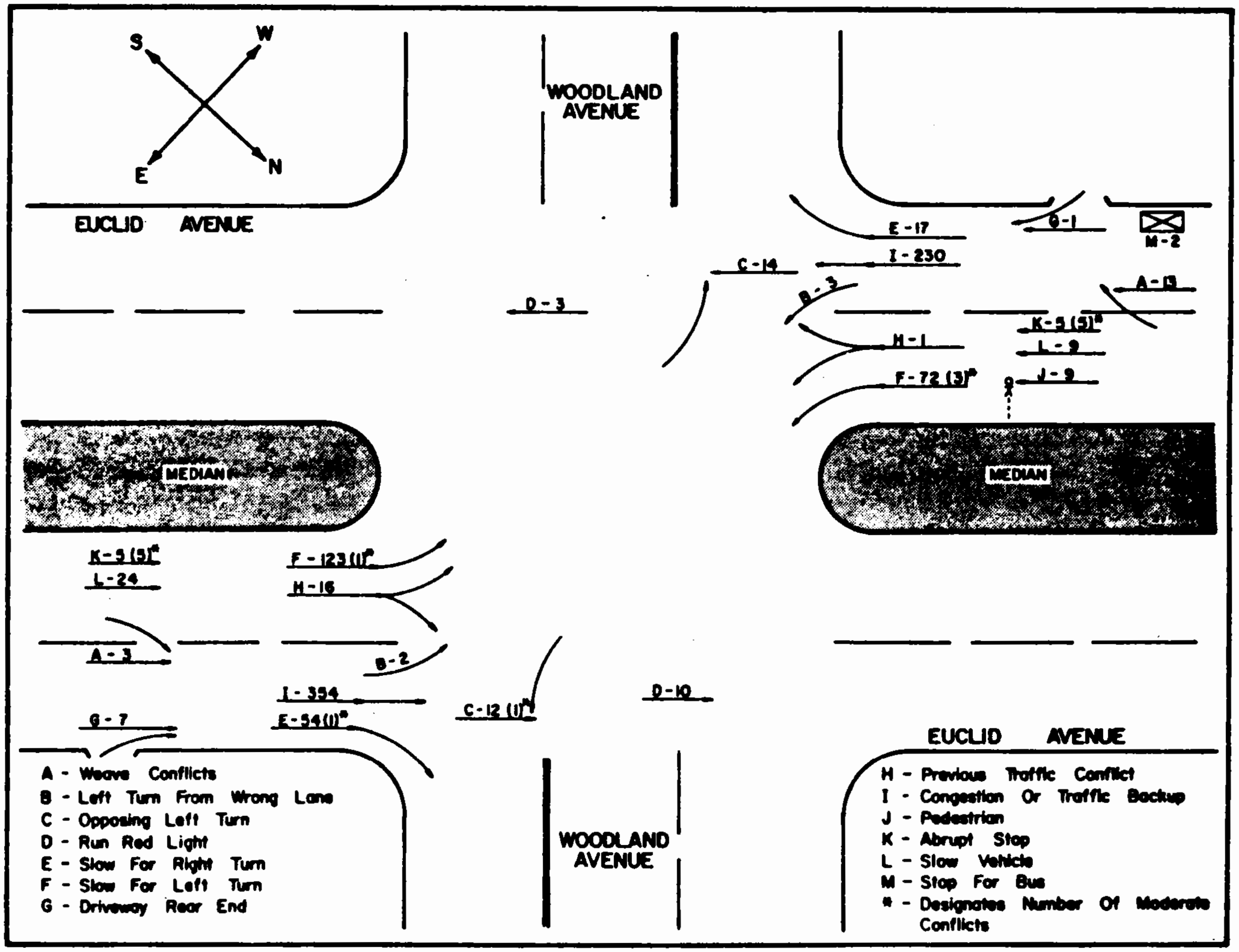
Another means of summarizing conflict data is by tabular summaries of conflict types or rates (sample shown in Figure 30). This method is useful in identifying conflict patterns but it fails to locate the conflicts as they occur along an approach.

● Use Of Findings

For analyzing traffic conflict data, techniques exist which are similar to accident procedures. Conflict types are reviewed for patterns of a specific conflict type. They may be visually assessed or compared to an

Table 29. Primary considerations for Traffic Conflicts Study technique.

Consideration / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
. Traffic Conflicts Technique (TCT)	. Provides assistance in the diagnosis of safety problems and the evaluation of countermeasures through the use of field measurements of a non-accident measure-traffic conflicts	. Data sheets . Volume counter	. Technician to record conflicts at an approach . If available, technician to record volume data	. Three days for most purposes; longer for evaluation of site improvements	. Volume counter (usually available)	. Defined location . Roadway inventory	. Number of specific conflict types . Volume data	. Conflict patterns . Conflict rates . Possible safety deficiencies



*Source: "Development of a Traffic Conflicts Procedure for Kentucky", Zegeer, C.V., Kentucky DOT, January 1980.

Figure 29. Sample conflict diagram.

CONFLICT NUMBERS AND RATES AT THE TEST SITES (12)

INTERSECTION	APPROACH	TOTAL CONFLICTS (11-HOURS)	CONFLICTS PER HOUR	PEAK-HOUR CONFLICTS	CONFLICT RATE**
New Circle Road at Woodhill Drive	S	894	81	127	89.5
Euclid Avenue at Woodland Avenue	NW (IB)*	601	55	97	144.9
	SE (OB)	361	33	81	111.6
Limestone Street at Virginia Avenue	N (IB)	631	57	95	92.2
	S (OB)	595	54	98	88.3
Main Street at Jefferson Street	SE (IB)	913	83	103	152.9
	NW (OB)	496	45	65	79.3
Harrodsburg Road at Larkspur Drive	NE (IB)	349	32	52	47.1
	SW (OB)	470	43	119	71.8

*Signifies Inbound or Outbound.
**Conflicts per 1,000 Vehicles.

*Source: "Development of a Traffic Conflicts Procedure for Kentucky", Zegeer, C.V., Kentucky DOT, January 1980.

Figure 30. Tabular summaries of traffic conflict data.

expected value. If data are available, the use of expected values is preferred.

After traffic conflict patterns have been defined, the results may be used along with accident information or other safety measures to diagnose safety deficiencies. To assist in selecting countermeasures to alleviate the deficiencies identified by the conflict patterns, a set of tables was developed by Glauz in NCHRP 219 [10]. They include the type of intersection improvements that are appropriate for alleviation of specific conflict types. A sample table for a signalized, four-leg (four lane) intersections, Table 30, contains 19 possible improvements as a function of specific conflict types. These tables are useful in developing possible countermeasures at intersections. While the conflicts technique may be applicable to locations other than intersections, its use has not been well documented.

● Example

From the intersection conflict diagram shown in Figure 31, define the conflict patterns and possible safety-related improvements to alleviate these patterns. The intersection geometrics at the four-leg, fourlane, signalized intersection are displayed in the lower portion of Figure 31.

From a visual review of conflict patterns (using similar criteria as in the accident procedures), the following patterns are noted (conflict numbers are noted on the conflict diagram).

1. East and West legs - "Same Direction (Rear-End)"
   - Left Turn
   - Lane Change
2. East and West legs - "Opposing Left-Turn"
3. North leg - "Same Direction (Rear-End)"
   - Right Turn
   - Lane Change
4. South leg - "Same Direction (Rear-End)"
   - Left Turn
   - Lane Change
5. South leg - "Opposing Left-Turn"

Using Table 30 for a signalized, four-leg, four-lane intersection, the following possible improvements can be suggested.

- Pattern 1 & 2 (East and West legs)
  - Left-Turn Bay
  - Left-Turn Phase

Table 30. Feasible improvements for conflict patterns - signalized, four-leg (four-lane) intersections.

Improvement	Same Direction (Rear-End): Left-Turn	Same Direction (Rear-End): Right-Turn	Same Direction (Rear-End): Slow Vehicle	Same Direction (Rear-End): Lane Change	Same Direction (Rear-End): Total Rear-End	Opposing Left-Turn	Right Turn Cross Traffic: From Left	Right Turn Cross Traffic: From Right	Left Turn Cross Traffic: From Left	Left Turn Cross Traffic: From Right	Thru Cross Traffic: From Left	Thru Cross Traffic: From Right	Pedestrian	Opposing RTOR
Left-Turn Bay	X			X		X								
Left-Turn Phase	X			X		X								
Left-Turn Restriction	X			X		X								
Right-Turn Bay		X		X										
Right-Turn Radius or Roadway		X		X			X	X						
Signal Cycle or Phase Length	X		X	X	X	X							X	
Actuated Signals								X	X	X	X	X		
Longer Amber or all Red Clearance					X			X	X	X	X	X		
RTOR Restrictions							X	X						X
Pedestrian Barriers													X	
Pedestrian Phase													X	
Add Lanes	X	X	X		X		X							
Parking Restrictions	X	X												
Install Median							X							
Improve Corner Sight Distance								X					X	
Speed Zone	X	X	X		X			X						
Advance Warning or Sight Distance Control	X	X	X	X	X			X						
Advance Street Name Sign	X	X	X	X	X									
Enforcement								X	X	X	X	X		

*Source: "Application of Traffic Conflict Analysis at Intersections", Glauz, W.D. and Migletz, D.J., NCHRP 219, February 1980.

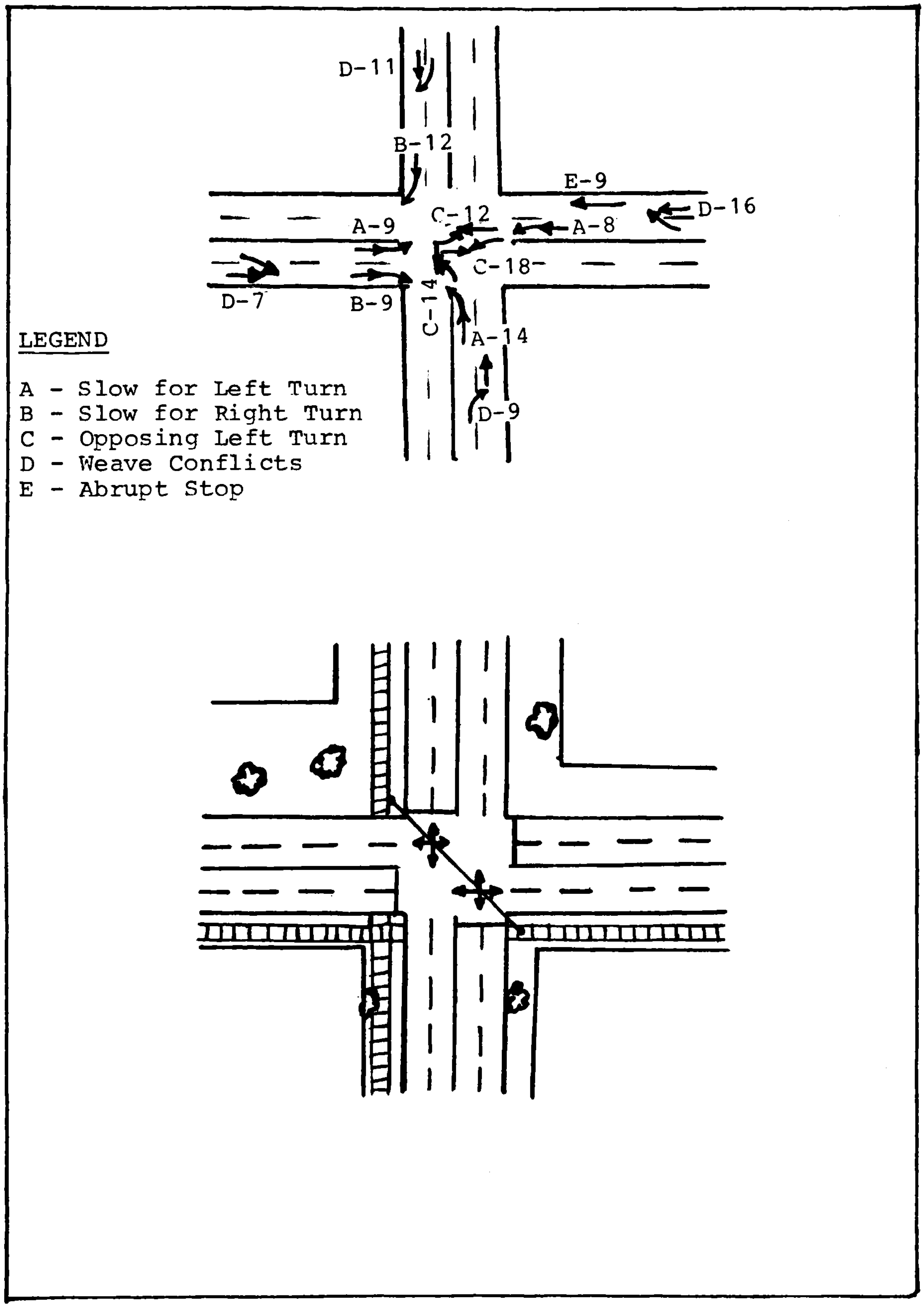


Figure 31. Conflict diagram example.

- Left-Turn Restriction
- Signal Cycle or Phase Length

- Pattern 3 (North Leg)

  - Right-Turn Bay
  - Right-Turn Radius
  - Advance Warning or Sight Distance Control
  - Advance Street Name Sign

- Pattern 4 & 5 (South Leg)

  - Left-Turn Bay
  - Left-Turn Phase
  - Left-Turn Restriction
  - Signal Cycle or Phase Length

The findings from other procedures, such as volume studies, safety performance studies and traffic control device studies, can be combined with the conflict data to justify a specific countermeasure.

PROCEDURE 12 GAP Study

Purpose

Gap studies are used to measure the time headway or gap between vehicles along a highway or at an intersection and to analyze the capability of a major traffic stream to accomodate a minor or alternate traffic stream.

Application

- Definitions

Two terms, i.e., gap and lag are normally used to describe gap characteristics. A gap is a measure of the time or distance between successive vehicles passing a particular point on a highway. Lag is a measure of time between the arrival of a minor stream vehicle and the arrival of a conflicting major stream vehicle. A pictorial representation of these terms is shown in Figure 32.

Several measures are used to describe the gap characteristics for a traffic situation. They include: (1) the gap accepted by half of the drivers; (2) the gap for which the number of accepted gaps shorter is equal to the number of rejected lags longer, defined as critical gap; (3)

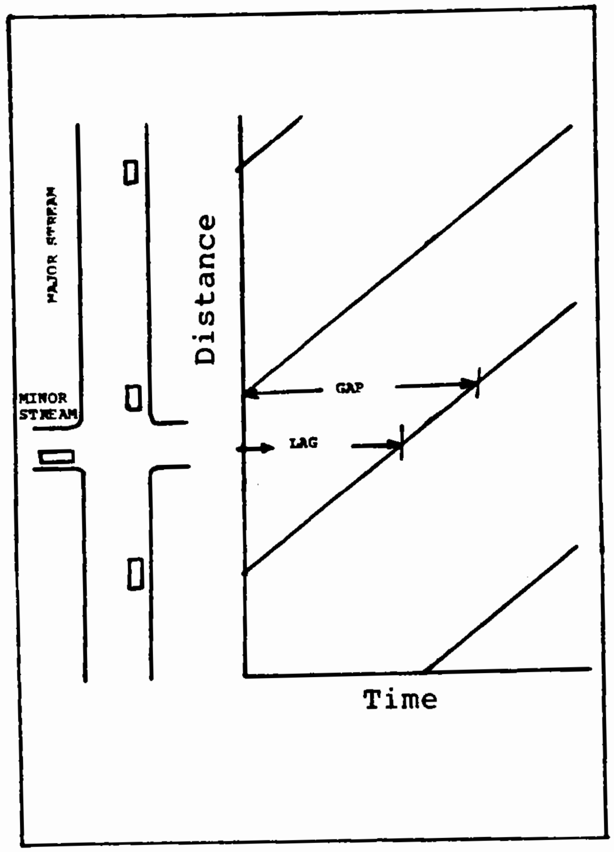


Figure 32. Pictorial representation: gap and lag.

the average gap, and (4) the lag between side street and main street traffic such that the number of rejected lags larger and accepted lags smaller will be equal, defined as the critical lag.

In most intersection studies, the use of lag data is preferred, as lag describe conditions relating to both the major and minor stream traffic flow. Gap data describes solely the major traffic stream. However, depending on the field situation, both terms have been used in intersection studies.

● Need For Gap Study

The need for a gap study is normally indicated by the occurrence of accidents involving crossing or merging traffic. Although defined relationships between gap characteristics and safety at a site have not been developed, it is generally felt that inadequate gaps in a major traffic stream can result in unnecessary risk being taken by a minor stream traffic flow which can result in accidents. Typical accident patterns are shown in Table 31.

Table 31. Accident patterns relating a need for a Gap Study.

Location	Situation	Factor Reviewed
Freeway Ramp or Weave Junction	● Pattern of Sideswipe Accidents and Rear-End Accidents	● Vehicular Gap ● Length of Weave or Merge
Signalized Intersection	● Pattern of Pedestrian Accidents or Conflicts	● Pedestrian Crossing Gaps ● Speed Distribution
Unsignalized Intersection	● Pattern of Right-Angle or Rear-End Accidents	● Vehicular Gap ● Traffic Signal Needs ● Speed Distribution ● Sight Obstruction
Unsignalized Intersection	● Pattern of Pedestrian Accidents or Conflicts	● Pedestrian Crossing Gap ● Speed Distribution
Mid-Block Locations	● Pattern of Pedestrian Accidents or Conflicts	● Pedestrian Crossing Gap ● Speed Distribution
	● Pattern of Right-Angle Accidents	● Vehicular Gap ● Traffic Signal Needs ● Speed Distribution ● Sight Obstruction

In addition to these situations, the need for a gap study can be determined from field reviews of the location and from complaints by local citizens.

● Use of Gap Study

The information obtained from gap studies is useful for:

- Identifying operational deficiencies in a traffic situation.
- Determining the safety of crossing, merging and weaving situations.
- Assessing the need for additional traffic controls i.e., countermeasure development.
- Evaluating the effectiveness of a safety improvement.

- <u>Period of Data Collection</u>

The period of the data collection activities is normally determined from the accident data.

The studies should also be performed under favorable weather conditions. Poor weather conditions will tend to lower traffic speeds, thus influencing the gap distribution.

- <u>Sample Size Determination</u>

In collecting gap information, a variety of methods are available to compute a minimum sample size [1,3]. The method used depends upon the field situation. For most highway safety applications, the sample size can be determined from the following formula.

$$N = \left[\frac{SK}{E}\right]^2$$

Where N = minimum sample size

S = standard deviation (sec.)

K = constant corresponding to the selected confidence level

E = permitted error in the gap or lag estimate (sec.)

The standard deviation and the permitted error, E, depend on the situation under study. Sample data taken at the site will assist in defining S and E for use in the above formula. Values of the constant, K, for given confidence levels are:

K	Confidence Level (%)
1.64	90.0
1.96	95.0
2.58	99.0

Gap Study Techniques

Available techniques for collecting gap information include:

- Manual method.
- Manual/machine method.
- Photographic techniques (time lapse and videotape).
- The Instrumented site method.

Primary considerations of these techniques are included in Table 32.

Manual Method

The manual method [2,4] requires an observer (technician) at the location to record gaps manually with a stopwatch. The observer is stationed at the study location, situated in a position to view and accurately time all vehicles. Care should be taken to insure that the observer's presence does not influence driver behavior in the area.

As the first vehicle's front end passes over a defined reference point, the observer activates a stopwatch. When the front end of the second vehicle crosses the reference point, the stopwatch is stopped and the time (measured as the time gap between vehicles) is recorded onto a summary data sheet. A second observer can be used to record the minor stream gap needs by assuming an average demand rate for the study period (based on the volume of approach vehicles divided by the period of data collection) or by actual measurement of the accepted and rejected gaps or lags.

A sample data sheet is shown in the Appendix (page I-12).

Advantages:

1. Equipment needs are minimal.
2. Data are reliable.
3. Can be performed with very little preparation or setup.
4. Data manipulation is minimal.

Disadvantages:

1. Personnel costs could be high.
2. Timing subject to human biases.
3. Data can be influenced by the presence of the observer.

This method is suitable for pedestrian situations (signalized or unsignalized intersection, or midblock locations) and for many unsignalized intersections and midblock situations. However, where volumes or the complexity of the situation make the manual technique difficult to apply, other more efficient means may be utilized.

Table 32. Primary considerations of Gap Study techniques.

Consideration / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements
. Manual Method	. Obtains gap data by observer timing individual vehicles	. Stop watch . Data sheets	. Technician to observe and record data . Engineer to adjust data	. One half-one hour per study . Approx. one-half hour to adjust data
. Manual/Machine Method	. Obtains gap data using observer to activate the gap recording device	. Recorder . Data summary sheets	. Technician to observe data . Technician to record tape data on summary sheets . Engineer to adjust data	. One half-one hour per study . Approx. one hour to record tape data onto summary sheets . Approx. one-half hour to adjust data
. Photographic Technique	. Obtains gap data manually from film records of location	. Camera equipment . Stop watch or timing mechanism . Data sheets	. Trained technician to set up camera . Trained technician or engineer to record data from film . Engineer to adjust data	. Approx. one hour to set up or remove camera equipment . One-half to one hour filming time . One-two hours to view and record data . Approx. one-half hour to adjust data
. Instrumented Site Method	. Obtains gap data through field detection and sampling methods	. Detection device . Recording device . Program instrument . Data summary sheets	. Two technicians to set up and remove equipment . Trained technician to record data . Engineer to adjust data	. Approx. one-half hour to set up or remove equipment . Approx. one-half hour to record data . Approx. one-half hour to adjust data

Table 32. Primary considerations of Gap Study techniques (continued).

Technique \ Consideration	Associated Cost	Data Input	Data Obtained	Data Output
. Manual Method	. Stop watch $25 to $150	. Defined location . Study period	. Vehicle gap durations	. Gap distribution characteristics (mean gap, standard duration, etc.)
. Manual/Machine Method	. Recording device $50 - $300	. Defined location . Study period	. Vehicle gap durations . Tape record of gap data	. Gap distribution characteristics
. Photographic Techniques	. Camera equipment $500 - $2,000	. Defined location . Study period	. Film record of location . Traffic stream characteristics	. Various traffic stream characteristics, including gap distribution characteristics
. Instrumented Site Method	. Detection and recording equipment $500 - $3,000	. Defined location . Study period	. Tape record of gap data . Traffic stream characteristics	. Various traffic stream characteristics, including gap distribution characteristics

● Manual/Machine Method

The manual/machine method [2,4] uses an observer to record the gap distribution data using a recorder-type machine. Typically, the recorder utilizes a marking pen and a timer. The recording pen is actuated as the first vehicle passes the reference line. As the second vehicle passes the reference line, the pen is de-activated. The length of the pen line (based on the time relationship of the gap timer to the pen movement) records the gap size relationship. From these recordings, the gap data are computed using simple mathematical relationships.

This technique requires a minimum of one recording device be used per gap study. For a section of roadway requiring both directions of travel to be studied, separate recorders are required for each direction. Observers may also be used to minimize the possibilities of error in recording the data.

The gap acceptance characteristics are obtained by manual methods, as described in the previous technique.

Advantages:

1. Provides a record of the gap data.
2. Requires minimal setup or preparation.
3. Simple to perform.
4. Reduces bias by observer.

Disadvantages:

1. Maintenance of portable power source for gap recorder is required.
2. Personnel costs could be high.
3. Data can be influenced by presence of observer and equipment.

This method is favorable for use in situations similar to the manual methods. However, it is more appropriate under higher volume or more complex situations due to the automatic recording capabilities of the equipment.

● Photographic Technique

The photographic technique is described in Procedure 7 - "VOLUME STUDIES."

Advantages:

1. Able to obtain other traffic variables.
2. Provides a permanent record.
3. Obtains reliable data.

Disadvantages:

1. Requires time-consuming review and analysis of data.
2. Relatively high cost due to personnel and equipment needs.

This method is most favorable for complex traffic situations (freeway cross-weave situations, merge situations) where the high number of movements can limit the accurate study of conditions by manual methods. The film record permits the review of the field situation under a controlled environment.

● Instrumented Site Method

The instrumented site method [5] uses sensors placed on the pavement to detect the vehicle gap. This information is recorded onto a tape or cassette. Gap characteristics can be obtained directly or indirectly by computer programs.

The detection device is connected to a recorder located along the side of the road. Various recording devices are available. One such device is the FHWA Traffic Analyzer which is a multi- channel recorder used for complex traffic studies. Another device is the Traffic Counter Device (also developed for FHWA). This unit uses a reconverted traffic counting device to record gap and volume data. A third device is the RATEM (Recording and Analysis of Traffic Engineering Measures) system. This device utilizes microprocessor control to scan 16 input channels and perform seven different types of traffic studies, including: speed, volume, and occupancy. Other devices providing similar capabilities have been developed. These devices can record the gap data and other output in a variety of forms, dependent on the recorder capabilities. Available programs for each device can directly provide gap distribution curves and other gap characteristics.

Advantages:

1. Able to obtain other traffic data.
2. Output is reliable.
3. Eliminates human biases in recording data.
4. Available computer program can easily output data in a usable form.

Disadvantages:

1. Equipment setup and costs can be considerable.
2. Requires trained personnel to operate equipment.
3. Difficult to detect malfunctioning equipment.

This technique is favorable for most highway situations due to its ability to obtain a number of traffic variables; i.e., speed, volume, occupancy, etc. in a limited amount of time. However, the availability and high costs associated with the use of this technique have tended to limit its use in most cases.

Selection Of Alternate Techniques

The use of a particular data collection technique is related to the management concerns involved in the study. The primary management concerns include: the time, equipment, and manpower requirements, the data needs and the level of accuracy. Table 33 displays the technique utility of each technique based on the management concerns.

Either of the four listed techniques are applicable in most situations. To select a favorable technique, a review of the management concerns is necessary. A major requirement in this selection process is equipment availability. In the absence of special recording equipment, the manual method must be used. The availability of other equipment will dictate the gap measurements technique to be used.

Several guidelines are provided for selecting a technique.

1. The use of the instrumented site method is recommended for complex traffic situations where additional traffic data should be collected.

2. The photographic techniques are preferable where a film record of the field situation is needed.

3. For most gap studies, the manual methods are feasible. To reduce the data collection load for an observer, the manual/machine method is favorable. The manual method should be used where gap recording equipment is not available.

Findings

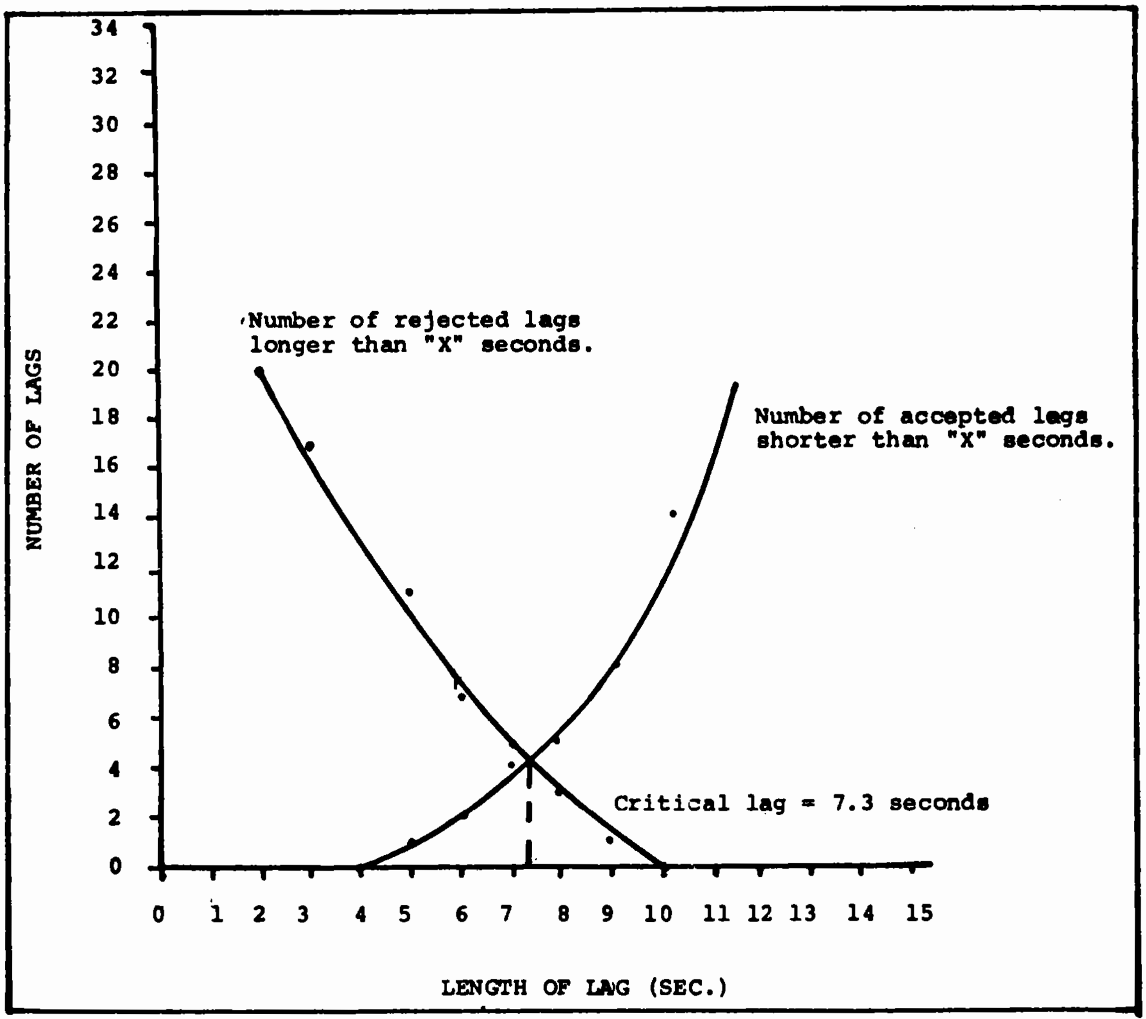
The data obtained from a gap study can be presented in a variety of formats. The simplest method of presenting gap distribution information for a traffic stream is a tabular list of the gap information by frequency, similar to a spot speed summary sheet. For data analysis, the average gap value within an increment is used to represent each observed gap.

Alternate means of presenting gap distribution data is by a graphical summary. Graphs of the frequency of gaps versus the gap duration may be prepared.

Gap acceptance data are typically presented in graphical form, as shown in Figure 33. One axis indicating the length of the gap (or lag) and the other axis represents the frequency of gaps (or lags) of a particular gap (or lag) duration. Two criteria are plotted, the number of accepted gaps (or lags) shorter than "X" seconds; and (2) the number of rejected

Table 33. Technique Utility for Gap Study.

Technique / Management Concerns	Manual Method	Manual/Machine Method	Photographic Techniques	Instrumented Site Mehtod
. Equipment Requirements	. Stop watch . Other needs, minimal	. Gap recording machine . Other needs, minimal	. Camera equipment . Stop watch or gap recording machine . Other needs, minimal	. Detection, recording and analyzing device
. Manpower Requirements	. Technician level to collect data . Engineer level to manipulate data	. Technician level to collect data . Engineer level to manipulate data	. Technician level to collect data . Engineer level to manipulate data	. Technician level to set up and collect data . Data manipulation can be performed by recording device
. Time Requirements	. Data Collection	. Equipment set up . Data collection	. Equipment set up . Equipment checks . Data Collection	. Equipment set up
. Data	. Obtains gap distribution and acceptance data	. Obtains gap distribution and acceptance data	. Obtains gap distribution and acceptance data and others (limited traffic data-volume, speed)	. Obtains gap distribution and acceptance data and a wide number of traffic variables (volume, speed, occupancy, density, etc.)
. Level of Accuracy	. Reliable	. Reliable	. Very reliable	. Reliable



LOCATION: Adams Rd. North of Tienken Rd.

TIME: 2:40 pm-2:55 pm DATE: 5/22/79

WEATHER: Clear

Figure 33. Graphical presentation of gap acceptance data.

gaps (or lags) longer than "X" seconds. "X" represents the gap (lag) duration along the axis. The crossing of these data lines represents the critical gap.

- Use of Findings

The findings obtained from such methods as the graphical summary (Figure 33) are used to evaluate the field situations by comparing the gap acceptance characteristics of the minor stream to the gap distribution characteristics of the major stream. Where conditions are found deficient, countermeasures to alleviate the deficiency will be warranted.

Analysis methods for specific situations are provided in the following references.

- Freeway or highway merging [6,7].
- Weaving [4,6,7].
- Crossing stop sign controlled intersections [2,8].
- Signalized intersections [2].
- Pedestrian crossing [Procedure 20].

PROCEDURE 13 Traffic Lane Occupancy Study

Purpose

A traffic lane occupancy study provides a measure of the traffic performance of a highway facility by measuring the percent of time a point on a roadway is occupied by a vehicle.

Application

Lane occupancy is defined as the ratio of time that vehicles are present at a station for a specific traffic lane. Related to traffic volumes over a period of time, the occupancy data is used to identify the traffic performance at a site.

- Need For Study

The need for a lane occupancy study is identified by the presence of congestion at a location (obtained from field reviews or complaints) or from accident information, as defined by a pattern of rear-ends and other congestion-related accident types.

With an increase in the use of vehicle detection equipment, occupancy characteristics as a measure of traffic performance has increased significantly. With permanent-type detectors, regular monitoring of the occupancy and other traffic variables can be conducted.

- Use of Occupancy Study

The information obtained from occupancy studies is useful for:

- Defining the level of operation of freeway, arterial, and other major facilities.
- Identifying the location of bottlenecks.
- Selecting countermeasures related to traffic control.
- Determining the effects of traffic control changes, such as: signal timing.
- Evaluating safety improvements.

- Period of Data Collection

The data collection period is normally identified from the accident data. The study is typically performed on a representative weekday during the peak hours. It is also preferable that data collection activities be performed under favorable weather conditions.

Lane Occupancy Techniques

The collection of lane occupancy data can be obtained by:

- Roadway detector methods.
- Manual methods.
- Photographic techniques.

Primary considerations for these techniques are defined in Table 34.

- Roadway Detector Methods

The principal means of data collection is the use of detectors [1,2,3]. Detection and recording equipment used consist of two types: permanent or portable. The operational procedures of the detectors are identical to those discussed in PROCEDURE 7 - "Volume Study". In most cases, detectors are used for traffic control purposes.

The detector for each lane transmits a continuous electronic pulse for each vehicle during the time period required to travel through the detection zone. Each detected vehicle produces a unique pulse having a defined length. The detected information is transmitted to a small computer or central computer programmed to calculate the lane occupancy

Table 34. Primary considerations for Traffic Lane Occupancy Study techniques.

Consideration / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements
. Detector Method	. Obtains occupancy data through use of detection equipment within roadway	. Detection and recording equipment	. Technician to record and adjust field data	. Limited to data recording and adjusting time . Time requirements, minimal
. Manual Method	. Obtains occupancy data by manual speed and volume field studies	. Volume counting device (volume measurement) . Stop watch . Data sheets	. Technician to record volume data . Technician to summarize data . Technician to adjust data	. Requires technician for collection of volume data during study period . Data recording and adjustment 1-2 hours per site
. Photographic Technique	. Obtains occupancy data by reviewing film records of study area taken during a defined study period	. Camera equipment . Volume counting device (volume measurement) . Stop watch . Data sheets	. Technician to set up and remove camera equipment . Trained technician or engineer to review film . Technician to adjust data	. Camera set up and removal time (approx. 1/2 hour each) . Reviewing film dependent on study period . Data adjusting time is minimal

Table 34. Primary considerations for Traffc Lane Occupancy Study techniques (continued).

Technique \ Consideration	Associated Cost	Data Input	Data Obtained	Data Output
. Detector Method	. Detection equipment $1,000 to $18,000	. Defined location . Study period	. Occupancy or volume and time measurements	. Occupancy characteristics by time of day
. Manual Method	. Stop watch $25 to $150	. Defined location . Study period	. Volume measurements	. Occupancy characteristics for study period
. Photographic Technique	. Camera equipment $500 to $2,000 . Stop watch $25 to $150	. Defined location . Study period	. Volume measurements	. Occupancy characteristics for study period

at each station. Other data such as lane volume and vehicle speeds are also obtained.

The occupancy, Occ. is referred to as [1]:

$$Occ. = \frac{100}{T} \sum_{i=1}^{N} t_i$$

Where:

N = number of vehicles detected during the time period, T
T = specified time period
t_i = measured presence time of the "i"th vehicle

Advantages:

1. Can provide instantaneous or continuous data.
2. Time and manpower requirements are minimal.
3. Able to obtain other traffic data.
4. Data are reliable.

Disadvantages:

1. Initial cost of equipment is high.
2. Technique is limited to locations where equipment exists.
3. Malfunctioning equipment is difficult to detect.

The use of this technique requires the availability of detection equipment. It is favorable for use in highway safety situations due to its accuracy and reliability.

● Manual Methods or Photographic Techniques

Lane occupancy data can also be collected by manual methods [2,3] using speed and volume measurement techniques listed in PROCEDURE 7 - "Volume Study" and PROCEDURE 8 - "Spot Speed Study." These methods produce average or estimated results. Precise speed or "passage time" measurements are extremely difficult to obtain for each vehicle in the traffic stream during the period studied, particularly under high speed situations.

With these techniques, lane occupancy data are obtained by manually recording the number of vehicles occupying a traffic lane zone during specific time intervals. A zone length is defined prior to the study performance. Minimum zone lengths should be the length of a vehicle. It is preferable that zone lengths be an even increment of 50 or 100 feet. The zones should be clearly marked for increased accuracy.

The occupancy is determined as [1]:

$$Occ. = 100KL$$

Where: Occ. = occupancy (percent)
K = density (vehicles per lane per unit of roadway)
L = mean vehicle length = 20 feet

Density is obtained by recording the number of vehicles occupying a defined space (unit of roadway).

The lane is sampled throughout the defined study period to obtain an average density.

Photographic techniques [2,3] are similar except the data are obtained from a film record of the study location. Further operational characteristics are provided in PROCEDURE 7 - "Volume Study".

Advantages:

1. Able to be performed for a variety of situations.
2. Equipment needs can be minimal.
3. Results can be reliable.

Disadvantages:

1. Substantial personnel may be required.
2. Photographic techniques will result in a significant number of equipment needs.
3. Analysis of results can be tedious.

The manual technique should be used for situations where detection equipment is not available. Where a record of the situation is required or sufficient personnel are unavailable to perform the study, photographic techniques are encouraged.

Selection Of Alternate Techniques

To select the appropriate technique for performing a traffic lane occupancy study, information on the management concerns associated with the procedure is required. The management concerns for this procedure include: the time, manpower, and equipment requirements and the level of comprehensiveness and accuracy of each technique. Table 35 provides the technique utility of each technique based on these management concerns. Table 36 identifies the preferred techniques as a function of the field situation.

Based on the utility of each technique, a favorable technique can be selected. Equipment requirements are a principal factor in the selection. Several general guidelines are provided below.

Table 35. Technique utility for Traffic Lane Occupancy Study.

Technique / Management Concern	Detector Method	Manual Method	Photographic Techniques
. Time Requirements	. Requires review of results	. Data collection . Data manipulation time	. Equipment set up time . Data extraction time . Data manipulation time
. Manpower Requirements	. Technician level	. Technician level	. Technician level
. Equipment Requirements	. Roadway detection equipment . Other needs, minimal	. Stop watch . Other needs, minimal	. Camera equipment . Stop watch . Other needs, minimal
. Level of Comprehensiveness	. Obtain occupancy data and other traffic variables (volume, speed, gap, etc.)	. Obtain occupancy characteristics	. Obtains occupancy and other limited traffic data (volume, speed, gap)
. Level of Accuracy	. Precise	. Approximate	. Approximate

Table 36. Favorable Traffic Lane Occupancy techniques.

Technique / Situation	Detector Method	Manual Method	Photographic Techniques
. Freeway Surveillance	X		X
. Freeway Merge	X		X
. Urban Arterial	X	X	X
. Urban Collector		X	X
. Rural Route		X	X

1. The use of the detector method should be made where permanent detectors exist.

2. Where detection equipment is unavailable, the use of the manual method is favorable. It requires minimal equipment and can be performed at most locations due to its flexibility.

3. Similar characteristics in the manual method also exist in the photographic technique. However, equipment setup, data extraction, and familiarity with photographic procedures discourage its use except for complex situations or where a film record of the situation is required.

Findings

"Occupancy" may be obtained directly using detector systems or can be computed from field information obtained manually.

● Example

A sample problem is given based on a roadway approach zone length of 200 feet. At consecutive intervals during the study period, the traffic volumes within the study zone were recorded as 2,3,2,4,6,1. These values represent the density, i.e., "x" vehicles per lane per 200 foot section of roadway. The average density, K, is the average of these values, i.e., 3 vehicles. The occupancy, "Occ.", equals:

$$\text{Occ.} = 100 \times \frac{3}{200} \times 20 \text{ feet} = 30.0\%$$

● Use Of Findings

The output or presentation of occupancy data can be in the form of a tabular listing of the occupancy or in the form of a volume/occupancy curve (Figure 34). Based on a history of volume vs. occupancy data, the accumulation of groups of data for a specific location or situation will define a curve. From the curve, the peak volume point can be assumed as the volume and occupancy under stable flow conditions. An occupancy rate at less than "x" percent would represent stable flow conditions. At "x" or greater rates, an unstable flow of traffic would result. This relationship is used to assess the highway operating conditions for the study location and to plan and evaluate traffic control improvements.

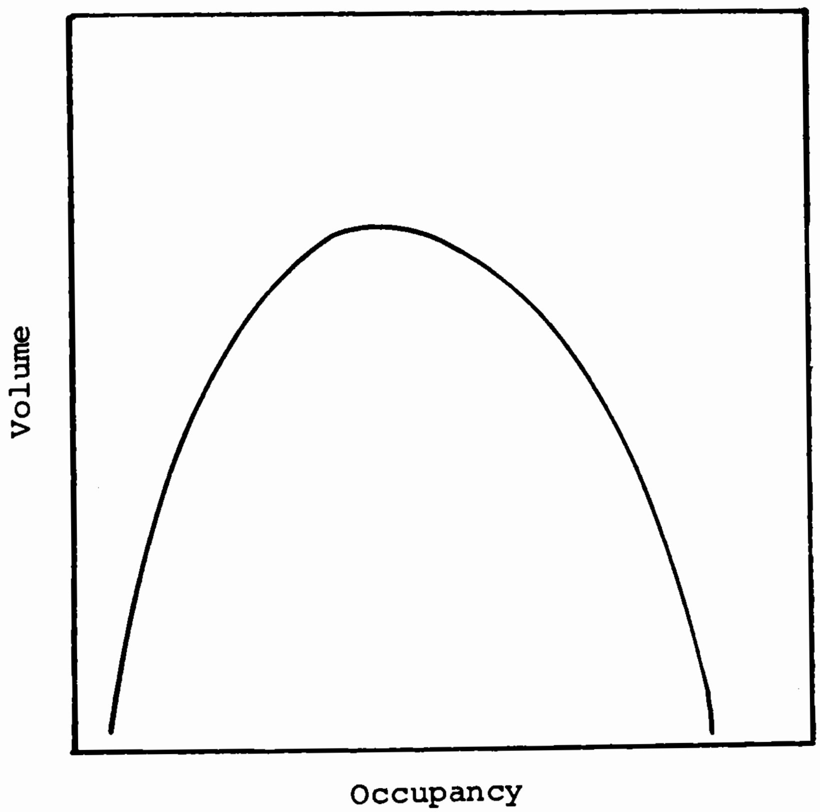


Figure 34. Volume/occupancy output.

In freeway merge studies [1], the difference between a predetermined estimate of capacity and the field volume conditions would represent the metering rates for safe merging. In some cases, it will identify a low metering rate. If the demand is greater than the metering rate, additional metering-related improvements will be necessary.

Occupancy data can also be used to evaluate the effectiveness of safety-related countermeasures. Measurement of the occupancy characteristics during a defined time period "before" and "after" implementation of a safety improvement and statistical testing of the results can determine the significance of the project. In this case, the occupancy factor is used as a measure of the effectiveness of the countermeasure.

PROCEDURE 14 Queue Length Study

Purpose

Queue length studies are conducted to identify the number of vehicles that are stopped in a traffic lane behind the stop line at an intersection. These data are primarily used as a measure of traffic performance at an intersection, but can also measure the vehicular backup at locations such as: lane drop sections, railroad crossings, freeway incident locations, and other bottleneck situations.

Application

- Need for Study

The need for a queue length study is determined by accident information identifying congestion along an intersection approach or in an individual traffic lane. These accidents will typically include rear-ends within the queue, although some right-angle, left-turn and sideswipe accidents may result from drivers making unsafe movements resulting from lengthy delays. Other sources of input may include complaints by local citizens or a field review of the site.

- Use of Queue Length Study

The information obtained from queue length studies is useful for:

- Describing the level of operation at a location.
- Identifying the location of bottlenecks, such as freeway incident detection.
- Selecting appropriate countermeasures.
- Evaluating safety improvements.

- Period of Data Collection

As in the case of the traffic lane occupancy procedure, the collection of queue length data is primarily related to the accident by time of day patterns for congestion-related accidents. The study is typically performed on a weekday during the peak hours. It is also preferable that data collection activities be performed under favorable weather conditions.

Queue Length Techniques

Queue length studies can be performed in a number of ways. They include:

- Manual measurement.
- Roadway detector methods.

- Photographic techniques.
- Mathematical models.

Primary considerations of these techniques are given in Table 37.

Manual Measurement

Manual measurements [1] are obtained by an observer manually recording queue lengths (number of stopped vehicles) by lane along an approach. The observer records the queue length at specified intervals of time. A sample data sheet is shown in the Appendix (page I-13).

The time interval used in recording data varies with the study purpose. At signalized intersections, the effectiveness of traffic controls on moving traffic is determined by recording the queue lengths at the beginning of the green phase and at the end of the amber phase. To define an average or maximum queue length, data are recorded at regular intervals. A 15-second interval is typically used; however, where high traffic volumes or more than a single lane is studied, a longer time interval may be used to allow data to be recorded on all approach lanes with minimal personnel requirements.

Where traffic signals exist, the time interval selected should not result in the regular recording of data during similar times of the cycle length. For example, in a 60-second cycle length, the recording interval should be 25-seconds rather than 15-seconds. A 15-second interval would result in the recording of similar data from consecutive cycle lengths and would produce in biased findings.

Advantages:

1. Provides direct field observance of conditions.
2. Equipment needs are minimal.
3. Data are reliable.

Disadvantage:

1. Extensive manpower requirements could result at high-volume, multi-lane approaches.

This technique is favorable for collecting queue length data for most highway safety applications. For complex situations or high volume locations, additional personnel are required.

Photographic Techniques

Photographic techniques [1] use film records of the location taken during the study period to extract queue length data. It is similar to the manual method of measurement in that an observer records the data from

Table 37. Primary considerations for Queue Length Study techniques.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Manual Method	. Obtains queue length data over time from field observation of study location	. Stop watch . Data sheets	. Technician to record queue length data . Technician or engineer to reduce data	. Limited to study period length (1-2 hours)	. Stop watch - $25 - $150	. Defined location . Study period	. Queue length data	. Queue length characteristics
2. Detector Method	. Obtains an estimate of queue length over time using field detectors	. Detection Equipment . Summary sheets	. Technician to record data from vehicle detection recorders	. Data recording and adjusting time is minimal	. None (detection equipment inplace)	. Defined location . Study period	. Traffic stream characteristics . Queue length data	. Queue length and other traffic stream characteristics
3. Photographic Techniques	. Obtains queue length data over time from film record of field conditions	. Camera equipment . Summary sheets	. Technician to set and remove camera equipment . Engineer to review and reduce data	. Camera setup and removal 1/2 hour per event . Study period . Film viewing limited to study period length	. Camera equipment - $500-$2,000	. Defined location . Study period	. Queue length data . Traffic stream characteristics	. Queue length and other traffic stream characteristics
4. Mathematical Models	. Obtains average queue length data for a specific period based on field observations and defined mathematical relationships	. Based on unavailable data needs	. Based on manpower needs for individual studies . Engineer for reducing data	. Related to individual study needs . Data adjusting 1/2 hour per approach	. Dependent on unavailable data needs	. Defined location . Study period . Gap data . Volume data	. Average queue length data	. Average queue length data

field observations. However, review of the film is done under a controlled (office) environment.

To obtain time-related data, a time clock or timer is used in conjunction with the camera. It permits identification of the queue length data to a specific time period or by a specific time interval.

Advantages:

1. Provides a film record of the field conditions.
2. Permits review of other traffic data.
3. Results are reliable.

Disadvantages:

1. Equipment requirements are substantial.
2. Data extraction can be time-consuming.
3. Requires favorable weather and lighting conditions.

The use of photographic techniques for obtaining queue length data is limited to those agencies having available camera equipment. This method is favorable where a film record of the data is necessary, at complex intersections, and where collection of other traffic data may be desired.

● Detector Methods

The detector methods [2] utilize in-place, permanent type detectors to record queue length data. This method uses a series of detectors along a traffic lane to provide an account of the queue length. The detectors, spaced at specified lengths apart (e.g. 50 ft.(m), 150 ft.(m), etc.), permit the estimation of the queue length from a determination of occupancy, speed, volume, and an assumed vehicle length. This information is recorded onto a tape or cassette.

Advantages:

1. Provides continuous recording of queue length and related data.
2. Able to record other traffic data.
3. Can easily provide comparison data during non-peak periods.
4. Can provide queue length output as a function of other traffic data for use in other analyses.
5. Time and manpower costs are minimal.

Disadvantages:

1. Equipment costs can be high.
2. Difficult to detect equipment malfunctions.
3. Results are approximate.

This technique is limited to situations where the appropriate detection equipment is available.

● Mathematical Models

Mathematical models [1,3] can be used to derive an average queue length as a function of the arrival rate and the service rate. The measured arrival rate can be obtained from a volume count taken over a specified period. For example, if 200 vehicles were recorded over a 20 minute period, the arrival rate (vps) would be:

$$\frac{200 \text{ vehicles}}{20 \text{ minutes}} \times \frac{\text{minute}}{60 \text{ seconds}} = 0.17 \text{ vps}$$

The service rate is defined as a function of the flow of the conflicting traffic stream and the arrival rate. It is based on the gap acceptance characteristics of the traffic stream. Information on gap acceptance characteristics is given in PROCEDURE 12 - "Gap Study".

For uncontrolled or stop-yield sign intersections [1], the expected queue length may be defined by:

$$N = \frac{X}{U-X}$$

Where N = average queue length
X = arrival rate (vps)
U = average service rate ($1/\bar{d}$) (vps)

If the service rate is less than the arrival rate, "N" would be a negative number. In this case the queue length would increase until the arrival rate was below the service rate.

For signalized intersections, [1] the average queue length is defined as the larger of the following values:

$$N = qR$$

or

$$N = q\left(\frac{R}{2} + \bar{d}\right)$$

where N = average queue length
q = approach flow (vps)
R = red time (sec)
$\bar{d}$ = average individual delay (sec)

The latter value is more precise and would tend to account for downstream traffic patterns. However, both equations are used to estimate the expected average queue length.

Information on the average individual delay at a signalized intersections is also found in PROCEDURE 9 - Travel Time and Delay Study.

The mathematical method produces an estimate of the queue length. For most highway safety applications, the results are adequate.

Advantages:

1. Data analysis is relatively simple.
2. Calculations are based on defined and proven mathematical models.

Disadvantages:

1. Results provide an average queue length for the study period.
2. Substantial field data collection may be required.

This technique is appropriate where data on the service rate, arrival rate and delay information are available. It is useful for deriving the average queue length value as a "measure of effectiveness" of a safety-related countermeasure. For other safety applications where more specific data are necessary (for example, queue length over a time interval), other techniques are more favorable.

Selection Of Alternate Techniques

To select the appropriate technique for performing a queue length study, information on the management concerns associated with the procedure is required. The management concerns in this study include: the time, manpower, and equipment requirements, the level of comprehensiveness and the level of accuracy associated with each technique. Table 38 provides the technique utility of each technique based on these management concerns. Table 39 relates the favorable techniques as a function of the field situation.

Several general guidelines in selecting a technique are provided.

1. The manual method is favorable for most field situations due to its flexibility and the time, manpower, and equipment requirements.
2. Where appropriate vehicle detection equipment exists, this technique should be utilized.
3. Photographic techniques are recommended for use when situations are too complex for manual methods or where a film record is necessary.
4. The use of mathematical models is favorable where accurate delay information is available. It provides an estimate of the average queue length over a defined time period.

Table 38. Technique utility for Queue Length Study.

Technique / Management Concern	Manual Method	Detector Method	Photographic Techniques	Mathematical Models
.Time Requirements	.Data collection .Data manipulation	.Data review	.Equipment set-up .Data extraction .Data manipulation	.Equipment set-up .Data collection .Data manipulation
.Manpower Requirements	.Technician level	.Technician level	.Technician and Engineer level	.Engineer level
.Equipment Requirements	.Minimal	.Vehicle detection equipment	.Camera equipment	.Minimal
.Level of Comprehensiveness	.Obtains queue length data by interval (1-min., 2-min., etc.)	.Obtains queue length data and other traffic stream characteristics by intervals (1-min., 2-min., etc.)	.Obtains queue length data and limited traffic stream characteristics by interval (1-min., 2-min.,m etc.)	.Obtains average queue length by time period (hourly, etc.)
.Level of Accuracy	.Precise	.Approximate	.Precise	.Approximate

Table 39. Favorable Queue Length Study technique.

Technique / Situation	Manual Method	Detector Method	Photographic Techniques	Mathematical Models
.Freeway	X		X	X
.Urban Signalized Intersection	X	X	X	X
.Urban Unsignalized Intersection	X		X	X
.Rural Intersection	X		X	X

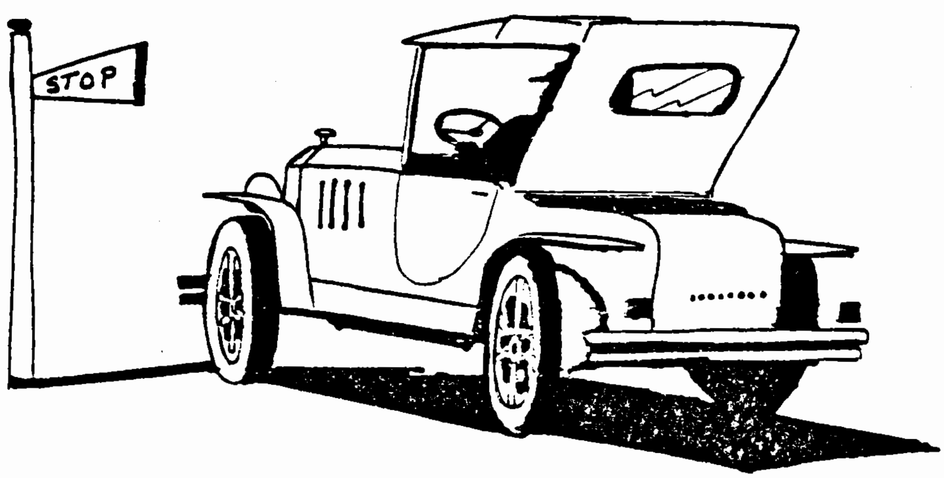
Findings

Queue length data can be output in tabular form by time of day or in a graphical summary.

● Use Of Findings

Queue length information is used in "before-after" studies as a measure of effectiveness. For this purpose, the before and after findings can be used to test the significance of any reductions in the average queue length as a result of a safety improvement.

Queue length studies can also be used to define a measure of traffic performance. By comparing average queue lengths during a distinct peak and off-peak time, a level of traffic flow can be determined. This measure can be used to describe traffic operations for a specified time period. In addition, queue length data can be used to assist in selecting countermeasures where it is determined that a stopped queue of vehicles is related to a hazardous condition. For instance, where a queue of vehicles at an intersection block a driveway and result in the driveway traffic making hazardous movements, the queue length data can be used to define a probable accident cause and suggest a safety-related countermeasure.



ENVIRONMENT-BASED PROCEDURES

Introduction

Environment-based procedures are used to determine the effect of physical roadway and roadside environment characteristics at a high accident location. Environmental characteristics include roadway geometrics, roadside structures and appurtenances, pavement surface conditions, and lighting and weather conditions.

Selection of a procedure is based upon the possible accident causes at a site. By identifying the environment-related characteristics which contribute to accident experience, appropriate countermeasures may be selected.

The environmental-based procedures include:

- Procedure 15 - Roadway Inventory Study
- Procedure 16 - Sight Distance Study
- Procedure 17 - Skid Resistance Study
- Procedure 18 - Highway Lighting Study
- Procedure 19 - Weather-Related Study

PROCEDURE 15 Roadway Inventory Study

Purpose

A roadway inventory study provides information on the physical and environmental characteristics at a location. In this study, the location and dimensions of roadway and roadside characteristics are obtained and recorded. These items are usually illustrated in a condition diagram.

Application

● Need For Study

A roadway inventory should be performed for all locations under study.

● Use of Study

An inventory can be used as input in other procedures such as: highway capacity studies, sight distance studies and traffic control device studies. Inventory information can also be used in the accident procedures to identify possible causes of accidents. For example, an inventory may indicate that a sideswipe accident problem is due to inadequate lane widths and the location of fixed-objects near the edge of the pavement.

The inventory information is also used to insure that countermeasures are feasible for the site conditions.

● Data Collection Needs

Roadway inventory information is typically displayed in the form of a condition diagram, as shown in Figure 35. Condition diagrams are scaled drawings of the location under study which illustrate measured distances and locations of the roadway and roadside characteristics. A condition diagram displays such characteristics as:

- Traffic lanes
- Lane widths
- Crosswalks
- Pavement Markings
- Traffic controls
- Curb lines
- Property lines
- Sidewalks
- Driveways
- Medians
- Shoulders
- Lane usage
- Sight obstructions
- Physical obstructions in and near the roadway.

Steps in performing an inventory and preparing a condition diagram include:

1. Establish the boundaries of the site to be inventoried.

2. Identify data items to be recorded.

3. Obtain inventory data.

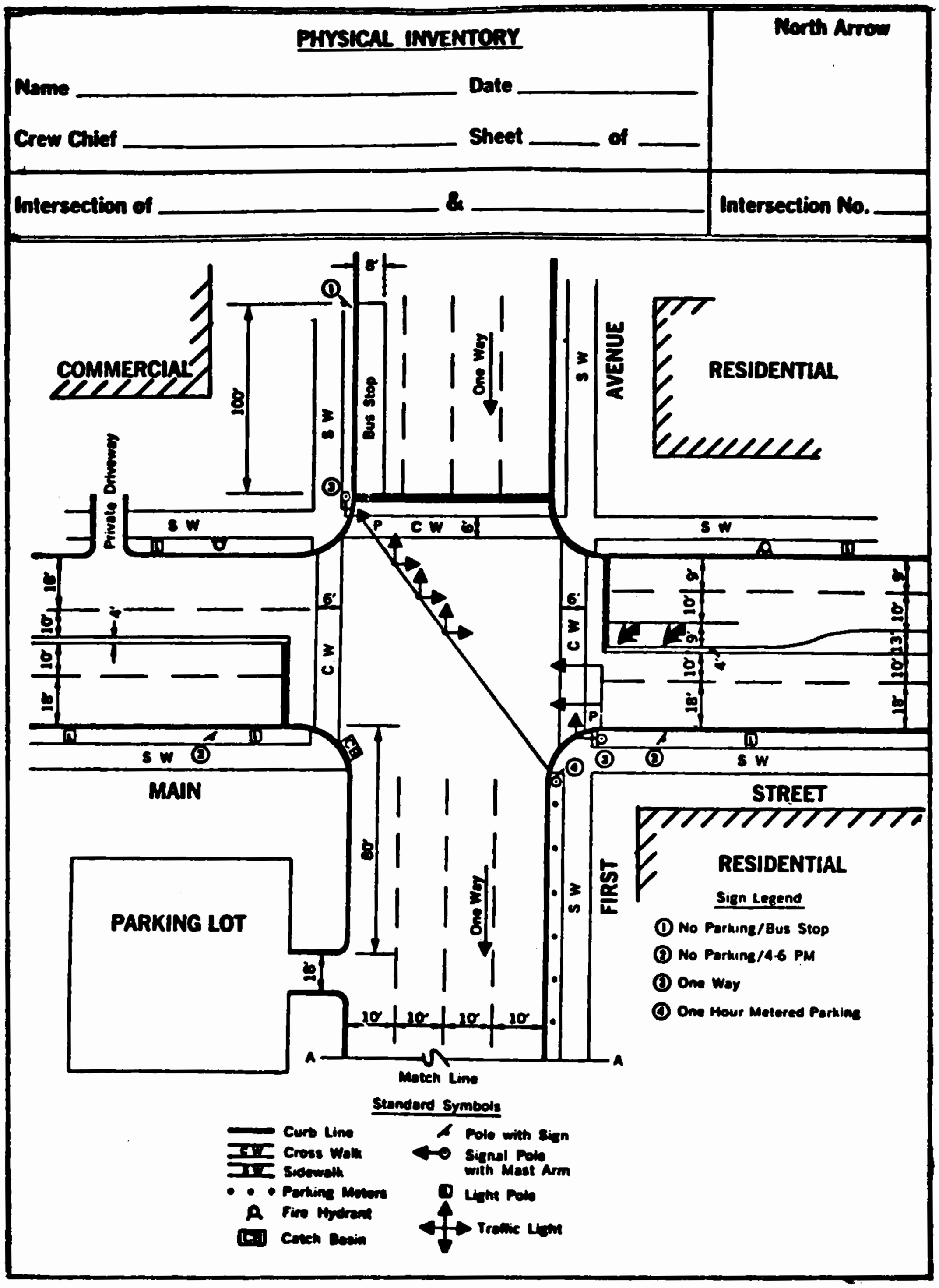
4. Check to see that all available information has been recorded and is reasonable.

5. Take photographs to supplement inventory data.

6. Prepare condition diagram, using symbols where appropriate.

7. Check for inclusion of all pertinent data items and their accuracy.

The boundaries of the condition diagram are dictated by the safety problem. Boundaries should be established to include the portion of the roadway and roadside which may impact or influence accident experience. Distances should be defined, as dictated by traffic volumes and roadway characteristics which may affect the intersection operation. For roadway sections, the boundaries of the study area are defined from the link description used in the identification of the hazardous location.



Source: Manual of Traffic Engineering Studies, Institute of Transportation Engineers, 1976.

Figure 35. Roadway condition diagram.

● Period of Data Collection

Unless weather related data are of concern, data collection activities should be conducted under favorable weather conditions. Poor weather conditions can result in the data collector "rushing" the study and omitting key data items. Also, snowy conditions or wind driven sand may cover or obliterate pavement markings, curb lines, etc. and result in an inaccurate inventory of roadway data.

Inventory data should represent the field conditions for the accident review period. Where roadway conditions were altered from or during the study period, all changes (and date of occurrence) should be noted. Such changes can adversely affect the safety study results.

Roadway Inventory Study Techniques

Several data collection methods are available to obtain inventory data:

- Manual method
- Data files search
- Photographic techniques

Table 40 summarizes the primary considerations for each technique.

● Manual Method

The manual method [1,2] is widely used by highway agencies. The method requires two field observers. One observer measures longitudinal and lateral distances to the data items with respect to a selected reference point while the second observer records the measurements on a hand drawn sketch of the study area. Reference points are typically a curb line or any permanent landmark that can be easily identified at the study site. A scale drawing (condition diagram) is then prepared from the field notes.

Advantages:

1. Provides a current record of field conditions.
2. Data are generally more accurate and reliable than other methods.
3. Equipment needs are minimal.

Disadvantages:

1. Time requirements may be substantial.
2. Manpower requirements may be substantial for complex locations.

Table 40. Primary considerations for Roadway Inventory Study techniques.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Field Method	. Obtain inventory data through direct measurement of field conditions	. Measuring wheel . Data sheets	. Technician to measure data . Technician to record data . Draftsman to display data	. Approx. one hour per intersecion . Segment dep. on length (approx. one hour per 1/10 mile)	. Measuring wheel $25-$50	. Defined location . Specific data items required	. Roadway and roadside environment characteristics	. Condition diagram of location
2. File Search Method	. Obtain inventory data through office file records supplemented by minimal field measurement	. Measuring wheel . Data sheets . Computer capabilities	. Technician to search data . Technician to field collect data . Draftsman to display data	. Dep. on availability of data (good system will produce minimal time effort)	. Measuring wheel $25-$50	. Defined location . Specific data items required . Data files	. Roadway and roadside environment characteristics	. Condition diagram . Segment characteristics
3. Photolog Method	. Obtain inventory data using photolog process (continuous filming by frame)	. Instrumented vehicle . Photolog camera equipment . Film viewer . Computer capabilities	. Technician to film . Film processor . Technician to view film . Technician to reduce data	. Filming speed based on vehicle speed (can attain speeds of 40 mph); film viewing approx. one hour/1/2 mile . Data reduction minimal	. Instrumented vehicle $20,000 to $25,000 . Film viewer $150-$1,000	. Defined location . Specific data items required	. Roadway and roadside environment characteristics	. Condition diagram . Segment characteristics . Computer summary
4. Videolog Method	. Obtain inventory data using videolog process (continuous filming - high speed)	. Instrumented vehicle . Videolog camera equipment . Film viewer . Computer capabilities	. Technician to film . Technician to drive vehicle . Technician to view film . Technician to reduce data	. Filming speed based on vehicle speed (can attain speeds of 40 mph); film viewing approx. one hour/1/2 mile . Data reduction minimal	. Instrumented vehicle $20,000 to $25,000 . Camera equipment $500 - $2,500 . Film viewer $500-$1,000	. Define location . Specific data items required	. Roadway and roadside environment characteristics	. Condition diagram . Segment characteristics . Computer summary

● Data Files Search

When an existing highway data file is available, a data file search may provide sufficient information for a roadway inventory study and condition diagram. An example of a highway inventory file is shown in Figure 36. However, a field review is recommended to check the resulting condition diagram for completeness and accuracy.

Advantages:

1. May require less time and manpower than the manual method if existing files are accurate and current.

Disadvantages:

1. File data may be incomplete, and thus require time and manpower for field review.

A basic limitation of the use of this method is the availability of a highway data file. Many agencies retain highway data but not to the accuracy required for an inventory study. Thus, an extensive field review may be required. However, data collection efforts are usually less than that required for the manual method.

● Photographic Techniques

Another inventory method requires the use of photographic techniques [3] to obtain inventory data for a study location. Two common photographic techniques in use today are photologs and videologs. The photographic process involves the continuous or time lapse filming of the roadway and its environment using a camera mounted in an instrumented vehicle. Pictures are shot as the vehicle traverses the study area. On each frame of the film, identification information such as: distance, date, and direction of travel can be superimposed. Data extraction and measurement is accomplished by projecting the film or video tape onto a calibrated screen. The data are then used to develop a condition diagram.

Advantages:

1. Provides a permanent pictorial record which can be used for other purposes.

Disadvantages:

1. Equipment costs are relatively high.
2. Requires trained personnel for data collection and extraction.
3. Use of grids or calibration devices may reduce accuracy of measurements.

Typically, the photographic method is performed on an agencywide, corridor, or road segment basis where its use as an inventory procedure

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* MAIN STREET NAME - AIRPORT RD *

LINE NUMBER	BEGINNING CROSS NAME	INT TYPE	MILE POINT	THRU LNE	TRN LNE	SURF TYPE	CURB TYPE	SHLD TYPE	SHLD WID	APPR WID	MEDIAN TYPE	MEDIAN WID	MEDIAN CURB	DOT	DATE	LND USE
00412301P	DWIGHT		1.30	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00412400X	WINSLOW	T	1.35	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00412500X	JEROSE	T	1.39	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	F
00412501P	JEROSE		1.40	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00412502P	JEROSE		1.50	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00412600X	TUBBS RD	T	1.57	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	F
00412601P	TUBBS RD		1.60	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00412602P	TUBBS RD		1.70	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00412603P	TUBBS RD		1.80	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	R
00412700X	JONQUIL	T	1.89	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	R
00412701P	JONQUIL		1.90	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	F
00412702P	JONQUIL		2.00	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00412800S	PAVEMNT WIDENS		2.01	2	1	ASPH	NONE	GRAV	3	32	NONE		NONE	N	10/13/76	P
00412900S	B CURB		2.04	2	1	ASPH	CONC	NONE		32	NONE		NONE	N	10/13/76	F
00413000X	HATCHERY RD	RA	2.08	2	1	ASPH	CONC	NONE		32	NONE		NONE	N	10/13/76	P
00413001P	HATCHERY RD		2.10	2	1	ASPH	CONC	NONE		32	NONE		NONE	N	10/13/76	P
00413100S	E CURB		2.10	2	1	ASPH	NONE	GRAV	3	32	NONE		NONE	N	10/13/76	P
00413200S	PAVEMNT NARROWS		2.14	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00413201P	PAVEMNT NARROWS		2.20	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00413300S	B BY PASS LANE		2.30	3		ASPH	NONE	GRAV	3	32	NONE		NONE	N	10/13/76	P
00413301P	B BY PASS LANE		2.30	3		ASPH	NONE	GRAV	3	32	NONE		NONE	N	10/13/76	P
00413400X	CAMPBELL GATE	T	2.35	3		ASPH	NONE	GRAV	3	32	NONE		NONE	N	10/13/76	R
00413500S	E BY PASS LANE		2.38	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	P
00413501P	E BY PASS LANE		2.40	2		ASPH	NONE	GRAV	3	21	NONE		NONE	N	10/13/76	R

Figure 36. Computerized summary of roadway inventory data.

Table 41. Technique utility for Roadway Inventory Study.

Management Concern \ Technique	Field Method	File Search Method	Photolog Method	Videolog Method
. Time Requirements	. Data collection . Diagram preparation	. File review . Data collection . Diagram preparation	. Filming . Data extraction . Data collection . Diagram preparation	. Filming . Data extraction . Data collection . Diagram preparation
. Equipment Requirements	. Hand measuring equipment . Other needs, minimal	. Minimal	. Photolog equipment or capabilities	. Videolog equipment or capabilities
. Manpower	. Technicians to measure and record field data	. Clerk or technician to record data from files	. Technicians trained in photolog procedures	. Technicians trained in videolog procedures

Table 42. Favorable Roadway Inventory Study techniques.

Situation \ Technique	Field Method	File Search Method	Photolog Method	Videolog Method
. Agencywide			X	X
. Corridor Basis		X	X	X
. Segment Basis	X	X	X	X
. Intersection or Spot Basis	X	X		

makes it more cost-effective. For spot locations or short sections, this method may not be cost-effective unless the photographic equipment is owned by the agency.

Selection of Alternate Techniques

The selection process should be based on the time, manpower, and equipment requirements of the highway agency. Table 41 summarizes these resource issues for each technique. In addition, techniques are suggested in Table 42 according to the type of location under study.

General guidelines to assist in the selection process are summarized as follows:

1. A search of existing data files is appropriate where data are known to be complete and accurate.

2. For segment lengths greater than 500 feet, it is desirable to utilize a photographic technique. Manual inventories of relatively long segments may contain substantial errors, inaccuracies, and omissions.

3. For short segments (500 feet or less), spot locations, or intersections, the manual method is more favorable due to the lower time and cost requirements of the technique.

Findings

The data obtained by this study procedure is used as supplementary information in the accident, traffic, other environment, and the special study procedures. The output from such a study is a record of the roadway and roadside environment at a study location.

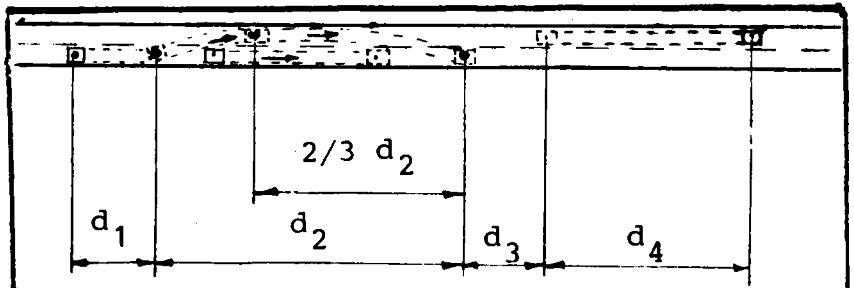
PROCEDURE 16 Sight Distance Study

Purpose

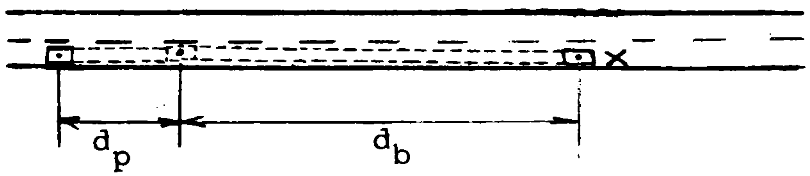
This procedure is used to measure the sight distance at intersections or along a roadway section.

Application

Three situations are commonly considered in sight distance studies. They are "passing sight" distance, "stopping sight" distance and "intersection sight" distance. These situations are shown in Figures 37 and 38. "Passing sight distance" is defined as the minimum distance required to safely pass another vehicle on a two-lane roadway. "Stopping sight distance" is the minimum distance required to safely react and stop in response to an unsafe condition. "Intersection sight distance" is the



a) Passing sight distance

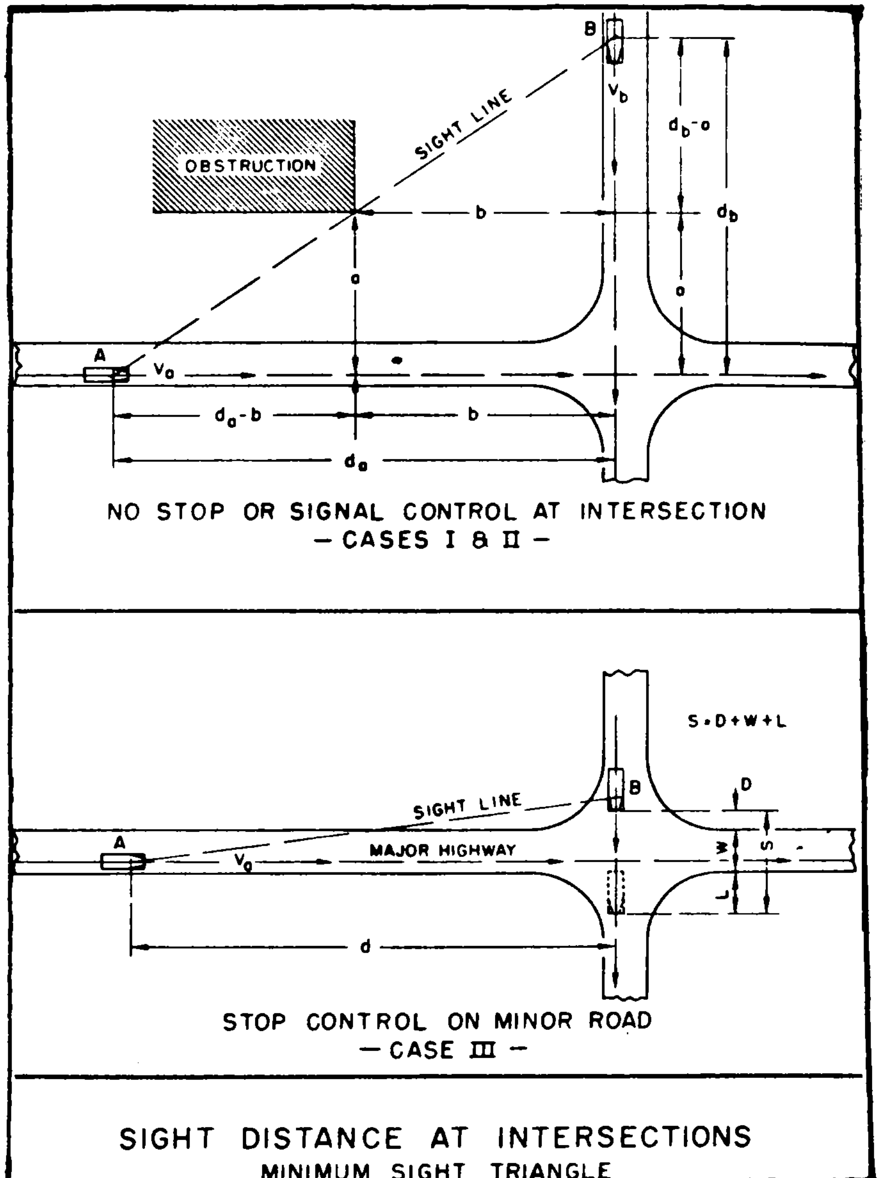


b) Stopping sight distance

LEGEND

d_1 = initial maneuver distance
d_2 = distance while vehicle occupies left lane
d_3 = clearance length
d_4 = distance traversed by opposing vehicle
d_p = perception and reaction distance
d_B = braking distance

Figure 37. Roadway sight distance cases.



Source: "A Policy on Geometric Design of Rural Highways", AASHO, 1965

Figure 38. Intersection sight triangles.

minimum distance required to respond appropriately to approaching cross traffic.

● Need For Study

The need for a sight distance study can be based on either one of three conditions, (1) accident patterns which indicate a possible sight distance problem, (2) a field review which indicates that sight distance may be inadequate, and (3) complaints made by local users of the roadway. Various accident patterns and appropriate sight distance studies are shown in Table 43.

Table 43. Accident patterns relating a need for a Sight Distance Study.

Study Situation	Accident Pattern	Sight Distance Study
Section of highway	● Head-on Collisions	● Passing sight distance
Intersection (uncontrolled, "STOP" or "YIELD" controlled)	● Right-angle accidents	● Intersection sight distance
	● Rear-end accidents on major roadway between left-turn and through vehicles (in same direction	● Stopping sight distance
Intersection ("STOP" or "YIELD" contolled)	● Rear-end accidents	● Stopping sight distance
Intersection (signal controlled)	● Rear-end accidents	● Stopping sight distance
	● Right-angle accidents	● Stopping sight distance or intersection sight distance

● Use of Study

The design standards [1] for minimum stopping sight distance is expressed as a function of the design speed of the roadway.

DESIGN SPEED (MPH)	MINIMUM STOPPING SIGHT DISTANCE (FT)
25	175
30	200
35	250
40	275
45	325
50	350
55	525

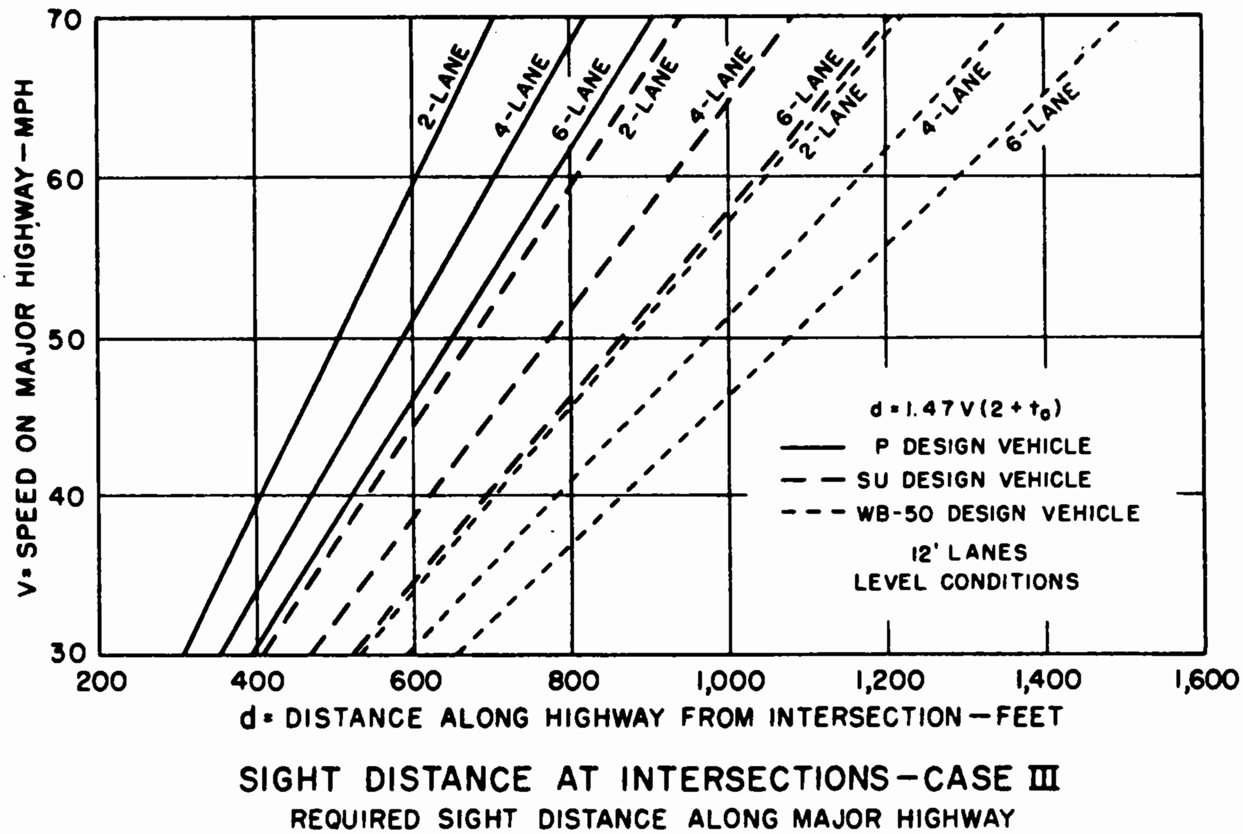
For passing sight distances, minimum standards based on MUTCD pavement marking requirements are [2]:

DESIGN SPEED (MPH)	MINIMUM PASSING SIGHT DISTANCE (FT)
30	500
40	600
50	800

Where the measured sight distance is greater than the standard (passing or stopping), safe sight distance conditions are assumed to exist. However, where measured sight distance conditions are insufficient, a safety deficiency is identified. From this study, appropriate safety improvements can be determined.

At intersections, sight triangles are used to define the stopping sight distance. The legs of the triangle are formed along the intersecting paths of the conflicting vehicles. The length of each leg is a function of the speed of approaching vehicles. Three different cases are illustrated in Figure 38.

For cases I and II, the minimum stopping distance criteria is used to determine the length of the triangle legs. In case III, the graph shown in Figure 39 is used to determine the sight triangle legs as a function of the travel speed and the number of traffic lanes for the major roadway. A safety deficiency is assumed to exist where sight distance is inadequate. Based on this finding, appropriate safety improvements can be identified.



Source: AASHTO Bluebook (1965)

Figure 39. Intersection sight distance criteria for minor street crossing major streets.

● Period of Data Collection

Data collection should be performed during the time of predominant accident occurrence. For instance, if accident patterns reflect a specific time of day or season of the year, the study should be performed during periods which reflect similar conditions. In many cases, changing foliage conditions or sun angles will affect sight distance but may not be observed unless the time of accident occurrences are considered. Where the accident activity is not related to a specific season or time period, the study should be performed under favorable weather conditions, preferably during a summer period.

Sight Distance Study Techniques

In performing a sight distance study, two techniques are commonly used. They include:

- Manual method.
- Vehicle method.

Table 44 summarizes the primary considerations for each technique.

● Manual Method

The manual method [3] utilizes two technicians. For intersection sight distance studies, one technician is stationed at a point on the minor intersection approach, representing a stopped or approaching vehicle. The second technician moves away from the intersection on the major approach with a vertical marker, stopping at intervals of 50 feet and placing the vertical marker on the pavement surface. This marker may consist of a survey range pole or other device, with a highly visible indicator at a height level of six inches. The technician stationed at the reference point then attempts to view the range pole from a position equivalent to the standard driver's eye height. The current standard is 3.75 feet although recent studies have shown that smaller vehicles may have eye heights of 3.00 to 3.50 feet. If the 6-inch mark on the range pole remains visible, the second technician continues to move down the roadway. The study continues until the observed sight distance becomes greater than the design sight distance (based on vehicle speed and roadway geometrics). It may also be performed graphically, where an accurate roadway inventory is provided.

For passing and stopping sight distance studies along a link, the technicians move along the roadway separated by a distance equal to the passing or stopping sight distance, respectively. Locations having inadequate sight distance are recorded on a scaled map of the study area. Minimum lengths of a no passing zone are shown in Figure 40.

Table 44. Primary considerations for Sight Distance Study techniques.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. **Manual Method**	. Obtains field sight distance conditions using observers	. Field poles . Hand measuring device . Diagram sheets	. Two technicians to review field conditions and sketch data . Trained technician or engineer to review data	. Approx. 1/2-1 hr. per site (intersection) . Several hrs. per mile (roadway segment)	. Measuring wheel $25-$75	. Defined location . Speed limit . Design standard	. Safe sight distance (ft. or m.) based on field conditions	. Assessment of safe distance conditions . Probable cause for insufficient sight distance
2. **Vehicle Method**	. Obtains field sight distance conditions using instrumented vehicle	. Instrumented vehicle . Hand measuring device (possibly) . Diagram sheets	. Two technicians operate vehicle . Trained technician to adjust and review data	. Approx. 1/2-1 hr. per site (intersection) . Approx. 1/2 hr. per mile (roadway segment)	. Instrumented vehicle $20,000	. Defined location . Speed limit . Design standards	. Sight distance conditions based on field review	. Assessment of safe distance conditions . Probable cause for insufficient sight distance

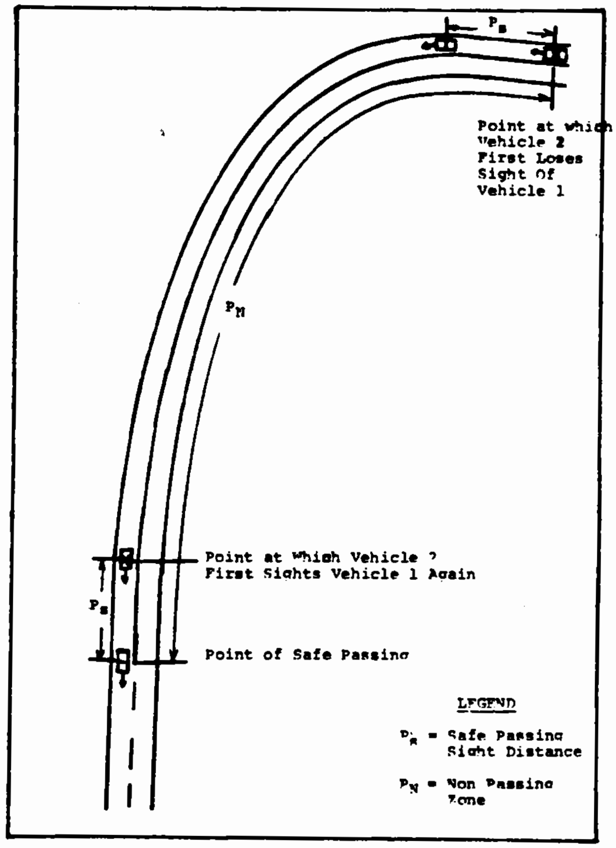


Figure 40. Non-passing zone measurement.

Advantages:

1. Equipment needs are minimal.
2. Able to study field conditions under a variety of eye height and object height situations.

Disadvantages:

1. Not appropriate for long segment lengths.
2. Time requirements can be substantial.

- <u>Vehicle Method</u>

The vehicle method requires two vehicles. The rear of one vehicle is marked at standard heights related to the sight distance criteria (passing or stopping) under review. The other vehicle is designated as a reference vehicle to observe field sight distance conditions. For link studies, the vehicles are separated by the minimum passing or stopping sight distance based on the 85th percentile speed or the posted speed limit. A distance meter may assist in maintaining a constant vehicle separation. Throughout the survey, two-way radio communications are used to enhance a constant vehicle separation. When the designated mark on the lead vehicle is not visible to the driver of the trailing vehicle, the location along the roadway is noted on a distance meter. When the trailing driver is again able to see the designated mark on the lead vehicle, this location is recorded. This procedure is continued along the length of the roadway segment.

Special mechanical devices may also be used to note these locations and distances. They require manual actuation, though.

For intersection sight distance, one vehicle is used to simulate an approach vehicle on the minor roadway, and the second vehicle simulates the approach vehicle on the major roadway. Through the use of walkie-talkies or observations by the minor stream vehicle, or a third party and subsequent manual measurement of distances, the field sight distance conditions are recorded.

Advantages:

1. Able to obtain a significant amount of information in a relatively short amount of time.
2. Measurements are generally reliable.
3. Field conditions are viewed as drivers would actually observe conditions.

Disadvantages:

1. Equipment needs and costs are relatively high.
2. Studies are limited by specific test vehicle characteristics.

Selection of Alternate Techniques

Tables 45 and 46 may be used to select a technique. General guidelines for the selection process are summarized below:

1. It is favorable to use the vehicle method for studying most roadway links due to its ability to collect a large amount of data in a relatively short amount of time.

2. For spot locations (500 feet in length or less) or intersections, the manual method may be more appropriate. It permits greater maneuverability of personnel to allow the study of a greater variety of situations.

3. A graphical approach may be used at intersections where an accurate record of the roadway and roadside characteristics exist.

Findings

Sight distance data for intersections can be presented on a condition diagram as shown in Figure 38 to show existing and minimum sight distances and sight obstructions.

For link studies, sight distance data can also be presented on condition diagrams which contain horizontal or vertical curve (crest and sags) data, and obstructions within the required sight distance area. These figures include the observed field conditions and sight distance.

Table 45. Technique utility for Sight Distance Study.

Management Concern \ Technique	Manual Method	Vehicle Method
. Time Requirements	. For spot location or intersection studies, time effort is not substantial . For link studies, time effort will be substantial	. For spot location or intersection studies, time effort will be similar to manual method . For link studies, time effort will be significantly less than manual method
. Manpower Requirements	. Two technicians	. Two trained technicians
. Equipment Requirements	. Hand measuring device . Other needs, minimal	. Vehicles, special measuring equipment
. Level of Accuracy	. Very reliable for intersection and short segments of roadway . For links, accuracy can be reliable, however, where segments lengths are considerable, human limitations may reduce accuracy	. Reliable for intersection, and link studies
. Comprehensiveness of Results	. Can study sight distance under varying height conditions	. Study limited by test vehicle's characteristics

Table 46. Favorable Sight Distance Study techniques.

Situation/Technique	Manual Method	Vehicle Method
Section of Highway		X
Intersection of Major roadway with minor roadway (uncontrolled, "stop" or "yield" controlled)	X	X
Signalized intersection	X	X

● Major Consideration

Minimum design values for passing sight distance along links are based on AASHTO (American Association of State Highways and Transportation Officials) criteria. These standards are in the AASHTO "Bluebook" [1] and "Redbook" volumes. The criteria for marking (operational) "no passing" zone differs considerably from the design standards. Design standards developed by AASHTO and the marking standards contained in the Manual of Uniform Traffic Control Devices (MUTCD) are shown in the table below.

Table 47. Comparison between AASHTO and MUTCD allowed passing distances.

SPEED (MPH)	AASHTO DESIGN VALUES (FT)	MUTCD MARKING VALUES (FT)
30	1100	500
40	1500	600
50	1800	800
60	2100	1000

Significant differences between these values occur. They are due primarily to the assumptions made in determining each standard [4]. For instance:

1. The MUTCD values are based on an off-peak 85th percentile speed, while the AASHTO values are based on the roadway design speed. The MUTCD speed is typically lower than the AASHTO design speed.

2. In computing minimum required sight distances, the MUTCD assumes that a driver is able to abandon the passing maneuver while in the passing lane if a safe passing maneuver cannot be completed. Thus, the safe passing sight distance is equivalent to the distance travelled by an opposing vehicle during the passing maneuver plus a safety factor. AASHTO, on the other hand, considers safe passing sight distance to be the distance travelled during the time a driver first perceives that he is able to pass and the time when the passing maneuver is completed (see Figure 37a).

When using these criteria, these different assumptions should be kept in mind. AASHTO design standards are for roadway design purposes where MUTCD marking standards are for traffic control. For safety studies of the passing sight distance, the MUTCD criteria are used.

- <u>Use of Study</u>

Where field conditions are found to be deficient or sufficient sight distance is not available, upgrading of these conditions is warranted. Available countermeasures may include:

- Removal of sight obstruction.
- Pavement marking improvements or alterations.
- Roadway alignment changes (grade reductions or curve realignment).
- Speed limit reductions.
- Advance warning signing.

This study identifies whether sight distance deficiencies exist at or along a highway facility. Such a determination assists in the selection of appropriate safety-related countermeasures.

PROCEDURE 17 Skid Resistance Study

<u>Purpose</u>

A skid resistance study commonly measures the frictional properties of a pavement surface.

<u>Application</u>

Skid resistance, normally expressed as a skid number (SN) [1], describes the level of friction between a roadway surface and vehicle tire when the tire is prevented from rotating.

The SN is defined as 100 times the coefficient of friction. The standard procedure for obtaining the skid number is described in the ASTM Standard E-274.

- <u>Need For Study</u>

The need for a skid resistance study is generally based on a pattern of "wet weather" or "skidding" accidents. Such a pattern may emerge as a predominant accident type or the number or rate of accidents may exceed an area-wide average value (threshold value) for the accident type.

Two threshold measures may be used. The first is the comparison of "wet pavement" accident rates for similar sites. The second technique is the ratio of "wet pavement" to "total" accidents. The "wet pavement" accident rate technique may produce a more usable threshold level since the use of an exposure factor may tend to discount the differences in traffic volumes between sites. It will permit a greater number of sites to be used for comparison purposes.

Other sources which may identify the need for a skid resistance study include field reviews and input from local sources. Observance of "skidding" vehicles during wet or dry pavement conditions may justify a skid resistance study.

● Measurement Modes

There are several modes of measuring skid resistance. The most common method is the locked wheel braking mode. The locked wheel braking mode measures the force required to pull a specified tire, while it is prevented from rotating (see Figure 41).

Other measurement modes include: the brake slip, the drive slip, and the cornering (YAW) mode. These modes have an advantage over the locked wheel mode in that continuous measurements are obtained while the tire rotates during the test procedure. However, they are not highly used in the U.S. at the present time.

In the slip mode [1] (brake or drive), the friction factor is a function of the "slip" of the test wheel as it rides over the pavement. For example, as the brake of a wheel is applied with an increasing force, the wheel develops increased "slip" (as illustrated in Figure 42). The slip gradually increases until at its maximum, the wheels lock up, resulting in a lower friction factor.

This mode has not been used to measure skid resistance characteristics of highways throughout the U.S. It has, however, been used successfully throughout Europe.

The YAW mode [1] uses a test wheel in the cornering mode at an angle to the direction of motion. The use of this test procedure assumes that the critical situation for skid resistance occurs in a cornering mode. This test allows a continuous measurement of the friction force since the tires rotate during the test. It can provide a summary of skid characteristics as a function of time. One such measuring device which has been used successfully in some parts of the United States is the Mu-meter, which consists of a trailer unit connected to a test vehicle.

Other testing modes have been used which include portable and laboratory testers. To date, these devices have not been widely used for highway safety study purposes.

● Use Of Study

The measures of skid resistance which result from each test mode are usually compared to a pre-established standard based on vehicle travel speeds. Since the friction factor may vary significantly with speed, as shown in Figure 43, a determination of skid characteristics under varying speed conditions is performed. This review indicates the rate at which the skid number decreases with increasing speed (referred to as skid number - speed gradient). A pavement with a rate of decrease near zero (skid number vs. speed) typically retains a higher skid resistance at

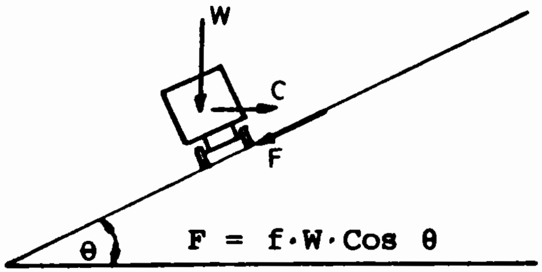


Figure 41. Skid resistance dynamics.

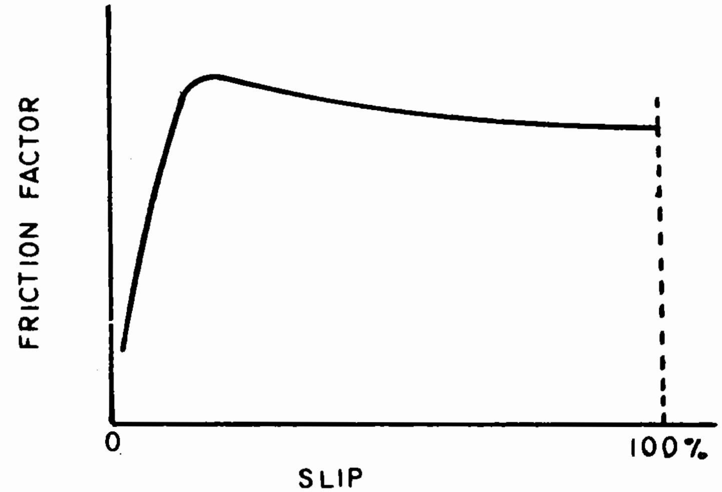


Figure 42. Skid number vs. brake slip.

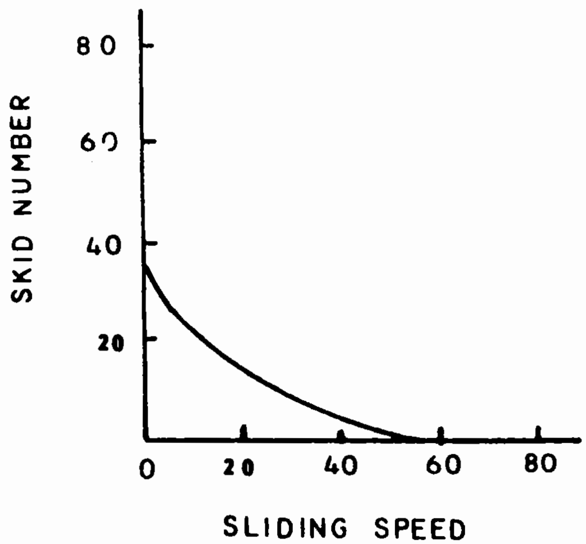


Figure 43. Skid resistance vs. vehicle speed.

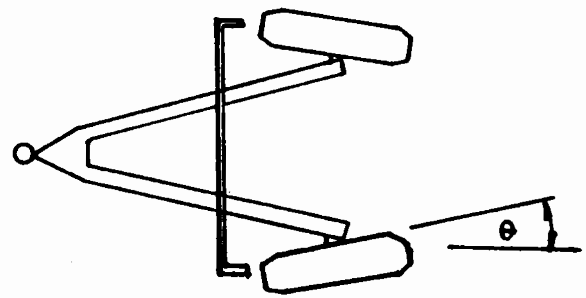


Figure 44. Schematic displaying yaw angle.

higher speeds than a pavement with a high rate of decrease. In addition, it will define the skid resistance of a pavement at the roadway travel speeds and be used to determine the pavement skid characteristics at these speeds.

Where unfavorable skid numbers or skid number - speed gradients exist, this information can be used to verify a safety deficiency, as previously identified by the accident procedures, and to select a countermeasure to alleviate the condition.

- Factors to Consider

Several factors should be considered when reviewing skid test results. First, a skid number can change over time due to traffic. Although some pavement aggregate particles may wear and become polished, others may, through the breaking of fragments, expose fresh surfaces. Also, wear may open new water escape passages in the surface.

Second, research on skid resistance measurements have shown that skid numbers vary with the seasons of the year and air and pavement moisture content, temperature, precipitation, and other factors. Therefore, skid measurements should be performed under the conditions described in the ASTM Standards.

Finally, skidding accidents may occur where an acceptable skid number exists. In these cases, accidents may be caused by the presence of water on the roadway. Therefore, consideration of pavement drainage characteristics is necessary.

- Period Of Data Collection

For safety reasons, data collection may require that a portion of the roadway be blocked off or that the study be performed under low volume conditions to attain the necessary range of travel speeds. It is recommended that skid resistance studies be performed during off-peak periods to minimize disruption to traffic. At high volume, urbanized locations, the study should be performed on the weekend. Studies can also be performed at night when lighting conditions are favorable.

As previously stated, the results of skid tests are affected by the season of the year. Time of day conditions can also affect the results. Periods of moisture (precipitation) and high or low temperature affect study results and should be avoided.

Skid Resistance Study Techniques

Several methods of obtaining skid resistance data are available. They include:

- Locked wheel trailer methods.

- Mu-meter tester.
- Automobile methods.
- Portable/laboratory testers.

Table 48 summarizes the primary considerations for each technique.

- Locked-Wheel Trailer Method

The locked-wheel trailer method [1,2,3,4,5] is the most widely used method within the U.S. for skid resistance measurement. It is based on the ASTM Method of Test E-274. The method utilizes a test tire (ASTM Standard E-501) installed on the wheels of a test trailer. The trailer is towed by a truck at a speed of 40 mph while water is applied uniformly in front of the test wheels. The rate of application of the water, according to the ASTM specifications, is 4.0 gal./min./in. (0.60 liters/min./mm) of wetted width, resulting in a standard thickness of water of 0.5mm (0.02 inch). A deviation of $\pm$ 5 SN may occur at 40 mph.

The test wheel(s) is locked by a brake and a recording of the wheel torque during braking is made using either manual or electronic measurements. Analysis of this torque results in a skid number (SN). Further details in this method is given in ASTM Method E-274.

Advantages:

1. Recognized as standard practice.
2. Economical and convenient to perform for a large number of tests.
3. Skid trailers available commercially.

Disadvantages:

1. Requires relatively expensive equipment (trailer).
2. Difficult to perform except under low traffic volume conditions.

- Mu-Meter Tester

The Mu-meter tester [1,4,5] typically employs methods as stated in ASTM-E-670. It uses a trailer type device with both wheels (treadless) yawed inwardly during field testing. In this mode, it simulates the cornering effect. However, since the wheels are yawed in opposite (but equal) angles, the trailer continues to move straight ahead.

In using this device, it is necessary that the yaw angle, as shown in Figure 44, be set such that the test results are minimally affected by surface characteristics or operating conditions. For highway safety applications, a yaw angle in the range of 10-15 degrees is suggested.

Table 48. Primary considerations for Skid Resistance Study.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Locked-Wheel Method	. Measures friction force using trailer device in locked wheel mode (ASTM Method E 274)	. Trailer device . Data sheets	. Technician to drive vehicle/ trailer unit . Engineer to evaluate data	. 1/2 hr. per site or mile	. Trailer device $70,000-$100,000	. Defined location	. Friction force or skid number	. Skid resistance capability of pavement
2. Automobile Method	. Measures friction force using test vehicle in locked wheel mode (ASTM Method E 445-71T)	. Test vehicle . Hand measuring device, stop watch or decelerometer	. Technician to drive vehicle . Technician to measure and record data . Engineer to adjust data	. 1/2 hr. per site . 1/2 hrs. per mile	. Hand measuring device $25-$150 . Stop watch $25-$150 . Decelerometer $15-$350	. Defined location	. Length of skid mark or time to decelerate (from X to Y mph) or deceleration rate	. Skid resistance capability of pavement
3. Mu-Meter Tester	. Measure friction force using skid trailer in yaw mode	. Mu-meter trailer . Data sheets	. Technician to drive vehicle/ trailer unit . Engineer to evaluate data	. 1/2 hr. per site or mile	. Mu-meter $70,000-$100,000	. Defined location	. Friction force or skid number	. Skid resistance capability of pavement
4. British Pendulum Tester	. Measures energy unit using pavement samples tested in a laboratory environment or on-site	. British pendulum tester . Data sheets	. Technician to drive vehicle . Technician to operate tester . Engineer to adjust data	. Testing approx. 1-2 hr. per sample	. Tester $500-$2,500	. Defined location . Pavement sample	. Measure of frictional resistance of pavement	. Skid resistance capability of pavement

The result of this method consists of a set of measurements of a Mu number. Measurements of the Mu number are made for both wheels and averaged. The results can correlate extremely well with the locked wheel method using similar test conditions, such as treadless tires (standard practice for Mu-meter) and an external water source (sprinkler truck). However, a maximum deviation of ± 5 SN at 40 mph can occur.

Advantages:

1. Are performed under ASTM standards.
2. Trailers are commercially available.
3. Economical and convenient to perform for a large number of tests.

Disadvantages:

1. Results can differ from locked wheel methods (recognized as the standard method).
2. Equipment is relatively expensive.
3. Requires testing, for safety reasons, under low traffic volume conditions.

● Automobile Method

The automobile method [1,4,6] uses a standard automobile driven along the roadway at a speed of 40 mph. An external water source is used to simulate the "wet pavement" conditions. The automobile's brakes are locked and measurement is made of how far the vehicle travels until it comes to a full stop. The braking distance, D, is then used in the following relationship to obtain the friction factor.

$$f = \frac{V_i^2 - V_f^2}{30D} \pm G$$

Where:

f = friction factor
D = braking distance (ft. or m.)
V_i = initial velocity (mph or kph)
V_f = final velocity (mph or kph)
G = percent of grade (+ or -)

The friction factor may be transformed to the skid number (SN) using the following formula:

$$SN = 100f$$

If performed properly, this technique can produce more consistent results than the road friction testers since it simulates actual driving conditions.

Advantages:

1. Equipment needs are minimal.
2. Requires a low capital investment.
3. If performed and measured according to ASTM standards, usable results may be obtained.

Disadvantages:

1. Technique can be dangerous to perform under high speed conditions.
2. Requires testing under low volume or blocked off road conditions.

● Laboratory and Portable Field Testers

Many laboratory and portable field testers [1,7] have been developed. However, in highway safety studies, they are not as applicable as the previous methods. This is primarily due to the fact that measurements obtained by many of these methods fail to correlate well with the standard tests suggested in the ASTM standards. One such device which has shown to be suitable for some safety uses and is gaining acceptance is the British Pendulum Tester. The tester consists of a pendulum to which a spring-loaded rubber shoe is attached. A vehicle (tester connected to vehicle) drives slowly (7 mph) over the roadway section, and the pendulum is dropped after which the shoe slides over the surface to be tested. The height of the rebound serves to measure the frictional resistance. Details of the testing procedure is based on ASTM Method E-303.

The results of this tester can be developed into a British Pendulum Number (BPN). This number is unique to this device and cannot be directly correlated to the results of other testing methods. However, it is used widely throughout other parts of the world for pavement evaluation.

Advantages:

1. Device is simple to operate.
2. Is adaptable to use as field or as laboratory tester.

Disadvantages:

1. Results do not correlate directly with locked-wheel results.
2. Cost per test can be quite high.
3. For field use, setup and preparation is usually extensive.
4. If used for laboratory testing, it may not fully reflect the field conditions.

Table 49. Technique utility for Skid Resistance Study.

Management Concern \ Technique	Locked Wheel Method	Mu-Meter Method	British Pendulum Method	Automobile Method
1. Time Requirements	. Requires data collection typically at 40 mph speed . Meter readings	. Requires data collection typically at 40 mph speed . Meter readings	. Requires data collection on pavement sample under static conditions . Meter readings	. Requires data collection typically at 40 mph speed . Require measurements and computations
2. Equipment Requirements	. Locked wheel trailer and measuring device . Other needs, minimal	. Mu-Meter trailer and measuring device . Other needs, minimal	. Trailer and measuring device . Other needs, minimal	. Automobile . Standard test tires (ASTM E 50.1) . Measuring instruments
3. Manpower Requirements	. Technician level	. Technician level	. Technician level	. Technician level
4. Level of Accuracy	. Highly reliable if well calibrated and maintained	. Highly reliable if well calibrated and maintained	. Highly reliable if well calibrated and maintained	. Accurate where measurements are obtained mechanically . Manual measurements may produce slight inaccuracies

Selection of Alternate Technique

Table 49 summarizes the utility of the techniques based on agency resource limitations and the accuracy of the technique. General guidelines for selecting a technique are:

1. The locked-wheel methods are considered as standard practice for performing skid resistance studies. Where locked- wheel testers are available, they are preferred due to their recognition as accurate, safe and reliable methods. However, where this equipment is unavailable, the automobile method can be suitable. It can adequately simulate the locked-wheel condition.

2. Mu-meter tests may be appropriate because they simulate the locked wheel condition in a cornering mode. The results differ slightly from those obtained by the locked wheel testers.

3. The automobile method can provide reliable results given the appropriate measuring instrumentation. However, due to the potential hazard involved in performing this method, its use is not encouraged.

4. The portable/laboratory testers do not produce results correlative with the locked wheel results and, as such, their use in highway safety studies is not encouraged. However, as a tool for pavement comparison and other similar purposes, they can produce effective results. One device which is gaining more widespread attention in skid resistance studies is the British Pendulum Tester.

Findings

The output of a skid resistance study can be presented in a chart by test run (page I-14 of the Appendix). Since the skid number results are sensitive to many factors, (precipitation, air temperature, and vehicle speed [8,9]), documentation of these conditions is important.

● Use Of Findings

In evaluating the skid resistance qualities of a pavement, a review of the skid number at a 40 mph speed and the skid number - speed gradient of the pavement is performed. This review not only assists in evaluating the pavement skid characteristics based on standards for the ASTM test methods, but also assesses the pavement's skid resistance characteristics under varying speed conditions, in particular, actual field conditions. The speed gradient is used to assess the skid resistance qualities for the range of travel speeds expected along a roadway.

The skid numbers at various speeds are compared to minimum standards defined by the state highway agency in which they are used. Skid numbers lower than these values will usually dictate the need for upgrading (countermeasures) of the pavement skid characteristics. Countermeasures may include pavement grooving, surface overlay, roadway speed reductions, and warning signing.

PROCEDURE 18 Highway Lighting Study

Purpose

Highway lighting studies are used to determine the adequacy of existing lighting systems and the need for new, additional, or improved systems. These studies may be used to evaluate sites with existing lighting facilities and sites which may need lighting based on accident experiences.

Application

- Need for Study

Highway lighting studies may be warranted based on an observed pattern of nighttime accidents. In addition, field reviews performed under nighttime conditions may show insufficient or inadequate lighting or delineation of the study area. Input from local users can also justify a highway lighting study.

- Use Of Study

When the need for a highway lighting study exists, site data (roadway volumes, area type, accident rate, existing lighting in area, roadway geometrics, etc.) should be collected, reviewed, and compared to roadway lighting warrants to determine the effectiveness of the current highway lighting conditions. The warrants are primarily directed at those locations where highway lighting currently does not exist.

When there is a need to assess the adequacy for an existing lighting system, a study comparing existing lighting characteristics to design standards can be performed. The design standards are set forth by AASHTO [1], the Illuminating Engineering Society [2], or independent local standards.

The study can determine whether a safety deficiency exists and assist in identifying a countermeasure where lighting conditions are considered deficient.

Lighting Study Techniques

The following techniques are available:

- American Association of State Highways and Transportation Officials (AASHTO) criteria.

Table 50. Primary considerations for Highway Lighting Study technique.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. AASHTO Criteria	. Evaluates lighting needs for freeways, interchanges, tunnels and underpasses, etc. based on traffic volume, area description, and accident data applied to guidelines for these conditions	. Volume counters . Data sheets	. Technicians to perform volume surveys . Engineer to calculate accident data . Engineer to review warrants	. With available volume data, approx. 1 hrs. per site	. None	. Defined location . Volume data for specific location . Area description . Accident data by time of day	. Assessment of warrants	. Review of need for lighting
2. NCHRP Report No. 152 Method	. Evaluates lighting need for freeways, interchanges, noncontrolled access facilities and intersections based on geometric, operational, environmental, and accident factors applied to tabular form and compared to warranting value	. Radar meter (speed) measuring device . Data sheets	. Technician to obtain field data . Engineer to evaluate weighting plan	. Field data collection - approx. 1-2 days . Adjust data sheet approx. 1-2 hrs. per site	. None	. Defined location . Field data (per tabular form) . Area description . Accident data	. Compilation of tabular form . Comparison value to warranting condition	. Review of need for lighting

Table 50. Primary considerations for Highway Lighting Study technique (continued).

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
3. Individual Warrants - Rural Intersection Lighting Method	. Evaluates lighting needs for rural intersection based on accident data applied to guidelines for this condition	. Data sheets	. Engineer to review accident data and assess warrants	. Approx. 1 hr. per site	. None	. Defined location . Accident data	. Assessment of warrants	. Review of need for lighting
- Pedestrian Crosswalk	. Evaluates special lighting needs for crosswalks based on traffic volume, accident, area description, and pedestrian behavior data applied to guidelines for these conditions	. Volume counters . Data sheets	. Technician to perform volume surveys . Engineer to perform field review and evaluate accident data . Engineer to review warrants	. With available volume data, approx. 1 hour per site	. None	. Defined location . Volume data for specific location . Area description . Accident data	. Assessment of warrants	. Review of need for special lighting
4. Field Condition Method	. Evaluates adequacy of existing lighting system based on a comparison of existing hardware in field to design standards	. Data sheets	. Engineer to field review location, obtain existing hardware characteristics and compare to design standards	. Approx. 1/2 days per site	. None	. Defined location . Existing lighting hardware . Area description . Design standards	. Evaluation of field system to design system	. Review of adequacy or need for further lighting needs
5. Light Meter Method	. Evaluates adequacy of existing luminaries to provide proper lighting based on field measurement of illumination level and comparison to design standards	. Light meter . Data sheets	. Engineer to field review location and sample illumination levels . Engineer to compare field results to design standards	. Approx. 1/2 day per site	. Light meter $600-$1,000	. Defined location . Area description . Design standards	. Illumination level at sample locations	. Review of adequacy or need for further lighting needs

- NCHRP Report No. 152 method.
- Selected individual warrants based on individual research,
- Field review method.
- A light meter technique.

Table 50 summarizes the major considerations for each technique.

- AASHTO Criteria

The AASHTO criteria [1,3] were prepared by the Joint Task Force for Highway Lighting of the AASHTO Operating Subcommittees on Design and Traffic Engineering. The criteria is based on a description of operational, geometric, and developmental conditions that must be matched or exceeded to justify the installation of roadway lighting. AASHTO warrants are currently developed for the following area types:

- Freeways
- Interchanges
- Tunnels and underpasses
- Roadway safety rest areas
- Roadway sign lighting

Basic data needs for these warrants include traffic volumes (by time of day for a 24-hour period), accident frequency (night vs. day), and a knowledge of the study area and its environs.

The warrants for freeways and interchanges are shown in Table 51. Warrants for other field situations are provided in Reference 1. Additional general warrants which may be used to justify lighting improvements are:

1. Where there is continuous freeway lighting, there should be complete interchange lighting.

2. When continuous freeway lighting is warranted, but not initially installed, partial interchange lighting is justified.

3. Where complete interchange lighting is warranted, but not initially fully installed, a partial lighting system which exceeds the normal partial installation in number of lighting units is justified.

4. Lighting of crossroad ramp terminals is warranted where the design requires the use of raised channelizing or divisional islands, and/or where there is poor sight distance.

Advantages:

1. Provides a simple, usable method.

Table 51. Lighting warrants (AASHTO criteria).

Criteria / Situation	Average Daily Traffic (ADT): Freeway or Ramp	Average Daily Traffic (ADT): Other	Interchange Spacing	Night/Day Accident Rate	Other
1. Continuous Freeway	. In or near cities, ADT's 30,000 or more	. Not applicable	. Three or more successive interchanges with an average spacing of 1.5 miles or less in an urban-type area	. 2.0 or higher; or . Higher than Statewide average for similar, unlighted areas	. For a two or more mile length of freeway (through an urban or suburban area) a. local traffic uses street having lighting which is visible to freeway traffic; b. freeway runs through lighted area; c. streets crossing freeway having an average spacing of 1.2 mile or less; or d. narrow medians or borders are used.
2. Complete Interchange Lighting	. Total ramp traffic ADT exceeds: - urban (10,000) - suburban (8,000) - rural (5,000)	. Crossroad ADT traffic exceeds: - urban (10,000) - suburban (8,000) - rural (5,000)	. Not applicable	. 1.5 or higher; or . Higher than Statewide average for similar, unlighted sections	. Immediate area is lighted; or . Crossroad approach legs are lighted for 1/2 mile or more
3. Partial Interchange Lighting	. Total ramp traffic ADT exceeds: - urban (5,000) - suburban (3,000) - rural (1,000)	. Freeway ADT exceeds: - urban (25,000) - suburban (20,000) - rural (10,000)	. Not applicable	. 1.25 or higher; or . Higher than Statewide average for similar, unlighted areas	. Not applicable

2. Requires minimal data.
3. Produces reliable results based on present experience.
4. Accepted as a national guideline.

Disadvantages:

1. Is not effective for most urban street and rural highway situations.

● NCHRP Report No. 152 method

The NCHRP Report No. 152 method [1,4] is based on research related to the driver visual information needs. Information needs for this method include roadway geometric factors, operational factors, environmental factors, and accident data. These factors are compiled in separate tabular forms for situations such as: non-controlled access facilities, intersections, freeways, and interchanges. The forms are displayed in Figures 45-48.

Within these forms, the "CLASSIFICATION FACTOR" refers to the specific data item or information to be studied and for which data are to be obtained. The "RATING" is based on the specific characteristics of the data. Individual data items are weighted based on their expected significance as an evaluation factor. The weighting is accomplished by comparing weights for a "lit" and an "unlit" situation. The sum of the weighted ratings for the individual factors are computed and this value is compared to a warrant value (condition). However, the warrant condition may be adjusted according to the agency's experiences. General guidelines for warrant values are shown in Figures 45-48.

This technique requires substantial data collection to provide an accurate inventory of existing conditions and lighting needs. Where data are unavailable, estimated values based on engineering judgment should be used.

Advantages:

1. Technique is flexible (by assigned weightings and warranting condition) to meet individual agency's needs and experiences.
2. Produces evaluation criteria for wide range of situations.

Disadvantages:

1. Requires extensive data collection.
2. Guidelines for "WARRANTING CONDITION" not based on extensive previous experience.
3. Time requirements may be substantial.

This technique is appropriate for intersections and non-access controlled facilities. For these situations, it provides a defined, reliable technique for evaluation of highway lighting conditions. The technique is

EVALUATION FORM FOR CONTROLLED ACCESS FACILITY (FREEWAY) LIGHTING

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A - B)	SCORE [RATING X (A - B)]
Geometric Factors									
Number of Lanes	4		6		≥ 8	1.0	0.8	0.2	______
Lane Width	> 12'	12'	11'	10'	≤ 9'	3.0	2.5	0.5	______
Median Width	> 40'	24-39'	12-23'	4-11'	0-3'	1.0	0.5	0.5	______
Shoulders	10'	8'	6'	4'	0'	1.0	0.5	0.5	______
Slopes	≥ 8:1	6:1	4:1	3:1	2:1	1.0	0.5	0.5	______
Curves	0-1/2°	1/2-1°	1-2°	2-3°	3-4°	13.0	5.0	8.0	______
Grades	< 3%	3 - 3.9%	4 - 4.9%	5 - 6.9%	> 7%	3.2	2.8	0.4	______
Interchange Frequency	4 miles	3 miles	2 miles	1 mile	< 1 mile	4.0	1.0	3.0	______
							Geometric Total		______
Operational Factors									
Level of Service (any dark hour)	A	B	C	D	E	6.0	1.0	5.0	______
							Operational Total		______
Environmental Factors									
% Development	0%	25%	50%	75%	100%	3.5	0.5	3.0	______
Offset to Development	200'	150'	100'	50'	< 50'	3.5	0.5	3.0	______
							Environmental Total		______
Accidents									
Ratio of Night-to-Day Accident Rates	1.0	1-1.2	1.2 - 1.5	1.5 - 2.0	2.0°	10.0	2.0	8.0	______
							Accident Total		______

°Continuous lighting warranted.

GEOMETRIC TOTAL = ______
OPERATIONAL TOTAL = ______
ENVIRONMENTAL TOTAL = ______
ACCIDENT TOTAL = ______
SUM = ______ POINTS
WARRANTING CONDITION = 95 points

Figure 45. Highway lighting warrant form - freeway.

EVALUATION FORM FOR INTERCHANGE LIGHTING

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A - B)	SCORE [RATING X (A - B)]
Geometric Factors									
Ramp Types	Direct	Diamond	Button Hooks Cloverleafs	Trumpet	Scissors and Left-side	2.0	1.0	1.0	______
Cross-Road Channelization	none		continuous		at interchange intersections	2.0	1.0	1.0	______
Frontage Roads	none		one-way		two-way	1.5	1.0	0.5	______
Freeway Lane Widths	> 12'	12'	11'	10'	< 10'	3.0	2.5	0.5	______
Freeway Median Widths	> 40'	34 - 40'	12 - 24'	4 - 12'	< 4'	1.0	0.5	0.5	______
No. Freeway Lanes	4 or less		6		8 or more	1.0	0.8	0.2	______
Main Lane Curves	< 1/2°	1-2°	2-3°	3-4°	> 4°	13.0	5.0	8.0	______
Grades	3%	3 - 3.9%	4 - 4.9%	5 - 6.9%	7% or more	3.2	2.8	0.4	______
Sight Distance Cross Road Intersection	> 1000'	700 - 1000'	500 - 700	400 - 500'	< 400'	2.0	1.8	0.2	______
							Geometric Factors		______
Operational Factors									
Level of Service (any dark hour)	A	B	C	D	E	6.0	1.0	5.0	______
							Operational Factors		______
Environmental Factors									
% Development	none	1 quad	2 quad	3 quad	4 quad	2.0	0.5	1.5	______
Set-Back Distance	> 200'	150 - 200'	100 - 150'	50 - 100'	< 50'	0.5	0.3	0.2	______
Cross-Road Approach Lighting	none		partial		complete	3.0	2.0	1.0	______
Freeway Lighting	none		interchanges only		continuous*	5.0	3.0	2.0	______
							Environmental Factors		______
Accidents									
Rate of Night-to-Day Accident Rates	< 1.0	1.0 - 1.2	1.2 - 1.5	1.5 - 2.0	> 2.0*	10.0	2.0	8.0	______
*Complete lighting warranted.							*Accident Factors*		______

GEOMETRIC TOTAL = ______
OPERATIONAL TOTAL = ______
ENVIRONMENTAL TOTAL = ______
ACCIDENT TOTAL = ______
SUM = ______ POINTS
COMPLETE LIGHTING WARRANTING CONDITION = 90 points
PARTIAL LIGHTING WARRANTING CONDITION = 60 points

Figure 46. Highway lighting warrant form - interchange.

EVALUATION FORM FOR INTERSECTION LIGHTING

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A - B)	SCORE [RATING X (A - B)]
Geometric Factors									
Number of Legs		3	4	5	6 or more (including traffic circles)	3.0	2.5	0.5	______
Approach Lane Width	> 12'	12'	11'	10'	< 10'	3.0	2.5	0.5	______
Channelization	no turn lanes	left turn lanes on major legs	left turn lanes on all legs, right turn lanes on major legs	left and right turn lanes on major legs	left and right turn lanes on all legs	2.0	1.0	1.0	______
Approach Sight Distance	> 700'	500-700'	300-500'	200-300'	< 200'	2.0	1.8	0.2	______
Grades on Approach Streets	< 3%	3.0 - 3.9%	4.0 - 4.9%	5.0 - 6.9%	7% or more	3.2	2.8	0.4	______
Curvature on Approach Legs	< 3.0°	3.0 - 6.0°	6.1 - 8.0°	8.1 - 10.0°	> 10°	13.0	5.0	8.0	______
Parking in Vicinity	prohibited both sides	loading zones only	off-peak only	permitted one side only	permitted both sides	0.2	0.1	0.1	______
							Geometric Total		______
Operational Factors									
Operating Speed on Approach Legs	25 mph or less	30 mph	35 mph	40 mph	45 mph or greater	1.0	0.2	0.8	______
Type of Control	all phases signalized (incl. turn lane)	left turn lane signal control	through traffic signal control only	4-way stop control	stop control to minor legs or no control	3.0	2.7	0.3	______
Channelization	left and right signal control	left and right turn lane signal control on major legs	left turn lane signal control on all legs	left turn lane signal control on major legs	no turn lane control	3.0	2.0	1.0	______
Level of Service (Load Factor)	A 0.0	B 0-0.1	C 0.1 - 0.3	D 0.3 - 0.7	E 0.7 - 1.0	1.0	0.2	0.8	______
Pedestrian Volume (peds/hr crossing)	very few or none	0-50	50-100	100-200	> 200	1.5	0.5	1.0	______
							Operational Total		______
Environmental Factors									
Percent Adjacent Development	0	0-30%	30-60%	60-90%	100%	0.5	0.3	0.2	______
Predominant Development near Intersection	undeveloped	residential	50% residential 50% industrial or commercial	industrial or commercial	strip industrial or commercial (no circuity)	0.5	0.3	0.2	______
Lighting in Immediate Vicinity	none	0-40%	40-60%	60-80%	essentially continuous	3.0	1.5	1.5	______
Crime Rate	extremely low	lower than city average	city average	higher than city average	extremely high	1.0	0.5	0.5	______
							Environmental Total		______
Accidents									
Ratio of night-to-day Accident Rates	1.0	1.0-1.2	1.2-1.5	1.5-2.0	2.0*	10.0	2.0	8.0	______
							Accident Total		______

*Intersection lighting warranted.

GEOMETRIC TOTAL = ______
OPERATIONAL TOTAL = ______
ENVIRONMENTAL TOTAL = ______
ACCIDENT TOTAL = ______
SUM = ______ POINTS
WARRANTING CONDITION = 75 points

Figure 47. Highway lighting warrant form - intersection.

EVALUATION FORM FOR NON-CONTROLLED ACCESS FACILITY LIGHTING

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A - B)	SCORE [RATING X (A - B)]
Geometric Factors									
No. of lanes	4 or less	-	6	-	8 or more	1.0	0.8	0.2	____
Lane Width	> 12'	12'	11'	10'	< 10'	3.0	2.5	0.5	____
Median Openings Per Mile	< 4.0 or one-way operation	4.0 - 8.0	8.1 - 12.0	12.0 - 15.0	> 15.0 or no access control	5.0	3.0	2.0	____
Curb Cuts	< 10%	10-20%	20-30%	30-40%	> 40%	5.0	3.0	2.0	____
Curves	< 3.0°	3.1 - 6.0°	6.1 - 8.0°	8.1 - 10.0°	> 10°	13.0	5.0	8.0	____
Grades	< 3%	3.0 - 3.9%	4.0 - 4.9%	5.0 - 6.9%	7% or more	3.2	2.8	0.4	____
Sight Distance	> 700'	500 - 700'	300 - 500'	200 - 300'	< 200'	2.0	1.8	0.2	____
Parking	prohibited both sides	loading zones only	off-peak only	permitted one side	permitted both sides	0.2	0.1	0.1	____
							Geometric Total		____
Operational Factors									
Signals	all major intersections signalized	substantial majority of intersections signalized	most major intersections signalized	about half the intersections signalized	frequent non-signalized intersections	3.0	2.8	0.2	____
Left Turn Lane	all major intersections or one-way operation	substantial majority of intersections	most major intersections	about half the major intersections	infrequent turn bays or undivided streets	5.0	4.0	1.0	____
Median Width	30'	20 - 30'	10 - 20'	4 - 10'	0 - 4'	1.0	0.5	0.5	____
Operating Speed	25 or less	30	35	40	45 or greater	1.0	0.2	0.8	____
Pedestrian Traffic at Night (peds/mi)	very few or none	0 - 50	50 - 100	100 - 200	> 200	1.5	0.5	1.0	____
							Operational Total		____
Environmental Factors									
% Development	0	0 - 30%	30 - 60%	60 - 90%	100%	0.5	0.3	0.2	____
Predominant Type Development	undeveloped or back-up design	residential	half residential &/or commercial	industrial or commercial	strip industrial or commercial	0.5	0.3	0.2	____
Setback Distance	> 200'	150 - 200'	100 - 150'	50 - 100'	< 50	0.5	0.3	0.2	____
Advertising or Area Lighting	none	0 - 40%	40 - 60%	60 - 80%	essentially continuous	3.0	1.0	2.0	____
Raised Curb Median	none	continuous	at all intersections	at signalized intersections	a few locations	1.0	0.5	0.5	____
Crime Rate	extremely low	lower than city average	city average	higher than city average	extremely high	1.0	0.5	0.5	____
							Environmental Total		____
Accidents									
Ratio of Night-to-Day Accident Rates	< 1.0	1.0 - 1.2	1.2 - 1.5	1.5 - 2.0	2.0*	10.0	2.0	8.0	____
							Accident Total		____

*Continuous lighting warranted.

GEOMETRIC TOTAL = ________
OPERATIONAL TOTAL = ________
ENVIRONMENTAL TOTAL = ________
ACCIDENT TOTAL = ________
SUM = ________ POINTS
WARRANTING CONDITION = 85 points

Figure 48. Highway lighting warrant form - highway section.

also favorable for freeway and interchange evaluation; however, due to the large amount of data collection involved with this method, it is generally not encouraged for freeways and interchanges.

- Other Selected Warrants

Warrants for rural intersection lighting [3] were developed by the University of Illinois in cooperation with the Illinois Department of Transportation. This warrant relates the need for lighting where the average frequency of nighttime accidents is one-third or greater than the day accidents. It is also recommended that lighting be installed at rural intersections where channelization exists.

In a research project for the Federal Highway Administration, warrants for special lighting of pedestrian crosswalk facilities [5] were developed. The warrants are based on volumes (pedestrians and vehicles), accidents, pedestrian behavior, or a combination of the above. The "volume criteria" are shown in Table 52.

The "accident criteria" are met if over a period of four consecutive years, a minimum of three pedestrian accidents occur in the crosswalk per year, at night. These accidents should be partially or wholly attributed to reduced visibility of the pedestrian which could be alleviated by illumination.

The "pedestrian behavior warrant" can be met when it is determined that a minimum of 5% of observed pedestrians demonstrate unsafe crossing patterns.

A "combination warrant" can be met if any two of the above warrants meet two-thirds of the prescribed levels or it is determined by engineering judgment that special lighting is warranted.

Advantages:

1. Based on research findings.
3. Simple to perform.

Disadvantages:

1. Requires further testing on a nationwide basis.
2. Limited scope.

For the study of existing lighting systems, the following methods are available: (1) the field lighting conditions can be compared to design standards, or (2) light meters can be used to record lighting outputs for comparison to design guidelines.

Table 52. Pedestrian crosswalk lighting warrants.

WARRANTING CONDITIONS ACCORDING TO VOLUME				
		ROADWAY CLASSIFICATION		
		MAJOR ARTERIAL	COLLECTOR DISTRIBUTOR	LOCAL
AREA	CBD (COMMERCIAL)	*	500 veh/night 100 ped/night	200 veh/night 50 ped/night
AREA	FRINGE (INTERMEDIATE)	1000 veh/night 100 ped/night	500 veh/night 100 ped/night	200 veh/night 50 ped/night
AREA	OBD (INTERMED-COMM)	1000 veh/night 100 ped/night	500 veh/night 100 ped/night	200 veh/night 50 ped/night
AREA	RESIDENTIAL	1000 veh/night 50 ped/night	500 veh/night 50 ped/night	200 veh/night 50 ped/night

Source: Roadway Lighting Handbook, FHWA, December (1979).

● Field Condition Method

In the field conditions [6,7] method, the collection of field data for the roadway environment and office data for the lighting hardware information is necessary. The field data to be collected include:

- Roadway classification (freeway, expressway, major arterial, collector, local or alleys).
- Land use (commercial, residential, or intermediate),
- Lighting (luminaire) spacing.
- Lighting (luminaire) mounting height.
- Lighting (luminaire) lateral location.

Office data, from existing inventory files, include:

- Light source size (lumen output).
- Light source type (incandescent, flourescent, mercury vapor, metal halide, high pressure or low pressure sodium).
- Luminaire type.

The characteristics of the existing luminaire system are compared to the design criteria based on design methods and guidelines given in the Roadway Lighting Handbook [3] (FHWA).

Advantages:

1. Produces a direct comparison with design standards.
2. Results provide direct recommendations for upgrading conditions.
3. Results are based on actual field conditions.

Disadvantages:

1. Requires substantial time and manpower expenditures.

This technique is appropriate for all field situations. It can be used to evaluate other highway lighting characteristics such as: glare, reflectivity, etc. However, the method requires a substantial number of calculations.

● Light Meter Method

Light meters [6,7] can be used to measure the illumination output of the lighting sources. Measured at various points within the study area, field characteristics (light intensity, light distribution) are recorded. These measurements are compared to the design illumination guidelines stated in the Roadway Lighting Handbook [3]. Deficiencies are noted by differences in the illumination level at the test locations.

Advantages:

1. Provides a comparison with design guidelines.
2. Results provide recommendations for upgrading conditions.
3. Results are based on field measurements.

Disadvantages:

1. Measured output does not account for glare, reflectance, etc.
2. Requires measurement of light output under favorable weather conditions.
3. Requires considerable data collection effort.

Selection of Alternate Technique

Table 53 summarizes the utility of each technique. Table 54 identifies the favorable study technique as a function of the field situation. To assist in selecting a technique, the following general guidelines are provided.

1. The use of AASHTO criteria for evaluation of highway lighting needs is recommended for freeway and interchange locations.

2. For non-controlled access locations and intersection situations, the NCHRP Report No. 152 method is preferred. It is also favorable for freeways and interchanges; however, the data collection needs are considerable.

3. For evaluation of existing lighting systems, the AASHTO method is preferred. It is an easy and simple method. For a detailed evaluation, the light meter method may be more favorable than the field condition method since it directly measures the light output.

Findings

A checklist can be used to compare site data with the AASHTO criteria, the rural intersection method, and the pedestrian crosswalk method.

Output forms for the NCHRP Report No. 152 method were displayed in Figures 45-48. Further information is provided in Chapter 6 of the Roadway Lighting Handbook[3].

Table 53. Technique utility for Highway Lighting warrants.

Technique / Management Concern	Pedestrian Crosswalk Facilities Method	Field Condition Method	Light Meter Method	AASHTO Criteria	NCHRP Report No. 152	Rural Intersection Lighting Method
1. Time Requirements	. Requires minimal data collection and review effort	. Requires substantial data collection and review effort	. Requires substantial data collection and review effort	. Requires minimal data collection and review effort	. Requres extensive data collection and review effort	. Requires minimal data collection and review effort
2. Manpower Requirements	. Technicians, Engineer	. Engineers	. Engineers	. Technicians, Engineer	. Technicians, Engineer	. Engineer
3. Equipment Requirements	. Volume counters . Other needs minimal	. Minimal	. Light meter . Other needs minimal	. Volume counters . Other needs minimal	. Volume counters . Measuring wheel . Other needs minimal	. Minimal
4. Level of Comprehensiveness	. Based on volume, general area description, accident, and pedestrian behavior data	. Based on existing hardware system as compared to design standards	. Based on illumination output onsite as compared to design standards	. Based on volume, general area description, and accident data for site	. Based on detailed geometric, operational, evironmental, and accident data for site	. Based on accident data
5. Level of Accuracy	. Primarily unproven	. Objective approach; relates to all standards	. Objective approach; relates illumination level	. Subjective approach; commonly used as standard	. Subjective approach; accepted as upcoming standard	. Primarily unproven

Table 54. Favorable Highway Lighting Study techniques.

Technique / Situation	AASHTO Criteria	NCHRP Report No. 152	Informational Needs Approach	Rural Intersection Lighting Method	Pedestrian Crosswalk Method	Field Condition Method	Light Meter Method
1. Freeways	X	X	X			X	X
2. Interchanges	X	X	X			X	X
3. Urban Intersection		X	X			X	X
4. Rural Intersection		X	X	X		X	X
5. Pedestrian Crosswalks			X		X	X	X
6. Tunnels and Underpasses	X		X			X	X
7. Non-Controlled Assess Facility		X	X			X	X

In addition to the warrants, a nighttime field review of the area is performed to obtain the following information.

1. Driver's visual field (as related to characteristics of the traffic facility).
2. Roadway facility function.
3. Supplemental information for the lighting warrants.
4. Subjective comfort benefits of existing roadway lighting.
5. Information for the design guidelines.

● Use of Findings

Where existing lighting is found inadequate, upgrading of conditions is warranted. Where further lighting needs are not warranted, yet the accident data or field review show nighttime accident problems, the need for improved positive guidance may be required [8]. These guidance measures can include: improved roadway delineation (thermoplastic, raised reflectors, delineators, etc.), improved signing (advance warning, target arrows, chevrons, etc.), or internal illumination of signing. These improvements will be identified based on a field review of the study situation and the past experience of the agency. Information on this concept is included in the FHWA Manual "A User's Guide to Positive Guidance" (June, 1977).

● Example

A sample problem for an urban intersection using the NCHRP Report No. 152 method is shown below.

Intersection: 3 Mile Road and Blake Road, Anytown, USA

1. Geometric Factors

Number of Legs: 4
Approach Lane Width: 11 feet
Channelization: Left-turn lanes on all legs, right-turn lane on major legs

Approach Sight Distance: > 700 feet
Grades on Approach Street: < 3°
Parking in Vicinity: Prohibited both sides

2. Operational Factors

Operating Speed on Approach Legs: 40 mph
Type of Control: All movements signalized
Channelization: Left and right signal control
Level of Service: E(1.0)
Pedestrian Volume: 0-50

EVALUATION FORM FOR INTERSECTION LIGHTING

CLASSIFICATION FACTOR	RATING 1	2	3	4	5	UNLIT WEIGHT (A)	LIGHTED WEIGHT (B)	DIFF. (A - B)	SCORE [RATING X (A - B)]
Geometric Factors									
Number of Legs		3	4	5	6 or more (including traffic circles)	3.0	2.5	0.5	1.5
Approach Lane Width	> 12'	12'	11'	10'	< 10'	3.0	2.5	0.5	1.5
Channelization	no turn lanes	left turn lanes on major legs	left turn lanes on all legs, right turn lanes on major legs	left and right turn lanes on major legs	left and right turn lanes on all legs	2.0	1.0	1.0	3.0
Approach Sight Distance	> 700'	500-700'	300-500'	200-300'	< 200'	2.0	1.8	0.2	0.2
Grades on Approach Streets	< 3%	3.0 - 3.9%	4.0 - 4.9%	5.0 - 6.9%	7% or more	3.2	2.8	0.4	0.4
Curvature on Approach Legs	< 3.0°	3.0 - 6.0°	6.1 - 8.0°	8.1 - 10.0°	> 10°	13.0	5.0	8.0	8.0
Parking in Vicinity	prohibited both sides	loading zones only	off-peak only	permitted one side only	permitted both sides	0.2	0.1	0.1	0.1
							Geometric Total		14.7
Operational Factors									
Operating Speed on Approach Legs	25 mph or less	30 mph	35 mph	40 mph	45 mph or greater	1.0	0.2	0.8	3.2
Type of Control	all phases signalized (incl. turn lane)	left turn lane signal control	through traffic signal control only	4-way stop control	stop control to minor legs or no control	3.0	2.7	0.3	0.3
Channelization	left and right signal control	left and right turn lane signal control on major legs	left turn lane signal control on all legs	left turn lane signal control on major legs	no turn lane control	3.0	2.0	1.0	1.0
Level of Service (Load Factor)	A 0.0	B 0-0.1	C 0.1 - 0.3	D 0.3 - 0.7	E 0.7 - 1.0	1.0	0.2	0.8	4.0
Pedestrian Volume (peds/hr crossing)	very few or none	0-50	50-100	100-200	> 200	1.5	0.5	1.0	2.0
							Operational Total		10.5
Environmental Factors									
Percent Adjacent Development	0	0-30%	30-60%	60-90%	100%	0.5	0.3	0.2	1.0
Predominant Development near Intersection	undeveloped	residential	50% residential 50% industrial or commercial	industrial or commercial	strip industrial or commercial (no circuity)	0.5	0.3	0.2	1.0
Lighting in Immediate Vicinity	none	0-40%	40-60%	60-80%	essentially continuous	3.0	1.5	1.5	6.0
Crime Rate	extremely low	lower than city average	city average	higher than city average	extremely high	1.0	0.5	0.5	0.5
							Environmental Total		8.5
Accidents									
Ratio of night-to-day Accident Rates	1.0	1.0-1.2	1.2-1.5	1.5-2.0	2.0*	10.0	2.0	8.0	24.0
							Accident Total		24.0

*Intersection lighting warranted.

GEOMETRIC TOTAL	= 14.7	
OPERATIONAL TOTAL	= 10.5	
ENVIRONMENTAL TOTAL	= 8.5	
ACCIDENT TOTAL	= 24.0	
SUM	= 57.7	POINTS
WARRANTING CONDITION	= 75 points	

Figure 49. Lighting warrants (NCHRP 152 criteria) - example.

3. Environmental Factors

Percent Adjacent Development: 100%
Predominant Development Near Intersection: Strip commercial
Lighting in Immediate Vicinity: 60-80%
Crime Rate: Extremely low

4. Accidents

Ratio of night-to-day accident rates: 1.2 - 1.5

The application of these factors is shown in Figure 49. The total score for this review was 57.7 points. Warrant conditions required a 75.0 point total. From this comparison, further intersection lighting is not necessary. If the score was greater than the warrant condition, however, it would require further lighting.

PROCEDURE 19 Weather-Related Study

Purpose

These study procedures can be used to determine whether and to what extent fog, ice, or other weather-related characteristics contributed to a safety problem. The impact these conditions have at a location may dictate countermeasures to reduce the hazardousness of the location.

Application

- Need For Study

Patterns of accidents in which the contributing circumstances consisted of such statements as "reduced visibility due to fog" or "slippery pavement due to icy conditions" may indicate that a weather related study is warranted. Field reviews and local input can also indicate the need for these studies.

Areas for which these studies may be required include:

A. Hazardous Fog Conditions

- Swampy areas
- Low lying areas
- Bridges over water
- Mountainous areas

B. Hazardous Icy Conditions

- Bridge decks
- Underpasses
- Curves in mountainous areas
- Roadway near a body of water

● Use of Study

The information obtained by these studies is used to:

- Verify accident findings.
- Select countermeasures to reduce or restrict the hazardousness of the situation.

● Period of Data Collection

Data on weather conditions should be collected during actual occurrence of the condition. Weather reports, forecasts, or discussions with local weather forecasters can assist in determining when these conditions are likely to occur.

Weather-Related Study Techniques

Several methods of analysis are available to study weather-related safety hazards. The following alternate techniques may be used for special conditions.

A. Fog-Related Conditions

- In-field direct measurement
- Use of field instrument

B. Ice-Related or Other Weather Conditions

- Field reviews

Table 55 summarizes the primary considerations for each technique.

Fog-Related Conditions

● In-Field Measurement Technique

The in-field measurement technique [1] involves determining sight distance during fog conditions using two vehicles or a vehicle and a portable target device. One vehicle or target is stationed in the study area and the second vehicle moves through the study area. When the second vehicle observes the stationary vehicle (or target), the location and distance to the target is recorded as the feasible sight distance. The measured sight distance is compared to the design stopping sight distance [2] based on the posted speed limit for the area. This study should be performed at several locations in the study area to determine a representative sight distance under the prevailing environmental conditions.

Table 55. Primary considerations for Hazardous Fog and Ice Condition Study techniques.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. In-Field Measurement Method	. Obtains sight distance under fog conditions utilizing test vehicles under field conditions	. Two test vehicles or test vehicle and portable target . Distance measuring device . Data sheets	. Technicians to set up and measure sight distance . Technicians to test conditions	. 2-3 hours per day; 3-day minimum	. Distance measuring instrument $25-$125	. Defined location . Accident pattern	. Sight distance under field conditions	. Safe travel speed under fog conditions
2. Field Instruments	. Obtains sight distance under fog conditions utilizing field measurements of fog density characteristics	. Fog measurement device . Data sheets	. Technician to record field data . Engineer to reduce data and compare to design values	. One hour per day; 3-days minimum	. Fog measurement device $300-$1,500	. Defined location . Accident pattern	. Fog density characteristics throughout study area	. Sight distance under field conditions . Safe travel speed under fog conditions
3. Field Review Method	. Obtains a review of icy pavement conditions by field observance of study area under operating conditions	. Data sheets	. Engineer to perform field review and assess data	. 2-3 hours per day; 2-day minimum	. None	. Defined location . Accident pattern	. Conflict data at site . General comments related to study area	. Review of icy conditions

Advantages:

1. Measurements are based on actual driving conditions.
2. Equipment needs are minimal.

Disadvantages:

1. Field tests may result in safety problems.
2. Results may be biased by drivers knowledge of test objectives.

● Field Instrument Methods

The use of field instruments [1,3] to measure the fog density is an alternate technique. Fog index measuring devices include videographs, nephelometers, transmissometers, and others [1]. The predicted visual range or fog index is determined using the device input and the following relationship:

$V = FI = BV_{p}n$

where:

V = predicted visual range (ft.)
FI = fog index
V_p = photometric visibility distance (ft.)
B,n = parameters

Sample values of "B" and "n" for general conditions can be used as follows:

Accident Illumination Condition	B	n
Night	4.32	0.81
Early Dawn	4.28	0.80
Day	0.75	1.00

The visual range and the minimum stopping sight distance based on posted speed limit for the area should be compared. When the visual range is less than the minimum stopping distance, warning or speed control countermeasures may be appropriate. If the predicted range is greater than th minimum stopping sight distance, conditions may be considered acceptable.

Advantages:

1. Simple to perform.
2. Time and manpower requirements are minimal.

Disadvantages:

1. Equipment costs are relatively high.
2. Measuring devices may have limited accuracy.

Ice-Related or Other Weather Conditions

● Field Review Method

Data on traffic operations, physical conditions, and driver behavior during icy or other special conditions can be collected during field reviews [4,5,6]. The Traffic Conflicts Study (Procedure 10) or the Safety Performance Study (Procedure 6) may be made appropriate for evaluating these conditions.

Advantages:

1. Provides field review of area.
2. Provides a structured, organized review of conditions.
3. May be used to record other usable data, such as speeds and volumes.

Disadvantages:

1. On-site review may present a safety hazard to observers.
2. May require lengthy time period to obtain sufficient study findings.
3. Requires presence of icy or other environmental condition to perform study.

Selection of Alternate Techniques

Table 56 displays the utility of each technique and may be used in selecting a technique. General guidelines to assist in selecting a technique are provided below:

1. The field instrument method should be used for fog-related studies when the equipment is available. It requires less time, provides reliable results, and is safer than the in-field measurement technique.

2. When equipment is unavailable, the in-field measurement method can provide reliable results for fog-related studies; however, this technique results in a safety hazard to the data collectors.

3. For review of ice-related and other weather-related conditions, the field review method provides a structured review of these conditions.

Findings

The output of the fog-related studies should be recorded in a tabular format, as shown in the Appendix (page I-16).

Table 56. Technique utility for Hazardous Fog and Ice Condition Study.

Technique / Management Concern	In-Field Measurement Method	Field Instruments Method	Field Review Method
.Time Requirements	.Requires substantial data collection and minimal data manipulation needs	.Requires minimal data collection and manipulation needs	.Requires substantial data collection and evaluation needs
.Manpower Requirements	.Technician level	.Technician and engineer level	.Engineer level
.Equipment Requirements	.Vehicle availability .Distance measuring instrument .Other needs, minimal	.Fog measurement device .Other needs, minimal	.Minimal
.Study Objective	.Review hazardous fog condition	.Reviews hazardous fog condition	.Review hazardous ice condition

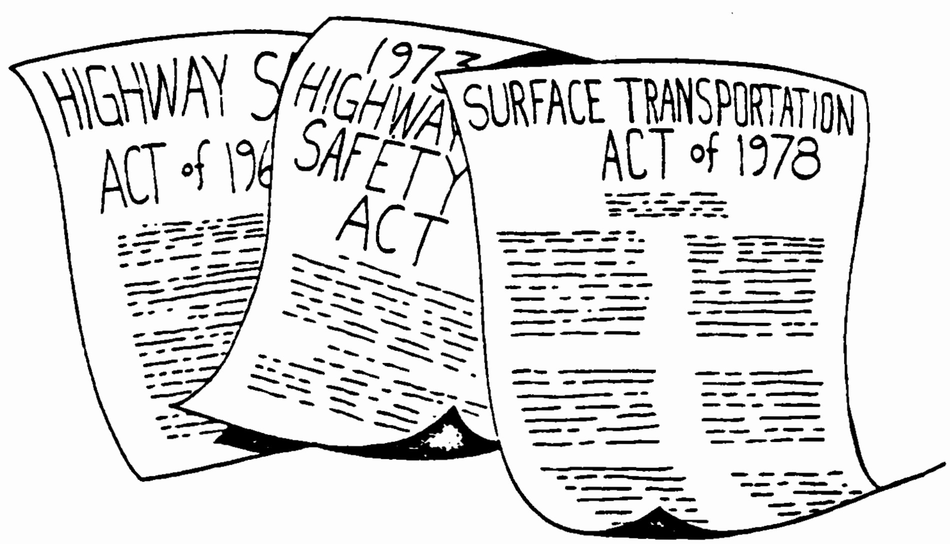
Use Of Findings

The output of the fog-related studies is typically a predicted or estimated sight distance under the fog field conditions. The predicted visual range or sight distance value is compared to the design values based on the posted speed limit for the area. Minimum stopping sight distances (according to AASHTO) for various travel speeds [2] are:

Travel speed - mph	(kph)	Sight Distance - ft.	(m)
30	(48)	200	(60)
40	(64)	275	(83)
50	(80)	350	(105)
55	(88)	420	(126)

Where field sight distance values are lower than the design values, conditions can be considered deficient and countermeasures can be selected to improve the situation.

For ice or other weather-related studies, conflict data (Procedure 10) and safety performance study (Procedure 6) summary sheets should be used. The output of these studies is a review of the traffic operations under the specific conditions. From the data and analysis performed by the conflict and/or safety performance studies, a safety deficiency may be detected. Based on this review, feasible countermeasures can be developed [5,6,7].



SPECIAL ENGINEERING STUDIES

Introduction

This section contains special engineering study procedures. These studies are considered special in that they cannot be specifically identified as an accident, traffic, or environmental-based procedure. They are performed on a site basis and define a special situation at a highway location.

Within this section, the following procedures are discussed:

- PROCEDURE 20 - School Crossing Study
- PROCEDURE 21 - Rail-Highway Crossing Study
- PROCEDURE 22 - Traffic Control Device Study
- PROCEDURE 23 - Bicycle or Pedestrian Study

PROCEDURE 20 School Crossing Study

Purpose

The purpose of these studies are to provide optimal safety conditions for school-age pedestrians within the roadway environment in and around school areas. This study is conducted to identify safety deficiencies at a site based on the roadway physical and operational characteristics, and student crossing characteristics.

Application

- Need For Study

School crossing accidents are random events and their rate of occurrence is typically very low. Accident data usually may not exist or is insufficient for study of most school crossings. In lieu of this deficiency, the use of traffic conflict data can supplement accident data and verify a need for a study of a school crossing.

Another source of information, perhaps the primary one, is obtained from a field review of the school site provided by a local governing highway agency. The review can be based on either a regular planned schedule or complaints from school officials, students, parents, and other concerned groups.

- Use Of Study

In studying school crossing areas, details of the physical and operational characteristics and site characteristics are defined. These characteristics are related to the roadway operation, i.e., the availability of safe crossing gaps, to identify whether a safety deficiency exists. From the results of this study, countermeasures can be suggested.

The use of pedestrian conflict data can also be used as an integral part of the study. The findings obtained from the conflict study can be used to identify other safety deficiencies and to assist in the development of countermeasures. The conflict data can also be used as a measure of effectiveness when evaluating countermeasures.

● Period of Data Collection

Pedestrian characteristics at school crossings vary markedly during several periods of pedestrian demand throughout the day. The school closing hour is typically the critical period used to collect pedestrian data. However, where pedestrian volumes exist during other times, these periods should also be reviewed. Different conditions during these time periods may result in the identification of other deficiencies.

The study of the crossing under favorable weather conditions during early fall or late spring conditions is preferred. During these times, pedestrian volumes usually occur at their highest levels.

School Crossing Study Techniques

Two techniques are available to assess the effectiveness of a school crossing.

- Institute of Traffic Engineers (ITE) - "A Program for School Crossing Protection".
- Pedestrian conflict studies.

Information on the major considerations of these techniques is provided in Table 57.

● Institute of Traffic Engineers Method

The ITE method [1,2,3] is described in the manual "A Program for School Crossing Protection." It is based on a six step program as outlined below.

Step 1 - Organize a School Traffic Safety Committee.

Step 2 - Develop a School Route Plan.

Step 3 - Study the School Crossings Where Apparent Hazards Exist.

Step 4 - Analyze the Need for School Crossing Protection.

Step 5A - Select Appropriate Measures for Locations Where Control is Needed.

Step 5B - Select Appropriate "Assistance" Measures.

Table 57. Primary considerations for School Crossing Study techniques.

Technique / Considerations	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. ITE Method	. Evaluates need for special traffic control at school cross-walks based on pedestrian delay and demand	. Volume counter . Distance measuring device . Data sheets	. Technicians to count pedes-trian volume . Technicians to observe and record vehicu-lar gap data . Technician to assess data	. Approx. 1 hr. per day; 2 day mini-mum	. Counting de-vice - $125 . Measuring wheel - $50-$125	. Defined location	. Pedestrian volume data . Vehicular gap data . Roadway cross-ing width . Percent pedes-trian delay time	. Percent pedestrian delay time . Assessment of need for special traffic con-trol
2. Pedestrian Conflict Study	. Obtains data on pedestrian/vehi-cle conflicts in crossing area	. Data sheets	. Technician to record con-flict data . Engineer to evaluate con-flict data	. Approx. 1-1/2 hrs. per day;2 day minimum	. None	. Defined location	. Pedestrian/vehicle con-flicts	. Review po-tential pedestrian hazards at crossing

Step 6 - Select the Standard Devices Needed to Carry Out the Protection Measures.

Step 3 and 4 involve the direct study of the crossing and will be covered in considerable detail.

In Step 1, a School Traffic Safety Committee is organized to guide and coordinate all activities of the school safety program. A safe school route plan for each school serving elementary and kindergarten students is developed in Step 2.

In Step 3, a program for studying identified hazardous crossing locations is developed [5,6]. The program is based on three basic assumptions:

- Alternating gaps and blockades in the vehicular traffic stream are peculiar to each location; consequently an individual study of each crossing is required.
- Pedestrians will wait a "reasonable" time for an adequate safe gap in the vehicular traffic stream before crossing a street.
- A traffic control signal does not exist at the crossing. Where a signal does exist, alternate study means are necessary.

Several items must be determined for this study including: the pedestrian demand, and the pedestrian delay time. The pedestrian demand is determined from a manual count of the crossing using a sample data sheet, as shown in the Appendix (page I-17). The group size is determined from the accumulation of pedestrians as they wait for a break or gap in the traffic stream. It is assumed that five pedestrians will walk abreast when a group crosses a roadway. Thus, the number of rows required in crossing the roadway is found by dividing the number of waiting pedestrians by five. The 85th percentile group size is used to represent most field situations.

To determine the pedestrian delay time, the adequate gap time must be derived. It is computed by:

$$\text{ADEQUATE GAP TIME (SECS.)} = \frac{W}{3.5} + 3 + (N-1)2$$

Where:

W = Roadway crossing width.
3.5 = Walking speed (fps) of pedestrians (1.05 m/sec.).
3 = Perception and reaction time.
N = Group size (85th percentile).
1 = First row.
2 = Time interval between rows.

The adequate gap time represents the safe crossing gap for pedestrians.

The roadway crossing width is measured manually as the curb-to-curb (shoulder-to-shoulder) width. If a median exists and is wide enough to service the waiting pedestrian demand, the median-to-curb width may be used to represent the required roadway crossing width.

Once a safe crossing gap has been determined, a field study is performed to determine the number of available safe crossing gaps. It is performed simultaneous with the pedestrian demand effort. A sample data collection sheet for this purpose is shown in the Appendix (page I-18). Vehicular gaps at the crossing are measured using a stop watch. The total number of gaps equal to or greater than the safe crossing gap is summarized.

From the above data, the pedestrian percent delay time is obtained. Using data from the available adequate gaps, the gap size is multiplied by the number of available gaps within this increment. The summary of this computation derives the total safe gap time (seconds) which is known as "t". The total survey time, T, equals the length of the survey period in seconds. These items are shown on the bottom of the survey sheet. The pedestrian delay, D, therefore, is equal to:

$$D \text{ (in \%)} = (T-t/T)100$$

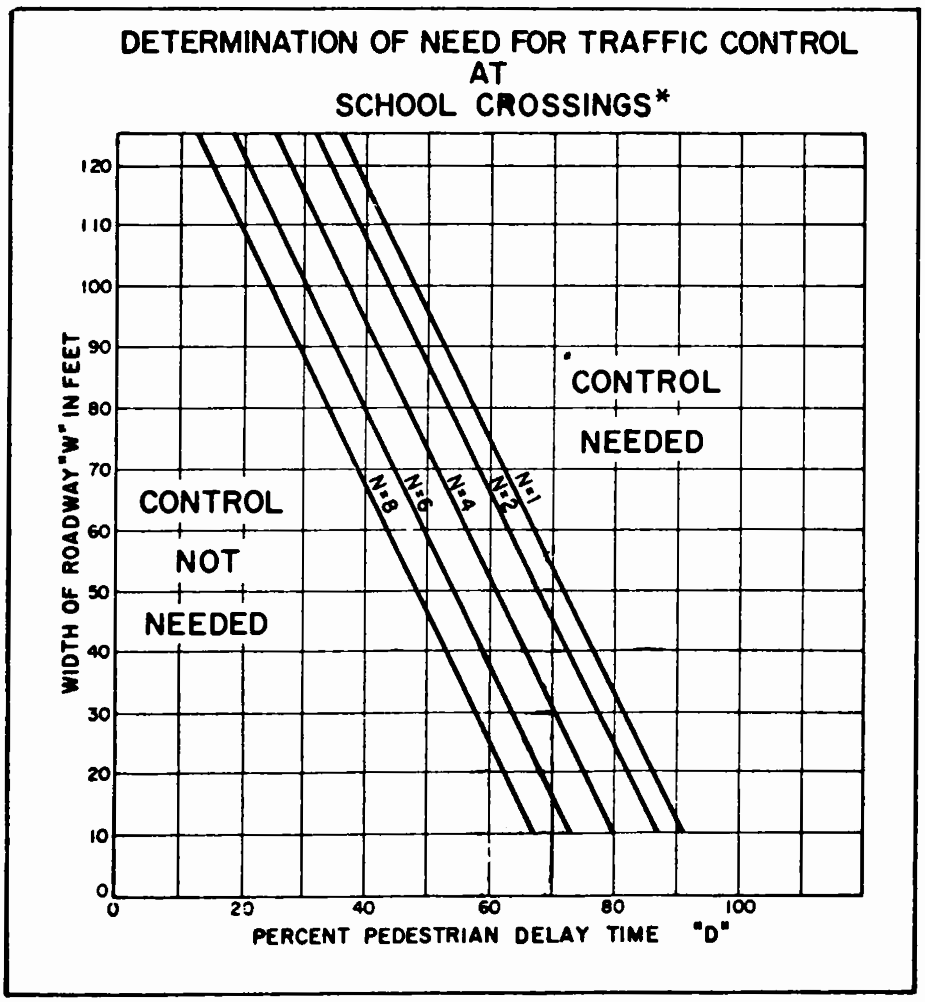
These data are summarized for analysis purposes in the next step.

The need for special school crossing protection is analyzed in Step 4. Two assumptions are used in this analysis. First, it is assumed that when the delay time between adequate gaps becomes excessive, children may become impatient and endanger themselves by crossing the street with an inadequate gap. Second, the delay time may be considered excessive when the number of adequate gaps in the traffic stream, during the school crossing period, is less than the number of minutes in that period. In this case, one safe gap per minute represents a satisfactory situation.

Based on these assumptions and other research, the relationships shown in Figure 50 were developed. The graph is used to evaluate the need for special crossing protection as a function of the roadway width, the pedestrian group size, and the percent pedestrian delay time. These values are on the axis of the graph. When the lines intersect to the left of the group size (N) line, control is not needed at the site. Values to the right of the group size (N) line require that further control be used at the crossing.

For signalized crossings, a similar technique is used. The allowable pedestrian delay time (%), however, is equal to:

$$D_a = (C-G/C)\ 100$$



Source: "A Program For School Crossing Protectio:.
ITE, (1962)

Figure 50. Crossing protection evaluation - ITE method.

where:

D_a = Allowable pedestrian delay time (%).
C = Cycle length (seconds).
G = Adequate gap time (seconds) where $G = W/3.5 + 3 + (N-1)2$.

The adequate gap time is used as the green and yellow signal interval of the pedestrian phase or of the allowable pedestrian movement at a signal. To determine whether a special form of protection is needed, the calculated "D_a" is compared to the field measured "D" (as described earlier). Where "D" is less than "D_a", special control is not needed; however, where "D" is greater than "D_a", further special controls are necessary.

Steps 5A and 5B are conducted to select the appropriate countermeaures [1,7] for the study locations based on the findings obtained in Step 4. Countermeasures are grouped by (1) those which can control traffic streams and (2) those which provide assistance in the pedestrian crossing maneuver.

Finally, Step 6 entails the selection of the specific traffic control devices needed to carry out the recommendations. Use of the MUTCD standards is required for all traffic control devices.

● Pedestrian Conflict Study

Pedestrian conflict studies are a useful tool in the study of school crossing data. From patterns of specific conflict types, a review of potential safety hazards can be obtained, as outlined in the Traffic Conflict Study (Procedure 11). Conflict data provide valuable information on pedestrian and driver behavior characteristics and their adherence to existing safety regulations or standards. It provides additional information on safety-related characteristics which are not defined in the ITE guidelines.

In collecting the conflict data, operational procedures are similar to the steps in Procedure 11 - Traffic Conflict Study. A sample pedestrian conflict data form is shown in the Appendix (page I-19). Definitions of feasible conflict types are shown in Figure 51. The use of conflict data as a supplementary study for school crossings is encouraged.

Selection of Alternate Technique

Within this procedure, the use of both techniques is recommended. The ITE method evaluates the effectiveness of the school crossing in providing safe crossing conditions. To supplement this assessment, conflict data are obtained to identify further safety deficiencies on driver behavior and pedestrian behavior characteristics within the study area.

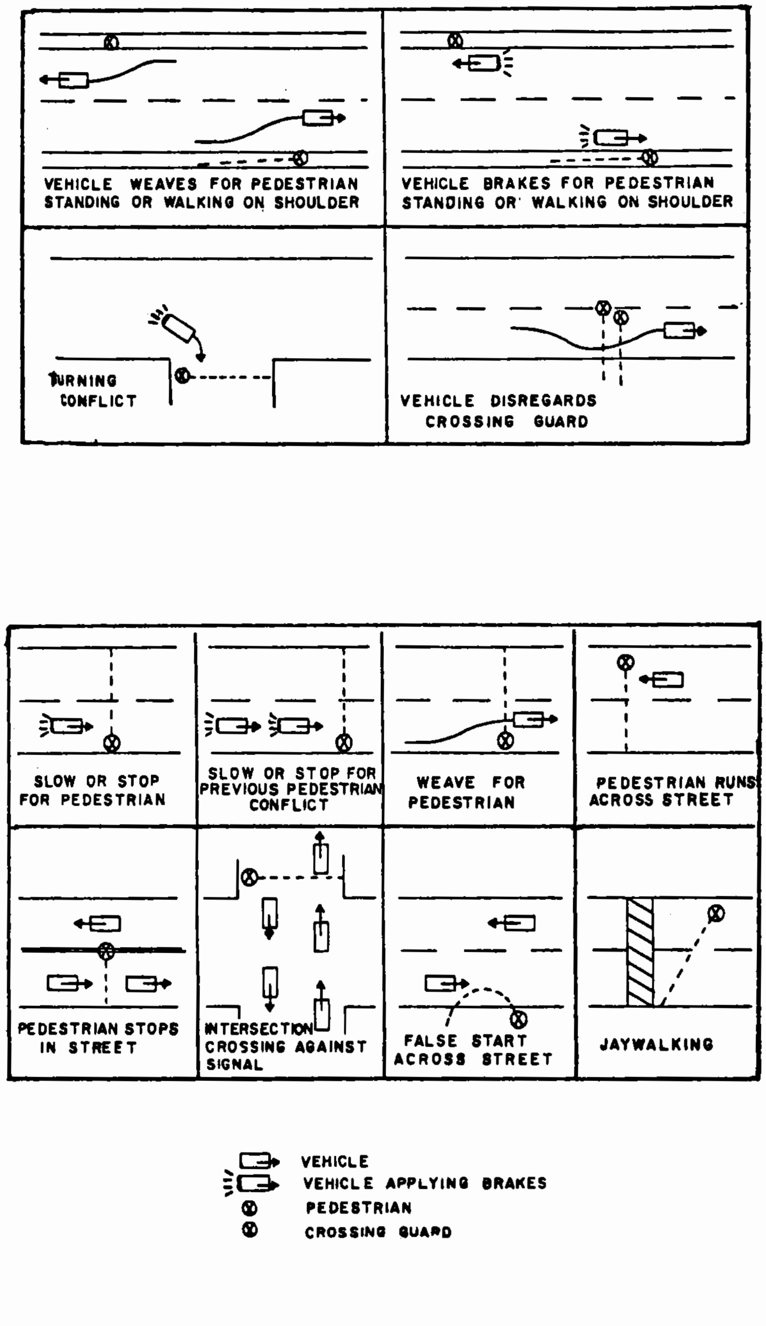


Figure 51. Pedestrian conflict types.

Findings

The output of this study determines the need for additional control at a crossing. A conflict diagram can be obtained from the conflict data.

● Use Of Findings

Where it is determined that special protection is needed, a number of devices can be used [1,2,3,4,5]. Protection can vary from the use of student patrols to the installation of a grade-separated pedestrian walkway. In many cases, the level of control is dictated by the experiences of the individual agency. The criteria for implementation will vary among States. General criteria for warranting specific controls, based on ITE guidelines, have been developed and are included in Reference 1.

All traffic control devices shall be in conformance with the Manual of Uniform Traffic Control Devices [8]. For information on providing increased safety within or around the school area, use of the manual "Traffic Safety Planning on School Sites" (ITE) is recommended [9]. It provides general design guidelines on safety at:

- School bus zones.
- Parent pickup/dropoff zones.
- Parking areas.
- Pedestrian and bicycle facilities.
- Playground areas.
- Service roads.
- Driveways.
- Off-site locations.

● Example

The sample crossing (unsignalized) is located near a junior high school in a suburban community. From data collection activities the observed data are shown in Figure 52. The adequate gap time is computed by:

$$\text{Adequate gap time} = \frac{W}{3.5} + 3 + (N-1)2$$

$$= \frac{22}{3.5} + 3 + (3-1)2$$

$$= 6.3 + 3 + 4 = 13.3 \text{ seconds} \approx 14.0 \text{ seconds}$$

Based on these calculations and the gap data, the percent pedestrian delay time (upper portion of Figure 52) equals 79 percent. The ITE chart shown in Figure 52 is used for the following conditions:

PEDESTRIAN GROUP SIZE STUDY

Study date 5-1-79 Time: From 2:55pm to 3:25pm Location Avon Twp.

Crosswalk across Adams Rd. Curb-to-curb distance 22'

Divided roadway? Yes (No) Width of island None

Group size	Number of Rows (N)	Number of Groups: Tally	Number of Groups: Total	Cumulative	Computations
46 - 50	10				
41 - 45	9				
36 - 40	8				
31 - 33	7				
26 - 30	6				
21 - 25	5				
16 - 20	4				
11 - 15	3	//	2	2	
6 - 10	2	~~////~~ /	6	8	
5 or Less	1	~~////~~ ////	9	17	
		Total Number of Groups	17	x 0.15 = 2.6	N = 3

(A)

PEDESTRIAN DELAY TIME STUDY

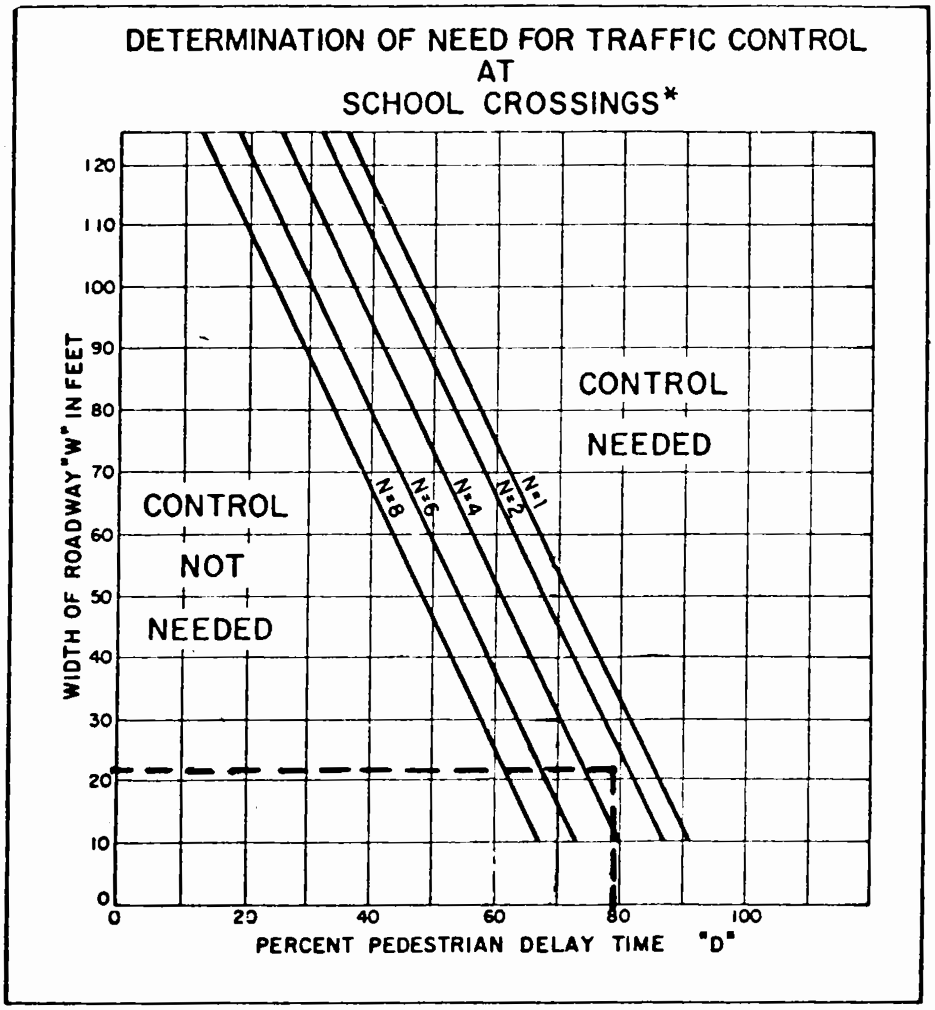
Study date 5-1-79 Location Avon Twp. Crosswalk across Adams Rd.

End of Survey (to nearest minute) 3:25pm	Number of Rows - "N" 13
Start of Survey (to nearest minute) 2:55pm	Roadway Width - "W" 22 ft.
Total Survey Time (minutes) 30	Adequate Gap Time - "G" 14 secs.

Gap Size (Seconds)	Number of Gaps: Tally	Number of Gaps: Total	Multiply by Gap Size	Computations
8				
9				
10				
11				
12				
13				
14				
15	~~////~~ /	6	90	
16				
17	//	2	34	
18	/	1	18	
19				
20	//	2	40	
21				
22	~~////~~	5	110	
23				
24	/	1	24	
25				
26				T = Total survey time x 60
27				
28				
29				
30	/	1	30	T = 30 X 60
31				
32				T = 1800 secs.
33				
34	/	1	34	
35				
36				
37				$D = \left(\frac{T - t}{T}\right) 100$
38				
39				$D = \frac{1800-380}{1800}$
40				
41				$D = \frac{1800-1420}{1800}$
42				
43				
"t" (total time of all gaps equal or greater than "G")			380 secs.	D = 79%

(B)

Figure 52. School crossing data - example.



Source: "A Program For School Crossing Protection
ITE, (1962)

(C)

Figure 52. School crossing data - example. (Continued).

roadway width = 22 feet
percent pedestrian delay time = 79%
group size, N (85th percentile) = 3

It is determined that a special form of traffic control may be needed, as represented by the intersection of the axis lines at the group size (N=3) line. In this case, a recommendation is not well defined. A review of pedestrian conflict data for the site could be used to determine the need for traffic control or other improvements. For these situations, engineering judgment based on past experiences should be exercised.

PROCEDURE 21 Rail-Highway Crossing Study

Purpose

Rail-highway crossing studies are performed to evaluate existing and potential conflicts between vehicular and train traffic at a rail-highway crossing. These studies constitute a professional examination of the physical and operational characteristics of both highway and railroad elements of a rail-highway crossing.

Application

- Need for Study

The need for a safety study at an at-grade rail-highway crossing can be identified from several sources. First, from the accident records, a pattern of "vehicle-train" accidents may indicate a hazardous condition. Typically, however, the frequency of "vehicle-train" accidents at a railroad crossing are low compared to other hazardous accident locations [1]. However, the severity index for grade crossing accidents is relatively high when compared to other types of traffic accidents.

A second source of "hazardous" location identification is through a hazard index [2,3,4,5] for each railroad crossing. Such an index is used to assess the potential hazardousness of a site based on field characteristics. Application of a hazard index on an areawide basis will provide a priority ranking of the at-grade rail-highway crossings. Selection of the top "X" number of sites can be included for study of hazardous conditions.

Other sources of identification include field review by local engineers or input received from users of the crossing.

- Use of Study

After identifying a rail-highway crossing for study, a review of the existing conditions at the crossing is made. This review consists of the study of available accident data (if any), the site characteristics, the existing rail-highway crossing warning system, and the roadway and crossing operational characteristics. Based on a review of these conditions, an assessment of the existing or potential safety hazards can be made. Once the safety deficiencies are identified, countermeasures can be determined.

● Data Collection Requirements

In conducting a rail-highway crossing study, a questionnaire is recommended to assess safety at the crossing. The questionnaire will provide a structured account of the crossing characteristics and its impact on highway safety. The questionnaire can be grouped into four areas of review. Two sections are to be completed for each roadway approach and one on the crossing in general. A fourth section includes a review of the driver requirements approaching the crossing. A general description of these sections follows.

SECTION I - Items related to driver awareness of the presence of the crossing.

- Driver awareness (including "repeat drivers").
- Visibility.
- Effectiveness of advance warning signs and signals.
- Geometric features of the roadway.

SECTION II - Items related to whether or not the driver has sufficient information to make correct decisions while traversing the crossing area.

- Awareness of approaching trains.
- Driver dependence on crossing signals.
- Sight obstructions to train.
- Roadway geometrics diverting driver attention.
- Location of stationary railroad cars.
- Removal of sight obstructions.
- Availability of information for driver decisions.

SECTION III - Items concerning the roadway area adjacent to the crossing.

- Pavement markings.
- Roadway conditions.
- Other nearby traffic control devices.
- Hazards presented by certain vehicles required to stop at all crossings.
- Signs and signals near crossing.
- Opportunity for evasive action by drivers.

SECTION IV - Items concerning the general features of the crossing.

- Major features of crossing which contribute to safety.
- Features which reduce safety.
- Possible methods for improving safety at the crossing.
- Overall crossing evaluation.
- Comments and suggestions.

LOCATION: ____________________

CITY OR TWP: ____________________ R.R. COMPANY: __________

VEHICLE DATA

No. of Approach Lanes: __________

Approach Speed Limit: __________

Approach Gradient: __________

Approach Curvature: __________

ADT: __________

TRAIN DATA

No. of Tracks: __________

Train Speed Limit: _____

Track Gradients: _____

Train Use Per Day: _____

SECTION I

1. Is advance warning of railroad crossing available? _______ If so, what devices are used? __________
2. Does advance warning of the railroad crossing allow drivers to react to approaching train traffic adequately? _____
3. Do approach grades, roadway curvature, or obstructions limit the view of advance warning devices? _____ If so, how? __________
4. Are advance warning devices readable under night, rainy, snowy, or foggy conditions? _____
5. Do advance warning devices adequately alert drivers to the presence of the railroad grade crossing? _____ If so, why not? __________

SECTION II

1. Is the sight distance to an approaching train adequate for the driver to safely react? _____
2. If sight distance is inadequate, do other means of alerting drivers of an approaching train exist? _____ If so, what? __________
3. Where the driver's sight to an approaching train is obstructed, can the sight obstruction be removed to improve the safety situation in the crossing area? _____
4. Do approach grades or roadway curvature restrict the driver's view of the crossing? _____
5. Are railroad crossing signals or other active warning devices acting properly and visible to adequately warn drivers of oncoming trains?

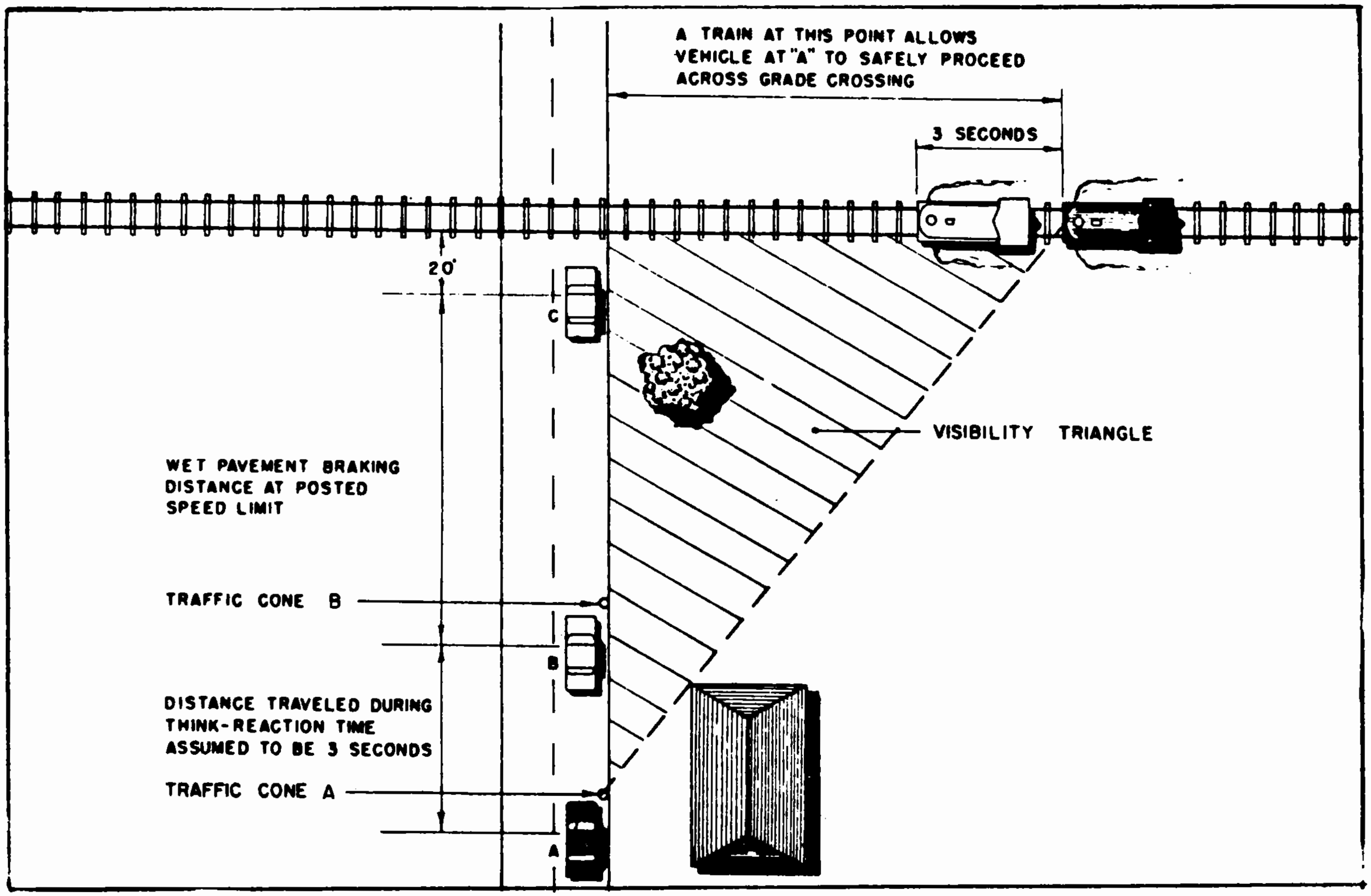
SECTION III

1. Is a nearby traffic signal or other control device affecting the crossing operation? _____ If so, how? __________
2. Is the stopping area at the crossing adequately marked? _____
3. Do vehicles required by law to stop at all crossings present a hazard at the crossing? _____
4. Do conditions at the crossing contribute to or are they conducive to a vehicle stalling at or on the crossing? __________
5. Are nearby signs, railroad crossing signals, etc. adequately protected to minimize hazards to oncoming traffic? _____
6. Is the crossing surface satisfactory? _____ If not, how and why? ___

SECTION IV

1. List major attributes of the crossing which may contribute to safety?
   a. __________
   b. __________
   c. __________
2. List features which reduce crossing safety?
   a. __________
   b. __________
3. Possible methods for improving safety at the crossing?
   a. __________
   b. __________
   c. __________
4. Overall evaluation of crossing? __________
5. Other comments: __________

Figure 53. Sample railroad crossing review questionnaire form.



Source: Railroad-Highway Grade Crossing Handbook, FHWA, August (1978)

Figure 54. Sight distance check points at rail-highway crossings.

Table 58. Data for visibility triangles.

REQUIRED DESIGN SIGHT DISTANCES FOR COMBINATIONS OF HIGHWAY AND TRAIN VEHICLE SPEEDS*

Train Speed	Highway Speed in MPH							
	0	10	20	30	40	50	60	70
	Distance Along Railroad From Crossing							
10	162	126	94	94	99	107	118	129
20	323	252	188	188	197	214	235	258
30	484	378	281	281	295	321	352	387
40	645	504	376	376	394	428	470	516
50	807	630	470	470	492	534	586	644
60	967	756	562	562	590	642	704	774
70	1129	882	656	656	684	750	822	904
80	1290	1008	752	752	788	856	940	1032
90	1450	1134	844	844	884	964	1056	1160
	Distance Along Highway From Crossing							
	20	65	125	215	330	470	640	840

NOTE: 1 mph = 1.61 kph
1 foot = .304 metres

SOURCE: Reference (2)

* Single Track

NOTE: For multiple track crossings, consideration must be given to the additional distance required to completely clear all tracks.

A sample questionnaire is shown in Figure 53. This questionnaire should be altered to reflect the individual agencies' needs. Further information on the formulation of the questionnaire is provided in the Railroad-Highway Grade Crossing Handbook [1] (Federal Highway Administration, FHWA-TS-78-214).

To adequately complete the questionnaire, study of the sight distance characteristics at the crossing is required. In this review, a visibility triangle is formed based on the vehicle and train speeds as shown in Figure 54 and Table 58. The criteria for study of a safe sight distance is that all areas within the triangle must be clear to afford the driver adequate visibility.

For locations without active warning devices (signals, gates, bells), the posted speed limit can be used to obtain the length of the driver's leg of the sight triangle. Where active warning devices are afforded, a "stopped" (0 mph) condition is used.

● Period of Data Collection

Review of the rail-highway crossing should typically be performed under conditions identified by the accident summaries (time of day, etc.). For sight distance determinations, field reviews should generally be performed during summer to assure maximum foliage conditions. If this is not feasible, full foliage conditions should be assumed.

It is preferable where night train movements are made at a crossing, to perform a night review of conditions to assess the adequacy of signing, pavement markings, and lighting under these conditions.

Rail-Highway Crossing Study Techniques

Two methods of providing rail-highway crossing reviews are commonly used.

- Multi-disciplinary diagnostic team approach.
- Evaluation by individuals.

Primary considerations of these techniques are shown in Table 59.

● Multi-disciplinary Diagnostic Team Approach

In the multi-disciplinary diagnostic team approach [1], use is made of experienced individuals from various agencies and disciplines. These individuals review the site and, collectively, identify safety hazards and develop countermeasures.

To be effective, the team requires individuals with a variety of experience including representatives of the agencies or groups responsible for the safe operation of the grade crossings. To ensure appropriate

Table 59. Primary considerations for Railroad Crossing Study techniques.

Technique / Considerations	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Diagnostic Team Approach	. Reviews railroad crossing situation using a selected team of individuals with varying disciplines	. Data sheets . Targets (Cones)	. Traffic Engineer (with safety experience) . Railroad signal engineer . Railroad official . Highway official . Law enforcement officer . Regulatory agency official	. Data collection needs are minor . Review needs 2-8 hrs. per team member dependent on crossing	. Targets (Cones) $5-$25	. Defined location . Accident data . Traffic volume data . Train data . Roadway operational and physical data	. Assessment of visibility triangle . Sufficiency of crossing and warning devices (subjective basis) . Presence of hazards	. Identification of safety deficiencies . Recommendations for upgrading of conditions
. Individual Approach	. Review railroad crossing situation using an experienced observer	. Targets (Cones) . Data sheets	. Single individual with extensive knowledge in railroad crossing area (typically, local traffic engineer)	. Data collection needs are minor . Review needs 4-8 hrs., dependent on crossing	. Targets (Cones) $5 $25	. Same as above	. Same as above	. Same as above

representation, the Railroad-Highway Grade Crossing Handbook [1] suggests that a team be composed of members chosen from the following disciplines:

a. Traffic engineer* with highway safety experience.
b. Railroad signal engineer**.
c. Railroad administrative *officials.
d. Highway administrative officials.
e. Human factors engineer.
f. Law enforcement officer.
g. Regulatory agency official (where applicable).

The diagnostic team assembles at the study crossing to verify vehicle and train operational data. In addition, instructions and clarification of the questionnaire form is made. Finally, the accident data are reviewed by the team members.

A member of the project team should locate targets for both crossing approaches at (1) the point where a driver would begin to make a decision as to whether or not he may safely proceed over the crossing and (2) the point where a driver must begin applying the brakes if he is to stop short of the crossing. These targets are shown on Figure 54. The targets are used in identifying the critical points to use in the safety analysis. The distances are based on the operating speed of the roadway and minimum stopping distances for "wet pavement" conditions. A list of these distances is shown in Table 60.

Table 60. Clear approach distances for railroad crossing review.

HIGHWAY SPEED LIMIT - mph(kph)		DECISION 'POINT 1'		STOPPING 'POINT 2'	
		FT.	M.	FT.	M.
30	(48)	215	65	73	22
40	(64)	330	99	131	40
50	(80)	470	141	208	63
55	(88)	560	168	300	91

During the review, team members drive each approach several times to become familiar with all crossing conditions. If the approach is signalized, the signals should be activated so that the operation can be observed and evaluated. While at the approaches, each team member individually completes the questionnaire.

---

* Desirable on all teams.

** Desirable where active traffic control devices are present or under consideration.

The physical characteristics inventory of the crossing is also completed. A sample inventory form is shown in Figure 55. Photographs may also be taken to supplement the physical data. These data are used in a team discussion of findings to identify the site characteristics during the session.

After the questionnaires have been completed, the team members are reassembled for a short critique and discussion period. The critique usually begins with the local traffic engineer's summary of observations. Input from other team members is included in the discussion phase. The findings are reviewed and feasible countermeasures discussed. Based on these discussions, the team members generally reach agreement on the appropriate improvements.

This technique, through involvement of persons with multi-disciplinary backgrounds, will result in a critical review of the railroad crossing situation.

Advantages:

1. Provides a means of focusing the attention of all concerned agencies on the problem.
2. Combines the expertise and experience of a group of individuals.
3. Is recognized as one of the best techniques available for selecting countermeasures.

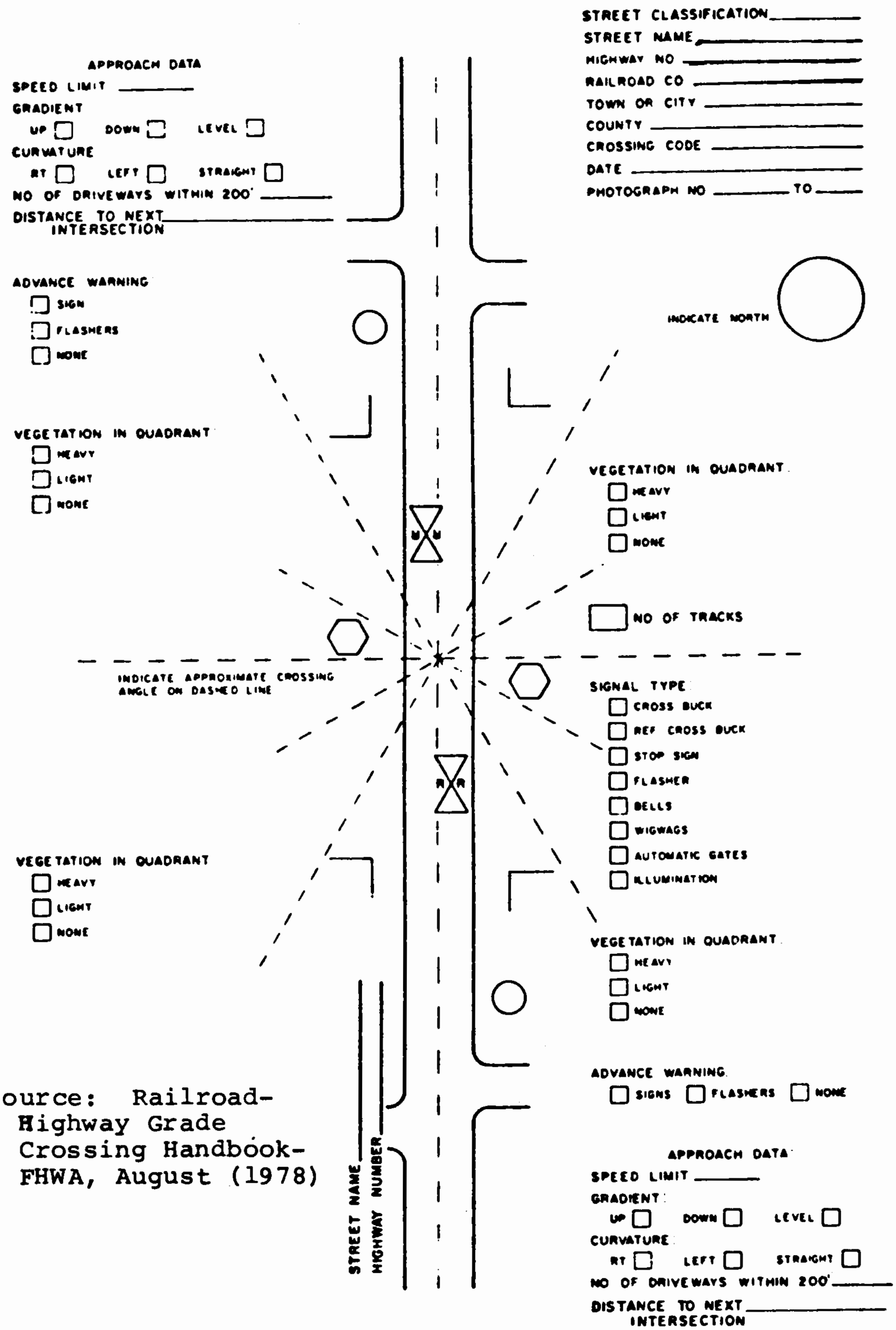
Disadvantages:

1. Requires the presence of several specially trained individuals.
2. Difficult to schedule a specific time for review among various team members.
3. Requires cooperation of all team members.

Although this technique requires the cooperation of various professional personnel, the success of using personnel with varying disciplines within the team carries extensive advantages. Where feasible, this technique should be used for the safety evaluation of all railroad crossing situations.

- <u>Evaluation By Individuals</u>

In the evaluation by an individual [1,2], a safety review of the crossing using a single experienced individual is conducted. This individual is typically a local traffic engineer with experience in rail-highway crossing and highway safety. A background in signal control and safety program administration would also be advantageous.



Source: Railroad-Highway Grade Crossing Handbook-FHWA, August (1978)

Figure 55. Sample railroad crossing inventory form.

The individual review is performed similar to the team approach. The steps for performing the study include:

1. The roadway approaches are driven to familiarize the individual with the crossing.
2. The railroad crossing review questionnaire is completed.
3. A physical characteristics inventory is prepared.
4. An overall review of the findings is made.
5. Countermeasures are selected.

Countermeasure selection, however, may be performed using a team approach based on the field review and findings made by the individual observer.

Advantages:

1. Requires minimal manpower needs.
2. Difficulties associated with team approach minimized.

Disadvantages:

1. Findings may be biased.
2. Individual's expertise and experience may vary.

Where the availability of sufficient manpower and expertise is a factor, this technique is favorable. However, it should be noted that the review represents a single observer's viewpoints and can be biased by the individual's background.

Selection of Alternate Technique

In selecting a study technique, a review of the management concerns for each technique is performed. Table 61 identifies the utility of each technique based on the management concerns.

General guidelines to assist in the selection process are provided below.

1. It is preferred that the team approach be used for the safety study of railroad crossings. This technique permits the review of the crossing and the selection of safety countermeasures based on several viewpoints.

2. Where sufficient personnel are unavailable to perform a team study, the individual approach can be used successfully. By using an experienced individual, the study findings and results can be quite comparable to the team approach.

Table 61. Technique utility for Railroad Crossing Study.

Technique / Management Concerns	Diagnostic Team Approach	Individual Approach
1. Time Requirements	. 2-8 hours per team member	. 4-8 hours for review person
2. Equipment Requirements	. Minimal	. Minimal
3. Manpower Requirements	. Traffic Engineer . Railroad signal engineer . Railroad and highway officials . Human factors engineer . Law enforcement officer . Regulatory agency official	. Highly experienced traffic engineer
4. Level of Comprehensiveness	. Based on viewpoint of individuals with varying backgrounds on a collective basis	. Based on single individual's viewpoint

Findings

● Use of Findings

The findings of this procedure are used collectively to identify safety deficiencies and to select countermeasures.

A primary safety factor at a crossing is the determination of the sight triangle. Based on the premise that all areas within the triangle must be clear to allow the vehicle driver adequate visibility, recommendations to upgrade the required sight distance are made.

In most cases, restricted sight distance is the result of obstructions within the sight triangle. If these obstructions consist of vegetation or other natural features, they should be removed. Other obstructions (e.g., buildings, electrical towers) may be difficult to remove. For these cases, speed reduction measures may be used to reduce vehicle speeds to a level in which adequate sight distance is provided. Active control devices can also be implemented.

A second safety concern at rail-highway crossings is providing sufficient advance warning of the crossing. Where it is determined that insufficient advance warning exists, adherence to the Manual of Uniform Traffic Control Devices [6] (MUTCD) recommendations is required.

Other areas of concern are related to the crossing area. Typical deficiencies include: the quality of the crossing surface; the protection of vehicle occupants in the crossing area; drainage of the surface crossing; and illumination of the crossing. Where it is noted that these deficient conditions exist, an appropriate countermeasure can be selected to alleviate the deficiency. A summary of these countermeasures can be found in the Railroad-Highway Grade Crossing Handbook (FHWA-TS-78-214).

PROCEDURE 22 Traffic Control Device Study

Purpose

A traffic control device study procedure is conducted to review the effective application of a traffic control device. These studies include the review of "STOP"/"YIELD" sign application, traffic signal requirements, and the observance and enforcement levels of traffic control devices.

● Need for Study

The need for a traffic control device safety study is dictated primarily by accident data for the study location. Certain accident types, in particular right angle accidents, identify a safety deficiency resulting from an inadequate use of a traffic control device. A listing of typical accident patterns for intersections is provided in Table 62:

Table 62. Accident patterns at intersections relating a need for a Traffic Control Device Study.

Situation	Accident Characteristics	Required Study
Uncontrolled intersection	● Right angle accidents	● Need for "STOP" or "YIELD" control
"YIELD"-controlled intersection	● Right angle accidents	● Need for "STOP" or signal control
"STOP"-controlled intersection	● Right angle accidents	● Need for signal control or increased enforcement of control
Signal-controlled intersection	● Right angle accidents	● Increased enforcement of control

Non-intersection accident types which may identify the need for a traffic control device study may include sideswipes (at lane drop sections), head-on collisions (in no-passing zones) and other similar patterns.

Other sources can include field review data and local input from users of the area.

● Use Of Study

Where a traffic control device study is needed at a location, a review of the site characteristics is performed. The review involves the determination of sight distance characteristics, observance of the control device in operation, and review of accident data. A review of the effectiveness of the devices is then made. If conditions are found deficient, upgrading the type or application of the control, or increased enforcement of the existing control may be warranted. The techniques for conducting this procedure are also used as a tool in evaluating the effectiveness of a recently installed traffic control device using a "before" and "after" evaluation. Further information on the Traffic Control Device Study is defined in A User's Guide to Positive Guidance (1977) [6].

● Period of Data Collection

The data collection period is typically defined by a review of the accident characteristics for the site. Where a defined period does not exist, data collection during peak volume periods is suggested. A similar study should be conducted during off-peak periods to provide comparison data.

Traffic Control Device Study Techniques

Data needs for the traffic control device study will consist of accident data, sight distance information (including a review of travel speeds in the area), and traffic control device observance characteristics. Means to collect accident data and sight distance information are provided in Procedure 1 - "Accident Summary By Type" and Procedure 16 - "Sight Distance Study", respectively.

Two techniques are commonly used to perform a traffic control device study.

- Field observer method.
- Photographic techniques.

Major considerations for these techniques are given in Table 63.

● Field Observer Method

In the field observer method [1,2,3], a technician is stationed in the field and observes the study area for adherence of motorists to traffic control devices. Sample data sheets for this study at intersections are displayed in the Appendix (pages I-20 to I-22). During the study the observer records the field information on these sheets.

The observer should be stationed within view of the study area but should remain inconspicuous so as not to unduly influence driver behavior. The data should be sampled continuously during the study period to minimize bias in the results.

Advantages:

1. Permits a review of operations in the study area.
2. Allows flexibility by observer in performing study.
3. Equipment requirements are minimal.
4. Produces reliable results.

Disadvantages:

1. Lack of inconspicuity by observer can bias results.
2. Record of study results are limited to data sheets.

This technique is favorable for conducting a law or regulation observance study. It allows the observer to review the situation under actual field conditions and to interpret the data based on the field operations of all traffic.

● Photographic Techniques

The photographic techniques [2,3] use time-lapse or continuous photography to obtain a record of the field data. The film record is extracted

Table 63. Primary considerations for Traffic Control Device Study techniques.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Field Observer Method	. Reviews driver (or pedestrian) observance of traffic control devices from field observation of location	. Data sheets	. Technician to collect data . Engineer to review data	. Data collection approx. 1 hr. . Data review approx. 1/2 hour	. None	. Defined location . Law observance problem	. Observance of traffic control devices	. Adequacy or effectiveness of existing traffic control devices
2. Photographic Techniques	. Reviews driver (or pedestrian) observance of traffic control devices from review of film records of study location	. Photographic equipment . Film screen . Data sheets	. Technician to set up camera equipment . Trained technician to observe film data . Engineer to review data	. Data collection 2-4 hrs. . Data review 1-4 hrs.	. Photographic equipment $500-$2,000	. Defined location . Law observance problem	. Film record of location . Observance of traffic control devices	. Adequacy or effectiveness of traffic control devices

by a trained observer. Data summary sheets are similar to those used in the field observer method. The film record can be also used to obtain and review other traffic data at the study location.

Advantages:

1. Provides a film record of traffic conditions at the study location.
2. Observers are able to review other traffic data.

Disadvantages:

1. Equipment needs are considerable.
2. Camera view may be limited.
3. Time requirements can be considerable.

This technique is appropriate where a permanent record of the study location is required or where conditions are complex, such that extensive manpower requirements would be needed if the field observer method was used.

Selection of Alternate Techniques

Criteria for selection of a study technique are based on the management concerns of the agency. Table 64 gives the technique utility based on the management concerns. General guidelines to assist in the selection of a technique procedure are provided.

1. The field observer method is the preferred technique due to lower time, manpower, and equipment requirements.
2. For situations where the need to maintain a film record of the situation occurs or where the location is complex, the photographic technique may be favorable.

Findings

In analyzing the study findings, the accident data are used as the primary source of input. Other information, such as sight distance characteristics and law or traffic regulation observance data provide additional input.

● Use Of Findings

The occurrence of right angle accidents, sight distance problems, or the lack of adherence to a specific control (as identified by law observance study) can identify safety deficiencies and the need for upgrading traffic control devices.

The review of these data will assist in selecting appropriate countermeasures which may consist of:

Table 64. Technique utility for Traffic Control Device Study techniques.

Management Concerns \ Technique	Field Observer Method	Photographic Techniques
1. Time Requirements	. Requires data collection and data manipulation	. Requires data collection, data extraction, and data manipulation
2. Equipment Requirements	. Minimal	. Photographic equipment . Other needs minimal
3. Manpower Requirements	. Technical level	. Experienced Technician level
4. Level of Comprehen-siveness	. Reviews full scope of study area	. Scope of study area limited by camera field of view

- Installation of "special signing".
- Upgrading of existing traffic control devices.
- Installation of signal control.
- Reduction of approach speeds.
- Increased enforcement of existing or planned device.
- Removal of a traffic control device.

Countermeasures should be selected and designed in accordance with the MUTCD [4] criteria.

PROCEDURE 23 Bicycle And Pedestrian Study

Purpose

The purpose of this procedure is to study safety situations involving the bicycle or pedestrian modes.

Application

The bicycle or pedestrian study procedures provide a structured safety review of a situation where an existing or potential hazard between these transportation modes and other vehicular traffic occurs. Due to the severity of bicycle/vehicle or pedestrian/vehicle accidents, the study of hazardous situations involving these modes represents an important phase of highway safety.

Need for Study

The need for a bicycle or pedestrian safety study can be determined from available accident data, as identified by a pattern of "bicycle/vehicle" or "pedestrian/vehicle" accidents. Other sources of identifying the need for a study include field review data, or input by local users.

Use of Study

Where a bicycle or pedestrian safety study is performed, a review of the following field information should be made [1,2,3].

1. Review of accident characteristics.
2. Review of field conditions.
3. Collection of vehicular and pedestrian or bicycle volume counts and conflict data during the period where a safety problem is evident.
4. Review of field notes made during field review of the location.
5. Review of the effectiveness of existing traffic control devices as related to both the vehicular and bicycle or pedestrian traffic.

LOCATION: ______________________________

CITY OR TWP: ______________________________

DATE: ____________________ WEATHER: ____________________

TIME: ____________________ OBSERVER: ____________________

OPEATIONAL CHECK LIST:	NO	YES
1. Do obstructions block the drivers view of opposing or conflicting bicyclists or pedestrians?	___	___
2. Do pedestrians, bicyclists, or vehicles respond incorrectly to signals, signs, or other traffic control devices?	___	___
3. Are vehicle speeds too high?	___	___
4. Do pedestrian or bicyclist movements through the location cause conflicts?	___	___
5. Is pedestrian or bicyclist movement in the area accounted for in the area's design of highway facilities?	___	___
6. Is existing lighting operating effectively for nighttime travel by bicyclists or pedestrians?	___	___
PHYSICAL CHECKLIST:		
1. Can sight obstructions by removed or decreased?	___	___
2. Should pedestrian or bicycle crosswalks be relocated? Repainted?	___	___
3. Are signs adequate as to usefulness, message, size, conformity and placement? (see MUTCD - Sections II - A, B, C, D, E, and F)	___	___
4. Are signals adequate as to placement, conformity, number of signal heads, or timing? (see MUTCD - Section IV)	___	___
5. Are pavement markings adequate as to their visibility or location? (see MUTCD - Section III)	___	___
6. Do speed limits appear safe and reasonable?	___	___
7. Is street lighting adequate?	___	___

COMMENTS:

____

____

____

Figure 56. Sample safety review form for Bicycle and Pedestrian Study.

Based on the information obtained in these steps, identification of safety deficiencies can be made. These deficiencies are used to develop safety-related countermeasures.

- Period of Data Collection

Periods of data collection for these studies will be determined by the time of day accident data related to the bicycling or walking modes.

For accurate results, field data collection should be performed under favorable weather conditions. This is important since favorable weather conditions tend to generate maximum pedestrian and bicycle traffic.

- Data Collection Requirements

A bicycle or pedestrian study will typically involve the performance of a conflict study and a field review of the situation. To assist in the field review, a questionnaire may be used to assure review of key data items. The questionnaire is completed during the field review. A sample questionnaire is shown in Figure 56.

A special conflict summary form is used to collect the data, as shown in page I-19 of the Appendix. The form can be altered slightly to also include conflicts resulting from bicycle activity.

Bicycle or Pedestrian Study Techniques

Two techniques are available to perform a bicycle or pedestrian study.

- Field observer method.
- Photographic techniques.

Information on the primary considerations of these techniques are displayed in Table 65.

- Field Observer Method

The field observer method [1,4] uses an observer to record volume count data; review the study area operation; and to record conflict data and notes on observed deficiencies or special situations. The observer should remain inconspicuous during this effort so as not to influence driver, pedestrian, or bicyclist behavior in the area. This technique requires an observer experienced in bicycle and pedestrian operations as well as highway safety.

Advantages:

1. Equipment needs are minimal.
2. Data are normally reliable.

Table 65. Primary considerations of Bicycle and Pedestrian Study techniques.

Considerations / Technique	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Associated Costs	Data Input	Data Obtained	Data Output
1. Field Observer Method	. Reviews field operations using film record of field situation	. Data sheets	. Engineer to observe field operations	. Approx. 1-2 hours	. None	. Defined location . Accident characteristics . Volume data	. Assessment of safety operations	. Evaluation of observed safety deficiencies
2. Photographic Techniques	. Reviews field operations using film record of field situation	. Camera equipment	. Technician to set up, check and remove camera . Engineer or trained technician to review film data	. Camera set up, removal time approx. 1 hour . Data review time-several hours	. Camera equipment $500-$2,500	. Defined location . Accident characteristics . Volume data	. Assessment of safety operations	. Evaluation of observed safety deficiencies

3. Able to view total study area operations.
4. Permits flexibility in performing the studies.

Disadvantages:

1. Results can be influenced by presence of observer.
2. Data sheets serve as the only record.

This technique is preferred for pedestrian and bicycle studies due to its overall low cost and minimal personnel needs.

● Photographic Techniques

The photographic techniques [4] make use of time-lapse or continuous photography to obtain the field data. The cameras are situated to observe the desired operations. The data are extracted in an office environment and recorded on data sheets similar to those used in the field observer technique.

Advantages:

1. Provides a film record.
2. Able to obtain other traffic data.

Disadvantages:

1. Equipment requirements are substantial.
2. Camera may limit field of view.

Selection of Alternate Techniques

The selection of the alternate technique is based on specific management concerns, i.e., time, equipment, and manpower requirements and the level of comprehensiveness of the technique. Table 66 can be used to identify the technique utility of the management concerns.

General guidelines to assist in the selection process are provided below.

1. The field observer method is preferred for most bicycle or pedestrian-related studies due primarily to its lower cost and minimal personnel needs.

2. The photographic techniques are favorable where a long data collection period is required.

Table 66. Technique utility for Bicycle and Pedestrian Study.

Technique / Management Concerns	Field Observer Method	Photographic Techniques
1. Time Requirements	. Requires data collection	. Requires camera setup, check and removal time and data extraction review
2. Equipment Requirements	. Minimal	. Camera equipment . Other needs are minimal
3. Manpower Requirements	. Trained technician or engineer level	. Technician for camera set-up, etc. . Trained technician or engineer for data review
4. Level of Comprehensiveness	. Areawide scope	. Limited by camera field range

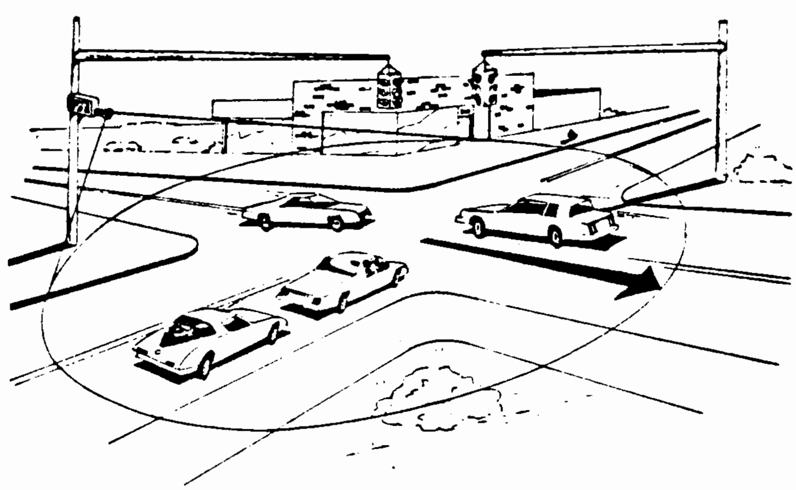
Findings

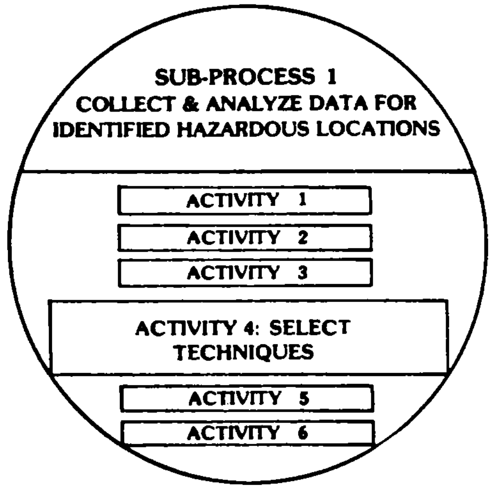
In reviewing the study findings, safety problems are defined from various input sources. These findings will identify safety deficiencies and assist in developing appropriate countermeasures.

A review of feasible countermeasures for pedestrian and bicycle-related safety deficiencies can be defined in the DOT publications:

- Model Pedestrian Safety Program - User's Manual - Implementation Package 78-6 (June, 1978)

- A Study of Bicycle/Motor Vehicle Accidents: Identification of Problem Types and Countermeasure Approaches, Volumes I, II, and III, DOT-HS-803-315.





ACTIVITY 4 Select Techniques

Purpose

The purpose of this activity is to select the techniques for performing the study procedures required for a site. This activity is conducted to identify the available techniques to perform each procedure and to assist in selecting the most favorable techniques for an individual agency.

Overview

Within all highway agencies, the financial budget is a major factor in providing safe and efficient highway operations. Typically, available funds, manpower, and time resources tend to limit the safety engineer's abilities to provide a fail-safe roadway environment. In efforts to obtain as safe a roadway environment as possible, the safety engineer is required to make optimum use of resources, i.e., time, equipment and manpower.

The effective performance of a highway safety program requires that highway safety studies be performed as a key phase in the study of hazardous locations. These studies permit an organized approach for data collection, review, and analysis of conditions. In an effort to attain the above objectives, it is necessary that each study procedure be performed to produce effective results.

Very often, the two objectives of the safety program conflict. That is, the need to perform the procedures in a comprehensive manner and the optimization of available resources are difficult to achieve simultaneously. For example, to obtain a 24-hour traffic volume at a location, the lack of mechanical volume counters and the feasibility of performing a manual 24-hour count will limit the collection of these data. Options may include: (1) obtain manual volume counts for a shorter period of time and expand them to a 24-hour total and (2) use a shorter period manual count in the analysis. Either technique may result in less direct and, possibly, less effective results. The selected technique, however, must be within the resource limits available to the safety engineer.

- <u>Selection Criteria</u>

To optimize the overall performance and results of the study procedures, the technique selection process requires that a review of the available resources and the study objectives be made as they pertain to the study procedures. This review requires an assessment of the basic management concerns related to each study technique. Typical management concerns include:

- Time requirements.
- Manpower requirements.
- Equipment requirements.
- Information capabilities.
- Level of accuracy.

The demands each management concern requires for a particular technique are determined and evaluated by the safety engineer based on the agency's resources and study demands.

Using either qualitative or quantitative methods, an evaluation of the individual techniques based on an agency's resources is performed for each procedure. A review of the selected techniques for the selected procedures will then result in the selection of the most effective overall methods.

- <u>Selection Plan</u>

To aid in the selection of the appropriate techniques, the following steps are suggested:

1. Identify the field situation and information needs for each required procedure. Field situations may consist of either:

    - Freeway, ramps, arterials, collectors, etc.
    - Link and intersection.

    Information needs will identify the specific information desired from the procedure, such as peak hour volume count, 24-hour volume count, peak hour level of service.

2. Utilize the information obtained in Step 1 to identify the most favorable techniques for each study procedure. In most cases,

more than a single technique will be favorable. A list of techniques is shown in Table 67.

3. Review the management concerns (time, manpower, and equipment resources; level of comprehensiveness; and level of accuracy) for the favorable techniques.

4. Relate the management concerns to the particular agency's requirements.

5. Select the appropriate technique for each required procedure.

● Selection Methods

Two means are available to select techniques. First, a qualitative comparison can be performed. This approach requires that a safety engineer or team of engineers evaluate the management concerns and develop an assessment of each favorable technique. The evaluation is based on the overall effectiveness of the technique in performing the procedure given the agency's capabilities. From statements for each management concern, a single technique can be selected.

The second approach uses a numerical weighting scheme as a basis for selecting a technique. Each management concern is provided a weighted value based on its importance to the agency in performing the technique. The sum of these weights should, preferably, equal 100 percent.

Each management concern is evaluated based on the technique's effectiveness in meeting the management concern. Six levels may be described:

0 - not feasible
1 - poor
2 - below average
3 - average
4 - above average
5 - desirable

The numerical approach is described in the following equation:

$$UI = \sum_{i=1}^{j} W_i L_i$$

where: UI = utility index.
W_i = weighted value for management concern "i".
L_i = level rating for management concern "i".
i,j = number of management concerns.

A sample computation form is shown in the Appendix (page I-23).

Table 67. Summary of available techniques for traffic, environment, and special study procedures.

Procedure Type	Procedure	Available Techniques
Traffic	. Safety Performance Study	. Field Method . Photographic technique
	. Volume Study	. Mechanical counter - Permanent - Portable . Manual counting . Moving vehicle method . Photographic techniques
	. Spot Speed Study	. Stop watch methods . Electric or electronic methods . Photographic techniques . Radar meters
	. Travel Time and Delay Study	. Test car technique . Moving vehicle method . Sampling method . License plate method . Photographic techniques . Graphic pen recorder . Observer method . Delay meter . Interview method
	. Roadway and Intersection Capacity Study	. Highway Capacity Manual method . Northwestern University capacity nomographs . TRB 212 method . Critical movement analysis . Cycle sampling
	. Traffic Conflict Study	. Field method
	. Gap Study	. Manual method . Manual/machine method . Photographic techniques . Instrumented site method
	. Traffic Lane Occupancy Study	. Detector method . Manual method . Photographic technique
Traffic (Cont.)	. Queue Length Study	. Detector method . Manual method . Photographic techniques . Mathematical models
Environment	. Roadway Inventory Study	. Field method . File search method . Photolog method . Videolog method
	. Skid Resistance Study	. Locked wheel method . Mu meter . Automobile method . Portable/Laboratory method
	. Highway Lighting Study	. AASHTO criteria . NCHRP Report No. 152 method . Individual specific warrants . Field conditions method . Light meter method
	. Weather-Related Study	. In-field measurement method . Field instruments method . Field review method
Special Studies	. School Crossing Study	. ITE method . Pedestrian conflicts method
	. Railroad Crossing Study	. Multi-disciplinary diagnostic team approach . Subjective evaluation by individual
	. Traffic Control Device Study	. Field observer method . Photographic techniques
	. Bicycle and Pedestrian Study	. Field observer method . Photographic techniques

The utility index will produce a numerical value for each technique. A higher rating will result in a more desirable technique. It should be noted, however, that the utility index provides a rating value for each technique specific to the agency using the rating method. It is not meant to be used as a rating method between agencies since each agency typically has different resources and study needs.

- Other Considerations in Technique Selection

When making the final selection of techniques, several considerations should be reviewed. First, resources available to an agency should be checked. For instance, a city traffic engineering department may not have a radar speed meter. A check with the local or nearby police agency may identify the availability of the device. Also, in the case of skid resistance studies, a phone call to the State Highway Department may allow the agency to obtain use of State equipment. A check of all feasible sources for available resources is suggested.

Secondly, combining study procedures by a single technique should be encouraged. For instance, where detection devices are available to collect traffic volume, speed, gap, lane occupancy, and queue length data or any combination of the above, these devices should be selected. Where a manual field study is performed at a location, it could be planned to utilize manual data collection for other activities concurrently. Proper planning will usually result in the optimization of available resources.

Finally, once the techniques have been selected for each procedure, a review of the list of selected techniques should be made. Duplication of efforts and resources may then be avoided by assuring that the techniques selected are most favorable to the overall study of a specific location.

Findings

This activity will result in the selection of techniques which will optimize the use of resources available to an agency. It will also allow the collection of the data required by a specific procedure. The results of this activity will be used in developing the data collection plan for the study location.

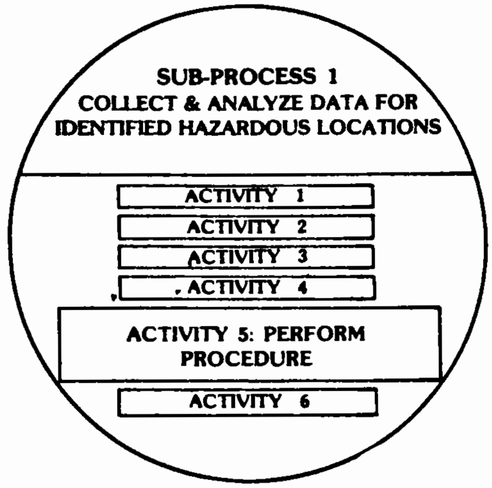
Inputs and Outputs of Activity

- Inputs
  - Required traffic, environment, and special study procedures for study location.
  - List of available and preferred techniques to perform procedures.

- Characteristics of management concerns for each technique.
- Assessment of available resources.
- Assessment of study needs.

- <u>Outputs</u>

  - Evaluation of management concerns for each favorable technique
  - Selected technique for each procedure.
  - List of selected techniques for safety study of location.



ACTIVITY 5 PERFORM PROCEDURE

Purpose

The purpose of this activity is to develop a data collection plan for the study procedures and to perform the procedures using the techniques selected in Activity 4.

Overview

Safety engineers are often faced with the challenge of performing safety studies with time, manpower, and equipment limitations. The selection of the most favorable study techniques aids in optimizing available resources. Resources can be further optimized with proper planning and the timely performance of the data collection techniques.

● Data Collection Plan Development

Development of a data collection plan is extremely desirable. Careful planning optimizes the use of available resources and minimizes the chance of collecting too much or too little data. Planning is an important factor in conducting an efficient study which will produce complete and reliable results.

The planning activities should consist of the following steps:

- Selection and training of manpower.
- Acquisition of equipment.
- Preparation of data collection forms.
- Development of data collection schedules.

Planning is often considered simple and routine. However, when a number of study procedures are required for a specific location, data collection efforts become more time-consuming. In addition, planning with existing resource limitations becomes more involved and more crucial to the outcome of the study, particularly with the limitations afforded the safety engineer.

To assist in the proper planning of the study procedures, the following guidelines are provided.

- Selection and Training of Manpower Resources

1. List the required tasks and anticipated manpower needs for each procedure and technique to be performed. For instance, to perform the roadway inventory study procedure by the manual method, two tasks are involved: (1) collect, measure, and record data and (2) prepare condition diagram. The first task typically involves two people, one to collect and measure the field information and a second individual to record the data. The second task requires one person to transform field notes and measurements into a condition diagram.

2. Determine available manpower resources. Manpower may come from existing staff personnel, staff from other departments, or personnel from other agencies. For each person, their background and capabilities, such as data collection, data recording, diagram preparation, data analysis, etc. should be listed.

3. Compare manpower needs and manpower resources. If manpower availability permits, select individuals with direct experience in conducting the study procedures to be performed. In many cases, however, this may not be possible. This makes the training of inexperienced personnel an extremely important issue.

4. Train selected personnel. Although highly experienced personnel may be available, it is recommended that training be performed to acquaint all personnel with specific details of the study procedure including:

    - Study purpose.
    - Preliminary information regarding the study site.
    - Tasks to be performed.
    - Information on the task and study output.
    - Period of data collection.
    - Operation of data collection equipment.
    - Proper use of data sheets.
    - Pitfalls of the task.
    - Need for accuracy and efficiency.

Following training, a question-and-answer period for the personnel should be held. If inexperienced personnel are being used, it is advisable to conduct supervised trial-runs of the study procedures.

- Acquisition of Equipment

1. List the equipment needs of each task in the technique. For the example given in the previous section, two tasks are required:

   - Collect, measure, and record field information.
   - Prepare condition diagram.

   Equipment requirements for these tasks would include:

   - Measuring instrument (i.e., hand measuring wheel, or tape measure, etc.).
   - Blank data sheets.
   - Clipboard.
   - Pencils.

2. Inventory the agency's existing equipment resources. The availability of these resources are usually known by the safety engineer. However, the location of the equipment should be checked to guarantee availability.

3. Compare equipment requirements and availability. Make a list of additional equipment needs. In some cases, this equipment may be borrowed from another department. Typically, access to major equipment and its availability were considered when the technique was selected.

4. Check all equipment for reliability prior to conducting the study.

- Preparation of Data Collection Forms

1. List the required data forms for each procedure.

2. Check existing files for data sheets. Very often, an agency maintains a file of data collection forms. Where data forms are unavailable, use of forms included in the Appendix or in the ITE Manual of Traffic Engineering Studies [1] is recommended.

3. Fill out as much of the data forms as feasible prior to the data collection effort. Make sure extra copies of the data sheets are available to the data collectors.

● Development of Schedules for the Data Collection

1. Define the data collection periods as determined from the accident summaries. This is of particular importance for operational data items. For many physical data items, data collection is not necessarily related to the time of day.

   When performing the data collection, favorable weather conditions should exist. The data collection, however, should be planned for the early part of the week. In this way, if one day is unfavorable, the next regular day may be used for data collection. Significant time and effort may be wasted when surveys are postponed.

2. When feasible, combine data collection activities for different tasks on the same day. This will typically maximize use of available manpower.

A sample Task, Manpower, and Equipment Summary Sheet is included in the Appendix (page I-24). Once the plan has been developed and the personnel and equipment are prepared, the data collection activities can be performed.

● Performing the Procedure

When manual data collection methods are used, the data collectors should assemble at or near the site at least 1/2 hour prior to the data collection activity. This serves several purposes. First, it allows a check that all data collectors are present. When a data collector(s) is absent, plans to perform that person's activities can be made. Second, it aids in assuring that the data collection activity starts on time. Late arrival of data collectors can result in a postponement of starting times. Finally, it allows the data collectors to observe the study site, test the equipment, and ask questions regarding the study procedure.

Once final instructions are completed, the observers should go to their respective stations. This allows a brief time for them to familiarize themselves with the location and the demands of the data collection effort.

When machine methods are used in data collection, the equipment should be installed at least one-half hour prior to the data collection period. This will allow sufficient time for the installation and operational check of the equipment. Operational checks involve the testing of the machine data versus observed data using manual measurements. For example, when installing volume counters, a manual count is used to check the accuracy of the volume counting machine.

The equipment should be installed on the same day as the data collection effort to minimize chances of vandalism or equipment failures. When it is necessary that the equipment be installed the day before the study, operational checks should be performed at the time of installation and again prior to the study period. Backup equipment should be available and carried to the site in all situations.

The study procedure should be performed in accordance with the directives provided by the safety engineer and the techniques described for each procedure.

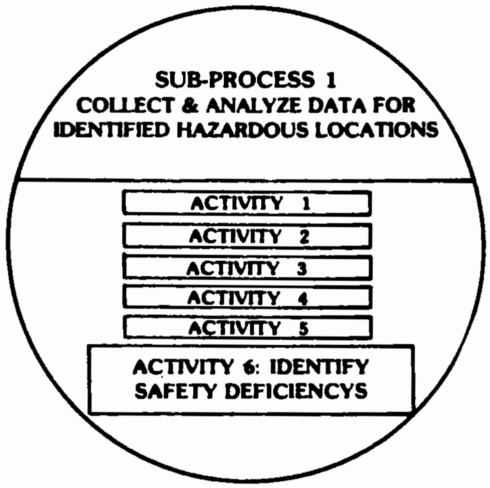
Following completion of the data collection effort, the data collectors should again assemble near the site. At this time, the data sheets are reviewed and any questions by data collectors are answered. Also, all equipment is checked for accuracy and all data are briefly double-checked for completeness.

Findings

The output of this activity will be a data collection plan and the performance of the study procedures required for the site. The findings from this activity are used in the identification of safety deficiencies and the development of safety-related countermeasures.

Inputs and Outputs of Activity

- Inputs
  - Defined location.
  - Period of data collection.
  - Technique(s) to be performed.
  - Available time, manpower, and equipment resources.
  - Time, manpower, and equipment requirements.
  - Data collection forms.
- Outputs
  - Selected manpower and task assignments.
  - Schedule of data collection efforts.
  - Data sheets by data collector.
  - Summarized data findings by procedure.



ACTIVITY 6 IDENTIFY SAFETY DEFICIENCY(S)

Purpose

The purpose of this activity is to assemble and analyze the various data collected at a study site, review the findings, and verify or identify safety deficiencies.

Overview

Safety problems at a site are identified by the following factors.

- Field conditions identifying a deficiency.
- Measure (extent) of a deficiency.
- Probable accident cause or safety deficiency.

This activity will result in the accumulation and analysis of the site data collected from the procedures. The results will be used to identify the safety deficiencies and to develop feasible countermeasures.

- Accumulation of Data

After the procedures have been performed, the data should be assembled and placed in a format amenable to analysis. This format should permit an effective determination of the safety deficiencies at the site. A favorable format should list the data in the order used to define a safety problem, i.e., conditions, measures, and the cause of the problem. In this way, once site conditions and measures of the problem are defined, the

Table 68. Data purpose by procedure.

PROCEDURE	DATA PURPOSE
1. Accident Summary By Type	A
2. Accident Summary By Severity	A
3. Accident Summary By Contributing Circumstances	A
4. Accident Summary By Environmental Conditions	A
5. Accident Summary By Time Period	A
6. Safety Performance Study	A,B,C
7. Volume Studies	B
8. Spot Speed Studies	B,C
9. Delay and Travel Time Studies	C
10. Roadway and Intersection Capacity Study	C
11. Traffic Conflict Study	A,C
12. Gap Study	C
13. Traffic Lane Occupancy Study	C
14. Queue Length Study	C
15. Roadway Inventory Study	B
16. Sight Distance Study	C
17. Skid Resistance Study	C
18. Highway Lighting Study	C
19. Weather-Related Study	C
20. School Crossing Study	C
21. Railroad Crossing Study	C
22. Traffic Control Device Study	C
23. Bicycle and Pedestrian Study	C

LEGEND:

A - Defining "probable accident cause"
B - Identifying field (site) conditions relating probable cause
C - Identifying measure (extent) of safety deficiency(s)

probable accident cause or safety deficiency can be readily identified. To assist in ordering the data by its purpose, Table 68 is used. The table lists the purpose of the data obtained by each of the study procedures. The data from each procedure is then assembled and prepared for analysis.

- Analysis of Data

The data obtained from each procedure are reviewed using the analysis methods described within each procedure. The outputs are then used to identify and describe the conditions and measures of each safety problem at the study location.

Once the safety data are summarized and reviewed, the results are used to make a final assessment of the safety deficiencies. Each of the possible accident causes noted from the accident summaries and the field review are assessed with the findings of the other study procedures. From this assessment, a list of probable causes or safety deficiencies is identified. The probable cause list may differ from the list of possible causes. The results are used in the countermeasure development activity.

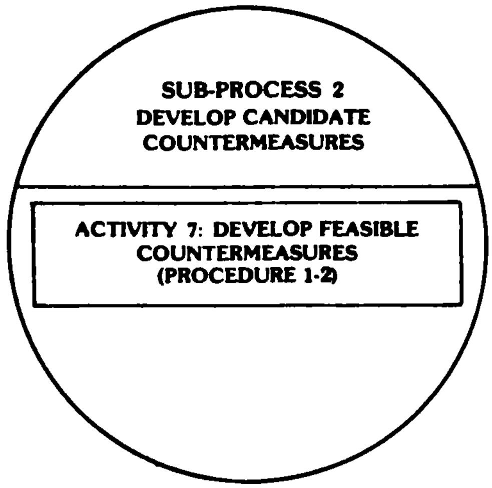
Where all "possible accident causes" have been deleted based on the procedure findings, a re-check of the accident summaries, field review notes, and other study procedure findings should be performed. This check may reveal inaccurate assumptions or findings. In NO CASE should a safety problem lack a probable accident cause. Without this information, effective countermeasures cannot be developed.

Findings

The purpose of this activity is to assemble and review the study site data and to format the data in a manner favorable to the identification of safety deficiencies. This format will allow a more effective identification of the safety deficiencies. The output of this activity will be used in the development of feasible countermeasures.

Inputs and Outputs of Activity

- Inputs
  - Defined location.
  - List of probable accident causes.
  - Study findings from traffic, environment, and/or special study procedures.
- Outputs
  - Summary of study findings.
  - Review of probable accident causes.
  - Definition of safety deficiencies.



Subprocess 2 - Develop Candidate Countermeasures

ACTIVITY 7 DEVELOP FEASIBLE COUNTERMEASURES

Purpose

The purpose of this activity is to develop candidate countermeasures for a location based on the identified safety deficiencies at the location.

Overview

Prior to this activity, a detailed study of the identified hazardous location was made. The study activities identified the safety deficiencies at the site. The studies identified the following factors.

- Probable accident causes.
- Site characteristics identifying the probable accident causes.
- Measures (extent) of the safety problems or deficiencies.

From these results, feasible countermeasures can be developed by the safety engineer.

- Factors To Consider

Several factors [1] need to be considered when developing countermeasures. First, countermeasures should be selected carefully based on a knowledge and understanding of the effectiveness of similar improvements. Inputs from past project and program evaluations (Evaluation Component of HSIP) are very important to the results of this activity. If a past project resulted in favorable safety benefits at a similar location, such improvement would likely be considered as a candidate countermeasure.

Second, countermeasures which may have produced major safety improvements in one area of the country may not necessarily produce similar improvements in another part of the country or at alternate locations in the same area. This is due to the complex interrelationships among the various traffic variables at the site. A careful review of traffic and site conditions should be performed when developing countermeasures. This will assure effective coordination of countermeasures with the existing conditions.

Third, several candidate countermeasures can be proposed for the same location if it is expected that a combination of countermeasures are practical and will produce an overall improvement in safety. In this activity, it is suggested that all practical combinations of countermeasures be identified.

Fourth, the list of feasible countermeasures should be comprehensive. It is more favorable to include a greater number of countermeasures than have an inadequate list. All practical improvements, from the "do nothing" alternative to ultimate improvements, should be identified and considered so that no feasible alternative is overlooked.

Finally, the potential safety-related effect of each alternative improvement or combination should be identified. This step will assure that the countermeasures developed are based on safety objectives.

Findings

The output of this activity will be a comprehensive list of feasible countermeasures and the potential or anticipated effect the improvement will have on safety at the site. For instance, a feasible countermeasure consisting of the construction of a separate left turn lane may have the following potential effects on the study location.

1. A reduction of left turn accidents.

2. A reduction of rear-end collisions between through and left turn movements.

3. A reduction in sideswipe accidents.

4. An increase in the capacity of the facility.

5. A reduction in delay to through traffic.

6. An increase in safe sight distance for left turning traffic.

The list will serve as input to assist in selecting a single safety project.

Inputs and Outputs of Activity

- Inputs
  - Defined hazardous location.
  - Definition of safety deficiencies at each location.
  - Basic understanding of available safety improvements which are effective in reducing accidents.
  - Past experiences of agency and others regarding the effectiveness of specific countermeasures.

- Outputs
  - List of feasible countermeasures.
  - List of potential effects of the improvements.

Procedure Description

Two procedures are available to develop the feasible safety-related countermeasures for a location.

- Procedure 1 - Accident Pattern Tables.
- Procedure 2 - Multi-Disciplinary Investigation Team.

Primary considerations for these procedures are shown in Table 69.

Procedure 1 Accident Pattern Tables

Purpose

The purpose of this procedure is to identify feasible countermeasures based on defined accident patterns at a study location. Using findings obtained from the accident summaries and field review, and supplemented by the traffic, environment, and special study procedures, candidate countermeasures can be developed.

Application

The development of accident pattern tables is based on the following assumptions.

- Patterns of accident types are associated with probable accident causes.

- The need for specific improvements can be inferred from analysis of probable accident causes.

Table 69. Primary considerations for countermeasure development procedures.

Consideration / Procedure	Function	Equipment Requirements	Manpower Requirements	Time Requirements	Data Input	Data Obtained	Data Output
1. Accident Pattern Tables	. Determine countermeasures using tables based on accident situation and probable cause	. Accident pattern tables	. Engineer to review tables	. Very little where data is adequate	. Accident pattern . Probable causes . Site data	. List of possible countermeasures	. List of possible countermeasures
2. Multi-Disciplinary Team Approach	. Determine countermeasures using a team of individuals to study and select the countermeasure(s)	. None	. Individuals with varying disciplines	. Each individual devotes one to two hours per site	. Accident summaries . Site data	. Probable causes . List of possible countermeasures	. List of possible countermeasures

Using these assumptions, accident pattern tables can be developed. The background for the tables are based on traffic safety engineering experience, the past experiences and evaluations of agencies, and the results of various research conducted throughout the United States.

Accident pattern tables have been developed by various groups (1,2,3, 4). These tables are summarized in Table 70 which provides a general accident pattern table to assist in the development of countermeasures.

● Use Of Tables

In using these tables or locally developed tables, accident patterns and probable accident causes, as identified from previous activities, are used to identify a list of general countermeasures. For example, at a signalized intersection, it was determined that a pattern of right angle collisions occurred. From previous activities, the probable accident cause was identified as "restricted sight distance."

The list of general countermeasures associated with these accident causes was obtained from Table 70.

- Remove sight obstructions.
- Restrict parking near corners.
- Install stop signs and remove signals (see MUTCD).
- Install advance warning signs (see MUTCD).
- Reduce speed limit on approaches.
- Install yield signs (see MUTCD).
- Channelize intersections.
- Install advance markings to supplement signs.
- Install "STOP" lines.

The list of feasible countermeasures is the output of this procedure and is used in further activities to select safety projects.

● Other Situations

Where several "probable causes" may have contributed to a particular accident pattern, feasible countermeasures are determined on a collective basis. For instance, in the above example, if "poor visibility of signals" was determined to be an additional or a secondary "probable" cause, the list of general countermeasures would consist of the previous list and the following items.

- Install advanced warning devices.
- Install 12-in. signal lenses.
- Install overhead signals.
- Install signal visors.
- Install back plates.
- Improve location of signal heads.

Table 70. General accident pattern table.

Accident Pattern	Probable Cause	General Countermeasure
Left-turn head-on collisions	Large volume of left-turns	. Create one way street . Widen road . Provide left-turn signal phases . Prohibit left-turns . Reroute left-turn traffic . Channelize intersection . Install stop signs (see MUTCD) . Revise signal sequence . Provide turning guidelines (if there is a dual left-turn lane) . Provide traffic signal if warranted by MUTCD . Retime signals
	Restricted sight distance	. Remove obstacles . Provide adequate channelization . Provide special phase for left-turning traffic . Provide left-turn slots . Install warning signs . Reduce speed limit on approaches
	Too short amber phase	. Increase amber phase . Provide all red phase
	Absence of special left-turning phase	. Provide special phase for left-turning traffic
	Excessive speed on approaches	. Reduce speed limit on approaches
Rear-end collisions at unsignalized intersections	Driver not aware of intersection	. Install/improve warning signs
	Slippery surface	. Overlay pavement . Provide adequate drainage . Groove pavement . Reduce speed limit on approaches . Provide "slippery when wet" signs
	Large numbers of turning vehicles	. Create left- or right-turn lanes . Prohibit turns . Increase curb radii
	Inadequate roadway lighting	. Improve roadway lighting

Figure 70. General accident pattern table (continued).

Accident Pattern	Probable Cause	General Countermeasure
Rear-end collisions at unsignalized intersections	Excessive speed on approach	. Reduce speed limit on approaches
	Lack of adequate gaps	. Provide traffic signal if warranted (see MUTCD) . Provide stop signs
	Crossing pedestrians	. Install/improve signing or marking of pedestrian crosswalks
Rear-end collisions at signalized intersections	Slippery surface	. Overlay pavement . Provide adequate drainage . Groove pavement . Reduce speed limit on approaches . Provide "slippery when wet" signs
	Large number of turning vehicles	. Create left- or right-turn lanes . Prohibit turns . Increase curb radii . Provide special phase for left-turning traffic
	Poor visibility of signals	. Install/improve advance warning devices . Install overhead signals . Install 12-in. signal lenses (see MUTCD) . Install visors . Install back plates . Relocate signals . Add additional signal heads . Remove obstacles . Reduce speed limit on approaches
	Inadequate signal timing	. Adjust amber phase . Provide progression through a set of signalized intersections . Add all-red clearance
	Unwarranted signals	. Remove signals (see MUTCD)
	Inadequate roadway lighting	. Improve roadway lighting

Figure 70. General accident pattern table (continued).

Accident Pattern	Probable Cause	General Countermeasure
Rear-end collisions at signalized intersections	Crossing pedestrians	. Install/improve signing or marking of pedestrian crosswalks . Provide pedestrian "WALK" phase
Right-angle collisions at signalized intersections	Restricted sight distance	. Remove sight obstructions . Restrict parking near corners . Install warning signs (see MUTCD) . Reduce speed limit on approaches . Channelize intersections . Install advance markings to supplement signs
	Excessive speed on approaches	. Reduce speed limit on approaches . Increase amber phase . Install rumble strips
	Poor visibility of signal	. Install advanced warning devices . Install 12-in. signal lenses . Install overhead signal . Install visors . Install back plates . Improve location of signal heads . Add additional signal heads . Add illuminated name signs
	Inadequate signal timing	. Adjust amber phase . Provide all-red clearance phase . Add multi-dial controller . Install signal actuation . Retime signals . Provide progression through a set of signalized intersections
	Inadequate roadway lighting	. Improve roadway illumination
	Inadequate advance intersection warning signs	. Install advance intersection warning signs
	Large total intersection volume	. Retime signals . Add traffic lane
Right-angle collisions at unsignalized intersections	Restricted sight distance	. Remove sight obstructions . Restrict parking near corners . Install stop signs (see MUTCD) . Install warning signs (see MUTCD) . Reduce speed limit on approaches

Table 70. General accident pattern table (continued).

Accident Pattern	Probable Cause	General Countermeasure
Right-angle collisions at unsignalized intersections	Restricted sight distance	• Install signal (see MUTCD) • Install yield signs (see MUTCD) • Channelize intersection • Install advance markings to supplement signs • Install limit lines
	Large total intersection volume	• Install signal (see MUTCD) • Reroute through traffic
	Excessive speed on approaches	• Reduce speed limit on approaches • Increase amber phase • Install rumble strips
	Inadequate roadway lighting	• Improve roadway illumination
	Inadequate advance intersection warning signs	• Install advance intersection warning signs
	Inadequate traffic control devices	• Upgrade traffic control devices • Increase enforcement
Pedestrian-vehicle collisions	Restricted sight distance	• Remove sight obstructions • Install pedestrian crossings • Install/improve pedestrian crossing signs • Reroute pedestrian paths • Prohibit curb parking near crosswalks
	Inadequate protrection for pedestrians	• Add pedestrian refuge islands • Install pedestrian barriers
	School crossing area	• Use crossing guards at school crossing areas
	Inadequate signals	• Install pedestrian signals (see MUTCD)
	Inadequate phasing signal	• Change timing of pedestrian phase

Table 70. General accident pattern table (continued).

Accident Pattern	Probable Cause	General Countermeasure
Pedestrian-vehicle collisions	Driver had inadequate warning of frequent mid-block crossings	. Prohibit parking . Install warning signs . Lower speed limit . Install pedestrian barriers
	Inadequate pavement markings	. Install thermoplastic markings . Supplement markings with appropriate signing (see MUTCD) . Upgrade pavement markings (see MUTCD)
	Inadequate gaps at unsignalized intersections	. Install traffic signal, if warranted by MUTCD . Install pedestrian crosswalk and signs . Install pedestrian "WALK-DON'T WALK" signals
	Inadequate roadway lighting	. Improve roadway lighting
	Excessive vehicle speed	. Reduce speed limit . Install proper warning signs . Install pedestrian barriers . Enforcement
Run-off-roadway collisions	Slippery pavement	. Overlay existing pavement . Provide adequate drainage . Groove existing pavement . Reduce speed limit . Provide "slippery when wet" signs
	Roadway design inadequate for traffic conditions	. Widen lanes . Relocate islands . Close curb lanes . Install guardrails
	Poor delineation	. Improve/install pavement markings . Install roadside delineators . Install advance warning signs
	Inadequate roadway lighting	. Improve roadway lighting
	Inadequate shoulder	. Upgrade roadway shoulders

Table 70. General accident pattern table (continued).

Accident Pattern	Probable Cause	General Countermeasure
Run-off-roadway collisions	Improper channelization	. Improve channelization
	Inadequate pavement maintenance	. Perform road surface repair
	Poor visibility	. Increase size of signs
	Excessive speed on approaches	. Reduce speed limit
Fixed object collisions	Obstructions in or too close to roadway	. Remove obstacles . Install barrier curbing . Install breakaway features to light poles, signposts, etc. . Protect objects with guardrail . Install crash cushioning devices
	Inadequate roadway lighting	. Improve roadway lighting
	Inadequate pavement marking	. Install reflectionized pavement lines
	Inadequate signs, delineators and guardrails	. Install reflectionized paint and/or reflectors on the obstruction
	Inadequate road design	. Provide proper superelevation . Improve superelevation at curve . Install appropriate warning signs and delineators
	Slippery surface	. Improve skid resistance . Provide adequate drainage . Provide "slippery when wet" signs . Provide wider lanes
	Excessive vehicle speed	. Reduce speed limit
Collisions with parked or parking vehicles	Improper pavement markings	. Paint parking stall limits 7 feet from curb face
	Improper parking clearance at driveways	. Post parking restrictions near driveways

Table 70. General accident pattern table (continued).

Accident Pattern	Probable Cause	General Countermeasure
Collisions with parked or parking vehicles	Angle parking	. Convert angle parking to parallel parking
	Excessive vehicle speed	. Reduce speed limit if justified by spot speed studies . Widen lanes
	Illegal parking	. Enforcement
	Improper parking	. Prohibit parking . Create off street parking
	Large parking turnover	. Create one-way streets . Reroute through traffic
Sideswipe or head-on collisions	Inadequate roadway design	. Create one-way streets provide wider lanes
	Improper road maintenance	. Perform necessary road surface repairs
	Inadequate shoulders	. Improve shoulders
	Excessive vehicle speed	. Reduce speed limit . Install median devices . Remove constriction such as parked vehicles
	Inadequate pavement markings	. Install or refurnish center lines, lane lines and pavement edge lines . Install reflectorized lines, edges
	Inadequate channelization	. Install acceleration and deceleration lanes . Channelize intersection . Provide turning bays
	Inadequate signing	. Place direction and lane change signs to give proper advance warning . Add illuminated name signs

Table 70. General accident pattern table (continued).

Accident Pattern	Probable Cause	General Countermeasure
Driveway-related collisions	Left-turning vehicles	• Install median devices • Install two-way left-turn lanes
	Improperly located driveway	• Regulate minimum spacing of driveways • Regulate minimum corner of clearance • Move driveway to sidestreet • Install curbing to define driveway location • Consolidate adjacent driveways
	Right-turning vehicles	• Provide right-turn lanes • Restrict parking near driveways • Increase the width of driveways • Widen through lanes • Increase curb radii
	Large volume of through traffic	• Move driveway to sidestreet • Construct a local service road • Reroute through traffic
	Large volume of driveway traffic	• Signalize driveway • Provide acceleration and deceleration lanes • Channelize driveway
	Restricted sight distance	• Remove sight obstructions • Restrict parking near driveway • Install/improve street lighting • Reduce speed limit
	Inadequate roadway lighting	• Improve street lighting
	Excessive speeds on approaches	• Reduce speed limit
Train-vehicle accidents	Restricted sight distance	• Remove sight obstructions • Reduce grade • Install train actuated signals (see MUTCD) • Install stop signs (see MUTCD) • Install advance warning signs (see MUTCD) • Install automatic flashers and gates

Table 70. General accident pattern table (continued).

Accident Pattern	Probable Cause	General Countermeasure
Train-vehicle accidents	Poor visibility	• Improve roadway lighting • Increase size of signs
	Improper traffic signals pre-emption timing	• Retime traffic signals
	Excessive vehicle speeds on approaches	• Revise speed limit
	Inadequate pavement markings	• Install advance markings to supplement signs • Install limit lines • Install/improve pavement markings
	Slippery surface	• Skidproof roadway
	Improper pre-emption of RR signals or gates	• Retime RR signals and gates
	Rough crossing surfaces	• Improve crossing surface
	Sharp crossing angle	• Rebuild crossing with proper angle
Wet-pavement accidents	Slippery pavement	• Overlay existing pavement • Groove existing pavement • Reduce speed limit • Provide "slippery when wet" signs • Skidproof roadway
	Inadequate drainage	• Provide adequate drainage
	Inadequate pavement markings	• Upgrade pavement markings
Night accidents	Poor visibility or Lighting	• Install/improve street lighting • Install/improve delineation markings • Install/improve warning signs
	Poor sign quality	• Upgrade signing • Provide illuminated signs
	Inadequate channelization or delineation	• Install pavement markings • Improve delineation markings • Provide raised markers • Upgrade advance warning signing

- Add additional signal heads.
- Reduce speed limit on approaches.
- Add illuminated street name signs.

The findings obtained from the study procedures would produce a list of feasible countermeasures. This list would then be subjected to economic analysis to develop a single project.

A similar approach would be used to develop feasible countermeasures where two or more accident patterns are defined at a location. The countermeasures would be assessed collectively to develop feasible countermeasures.

- Limitations

Advantages:

1. Provides a method which is inexpensive.
2. Tables are simple to use.
3. Requires very little manpower needs.

Disadvantages:

1. May result in incomplete or inconclusive findings.
2. Requires individuals with substantial highway safety experience to develop countermeasures.
3. Is difficult to apply for complex situations.

This procedure requires that an individual experienced in highway safety be used for selection of feasible countermeasures. This process has been found favorable for most locations due to its low cost and ease of application. Where situations are complex, an alternate method, such as the team approach, may be more favorable.

Findings

This procedure is conducted to develop a list of feasible countermeasures for a location based on the identified accident patterns and probable causes. The output will be used as input in the economic analysis and project selection activities.

Procedure 2 Multi-Disciplinary Investigation Team

Purpose

The purpose of this procedure is to define feasible countermeasures based on the input received from a study of the location by a team of individuals from varying disciplines. From the input and discussion of the team members, a consensus of the causal factors and countermeasures to correct the hazards at a location is developed.

Application

With this procedure, individuals from various agencies and disciplines are used to review the safety problems and develop feasible countermeasures for a site. These individuals collectively serve as an advisory group.

● Team Selection

To be effective the team requires individuals with a variety of experience. It should also contain representatives of the agencies or groups responsible for the safe operation of the study location.

The following criteria must be met when developing an investigation team [9].

1. The team should be small enough to be manageable and easily organized, yet large enough to incorporate all desired disciplines.

2. The professional disciplines should cover the areas of roadway, driver, and vehicle aspects of highway safety to obtain a comprehensive analysis of the location.

3. There should be a variation in the degree of familiarity with the location by team personnel.

In addition to safety and traffic engineers, the study team may include:

- Highway design engineers.
- Law enforcement officers.
- City Council members.
- Planning Officials.
- Lay persons.

● Study Performance

In performing a study of a hazardous location, the team should assemble at the site to conduct a brief review session. At that time, the team leader (typically a safety engineer) supplies each individual with copies of the available site data; e.g., collision diagrams, volume data, and condition diagrams. These data are discussed briefly and any questions answered.

In the next step, each team member conducts a site investigation during the period of significant accident experience. The person drives along all approaches, observes operations at the location, and inspects any characteristics which he feels may be important to the study. All observations and findings are recorded.

While at the study location, each team member reviews the collision diagrams, possible causes, and other site data. They determine from personal judgement the predominant accident types, causal factors, and possible countermeasures.

Each team member then prepares a short report describing the findings. The reports are submitted to the team leader.

The team members are then reassembled for a short critique and discussion period. The critique usually begins with the safety engineer's summary of observations. Input from other team members is encouraged in the discussion phase. During this phase, the findings of each team member are reviewed and countermeasures discussed. From this discussion, the team members reach a general consensus on the safety deficiencies and the feasible countermeasures.

- Limitations

Advantages:

1. Attempts to view hazardous locations from the standpoint of human factors, law enforcement, etc., as well as from the highway and traffic engineering standpoint.
2. Provides extensive, detailed, in-depth analyses.
3. Provides an excellent means of focusing the attention of all involved agencies to the hazardous situation.

Disadvantages:

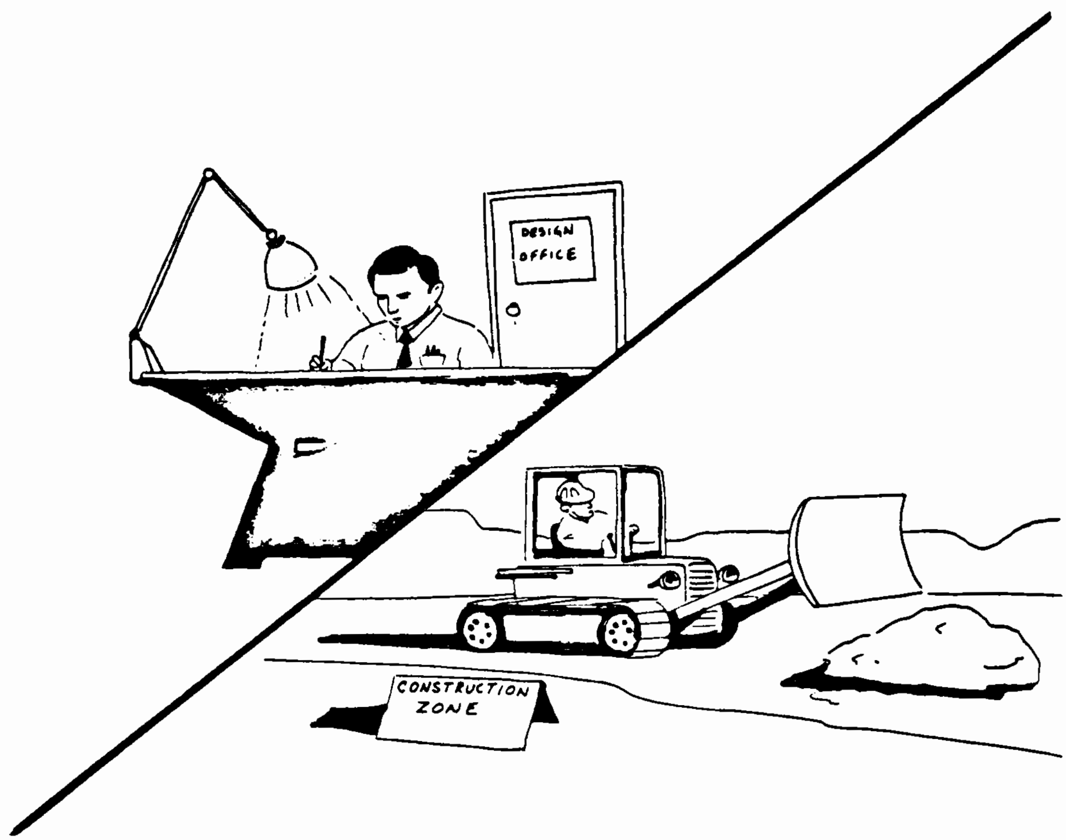
1. Requires large amounts of time, effort, and funding.
2. Difficult to schedule a specific time for review among various team members.
3. Requires the use of several specially trained individuals.
4. Requires the cooperation of all team members, both on an individual and on a team basis.

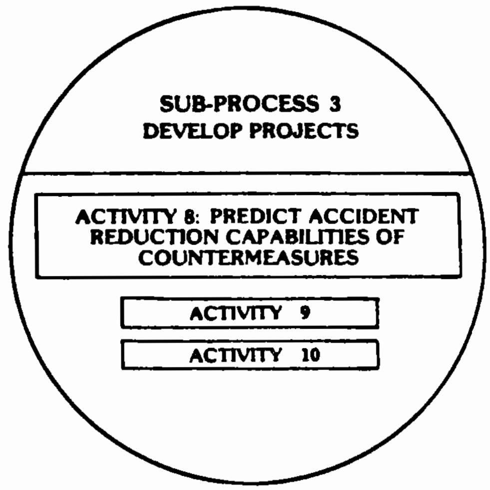
By involving persons with varying backgrounds, this procedure can result in a more comprehensive and critical review of a location. It does require, though, that the team leader be capable of handling the team and able to lead the various discussions.

Although this technique requires the cooperation of the involved personnel, the success of using personnel with varying disciplines carries extensive advantages. Not only is the viewpoint of differing individuals important but the inclusion of personnel from the involved agencies will typically facilitate the implementation of the project. This procedure is favorable for most locations when sufficient personnel is available. The team approach is especially recommended for use in complex highway safety situations.

Findings

This procedure is conducted to develop a list of feasible countermeasures for a location based on the input received from a team of individuals. The output will be used in the economic analysis and project selection activities.





Subprocess 3 - Select Projects

ACTIVITY 8 PREDICT ACCIDENT REDUCTION CAPABILITIES OF COUNTERMEASURES

Purpose

The purpose of this activity is to predict the number of accidents expected to be prevented (reduced) as a result of the implementation of a proposed countermeasure. The information obtained from this activity is used in the economic analysis of feasible countermeasures.

Overview

The major objective of a highway safety project is to reduce accidents and severity or the accident potential along the highway facility. In this regard, the effectiveness of a safety project is judged by its ability to reduce the number and severity of accidents. Similarly, in selecting safety improvements for a site, the anticipated effectiveness of a project to reduce accidents and/or severity serves as a major criteria. Project effectiveness is expressed in the economic analysis as a benefit if accidents decrease and as a disbenefit if accidents increase.

- Accident Reduction Factors

To obtain an indication of the effectiveness of a safety project, the development of factors estimating the potential reduction of accidents associated with an improvement is necessary. These factors, commonly referred to as "accident reduction factors" (AR), have been developed by numerous states and agencies. They are based on past and current evaluation efforts of safety projects and research data developed by various groups. Because of the variability in accident frequencies among sites and sections of the country, differences in accident reduction factors for specific improvements exist among agencies. In a completed FHWA publication [1], accident reduction factors for nationwide use are available. Through these efforts, a detailed list of safety improvements and their respective accident reduction capabilities were developed. The factors are measured as a percent reduction of accidents by severity type or accident type. A sample of these factors [1] are shown in Appendix F.

● Use Of AR Factors

Accident reduction factors are used to determine the economic benefits of feasible countermeasures. They represent a critical factor in the economic analysis since: (1) accident reductions are the primary objective of any safety program and (2) accident reductions will serve as a primary benefit to offset safety improvement project costs. In determining the benefits of a feasible countermeasure, the following formula [2,3] is used:

$$\text{Accidents Prevented} = N \times AR \; \frac{(\text{ADT - after period})}{(\text{ADT - before period})}$$

Where:

N = Expected number of accidents without implementation of the improvement project

AR = Accident reduction factor (percent).

ADT = Average daily traffic volume

In computing the number of accidents prevented, values of "N" can be based on average results for the study period. For instance, if over a 3-year period, the left-turn accident occurrence was 8, 12 and 9 accidents, respectively, the value of "N" would be 29/3 or 9.67 accidents. The use of average values throughout a study period is encouraged to reduce variability in the results and to minimize the likelihood of uncharacteristic results influencing the data.

Similarly, the "ADT-before period" volumes are based on average values throughout the 'before' study period. The "ADT-after period" volumes are based on the anticipated volumes during the period following implementation of a safety project. This period will be determined by the planned implementation period for the project. Estimates of future volumes can be computed based on the normal traffic growth, historical trends, or the results of detailed transportation models.

Where individual states or areas have a reliable list of AR factors, these lists should be used. Where a list does not exist or it is inade quate, the factors provided in Appendix F are recommended. The factors are stated in terms of "percent of accidents reduced" and are usually classified by improvement type as a function of accident type, severity, or total number of accidents.

The use of the accident reduction factor in the above formula will result in the expected number of accidents to be reduced with the implementation of a specific countermeasure. In most cases, this value can be obtained for total accidents at a location, specific accident types, or by severity class.

● Multiple Improvements

Accident reduction factors are provided for a single countermeasure at a location. However, where multiple countermeasures are being proposed, the accident reduction factor will be a combination of the individual accident reduction factors. Since it is not feasible to reduce accidents by more than 100 percent, the following formula [3] is used to develop an overall accident reduction factor for multiple improvements at a location.

$$AR_M = AR_1 + (1-AR_1)\,AR_2 + (1-AR_1)(1-AR_2)\,AR_3 + \ldots$$
$$+ (1-AR_1)(1-AR_{i-1})\,AR_i$$

where: AR_M = overall accident reduction factor for multiple improvements (mutually exclusive) at a single location
AR_i = accident reduction factor for specific improvement or countermeasure
i = number of improvements at a single location.

The accident reduction factors for the individual improvements should be listed by degree of importance. For instance, AR_1 should be the factor with the highest accident reduction factor; AR_2, the second highest factor; and so on. A different order of sequence will result in a different and, possibly, inaccurate overall accident reduction factor, AR_M.

● Example

An example of the use of the multiple improvement formula is shown for three improvements at a single location with individual accident reduction factors of 0.45, 0.15, and 0.30, respectively. Placing these factors in their order of significance, the accident reduction factors are as follows:

$AR_1 = 0.45$
$AR_2 = 0.30$
$AR_3 = 0.15$

The overall accident reduction factor is:

$$
\begin{aligned}
AR_M &= AR_1 + (1-AR_1)\ AR_2 + (1-AR_1)(1-AR_2)\ AR_3 \\
&= 0.450 + (1-0.45)(0.30) + (1-0.45)(1-0.30)(0.15) \\
&= 0.450 + 0.165 + 0.058 \\
&= 0.673 = 0.67
\end{aligned}
$$

Where individual accident reduction factors are available by severity, a separate AR_M factor can be developed for each severity class by applying the accident reduction factor for each severity class to the above formula.

- Other Situations

Current state-of-the-art does not adequately provide a means to use accident reduction factors for multiple improvements where different data bases are provided. For instance, one set of AR factors may be based on the severity of the accidents whereas another set may be based on the reduction of certain accident types or total accidents. For this case, the use of a general or total accident reduction factor for each improvement type may be desirable. It may, however, result in the over- or under-estimation of the accident reduction potential since this factor is applied to total accidents while the improvement may actually impact only one group of accidents.

Also, the AR factor for the principal countermeasure may be used and adjusted upward or downward dependent upon the judgement of the safety engineer. Experience in engineering and safety evaluation is required to permit a reasonable estimate of the accident reduction potential.

- Update of AR Factors

For reliable use of AR factors, the individual States should regularly update the factors based on the evaluation efforts of the State. Updating will permit the factors to be current and more representative of the effectiveness of the proposed improvement.

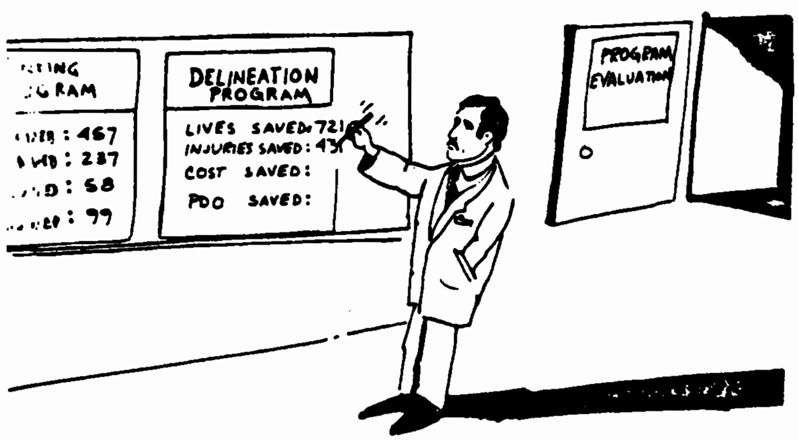
- Summary

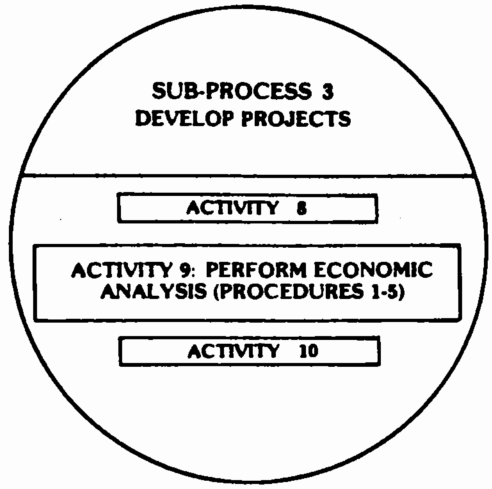
This activity will provide an estimate of the number of accidents that would be expected to be prevented by a countermeasure. Relationships between the number of accidents prevented and accident costs will be used to derive the major portion of the benefits anticipated for a countermeasure. This output will be used in the economic analysis of the feasible countermeasures.

Inputs and Outputs of Activity

- **Inputs**
  - Accident data at location for study period prior to improvement or the expected accident frequency without the improvement.
  - ADT volumes at study location during study period.
  - Future traffic volumes at study location.
  - Table of accident reduction factors for various improvements.
  - List of feasible countermeasures.

- **Outputs**
  - Accident reduction factor for countermeasure(s).
  - Number of "expected accidents prevented" as a result of feasible countermeasures.





ACTIVITY 9 PERFORM ECONOMIC ANALYSIS

Purpose

The purpose of this activity is to perform an economic analysis of the feasible countermeasures with primary emphasis on the accident reduction benefits and the cost of the project. The output consists of a numerical value assessing the economic feasibility of each project.

Overview

The economic analysis of countermeasures is a primary tool in the selection of a safety project. The analysis uses the expected economic benefits of an improvement to determine the cost-effectiveness of the countermeasure. A primary input to this analysis is the accident reduction benefits derived in the previous activity. These benefits are compared to the project cost to obtain a numerical relationship which is used as the measure of the cost-effectiveness.

● Factors in Economic Analysis

Key factors to consider in performing an economic analysis include the following.

- Accident savings.
- Initial implementation costs.
- Operation and maintenance costs.
- Service life of improvement.
- Salvage value of improvement.
- Current or expected interest rates.

Other factors which may be used in the economic analysis include vehicle delay-related costs, traffic growth rates, and the effects of inflation.

● Accident Cost or Savings

The accident savings represent the primary benefit anticipated for a countermeasure. The results of Activity 8 (Predict Accident Reduction Capabilities of Countermeasures) are used to obtain the expected "number of accidents prevented" per year resulting from the countermeasure. This value is used as basic input in the economic analysis.

The accident savings can be expressed in several ways. It can be stated as the expected "number of accidents prevented", as obtained directly from Activity 8. Where feasible, this factor may also be separated by the severity of the accidents (e.g. number of fatal accidents prevented, number of personal injury accidents prevented) or by the number of "equivalent property damage only" accidents.*

A second method of expressing accident savings is the anticipated accident cost savings resulting from the improvement. The number of accidents prevented as obtained from Activity 8 is assigned a cost per accident to develop a total accident cost savings. This results in a dollar value assigned to the expected number of accidents prevented.

This method requires that the "number of accidents prevented" be separated by the severity type and number of persons (or vehicles in PDO accidents only) involved in each severity group. Since available accident costs are typically stated in terms of the fatalities or injuries, the accident savings data must be arranged in this format to be usable. This procedure is performed by defining ratios of the accident data as follows:

$$\frac{\text{No. of persons killed}}{\text{No. of fatality accidents}}$$

$$\frac{\text{No. of persons injured}}{\text{No. of injury accidents}}$$

$$\frac{\text{No. of vehicles involved}}{\text{No. of property damage only accidents}}$$

*Obtained by use of equivalency factors for each accident severity group (i.e., fatal accident = 12, personal injury accident = 3, property damage accident = 1) and accumulating the groups to an EPDO (equivalent property damage only) accident. Source: Transportation and Traffic Engineering Handbook, ITE, (1976) This information is identified from the accident summary data for the study period. Using these ratios and multiplying by the expected number of injury, fatality or PDO accidents prevented, the expected number of injuries or fatalities or damaged vehicles (for PDO accidents) prevented can be defined. Accident costs are applied to these values to determine the savings.

Several sources of accident costs currently used are listed below.

- Individual States.
- National Safety Council (NSC).
- National Highway Traffic Safety Administration (NHTSA)

Many states maintain records on accident costs. These agencies assign a dollar value to accidents that are unique to that particular agency. If a set of cost figures has been adopted by the agency, they should be used in the economic analysis and documented in the economic analysis report.

Accident costs for other sources, shown in Table 71 [1,2], apply to nationwide statistics. Differences exist between the costs developed by these two sources. However, they can be attributed to the different factors used to determine the cost in each source. For example, National Safety Council (NSC) costs include wage losses, medical expenses, insurance, administrative costs, and property damage. National Highway Traffic Safety Administration (NHTSA) includes the calculable costs associated with each fatality and injury plus the cost to society (i.e., consumption losses of individuals and society at large caused by losses in production and the inability to produce). It should be noted that the NHTSA costs are given for 1975. It is necessary to be consistent with the use of cost figures in the economic analysis.

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

- <u>Example</u>

An example of the use of accident cost savings is shown below. Based on the following average annual accident reductions:

- 1.33 fatal accidents (1.00 fatalities/fatal accidents)
- 4.00 injury accidents (1.50 injuries/injury accidents)
- 9.25 property damage only accidents (2.00 vehicles per accident)

the expected number of units saved are determined to be:

Table 71. NSC and NHTSA accident costs.

Source/Accident Severity	Cost Per Involvement (1)
NSC (1979)/ Fatal	$160,000
Nonfatal disabling injury	6,200
Property damage (including minor injuries)	870
	Cost Per Involvement (2)
NHTSA (1975)/ Fatality	$287,175
Critical injury	192,240
Severe injury - life threatening	86,955
Severe injury - not life threatening	8,085
Moderate injury	4,350
Minor injury	2,190
Average injury	3,185
Property damage only	520

(1) Cost per fatality, injury or per PDO accident

(2) Cost per fatality, injury, or per vehicle (for PDO accidents)

Expected "number of killed persons" saved

$$= \frac{1.00 \text{ fatality}}{1.00 \text{ fatal accidents}} \times 1.33 \text{ expected fatal accidents saved}$$

= 1.33 "expected fatalities" saved.

Expected "number of injured persons" saved

$$= \frac{1.50 \text{ injured persons}}{1.00 \text{ injury accidents}} \times 4.00 \text{ expected injury accidents saved}$$

= 6.00 "expected injured persons" saved.

Expected "number of vehicles" (PDO accidents) saved

$$= \frac{2.00 \text{ vehicles}}{1.00 \text{ PDO accidents}} \times 9.25 \text{ expected PDO accidents saved}$$

= 18.50 "expected vehicles" saved.

Using NSC figures (1979), the total accident cost savings would be:

FATALITY: 1.33 "expected fatalities saved" X $\frac{\$160,000}{\text{fatality}}$ = $212,800.00

INJURY: 6.00 "expected injuries saved" X $\frac{\$6200}{\text{injury}}$ = 37,200.00

PDO: 9.25 "expected vehicles saved" X $\frac{\$870}{\text{PDO accident}}$ = 8,047.50

TOTAL = $258,047.50

Using NHTSA figures (1975), the total accident cost savings would be:

FATALITY: 1.33 "expected fatalities saved" X $\frac{\$287,175}{\text{fatality}}$ = $382,900.00

INJURY: 6:00 "expected injuries saved*" X $\frac{\$3,185}{\text{injury}}$ = 19,110.00

PDO: 18.50 "expected vehicles saved" X $\frac{\$520}{\text{vehicle}}$ = 9,620.00

TOTAL = $411,630.00

*Assuming "average injuries"

These values are input into the economic analysis models as benefit factors. A noticeable difference exists between the accident cost savings of the two sources, NSC and NHTSA. Either method, however, can be used. An agency should be consistent with its use of a source, particularly when comparing countermeasures for the same location.

● Initial Implementation Costs

These costs represent the estimated initial cost to implement a countermeasure. They include all costs associated with right-of-way acquisition, construction, site preparation, labor, equipment design, traffic maintenance, and other costs that may be associated with the implementation of the project. The overhead and administrative costs, however, are usually included as a percentage of labor and material costs.

Individual agencies normally maintain a cost estimate file which lists the various materials or construction units and their associated cost per unit of measurement. These files should represent current data and be updated regularly based on recent costs or construction projects. Overhead and administrative costs may differ slightly each year. However, these costs should be monitored to provide more accurate results. A sample cost estimate form is displayed in the Appendix (page I-25).

● Operation and Maintenance Costs

The operation and maintenance (O&M) costs represent the estimated costs to operate and maintain the facility both before and after the implementation of a proposed countermeasure. These costs typically differ due to changes in the highway conditions.

The "before implementation" O&M costs are derived from a review of historical records of costs associated with the location. Typical operation and maintenance cost items include traffic sign upgrading, periodic pavement marking, roadway repairs, power costs of signals, and other site-related items. These costs are usually summarized on an annual basis and averaged over a period of time to represent the average O&M costs. Where a single large maintenance cost is involved, it may be more favorable to defer this cost over a period of years using interest formulas.

The "after implementation" costs are based on the anticipated O&M costs as expected by the safety engineer. These costs are based on the agency's experiences in O&M costs due to changes in the site conditions. The costs are normally given on an annual basis.

● Service Life Of Improvement

The service life of an improvement represents the time period that the improvement can reasonably be expected to affect accident rates [3]. Both costs and benefits are usually calculated for this time period. The expected service life reflects this time period and not necessarily the physical life of the improvement.

Generally, major construction or geometric improvements have a maximum service life of 20 years. The prediction of service life for specific highway improvements can be made reasonably accurately if the agency maintains service life data and survivor curves for various types of improvements and projects.

It is desirable for each highway agency to maintain files to accumulate service life experiences and to develop service life estimation criteria. The procedure for the development of survivor curves for the service life estimations are available in most engineering economy texts. In the absence of service life data, past experience and engineering judgement should be applied for estimating service lives. The evaluator may also wish to use service life estimates generated by other agencies. Table 72 provides estimates of several commonly used service life estimates for safety improvements.

Several States, including California and Iowa, have developed survivor curves. Existing survivor curves may provide a starting point for an agency to determine the expected service life of safety improvements. The service lives of safety improvements such as traffic signs and pavement markings can be estimated from the life expectancy data of the manufacturer and modified by actual field experience. The engineer is encouraged to develop service life data files.

Based on the interest formulas used in the economic analysis of countermeasures, it has been shown that the selected service life can have a profound effect on the economic evaluation of improvement alternatives. For this reason, an accurate account of the expected service life is needed.

● Salvage Value Of Improvement

The salvage value of an improvement represents the cost value of an improvement at the end of its defined service life minus the costs involved in removing, repairing, transferring, or selling a device. For instance, part of a traffic signal will have some worth following its effective life. Similarly, the value of replaced (upgraded) traffic signs will contain some value in either the aluminum blank or the sign post.

Agency maintained histories of safety improvements, service life data, and subsequent usage should provide the basis for estimating the salvage value of a project or an improvement. In the absence of data

Table 72. Sample service life estimates.

SAFETY IMPROVEMENT PROJECT CODES, DESCRIPTIONS, AND SERVICE LIVES USED IN EFFECTIVENESS EVALUATION

Code	Description	Service Life (Years)
	Intersection Projects	
10	Channelization, left-turn bay	10
11	Traffic signals	10
12	Combination of 10 and 11	10
13	Sight distance improved	10
19	Other intersection, except structures	10
	Cross Section Projects	
20	Pavement widening, no lanes added	20
21	Lanes added without new median	20
22	Highway divided, new median added	20
23	Shoulder widening or improvement	20
24	Combination of 20-23	20
25	Skid treatment - grooving	10
26	Skid treatment - overlay	10
27	Flattening, clearing side slopes	20
29	Other cross section or combinations of 20-27	20
	Structures	
30	Widening bridge or major structure	20
31	Replace bridge or major structure	30
32	New bridge or major structure (except 34 and 51)	30
33	Minor structure	20
34	Pedestrian over- or under-crossing	30
39	Other structure	20
	Alignment Projects	
40	Horizontal alignment changes (except 52)	20
41	Vertical alignment changes	20
42	Combination of 40 and 41	20
49	Other alignment	20
	Railroad Grade Crossing Projects	
50	Flashing lights replacing signs	10
51	Elimination by new or reconstructed grade separation	30
52	Elimination by relocation of highway or railroad	30
53	Illumination	10
54	Flashing lights replacing active devices	10
55	Automatic gates replacing signs	10
56	Automatic gates replacing active devices	10
57	Signing, marking	10
58	Crossing surface improvement	10
59	Other RR grade crossing	10
5A	Any combination of 50, 53, 54, 55, 56, 57, 58	10
	Roadside Appurtenances	
60	Traffic signs	6
61	Breakaway sign or luminaire supports	10
62	Road edge guardrail	10
63	Median barrier	15
64	Markings, delineators	2
65	Lighting	15
66	Improve drainage structures	20
67	Fencing	10
68	Impact attenuators	10
69	Other roadside	10
6A	Combination of 60-64	10
6C	Combination of 60 and 62	8
6D	Combination of 60 and 64	4
	Other Safety Improvements	
90	Safety provisions for roadside features and appurtenances	20
99	All projects not otherwise classifiable	20

Source: Manual on Identification, Analysis and Correction of High Accident Location, FHWA, 1976.

files, past experience and literature should be used to estimate the salvage value. Although salvage value is generally considered as a positive cost item, some projects may require an expenditure to remove the residual elements themselves. In these instances, the difference between the cost of removal should be deducted from the value of the scrap or residual elements in estimating the final salvage value. At times, salvage value can be zero or negative.

For most highway safety projects, the salvage values are generally very small, particularly for those with a relatively long service life. They often represent a small difference in the economic analysis whether they are used or not. For many highway safety improvements, a zero salvage value is assumed.

● Current or Expected Interest Rate

An interest rate represents the expected rate of return of funds over the service life of the countermeasure. Stated in other terms, it is the "opportunity cost of capital" [4] or the assumed rate that could be earned by funds if privately invested.

In selecting an interest rate, several viewpoints have been used, which account for the wide range of rates used throughout the United States. These viewpoints include the following.

1. The interest rates should be zero for safety improvements financed from current taxation rather than borrowing.

2. The interest rate should equal the rate for borrowing monies. If the proposed safety improvement is to be financed by borrowing, the interest should correspond to the cost of borrowing money. If the proposed safety improvement is to be financed from existing funds (current taxation), the interest rate should be similar to that for long-term investment.

3. The interest rate should represent the rate of minimum attractive return on invested money. This rate will include the cost of borrowing money and, usually, a safety factor to account for uncertainty in the data used in the economic analysis models.

Current state-of-the-art does not provide a single criterion for the selection of an interest rate except that an agency be consistent in the use of the rate when comparing alternatives and that the rate be documented.

Many agencies adopt interest rates as a matter of policy. However, in some instances the engineer may be required to assume an interest rate. The interest rate should consider:

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

The importance of the interest rate can be shown in the effect of the rate on an improvement. Based on past analyses, it has been shown that low interest rates will generally favor alternatives with large capital investments while high interest rates will tend to favor small capital investment programs. In addition, a low interest rate will place more emphasis on improvement impacts in the future. High interest rates will tend to discount the effect of long-term impacts.

It may be advisable to vary the interest rate to determine the economic effectiveness of the countermeasure. If a countermeasure is found to change from a fiscally effective countermeasure to a marginally effective countermeasure with small changes in interest rates, the evaluator may obtain additional insight as to the true effectiveness of the countermeasure and draw appropriate conclusions in the final analysis of the total countermeasure effectiveness.

These findings should be reviewed prior to selection of an interest rate since the selection of an inappropriate rate could easily result in inappropriate countermeasure costs and benefits.

- Other Factors

Other factors which may be important in the economic analysis include the vehicle delay-related costs, traffic growth rates, and effects of inflation. These factors traditionally produce little effect on the economic analysis findings.

Vehicle delay-related costs represent the expected costs resulting from delay-related impacts. Considerations involved in computing these costs include the number of stops, the length of stops, and the acceleration/deceleration costs associated with each stop. The cost of fuel, wear of tires and brakes, oil, repairs, etc. are higher for stopping and starting than for continuous operation. In addition, the time costs associated with delay represent a negative cost item. It is assumed that this time may be used for more productive purposes.

AASHTO [4] and others [5,6,7] have developed costs based on the additional costs per stop. These costs include the acceleration/deceleration-related costs. Standing delay, obtained from delay studies, is also included. These costs are usually calculated for a 1-year period. Daily totals are summed for a 365-day period based on average daily delay-related factors obtained from the Travel Time and Delay Study Procedure.

Traffic growth rates represent the expected growth rate in traffic volumes. These rates are used in determining the number of accidents prevented and the vehicle delay-related costs. Since road user costs are directly proportional [4] to the estimated ADT, any projected increase in ADT will affect the overall road user and accident costs.

Traffic growth rates may be obtained based on a historical trend of volume data where the safety improvement is not expected to attract a significant change in traffic volumes. Where a significant change may be expected, the use of traffic projection models may be necessary. Many of these models are discussed in transportation planning textbooks and research papers [4,8,11].

The effects of inflation on a safety project may be included to reflect price changes over the life of the project. Although the effects of inflation are difficult to predict, an approximate figure of 2 percent per year [4], compounded, has been used throughout the United States for a long-term rate. Since many safety projects may not be considered "long-term", the use of an inflation rate may not be necessary. In addition, the effect of inflation may be accounted for in the selection of an appropriate interest rate.

- Use of Factors

The above information can be used as input to economic analysis models to assess the effectiveness of proposed safety countermeasures. Their inclusion will be dependent on the means selected to perform the economic analysis. Only those factors needed will be used in the specific economic analysis procedure.

The findings produced by these methods for several countermeasures will consist of a range of values identifying the economic desirability of the countermeasures. The values are used to assess the economic effectiveness of the countermeasures and to rank the countermeasures based on the economic analysis.

To provide a proper comparison for the countermeasures, a single procedure should be used to provide a common and consistent value. The findings obtained from this activity will be used as input to Activity 10 to select a safety project.

The economic analysis will prove to be a particularly valuable tool since it determines not only the effectiveness of a project based on safety objectives but also assesses the economic effectiveness of the countermeasures. This aspect is important since it is possible to have an extremely effective countermeasure in terms of reducing accidents but one which is cost-prohibitive.

Inputs and Outputs of Activity

- **Inputs**

  - List of feasible countermeasures.
  - Accident data.
  - Accident reduction factors.
  - Cost information for project implementation, operation, and maintenance of project.
  - Traffic volume data.
  - Traffic growth rates.
  - Service life of improvements (Optional).
  - Salvage value of improvements (Optional).
  - Current expected interest rate (Optional).
  - Vehicle delay-related costs (Optional).
  - Effects of inflation (Optional).

- **Outputs**

  - Economic feasibility of each countermeasure.
  - Ranked list of feasible countermeasures based on economic analysis results.

Procedure Descriptions

The following procedures are used to determine the economic feasibility of countermeasures.

- Cost-Effectiveness Method (Procedure 1).
- Benefit-to-Cost Ratio Method (Procedure 2).
- Rate-of-Return Method (Procedure 3).
- Time-of-Return Method (Procedure 4).
- Net Annual Benefit Method (Procedure 5).

Major considerations of these procedures are given in Table 73. Following is a detailed description of these procedures.

PROCEDURE 1 Cost-Effectiveness Method

Purpose

The purpose of this procedure is to determine the cost to an agency to prevent a single accident (or "property damage", "injury", "fatal" accident). The cost is measured in terms of the dollar cost to prevent a single accident.

Application

This procedure provides the cost to the agency of preventing a single accident. All costs are valued on a dollar basis. However, expected benefits are not priced but are used to determine the expected cost of reducing the type or total number of accidents. This can only be per-

Table 73. Primary considerations for economic analysis procedures.

Consideration / Procedure	Function	Data Input	Data Obtained	Data Output
1. Cost-Effectiveness Method	. Determines cost-effectivenss of alternatives as a function of cost (dollars) per accident reduced	. Alternative projects . Number of accidents reduced or saved . Project costs . Service life . Salvage value . Interest rate	. Equivalent uniform annual costs . Present worth of cost . Cost per accident reduced	. Cost per accident reduced (or saved) for each alternative
2. Benefit-To-Cost-Ratio Method	. Determines cost-effectiveness of alternatives as a function of ratio identifying benefits derived vs. cost incurred	. Alternative projects . Number of accidents saved . Project costs . Service life . Salvage value . Interest rate	. Dollar worth of accidents saved . Equivalent uniform annual cost and benefits . Present worth or costs and benefits . Ratio of benefit-to-cost	. Benefit-to-cost ratio for each alternative
3. Rate-of-Return Method	. Determines cost-effectiveness of alternatives as a function of "yield" returned by each alternative (by trial-and-error approach)	. Alternative projects . Number of accidents saved . Project costs . Service life . Salvage value	. Dollar values of accidents saved . Annual benefits . Rate-of-return	. Effective rate-of-return for each alternative
4. Time-Of-Return Method	. Determines cost-effectiveness of alternatives as a function of time in which benefits derived will equal the costs incurred	. Alternative projects . Number of accidents reduced or saved . Traffic volume data . Traffic growth rates . Project costs . Interest rate	. Dollar worth of accidents saved or reduced . Total benefits . Annual benefits . Time-of-return	. Time-of-return for each alternative
5. Net Benefit Method	. Determines cost-effectiveness of alternatives as a function of the net annual benefit derived by the improvement	. Alternative projects . Number of accidents saved . Salvage value . Service life . Interest rate	. Dollar value of accidents reduced or saved . Total benefits . Equivalent uniform annual benefits and costs . Net annual benefit	. Net annual benefit of alternatives

formed for one type of accident at a time. For example, the outcome of a cost-effectiveness analysis may indicte that the cost for each expected accident to be reduced is $750. In the same analysis, it can also be concluded that the cost for each expected injury accident to be reduced is $2500.

If the agency conducting the study has neither adopted a set of accident cost figures nor is willing to select established figures, it is recommended that the cost-effectiveness technique be used. Also, if the measure of effectiveness (MOE) of major interest is related to a specific accident type (as opposed to severity), this method may provide a good measure of economic effectiveness.

- Procedure Steps

The following steps are performed [5] in the cost-effectiveness method.

1. Determine the initial estimated cost of implementation of the safety improvement being studied. Typically, such cost data are available from right-of-way (ROW), design and construction files and reports.

2. Determine the net estimated annual operating and maintenance costs. The net annual operating and maintenance cost should reflect the annual difference between the costs incurred before countermeasure implementation and those expected to occur following the implementation of the countermeasure. Therefore, if the countermeasure is expected to result in a low combined annual operating and maintenance cost following the implementation, a negative cost could result. On the other hand, if the after operating and maintenance costs will be greater, the difference is positive.

3. Select the units of effectiveness to be used in the analysis. The desired units of effectiveness may include the following measures.

    a. Expected number of total accidents prevented.
    b. Expected number of accidents by type prevented.
    c. Expected number of fatalities or fatal accidents prevented.
    d. Expected number of personal injuries or personal injury accidents prevented.
    e. Expected number of EPDO accidents prevented.

4. Determine the anticipated annual safety benefits derived from the countermeasure. Safety benefits in this analysis primarily refer to the reduction in the accident frequency associated with each severity MOE. This is the difference between the "before"

frequency and the expected 'after' frequency for each severity MOE. These values were determined in Activity 8.

5. Estimate the anticipated service life of the countermeasure.

6. Estimate the projected salvage value of the countermeasure.

7. Determine the interest rate.

8. Using the information described in items 1, 2, 5, 6, and 7 above, the equivalent uniform annual costs (EUAC) or present worth of costs (PWOC) should be determined. The EUAC is determined from the following equation:

- $EUAC = I\,(CR^{i}_{n}) + K - T\,(SF^{i}_{n})$

Where:

EUAC = equivalent uniform annual cost ($).

I = estimated initial cost of the project ($).

i = assumed interest rate (%).

n = estimated service life of the countermeasure (years).

T = net estimated salvage value ($).

K = net estimated uniform annual cost of operating and maintaining the improvement ($/year).

CR^{i}_{n} = capital recovery factor for n years at interest rate, i.

SF^{i}_{n} = sinking fund factor for n years at interest rate, i.

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

$$CR^{i}_{n} = (i(1+i)^{n})/(i+1)^{n} -1$$

The sinking fund factor may be found in the compound interest tables provided in Appendix G or it may be calculated as follows:

$SF_n^i = CR_n^i - i$

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

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

Where:

PWOC = present worth of costs ($).

I = estimated initial cost of the project ($).

i = assumed interest rate (%).

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

T = estimated net salvage value ($).

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

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

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

9. Calculate the expected average annual benefit, $\bar{B}$, in the desired units of effectiveness.

10. Calculate the C/E value using one of the following equations:

- $C/E = EUAC/\bar{B}$

or

- $C/E = PWOC\,(CR_n^i)/\bar{B}$

Where:

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

(This changes the PWOC to an annualized cost for compatibility with $\overline{B}$.)

This procedure is not applicable for multiple improvements with unequal service lives. A C/E worksheet is provided in the Appendix (page I-26).

Advantages:

1. Does not require assigning a dollar value to human life or injury.
2. Is able to consider the optimization of benefits on a systemwide basis.

Disadvantages:

1. May be difficult to determine when a project is justified.
2. Difficult to evaluate the effects of multiple improvements.

This procedure is generally applicable to agencies which do not wish to directly assign dollar values to human injuries and fatalities. It can be applied using either manual or computer techniques.

- Example

A highway safety countermeasure to provide increased lighting levels at an urban intersection with a high level of night accident occurrence is proposed. The following summary shows estimated initial implementation costs, net estimated operating and maintenance costs, and anticipated annual benefits. The expected annual benefits were obtained by subtracting the expected 3-year accident frequency for the after period with the countermeasures from the expected 3-year after accident frequency without the countermeasure and annualizing the difference. They are expressed as annual savings in injury accidents. The service life of the countermeasure is estimated at 15 years with a salvage value of 10 percent of the initial cost.

Initial Construction Costs	Net Operating and Maintenance Costs			Benefits (Injury Accidents Prevented)		
	1974	1975	1976	1974	1975	1976
$40,000	$1,000	$1,000	$1,000	8	7	6

An interest rate of 10 percent is used in the analysis. The cost-effectiveness calculations are shown in Figure 57.

C/E ANALYSIS WORKSHEET

Evaluation No: 1

Project No: 1

Date/Evaluator: 9/20/80 (MAF)

1. Initial Implementation Cost, I: $ 40,000

2. Annual Operating and Maintenance Costs Before Project Implementation: $ 0

3. Annual Operating and Maintenance Costs After Project Implementation: $ 1,000

4. Net Annual Operating and Maintenance Costs, K (3-2): $ 1,000

5. Annual Safety Benefits in Number of Accidents Prevented, $\bar{B}$: 7.0

Accident Type		Expected Annual Benefit
Injury	(1974)	8
	(1975)	7
	(1976)	6
Total		
		= 21/3 = 7.0

6. Service Life, N: 15 yrs

7. Salvage Value, T: $ 4,000

8. Interest Rate: 10 % = 0.10

9. EUAC Calculation:

CR_n^i = 0.1315

SF_n^i = 0.0315

EUAC = I (CR_n^i) + K − T (SF_n^i)

$40,000 (0.1315) + $1,000 − $4,000 (0.0315)

= $6,134

10. Annual Benefits:

$\bar{B}$ (from 5) = 7.0 Injury accidents prevented per year

11. C/E = EUAC/$\bar{B}$ = $6,134/7.0 = $875/Injury accident saved

12. PWOC Calculation:

PW_n^i = 0.2394

SPW_n^i = 7.606

PWOC = I + K (SPW_n^i) − T (PW_n^i) = $40,000 + (7.606) $1,000 −$4,000 (0.2394) = $46,648.40

13. Annual Benefit

n (from 6) = 15 yrs.

$\bar{B}$ (from 5) = 7.0 accidents prevented per year

14. C/E = PWOC (CR_n^i)/B = $46,648.40 (0.1315)/7.0 = $6,134/7.0 = $875/injury accident saved

Figure 57. Cost-effectiveness method - example.

A cost-effectiveness (C/E) value of $875/injury accident saved was derived. The results of this analysis may be interpreted by comparing this C/E value with those from other competing highway safety countermeasures.

PROCEDURE 2 Benefit-To-Cost Ratio Method

Purpose

The purpose of this procedure is to determine the ratio of expected benefits accrued to the costs incurred for a countermeasure. The ratio is measured in terms of a numerical value (ratio) comparing the expected benefits to be achieved at an estimated cost.

Application

The benefit/cost ratio is the ratio of the expected benefits accrued from an accident and/or severity reduction resulting from a countermeasure to the costs needed to implement the countermeasure. The method requires that a dollar value be placed on all estimated costs and expected benefits related to the countermeasure. Any countermeasure that has a benefit/cost ratio greater than 1.0 is considered economically successful.

The selection of a dollar value for the expected benefits must be made by the evaluator in order to use the technique. These values should be documented in the analysis. If the agency conducting the analysis has adopted a set of cost figures for highway fatalities, injuries, and property damage accidents, the benefit/cost analysis technique is recommended. Also, if the MOE of major interest is related to accident severity, the benefit/cost method may provide a good measure of economic effectiveness.

The benefit/cost method may be performed for either an individual countermeasure or one consisting of several improvements.

● Procedure Steps

The benefit/cost method requires the following steps be performed. [5]

1. Determine the estimated initial cost of design, construction, right-of-way, and other costs associated with countermeasure implementation.

2. Determine the annual estimated operating and maintenance cost for the countermeasure.

3. Determine the annual safety benefits derived from the countermeasure. Safety benefits in this analysis refer to the anticipated reduction in the accident frequency, using AR factors, associated with each severity MOE.

Many economic analyses consider the difference in road user costs as a highway safety benefit. Since the basic purpose of this analysis is to evaluate proposed highway safety countermeasures, the road user cost may be used.

4. Assign a dollar value to each expected safety benefit unit.

5. Estimate the predicted service life.

6. Estimate the projected net salvage value.

7. Assume an interest rate.

8. Calculate the B/C ratio using equivalent uniform annual (estimated) costs and (expected) benefits. The use of these economic parameters provides the evaluator with the first of two alternatives for obtaining a B/C ratio for the analysis of highway safety countermeasures. This formulation of the B/C ratio can be used when the expected service lives of individual countermeasures within a single countermeasure are equal or unequal.

   The EUAC is described in Step 8 of Procedure 1.

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

$$EUAB = \overline{B}$$

   Where:

   EUAB = expected equivalent uniform annual benefit ($).

   $\overline{B}$ = anticipated uniform annual benefit derived from the countermeasure throughout its service life. This estimate is based on the expected annualized savings in various severity categories times the appropriate accident cost values ($/year).

   The B/C ratio for a countermeasure can be calculated using the following formula.

   - B/C = EUAB/EUAC

   An alternate means to calculate the B/C ratio uses the present worth of costs and benefits. The use of these parameters provides an alternative for obtaining the B/C ratio for analysis of highway safety countermeasures. However, this approach of calculating B/C cannot be used for projects having multiple improvements with unequal service lives.

The PWOC is calculated as described in Step 8 of Procedure 1.

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

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

Where:

PWOB = expected present worth of benefits ($).

$\overline{B}$ = anticipated uniform annual benefit derived from the countermeasure or improvement throughout its anticipated service life ($/year).

n = predicted service life of the countermeasure (years).

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

The B/C ratio for a countermeasure can be calculated with this approach using the following formula.

- B/C = PWOB/PWOC.

The B/C worksheet is included in the Appendix (page I-27).

This method can also be applied on an incremental basis to determine the expected advantages resulting from adding improvements to a countermeasure. If the added improvement results in an increase of the B/C ratio, it can be concluded that the added improvement is favorable.

Advantages:

1. Provides a straight-forward, traditional method for performing economic evaluations.
2. Useful for situations where accident severity is the most important measure of effectiveness.
3. Can consider the optimization of expected benefits on a systemwide basis.

B/C ANALYSIS WORKSHEET

Evaluation No: 1

Project No: 2

Date/Evaluator: 9-20-80 (MAF)

1. Initial Implementation Cost, I: $ 200,000
2. Annual Operating and Maintenance Costs Before Project Implementation: $ 4,500
3. Annual Operating and Maintenance Cost After Project Implementation: $ 4,500
4. Net Annual Operating and Maintenance Costs, K (3-2): $ - 0 -
5. Annual Safety Benefits in Number of Accidents Prevented:

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

6. Accident Cost Values (Source NHTSA):

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

7. Annual Safety Benefits in Dollars Saved, $\bar{B}$: $45,000

5a) x 6a) =

5b) x 6b) = ($40,000 + $45,000 + $50,000)/3

5c) x 6c) =

Total = $ 45,000

8. Services life, n: 10 yrs
9. Salvage Value, T: $ 0
10. Interest Rate, i: 10 % = 0.10

11. EUAC Calculation:

CR_n^i = 0.16275

SF_n^i = 0.06275

EUAC = I (CR_n^i) + K − T (SF_n^i) = $200,000 (0.16275) + 0 − 0 (0.06275) = $32,550

12. EUAB Calculation:

EUAB = $\bar{B}$

= $45,000

13. B/C = EUAB/EUAC = $45,000/$32,550 = 1.38

14. PWOC Calculation:

PW_n^i = 0.3855

SPW_n^i = 6.1466

PWOC = I + K (SPW_n^i) − T (PW_n^i) = $200,000 + 0 (6.1466) − 0 (0.3855) = $200,000

15. PWOB Calculation:

PWOB = $\bar{B}(SPW_n^i)$ = $45,000 (6.1466) = $276,507

16. B/C = PWOB/PWOC = $276507/$200,000 = 1.38

Figure 58. Benefit-to-cost ratio method - example.

Disadvantages:

1. Results are often affected considerably by the accident cost values (NSC, NHTSA, or States' costs) selected, particularly when fatal accidents are being considered.
2. Relies on the placement of a dollar value on a human life.

This procedure is favorable for all highway systems, in particular, agencies which have no objection to the placement of a dollar value on human injuries or fatalities. The benefit/cost method may be applied using either manual or computer techniques.

● Example

In an effort to reduce the number of rear-end collisions due to skidding of vehicles during wet-weather conditions, a highway agency is planning to undertake a safety project of skid-proofing a 1/2-mile roadway section by constructing a texturized pavement section at an estimated cost of $200,000. The estimated service life of the project is estimated at 10 years with a zero salvage value. The average estimated annual maintenance cost of the grooved pavement is essentially zero. The highway department estimates the dollar benefits of the countermeasure in terms of injuries prevented as $40,000, $45,000 and $50,000 for the 3 years following the implementation of the countermeasure.

An interest rate of 10 percent is assumed. The B/C calculations are shown in Figure 58.

When the B/C ratio is greater than unity, the benefits derived from the project outweigh the incurred costs. In this particular case, the B/C ratio is 1.38. The project is considered a desirable alternative.

The B/C ratio should be compared with competing highway safety countermeasures to determine the most favorable alternative.

PROCEDURE 3 Rate-Of-Return Method

Purpose

The purpose of this procedure is to determine the rate of return of benefits expected to be obtained by an improvement. The rate of return is a measure of the expected "yield" or effective return of a safety countermeasure.

Application

This technique computes an estimated interest rate for a safety countermeasure at which the estimated net present annual worth of the countermeasure minus the estimated improvement cost is equal to zero. In this case the net present annual worth of the countermeasure is the expected dollar value of safety benefits in terms of accidents prevented. The estimated improvement costs include those expected costs required for implementation and maintenance of the countermeasure.

This method is based on the two assumptions listed below [4].

- The relative merit of an improvement is measured by the interest rate that sets the expected benefits equal to zero.

- The estimated costs and expected benefits remain constant each year.

Based on these assumptions, an estimated interest rate is determined. It is considered as the "yield" of a possible investment. When a number of countermeasures are considered for implementation, the project with the highest "yield" is considered to be the most desirable, subject to its meeting a minimum attractive rate of return.

- <u>Procedure Steps</u>

Steps for using the rate of return method are listed below.

1. Determine the estimated initial implementation costs.

2. Determine the estimated annual operating and maintenance cost for the countermeasure.

3. Estimate the expected service life.

4. Estimate the expected net salvage value.

5. Estimate the expected benefits for each improvement as in Steps 3 and 4 of the Benefit-To-Cost Ratio Method.

6. Calculate the estimated internal rate-of-return (ROR), on a trial-and-error basis that sets either of the following formulas equal to zero:

- $I = (B-K)\ SPW_n^i - (T)\ PW_n^i$ ... (A) or

- $\frac{B-K}{I} = CR_n^i$ ....(B)

Where:

i = estimated rate of return (ROR).

I = estimated initial countermeasure implementation costs.

B = expected annual benefits.

K = estimated annual O&M costs.

SPW_n^i = series present worth factor for n years at interest rate i.

T = estimated net salvage.

PW_n^i = present worth factor for n year at interest rate i.

n = predicted service life of improvement.

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

Equation B is used for safety improvements with no terminal value or a perpetual service life. This formula can also be used in the iterative process to identify a starting rate of return in the trial-and-error process.

The use of this technique in analyzing highway safety countermeasures has been infrequent primarily because of the "trial-and-error" type of approach needed to calculate the estimated "yield" if manual techniques are used. The technique, however, lends itself to convenient solution when a computerized procedure is used by initiating an automatic search process as a part of the software. A mathematical algorithm may be formulated with the objective of "converging" to the required solution when specific "bounds" of the solution are defined in order to minimize the searching effort. The technique is based upon sound economic theory and derives its primary merit from the fact that a pre-specified interest rate is not to be assumed as part of the analysis. Instead of working with figures that are based upon an assumed interest rate, the interest rate itself is the "unknown" quantity.

Advantages:

1. Does not rely on an assumed interest rate.
2. Able to consider the optimization of benefits on a systemwide basis.

Disadvantages:

1. Must be performed on an iterative, i.e.; "trial-and-error" basis. This can be very time consuming, particularly for manual methods.
2. Results may be difficult to interpret.

This procedure is generally applicable for agencies with no objection to assigning dollar values to human lives and whose primary objective is to insure selection of the most appropriate countermeasure on a location-by-location basis.

● Example

For the previous problem of skidding accidents, the following anticipated values are used:

I = $200,000 (estimated initial cost).
K = $0 (estimated O&M costs).
T = $0 (estimated salvage value).
n = 10 years (estimated service life).
B = ($40,000 + $45,000 + $50,000)/3 = $45,000 (expected net benefit).

The estimated rate of return, "i," is found from the following formula by a trial-and-error method.

$$I = (B-K)\ SPW^{i}_{n} - (T)\ PW^{i}_{n}$$

$$\$200,000 = (\$45,000-\$0)\ SPW^{i}_{10} - (\$0)\ PW^{i}_{10}$$

$$\$200,000 = (\$45,000)\ SPW^{i}_{10}$$

$$SPW^{i}_{10} = \frac{\$200,000}{\$45,000} = 4.44$$

A review of interest tables for the series present worth factor of 4.44 with a 10-year estimated service life yields the following results.

$$SPW^{15}_{10} = 5.019$$

$$SPW^{20}_{10} = 4.192$$

Linear interpolation results in an estimated rate-of-return of 16.5 percent. This rate-of-return may represent a favorable return. The ROR value is compared with competing highway safety countermeasures to select a project.

PROCEDURE 4 - Time-Of-Return Method

Purpose

The purpose of this procedure is to determine the estimated time period in which the expected benefits anticipated by a countermeasure begin to exceed the estimated overall costs. A low time of return may signify a favorable countermeasure.

Application

In the time-of-return (TOR) method, expected accident reductions and resulting benefits are forecast as in the other economic methods. An expected TOR value is computed by dividing the estimated cost of the countermeasure by the estimated annual benefit. Interest rates and salvage values are not considered in the analysis, and service lives of all projects are not taken into account. Countermeasures with the lowest TOR values are considered to be the best.

● Procedure Steps

The following steps should be carried out in this procedure:

1. Determine the accident types to be affected by the countermeasure.

2. Estimate the reduction in each accident type, as in Activity 8. This estimate should be performed for a defined period of time; e.g., 2 years. This period should not be set such that improvements will not begin to require replacement. A 1- or 2-year period is normally selected.

3. Estimate the expected traffic growth rates for the defined period.

4. Determine the estimated total costs (initial Operations and Maintenance costs) of the countermeasure for the defined period.

5. Determine the estimated total benefits (dollars) derived by the countermeasure based on the number of years of data analyzed.

6. Compute the expected annual benefit by dividing the expected benefits (dollars) by the defined period.

7. Compute the estimated time-of-return by dividing the expected annual benefits by the estimated annual costs.

A sample worksheet for the time-of-return method is included in the Appendix (page I-28).

Advantages:

1. Results directly in the estimated amount of time required for a given countermeasure to pay for itself.
2. Can consider the optimization of expected benefits on a systemwide basis.

Disadvantages

1. A time measure is often misleading or difficult to interpret. For example, a time of return of 5 years may be considered very good for a highway reconstruction countermeasure which has a 20-year service life, but not desirable for a pavement striping countermeasure with a service life of less than 2 years.
2. Does not normally account for estimated interest rates, estimated service lives of all projects, or estimated salvage values which may affect an economic analysis.
3. May not consider the optimization of expected benefits for each individual location.

This procedure is generally applicable for agencies with no objection to the placement of dollar values on human lives or agencies who wish to compare countermeasures based on the time in which they will pay for themselves in terms of expected accident savings.

● Example

The accident occurrence at an urban signalized intersection is expected to have the following accident reduction characteristics as based on a states individual statistics.

Period	Accident Types		
	Driveway Related	Rear End	Opposing Left-Turn
1977	14 acc. 7PD 7INJ	16 acc. 10PD 6INJ	12 acc. 5PD 7INJ
1978	10 acc. 9PD 1INJ	18 acc. 13PD 5INJ	14 acc. 6PD 8INJ
TOTAL	24 acc. 16PD 8INJ	34 acc. 23PD 11INJ	26 acc. 11PD 15INJ

Estimated Accident Reduction By Accident Type

Driveway-Related 50% Red.	Rear-End 10% Red.	Opposing Left-Turn 25% Red.
12 acc. 8PD 4INJ (6PI)	3 acc. 2PD 1INJ (2PI)	7 acc. 3PD 4INJ (6PI)

COMPUTED BENEFITS DERIVED THROUGH ACCIDENT REDUCTION

Location 10 Mile & Foster Rd. City/Twp. Sussex County Milan

The method of evaluating accident costs, used below, is given on page 67 of Roy Jorgensen's report of Highway Safety Improvement Criteria, 1966 edition. This same method is given in the Bureau of Public Roads IM21-3-67.

In the following analysis the costs provided by the National Safety Council are: 1979 values

Death - $160,000

Nonfatal Injury - $6200

Property Damage Accident - $870

$$B = \frac{ADT_a}{ADT_b} \times (Q\, R_1 + 870\, R_2)$$

where

B = benefit in dollars

ADT_a = Average traffic volume after the improvement 72,600

ADT_b = Average traffic volume before the improvement 66,000

R_1 = Reduction in fatalities and injuries combined 14

R_2 = Reduction in property damage accidents 13

Q = 5500 if no fatal accidents occurred, and

$$Q = \frac{160{,}000 + (I/F \times 6{,}200)}{1 + I/F} = 7{,}001 \text{ if at least 1 fatality occurred.}$$

where

I/F = Ratio of injuries to fatalities that occurred statewide during the year 1979

$$= \frac{166{,}389}{1{,}950} = 85.3$$

Time of Return (T.O.R.) based on 2 years of data.

2 yrs. B= 1.1 [(5500 or 7001) 14 + (800) 13]

2 yrs. B= 1.1 [(86,800) + (11,310)] = $107,920

Annual B= $53,960 dollars

C= Total cost of project

$$T.O.R. = \frac{C}{B} = \frac{20{,}715}{53{,}960} = 0.38 \text{ years} = 4.61 \text{ Months}$$

Location 10 Mile and Foster Rd.

City/Twp. Sussex County Milan

Control Section SII #

Type of Improvement Driveway reconstruction, driveway signing, upgrade signals, pavement markings

PERIOD	ACCIDENT TYPES							
	Driveway related (A)		Rear-end (B)		Opposing left-turn			
1977	14	7 PD / Injd 7	16	10 PD / Injd 6	12	5 PD / Injd 7		PD / Injd
1978	10	9 / 1	18	13 / 5	14	6 / 8		
TOTALS	24	16 / 8	34	23 / 11	26	11 / 15		

Estimated Accident Reduction	50 % Red.		10 % Red.		25 % Red.		% Red.	
	12	8 / 4(6)	3	2 / 1(2)	7	3 / 4(6)		

Remarks

A- Includes only those accidents at driveways where improvements are proposed. Includes left-turn out of driveways, and rear-ends, sideswipes, and angles caused by right turns into or out of the driveways.

B- Includes only those accidents on the approaches (not driveway-related).

Estimated Project Cost $20,715

Anticipated Annual Benefit $53,960

Project Amortization (T.O.R.) 0.38 years

Figure 59. Time of return method - example.

The estimated initial implementation costs are:

Upgrade Signal Heads	$ 3,860.00
Pavement Markings	$ 255.00
Driveway Signing	$ 1,600.00
Driveway Reconstruction	$15,000.00

ADT volumes before and after (estimated) the improvements are 66,000 and 72,600, respectively.

The time-of-return (TOR) calculations are shown in Figure 59.

The time-of-return method yields an expected pay-off period of 0.38 years for the proposed countermeasure. This value is very good for any countermeasure. A comparison of this countermeasure to other competing countermeasures should be made to select a single project.

PROCEDURE 5 Net Benefit Method

Purpose

The purpose of this procedure is to determine the expected net benefits to be derived by a countermeasure. The net benefit is obtained by subtracting the estimated annual costs from the expected annual benefits.

Application

This procedure is based on the premise that the relative merit of a countermeasure is measured by its expected net annual benefit. The expected net annual benefit of a countermeasure is defined as [4].

- Net Annual Benefit = (EUAB)-(EUAC)

where:

- EUAB = Equivalent Uniform Annual Benefit
- EUAC = Equivalent Uniform Annual Cost

A positive value for the expected Net Annual Benefit indicates a feasible countermeasure. The countermeasure with the largest positive expected Net Annual Benefit is considered to be the best alternative.

- Procedure Steps

The following steps should be used to compute the expected Net Annual Benefit of a countermeasure:

1. Determine the estimated initial implementation costs, estimated annual Operation & Maintenance costs, predicted net

salvage value, and estimated service life of the countermeasure.

2. Estimate the expected benefits (in dollars) for the countermeasure.

3. Select an estimated interest rate.

4. Compute the expected Equivalent Uniform Annual Benefit, EUAB, as in Step 8 of the Benefit-to-Cost Ratio Method.

5. Compute the estimated Equivalent Uniform Annual Cost, EUAC, as in Step 8 of the Benefit-to-Cost Ratio Method.

6. Calculate the expected Net Annual Benefit of the countermeasure by subtracting the estimated EUAC from the expected EUAB.

A sample data sheet is shown in Figure I-29.

This method is used to select countermeasures that will insure maximum total benefits at each location. As an example, suppose location A is being considered for improvement. The alternative improvements with the corresponding B/C ratio and expected net benefit values are given in the following table:

Comparison of Net Benefit to B/C Ratio

Alternative	B/C	Net Benefit
1. Sign and Stripe	12.0	10,000
2. Pavement Overlay	7.0	20,000
3. Overlay, Sign and Stripe	5.0	25,000
4. Reconstruction	2.0	200,000

Using the Benefit/Cost Ratio methods, Alternative 1 would be selected, while the Net Annual Benefit method would result in the selection of Alternative 4. The benefit-to-cost ratio will allow for the selection of several low-cost alternative improvements which may enhance project selection on a systemwide basis. However, these improvements may not offer the optimum benefits for each individual location. On the other hand, the net benefit method results in the selection of countermeasures that generally offer the greatest safety benefits at each location. These alternatives are often high-cost improvements which may not be optimal on a systemwide basis. An agency should, therefore, be aware of both the expected net benefits and also the benefit-to-cost ratio (or cost-effectiveness, rate-of-return, etc.) for each countermeasure under consideration.

Advantages:

1. Relative ease of calculation.
2. Applicable when the selection of one alternative precludes the selection of another alternative at the same time.
3. Considers the optimization of benefits for each individual location.

Disadvantages:

1. Requires the placement of a dollar value on a human life.
2. Does not consider the optimization of benefits on a systemwide basis.

This procedure is generally applicable for agencies with no objection to assigning dollar values to human lives and agencies whose primary objective is to ensure selection of the most appropriate countermeasures on a location by location basis.

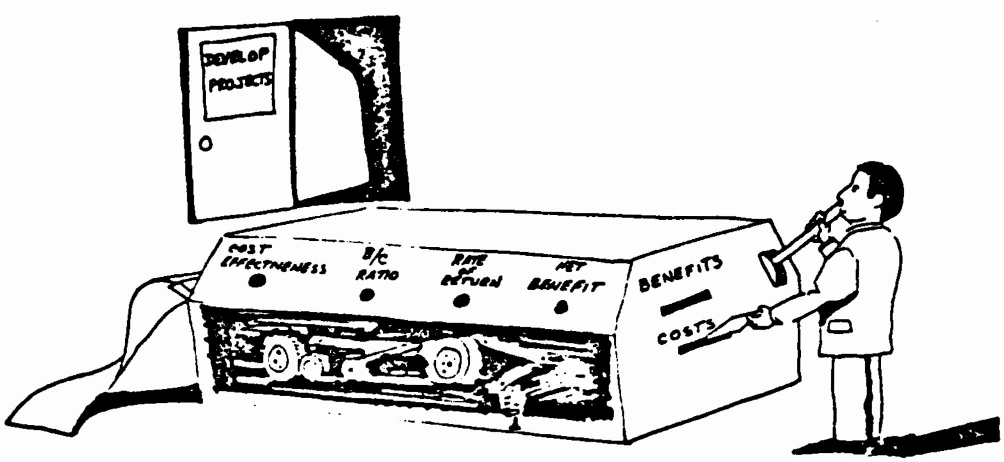
● Example

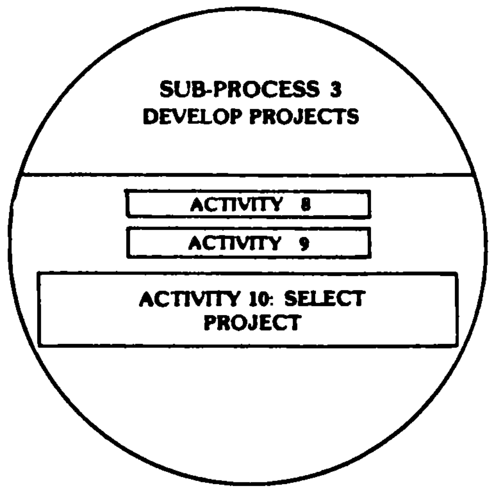
Using the sample problem from the cost-effectiveness procedure, the following estimated values were obtained from Figure 57.

EUAC = $32,550
EUAB = $45,000

The expected Net Annual Benefit = (EUAB - (EUAC)
= $45,000 - $32,550
= $12,450

This value may represent a favorable benefit. It requires comparison to other competing countermeasures to determine its selection for this location.





ACTIVITY 10: SELECT PROJECT

Purpose

The purpose of this activity is to select a safety countermeasure for a hazardous location based on the results of an economic analysis and other considerations.

Overview

The selection of a safety project for a site is the primary output of Process 3 ("Conduct Engineering Studies") of the Planning Component of the HSIP. Based on a comprehensive study of the hazardous location and the detailed review of the feasible countermeasures, a single safety project is selected.

In order to select and implement the most favorable project to enhance safety at a location, it is necessary that all important factors be considered. These factors will include both economic and non-economic considerations. A list of factors which may need to be considered include:

- Economic analysis results.
- Effect on safety.
- Effect on highway capacity.
- Effect on air and noise pollution.
- Effect on area surroundings.
- Energy conservation.
- Possible implementation period.
- Citizen opposition.

- Available funding sources.
- Budget limitations.

The factors used in the selection process are chosen based on their relevance to the study area. Not all factors may be important in the selection of alternatives.

- Description of Factors

Economic Analysis

Primary to the selection of a safety project are the economic analysis findings determined as an output of Activity 9. This analysis will provide a measure of the economic attractiveness of an investment for a countermeasure. The analysis basically determines whether a feasible countermeasure is expected to provide significant benefits to warrant implementation. In some cases, the selection of a countermeasure is based solely on the economic analysis results. Other factors such as those described below, however, should be included in the selection process.

Effect on Safety

In many cases, the effect a countermeasure may have on the overall safety at a location is taken into account in the economic analysis. However, other considerations are included in the economic analysis which may reduce the impact of the safety considerations (the Net Benefit Method may be an exception). Therefore, the overall impact of the countermeasures on the anticipated safety improvements may be considered.

Effect on Highway Capacity

In many cases, a safety improvement at a location will result in a change in the available capacity of a facility. For instance, the addition of an exclusive left-turn lane will increase the available capacity, while implementing a left-turn phase at a signalized intersection may decrease the total intersection capacity. These impacts may be critical in future years. Any possible impacts should be noted and documented.

Effect on Air and Noise Pollution

Many agencies have developed or are currently developing general estimates for the anticipated impacts of air and/or noise pollution related to a roadway improvement. Where these sources are unavailable, NCHRP 133 [1] can be used to determine the anticipated effect of the improvements on air and/or noise pollution in the area. These possible impacts should be recorded and documented.

● Effect on Area Surroundings

In some cases, the possible impact on an area following a safety improvement may result in increased land values and increased employment opportunities. An example may include the construction of a two-way exclusive left-turn lane along a strip commercial area. By making the area more accessible, it may become more attractive, thereby increasing its value to its owners. Where they occur, these impacts should be considered.

● Energy Conservation

Where countermeasures are such that vehicle delay is reduced, an improvement to energy conservation efforts results. Energy considerations being a major concern as they are today, energy conservation efforts may be a factor in the selection of a countermeasure.

● Possible Implementation Period

The implementation period is the time from the initial approval for construction or implementation of a countermeasure to the completion of the project in the manner in which it was designed. The time period may represent a key factor in the selection of a countermeasure. For instance, a high number of recurring accidents at a location may require that immediate attention be given to the location. If a long implementation period is required, an alternative improvement with a shorter implementation period (with reasonably similar benefits and cost-effectiveness) may be selected, or interim measures (short-range projects) may need to be implemented. These effects may need to be documented and used as a factor in the selection process.

● Citizen Involvement

Citizen opposition represents an important factor in the selection of countermeasures. Since the agency recommending an improvement is a representative of the public, input received from the public should be reviewed with interest. Although it is not always feasible or necessary to plan safety countermeasures based on public opinion or sentiment, the views received may provide valuable input in the selection process. They may also serve as criteria in the planning or implementation of similar future safety projects.

● Available Funding Sources

Based on the recent Highway Safety Act of 1966, funding is available for many safety projects. The Federal share of costs typically ranges from 75 to 100 percent. In addition, Federal Aid-Urban and other funds can be used to implement a safety project. Applicability and availability of these funds should be checked. A list and description of various funding sources is included in Appendix H.

The importance of these funds can be envisioned based on consideration of the cost of certain countermeasures. Limited local budget resources might restrict certain safety improvements. This assistance, primarily in the Highway Safety Act funds, has resulted in significant improvements in safety practices throughout the United States [2].

● Budget Limitations

Limited local agency budgets will restrict the selection of certain countermeasures. The extent that a countermeasure will detract from the budget and the implementation of other programs in its place should be noted.

● Selection Methods

Two methods are primarily used to select a project. In the first method, each selected factor is subjectively reviewed and the impact of each countermeasure is determined. For instance, it may be determined that each countermeasure has little or no effect on roadway capacity. However, another alternative may be anticipated to create significant public opposition. A third alternative may have prohibitive costs. These impacts and the countermeasures are judged against one another with the individual evaluators selecting the most desirable countermeasure. In this approach, the economic analysis findings are usually a prime consideration in the countermeasure selection.

A second method provides a quantitative means of selecting alternatives. The method is expressed in the following equation.

$$RI = \sum_{i}^{j} W_i L_i$$

where RI = rating index.

W = weighted value for factors "i".

L = level of impact of factor "i".

i = 1,2,3,...j; factors.

The rating index (RI) of each countermeasure evaluates the countermeasures based on a weighted rating of the selected factors as they impact the countermeasure. A higher RI value will result in a more desirable countermeasure. This value should not, however, be used to select the implementation of projects on an areawide basis.

In assigning weights to the factors, the economic analysis factor typically receives the largest weight. Other weights are assigned accordingly based on an agency's objectives in the study of the site. The sum total of weights should equal 100 percent.

The impact level refers to the impact of a countermeasure on the selected factors. The impacts are reviewed against a scale to determine its level of impact. Various schemes have been used to rate the level of application.

A suggested scale is given below.

0 - undesirable or not feasible.
1 - major negative impact (not desirable).
2 - moderate negative impact (less desirable).
3 - minor negative impact (desirable).
4 - very little negative impact (very desirable).
5 - no negative impact (highly desirable).

In selecting a scale, the key criterion is that an agency be consistent in its use of the scale, particularly when assessing countermeasures for the same location.

It should be noted that both countermeasure selection approaches can be performed by a single individual or a study team. The team approach may be favorable since it can be used to obtain viewpoints from varying disciplines. However, in the team approach, all team members should be fully aware of the study objectives and should be oriented to providing a team solution.

● <u>Other Considerations</u>

When a countermeasure is being planned for input onto an implementation schedule, several factors need to be considered.

1. Although the economic analysis results and other input data will identify a favorable countermeasure for a location, systemwide planning by an agency may result in the countermeasure being implemented several years in the future. In this case, interim measures (short-range improvements) may need to be implemented to provide immediate relief for some of the safety problems. These interim measures should be included in the overall programming schedule since they typically require additional funds above the regular maintenance and operations funds.

2. Where federal funding of a project is anticipated or planned, interim measures may be planned for the period until funds are made available. A lapse of several years may occur between initial application for funding and final approval. During this period, interim improvements to relieve immediate safety concerns may be necessary.

Table 74. Rating indices of countermeasures.

Countermeasure / Input Item	A			B			C		
	(1) Wt.	(2) Level	(1) x (2)	(1) Wt.	(2) Level	(1) x (2)	(1) Wt.	(2) Level	(1) x (2)
1. Economic Analysis Findings	0.40	4	1.60	0.40	5	2.00	0.40	2	0.80
2. Effects on Capacity	0.10	2	0.20	0.10	4	0.40	0.10	2	0.20
3. Effects On Air and Noise Pollution	0.10	1	0.10	0.10	4	0.40	0.10	3	0.30
4. Available Funding Sources	0.20	3	0.60	0.20	3	0.60	0.20	5	1.00
5. Budget Limitations	0.20	3	0.60	0.20	4	0.80	0.20	1	0.20
TOTAL	1.00	-	3.10	1.00	-	4.20	1.00	-	2.50

3. For a project planned for implementation "x" years in the future, continued monitoring of the location should be made to assure that the planned improvements will be applicable at the time of implementation. Changing conditions may have altered the problem or an interim measure may have been implemented and resolved the safety problem. In both cases, the planned improvement will not be necessary as in its original form.

Consideration of these factors can result in improved safety during the interim period prior to project implementation. The result will be more favorable safety conditions at the location.

● Example

An example of the index method is shown for a signalized intersection. Three countermeasures are being studied for consideration in selecting a single safety project. The selected and assumed weights are:

- Economic Analysis Findings - 40%
- Effects on Capacity - 10%
- Effects on Air and Noise Pollution - 10%
- Available Funding Sources - 20%
- Budget Limitations - 20%

The impact level of the factors and the resulting rating indices (RI's) are shown in Table 74. Based on the findings shown in the table, Alternative "B", with an RI value of 4.20, should be selected for implementation.

Findings

The findings of this activity will result in the selection of a safety project for the hazardous location. The project should meet the objectives developed at the outset of the safety study and be economically feasible. The selected project will serve as input to the programming of projects for implementation.

Inputs and Outputs of Activity

● Inputs

- Economic analysis of alternatives.
- Other input factors.

● Outputs

- Selected project for a location.
- Interim measures.

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APPENDIX B. GLOSSARY OF TERMS

AASHTO - American Association of State Highway and Transportation Officials

ACCIDENT - Any unplanned event that results in injury, property damage, or loss.

ACCIDENT-BASED EVALUATION - The assessment of a Highway Safety Project or program in terms of the extent to which the number and severity of accidents are reduced.

ACCIDENT-BASED PROCEDURES - The study procedures used to analyze the accident activity or pattern at a location.

ACCIDENT CAUSALITY CHAIN - The chain of events (major causal factor - major contributor factor - safety problem) which lead to accident experience or accident potential.

ACCIDENT COSTS - The dollar value of an accident relating the costs of the number of fatalities, injuries, and property damage involved in an accident. These costs may be defined by a State agency, the National Safety Council (NSC), or the National Highway Traffic Safety Administration (NHTSA).

ACCIDENT FREQUENCY - The number of accidents which occur during a specified period of time (i.e., accidents per year, accidents per three years).

ACCIDENT PATTERN TABLES - Tables used in identifying feasible safety countermeasures as a function of the accident type and "probable cause".

ACCIDENT POTENTIAL - An impending accident situation characterized by an unsafe roadway condition.

ACCIDENT RATE - The number of accidents which occur during a specified period of time, divided by a measure of the degree of vehicular exposure over the same period.

ACCIDENT REDUCTION FACTORS - Values of percent accident reduction derived from the observed accident reduction on one or several highway safety projects or programs.

ACCIDENT REPORT - A written report containing data concerning an individual accident including time, place, location description, property damage, injuries, violations, and possible cause. Such reports are submitted either by the investigating officer or the involved motorists.

ACCIDENT SEVERITY - A measure of the seriousness or violence of an accident or all accidents at a highway location. Accident severity may be expressed in terms of the number of fatalities, injuries, or property damage accidents or involvements which occur during a specified period of time.

ACCIDENT SURROGATE OR PROXY - Measurable traffic operational or driver behavioral characteristics which have quantitative relationship with accident measures and can be used as a substitute for accident experience.

ACCIDENT TYPE - The specific accident occurrence as related by the specific movements of the involved vehicle(s).

ACCURACY - The degree of freedom from error by which a measurement is taken or an operation performed. For example, if a measurement is stated as 1.02 $\pm$ 0.05, accuracy is plus or minus five hundredths.

ADEQUATE GAP TIME - Safe crossing time for a group of pedestrians as a function of the crossing distance, the number in the queue, and time between queues.

AERIAL SURVEILLANCE METHOD - Photographic technique from an overhead position, usually using an airplane or helicopter.

ANNUAL VOLUMES - Estimated or actual volume of traffic using a facility for a yearly (365 days) period.

APPROACH TIME - Time used by any vehicle to traverse approach delay section.

APPROACH DELAY - Approach time minus the approach free flow time.

APPROACH WIDTH - Distance accross a roadway from curb-to-curb or curb-to-median for divided facilities.

ASTM - American Society of Testing Materials

AUTOMATED COLLISION DIAGRAMS - Accident collision diagrams using computer plotting techniques to plot collisions.

AVERAGE ANNUAL DAILY TRAFFIC (AADT) - The total yearly volume divided by the number of days in the year.

BENEFIT-COST RATIO - The economic value of the reduction in fatalities, injuries, and property damage divided by the cost of the accident reducing measure.

BOTTLENECK - Physical or geometric features of a street of freeway which reduce the facility's capacity (or ability to accomodate flow) as compared to other locations on the same facility.

CANDIDATE COUNTERMEASURE - Feasible improvement to reduce safety hazards at a site.

CAPACITY - The maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or a roadway in one direction (or in both directions for a two lane or three lane highway) during a given time period under prevailing roadway and traffic conditions.

CATEGORIAL PROGRAMS - Highway safety improvement classification provided in FHPM 6-8-2-1.

CHI-SQUARE DISTRIBUTION - Distribution of test statistic used to test the null hypothesis of "independence" for two or more variables.

CLASSIFICATION VOLUME - Volume count of vehicles by specific type of vehicle, i.e., truck, passenger vehicle, or other similar breakdowns.

CLUSTER ANALYSIS - Method of accident pattern identification by eye inspection method, i.e., a visual search of accident data.

COLLECTOR STREET - Provides for traffic movement between major arterials and local streets, with direct access to abutting property.

COLLISION DIAGRAM - A schematic drawing that shows the direction of travel, prior to contact, of the vehicles and/or pedestrians whose presence contributed to the collision.

COMPARISON SITE(S) - A site or group of sites with similar characteristics which are used to study, for comparison purposes, conditions at a site.

COMPONENTS - Refers to the three general phases of the HSIP; (1) Planning, (2) Implementation, and (3) Evaluation.

COMPUTER TECHNIQUES - Use of computer facilities in recording, collecting, analyzing, and outputting data.

CONDITION DIAGRAM - A scaled drawing of the important physical conditions of a highway spot or section. It is used to relate the accident patterns on a collision diagram to the roadway and operational event at the hazardous location.

CONFIDENCE INTERVAL - A range of numbers computed from sample data, that form an interval which has a probability of including the population parameter.

CONFIDENCE LIMITS - The upper and lower limits of the confidence interval.

CONTRIBUTING CIRCUMSTANCES - Information identified in an accident report form which may be used to suggest possible accident causes. The information is supplied by the reporting officer.

CONTROL OF ACCESS - The condition where the right of owners or occupants of abutting land or other persons to access, light, air, or view in connection with a highway is fully or partially controlled by public authority. Full control of access means that authority to control access is exercised to give preference to through traffic by providing access connections with selected public roads only and by prohibiting crossings at grade or direct private driveway connection. Partial control of access means that the authority to control access is expected to give preference to through traffic to a degree that, in addition to access connections with selected public roads, there may be some crossings at grade and some private driveway connections.

CORRECTABLE ACCIDENTS - Accidents which could be alleviated by means of a feasible safety-related countermeasure specific to the study site.

COST/BENEFIT ANALYSIS - A form of economic evaluation in which input is measured in terms of dollar costs and output is measured in terms of economic benefit of a project as compared to the incurred cost of the project.

COST-EFFECTIVE ANALYSIS - A comparison study between the cost of an improvement (initial plus upkeep) and the benefits it provides. The latter may be derived from accidents reduced, travel time reduced, or increased volume of usage, and translated into equivalent dollars saved.

COUNTERMEASURE - A specific activity intended to improve one or more aspects of the traffic safety or contribute to the solution of a specific accident problem.

CRITICAL MOVEMENT ANALYSIS - Method to compute the level of service of an intersection by summing the observed volumes of critical movements (as a function of signal phasing) and comparing to design values.

CYCLE SAMPLING METHOD - Method to compute the level of service of an intersection by sampling the load utility of each cycle per approach and comparing to the number of cycles during the sampling period.

DATA BASE - The document collection or file of collected data which serves as the basis of an information retrieval system.

DATA COLLECTION - The process of accumulating statistical information relating to the empirical effects of a highway safety project.

DATA SET - A set of data pertaining to a single site or a single data collection period.

DATA TABULATION - The process of displaying experimental results in a table so that the information can more readily be interpreted.

DIVIDED HIGHWAY - A highway with separated roadways for two directional traffic.

"DO NOTHING" ALTERNATIVE - An alternative which refers to the existing state of the system.

ECONOMIC ANALYSIS - Determination of the cost-effectiveness of a project by comparing the benefits derived and the costs incurred by a project.

EFFECTIVENESS EVALUATION - A statistical and economic assessment of the extent to which a highway safety project of program achieves reduction in the number and severity of accidents (accident-based evaluation), or the intermediate impact of a project on observed traffic operations and road user behavior (non-accident based evaluation).

EFFECTIVENESS MEASURES - Indications of the extent to which program objectives are being attained.

EIS - Environmental Impact Statements.

85TH PERCENTILE SPEED - Vehicle speed at which 85 percent of vehicles drive at or below. It is commonly used in assigning speed limits for a section of roadway.

ENGINEERING - Pertaining to highway and traffic engineering, includes design, construction, maintenance, and traffic engineering and other branches having to do with the physical highway plan.

ENVIRONMENTAL BASED STUDIES - A study that involves collection and analysis of all information related to the physical features of the roadway for specific spots, sections, and elements.

EPDO - Equivalent Property Damage Only Accidents. A measure of accident experience based on attaching weights to accident severity categories as multiples of property damage only accidents.

ERRATIC MANEUVER - An unusual action by a road user which could lead to a traffic accident.

EVALUATION - A comparison process that measures an item of activity against certain predetermined standards or criteria. A judgement of value or worth.

EVALUATION COMPONENT (HSIP) - The third of three HSIP components. This component consists of one process and four subprocesses which involves the determination of the effect of Highway Safety Improvements through the appropriate use of 1) non-accident based project evaluation, 2) accident based project evaluation, 3) program evaluation, and 4) administrative evaluation.

EVALUATION OBJECTIVE - A brief statement describing the desired outcome of an evaluation study.

EXPECTED RANGES (ER'S) - Estimates of the variance associated with accident reduction factors (See ACCIDENT REDUCTION FACTORS).

"EXPECTED VALUE" ANALYSIS - Method to define a pattern of accidents by developing an expected value or range of values of an accident characteristic from comparison sites and comparing these values to the study location.

EXPOSURE - The quantity of vehicles, vehicle-miles of travel or other volume and/or time related factor which measures the degree of vehicular exposure to a particular situation.

FATALITY ACCIDENT - An accident event involving at least one fatality.

FHPM - Federal-Aid Highway Program Manual.

FIELD REVIEW - The observance of field conditions at a site by reviewing the site conditions using either manual or photographic techniques.

FOG INDEX - An index used in the measurement of fog density by identifying the visual range of a study area under fog conditions.

FREQUENCY - Number of observations falling in a cell or classification category.

FUNCTIONAL CLASSIFICATION - Division of a transportation network into classes, or systems, according to the nature of the service they are to provide.

FUNDAMENTAL OBJECTIVES - Four evaluation objectives which should always be included in Accident-based evaluation. These objectives are to determine the effect of the project/program on; 1) total accidents, 2) fatal accidents, 3) injury accidents, and 4) property damage accidents.

GAP - Time or distance between successive vehicles in a traffic stream.

GAP ACCEPTANCE - The acceptance or use of a gap in a major stream of traffic by a minor stream traffic flow.

GAP DISTRIBUTION - The frequency and range of measured gaps in a traffic stream.

GAP STUDIES - A study conducted to measure the time headway or GAP between vehicles along a highway section (or at a point), and to analyze the GAP acceptance characteristics where a minor or alternate traffic stream intersects a major traffic stream.

GRADIENT - Ratio of vertical to horizontal lengths.

GROUND LEVEL METHOD - Filming method to obtain traffic data. Camera is usually situated on a pole above the area to be viewed so as to provide a clear visual picture of the location's activities.

HAZARD - Conditions which exist on the highway system which are conducive to future accident occurrences.

HAZARDOUS LOCATION - Highway spots, intersections or sections experiencing abnormally high accident occurrences or potential.

HAZARDOUS ROADWAY FEATURES INVENTORY METHOD - A technique of selecting sites with a potential for high accident severity or numbers on the basis of identification of hazardous roadway features; narrow bridges, steep roadside slopes, etc.

HEADWAY - Distance between successive vehicles in a traffic stream.

HIGH COST PROJECT - Major highway safety projects which require a significant initial cost outlay. Examples include lane additions, bridge replacements, roadway alignment changes, constructing highway grade separations, etc.

HIGHWAY CAPACITY MANUAL - (Highway Research Board Special Report No. 87). It displays associated tables, charts, and formulas required to assess the level of service for freeway, ramp, weave sections, roadway links, and signalized intersection areas.

HIGHWAY SAFETY GOAL - Expected safety improvements resulting from a highway safety program.

HIGHWAY SAFETY PROJECT - One or more remedial countermeasures instituted to improve specific safety deficiencies on the highway or its environs.

HIGHWAY SAFETY TREATMENT - A single remedial countermeasure instituted to improve the overall safety environment of the highway system.

HISTOGRAM - Graphical method for describing a set of data.

HIGHWAY, STREET, OR ROAD - A general term denoting a public way for purposes of vehicular travel, including the entire area within the right-of-way.

HOURLY VOLUME - Volume of vehicular or pedestrian traffic for a 60-minute or one-hour period.

HSIP - Highway Safety Improvement Program, defined in FHPM 8-2-3.

HYDROPLANING - A condition where one or more tires of a moving vehicle are separated from the pavement by a film of water; usually due to a combination of depth of water, pavement surface texture, vehicle speed, tread pattern, tire pressure, and other factors.

IMPLEMENTATION COMPONENT (HSIP) - The second of three components. This component consists of one process and three subprocesses which involve; 1) the scheduling, 2) the design and construction, and 3) the operational review of project(s).

IMPLEMENTATION SCHEDULE - A listing of the events needed to complete a particular project activity. The listing is arranged in a chronological sequence according to the time for initiating each event and with an estimated time of completion.

INJURY ACCIDENT - An accident event involving an injury (Type A,B,or C) as the most severe characteristic.

INPUT-OUTPUT METHOD - Method of measuring the intersection travel time by sampling the vehicles as they enter into and exit from the study area.

INTERCHANGE - A system of interconnecting roadways in conjunction with one or more grade separations, providing for the movement of traffic between two or more roadways on different levels.

INTERSECTION - The general area where two or more highways join or cross within, which are included in the roadway and roadside facilities for traffic movements in that area.

INTERSECTION SIGHT DISTANCE - The measured clear sight distance in and around the intersection to provide safe movement.

INTERSECTION VOLUMES - The traffic volume, vehicular or pedestrian, recorded through the intersection area.

INVENTORIES - List of items or occurrences such as roadway and roadside features, accidents, high accident locations, etc.

ITE - Institute of Transportation Engineers.

LAG - The interval of time between the arrival of a minor stream vehicle and the arrival of a major-stream vehicle at a reference point in the area where the streams either cross or merge.

LANE DISTRIBUTION - The distribution of traffic by specific lane along a roadway or at an approach.

LANE OCCUPANCY - A measurement of vehicle presence within a zone of detection, usually expressed as the percent of time a given point or area is occupied by a vehicle.

LEVEL OF CONFIDENCE - Probability of accepting the null hypothesis when it is true ($1-\alpha$).

LEVEL OF SERVICE - Denotes any one of an infinite number of differing combinations of operating conditions that may occur on a given lane or roadway when it is accomodating various traffic volumes. It is a qualitative measure of the effect of a number of factors including speed, travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating costs. In practice, selected levels are defined in tems of particular limiting values of certain of these factors.

LEVEL OF SIGNIFICANCE - Refers to the outcome of specific statistical tests of hypothesis.

LIGHT METER - Meter devised to measure the output of light intensity of a light source.

LOCAL STREET OR LOCAL ROAD - A street or road primarily for access to residential, business, or other abutting property.

LOCATION - The name given to a specific point on a highway for which an identification of its linear position with respect to a known point is desired. A location may be where an accident occurred, where a roadway characteristic (such as surface width) changes, where an operational characteristic (such as traffic volume) changes significantly or where some maintenance activity started or ended.

LONG-RANGE TRANSPORTATION PLAN - A 10- to 20-year plan that has specific goals, is system- and major-project oriented, and includes the highest priority projects and a funding projection indicating that funds will probably be available for the plan's completion.

LOW COST PROJECT - Highway safety projects which require low or moderate initial cost outlays. Examples include pavement edgelining, traffic signal timing modifications, traffic sign installation, roadway delineator installations, etc.

MAJOR CAUSAL FACTORS - Specific hazardous elements associated with the highway, environment or vehicle, or actions associated with the road user which describe why an actual or potential accident problem exists.

MAJOR CONTRIBUTORY FACTOR - Elements or activities which lead to or increase the probability of a failure in the road user, the vehicle or the highway environment.

MAJOR STREET OR MAJOR HIGHWAY - An arterial highway with intersections at grade and direct access to abutting property and on which geometric design and traffic control measures are used to expedite the safe movement of through traffic.

MANUAL COLLISION DIAGRAM - Diagram displaying accident events at a site as manually prepared by an individual.

MANUAL METHODS - Method to obtain traffic data by physically obtaining data on-site.

MEAN - Average of a set of measurements. The symbols X and U denote the means of a sample and a population, respectively.

MEASURE OF EFFECTIVENESS (MOE) - A measurable unit or set of units assigned to each evaluation objective. The data collected in the units of the MOE will allow for a determination of the degree of achievement for that objective.

MECHANICAL VOLUME COUNTER - A mechanical device used for volume data collection when data are to be collected over long periods of time.

MEDIAN - The portion of a divided highway separating the travelled ways for traffic in opposite directions.

MEDIAN SPEED - 50th percentile or middle value in a speed distribution pattern, i.e., one-half of the observed values are higher than the median and one-half are lower.

MIDBLOCK VOLUME - Volume of traffic recorded on a roadway link between two major intersections.

MODAL SPEED - Speed at which greatest frequency of observations occurs. The speed most frequently observed.

MODELLING - Means of identifying a relationship in an event using mathematical tools.

MONITORING - The process of checking the actual progress and comparing it with the scheduled progress.

MOVING VEHICLE METHOD - Means to determine travel times and approximate volumes along a roadway facility by driving in a traffic stream and computing the necessary information using recorded values of opposing volumes, passed traffic volumes, passing traffic volumes, and time.

MULTI-DISCIPLINARY INVESTIGATION TEAM - A group of two or more analytical personnel with at least one representative from the engineering and enforcement agencies and, if desired, representatives from other agencies assigned to advise and assist in the analyses of crash occurrences and in recommendations and evaluations of corrective measures.

MUTCD - Manual of Uniform Traffic Control Devices

NCHRP - National Cooperative Highway Research Program: an objective national highway research program supported by participating member states and the Federal Highway Administration.

NEED - A deficiency which should be corrected in the interests of public safety.

NET BENEFIT - A measure of cost-effectiveness, gross benefit minus improvement cost.

NHTSA - National Highway Traffic Safety Administration.

NODE - An intersection of two major streets.

NON-ACCIDENT MEASURE - A measurable unit of safety which is logically related to accident measures such as traffic performance and operation (travel time, delay and speeds) and road user behavior (traffic control violations and erratic maneuvers).

NON-CORRECTABLE ACCIDENTS - Accidents of a random nature which are not specifically amenable to correction by a countermeasure.

NORMAL DISTRIBUTION - A symmetrical bell-shaped probability distribution. Many events in nature have frequency distributions which closely approximate the normal distribution.

NSC - National Safety Council.

NULL HYPOTHESIS - The hypothesis, tested in statistical analysis, that assumes there is no difference between the before and after accident experience.

OBJECTIVE - The specific accident or severity measures which are to be evaluated by the evaluation study. There are two types of objectives: 1) Fundamental objectives refer to those measures which must be evaluated in all studies. They are total accidents, fatal accidents, personal injury accidents and property damage only accidents; 2) Objectives relating to project purposes. These objectives may include one or more of the purposes of the project (See PURPOSE).

OPERATIONAL NON-ACCIDENT MEASURE - (See NON-ACCIDENT MEASURE)

PACE - The 10 mile-per-hour range in speeds containing the highest number of recorded observations.

PASSING SIGHT DISTANCE - Design standard for a given speed to permit safe passing conditions along a section of roadway.

PATH TRACE METHOD - Method of obtaining travel time and delay information by following a single vehicle's path and recording the appropriate travel time and delay characteristics.

PEAK-HOUR VOLUMES - Hourly traffic volumes during the highest or peak travel periods at a location.

PEDESTRIAN CONFLICT - Traffic conflict resulting from a pedestrian movement in an area (See TRAFFIC CONFLICT).

PEDESTRIAN VOLUMES - Volume count of pedestrian movement at a location.

PERMANENT COUNTERS - Traffic counters permanently installed at a location to record volume (and other data) over a long period of time. They may be used to obtain control counts for volume expansion purposes.

PERMITTED ERROR - Allowable difference (measured in percent) in results obtained by sampling methods.

PHOTOGRAPHIC TECHNIQUES - Method of data collection involving the use of film processes, ground level or aerial. It provides a film record of a highway situation.

PHOTOLOGGING - A technique that involves taking photographs of the highways and its environment from a moving vehicle at equal increments of distance.

PLANNING COMPONENT (HSIP) - The first of the three HSIP components. This component consists of four processes (and associated subprocesses) which involve; 1) identifying hazardous locations and elements, 2) conducting engineering studies, 3) developing candidate countermeasures, 4) developing projects based on the candidate countermeasures, and 5) prioritizing the developed safety improvement project.

POISSON DISTRIBUTION - A distribution which often appears in observed events which are very improbable compared to all possible events, but which occur occasionally since so many trials occur, e.g., traffic deaths, industrial accidents, and radioactive emissions. The mean and variance of the poisson distribution are equal.

POINT-SAMPLE METHOD - Means to obtain delay data by sampling vehicles at an approach in successive time intervals.

PORTABLE COUNTERS - Mechanical counters able to be installed from site-to-site. They are usually lightweight and able to be handled by a single person.

POPULATION - The total set of items defined by a characteristics of the items.

PRIORITY RANKING - The overall process of producing a rank order of priority projects and project sections, using technical and non-technical, quantifiable and non-quantifiable factors as the criteria for ranking.

PRIORITY RATING - A complex rating for evaluating or comparing projects.

PROBABILITY DISTRIBUTION - Representation of the theoretical frequency distribution for a random variable.

PROCEDURE - Possible ways in which each of the processes or subprocesses may be attained. For example, the procedure for conducting engineering studies (Process 3-Planning Component of HSIP) are: accident-based, traffic-based, environment-based, and special study procedures.

PROCESS - The sequential elements within each component of the HSIP.

PROGRAM - A group of projects (not necessarily similar in type or location) implemented to achieve a common highway safety goal of reducing the number and severity of accidents and decreasing the potential for accidents on all roads.

PROGRAMMING - The matching of available projects with available funds to accomplish the goals of a given period.

PROGRAMMED PROJECTS - A highway safety project, formally planned for implementation at some point in time. Projects contained in the Annual Work Program (AWP) are programmed projects.

PROGRAM/PROJECT BENEFITS - A measure of the positive effect of a highway safety program or project given in terms of accident measure reduction.

PROJECT - One or more countermeasures implemented to reduce identified or potential safety deficiencies at a location on the highway or its environs. Also, a project may consist of identical countermeasures implemented at several similar locations, which have been grouped to increase the evaluation sample size.

PROJECT IMPACT - Project effectiveness in achieving the evaluation objectives; also any unexpected consequences of the project such as public reaction.

PROJECT JUSTIFICATION STATEMENT - A formal statement of the perceived need for implementing a particular highway safety project. This statement is generally submitted to State funding agencies as a request for project funding. The statement generally provides a quantitative justification in terms of the existing adverse conditions (accidents) as well as the expected benefits to be derived from the project.

PROPERTY DAMAGE ACCIDENT - Accident event involving only property damage between the involved vehicles.

PURPOSE - The reason for which the highway safety project was implemented. The purpose refers to the reduction or elimination of a specific highway safety deficiency such as a type of accident, a severity class, a hazard potential indicator and/or a traffic performance variable.

QUEUE LENGTH STUDIES - A study that identifies the number of vehicles that are stopped in a traffic lane behind the stop line at an intersection.

RADAR METER - Meter device used to collect spot speed information. Based on the Doppler principle, it provides a direct reading of the vehicle speed.

RANDOM SELECTION - A process by which every element in a population has an equal probability of being chosen.

RANGE OF A SET OF MEASUREMENTS - Difference between the largest and smallest members of the set.

RATE-OF-RETURN METHOD - A form of economic evaluation based upon the computation of the interest rate at which the net present annual worth of the project minus the improvement cost is equal to zero.

REFERENCE POINT - A fixed, identifiable feature, such as an intersection, railroad crossing, or bridge, from which a location can be measured or referenced.

RESOURCE EXPENDITURES - Elements used in the implementation of a project or program such as: 1) the level of manpower involvement, 2) the amount of time used to complete specific activities or meet implementation milestones, 3) the quantities of materials used, and 4) the cost of manpower materials.

RIGHT-OF-WAY - A general term denoting land, property, or interest therein, usually in a strip, acquired for or devoted to transportation purposes.

ROADSIDE - A general term denoting the area adjoining the outer edge of the roadway. Extensive areas between the roadway of a divided highway may also be considered roadside.

ROADSIDE CONTROL - The public regulation of the roadside to improve highway safety, expedite the free flow of traffic, safeguard present and future highway investment, conserve abutting property values, or preserve the attractiveness of the landscape.

ROADWAY (GENERAL) - The portion of a highway, including shoulders, for vehicular use. A divided highway has two or more roadways. (In construction specifications, the portion of a highway within limits of construction).

SAFETY PROBLEM - Specific types of accidents or potential accidents which result from the existence of a causal and/or contributory factor.

SALVAGE VALUE - Estimated residual worth of program or project components at the end of their expected service lives.

SAMPLE - A subgroup of the population. A finite portion of a population or universe.

SCHOOL ROUTE MAP - Map displaying safe school routes for pedestrians in traversing to and from school. It is devised to minimize conflicts between pedestrians and potential safety hazards.

SERVICE LIFE - The period of time, in years, in which the components of a program or project can be expected to actively affect accident experience.

SERVICE VOLUME - Volume of traffic serviced by a highway facility.

SEVERITY INDEX - A number computed from applying weighting factors to injury and fatality accidents based on their severity.

SEVERITY WEIGHTING METHOD - Means to rate the hazardousness of a specific accident pattern by assigning weight values for the severity occurrences of the accidents.

SHOULDER - The portion of the roadway continuous with the travelled way for accomodation of stopped vehicles for emergency use, and for lateral support of base and surface courses.

SHORT-TERM VOLUMES - Volume count, vehicular or pedestrian for a period shorter than one-hour. It, typically, is in the range of 5 to 15 minutes.

SKEWNESS - The distribution pattern of a speed/frequency curve. A symmetrical set of speed values will represent more favorable conditions.

SKID NUMBER - The coefficient of friction times 100 (100X) of a tire sliding on wet pavement when tested at 40 mph with a two wheel skid trailer or equivalent device following the procedures outlined in ASTM E274-65T.

SPECIAL STUDY PROCEDURES - Procedures required in special engineering situations but are not classified as one of the other procedures.

SPOT MAPS - Maps often used by police and other public agencies to provide a quick visual picture of accident concentrations identified through "spot" marks or pins on a street map.

STANDARD - One of the 18 Highway Safety Programs Standards promulgated by the Department of Transportation to implement the Highway Safety Act of 1973, 23 USC 402.

STANDARD DEVIATION - Measure of data variation. Square root of the variance. It represents the population standard deviation. S represents the sample standard deviation.

STATISTICAL SIGNIFICANCE - The determination of whether an observed change in a MOE (by use of a selected statistical technique) constitutes a significant change within a selected level of confidence.

STOPPED DELAY - Time vehicle is stopped, with locked wheels. It is equal to the stopped time.

STOPPING SIGHT DISTANCE - Safe sight distance required for a vehicle to stop along a section of roadway upon sighting an object which will require the vehicle to stop.

SUBPROCESS - Specific activities which are contained within certain Processes. For example, under Process 3 of the Planning Component, the three subprocesses are: (1) Collect and Analyze Data; (2) Develop Candidate Countermeasures; and (3) Develop Projects.

TECHNIQUE - Feasible means to perform a selected procedure. For example, the volume study procedure may be performed by: mechanical methods, manual counts, photographic techniques, or the moving vehicle method.

TEST-CAR TECHNIQUE - Methods to obtain travel time and delay information by physically driving a vehicle within a traffic stream and measuring the appropriate travel time and delay characteristics.

THROUGH STREET OR THROUGH HIGHWAY - Every highway or portion thereof on which vehicular traffic is given preferential right-of-way, and at the entrances to which vehicular traffic from intersecting highways is required by law to yield right-of-way to vehicles on such through highway in obedience to either a stop sign or yield sign.

TIME-IN-QUEUE DELAY - Time from first stop to vehicle's exit across "STOP" line. It is equal to the time spent in the queue.

TIME-OF-RETURN (TOR) METHOD - A form of economic evaluation in which expected accident reductions are forecast using data from previous before-and-after accident studies and a TOR value is computed by dividing the estimated cost of the project by the computed annual benefit. Projects with the lowest TOR values are considered to be the best.

TRAFFIC CONFLICT - A traffic event involving two or more road users, in which one user performs some atypical or unusual action, such as a change in direction or speed, that places another user in jeopardy of a collision unless an evasive maneuver is undertaken.

TRAFFIC CONTROL DEVICE - A sign, signal, marking, or other device placed on or adjacent to a street or highway by authority of a public body or official having jurisdiction to regulate, warn, or guide traffic.

TRAFFIC ENGINEERING MEASURES - Engineering procedures for controlling or regulating the movement, direction, speed, right-of-way, and parking of vehicular traffic and, where applicable, pedestrian traffic on streets and highways. This includes such elements as one-way streets, turn controls, reversible lanes, crosswalks, etc.

TRAFFIC LANE OCCUPANCY STUDIES - Studies that provide a measure of the traffic performance of a highway facility as a function of vehicle lengths, volumes, and speed.

TRAFFIC OPERATIONS-BASED STUDIES - Studies which provide essential information to assist in the selection of the most appropriate safety improvements at identified hazardous locations.

ULTIMATE SAFETY OBJECTIVES - A significant reduction in the number and severity of accidents.

UTILITY INDEX - A means to provide a quantitative assessment of alternatives including non-quantifiable variables by assigning weights to each variable, setting a level value to each variable, multiplying the level value by the weight assignment, summing the values, and comparing them to each other.

VARIANCE - Measure of data variation. T^2 represents population variance S^2 represents sample variance.

VEHICLE DELAY-RELATED COSTS - Costs associated with the occurrence of delay at a location. It includes the extra vehicle costs (fuel, tires, etc.) and "time lost" costs to an individual.

VIDEOLOGGING - A technique that involves taking video tape pictures of highways and its environment as a substitute for photologging.

VOLUME - The number of vehicles passing a given point during a specified period of time.

WARRANTS - The minimum conditions which would justify the establishment of a particular traffic control regulation or device, usually including such items as traffic volumes, geometrics, traffic characteristics, accident experience, etc.

APPENDIX C: PROCEDURE AND DATA OBTAINED

PROCEDURE	DATA OBTAINED
A. Accident-Based Procedures . Accident Summary By Type	. Summary of accident data by specific accident type at a location. . Identified accident patterns or trends by accident type. . Possible accident causes.
. Accident Summary By Severity	. Summary of accident data by severity characteristics. . Identified severity patterns or trends for a location. . Weighted accident characteristics for a location. . Possible accident causes.
. Accident Summary by Contributing Circumstances	. List of "correctable" and noncorrectable" accidents at a site. . Summary of contributing circumstances by accidents at a location. . Identified patterns or trends of contributing circumstances. . Possible accident causes.
. Accident Summary by Environmental Conditions	. Summary of accident data by environmental characteristics. . Identified environmental characteristic patterns or trends for a location. . Possible accident causes
. Accident Summary By Time Period	. Summary of accident by time of . day, day of week, or month of year. . Identified time period accident patterns. . Possible accident causes.

APPENDIX C: PROCEDURE AND DATA OBTAINED (CONT'D)

PROCEDURE	DATA OBTAINED
B. Field Review Procedure . Safety Performance Study	. Review and notes of physical and operational characteristics of a study location. . Possible accident causes.
C. Traffic-Based Procedures . Volume Study	. Vehicular volume data by time period, location, or classification of vehicles. . Pedestrian volume data by time period and location.
. Spot Speed Study	. Spot speed characteristics (median speed, modal speed, 85th percentile speed, skewness, pace). . Speed distribution pattern. . Assessment of safe speed conditions. . Probable accident causes.
. Travel Time And Delay Study	. Travel time characteristics (travel time, approach time, approach free flow time, travel speeds.) . Delay characteristics (approach delay, stopped delay, time-inqueue delay, percentage of vehicles stopping). . Operating level of service of a roadway facility. . Major delay points. . Probable accident causes.
. Roadway And Intersection Capacity Study	. Capacity of facility. . Available service volume at various levels of service. . Operating level of service of facility. . Probable accident causes.
. Traffic Conflict Study	. Summary of conflicts, conflict rates, conflict types. . Conflict diagram displaying conflict types.

APPENDIX C: PROCEDURE AND DATA OBTAINED (CONT'D)

PROCEDURE	DATA OBTAINED
. Traffic Conflict Study (Cont'd)	. Probable accident causes. . Possible safety-related countermeasures.
. Gap Study	. Gap distribution of major and/or minor stream vehicles. . Lag distribution of merging, crossing or weaving traffic streams. . Gap acceptance characteristics of a minor stream of vehicles. . Critical gap or lag. . Evaluation of safety at gap situations. . Probable accident causes.
. Traffic Lane Occupancy Study	. Lane occupancy characteristics (density, occupancy). . Operating level of service of facility. . Probable accident causes.
. Queue Length Study	. Queue length characteristics. . Possible operating level of service of facility.
D. Environmental-Based Procedures . Roadway Inventory Study	 . Inventory of roadway and roadside characteristics. . Observed field sight distance conditions. . Required safe sight distance. . Assessment of safe sight distance conditions. . Sight obstructions. . Probable accident causes.
. Skid Resistance Study	. Friction force of pavement at 40 mph and varying speeds. . Assessment of pavement skid characteristics. . Probable accident causes.
. Highway Lighting Study	. Assessment of lighting warranting conditions.

APPENDIX C: PROCEDURE AND DATA OBTAINED (CONT'D)

PROCEDURE	DATA OBTAINED
. Highway Lighting Study (Cont'd)	. Assessment of adequacy of existing light. . Assessment of need for new or additional lighting. . Probable accident causes.
. Weather-Related Study	. Conflict data under specific conditions. . Safe sight distance under specific conditions. . Predicted visual range for for conditions. . Probable accident causes.
E. Special Study Procedures	
. School Crossing Study	. Pedestrian demand at crossing. . Available safe crossing gaps at crossing. . Pedestrian conflict data. . Assessment of crossing protection needs. . Probable accident causes.
. Railroad Crossing Study	. Railroad crossing site review. . Review of sight visibility triangle. . Probable accident causes.
. Traffic Control Device Study	. Observance characteristics of traffic control by drivers or pedestrians. . Probable accident causes.
. Bicycle and Pedestrian Study	. Conflict data for specific situations. . Review of operations. . Probable accident causes.
F. Countermeasure Selection Procedures	
. Accident Pattern Tables	. List of general countermeasures. . List of feasible countermeasures.

APPENDIX C: PROCEDURE AND DATA OBTAINED (CONT'D)

PROCEDURE	DATA OBTAINED
. Multi-Disciplinary Investigation Team	. Determination of probable causes and countermeasures by individual team members. . Determination of probable causes and countermeasures by team.
G. Economic Analysis Procedures . Cost-Effectiveness Method	. Annual safety benefits (accidents saved). . Equivalent uniform annual cost of present worth of costs. . Cost-effectiveness ratio.
. Benefit-To-Cost Ratio Method	. Annual safety benefits (accidents saved and dollar value). . Equivalent uniform annual cost and equivalent uniform annual benefit. . Present worth of cost and present worth of benefit. . Benefit-to-cost ratio.
. Rate-Of-Return Method	. Annual safety benefits (accidents saved and dollar value). . Capital recovery factor of improvement. . Expected rate-of-return of improvement investment.
. Time-Of-Return Method	. Annual safety benefit (accidents saved and dollar value). . Expected time-of-return of investment as based on expected benefits.
. Net Benefit Method	. Annual safety benefits (accidents saved and dollar value). . Average annual benefits. . Average annual costs. . Net benefit derived from improvement.

APPENDIX D: FILMING PROCESSES

I. PHOTOLOGGING

● Field Work

In photologging, an instrumented vehicle with a 35mm cine/pulse type camera is driven along the roadways and pictures are taken with a typical frequency of 100th or 200th of a mile (0.016 or 0.008 kilometers). These films become a permanent record of the roadway and its environment as seen during the day of the photologging. The photologs are then analyzed in the office under a controlled environment by technicians and analysts trained to perform the evaluation phases which are generally done in the field by a manual method.

There are two different types of photologging equipment available today. The first generation photologging method includes a 35mm cine/pulse camera connected to distance measuring equipment, and a control box which can directly input the mileage information dynamically in each frame of the photograph. Other information, such as: the roadway direction listing, roadway name, date of filming, route number, etc. also appears on each photograph.

Second generation systems include not only the data which can be obtained in the first generation, but also, other dynamic information, such as roadway roughness, superelevation, curvature, grade etc., displayed on each photograph.

The field work in most photologging methods involves filming the roadway using a first generation type photolog system. Only one person is normally required in the photolgging field work. Based on past experience, the use of a 2 person crew increases the probability of error in filming due to an increase of conversation by the photologgers. To insure an easier and more accurate data extraction capability, photologging is usally performed using a 1/200th of a mile filming rate.

● Data Extraction

The extraction of data in the photologging technique involves the viewing of the photolog film frame by frame to observe and/or evaluate the required data items. The mileage, distance from vehicle, lateral distance from roadway, and other pertinent features are recorded from the film onto inventory sheets provided for direct entry of the data onto computer files. The distance from vehicle and lateral placement measurements are obtained from a graduated grid, overlayed on the viewer. The use of an audio system, coordinated with the filming process, can be made to record other data, in particular, data unable to obtained accurately from a review of the film record.

● Check Of Accuracy

Photologging, typically, results in a longitudinal error of several feet over the course of the study area and a lateral placement error of less than 1 foot if the object is within 5 feet of the edge of the roadway and ± 1 foot if the object was beyond the 5 foot range. Color quality of the film is excellent and, thus, permits an accurate assessment of various conditions. Detailed information is able to be accurately noted.

● Summary

Photologging provides a cost effective technique for use in developing most computerized information systems. It provides pictorial records of the inventoried roadway system which are capable of use for other than for the inventory purpose. They can limit the use of field trips to check data. To-date, they have been used to extract over five different inventory types (sign, roadway, obstacle, pavement markings, etc.).

Photologging, due to the utilization of a single-man crew for the data collection activities, can be an inexpensive alternative. It is recommended for use when inventorying more than two information types, i.e., sign, roadway, etc.

II. VIDEOLOGGING

● Field Work

Videologging is another pictorial technique for data collection. Video camera systems are mounted in either an automobile or van and the pictures recorded on video tapes. With this system the data collectors have an option of verbally recording any additional information that may be pertinent to the data base, on the video tape itself. Videologging systems are available in both black and white as well as color. The color, 3/4 inch video tape format seems to have the most potential for the type of data collection necessary to develop roadway information systems.

In this method, a two person crew is normally utilized in a vehicle equipped with a distance measuring device. The display of the elapsed distances from the DMI are made a part of the picture. The driver of the vehicle observes the roadway and roadside features and selects a driving speed which is sufficient for the second person to record any necessary audio data to supplement the picture.

● Data Extraction

For the videologging technique, data extraction is very similar to the photolog procedure. The video tapes are played back on the TV monitors and viewed in a controlled, office environment. The data is recorded onto inventory sheets for entry onto the computer. Lateral placement of signs and obstacles are obtained using a grid overlay as is the distance from vehicle in high information areas. In areas where information density is low, the technician providing verbal comments could "mark" a feature on the audio track. However, in areas where information is more frequent, too many "marks" occur on the audio track under operation at the normal travel speeds. This can be alleviated by slowing or stopping the vehicle, which in turn, lowers productivity and increases the cost of this phase of work. The value of the input of the information on the audio track tends to offset the productivity costs.

Data extraction times are slightly higher for videologging than photologging. The video tape must be in continuous operation to take advantage of the audio information. This requires the technicin to listen to the audio backup, and then view the tape. Audio data may be required in describing information as the resolution of the viedolog system used may not be comparable to the degree of resolution found in the 35mm photolog systems.

● Check Of Accuracy

Videologging tends to produce results similar to photologging. The accuracy of distance measurements is similar as in photologging. Data concerning general descriptive characteristics is also very good; however, the lack of visual detail, as compared to photologs, does lead to some inaccuracies in defining details. Reliance on audio comments is required for some of this data.

● Summary

Videologging provides a cost effective technique for use in developing most computerized information systems. As in the photologging alternative, it provides a pictorial record of the inventoried roadway system which are capable of use for other than for the inventory purpose. Videologs provide the capability for an audio comment, but lack the visual resolution capable in the photolog technique. As such, a limited amount of information may be obtained from a single data collection pass using the videologging procedure.

Videologging systems suffer from a problem related to the size of the highway system. Extraction of data from the video pictures supplemented by the audio records is quite confusing at times unless the data collector (person recording) and data extractor are very proficient. However, future improvements in video equipment which may permit the development of portable equipment capable of a resolution comparable to the 35mm photologs may tend to modify these conclusions.

III. OTHER PHOTOGRAPHIC TECHNIQUES

In addition to photo and video-logging techniques, other photographic methods are used to collect traffic data. These methods employ continuous or time-lapse filming to record traffic data during the selected periods. Application of these methods can occur from either an elevated position or an aerial view.

● Field Work

In these photographic methods, a camera is positioned at an elevated position or an aerial view within range (view) of the study area. In an elevated position, use of existing poles or structures are made to attach the camera. The aerial method uses a helicopter or airplane to fly or hover over the study area. A helicopter is able to remain more stationary while filming the data and is able to film the study area at a much closer visual range, thereby able to better depict traffic situations.

The filming process can be performed continuous or in a time-lapse interval. The continuous filming permits the data to be recorded continuously at a high speed film rate. Time-lapse methods allow for the intermittent filming of the traffic situations. This method is usually preferred. Time-lapse intervals for traffic safety purposes usually range from 0.5 - 3.0 seconds. Camera capabilities, however, permit the interval to be as high as 99.5 seconds. The time-lapse process will permit significantly more data to be accumulated in a single roll of film. To identify time period characteristics in both processes, a timer, built into the camera, can be used to include the time-of-day information on each film frame or periodically.

● Data Extraction

The extraction of data for these film processes are similar to the videolog and photolog methods. The film is able to be viewed frame by frame to observe and/or evaluate the required data items. However, it is primarily viewed in a continuous manner to obtain the required data. The data is projected onto a screen for extraction or review purposes. In some aerial methods, individual film frames of the study area are blown up and used to collect the pertinent data items. Distance information is obtained using a given reference point on the film record; however, unless the reference distance is situated at approximately ninety degrees to the camera, the distance information may result in a high degree of inaccuracy.

● Check Of Accuracy

Where reference distances are used, the accuracy of the data is highly dependent on the dimensions of the study area and the camera angle to the reference distance. A greater area viewed within the camera range will typically result in greater inaccuracy. On a percentage basis, the error scale is typically less than ± 2 percent. This error is primarily due to camera parallax.

● Summary

The elevated method of filming is used in widespread use in studying traffic situations. It allows filming of a large amount of data with little manpower required (except for set up/removal time and periodic checks of the camera's function). Time-lapse methods are more appropriate for these uses.

Aerial methods are not as favorable as the elevated position method. It is significantly affected by available flying time and can be used for only short survey periods (one hour or less). In many cases, the traffic data requires time consuming data extraction methods.

Appendix E

Table of various types of improvements and corresponding accident types.

INTERSECTION ACCIDENTS

Type of Accident - Left Turn Head On Collision

Probable Causes -

1) Restricted sight distance due to presence of left turning traffic on the opposite approach and improper channelization and geometrics.
2) Too short amber phase.
3) Absence of special left turning phase when needed.
4) Excessive speed on approaches.

Study to be Performed -

1) Review existing intersection channelization.
2) Volume count for thru traffic.
3) Perform volume count for left turning traffic.
4) Review signal phasing.
5) Review intersection clearance times.
6) Study need for special left turn phase.
7) Study capacity of the intersection approaches in question for possible multi-phase operation.
8) Perform spot speed study.

Possible Counter Measures -

1) Provide adequate channelization.
2) Install traffic signal if warranted by MUTCD.
3) Provide left turn slots.
4) Install stop signs if warranted by MUTCD.
5) Increase amber phase.
6) Provide special phase for left turning traffic.
7) Widen road.
8) Prohibit left turns (study possible adverse effects on other nearby intersections).
9) Reduce speed limit on approaches if justified by spot speed study.
10) Reroute left turn traffic.
11) Provide all red phase.

INTERSECTION ACCIDENTS

Type of Accident - Rear End Collisions At Unsignalized Intersections

Probable Causes -

1) Improper channelization.
2) High volume of turning vehicles.
3) Slippery surface.
4) Lack of adequate gaps due to high traffic volume from the opposite direction.
5) Inadequate intersection warning signs.
6) Crossing pedestrians.
7) Excessive speed on approaches.
8) Inadequate roadway lighting.

Study to be Performed -

1) Review existing channelization.
2) Review pedestrian signing and crosswalk marking.
3) Perform turning count.
4) Perform volume count for thru traffic.
5) Check skid resistance.
6) Perform spot speed study.
7) Check for adequate drainage.
8) Check roadway illumination.

Possible counter measures -

1) Create right or left turn lanes.
2) Increase curb radii.
3) Prohibit turns (study possible adverse effects on other nearby locations).
4) Provide "Slippery When Wet" signs. (interim measure only)
5) Increase skid resistance.
6) Improve drainage.
7) Install or improve signing and marking of pedestrian crosswalks.
8) Reduce speed limit on approaches when justified by spot speed studies.
9) Provide advance intersection warning signs.
10) Improve roadway lighting.

(continued)

Source: Datta, T.K., A Procedure for the Analysis of High-Accident Locations for Traffic Improvements, 1976

INTERSECTION ACCIDENTS

Type of Accident - Rear End Collision at Signalized Intersections

Probable Causes -

1) Improper signal timing.
2) Poor visibility of signal indication.
3) Crossing pedestrians.
4) High volume of turning vehicles.
5) Slippery surface.
6) Excessive speed on approaches.
7) Inadequate roadway lighting.
8) Inadequate channelization.

Study to be performed -

1) Review existing channelization.
2) Review pedestrian signing and crosswalk markings.
3) Perform turning count.
4) Perform spot speed study.
5) Check skid resistance.
6) Check for adequate drainage.
7) Check visibility of traffic signals.
8) Check roadway illumination.
9) Review intersection clearance times.

Possible Counter Measures -

1) Create right or left turn lanes.
2) Increase curb radii.
3) Prohibit turns (study possible adverse effects on other nearby locations).
4) Increase skid resistance.
5) Provide adequate drainage.
6) Provide "Slippery When Wet" signs. (interim measure only)
7) Install advance intersection warning signs.
8) Install or improve signing and marking of pedestrian crosswalks.
9) Provide pedestrian walk - don't walk indicators.
10) Increase amber phase.
11) Provide special phase for left turning traffic.

(continued)

INTERSECTION ACCIDENTS

Type of Accident - Rear End Collision at Signalized Intersections

Possible Counter Measures -

12) Provide proper signalized progression.
13) Reduce speed limit on approaches.
14) Install backplates, larger lens, louvers, visors, etc. on traffic signal to improve contrast and visibility.
15) Relocate signals.
16) Add additional signal heads.
17) Improve roadway lighting.

INTERSECTION ACCIDENTS

Type of Accident - Pedestrian - Vehicle Collision

Probable Causes -

1) Inadequate pavement markings.
2) Inadequate channelization.
3) Improper signal phasing.
4) Restricted sight distance.
5) Inadequate pedestrian signals.
6) Inadequate roadway lighting.
7) Inadequate gaps at unsignalized intersection.
8) Excessive vehicle speed.

Study to be Performed -

1) Field observation for sight obstructions.
2) Pedestrian volume count.
3) Review channelization.
4) Check roadway illumination.
5) Review pavement markings.
6) Review signal phasing.
7) Perform gap studies.
8) Perform spot speed study.

Possible Counter Measures -

1) Install pedestrian crosswalks and signs.
2) Install pedestrian barriers.
3) Prohibit curb parking near crosswalks.
4) Install traffic signal if warranted by MUTCD.
5) Install pedestrian walk - don't walk signals.
6) Increase timing of pedestrian phase.
7) Improve roadway lighting.
8) Prohibit vehicle turning movements.
9) Remove sight obstructions.
10) Reroute pedestrian paths.
11) Reduce speed limits on approaches if justified by spot speed studies.
12) Use crossing guards at school crossing areas.

INTERSECTION ACCIDENTS.

Type of Accident - Right Angle Collisions at Signalized Intersections

Probable Causes -

1) Restricted sight distances.
2) Inadequate roadway lighting.
3) Inadequate advance intersection warning signs.
4) Poor visibility of signal indication.
7) Excessive speed on approaches.

Study to be Performed -

1) Volume count on all approaches.
2) Field observations for sight obstructions.
3) Review signal timing.
4) Check roadway illumination.
5) Perform spot speed study.

Possible Counter Measures -

1) Remove obstructions to sight distance.
2) Increase amber phase.
3) Provide all red phase.
4) Retime signals.
5) Prohibit curb parking.
6) Install advance intersection warning signs.
7) Install backplates, larger lens, louvers, visors, etc., on traffic signal to improve contrast and visibility.
8) Install additional signal heads.
9) Reduce speed limit on approaches if justified by spot speed studies.
10) Provide proper signalized progression.
11) Improve location of signal heads.

INTERSECTION ACCIDENTS

Type of Accident - Right Angle Collisions at Unsignalized Intersections

Probable Causes -
1) Restricted sight distance.
2) Inadequate roadway lighting.
3) Inadequate intersection warning signs.
4) Inadequate traffic control devices.
5) Excessive speed on approaches.

Study to be Performed -
1) Volume count on all approaches.
2) Field observation for sight obstructions.
3) Check roadway illumination.
4) Perform spot speed study.
5) Review signing.

Possible Countermeasures -
1) Remove obstructions to sight distance.
2) Prohibit parking near corners.
3) Improve roadway illumination.
4) Install yield or stop signs if MUTCD warrants are met.
5) Install traffic signal if MUTCD warrants are met.
6) Install advance intersection warning signs.
7) Reduce speed limits on approaches if justified by spot speed studies.

INTERSECTION ACCIDENTS

Type of Accident - Sideswipe Collisions

Probable Causes -
1) Inadequate pavement markings.
2) Inadequate channelization.
3) Inadequate signing.
4) Narrow traffic lanes.
5) Improper street alignment.

Study to be Performed -
1) Review pavement markings.
2) Review channelization.
3) Review sign placement.
4) Review lane width.
5) Check alignment.

Possible Counter Measures -
1) Provide wider lanes.
2) Install acceleration and deceleration lanes.
3) Place direction and lane change signs to give proper advance warning.
4) Install or refurbish centerlines, lane lines and pavement edge lines.
5) Provide turning bays.
6) Provide proper alignment.

LINK ACCIDENTS

Type of Accident - Off-Road Accidents

Probable Causes -

1) Inadequate signing and delineators.
2) Inadequate pavement marking.
3) Inadequate roadway lighting.
4) Slippery surface.
5) Improper channelization.
6) Inadequate shoulders.
7) Inadequate pavement maintenance.
8) Inadequate superelevation.
9) Severe curve.
10) Severe grade.

Study to be Performed -

1) Review signs and placement.
2) Review pavement marking.
3) Check roadway illumination.
4) Check skid resistance.
5) Review channelization.
6) Check roadside shoulders and road maintenance.
7) Check superelevation.
8) Check for adequate drainage.
9) Perform spot speed studies.

Possible Countermeasures -

1) Install proper center lines, lane lines, and pavement edge markings.
2) Increase skid resistance.
3) Improve roadway lighting.
4) Install warning signs to give proper advance warning and advisory speed limit.
5) Install roadside delineators, guard rails and redirecting barriers.
6) Perform necessary road surface repairs.
7) Improve superelevation at curves.
8) Reduce speed limit if justified by spot speed studies.
9) Upgrade roadway shoulders.
10) Provide "Slippery When Wet" signs. (interim measure only
11) Provide adequate drainage.
12) Flatten curve.
13) Provide proper superelevation.

LINK ACCIDENTS

Type of Accident - Head-on Collisions

Probable Causes -

1) Restricted sight distance.
2) Inadequate pavement markings.
3) Inadequate signing.
4) Narrow lanes.
5) Inadequate shoulders and/or maintenance.
6) Inadequate road maintenance.
7) Excessive vehicle speed.
8) Severe curve.
9) Severe grade.

Study to be Performed -

1) Review lane width.
2) Review pavement markings.
3) Review signing.
4) Check road shoulders where present.
5) Check road for proper maintenance.
6) Perform spot speed studies.
7) Field check for sight obstructions.

Possible Countermeasures -

1) Provide wider lanes.
2) Provide pennant signs.
3) Install no passing zones at points with restricted sight distances.
4) Install centerlines, lane lines and pavement edge markings.
5) Improve roadside shoulders.
6) Perform necessary road surface repairs.
7) Reduce speed limits if justified by spot speed studies.
8) Remove obstructions to sight distances.
9) Flatten curve.
10) Provide proper superelevation.

LINK ACCIDENTS

Type of Accident - Pedestrian - Vehicle Collisions

Probable Causes -

1) Restricted sight distance.
2) Inadequate roadway lighting.
3) Excessive vehicle speed.
4) Pedestrians walking on roadway.
5) Inadequate signing.
6) Sidewalks too close to roadway.
7) Improper pedestrian crossing.

Study to be Performed

1) Check sight distances.
2) Check roadway illumination.
3) Review existence of sidewalks.
4) Review warning signs and placement.
5) Perform spot speed study.

Possible Countermeasures -

1) Improve sight distance.
2) Prohibit curb side parking.
3) Improve roadway lighting.
4) Install sidewalks.
5) Install proper warning signs.
6) Reduce speed limit if justified by spot speed studies.
7) Install pedestrian barriers.
8) Move sidewlaks further from roadway.
9) Enforcement.

LINK ACCIDENTS

Type of Accident - Railroad Crossing Accidents

Probable Causes -

1) Inadequate signing, signals or gates.
2) Inadequate roadway lighting.
3) Restricted sight distance.
4) Inadequate pavement markings.
5) Rough crossing surfaces.
6) Improper traffic signal pre-emption timing.
7) Improper pre-emption timing of RR signals or gates.

Study to be Performed -

1) Review signing, signals and gates.
2) Check roadway illumination.
3) Review pavement markings.
4) Review sight distance.

Possible Countermeasures -

1) Install advance warning signs.
2) Install proper pavement markings.
3) Install proper roadway lighting on both sides of tracks.
4) Install automatic flashers and gates.
5) Improve sight distance.
6) Install stop signs.
7) Rebuild crossing.
8) Retime traffic signals
9) Retime RR signals and gates.

NOTE: For assistance in examining railroad crossing problems, it is recommended that agencies contact the Michigan Department of State Highways and Transportation, Transportation Regulatory Section.

LINK ACCIDENTS

Type of Accident - Parked Car Accidents

Probable Causes -

1) Improper pavement markings.
2) Improper parking clearance at driveways.
3) Angle parking.
4) Excessive vehicle speed.
5) Improper parking.
6) Illegal parking.

Study to be Performed -

1) Review pavement markings.
2) Review parking clearance from curb.
3) Review angle parking if it exists.
4) Perform spot speed studies.
5) Law observance study.

Possible Countermeasures -

1) Convert angle parking to parallel parking.
2) Paint parking stall limits 7 feet from curb face.
3) Post parking restrictions near driveways.
4) Prohibit parking.
5) Create off-street parking.
6) Reduce speed limit if justified by spot speed studies.
7) Widen lanes.
8) Enforcement.

LINK ACCIDENTS

Type of Accident - Fixed Object Collisions

Probable Causes -

1) Obstructions in or too close to roadway.
2) Inadequate channelization.
3) Inadequate roadway lighting.
4) Inadequate pavement marking.
5) Inadequate signs, delineators and guardrails.
6) Improper superelevation.
7) Slippery surface.
8) Excessive vehicle speed.
9) Severe curve.
10) Severe grade.

Study to be Performed -

1) Review pavement markings, signs and delineators.
2) Review channelization.
3) Field observation to locate obstructions.
4) Check illumination.
5) Check superelevation.
6) Check for adequate drainage.
7) Perform spot speed studies.

Possible Countermeasures -

1) Remove or relocate objects.
2) Improve roadway lighting.
3) Install reflectorized pavement lines.
4) Install reflectorized paint and/or reflectors on the obstruction.
5) Install crash cushioning devices.
6) Install guardrails or redirecting barriers.
7) Install appropriate warning signs and delineators.
8) Improve superelevation at curves.
9) Improve skid resistance.
10) Provide adequate drainage.
11) Provide "Slippery When Wet" signs. (interim measure only
12) Reduce speed limit if justified by spot speed studies.
13) Provide wider lanes.
14) Flatten curve.
15) Provide proper superelevation.

LINK ACCIDENTS

Type of Accident - Sideswipe Collision

Probable Causes -

1) Inadequate pavement markings.
2) Inadequate channelization.
3) Inadequate signing.
4) Narrow traffic lanes.
5) Improper road maintenance.
6) Inadequate roadside shoulders.
7) Excessive vehicle speed.

Study to be Performed -

1) Review pavement markings.
2) Review channelization.
3) Review sign placement.
4) Review lane width.
5) Check roadside shoulders.
6) Check road surface for proper maintenance.
7) Perform spot speed studies.

Possible Countermeasures -

1) Provide wider lanes.
2) Install acceleration and deceleration lanes.
3) Place direction and lane change signs to give proper advance warning.
4) Install or refurbish center lines, lane lines and pavement edge lines.
5) Perform necessary road surface repairs.
6) Improve shoulders.
7) Remove constrictions such as parked vehicles.
8) Install median divider.
9) Reduce speed limit if justified by spot speed study.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Right-angle collisions at unsignalized intersections	Restricted sight distance	Remove sight obstructions Restrict parking near corners Install stop signs (see MUTCD) Install warning signs (see MUTCD) Install/improve street lighting Reduce speed limit on approaches* Install signals (see MUTCD) Install yield signs (see MUTCD) Channelize intersection
	Large total intersection volume	Install signals (see MUTCD) Reroute through traffic
	High approach speed	Reduce speed limit on approaches* Install rumble strips
Right-angle collisions at signalized intersections (Continued)	Poor visibility of signals (Continued)	Install advanced warning devices (see MUTCD) Install 12-in. signal lenses (see MUTCD) Install overhead signals Install visors Install back plates

* Spot speed study should be conducted to justify speed limit reduction.

Source: Manual on Identification, Analysis, and Correction of High- Accident Locations, 1976.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
		Improve location of signal heads Add additional signal heads Reduce speed limit on approaches*
	Inadequate signal timing	Adjust amber phase Provide all-red clearance phases Add multi-dial controller Install signal actuation Retime signals Provide progression through a set of signalized intersections
Rear-end collisions at unsignalized intersections	Pedestrian crossing	Install/improve signing or marking of pedestrian crosswalks Relocate crosswalk
	Driver not aware of intersection	Install/improve warning signs
(Continued)	Slippery surface	Overlay pavement Provide adequate drainage Groove pavement Reduce speed limit on approaches* Provide "SLIPPERY WHEN WET" signs

* Spot speed study should be conducted to justify speed limit reduction.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
	Large numbers of turning vehicles	Create left- or right-turn lanes Prohibit turns Increase curb radii
Rear-end collisions at signalized intersections	Poor visibility of signals	Install/improve advance warning devices Install overhead signals Install 12 in. signal lenses (see MUTCD) Install visors Install back plates Relocate signals Add additional signal heads Remove obstacles Reduce speed limits on approaches*
	Inadequate signal timing	Adjust amber phase Provide progression through a set of signalized intersections
(Continued)	Pedestrian crossings	Install/improve signing or marking of pedestrian crosswalks Provide pedestrian "WALK" phase

* Spot speed study should be conducted to justify speed limit reduction.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
	Slippery surface	Overlay pavement Provide adequate drainage Groove pavement Reduce speed limit on approaches* Provide "SLIPPERY WHEN WET" signs
	Unwarranted signals	Remove signals (see MUTCD)
	Large turning volumes	Create left- or right-turn lanes Prohibit turns Increase curb radii
Pedestrian accidents at intersections	Restricted sight distance	Remove sight obstructions Install pedestrian crossings Improve/install pedestrian crossing signs Reroute pedestrian paths
	Inadequate protection for pedestrians	Add pedestrian refuge islands
	Inadequate signals	Install pedestrian signals (see MUTCD)
(Continued)	Inadequate signal phasing	Add pedestrian "WALK" phase Change timing of pedestrian phase

* Spot speed study should be conducted to justify speed limit reduction.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
	School crossing area	Use school crossing guards
Pedestrian accidents between intersections	Driver has inadequate warning of frequent mid-block crossings	Prohibit parking Install warning signs Lower speed limit* Install pedestrian barriers
	Pedestrians walking on roadway	Install sidewalks
	Long distance to nearest crosswalk	Install pedestrian crosswalk Install pedestrian actuated signals (see MUTCD)
Pedestrian accidents at driveway crossings	Sidewalk too close to traveled way	Move sidewalk laterally away from highway
Left-turn collisions at intersections (Continued)	Large volume of left turns	Provide left-turn signal phases Prohibit left turns Reroute left-turn traffic Channelize intersection Install STOP signs (see MUTCD) Create one-way streets Provide turning guidelines (if there is a dual left-turn lane)

* Spot speed study should be conducted to justify speed limit reduction.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
	Restricted sight distance	Remove obstacles Install warning signs Reduce speed limit on approaches*
Right-turn collisions at intersections	Short turning radii	Increase curb radii
Fixed-object collisions	Objects near traveled way	Remove obstacles near roadway Install barrier curbing Install breakaway feature to light poles, signposts, etc. Protect objects with guardrail
Fixed-object collisions and/or vehicles running off roadway	Slippery pavement	Overlay existing pavement Provide adequate drainage Groove existing pavement Reduce speed limit* Provide "SLIPPERY WHEN WET" signs
(Continued)	Roadway design inadequate for traffic conditions	Widen lanes Relocate islands Close curb lane

* Spot speed study should be conducted to justify speed limit reduction.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
	Poor delineation	Improve/install pavement markings Install roadside delineators Install advance warning signs (e.g., curves)
Sideswipe collisions between vehicles traveling in opposite directions or head-on collisions	Roadway design inadequate for traffic conditions	Install/improve pavement markings Channelize intersections Create one-way streets Remove constrictions such as parked vehicles Install median divider Widen lanes
Collisions between vehicles traveling in same direction such as sideswipe, turning or lane changing	Roadway design inadequate for traffic conditions	Widen lanes Channelize intersections Provide turning bays Install advance route or street signs Install/improve pavement lane lines Remove parking Reduce speed limit*
Collisions with parked cars or cars being parked (Continued)	Large parking turnovers (Continued)	Prohibit parking Change from angle to parallel parking Reroute through traffic Create one-way streets

* Spot speed study should be conducted to justify speed limit reduction.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
		Create off-street parking Reduce speed limit*
	Roadway design inadequate for present conditions	Widen lanes Change from angle to parallel parking Prohibit parking Reroute through traffic
Collisions at driveways	Left-turning vehicles	Install median divider Install two-way left-turn lanes
	Improperly located driveway	Regulate minimum spacing of driveways Regulate minimum corner clearance Move driveway to side street Install curbing to define driveway location Consolidate adjacent driveways
(Continued)	Right-turning vehicles	Provide right-turn lanes Restrict parking near driveways Increase the width of the driveway Widen through lanes Increase curb radii

* Spot speed study should be conducted to justify speed limit reduction.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
	Large volume of through traffic	Move driveway to side street Construct a local service road Reroute through traffic
	Large volume of driveway traffic	Signalize driveway Provide acceleration and deceleration lanes Channelize driveway
	Restricted sight distance	Remove sight obstructions Restrict parking near driveway Install/improve street lighting Reduce speed limit*
Night accidents	Poor visibility	Install/improve street lighting Install/improve delineation markings Install/improve warning signs
Wet pavement accidents	Slippery pavement	Overlay existing pavement Provide adequate drainage Groove existing pavement Reduce speed limit* Provide "SLIPPERY WHEN WET" signs

* Spot speed study should be conducted to justify speed limit reduction.

General Countermeasures for Accident Patterns and Their Probable Causes

ACCIDENT PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Collisions at railroad crossings	Restricted sight distance	Remove sight obstructions Reduce grades Install train actuated signals (see MUTCD) Install stop signs (see MUTCD) Install gates (see MUTCD) Install advance warning signs (see MUTCD)

APPENDIX F

ACCIDENT REDUCTION FACTORS

The accident reduction factors and the material describing the use of the factors was taken from "The Accident Reduction Factors Booklet," pages 16-18 and pages 21-29. The material included in this appendix only addresses accident reduction factors related to intersection conditions. The user should consult the booklet for factors related to other geometric and safety conditions.

chapter 4

Using AR factors

You can use the AR factors in Chapters 5 and 6 to do the following things:

1. Design and plan your overall highway safety improvement program.
2. Select improvement types for a specific problem.
3. Compute the cost-effectiveness of a specific improvement.

This chapter outlines a variety of situations in which the AR factor tables can be used.

SITUATION ONE

You are the head of the traffic engineering section. The state highway administrator is preparing legislative and budgetary recommendations and requests for the highway safety improvement program. He also is trying to encourage counties to join the state in a highly visible and concerted highway improvement effort. He wants to target certain improvement types. He asks you which five improvement types should be encouraged.

You don't want to gamble. So first, you review the general AR factors and select all improvements with an Index of Variability of 1 (or 2, if "1" is too restrictive). Then you review the refined AR factors for the selected improvements to see how AR factors differ relative to location characteristics. You decide to use improvements with wide spread effectiveness or you choose to zero in on a particular location type with an AR factor over 20% and a low Index of Variability. Any variety of rationale could be used to make your final selection. No matter what rationale you used, the AR factor tables contain enough information to allow a rational selection process. You can report your selections to the state highway administrator and have a basis for justifying them.

SITUATION TWO

You are a traffic engineer assigned the task of selecting potential improvements for a location identified as "hazardous" based on accident experience.

You analyze the types of accidents occurring at the location. If a clear pattern is apparent, you check the eight improvement objectives and select the appropriate corresponding AR factor subsets. Then, you go to the selected subsets and review the Affected Accident Matrix and the Refined AR factors to find improvements that affect the type of accident being experienced.

SITUATION THREE

You are the same engineer as in situation two. You are aware that AR factors are averages and that if the variation about that average is wide enough that there is some chance of failure. You want to minimize that chance. Therefore, you reject any improvement that does not meet the following criteria:

1. If the reduction factor is 0 to 15, the Index of Variability must be 1.
2. If the reduction factor is 15 to 35, the Index of Variability must be 2 or better.
3. If the factor is 35 to 55, the Index must be 3 or better.
4. If the factor is 55 to 85, the Index must be 4 or better.
5. If the factor is over 85, any Index will suffice.

Essentially you are saying that you will not accept an improvement whose expected range extends into the zone of net accident increase.

SITUATION FOUR

You are the planning and programming engineer and are developing cost and benefit data for a list of improvements from which only a limited number of projects are going to be installed this program period. The Indexes of Variability of the AR factors for the improvements are not all the same. You decide you want to give some advantage to improvements with low variability in the estimated range. Therefore, you arbitrarily adjust the calculated benefits according to the following schedule:

1. For Index 1--no adjustment.
2. For Index 2 or 6--10% reduction.
3. For Index 3 or 7--20% reduction.
4. For Index 4 or 8--30% reduction.
5. For Index 5 or 9--40% reduction.

As stated above, such a step is arbitrary, but valid nonetheless. In the real world project selection is not a 100% automatic process. Judgement and policy preferences play an important role. This situation demonstrates how judgement may be reflected in a quantitative way.

SITUATION FIVE

Again, you are developing cost and benefit data. The AR factor is an essential input into the benefit side of the equation. NCHRP Report 162 contains several methods for computing accident reduction benefits. Refer to Appendixes E, F and Q. In these methods, you first compute annual benefits and then compute the monetary value of these benefits. The equations for computing annual benefits require an accident reduction expressed as a decimal, and which is the expected reduction in the accident rate. If necessary you may use an AR factor based on reduction in numbers of accidents. Factors based on numbers of accidents usually are less accurate but more conservative--lower--than these based on accident rates. This is due to the fact that traffic volumes usually

AR FACTORS
SUBSET A

OBJECTIVE: To reduce numbers of accidents related to poor perception of the existance of and conditions at intersections and other points of conflict.

IMPROVEMENT TYPES:

Name	Page	Code
Advanced Warring Signs	24	A-60
Advanced Warning Signals	25	A- 2
Rumble Strips	26	A- 3
Sight Distance Improvements (FHWA Code 13)	28	A-13
Lighting (FHWA Code 65)	29	A-65

GENERAL COMMENTARY:

Studies of individual applications indicate good success where a clear link has been established between the accident problem and limited sight distance or other things that limit a driver's ability to perceive the presence of an intersection or its configuration or other information to make safe driving decisions.

Warning Devices

Warning signs appear to have a more consistent success record than advanced warning signals or rumble strips. Signs often are the first improvement made at locations where an accident problem has developed and where no warning device existed before. On the other hand, signals or rumble strips generally are installed to supplement existing signs. Hence, signs are more likely to reap success at untreated sites than supplemental improvements to previously treated sites. Low volume, rural unlighted intersections are most likely to need advance warning devices because of poorer geometrics and fewer visual cues. Visual cues are related to activity or development at a location.

Sight Distance Improvements

Accident reduction factors for sight distance improvements at intersections were developed from the Annual Report data. Most improvements have been applied to rural, undivided situations. Success rates have been higher and more statistically significant at low volume locations.

Lighting

By adding illumination to a location some nighttime accidents can be eliminated. When estimating the number that will be eliminated, it is difficult to determine to what extent the nighttime accident problem is related to darkness. Lighting projects according to the Annual Report data have a mixed record of success which averages out as a modest success. Careful analysis of each location is necessary. For more detailed information related to highway arterial lighting see the report by Janoff, et al (31).

AFFECTED ACCIDENT MATRIX FOR SUBSET A

TYPE OF IMPROVEMENT	ACCIDENT TYPE AFFECTED																					
															Lt. Cond.			Pvt. Cond.				
	All Accidents	Overturned	Pedestrian	Train	Pedalcyclist	Fixed Object	Parked M.V.	Rear-End	Head-On	Sideswipe (S.D.)	Sideswipe (O.D.)	Angle	Turning (L.)	Turning (R.)	Ran Off Road	Daylight	Darkness	Dk. Rd. Ltd.	Dry	Wet	Ice/Snow		Hour (specify)
Warning Signs	X															X	X	X	X	X	X		
Warning Signals	X															X	X	X	X	X	X		
Rumble Strips	X			X												X	X	X	X	X	X		
Improve Sight Distrance								X				X				X	X			X	X		
Lighting			X		X																		

AR factors

Type of Improvement: Warning Signs at Intersections

Refined Description: See Below

Code A-60

General AR factors

	Type of Accident				
	All	Fatal	Injury	Fatal/Injury	PDO
Reduction %	20			25	
Index of Variability	6			6	
Source Reference	33			33	

Refined AR factors

Description Refinements: Location Characteristics [1]	Type of Accident	% AR [2]	Index of Var.	Ref.
Stop Ahead @ Rural, 2 lane intersections	Fatal/Injury	96	2	33
	Total	47	2	33
Warning Signs @ Rural, 2 lanes	Fatal/Injury	19	2	33
	Total	37	2	33
" " " , more than 2 lanes	Fatal/Injury	-7	2	33
	Total	9	2	33
" " " , 2 lanes,	Fatal/Injury	43	4	33
tee intersection	Total	61	2	33
" " " , more than 2 lanes	Fatal/Injury	67	2	33
	Total	65	2	33
" " @ Urban, 2 lane intersec-	Fatal/Injury	51	3	33
tion	Total	29	2	33
" " " , more than 2 lanes	Fatal/Injury	47	3	33
	Total	41	2	33

1 Group I includes HH, RO, RR and FA programs. Group II includes SL, SO and SR programs.

2 Numbers in italics represent reductions in numbers. All other AR factors are reductions in accident rates.

AR factors

Type of Improvement: Advanced Warning Signals & Intersections

Refined Description: See Below

Code A-2

General AR factors

	Type of Accident				
	All	Fatal	Injury	Fatal/Injury	PDO
Reduction %	20	40	30		15
Index of Variability	9	9	9		9
Source Reference	66	66	66		66

Refined AR factors

Description Refinements: Location Characteristics [1]	Type of Accident	% AR [2]	Index of Var.	Ref.
Rural, 2 lane	Fatal/Injury	29	2	33
	Total	46	5	33
" , more than 2 lanes, tee intersec-	Fatal/Injury	--	-	33
tion	Total	21	5	33
Urban, More than 2 lanes	Fatal/Injury	73	5	33
	Total	-27	5	33

1 Group I includes HH, RO, RR and FA programs. Group II includes SL, SO and SR programs.

2 Numbers in italics represent reductions in numbers. All other AR factors are reductions in accident rates.

AR factors

Type of Improvement: Rumble Strips

Refined Description: No Refinements

Code A-3

General AR factors

	Type of Accident				
	All	Fatal	Injury	Fatal/Injury	PDO
Reduction %	27			26	
Index of Variability	5			5	
Source Reference	33			33	

Refined AR factors

Description Refinements — Location Characteristics [1]	Type of Accident	% AR [2]	Index of Var.	Ref.
At horizontal curves	Fatal	60	9	66
	Injury	40	9	66
	PDO	25	9	66
	Total	30	9	66
At railroad crossings	Fatal	50	9	66
	Injury	30	9	66
	PDO	15	9	66
	Total	20	9	66
At constrictions	Fatal	60	9	66
	Injury	40	9	66
	PDO	25	9	66
	Total	20	9	66
At intersections	Fatal	50	9	66
	Injury	30	9	66

[1] Group I includes HH, RO, RR and FA programs. Group II includes SL, SO and SR programs.

[2] Numbers in italics represent reductions in numbers. All other AR factors are reductions in accident rates.

AR factors

Type of Improvement: Rumble Strips

Refined Description: No Refinements

Code A-3

Page 2 of 2

Refined AR factors

Description Refinements — Location Characteristics	Type of Accident	% AR	Index of Var.	Ref.
At intersections	PDO	15	9	66
	Total	20	9	66

AR factors

Type of Improvement Sight Distance Improvements

Refined Description @ Intersections (See Below)

Code A-13

General AR factors

	Type of Accident				
	All	Fatal	Injury	Fatal/Injury	PDO
Reduction %	*27*	*59*	*20*	*22*	*29*
Index of Variability	2	4	3	3	2
Source Reference	74	74	74	74	74

Refined AR factors

Description Refinements: Location Characteristics [1]	Type of Accident	% AR [2]	Index of Var.	Ref.
Rural, Group I	Fatal	50	5	74
	Injury	1	4	74
	PDO	30	3	74
	Total	23	2	74
Rural, Group II	Fatal	64	4	74
	Injury	22	3	74
	PDO	43	2	74
	Total	37	2	74
All Locations	Angle	*50*	9	54

[1] Group I includes HH, RO, RR and FA programs. Group II includes SL, SO and SR programs.

[2] Numbers in italics represent reductions in numbers. All other AR factors are reductions in accident rates.

AR factors

Type of Improvement Lighting

Refined Description In General

Code A-65

General AR factors

	Type of Accident				
	All	Fatal	Injury	Fatal/Injury	PDO
Reduction %	12	38	-12	-11	-1
Index of Variability	1	4			2
Source Reference	74	74		74	74

Refined AR factors

Description Refinements: Location Characteristics [1]	Type of Accident	% AR [2]	Index of Var.	Ref.
Group II, Urban	Fatal	*100*	5	74
	Injury	*-15*	2	74
	PDO	*-4*	2	74
	Total	*-8*	2	74
Group II, Urban, divided, 4 lanes	Fatal	*100*	5	74
	Injury	*-18*	2	74
	PDO	*-5*	2	74
	Total	*-10*	2	74
Not Specified	Total-Night	50	8	8

[1] Group I includes HH, RO, RR and FA programs. Group II includes SL, SO and SR programs.

[2] Numbers in italics represent reductions in numbers. All other AR factors are reductions in accident rates.

Appendix G

7% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR	SINGLE PAYMENT: PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES: COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES: SINKING FUND FACTOR	EQUAL PAYMENT SERIES: PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES: CAPITAL RECOVERY FACTOR
1	1.070	0.9346	1.000	1.0000	0.9346	1.0700
2	1.145	0.8734	2.070	0.4831	1.8080	0.5531
3	1.225	0.8163	3.215	0.3111	2.6243	0.3811
4	1.311	0.7629	4.440	0.2252	3.3872	0.2952
5	1.403	0.7130	5.751	0.1739	4.1002	0.2439
6	1.501	0.6663	7.153	0.1398	4.7665	0.2098
7	1.606	0.6227	8.654	0.1156	5.3893	0.1856
8	1.718	0.5820	10.260	0.0975	5.9713	0.1675
9	1.838	0.5439	11.978	0.0835	6.5152	0.1535
10	1.967	0.5083	13.816	0.0724	7.0236	0.1424
11	2.105	0.4751	15.784	0.0634	7.4987	0.1334
12	2.252	0.4440	17.888	0.0559	7.9427	0.1259
13	2.410	0.4150	20.141	0.0497	8.3577	0.1197
14	2.579	0.3878	22.550	0.0443	8.7455	0.1143
15	2.759	0.3624	25.129	0.0398	9.1079	0.1098
16	2.952	0.3387	27.888	0.0359	9.4466	0.1059
17	3.159	0.3166	30.840	0.0324	9.7632	0.1024
18	3.380	0.2959	33.999	0.0294	10.0591	0.0994
19	3.617	0.2765	37.379	0.0268	10.3356	0.0968
20	3.870	0.2584	40.995	0.0244	10.5940	0.0944
21	4.141	0.2415	44.865	0.0223	10.8355	0.0923
22	4.430	0.2257	49.006	0.0204	11.0612	0.0904
23	4.741	0.2109	53.436	0.0187	11.2722	0.0887
24	5.072	0.1971	58.177	0.0172	11.4693	0.0872
25	5.427	0.1842	63.249	0.0158	11.6536	0.0858
26	5.807	0.1722	68.676	0.0146	11.8258	0.0846
27	6.214	0.1609	74.484	0.0134	11.9867	0.0834
28	6.649	0.1504	80.698	0.0124	12.1371	0.0824
29	7.114	0.1406	87.347	0.0114	12.2777	0.0814
30	7.612	0.1314	94.461	0.0106	12.4090	0.0806
31	8.145	0.1228	102.073	0.0098	12.5318	0.0798
32	8.715	0.1147	110.218	0.0091	12.6466	0.0791
33	9.325	0.1072	118.933	0.0084	12.7538	0.0784
34	9.978	0.1002	128.259	0.0078	12.8540	0.0778
35	10.677	0.0937	138.237	0.0072	12.9477	0.0772
36	11.424	0.0875	148.913	0.0067	13.0352	0.0767
37	12.224	0.0818	160.337	0.0062	13.1170	0.0762
38	13.079	0.0765	172.561	0.0058	13.1935	0.0758
39	13.995	0.0715	185.640	0.0054	13.2649	0.0754
40	14.974	0.0668	199.635	0.0050	13.3317	0.0750
41	16.023	0.0624	214.610	0.0047	13.3941	0.0747
42	17.144	0.0583	230.632	0.0043	13.4524	0.0743
43	18.344	0.0545	247.776	0.0040	13.5070	0.0740
44	19.628	0.0509	266.121	0.0038	13.5579	0.0738
45	21.002	0.0476	285.749	0.0035	13.6055	0.0735
46	22.473	0.0445	306.752	0.0033	13.6500	0.0733
47	24.046	0.0416	329.224	0.0030	13.6916	0.0730
48	25.729	0.0389	353.270	0.0028	13.7305	0.0728
49	27.530	0.0363	378.999	0.0026	13.7668	0.0726
50	29.457	0.0339	406.529	0.0025	13.8007	0.0725

8% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT COMPOUND AMOUNT FACTOR	SINGLE PAYMENT PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES SINKING FUND FACTOR	EQUAL PAYMENT SERIES PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES CAPITAL RECOVERY FACTOR
1	1.080	0.9259	1.000	1.0000	0.9259	1.0800
2	1.166	0.8573	2.080	0.4808	1.7833	0.5608
3	1.260	0.7938	3.246	0.3080	2.5771	0.3880
4	1.360	0.7350	4.506	0.2219	3.3121	0.3019
5	1.469	0.6806	5.867	0.1705	3.9927	0.2505
6	1.587	0.6302	7.336	0.1363	4.6229	0.2163
7	1.714	0.5835	8.923	0.1121	5.2064	0.1921
8	1.851	0.5403	10.637	0.0940	5.7466	0.1740
9	1.999	0.5002	12.488	0.0801	6.2469	0.1601
10	2.159	0.4632	14.487	0.0690	6.7101	0.1490
11	2.332	0.4289	16.645	0.0601	7.1390	0.1401
12	2.518	0.3971	18.977	0.0527	7.5361	0.1327
13	2.720	0.3677	21.495	0.0465	7.9038	0.1265
14	2.937	0.3405	24.215	0.0413	8.2442	0.1213
15	3.172	0.3152	27.152	0.0368	8.5595	0.1168
16	3.426	0.2919	30.324	0.0330	8.8514	0.1130
17	3.700	0.2703	33.750	0.0296	9.1216	0.1096
18	3.996	0.2502	37.450	0.0267	9.3719	0.1067
19	4.316	0.2317	41.446	0.0241	9.6036	0.1041
20	4.661	0.2145	45.762	0.0219	9.8181	0.1019
21	5.034	0.1987	50.423	0.0198	10.0168	0.0998
22	5.437	0.1839	55.457	0.0180	10.2007	0.0980
23	5.871	0.1703	60.893	0.0164	10.3711	0.0964
24	6.341	0.1577	66.765	0.0150	10.5288	0.0950
25	6.848	0.1460	73.106	0.0137	10.6748	0.0937
26	7.396	0.1352	79.954	0.0125	10.8100	0.0925
27	7.988	0.1252	87.351	0.0114	10.9352	0.0914
28	8.627	0.1159	95.339	0.0105	11.0511	0.0905
29	9.317	0.1073	103.966	0.0096	11.1584	0.0896
30	10.063	0.0994	113.283	0.0088	11.2578	0.0888
31	10.868	0.0920	123.346	0.0081	11.3498	0.0881
32	11.737	0.0852	134.214	0.0075	11.4350	0.0875
33	12.676	0.0789	145.951	0.0069	11.5139	0.0869
34	13.690	0.0730	158.627	0.0063	11.5869	0.0863
35	14.785	0.0676	172.317	0.0058	11.6546	0.0858
36	15.968	0.0626	187.102	0.0053	11.7172	0.0853
37	17.246	0.0580	203.070	0.0049	11.7752	0.0849
38	18.625	0.0537	220.316	0.0045	11.8289	0.0845
39	20.115	0.0497	238.941	0.0042	11.8786	0.0842
40	21.725	0.0460	259.057	0.0039	11.9246	0.0839
41	23.462	0.0426	280.781	0.0036	11.9672	0.0836
42	25.339	0.0395	304.244	0.0033	12.0067	0.0833
43	27.367	0.0365	329.583	0.0030	12.0432	0.0830
44	29.556	0.0338	356.950	0.0028	12.0771	0.0828
45	31.920	0.0313	386.506	0.0026	12.1084	0.0826
46	34.474	0.0290	418.426	0.0024	12.1374	0.0824
47	37.232	0.0269	452.900	0.0022	12.1643	0.0822
48	40.211	0.0249	490.132	0.0020	12.1891	0.0820
49	43.427	0.0230	530.343	0.0019	12.2122	0.0819
50	46.902	0.0213	573.770	0.0017	12.2335	0.0817

9% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

	SINGLE PAYMENT		EQUAL PAYMENT SERIES			
YEAR	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.090	0.9174	1.000	1.0000	0.9174	1.0900
2	1.188	0.8417	2.090	0.4785	1.7591	0.5685
3	1.295	0.7722	3.278	0.3051	2.5313	0.3951
4	1.412	0.7084	4.573	0.2187	3.2397	0.3087
5	1.539	0.6499	5.985	0.1671	3.8897	0.2571
6	1.677	0.5963	7.523	0.1329	4.4859	0.2229
7	1.828	0.5470	9.200	0.1087	5.0330	0.1987
8	1.993	0.5019	11.028	0.0907	5.5348	0.1807
9	2.172	0.4604	13.021	0.0768	5.9952	0.1668
10	2.367	0.4224	15.193	0.0658	6.4177	0.1558
11	2.580	0.3875	17.560	0.0569	6.8052	0.1469
12	2.813	0.3555	20.141	0.0497	7.1607	0.1397
13	3.066	0.3262	22.953	0.0436	7.4869	0.1336
14	3.342	0.2992	26.019	0.0384	7.7862	0.1284
15	3.642	0.2745	29.361	0.0341	8.0607	0.1241
16	3.970	0.2519	33.003	0.0303	8.3126	0.1203
17	4.328	0.2311	36.974	0.0270	8.5436	0.1170
18	4.717	0.2120	41.301	0.0242	8.7556	0.1142
19	5.142	0.1945	46.018	0.0217	8.9501	0.1117
20	5.604	0.1784	51.160	0.0195	9.1285	0.1095
21	6.109	0.1637	56.765	0.0176	9.2922	0.1076
22	6.659	0.1502	62.873	0.0159	9.4424	0.1059
23	7.258	0.1378	69.532	0.0144	9.5802	0.1044
24	7.911	0.1264	76.790	0.0130	9.7066	0.1030
25	8.623	0.1160	84.701	0.0118	9.8226	0.1018
26	9.399	0.1064	93.324	0.0107	9.9290	0.1007
27	10.245	0.0976	102.723	0.0097	10.0266	0.0997
28	11.167	0.0895	112.968	0.0089	10.1161	0.0989
29	12.172	0.0822	124.135	0.0081	10.1983	0.0981
30	13.268	0.0754	136.308	0.0073	10.2737	0.0973
31	14.462	0.0691	149.575	0.0067	10.3428	0.0967
32	15.763	0.0634	164.037	0.0061	10.4062	0.0961
33	17.182	0.0582	179.800	0.0056	10.4644	0.0956
34	18.728	0.0534	196.982	0.0051	10.5178	0.0951
35	20.414	0.0490	215.711	0.0046	10.5668	0.0946
36	22.251	0.0449	236.125	0.0042	10.6118	0.0942
37	24.254	0.0412	258.376	0.0039	10.6530	0.0939
38	26.437	0.0378	282.630	0.0035	10.6908	0.0935
39	28.816	0.0347	309.066	0.0032	10.7255	0.0932
40	31.409	0.0318	337.882	0.0030	10.7574	0.0930
41	34.236	0.0292	369.292	0.0027	10.7866	0.0927
42	37.318	0.0268	403.528	0.0025	10.8134	0.0925
43	40.676	0.0246	440.846	0.0023	10.8380	0.0923
44	44.337	0.0226	481.522	0.0021	10.8605	0.0921
45	48.327	0.0207	525.859	0.0019	10.8812	0.0919
46	52.677	0.0190	574.186	0.0017	10.9002	0.0917
47	57.418	0.0174	626.863	0.0016	10.9176	0.0916
48	62.585	0.0160	684.280	0.0015	10.9336	0.0915
49	68.218	0.0147	746.866	0.0013	10.9482	0.0913
50	74.358	0.0134	815.084	0.0012	10.9617	0.0912

10% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT COMPOUND AMOUNT FACTOR	SINGLE PAYMENT PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES SINKING FUND FACTOR	EQUAL PAYMENT SERIES PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES CAPITAL RECOVERY FACTOR
1	1.100	0.9091	1.000	1.0000	0.9091	1.1000
2	1.210	0.8264	2.100	0.4762	1.7355	0.5762
3	1.331	0.7513	3.310	0.3021	2.4869	0.4021
4	1.464	0.6830	4.641	0.2155	3.1699	0.3155
5	1.611	0.6209	6.105	0.1638	3.7908	0.2638
6	1.772	0.5645	7.716	0.1296	4.3553	0.2296
7	1.949	0.5132	9.487	0.1054	4.8684	0.2054
8	2.144	0.4665	11.436	0.0874	5.3349	0.1874
9	2.358	0.4241	13.579	0.0736	5.7590	0.1736
10	2.594	0.3855	15.937	0.0627	6.1446	0.1627
11	2.853	0.3505	18.531	0.0540	6.4951	0.1540
12	3.138	0.3186	21.384	0.0468	6.8137	0.1468
13	3.452	0.2897	24.523	0.0408	7.1034	0.1408
14	3.797	0.2633	27.975	0.0357	7.3667	0.1357
15	4.177	0.2394	31.772	0.0315	7.6061	0.1315
16	4.595	0.2176	35.950	0.0278	7.8237	0.1278
17	5.054	0.1978	40.545	0.0247	8.0216	0.1247
18	5.560	0.1799	45.599	0.0219	8.2014	0.1219
19	6.116	0.1635	51.159	0.0195	8.3649	0.1195
20	6.727	0.1486	57.275	0.0175	8.5136	0.1175
21	7.400	0.1351	64.002	0.0156	8.6487	0.1156
22	8.140	0.1228	71.403	0.0140	8.7715	0.1140
23	8.954	0.1117	79.543	0.0126	8.8832	0.1126
24	9.850	0.1015	88.497	0.0113	8.9847	0.1113
25	10.835	0.0923	98.347	0.0102	9.0770	0.1102
26	11.918	0.0839	109.182	0.0092	9.1609	0.1092
27	13.110	0.0763	121.100	0.0083	9.2372	0.1083
28	14.421	0.0693	134.210	0.0075	9.3066	0.1075
29	15.863	0.0630	148.631	0.0067	9.3696	0.1067
30	17.449	0.0573	164.494	0.0061	9.4269	0.1061
31	19.194	0.0521	181.943	0.0055	9.4790	0.1055
32	21.114	0.0474	201.138	0.0050	9.5264	0.1050
33	23.225	0.0431	222.252	0.0045	9.5694	0.1045
34	25.548	0.0391	245.477	0.0041	9.6086	0.1041
35	28.102	0.0356	271.024	0.0037	9.6442	0.1037
36	30.913	0.0323	299.127	0.0033	9.6765	0.1033
37	34.004	0.0294	330.039	0.0030	9.7059	0.1030
38	37.404	0.0267	364.043	0.0027	9.7327	0.1027
39	41.145	0.0243	401.448	0.0025	9.7570	0.1025
40	45.259	0.0221	442.593	0.0023	9.7791	0.1023
41	49.785	0.0201	487.852	0.0020	9.7991	0.1020
42	54.764	0.0183	537.637	0.0019	9.8174	0.1019
43	60.240	0.0166	592.401	0.0017	9.8340	0.1017
44	66.264	0.0151	652.641	0.0015	9.8491	0.1015
45	72.890	0.0137	718.905	0.0014	9.8628	0.1014
46	80.180	0.0125	791.795	0.0013	9.8753	0.1013
47	88.197	0.0113	871.975	0.0011	9.8866	0.1011
48	97.017	0.0103	960.172	0.0010	9.8969	0.1010
49	106.719	0.0094	1057.190	0.0009	9.9063	0.1009
50	117.391	0.0085	1163.909	0.0009	9.9148	0.1009

11% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

	SINGLE PAYMENT		EQUAL PAYMENT SERIES			
YEAR	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.110	0.9009	1.000	1.0000	0.9009	1.1100
2	1.232	0.8116	2.110	0.4739	1.7125	0.5839
3	1.368	0.7312	3.342	0.2992	2.4437	0.4092
4	1.518	0.6587	4.710	0.2123	3.1024	0.3223
5	1.685	0.5935	6.228	0.1606	3.6959	0.2706
6	1.870	0.5346	7.913	0.1264	4.2305	0.2364
7	2.076	0.4817	9.783	0.1022	4.7122	0.2122
8	2.305	0.4339	11.859	0.0843	5.1461	0.1943
9	2.558	0.3909	14.164	0.0706	5.5370	0.1806
10	2.839	0.3522	16.722	0.0598	5.8892	0.1698
11	3.152	0.3173	19.561	0.0511	6.2065	0.1611
12	3.498	0.2858	22.713	0.0440	6.4924	0.1540
13	3.883	0.2575	26.212	0.0382	6.7499	0.1482
14	4.310	0.2320	30.095	0.0332	6.9819	0.1432
15	4.785	0.2090	34.405	0.0291	7.1909	0.1391
16	5.311	0.1883	39.190	0.0255	7.3792	0.1355
17	5.895	0.1696	44.501	0.0225	7.5488	0.1325
18	6.544	0.1528	50.396	0.0198	7.7016	0.1298
19	7.263	0.1377	56.939	0.0176	7.8393	0.1276
20	8.062	0.1240	64.203	0.0156	7.9633	0.1256
21	8.949	0.1117	72.265	0.0138	8.0751	0.1238
22	9.934	0.1007	81.214	0.0123	8.1757	0.1223
23	11.026	0.0907	91.148	0.0110	8.2664	0.1210
24	12.239	0.0817	102.174	0.0098	8.3481	0.1198
25	13.585	0.0736	114.413	0.0087	8.4217	0.1187
26	15.080	0.0663	127.999	0.0078	8.4881	0.1178
27	16.739	0.0597	143.079	0.0070	8.5478	0.1170
28	18.580	0.0538	159.817	0.0063	8.6016	0.1163
29	20.624	0.0485	178.397	0.0056	8.6501	0.1156
30	22.892	0.0437	199.021	0.0050	8.6938	0.1150
31	25.410	0.0394	221.913	0.0045	8.7331	0.1145
32	28.206	0.0355	247.324	0.0040	8.7686	0.1140
33	31.308	0.0319	275.529	0.0036	8.8005	0.1136
34	34.752	0.0288	306.837	0.0033	8.8293	0.1133
35	38.575	0.0259	341.590	0.0029	8.8552	0.1129
36	42.818	0.0234	380.164	0.0026	8.8786	0.1126
37	47.528	0.0210	422.982	0.0024	8.8996	0.1124
38	52.756	0.0190	470.511	0.0021	8.9186	0.1121
39	58.559	0.0171	523.267	0.0019	8.9357	0.1119
40	65.001	0.0154	581.826	0.0017	8.9511	0.1117
41	72.151	0.0139	646.827	0.0015	8.9649	0.1115
42	80.088	0.0125	718.978	0.0014	8.9774	0.1114
43	88.897	0.0112	799.065	0.0013	8.9886	0.1113
44	98.676	0.0101	887.963	0.0011	8.9988	0.1111
45	109.530	0.0091	986.639	0.0010	9.0079	0.1110
46	121.579	0.0082	1096.169	0.0009	9.0161	0.1109
47	134.952	0.0074	1217.747	0.0008	9.0235	0.1108
48	149.797	0.0067	1352.700	0.0007	9.0302	0.1107
49	166.275	0.0060	1502.497	0.0007	9.0362	0.1107
50	184.565	0.0054	1668.771	0.0006	9.0417	0.1106

12% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR	SINGLE PAYMENT: PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES: COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES: SINKING FUND FACTOR	EQUAL PAYMENT SERIES: PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES: CAPITAL RECOVERY FACTOR
1	1.120	0.8929	1.000	1.0000	0.8929	1.1200
2	1.254	0.7972	2.120	0.4717	1.6901	0.5917
3	1.405	0.7118	3.374	0.2963	2.4018	0.4163
4	1.574	0.6355	4.779	0.2092	3.0373	0.3292
5	1.762	0.5674	6.353	0.1574	3.6048	0.2774
6	1.974	0.5066	8.115	0.1232	4.1114	0.2432
7	2.211	0.4523	10.089	0.0991	4.5638	0.2191
8	2.476	0.4039	12.300	0.0813	4.9676	0.2013
9	2.773	0.3606	14.776	0.0677	5.3282	0.1877
10	3.106	0.3220	17.549	0.0570	5.6502	0.1770
11	3.479	0.2875	20.655	0.0484	5.9377	0.1684
12	3.896	0.2567	24.133	0.0414	6.1944	0.1614
13	4.363	0.2292	28.029	0.0357	6.4235	0.1557
14	4.887	0.2046	32.393	0.0309	6.6282	0.1509
15	5.474	0.1827	37.280	0.0268	6.8109	0.1468
16	6.130	0.1631	42.753	0.0234	6.9740	0.1434
17	6.866	0.1456	48.884	0.0205	7.1196	0.1405
18	7.690	0.1300	55.750	0.0179	7.2497	0.1379
19	8.613	0.1161	63.440	0.0158	7.3658	0.1358
20	9.646	0.1037	72.052	0.0139	7.4694	0.1339
21	10.804	0.0926	81.699	0.0122	7.5620	0.1322
22	12.100	0.0826	92.503	0.0108	7.6446	0.1308
23	13.552	0.0738	104.603	0.0096	7.7184	0.1296
24	15.179	0.0659	118.155	0.0085	7.7843	0.1285
25	17.000	0.0588	133.334	0.0075	7.8431	0.1275
26	19.040	0.0525	150.334	0.0067	7.8957	0.1267
27	21.325	0.0469	169.374	0.0059	7.9426	0.1259
28	23.884	0.0419	190.699	0.0052	7.9844	0.1252
29	26.750	0.0374	214.583	0.0047	8.0218	0.1247
30	29.960	0.0334	241.333	0.0041	8.0552	0.1241
31	33.555	0.0298	271.293	0.0037	8.0850	0.1237
32	37.582	0.0266	304.848	0.0033	8.1116	0.1233
33	42.092	0.0238	342.429	0.0029	8.1354	0.1229
34	47.143	0.0212	384.521	0.0026	8.1566	0.1226
35	52.800	0.0189	431.663	0.0023	8.1755	0.1223
36	59.136	0.0169	484.463	0.0021	8.1924	0.1221
37	66.232	0.0151	543.599	0.0018	8.2075	0.1218
38	74.180	0.0135	609.831	0.0016	8.2210	0.1216
39	83.081	0.0120	684.010	0.0015	8.2330	0.1215
40	93.051	0.0107	767.091	0.0013	8.2438	0.1213
41	104.217	0.0096	860.142	0.0012	8.2534	0.1212
42	116.723	0.0086	964.359	0.0010	8.2619	0.1210
43	130.730	0.0076	1081.083	0.0009	8.2696	0.1209
44	146.418	0.0068	1211.813	0.0008	8.2764	0.1208
45	163.988	0.0061	1358.230	0.0007	8.2825	0.1207
46	183.666	0.0054	1522.218	0.0007	8.2880	0.1207
47	205.706	0.0049	1705.884	0.0006	8.2928	0.1206
48	230.391	0.0043	1911.590	0.0005	8.2972	0.1205
49	258.038	0.0039	2141.981	0.0005	8.3010	0.1205
50	289.002	0.0035	2400.018	0.0004	8.3045	0.1204

13% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT COMPOUND AMOUNT FACTOR	SINGLE PAYMENT PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES SINKING FUND FACTOR	EQUAL PAYMENT SERIES PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES CAPITAL RECOVERY FACTOR
1	1.130	0.8850	1.000	1.0000	0.8850	1.1300
2	1.277	0.7831	2.130	0.4695	1.6681	0.5995
3	1.443	0.6931	3.407	0.2935	2.3612	0.4235
4	1.630	0.6133	4.850	0.2062	2.9745	0.3362
5	1.842	0.5428	6.480	0.1543	3.5172	0.2843
6	2.082	0.4803	8.323	0.1202	3.9975	0.2502
7	2.353	0.4251	10.405	0.0961	4.4226	0.2261
8	2.658	0.3762	12.757	0.0784	4.7988	0.2084
9	3.004	0.3329	15.416	0.0649	5.1317	0.1949
10	3.395	0.2946	18.420	0.0543	5.4262	0.1843
11	3.836	0.2607	21.814	0.0458	5.6869	0.1758
12	4.335	0.2307	25.650	0.0390	5.9176	0.1690
13	4.898	0.2042	29.985	0.0334	6.1218	0.1634
14	5.535	0.1807	34.883	0.0287	6.3025	0.1587
15	6.254	0.1599	40.417	0.0247	6.4624	0.1547
16	7.067	0.1415	46.672	0.0214	6.6039	0.1514
17	7.986	0.1252	53.739	0.0186	6.7291	0.1486
18	9.024	0.1108	61.725	0.0162	6.8399	0.1462
19	10.197	0.0981	70.749	0.0141	6.9380	0.1441
20	11.523	0.0868	80.947	0.0124	7.0248	0.1424
21	13.021	0.0768	92.470	0.0108	7.1016	0.1408
22	14.714	0.0680	105.491	0.0095	7.1695	0.1395
23	16.627	0.0601	120.205	0.0083	7.2297	0.1383
24	18.788	0.0532	136.831	0.0073	7.2829	0.1373
25	21.231	0.0471	155.620	0.0064	7.3300	0.1364
26	23.991	0.0417	176.850	0.0057	7.3717	0.1357
27	27.109	0.0369	200.841	0.0050	7.4086	0.1350
28	30.633	0.0326	227.950	0.0044	7.4412	0.1344
29	34.616	0.0289	258.583	0.0039	7.4701	0.1339
30	39.116	0.0256	293.199	0.0034	7.4957	0.1334
31	44.201	0.0226	332.315	0.0030	7.5183	0.1330
32	49.947	0.0200	376.516	0.0027	7.5383	0.1327
33	56.440	0.0177	426.463	0.0023	7.5560	0.1323
34	63.777	0.0157	482.903	0.0021	7.5717	0.1321
35	72.069	0.0139	546.681	0.0018	7.5856	0.1318
36	81.437	0.0123	618.749	0.0016	7.5979	0.1316
37	92.024	0.0109	700.187	0.0014	7.6087	0.1314
38	103.987	0.0096	792.211	0.0013	7.6183	0.1313
39	117.506	0.0085	896.198	0.0011	7.6268	0.1311
40	132.782	0.0075	1013.704	0.0010	7.6344	0.1310
41	150.043	0.0067	1146.486	0.0009	7.6410	0.1309
42	169.549	0.0059	1296.529	0.0008	7.6469	0.1308
43	191.590	0.0052	1466.078	0.0007	7.6522	0.1307
44	216.497	0.0046	1657.668	0.0006	7.6568	0.1306
45	244.641	0.0041	1874.165	0.0005	7.6609	0.1305
46	276.445	0.0036	2118.806	0.0005	7.6645	0.1305
47	312.383	0.0032	2395.251	0.0004	7.6677	0.1304
48	352.992	0.0028	2707.633	0.0004	7.6705	0.1304
49	398.881	0.0025	3060.626	0.0003	7.6730	0.1303
50	450.736	0.0022	3459.507	0.0003	7.6752	0.1303

14% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

	Single Payment		Equal Payment Series			
YEAR	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.140	0.8772	1.000	1.0000	0.8772	1.1400
2	1.300	0.7695	2.140	0.4673	1.6467	0.6073
3	1.482	0.6750	3.440	0.2907	2.3216	0.4307
4	1.689	0.5921	4.921	0.2032	2.9137	0.3432
5	1.925	0.5194	6.610	0.1513	3.4331	0.2913
6	2.195	0.4556	8.536	0.1172	3.8887	0.2572
7	2.502	0.3996	10.730	0.0932	4.2883	0.2332
8	2.853	0.3506	13.233	0.0756	4.6389	0.2156
9	3.252	0.3075	16.085	0.0622	4.9464	0.2022
10	3.707	0.2697	19.337	0.0517	5.2161	0.1917
11	4.226	0.2366	23.045	0.0434	5.4527	0.1834
12	4.818	0.2076	27.271	0.0367	5.6603	0.1767
13	5.492	0.1821	32.089	0.0312	5.8424	0.1712
14	6.261	0.1597	37.581	0.0266	6.0021	0.1666
15	7.138	0.1401	43.842	0.0228	6.1422	0.1628
16	8.137	0.1229	50.980	0.0196	6.2651	0.1596
17	9.276	0.1078	59.118	0.0169	6.3729	0.1569
18	10.575	0.0946	68.394	0.0146	6.4674	0.1546
19	12.056	0.0829	78.969	0.0127	6.5504	0.1527
20	13.743	0.0728	91.025	0.0110	6.6231	0.1510
21	15.668	0.0638	104.768	0.0095	6.6870	0.1495
22	17.861	0.0560	120.436	0.0083	6.7429	0.1483
23	20.362	0.0491	138.297	0.0072	6.7921	0.1472
24	23.212	0.0431	158.659	0.0063	6.8351	0.1463
25	26.462	0.0378	181.871	0.0055	6.8729	0.1455
26	30.167	0.0331	208.333	0.0048	6.9061	0.1448
27	34.390	0.0291	238.499	0.0042	6.9352	0.1442
28	39.204	0.0255	272.889	0.0037	6.9607	0.1437
29	44.693	0.0224	312.094	0.0032	6.9830	0.1432
30	50.950	0.0196	356.787	0.0028	7.0027	0.1428
31	58.083	0.0172	407.737	0.0025	7.0199	0.1425
32	66.215	0.0151	465.820	0.0021	7.0350	0.1421
33	75.485	0.0132	532.035	0.0019	7.0482	0.1419
34	86.053	0.0116	607.520	0.0016	7.0599	0.1416
35	98.100	0.0102	693.573	0.0014	7.0700	0.1414
36	111.834	0.0089	791.673	0.0013	7.0790	0.1413
37	127.491	0.0078	903.507	0.0011	7.0868	0.1411
38	145.340	0.0069	1030.998	0.0010	7.0937	0.1410
39	165.687	0.0060	1176.338	0.0009	7.0997	0.1409
40	188.884	0.0053	1342.025	0.0007	7.1050	0.1407
41	215.327	0.0046	1530.909	0.0007	7.1097	0.1407
42	245.473	0.0041	1746.236	0.0006	7.1138	0.1406
43	279.839	0.0036	1991.709	0.0005	7.1173	0.1405
44	319.017	0.0031	2271.548	0.0004	7.1205	0.1404
45	363.679	0.0027	2590.565	0.0004	7.1232	0.1404
46	414.594	0.0024	2954.244	0.0003	7.1256	0.1403
47	472.637	0.0021	3368.838	0.0003	7.1277	0.1403
48	538.807	0.0019	3841.475	0.0003	7.1296	0.1403
49	614.239	0.0016	4380.282	0.0002	7.1312	0.1402
50	700.233	0.0014	4994.521	0.0002	7.1327	0.1402

15% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

YEAR	SINGLE PAYMENT: COMPOUND AMOUNT FACTOR	SINGLE PAYMENT: PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES: COMPOUND AMOUNT FACTOR	EQUAL PAYMENT SERIES: SINKING FUND FACTOR	EQUAL PAYMENT SERIES: PRESENT WORTH FACTOR	EQUAL PAYMENT SERIES: CAPITAL RECOVERY FACTOR
1	1.150	0.8696	1.000	1.0000	0.8696	1.1500
2	1.323	0.7561	2.150	0.4651	1.6257	0.6151
3	1.521	0.6575	3.473	0.2880	2.2832	0.4380
4	1.749	0.5718	4.993	0.2003	2.8550	0.3503
5	2.011	0.4972	6.742	0.1483	3.3522	0.2983
6	2.313	0.4323	8.754	0.1142	3.7845	0.2642
7	2.660	0.3759	11.067	0.0904	4.1604	0.2404
8	3.059	0.3269	13.727	0.0729	4.4873	0.2229
9	3.518	0.2843	16.786	0.0596	4.7716	0.2096
10	4.046	0.2472	20.304	0.0493	5.0188	0.1993
11	4.652	0.2149	24.349	0.0411	5.2337	0.1911
12	5.350	0.1869	29.002	0.0345	5.4206	0.1845
13	6.153	0.1625	34.352	0.0291	5.5831	0.1791
14	7.076	0.1413	40.505	0.0247	5.7245	0.1747
15	8.137	0.1229	47.580	0.0210	5.8474	0.1710
16	9.358	0.1069	55.717	0.0179	5.9542	0.1679
17	10.761	0.0929	65.075	0.0154	6.0472	0.1654
18	12.375	0.0808	75.836	0.0132	6.1280	0.1632
19	14.232	0.0703	88.212	0.0113	6.1982	0.1613
20	16.367	0.0611	102.444	0.0098	6.2593	0.1598
21	18.822	0.0531	118.810	0.0084	6.3125	0.1584
22	21.645	0.0462	137.632	0.0073	6.3587	0.1573
23	24.891	0.0402	159.276	0.0063	6.3988	0.1563
24	28.625	0.0349	184.168	0.0054	6.4338	0.1554
25	32.919	0.0304	212.793	0.0047	6.4641	0.1547
26	37.857	0.0264	245.712	0.0041	6.4906	0.1541
27	43.535	0.0230	283.569	0.0035	6.5135	0.1535
28	50.066	0.0200	327.104	0.0031	6.5335	0.1531
29	57.575	0.0174	377.170	0.0027	6.5509	0.1527
30	66.212	0.0151	434.745	0.0023	6.5660	0.1523
31	76.144	0.0131	500.957	0.0020	6.5791	0.1520
32	87.565	0.0114	577.100	0.0017	6.5905	0.1517
33	100.700	0.0099	664.666	0.0015	6.6005	0.1515
34	115.805	0.0086	765.365	0.0013	6.6091	0.1513
35	133.176	0.0075	881.170	0.0011	6.6166	0.1511
36	153.152	0.0065	1014.346	0.0010	6.6231	0.1510
37	176.125	0.0057	1167.498	0.0009	6.6288	0.1509
38	202.543	0.0049	1343.622	0.0007	6.6338	0.1507
39	232.925	0.0043	1546.165	0.0006	6.6380	0.1506
40	267.864	0.0037	1779.090	0.0006	6.6418	0.1506
41	308.043	0.0032	2046.954	0.0005	6.6450	0.1505
42	354.250	0.0028	2354.997	0.0004	6.6478	0.1504
43	407.387	0.0025	2709.246	0.0004	6.6503	0.1504
44	468.495	0.0021	3116.633	0.0003	6.6524	0.1503
45	538.769	0.0019	3585.128	0.0003	6.6543	0.1503
46	619.585	0.0016	4123.898	0.0002	6.6559	0.1502
47	712.522	0.0014	4743.482	0.0002	6.6573	0.1502
48	819.401	0.0012	5456.005	0.0002	6.6585	0.1502
49	942.311	0.0011	6275.405	0.0002	6.6596	0.1502
50	1083.657	0.0009	7217.716	0.0001	6.6605	0.1501

16% INTEREST FACTORS FOR ANNUAL COMPOUNDING INTEREST

	SINGLE PAYMENT		EQUAL PAYMENT SERIES			
YEAR	COMPOUND AMOUNT FACTOR	PRESENT WORTH FACTOR	COMPOUND AMOUNT FACTOR	SINKING FUND FACTOR	PRESENT WORTH FACTOR	CAPITAL RECOVERY FACTOR
1	1.160	0.8621	1.000	1.0000	0.8621	1.1600
2	1.346	0.7432	2.160	0.4630	1.6052	0.6230
3	1.561	0.6407	3.506	0.2853	2.2459	0.4453
4	1.811	0.5523	5.066	0.1974	2.7982	0.3574
5	2.100	0.4761	6.877	0.1454	3.2743	0.3054
6	2.436	0.4104	8.977	0.1114	3.6847	0.2714
7	2.826	0.3538	11.414	0.0876	4.0386	0.2476
8	3.278	0.3050	14.240	0.0702	4.3436	0.2302
9	3.803	0.2630	17.519	0.0571	4.6065	0.2171
10	4.411	0.2267	21.321	0.0469	4.8332	0.2069
11	5.117	0.1954	25.733	0.0389	5.0286	0.1989
12	5.936	0.1685	30.850	0.0324	5.1971	0.1924
13	6.886	0.1452	36.786	0.0272	5.3423	0.1872
14	7.988	0.1252	43.672	0.0229	5.4675	0.1829
15	9.266	0.1079	51.660	0.0194	5.5755	0.1794
16	10.748	0.0930	60.925	0.0164	5.6685	0.1764
17	12.468	0.0802	71.673	0.0140	5.7487	0.1740
18	14.463	0.0691	84.141	0.0119	5.8178	0.1719
19	16.777	0.0596	98.603	0.0101	5.8775	0.1701
20	19.461	0.0514	115.380	0.0087	5.9288	0.1687
21	22.574	0.0443	134.841	0.0074	5.9731	0.1674
22	26.186	0.0382	157.415	0.0064	6.0113	0.1664
23	30.376	0.0329	183.601	0.0054	6.0442	0.1654
24	35.236	0.0284	213.978	0.0047	6.0726	0.1647
25	40.874	0.0245	249.214	0.0040	6.0971	0.1640
26	47.414	0.0211	290.088	0.0034	6.1182	0.1634
27	55.000	0.0182	337.502	0.0030	6.1364	0.1630
28	63.800	0.0157	392.503	0.0025	6.1520	0.1625
29	74.009	0.0135	456.303	0.0022	6.1656	0.1622
30	85.850	0.0116	530.312	0.0019	6.1772	0.1619
31	99.586	0.0100	616.162	0.0016	6.1872	0.1616
32	115.520	0.0087	715.747	0.0014	6.1959	0.1614
33	134.003	0.0075	831.267	0.0012	6.2034	0.1612
34	155.443	0.0064	965.270	0.0010	6.2098	0.1610
35	180.314	0.0055	1120.713	0.0009	6.2153	0.1609
36	209.164	0.0048	1301.027	0.0008	6.2201	0.1608
37	242.631	0.0041	1510.191	0.0007	6.2242	0.1607
38	281.452	0.0036	1752.822	0.0006	6.2278	0.1606
39	326.484	0.0031	2034.273	0.0005	6.2309	0.1605
40	378.721	0.0026	2360.757	0.0004	6.2335	0.1604
41	439.317	0.0023	2739.478	0.0004	6.2358	0.1604
42	509.607	0.0020	3178.795	0.0003	6.2377	0.1603
43	591.144	0.0017	3688.402	0.0003	6.2394	0.1603
44	685.727	0.0015	4279.546	0.0002	6.2409	0.1602
45	795.444	0.0013	4965.274	0.0002	6.2421	0.1602
46	922.715	0.0011	5760.718	0.0002	6.2432	0.1602
47	1070.349	0.0009	6683.433	0.0001	6.2442	0.1601
48	1241.605	0.0008	7753.782	0.0001	6.2450	0.1601
49	1440.262	0.0007	8995.387	0.0001	6.2457	0.1601
50	1670.704	0.0006	10435.649	0.0001	6.2463	0.1601

Appendix H

FUNDING ISSUES

Section 105 (a) of Title 23 (United States Code) requires each State to submit a program of proposed projects for the utilization of apportioned funds. In accordance with the provisions of FHPM 6-3-2-2 ("Federal-Aid Programs Approval and Authorization"), an annual funding program is required to be submitted to FHWA. The submittal dates, and program content and format are to be determined jointly by the State and the FHWA Division Administrator.

Currently the following highway safety construction programs are:

<u>Program Title</u>

- Rail-Highway Crossings (Section 203 of 1973 Act)
- Pavement Marking Demonstration Program (Title 23, Section 151)
- Hazard Elimination Program (Title 23, Section 152)
- Safer Off-System Roads Program (1976 Highway Act)

Also, the Safer Off-System Roads Progrm (23 USC 219) provides for highway safety construction off the Federal-aid system. Details of the programs are given in Table 15, which includes summary information of (2)

- Type of system for funding
- Priorities and Required Surveys
- Percent of Federal funds
- Other information

Funds can also be used to implement the Highway Safety Program Standards. Primarily, these funds are used for planning and evaluation activities in support of the safety construction program.

Certain guidelines must be satisfied in order for tasks to be eligible for FHWA funding. Fundable tasks should be directed toward "reducing the frequency and severity of motor vehicle accidents", and should be oriented toward long-term benefits.

Tasks involving studies, surveys, inventories, data collection, and analysis, etc. should be directed toward (1):

- Identifying accident locations;
- Defining hazards,
- Determining needs and deficiencies (in the highway-related Standard areas),
- Developing programs for correction of identified hazards (and

Table I . Safety programs.

Program Requirements	Section 203 of 1973 Act Rail-Highway Crossings	23 USC 151 Pavement Marking Demonstration	23 USC 152 Hazard Eliminations	23 USC 402
Surveys	Conduct and maintain: for all highways	None	Conduct and systematically maintain for all highways	None
Priorities	All crossings signed ½ funds for protective devices	Rural areas first	Assignment required	Assignment required
Improvement Schedule	Required	None	Required	HSP required
Funds: Available For	All highway except Interstate	All highways except Interstate	Federal-aid system except Interstate	All public highways
Percent Federal Funds	90	100	90	75 or 100
Reporting States to DOT DOT to Congress	Yes Yes	Yes Yes	Yes Yes	Yes Yes
Miscellaneous	Federal funds may provide local share when State law requires local matching of State funds	Funds not needed may be released for off Federal-Aid system. High Hazard Improvements.		Support Safety Construction

high-accident locations), and
- Evaluating the effectiveness of improvements.

The benefits of tasks must be related to the reduction of traffic deaths, injuries, and property damage. Where practical, the benefits should also be measurable in quantitative terms (1).

According to Section 402 (g) Title 23, United States Code, safety funds may <u>NOT</u> be used for:

- Highway construction, maintenance, or design (other than highway design or safety features to be used in the standards), or

- Any purpose for which funds are authorized by Section 403 of this title.

There are several reasons why Section 402 funds cannot be used for the same purposes for which Section 403 funds are authorized (1):

- To insure that 402 funds are used to help the States initiate new safety activities and improve or expand existing safety activities.

- To insure that research programs are carried out under Section 403.

- To avoid unnecessary duplication of effort and expenditures which would occur if each State undertakes its own safety research and development program with Federal assistance.

Section 403 (Title 23, United States Code) is based on the idea that traffic safety research must be conducted from a total systems viewpoint. It authorized the expansion of the highway safety research and development (R and D) activities under 23 U.S.C. 307 (a) to cover all aspects of highway safety (1).

Guidelines for the funding of specific tasks are described in FHWA order number M75603 Volume 3, Chapter III ("Funding Eligibility"), as given in the Appendix. The tasks described include:

- Field Reference Systems
- Training
- Highway Safety Needs Studies
- Warning and Regulatory Signs
- Skid Resistance Program
- Bridge Inspection
- Equipment Purchases
- Public Information

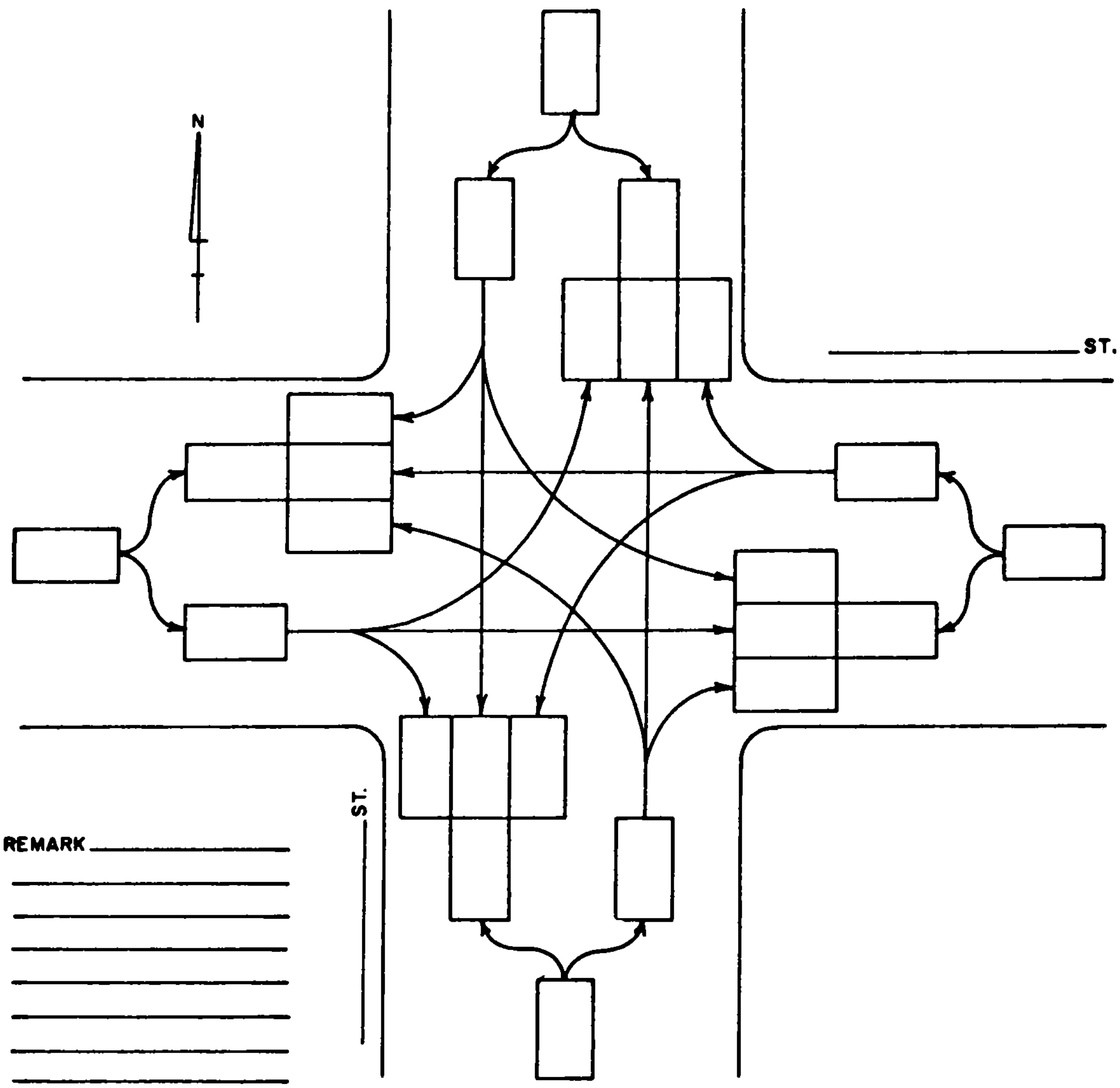
Specific Section 402 support tasks are also listed in the Appendix, as classified under the appropriate Component and Process of the Highway Safety Improvement Program (HSIP):

VEHICLE VOLUME COUNT

DATE ____________ DAY ______________ WEATHER __________ TIME ____________ TO ______________

COUNTY ______________________________ TWP, VILLAGE or CITY ______________________________

INTERSECTION OF ____________________________ AND ______________________________



REMARK ____________

INTERSECTION LEG		INBOUND	OUTBOUND	TOTAL
LEG OF	ST.			
LEG OF	ST.			
LEG OF	ST.			
LEG OF	ST.			
TOTAL				

VOLUME SUMMARY

DATE ______________ DAY ______________ TIME ______________

TWP, VILLAGE OR CITY ______________ VOLUME ON ______________

INTERSECTION OF ______________ AND ______________

WEATHER: CLEAR___ CLOUDY___ RAIN___ SNOW___ FOG___ ROAD SURFACE: DRY___ WET___ ICY___ SNOWY___

TIME	FROM ON				FROM ON			TOTAL	FROM ON				FROM ON			TOTAL	
12 — 1 MID.																	
1 — 2																	
2 — 3																	
3 — 4																	
4 — 5																	
5 — 6																	
6 — 7																	
7 — 8																	
8 — 9																	
9 — 10																	
10 — 11																	
11 — 12PM																	
12 — 1																	
1 — 2																	
2 — 3																	
3 — 4																	
4 — 5																	
5 — 6																	
6 — 7																	
7 — 8																	
8 — 9																	
9 — 10																	
10 — 11																	
11 — 12																	
																	24 Hr. Total
																	Bi-Dir. Total

SUMMARY
CLASSIFICATION SHEET FOR VEHICULAR TRAFFIC

Hour___ to___

Location____________________________________ Date ____________

______ Leg of Intersection

Hour Beginning	Passenger Cars		Single-unit Trucks			Bus		Tractor-truck Semitrailer			Full Trailer Combination		Total	Extra Axles	Machine Counts
	Local	Out-of-State	4 Tired	6 Tired	3 Axle	School	Other	3 Axle	4 Axle	5 or more Axles	4 Axle	5 Axle			
Total															

______ Leg of Intersection

Total															

______ Leg of Intersection

Total															

______ Leg of Intersection

Total															

Source: <u>Manual of Traffic Engineering Studies</u> (1976)
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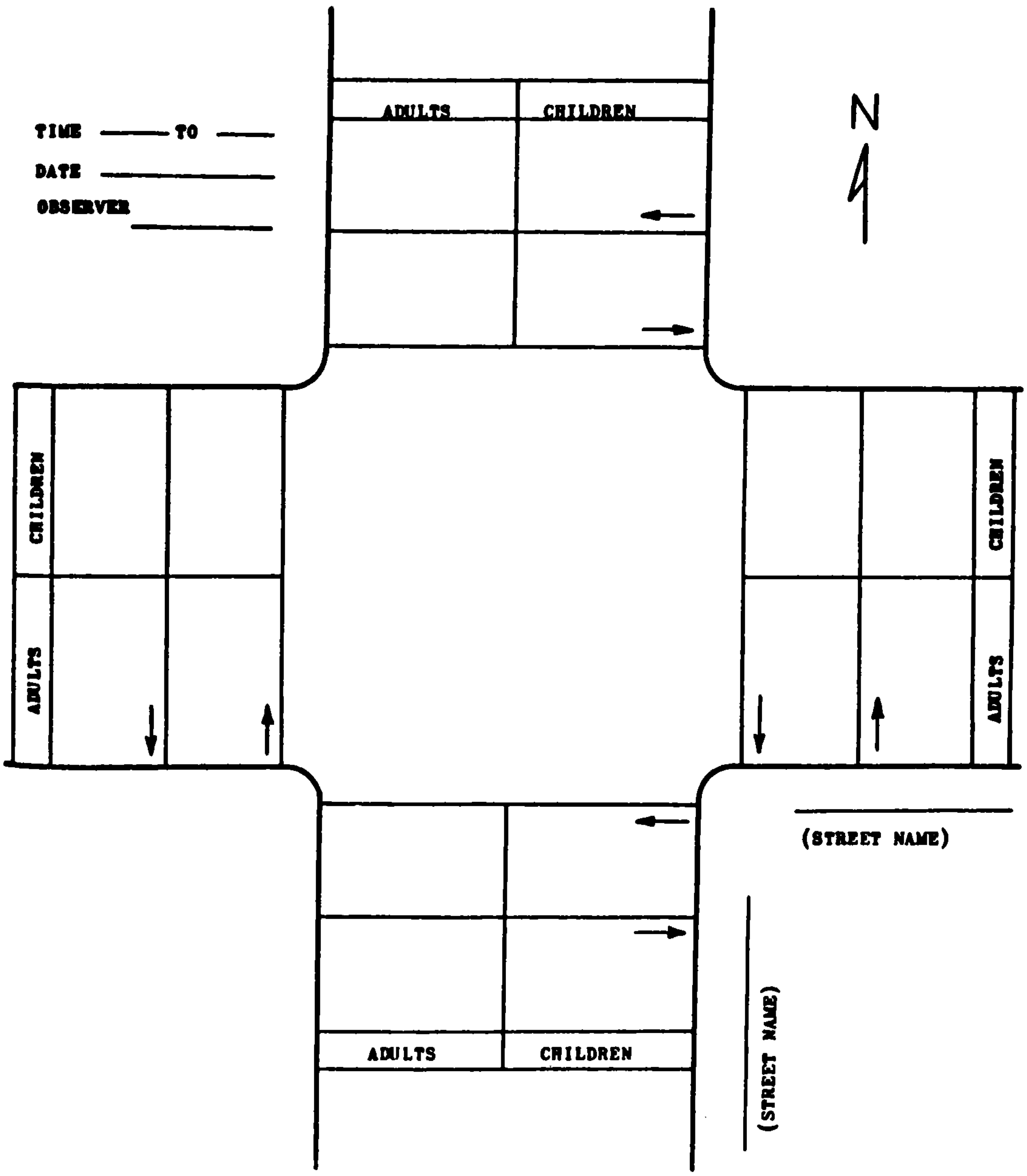
CROSSWALK FIELD SHEET
PEDESTRIAN COUNT



Source: Manual of Traffic Engineering Studies (1976)
Institute of Transportation Engineers
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Washington, D.C. 20024

SPEED SURVEY SHEET

ROAD: ______________________ BETWEEN ______________ AND: ______________

__________ N S E W OF ______________________________________

CITY OR TOWNSHIP: ______________________ DATE: ______________________

TIME: ______________ DIRECTION BEING SURVEYED: ______________________

WEATHER: CLEAR ____________ CLOUDY ____________ RAIN ____________ SNOW ________

PAVEMENT: DRY ____________ WET ____________ ICY ____________ SNOW ________

TEMPERATURE: ______________ WIND: LIGHT ________ STRONG ____________ GUST ________

70 ________	57 ________	44 ________	31 ________
69 ________	56 ________	43 ________	30 ________
68 ________	55 ________	42 ________	29 ________
67 ________	54 ________	41 ________	28 ________
66 ________	53 ________	40 ________	27 ________
65 ________	52 ________	39 ________	26 ________
64 ________	51 ________	38 ________	25 ________
63 ________	50 ________	37 ________	24 ________
62 ________	49 ________	36 ________	23 ________
61 ________	48 ________	35 ________	22 ________
60 ________	47 ________	34 ________	21 ________
59 ________	46 ________	33 ________	20 ________
58 ________	45 ________	32 ________	19 ________

TOTAL COUNT ______________

85% PERCENTILE ______________

AVERAGE ______________

SPOT SPEED STUDY
FIELD SHEET

Date ____________ Location ____________ Direction ____________

Time ____________ Weather ____________ Road Surface Condition ____________

SECONDS	mph for 88 ft	mph for 176 ft		PASSENGER VEHICLES	No Veh	BUSES	No Veh	TRUCKS	No Veh	TOTAL
1	60.0	120.0								
1-1/5	50.0	100.0								
1-2/5	42.8	85.7								
1-3/5	37.5	75.5								
1-4/5	33.3	66.6								
2	30.0	60.0								
2-1/5	27.2	54.5								
2-2/5	25.0	50.0								
2-3/5	23.0	46.1								
2-4/5	21.4	42.8								
3	20.0	40.0								
3-1/5	18.7	37.5								
3-2/5	17.6	35.2								
3-3/5	16.6	33.3								
3-4/5	15.7	31.5								
4	15.0	30.0								
4-1/5	14.2	28.9								
4-2/5	13.6	27.2								
4-3/5	13.0	26.1								
4-4/5	12.5	25.0								
5	12.0	24.0								
5-1/5	11.5	23.0								
5-2/5	11.1	22.2								
5-3/5	10.7	21.4								
5-4/5	10.3	20.6								
6	10.0	20.0								
6-1/5	9.6	19.3								
6-2/5	9.3	18.7								
6-3/5	9.0	18.1								
6-4/5	8.7	17.6								
7	8.5	17.1								
7-1/5	8.3	16.6								
7-2/5	8.1	16.2								
7-3/5	7.8	15.7								
7-4/5	7.6	15.3								
8	7.5	15.0								
8-1/2	7.0	14.1								
9	6.6	13.3								
9-1/2	6.3	12.6								
10	6.0	12.0								
11	5.4	10.9								
12	5.0	10.0								
13	4.6	9.2								
14	4.2	8.5								
15	4.0	8.0								
			TOTAL VEHICLES							

Source: <u>Manual of Traffic Engineering Studies</u> (1976)
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TRAVEL TIME AND DELAY STUDY
TEST CAR TECHNIQUE
FIELD SHEET

DATE ____________ WEATHER ________________ TRIP NO.__________

ROUTE __________________________DIRECTION ______________

TRIP STARTED AT __________ AT ______________ ____________
(LOCATION) (MILEAGE)

TRIP ENDED AT __________ AT ______________ ____________
(LOCATION) (MILEAGE)

CONTROL POINTS	
LOCATION	TIME

STOPS OR SLOWS		
LOCATION	SEC DELAY	CAUSE

TRIP LENGTH________TRIP TIME________TRAVEL SPEED________

RUNNING TIME______STOPPED TIME______RUNNING SPEED______

SYMBOLS OF DELAY CAUSE: S—TRAFFIC SIGNALS SS—STOP SIGN LT—LEFT TURNS
PK—PARKED CARS DP—DOUBLE PARKING T—GENERAL
PED—PEDESTRIANS BP—BUS PASSENGERS LOADING OR UNLOADING

COMMENTS ____

RECORDER ____________________

Source: Manual of Traffic Engineering Studies (1976)
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TRAVEL TIME STUDY
LICENSE PLATE TECHNIQUE
FIELD SHEET

LOCATION on ______________________ at ______________________ WEATHER __________

DATE ____________ ROUTE LENGTH ________________ DIRECTION OF TRAFFIC ____________

TIME OF START ____________ TIME OF END ____________ TIME CORRECTION ____________

0	1	2	3	4	5	6	7	8	9

NOTE ONLY RECORD LAST THREE DIGITS OF LICENSE PLATE NUMBER. UNDERLINE ANY BUS OR TRUCK WITH DUAL REAR WHEELS OR HEAVIER VEHICLES

OBSERVER ____________________ RECORDER ____________________

Source: Manual of Traffic Engineering Studies (1976)
Institute of Transportation Engineers
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INTERSECTION DELAY STUDY

FIELD SHEET

Location ______________________ Approach __________ Movement ______

Date __________ Weather ____________ Study No. __________ Observer ______

Time (minute starting at)	Total Number of Vehicles Stopped in the Approach at Time:				Approach Volume	
	+ 0 sec	+ 15 sec	+ 30 sec	+ 45 sec	Number Stopped	Number Not Stopping
Subtotal						
Total						

Total Delay = Total Number Stopped x Sampling Interval

= __________ x 15 = __________ veh-sec

Average Delay per Stopped Vehicle = $\frac{\text{Total Delay}}{\text{Number of Stopped Vehicles}}$

= __________ = __________ sec

Average Delay per Approach Vehicle = $\frac{\text{Total Delay}}{\text{Approach Volume}}$

= __________ = __________ sec

Percent of Vehicles Stopped = $\frac{\text{Number of Stopped Vehicles}}{\text{Approach Volume}}$ = __________ = ______ percent

Source: Manual of Traffic Engineering Studies (1976)
Institute of Transportation Engineers
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Highway Capacity Analysis Sheet

LOCATION: ______________________________

CITY OR TOWNSHIP: ______________________________

DATE: ______________________________

Description (1)	Design Capacity (2)	Existing Volume (3)	(3)/(2)	Level of Service

Day ______________ Date ______________________ Observer ______________________________

Conflict - C, Secondary Conflict - SC

COUNT START TIME (MILITARY)	TOTAL APPROACH VOLUME	Left Turn Same Direction		Slow Vehicle		Right Turn Same Direction		Opposing Left Turn		Left Turn from Left		Cross Traffic from Left		Left Turn from Right		Cross Traffic from Right		Right Turn from Right							
		C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC
TOTAL																									

Severe Conflicts:

Possible Causes of Slow Vehicle Conflicts:

Other Notes and Comments:

GAP STUDIES

DATE ____________________ TIME ____________________

WEATHER ____________________ LOC. ____________________

5 to 10 SEC.	11 to 15 SEC.	16 to 20 SEC.
21 to 25 SEC.	26 to 30 SEC.	31 to —

REMARKS:

Queue Length Data Summary Sheet

LOCATION: ______________________________

CITY: ____________________ DATE: ________________

DAY: ____________________ WEATHER: ________________

TIME: ________________

Time	Queue Length	Time	Queue Length	

Skid Resistance Study Summary Sheet

LOCATION: ______________________________

CITY OR TWP: ______________________ DATE: __________

WEATHER: ______________________________

AIR TEMPERATURE: ______________________________

METHOD USED FOR MEASURING: ______________________________

TEST NO.	DESCRIPTION*	SKID NUMBER (SN)

COMMENTS: ______________________________

*Includes identification of study section (route number, mile post, lane) and testing data (wheel locked, test speed, etc.)

Roadway Lighting Warrant Form

LOCATION: ______________________________

DESCRIPTION: ______________________________

CITY OR TWP: ____________________ DATE: __________

1. Volume Data

Description	Volume	Date

2. Accident Data

Time Period	Night/Day Accident Rate

3. Other Data

Fog-Related Study Output Form

LOCATION: ______________________________________

CITY OR TWP: ________________________ DATE: _____________

DAY: _____________ TIME: _____________ TEMP: _____________

TRAVEL SPEEDS: ___________________

Test No.	Description	Field Measurement (Sight Distance)	Design Value

PEDESTRIAN GROUP SIZE STUDY

Study date ______ Time: From ________ to ________ Location ________

Crosswalk across ____________ Curb-to-curb distance ________

Divided roadway? Yes No Width of island ________

Group size	Number of Rows (N)	Number of Groups Tally	Number of Groups Total	Cumulative	Computations
46 - 50	10				
41 - 45	9				
36 - 40	8				
31 - 33	7				
26 - 30	6				
21 - 25	5				
16 - 20	4				
11 - 15	3				
6 - 10	2				
5 or Less	1				
		Total Number of Groups		x 0.15 =	N =

Source: A Program for School Crossing Protection
Institute of Transportation Engineers
525 School St., S.W., Suite 410
Washington, D.C. 20024

PEDESTRIAN DELAY TIME STUDY

Study date ___________ Location ______________ Crosswalk across __________

End of Survey (to nearest minute) ______	Number of Rows - "N" __________
Start of Survey (to nearest minute) _____	Roadway Width - "W" _______ ft.
Total Survey Time (minutes) _______	Adequate Gap Time -"G" ____ secs.

Gap Size (Seconds)	Number of Gaps Tally	Number of Gaps Total	Multiply by Gap Size	Computations
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				T = Total survey time x 60
28				
29				
30				T = x 60
31				
32				T = secs.
33				
34				
35				
36				
37				$D = \left(\frac{T - t}{T}\right) 100$
38				
39				
40				
41				
42				
43				
"t" (total time of all gaps equal or greater than "G")			_____ secs.	D = _____%

Source: <u>A Program for School Crossing Protection</u>
Institute of Transportation Engineers
525 School St., S.W., Suite 410
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Data Collection Form For Pedestrian Conflicts and Events

Location ______________________ Observer __________________ Date ______ Weather ________

Time		Slow or Stop For Ped.	Slow or Stop For Ped. Previous	Weave For Ped. Cross.	Brake or Weave - Ped. Standing	Brake or Weave - Ped. Walking on Shoulder	Vehicle Ignore Crossing Guard	Turn Conflict	Ped. Run Across Street	Ped. Stop In Street	Ped. Traf. Signal Viola-tion	False Start Across Street	Jay Walk-ing	Total Ped. Volume
Start	End													

PEDESTRIAN OBSERVANCE OF TRAFFIC SIGNALS

FIELD SHEET

Location ____________________

Time __________ to __________ Weather __________

Pedestrians crossing __________ St. on the (N.S.E.W.)__________ side __________

of__________ St. in __________ direction __________

STEPPED FROM CURB ON	CROSSED STRAIGHT (crosswalk)	TOTAL
RED / WALK		
YELLOW / FLASHING DON'T WALK		
GREEN / STEADY DON'T WALK		
	CROSSED DIAGONALLY	
RED / WALK		
GREEN OR YELLOW / DON'T WALK		
TOTAL		

Date __________ Recorder __________

Source: <u>Manual of Traffic Engineering Studies</u> (1976)
Institute of Transportation Engineers
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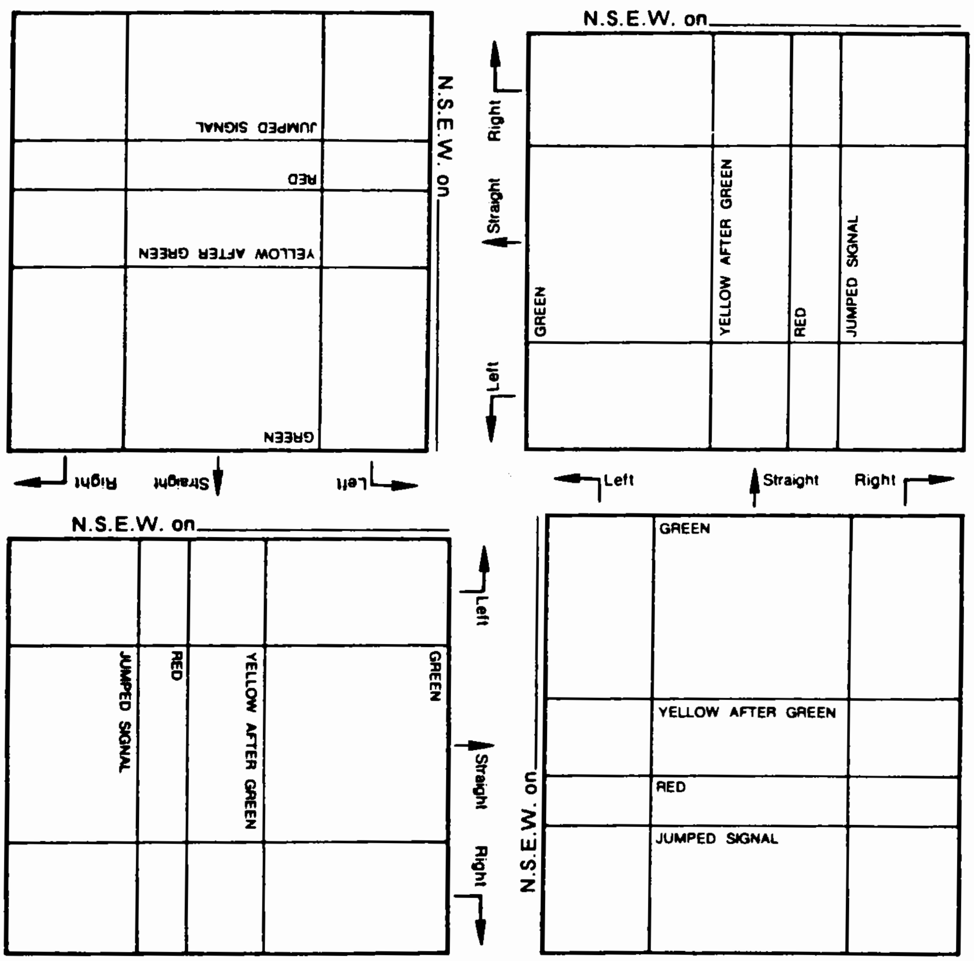
DRIVER OBSERVANCE OF TRAFFIC SIGNALS

FIELD SHEET

Location ______________________________ ______________________

Time ____________ to ________________ Weather ____________________________



Date ________________ Recorder ______________________________

Source: <u>Manual of Traffic Engineering Studies</u> (1976)
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DRIVER OBSERVANCE OF STOP SIGNS

FIELD SHEET

Location ________________________ ________________________

Time ____________ to __________ Weather ________________________

N.S.E.W. on ____________

	Right	Straight	Left
NON-STOPPING			
PRACTICALLY STOPPED - 0 to 3 mph			
STOPPED BY TRAFFIC			
VOLUNTARY FULL STOP			

N.S.E.W. on ____________

	Left	Straight	Right
VOLUNTARY FULL STOP			
STOPPED BY TRAFFIC			
PRACTICALLY STOPPED - 0 to 3 mph			
NON-STOPPING			

Date ____________________ Recorder ____________________

Source: <u>Manual of Traffic Engineering Studies</u> (1976)
Institute of Transportation Engineers
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Technique Utility Form

Techniques / Management Concerns	Technique			Technique		
	Wt. (1)	Level (2)	(1)x(2)	Wt. (1)	Level (2)	(1)x(2)
TOTAL						

Task, Manpower and Equipment Sheet

Procedure	Technique	Task, Manpower and Equipment Needs

Cost Estimate Form

LOCATION: ____________________

CITY OR AREA: ____________________ DATE: __________

GENERAL DESCRIPTION: ____________________

Item	Unit	Unit Cost	Quantity	Cost
Subtotal				
Engineering/Contingencies				
TOTAL				

Evaluation No:

Project No:

Date/Evaluator:

1. **Initial Implementation Cost, I:** $____________

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

3. **Annual Operating and Maintenance Costs After Project Implementation:** $____________

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

5. **Annual Safety Benefits in Number of Accidents Prevented, $\bar{E}$:** ____________

   Accident Type Expected Annual Benefit

   Total ________ ________ ____________

   = ____________

6. **Service Life, n:** ________yrs.

7. **Salvage Value, T:** $__________

8. **Interest Rate:** ________% = 0.__________

9. **EUAC Calculation:**

   CR_n^i = ____________________

   SF_n^i = ____________________

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

   =

10. **Annual Benefit:**

    $\bar{E}$ (from 5) =

11. $C/E = EUAC/\bar{E}$ =

12. **PWOC Calculation:**

    PW_n^i = ____________

    SPW_n^i = ____________

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

13. **Annual Benefit**

    n (from 6) = yrs.

    $\bar{E}$ (from 5) = accidents prevented per year

14. $C/E = PWOC\ (CR_n^i)/\bar{E}$

Cost-Effectiveness Worksheet

Evaluation No:

Project No:

Date/Evaluator:

1. Initial Implementation Cost, I: $__________

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

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

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

5. Annual Safety Benefits in Number of Accidents Prevented:

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

6. Accident Cost Values (Source__________):

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

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

5a) x 6a) =

5b) x 6b) =

5c) x 6c) =

Total = $

8. Services life, n: __________yrs

9. Salvage Value, T: $__________

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

11. EUAC Calculation:

CR_n^i = ________

SF_n^i = ________

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

12. EUAB Calculation:

$EUAB = \bar{B}$

=

13. B/C = EUAB/EUAC =

14. PWOC Calculation:

PW_n^i =

SPW_n^i =

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

15. PWOB Calculation:

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

16. B/C = PWOB/PWOC =

Benefit-Cost Worksheet

Location, ______ City/Twp. ______ County ______

The method of evaluating accident costs, used below, is given on page 67 of Roy Jorgensen's report of Highway Safety Improvement Criteria, 1966 edition.

In the following analysis the costs provided by the National Safety Council are: 19 values

Death -

Nonfatal Injury -

Property Damage Accident -

$$B = \frac{ADT_a}{ADT_b} \times (Q\ R_1 + \quad R_2)$$

where

B = benefit in dollars

ADT_a = Average traffic volume after the improvement ______

ADT_b = Average traffic volume before the improvement ______

R_1 = Reduction in fatalities and injuries combined ______

R_2 = Reduction in property damage accidents ______

Q = if no fatal accidents occurred, and

Q = $\frac{\_\_\_\_ + (I/F \times \_\_\_\_)}{1 + I/F}$ = if at least 1 fatality occurred.

where

I/F = Ratio of injuries to fatalities that occurred statewide during the year 19

=

Time of Return (T.O.R.) based on ______ years of data.

____ yrs. B= ____[(XXXXXX) ____ + ( ) ____]

____ yrs. B= ______[(______) + (______)] = ______

Annual B= ______ dollars

C= Total cost of project

T.O.R. = $\frac{C}{B}$ = years= Months

Location ______

City/Twp. ______ County ______

Control Section ______ SII # ______

Type of Improvement ______

PERIOD	ACCIDENT TYPES									
		Inj / PD		Inj / PD		Inj / PD		Inj / PD		Inj
TOTALS										

Estimated Accident Reduction	___% Red.		___% Red.		___% Red.		___% Red.		___% Red.	

Remarks

A- Includes only those accidents at driveways where improvements are proposed. Includes left-turns out of driveways, and rear-ends, sideswipes, and angles caused by right turns into or out of the driveways.

B- Includes only those accidents on the approaches (not driveway-related)

Estimated Project Cost ______

Anticipated Annual Benefit ______

Project Amortization (T.O.R.) ______ ______

Time-of-Return Worksheet

COUNTERMEASURE ANALYSIS WORKSHEET

Form #1

COUNTERMEASURE NO.______ ESTIMATED SERVICE LIFE _____ YEARS
COUNTERMEASURE DESCRIPTION
CURRENT 19__ ADT________ ESTIMATED 19__ ADT___________

Constant
Increasing by_____% annually
Increasing by_____VPD annually

ESTIMATED ANNUAL ACCIDENT REDUCTION:

	Estimated % Reduction ÷100	x	Accidents of this Type	=	Estimated Accident Reduction
Accident Type ______	______	x	PDO ____ F & I ____	=	PDO ____ F & I ____
Accident Type ______	______	x	PDO ____ F & I ____	=	PDO ____ F & I ____
Accident Type ______	______	x	PDO ____ F & I ____	=	PDO ____ F & I ____
Accident Type ______	______	x	PDO ____ F & I ____	=	PDO ____ F & I ____
			Total Reduction		PDO ____ F & I ____

AVERAGE ANNUAL BENEFITS:

1. Enter the estimated reduction of PDO Accidents ______
2. Enter the average cost of a PDO Accident ______
3. Multiply Line 1 by Line 2 (average annual benefit of reducing PDO Accidents) ______
4. Enter the estimated reduction of fatal and injury accidents ______
5. Enter the average cost of a fatal or injury accident ______
6. Multiply Line 4 by Line 5 (average annual benefit of reducing fatal and injury accidents) ______
7. Add Line 6 to Line 3 (average annual benefit from reducing accidents) ______

COMPLETE LINES 8 THROUGH 13 IF ADT WILL INCREASE DURING SERVICE LIFE OF IMPROVEMENT--IF NOT GO TO LINE 14

8. Enter the expected ADT at the end of the service life ______
9. Enter the present ADT ______
10. Add Line 9 to Line 8 ______
11. Divide Line 10 by 2 (average ADT during service life) ______
12. Divide Line 11 by Line 9 (ADT growth factor) ______
13. Multiply Line 7 by Line 12 (average annual benefits from reducing accidents--ADT increasing) ______
14. Enter secondary annual benefits from improvement (if known) ______
15. If ADT is constant add Line 14 to Line 7 } Average Annual ______
    If ADT is increasing add Line 14 to Line 13 } Benefits ______

*U.S. GOVERNMENT PRINTING OFFICE: 1981--363-930/7267

COUNTERMEASURE ANALYSIS WORKSHEET

Form #2

AVERAGE ANNUALIZED COST*:

1. Enter the initial cost of improvement ______
2. Enter the capital recovery factor for service life of the improvement (see Interest Factors Table in Appendix G) ______
3. Multiply Line 1 by Line 2 ______
4. Enter the terminal value of improvement ______
5. Enter the sinking fund factor at the service life of the improvement (see Interest Factors Table in Appendix G) ______
6. Multiply Line 4 by Line 5 ______
7. Enter the constant annual cost ______
8. Subtract Line 6 from Line 3, then add Line 7 (Average Annualized Costs) ______

AVERAGE ANNUAL NET RETURN:

1. Enter the Average Annual Benefits ______
2. Enter the Average Annualized Costs ______
3. Subtract Line 2 from Line 1 (Average Annual Net Return) ______

BENEFIT/COST RATIO:

1. Enter the Average Annual Benefits ______
2. Enter the Average Annualized Costs ______
3. Divide Line 1 by Line 2 (Benefit/Cost Ratio) ______

* Based on 5% interest, annual cost uniform throughout service life.

Net Annual Benefit Worksheet