SEMCOG Traffic Safety Manual

Second Edition

September 1997

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Abstract

This manual describes a comprehensive approach to traffic safety analysis, from collecting potentially useful information to ranking tentative solutions. Individual chapters can also be consulted and applied independently, such as to check a location's crash ranking (Chapter 3), alternative crash countermeasures (Chapter 4) or the relative safety benefits and costs of a specific countermeasure (Chapter 5). Methods in the manual are prescribed in a step-by-step manner, incorporating simple equations and worksheets.

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CHAPTER 1

INTRODUCTION

GENERAL BACKGROUND

Traffic crashes have been characterized as a neglected epidemic, claiming over 45,000 lives in the nation every year (SEMCOG, 1990).[1] These losses include over 1,500 people within the State of Michigan. On average, someone is killed in Southeast Michigan every 14 hours in a traffic crash. Crashes are the leading cause of death for the 16 to 24 year old age group.

In the late 1980s, over $1.7 billion in direct costs were incurred every year in Southeast Michigan as a result of traffic crashes (SEMCOG, 1989). In a more recent study by the University of Michigan Transportation Research Institute, the total cost of crashes in the state was estimated to be approximately $12 billion for 1993. In contrast, the total cost of crime committed in Michigan in 1993 was approximately $5 billion (Streff and Molnar, 1994; DeSmet, 1994).

The impacts of traffic crashes are felt by every resident. These crashes place enormous burdens on medical facilities, police and other public and private institutions, in addition to the physical and emotional sufferings of the victims and their families.

A comprehensive highway safety program is needed to reduce the large and varied impacts of traffic crashes on Southeast Michigan residents. A crucial element of such a program is the collection and effective use of crash data to identify and correct safety deficiencies in the roadway system.

Unfortunately, there is a general lack of relevant engineering assistance available to or within communities in the seven-county area of Southeast Michigan (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw and Wayne counties). The U.S. Department of Transportation has recommended that cities with a population greater than 50,000 employ at least one full-time traffic engineer and cities with a population of 25,000 to 50,000 have access to traffic engineering services through consultants or other governmental agencies. Currently, only seven cities in the seven-county SEMCOG region have full-time traffic engineers: Ann Arbor, Detroit, Farmington Hills, Novi, Pontiac, Rochester Hills and Southfield. There are 11 other cities in the region with populations exceeding 50,000 and many other cities with populations over 25,000 which do not have access to an adequate level of traffic engineering assistance.

While several communities use consultants for special projects or are assisted by county road commissions on limited issues, the overall lack of adequate engineering assistance indicates that numerous traffic safety problems are probably being overlooked in many communities. SEMCOG believes that more engineering assistance will translate into an overall improvement in traffic safety. However, with the limited resources available to most communities, hiring a traffic engineer is often not viewed as a viable option. Many communities in Southeast Michigan are forced to assign traffic safety as a collateral duty to law enforcement officers and public works personnel. While these people often do a good job of addressing traffic safety issues, it is not the primary focus of their jobs. SEMCOG has created this manual, therefore, to assist these personnel (and others) in their analysis of roadway-related traffic safety problems.

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[1] Full citation for source and year in parentheses can be found in list of References in Appendix G.

Many engineering disciplines have "sketch-planning" tools which allow them to evaluate specific projects or alternatives without conducting an in-depth engineering analysis. For example, a highway engineer can usually estimate how much it will cost to add a lane to an existing roadway simply by using sketch-planning techniques and without doing a complete site evaluation. Similarly, traffic volume-to-capacity ratios are often used in congestion analyses. Such techniques are primarily used to prepare budgets and proposals and are not considered to substitute for the detailed engineering analysis often needed later in the implementation process.

In the past, traffic safety personnel have not had the means for quickly and efficiently evaluating suspected safety problems and proposed solutions. However, the *SEMCOG Traffic Safety Manual* now provides a set of user-friendly tools for checking a location's crash history, identifying possible crash causes and countermeasures and conducting a preliminary benefit/cost analysis of those countermeasures selected for further consideration. Benefit/cost analysis is an economic tool for assessing and comparing possible countermeasures. For each countermeasure considered, it compares expected benefit to expected cost.

PURPOSE OF THE TRAFFIC SAFETY MANUAL

This manual has been designed to aid in identifying:

1. information relevant to safety analysis;
2. high-crash locations;
3. significant crash patterns and generally related causes and countermeasures;
4. default values for countermeasure service life, cost and effectiveness; and
5. safety project benefit/cost ratios, for use in planning and budgeting.

In addition, many communities have witnessed a growing portion of their limited budgets being consumed by the increasing costs of litigation resulting from crashes within their jurisdictions. The systematic use of this manual to develop traffic safety improvement priorities within available budgets will prove useful in defending against traffic crash litigation.

USING THE MANUAL

This manual describes a comprehensive approach to traffic safety analysis, from collecting potentially useful information to ranking tentative solutions. The scope of each remaining chapter is as follows:

- *Chapter 2 - Data Collection and Maintenance* -- Eight types of data useful in understanding traffic safety problems are described, along with manual and computerized methods for maintaining such data for easy access.
- *Chapter 3 - Identification of High-Crash Locations* -- Considerations in defining suspect locations are first reviewed. Seven methods of analyzing and ranking crash histories are then presented in detail. Lastly, several of these alternative methods are illustrated using data for a hypothetical intersection.
- *Chapter 4 - Determination of Countermeasures, Crash-Reduction Factors and Costs* -- A methodology is presented and illustrated for identifying a location's crash patterns and possible causes and countermeasures related to those patterns. Specific countermeasures are listed for consideration, along with representative values for their effectiveness and cost.
- *Chapter 5 - Benefit/Cost Analysis* -- A methodology for evaluating the economic attractiveness of alternative crash countermeasures is presented and the application of a detailed worksheet reflecting this methodology is illustrated using a continuation of the previous intersection example.

- *Chapter 6 - Summary and Conclusions* -- The manual is summarized, parts open to expansion and/or refinement are identified and conclusions are drawn regarding the expected near-term usefulness of the manual.

While the Traffic Safety Manual presents a comprehensive process for safety analysis, it should be recognized that opportunities will arise for applying selected parts of this process. For example, a mayor or council person may perceive a safety problem at an intersection on the basis of citizen complaints alone. He or she may immediately think that a traffic signal would be the best solution to the perceived problem. When staff is asked for its reaction, the first thing to do would be to see if the location is, indeed, a high-crash location possibly deserving of a significant capital investment. Applying the techniques demonstrated in Chapter 3 may show that the location has a better safety record than several other locations already on the waiting list for a signal. If the proposal lingers, Chapters 4 and 5 might be used to show that a signal would not be nearly as cost-effective as improved marking and signing. The importance of meeting the state's signal warrants should also be noted.

CHAPTER 2

DATA COLLECTION AND MAINTENANCE

Traffic safety problems can be identified and evaluated in an accurate, timely and efficient manner only through the analysis of systematically collected and maintained data bases. Crash records constitute the core data base. Also potentially useful is information on:

- traffic volume and composition,
- traffic control devices,
- roadway and roadside design features,
- perceived operational and safety problems,
- maintenance of objects struck in crashes,
- traffic citation patterns, and
- adverse litigation history.

This chapter describes the significance, collection and maintenance of these data types. It is recognized that few, if any, local agencies currently have a family of data bases as comprehensive as the above list implies. The primary purpose of the chapter, therefore, is to assist in the selection of the data and file types most suitable to local needs and interests.

METHODS OF COLLECTING DATA

The following paragraphs briefly explain each of the data types listed above. Emphasis is placed on the significance of the data and on the collection methods most applicable to local jurisdictions in Michigan.

Crash Data

Detailed information on past crashes by location provides the most direct means of identifying roadway safety deficiencies. It is important to keep in mind, however, that crash data describe only the <u>failures</u> of drivers, vehicles and/or roadway elements to function together successfully. Such data by themselves do not identify near-failures, potential failures or successes. Hence, other types of data, as discussed below, are also important in identifying significant safety improvement opportunities.

The primary source of crash data is the standard police-completed crash report. The Michigan State Police and all local law enforcement agencies in Michigan use the State of Michigan UD-10 report form. Prior to 1992, this was a one-page form also known as the *Official Traffic Accident Report*. Now, however, the UD-10 is a two-page form also known as the *Traffic Crash Report* (Figure 2-1).

The new form is used to record numerous details describing the crash scene, roadway conditions, persons and vehicles involved, sequence of events, type of crash and resulting injuries and property damage. Much of this information is now entered by blackening appropriate "bubbles" in multiple-choice lists of possible responses.

One of the most important sections of the UD-10 is the box on the second page entitled "Crash Diagram and Remarks." Completion of this section is legally required only for fatal crashes. However, due in part to its immense value in diagnosing roadway-related causal factors, this section should be completed carefully and conscientiously for all crashes.

When drawn in sufficient detail and referenced to identifiable roadway features, the crash diagram will show in a comprehensive fashion the relative pre-collision movements of all vehicles and other persons directly or indirectly involved. Space should be reserved within the box for summarizing cause-related observations by key crash participants and the investigating officer.

The intuitive value of a well-prepared diagram/remarks section was confirmed in recent (as yet unpublished) research which found that this section on another state's crash report form often shed more light on roadway causal factors than all other data entries combined. Information in the box has also proven very useful in relating specific crash sequences and circumstances to crash site features observed during field inspections.

The UD-10 is filled out by the local or state law enforcement officer, mostly at the time and place of the crash. Occasionally, amended reports or report supplements are also filed when additional information of importance comes to light. Before sending the original UD-10 to the state police for the entry of selected data into the state's central crash data computer files, copies should be made for local police department and traffic engineering files.

The usefulness of the UD-10 is keenly affected by its accuracy and whether or not all necessary details have been included in the report. Most law enforcement officers tend to be more complete and careful in filling in the UD-10 when they have a better understanding of how the resulting crash information is used. In some jurisdictions, traffic safety personnel and law enforcement officers meet on a regular basis to discuss traffic safety problems. These exchanges of information and opinion not only improve crash reporting by police officers, they also increase traffic safety personnel's appreciation of law enforcement findings (McShane and Roess, 1990).

Traffic Volume and Composition

The availability of traffic volume data allows for the computation of exposure-based crash rates (e.g., the number of crashes per million vehicles entering an intersection). The use of crash rates in comparing the crash experience between different time periods or between locations provides a basis for more accurate and meaningful conclusions since it accounts for the numbers of vehicles "exposed" to the hazards of driving within a given time period. The use of rates, for instance, prevents the potentially misleading classification of a relatively safe high-volume location as "high-crash" simply because it has experienced a relatively large number of crashes.

Information on the composition of traffic (i.e., the percentages of total traffic consisting of various vehicle types, sizes or weights) can be useful in explaining differing crash histories of two otherwise similar locations. Large trucks and recreational vehicles, for example, accelerate more gradually and often travel more slowly than automobiles. Higher percentages of such large vehicles in the traffic stream may contribute to increased crashes related to passing and congestion in lanes not regularly used by the larger vehicles. Large-profile vehicles also restrict the visibility of automobile drivers with respect to downstream traffic conflicts, signs and traffic signals.

Traffic counts are typically made at selected locations on at least a semi-regular basis by various state and local road agencies. Special counts are also made from time to time by consultants conducting traffic-impact, corridor and roadway-design studies. The availability of data on traffic volume and composition can be determined by contacting local traffic engineering personnel or the Transportation Department at SEMCOG.

Traffic Control Devices

Traffic control devices consist of the signs, signals and pavement markings used to regulate, warn and inform drivers of the performance requirements essential to safe operation. The evaluation of possible crash causes and countermeasures must therefore account for the type, location and condition of existing traffic control devices. Since driver conditioning and expectancy can strongly affect the likelihood of safely negotiating a particular roadway feature, it is important to know the traffic control devices not only at a location where crashes are officially recorded, but also for some distance upstream of that location. The necessary information can often be obtained from system-wide traffic control device inventories also established and maintained for maintenance purposes.

Figure 2-1.
State of Michigan Traffic Crash Report

Authority: 1949 PA 300, Sec. 257.622
Compliance: Required
Penalty: $100 and/or 90 days

Do Not Use

Form ______ Of ______ 2-3 UD-10 (1/94)

Complaint #

File Class

Complaint Disposition — Open / Closed — Reviewer

ORI: MI-

STATE OF MICHIGAN
Traffic Crash Report

Department Name

Crash Date — Month / Day / Year (9)
Crash Time — Military

No. of Units: 1 2 3 4 5 6 7 8 9

Crash Type
1. Single Motor Vehicle
2. Head On
3. Head On-Left Turn
4. Angle
5. Rear End
6. Rear End-Left Turn
7. Rear End-Right Turn
8. Sideswipe-Same
9. Sideswipe-Opposite
10. Other/Unknown

Special Circumstances
1. None
2. Deer
3. School Bus
4. Hit and Run
5. Fleeing Police

Special Study
1. Local
2. State

Weather (Mark Only One)
1. Clear
2. Cloudy
3. Fog/Smoke
4. Rain
5. Snow/ Blowing Snow
6. Severe Wind
7. Sleet/Hail
8. Other/Unknown

Light (Mark Only One)
1. Daylight
2. Dawn
3. Dusk
4. Dark-Lighted
5. Dark-Unlighted
6. Other/Unknown

Fatal (Report All)
Corrected Copy
Replace (Entire Report)
Delete (Entire Report)
Non-Traffic Area
ORV/ Snowmobile

County — City/Twp

Traffic Control
1. Signal
2. Stop Sign
3. Yield Sign
4. None of These

Construction Zone (if applicable) (Mark One From Each Group)

Type: 1. Const./Maint. 2. Utility
Lane Closed: 1. Yes 2. No
Activity: 1. On Road 2. Off Road 3. None

Location on

Name: ______

FT / MI — North / South — East / West — Beginning of Ramp / End of Ramp

Intersection: ______

Relation to Roadway (Location of First Impact)
1. On Road
2. Median
3. Shoulder
4. Outside of Shoulder/Curb
5. Gore
6. Other/ Unknown

Area

Road Condition (Mark Only One)
1. Dry
2. Wet
3. Icy
4. Snowy
5. Muddy
6. Slushy
7. Debris
8. Other/ Unknown

Total Lanes: 0 1 2 3 4 5 6 7 8 9

Speed Limit — Posted: Yes / No

Unit Number: 1 2 3 4 5 6 7 8 9

State — Driver License Number

Date of Birth — Month / Day / Year

License Type: O, CY, C, F, M, R

Sex: M, F

Hazard Action

First Name — Middle — Last

Position — Restraint — Ambulance/Hospital

Street Address — Phone Number

City — State — Zip

Injury: K, A, B, C, O

Ejected: Yes — **Trapped**: Yes

Citation Issued: 1. Hazardous 2. Other

Airbag Deployed: 1. Yes 2. No 3. Not Equipped

Unit Type: MV, B, P, E (train)

Alcohol — HBD: Yes / No

Test Type: Field, PBT, Breath, Urine, Blood

Test Results ______ (Submit Results To FARS When Available) — Refused — Not Offered

Total Occup

Vehicle Registration — State — VIN — Vehicle Description (year, make, color)

Insurance — Towed To/By

Vehicle Direction: North, East, South, West

Special Vehicles: 1 2 3 4 5 6

Location of Greatest Damage: 0 1 2 3 4 5 6 7 8 9 10 11 12

Vehicle Type: PA, VA, PU, ST, CY, MO, GC, SM, OR, Other, Truck/Bus (Complete Truck/Bus Section)

Vehicle Use: 1 2 3 4 5 6 7 8 9 10 11

First Impact

Extent of Vehicle Damage: 0 1 2 3 4 5 6 7

Driveable: Yes / No

Vehicle Defect: 1 2 3 4 5 6

Private Trailer Type: 1 2 3 4 5 6 7

First Name — Middle — Last

Date of Birth — Month / Day / Year

Sex: M / F — **Ejected**: Yes — **Trapped**: Yes

Street Address — Phone Number

Injury: K, B, O, A, C

City — State — Zip

Pos. — Rest. — Ambulance/Hospital

Airbag Deployed: 1. Yes 2. No 3. Not Equipped

First Name — Middle — Last

Date of Birth — Month / Day / Year

Sex: M / F — **Ejected**: Yes — **Trapped**: Yes

Street Address — Phone Number

Injury: K, B, O, A, C

City — State — Zip

Pos. — Rest. — Ambulance/Hospital

Airbag Deployed: 1. Yes 2. No 3. Not Equipped

Witness / Owner / Uninjured Passenger — Name — Address — Phone Number — Age — Pos. — Rest.

Witness / Owner / Uninjured Passenger — Name — Address — Phone Number — Age — Pos. — Rest.

Person Advised of Damaged Traffic Control — Date — Time — Name — Damaged Property — Public (Y) (N) — Owner & Phone

Do Not Write or Mark In This Area

UD-10 Form Number: 5978618 — Form Override Number

Do Not Write or Mark Below This Line — Do Not Write or Mark Below This Line

Do Not Write or Mark On This Side of The Line

ROTARY MULTIFORMS INC. (616) 943-2574

▲Unit Number 2-4

1 2 3 4 5 6 7 8 9

State | Driver License Number

First Name | Middle | Last

Street Address | Phone Number

City | State | Zip

Unit Type: MV, B, P, E (train)

Alcohol HBD: Yes, No

Test Type: Field, PBT, Breath, Urine, Blood

Test Results ______ (Submit Results To FARS When Available)

Refused, Not Offered

Date of Birth: Month | Day | Year

License Type: O, C, M, CY, F, R

Sex: M, F

Hazard Action: 0 0, 1 1, 2, 3, 4, 5, 6, 7, 8, 9

Position | Restraint | Ambulance/Hospital

Injury: K, A, B, C, O

Ejected: Yes

Trapped: Yes

Citation Issued: 1. Hazardous, 2. Other

Airbag Deployed: 1. Yes, 2. No, 3. Not Equipped

Total Occup: 0 0, 1 1, 2 2, 3 3, 4 4, 5 5, 6 6, 7 7, 8 8, 9 9

Vehicle Registration | State | VIN | Vehicle Description (year, make, color)

Insurance | Towed To/By

Vehicle Direction: North, South, East, West

Special Vehicles: 1 2 3 4 5 6

Location of Greatest Damage: 0 1 2 3 4 5 6 7 8 9 10 11 12

Vehicle Type: PA, VA, PU, ST, CY, MO, GC, SM, OR, Other, Truck/Bus (Complete Truck/Bus Section)

Vehicle Use: 1 2 3 4 5 6 7 8 9 10 11

First Impact

Extent of Vehicle Damage: 0 1 2 3 4 5 6 7

Driveable: Yes, No

Vehicle Defect: 1 2 3 4 5 6

Private Trailer Type: 1 2 3 4 5 6 7

First Name | Middle | Last

Street Address | Phone Number

City | State | Zip

Date of Birth: Month | Day | Year

Sex: M, F

Ejected: Yes

Trapped: Yes

Injury: K, A, B, C, O

Pos. | Rest. | Ambulance/Hospital

Airbag Deployed: 1. Yes, 2. No, 3. Not Equipped

First Name | Middle | Last

Street Address | Phone Number

City | State | Zip

Date of Birth: Month | Day | Year

Sex: M, F

Ejected: Yes

Trapped: Yes

Injury: K, A, B, C, O

Pos. | Rest. | Ambulance/Hospital

Airbag Deployed: 1. Yes, 2. No, 3. Not Equipped

Witness, Owner, Uninjured Passenger | Name | Address | Phone Number | Age | Pos. | Rest.

Witness, Owner, Uninjured Passenger | Name | Address | Phone Number | Age | Pos. | Rest.

◀ Unit Reported on Front

Action Prior		Sequence of Events First		Second		Third		Fourth	
0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3
	4	4	4	4	4	4	4	4	4
	5		5		5		5		5
	6		6		6		6		6
	7		7		7		7		7
	8		8		8		8		8
	9		9		9		9		9
Most Harmful:	M		M		M		M		

▲ Unit Reported Above

Action Prior		Sequence of Events First		Second		Third		Fourth	
0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3
	4	4	4	4	4	4	4	4	4
	5		5		5		5		5
	6		6		6		6		6
	7		7		7		7		7
	8		8		8		8		8
	9		9		9		9		9
Most Harmful:	M		M		M		M		

Crash Diagram and Remarks

North

Truck/Bus Information Unit No. 1 2 3 4 5 6 7 8 9

Carrier Name

Address

City | State | Zip

Carrier Source: Papers, Log Book, Vehicle, Driver

GVWR

ICCMC

USDOT

MPSC

Interstate, Intra (MI Only)

Driver's CDL Type: A, B, C, H, N, P, T, X, None

CDL Restrictions: 28, 29, 30, 35, 36

CDL Exempt: Farm, Other

Medical Card: Y, N

Vehicle Type: AA, AH, AN, AP, AT, AX, AY, AZ, AL, BB, BH, BN, BP, BX, CH, CP, CX, Other

Type & Axles Per Unit: First, Second, Third, Fourth

Cargo Body Type 1 2 3 4 5 6 7 8

Hazardous Material

Placard: Y, N

Cargo Spill: Y, N

Type # | Class #

UD-10 Form Number 5978618

Investigated at Scene: Y, N

Reported Date/Time | Photos By | Investigator Name(s) & Badge # (Print Only)

Do Not Write or Mark Below This Line

Do Not Write or Mark Below This Line

Forward Original To:

Michigan Department of State Police,
Criminal Justice Data Center, 7150 Harris Drive, Lansing, MI 48913

Do Not Write or Mark On This Side of The Line

Do Not Write or Mark On This Side of The Line

Do Not Write or Mark On This Side of The Line

Roadway and Roadside Design Features

Also of potential interest are data describing the severity and length of curves and grades; curve superelevation (or "banking"); lane and shoulder widths; side slopes and obstacles; and crest and corner sight restrictions. Changes due to safety improvement projects should be noted.

Perceived Operational and Safety Problems

Concerns come from the public, elected officials, agency management and other employees.

Complaints from the general public
Most local agencies receive citizen complaints about a variety of issues on a regular basis. It is important to have a systematic process for recording these complaints and insuring that they are addressed in a timely manner. Once a local agency has been notified of a perceived safety problem, the agency is legally considered to be on notice of the perceived problem and must assess the situation to determine if it constitutes a failure to provide a reasonable level of safety to the traveling public. Failure to correct a genuine problem about which the agency has been notified may leave the agency liable for any resulting injuries. However, in the event that litigation arises from such liability, the agency is in a more defensible position if it can show that it has assessed the problem and established a reasonable plan for resolving it.

Citizen complaints are useful in identifying potential crash locations. By summarizing the complaints, the agency can determine if there is a developing pattern of behavior that may lead to future crashes. In addition, comparing citizen complaints to a list of existing crash locations may highlight high-crash locations warranting more immediate attention.

The most constructive way to handle citizen complaints is to prepare a citizen complaint form and use it consistently. This form should record the date and time of the complaint; the name, address and telephone number of the complainant; and the location and nature of the complaint (MSU, 1991). Once the complaint has been received, it should be entered into a log or data base and forwarded to the proper department(s) within the agency. All decisions made and actions taken on the complaint should also be recorded in the log or data base, even if the agency decides that no action is necessary at the time. A sample citizen complaint form is shown in Figure 2-2.

Concerns expressed by local elected officials
Many of the same concerns raised by the general public are echoed by local elected officials, either on their own or in their role as the public's representatives. A good way of both recording this type of concern and denoting its source is to use the citizen complaint form printed on a special color of paper.

Concerns of agency management
Directors, managers and supervisors throughout a local agency are often well-positioned to both identify traffic safety problems and give impetus to their solution. They should be encouraged to submit their comments using the employee form discussed below.

Reports by other agency employees
All agency employees should remain alert to potential traffic safety problems as they drive about, whether during the course of their official work, commuting to and from work or in other personal travel. This is one of the best methods of getting questionable features and conditions reported and attended to on a timely basis. It is also the most affordable means of obtaining nighttime observations of traffic control device visibility which is important for safe nighttime driving. Situations observed can range from such obvious problems as burned out signal lights to such comparatively subtle problems as excessive tire marks entering intersections and curves.

The best way of collecting employee observations of questionable features and conditions is to prepare and consistently use a form similar to that used to record citizen complaints. The employee report form should record who made the report and when it was submitted. Information on the form is then entered into a log or data base and forwarded to the proper department(s). All decisions

Figure 2-2.
Citizen Complaint Form

1. Complaint Received: By Phone By Letter In Person
2. Time: ________ AM PM 3. Date: ________________ 4. Street Name: ____________________________
5. City/Township: ____
6. Location/Address (nearest cross street/landmark): ____
7. Complainant: ______________________________________ 8. Phone Number: ________________
9. Address: ____
10. Complaint Received By: ____

REPORTED COMPLAINT (CIRCLE APPROPRIATE ITEMS)

Pavement::	Rough Wash-out	Ice/Snow Edge Hole Settlement	Dust/Dirt Potholes	
Shoulder:	Potholes Wash-Out	Bush/Tree	Drop (Edge of Pavement)	
Trees/Brush:	Blocking Road Vision Obstruction	Hanging Limb	Blocking Sign	Requires Removal/Trimming
Drainage:	Standing Water in Ditch Ditching Request	Flooding Private Property Culvert/Catch Basin/Manhole	Ditching Request	
Traffic Control Devices:	<u>Signs</u> Damage Worn Missing Required	<u>Guardrail</u> Damage Required	<u>Signals</u> Damage Malfunction Required	<u>Pavement Markings</u> Worn Required
Miscellaneous:	Property Damage Roadside Hazards	Litter Pick-Up Work Quality	Roadside Mowing Construction Related	Overweight Veh

Remarks/Other: ____

____

____

____

Class of Road: Primary Local Subdivision State Trunkline

Surface Type: Paved Unpaved

DISPOSITION

Action Date: ________________________ Time: ____

Department: __________________________ Personnel Called: ______________________________

Repair or Corrective Action Taken: ____

____

____

____

Signed: ____ Date: ______________

Source: Road Commission for Oakland County; Datta, T. (1990).

made and actions taken in response to the report should also be recorded in the log or data base, even if the agency decides that nothing needs to be done at the time. Data on repairs should specify the date and time they were completed, the nature of the repairs, any materials and/or hardware used and any follow-up action required (MSU, 1991). An example of an employee report form is shown in Figure 2-3.

Maintenance of Objects Struck in Crashes

A truly comprehensive traffic records system would include a mechanism for recording work done to objects within the highway right-of-way which may have been struck by out-of-control motor vehicles. Such direct evidence of fixed-object collisions may indicate roadway deficiencies not evident in official crash data, since these collisions often involve single vehicles in unreported hit-and-run situations.

Damage caused by out-of-control vehicles is sometimes difficult to distinguish from damage due to intentional collisions or maintenance activities such as mowing. If doubt exists on this point, it is probably best to document the repair with comments added indicating the basis for doubt (e.g., the absence of visible tracks approaching the object). Then, follow-up investigation may only be necessary at locations where a history of repeated damage is noted.

Typical objects of interest include post delineators, sign posts, traffic signal equipment (e.g., poles and ground-mounted controller cabinets), guard rails, drainage appurtenances, utility poles and trees. The collection of data on the repair, replacement or relocation of utility poles would obviously require the close cooperation of the company owning the poles. Also of interest would be any unusually frequent grading required to reduce pavement-edge drop-offs or otherwise eliminate rutting found in near-roadside areas. Special attention should be paid to roadside and island repairs in the vicinity of curves, bridges, railroad crossings and intersections. The employee report form (Figure 2-3) could be adapted to record maintenance of struck objects. More specific recording of object location and type should be encouraged.

Traffic Citation Patterns

Traffic citations issued by state and local law enforcement agencies are another source of information regarding potential traffic safety problems. Similar to citizen complaints, citation data can assist an agency in determining if there is a developing pattern of behavior which may lead to increased crashes in the future. Also, comparing a list of high-citation locations to a list of high-crash locations may serve to highlight high-crash locations warranting more immediate attention.

Adverse Litigation History

Another possible way of prioritizing traffic safety investigations and improvements is to review patterns of adverse litigation awards and settlements. Lawsuits themselves are not necessarily good indicators of true driving hazards due to the occasional filing of frivolous lawsuits. On the other hand, litigation results financially unfavorable to the local road agency may be used as criteria when selecting locations for evaluation or as information to prioritize projects for implementation.

METHODS OF MAINTAINING DATA

For any of the data types described above to be used to their fullest extent, they need to be maintained in easily accessible files keyed to a standard location-referencing system. Appropriate filing methods depend mainly on the size of the community, availability of start-up funds and agency comfort level with small computers. Common methods include manual location files, spot maps and computerized record systems.

Figure 2-3.
Employee Report Form

From: ______________________________ Dept: ______________________________ Date: __________

_____ This is to follow up my report by radio/phone to: ______________________________ On Date: ________

_____ This is the only report I have made.

Street Name: ____

City/Township: ____

Location/Address (nearest cross street/landmark): ______________________________________

REPORTED COMPLAINT (CIRCLE APPROPRIATE ITEMS)

Pavement::	Rough Wash-out	Ice/Snow Edge Hole Settlement	Dust/Dirt Potholes	
Shoulder:	Potholes Wash-Out	Bush/Tree	Drop (Edge of Pavement)	
Trees/Brush:	Blocking Road Vision Obstruction	Hanging Limb	Blocking Sign	Requires Removal/Trimming
Drainage:	Standing Water in Ditch Ditching Request		Flooding Private Property Culvert/Catch Basin/Manhole	Ditching Request
Traffic Control Devices:	<u>Signs</u> Damage Worn Missing Required	<u>Guardrail</u> Damage Required	<u>Signals</u> Damage Malfunction Required	<u>Pavement Markings</u> Worn Required
Miscellaneous:	Property Damage Roadside Hazards	Litter Pick-Up Work Quality	Roadside Mowing Construction Related	Overweight Veh

Remarks/Other: ____
____
____
____

Class of Road:	Primary	Local	Subdivision	State Trunkline
Surface Type:	Paved	Unpaved		

DISPOSITION

Action Date: ______________________ Time: ______________________________

Department: ______________________ Personnel Called: ______________________________

Repair or Corrective Action Taken: ____
____
____
____

Signed: ____ Date: ____________

Source: Road Commission for Oakland County; Datta, T. (1990).

Manual Location Files

Manual location files are used to store by location the paper copies of crash reports and other traffic and roadway data of the types discussed above. Such files are valuable in an archival (or backup) sense even if computerized systems are used to facilitate data retrieval and analysis. One of the main advantages of manual files, aside from their relatively low set-up cost, is the access they provide to the crash diagrams and accompanying remarks so valuable in the detailed investigation of high-crash locations.

Establishing manual files for an urban area
Urban files are normally organized by intersections and mid-block segments. First, a primary file is established for each street. Subfiles are then set up for each intersection and mid-block segment on that street. Mid-block subfiles are commonly placed between corresponding intersection subfiles; however, an alternative is to separately group the two types of subfiles within each primary file. Mid-block address ranges are often noted.

In order to avoid having two (or more) subfiles for each intersection, a method must be developed for assigning an intersection to just one of the intersecting streets. One such method is to decide whether north/south or east/west streets will take priority and then place all intersection subfiles within the primary file of the street oriented in the priority direction. Another method is to locate intersection subfiles alphabetically; for example, the intersection of Washington Boulevard and Main Street would be located within the Main Street file since the letter M precedes the letter W.

Establishing manual files for a rural area
Rural files are also organized by intersections and intervening segments. Since rural road segments are generally much longer than typical urban blocks, however, a distance-based system is more important for recording the locations of crashes and other features along each segment. Milepost number, or distance and direction to the nearest intersection, are used most often to describe crash locations; hence, rural segment subfiles should state segment lengths to a precision no worse than 0.1 mile (preferably 0.01 mile to be compatible with the location measurements of prominent roadway features and fixed objects involved in particular crashes).

Retention of records
Central files should normally be kept current for at least three years, the minimum time period required to determine statistically reliable crash frequencies, rates and patterns on low- to mid-volume roadways (see Chapter 3). Record-retention policy should also recognize that any given crash analysis will need data for a multiple of 12 continuous months (e.g., 12, 24 or 36 months) to avoid seasonal biases due to weather and traffic variations.

While active files could be rotated monthly so as to never have more than 36 months of data on hand, this practice would limit the comparability of one location's three-year analysis to another location's three-year analysis done, say, three to six months later. The severity and significance of the limitation would depend on year-to-year variations in traffic volumes, weather and driving behavior.

The best practice from an analytical point of view is to maintain active files for the three full calendar years immediately preceding the current year. This practice provides maximum flexibility in the use of crash data, in that it allows the development and comparison between locations of crash statistics for the same three-year period, as well as the review of a particular location's crash history for an extended period up to the date of the data retrieval. The latter capability is important when a location's recent crash history has become a matter of public concern and a trend analysis appears warranted.

Local agencies may want to archive files for an additional two to four years after the files are removed from active status. The chief advantage of such retention is that it allows the development of more stable and reliable crash statistics for locations experiencing low traffic volumes and relatively few crashes in most years. Additional years of data also provide a better sense of the year-to-year variability in crash occurrence that is being averaged. The archived files should be organized in the same manner as the active files. To reduce the space consumed by such files, however, the records may be microfilmed.

Crash Summary Sheets

Some agencies choose to summarize all of a year's crashes at a location on a single sheet of paper. Data tabulated on the sheet might include the:

- specific crash location, date and time;
- lighting, weather and road surface conditions;
- number, types and pre-crash travel directions of involved vehicles;
- crash type and object(s) struck;
- number of fatalities and/or non-fatal injuries; and
- presence of unusual factors (e.g., drunk driver, construction or animal in road).

Crash summary sheets are helpful when maintained as part of the active crash files. Keeping the summary sheets within their respective subfiles provides quick access to a log of the crashes for a location and eliminates the need for sorting through all of the associated crash reports every time a question arises about the location's crash history. Also, retaining summary sheets for several years of data may allow the earlier disposal of individual hard-copy crash reports.

Spot Maps

Spot maps display crash frequencies by location in the roadway network. They provide a quick visual overview of crash concentrations and typically have been used in the past to supplement manual location filing systems for small- to medium-sized networks. However, recent developments in Geographic Information Systems (GIS) and related computer graphics are increasing the feasibility of also using spot maps with larger, computerized filing systems.

To create a spot map manually, a street map is posted and a pin is placed at the location of each crash as that crash's report is filed. Using a limited number of different sizes and colors of pins can be helpful in making the map less cluttered and more meaningful. For instance, a larger pin might represent ten crashes at the same location. Various colors of pins might indicate selected crash types of interest, such as those involving serious injuries and/or fatalities, pedestrians, darkness or driving under the influence of alcohol or drugs.

Normally, a one-year crash record is kept on a spot map. Two maps should be simultaneously maintained -- one for the current year and one for the preceding year -- to allow continuous monitoring of year-to-year changes in crash locations. Before removing the pins or otherwise disposing of each year's map, a color photograph of the map should be taken to maintain a permanent visual record.

Computerized Record Systems

Computerized record systems operate by coding selected data from hard-copy reports into electronic data bases. Most such systems contain several data bases to separately file crash reports, traffic volume data, traffic control device inventories and other reports of the types described above. These data bases should be set up so that they can be linked, by location and time period, for the computation of crash rates and for analyzing correlations between crash history and roadway features of interest.

While computerized record systems are essential to the efficient maintenance of large roadway network data bases, these systems are increasingly applicable to networks of almost any size. They permit the rapid sorting, retrieval and tabulation of data to identify crash trends and problems. They can be used to generate statistical reports at regular intervals and, as suggested above, they can integrate separate but related data bases to enable more comprehensive and powerful analyses.

Personal computers (PCs) and user-friendly software applications continue to gain in capability and ease of use while at the same time they continue to decrease in cost. Most local agencies should be using or exploring the possibility of using such systems.

A variety of traffic-record/crash-management software packages have been developed for use by state and local agencies (see, for example, McTrans, 1995). Several packages have now become fairly mature in terms of their years of use and refinement. The adaptation of existing PC software packages to new local applications is becoming more feasible, desirable and routine.

Michigan Accident Location Index (MALI) System

The Michigan State Police developed the MALI system in the mid 1970s as a computerized process for storing and analyzing crash information. The system was designed to identify crash locations within any given area throughout the state, thereby providing an efficient means of retrieving state-maintained crash data for distribution to corresponding government and law enforcement agencies (MDSP, 1982).

The MALI process locates crashes using a network-based concept known as a street index. This index assigns a physical route (PR) number and beginning and ending milepost to each roadway in Michigan. The Michigan State Police receive UD-10 crash reports from local and state police and enter selected information into the MALI data base. Using the street index, each crash in the MALI data base is located by its PR number and milepost based on information supplied by the crash's UD-10. Government agencies and law enforcement personnel may then use MALI to identify crash patterns and locate problem areas.

While MALI provides a variety of information, it has certain idiosyncracies and limitations. There have been problems with multiple PR numbers assigned to a highway when that highway is divided, requiring the analyst to verify that he or she has all the necessary information. Problems also arise when multiple PR numbers have been assigned consecutively to a segment of interest, since it is not a simple process to combine data for the different PR numbers prior to compiling the summary reports. In addition, it is necessary to remember that the beginning and end mileposts used in a roadway's MALI index do not always correspond to the milepost numbers actually posted along the road.

SEMCOG Accident Analysis System (SAAS)

Several local agencies in Michigan have developed their own programs to enhance MALI data. One such program is SAAS.

SAAS allows SEMCOG to provide MALI data to its local communities in easy-to-use formats. Typically, SEMCOG provides two types of crash data. First, staff will provide selected crash data for specific locations upon request. This information is available for both intersections and roadway segments. Figure 2-4 shows a response to a typical data request. SAAS can be used to prepare such a crash log using any of the variables coded from the UD-10 crash report form.

Second, SEMCOG will provide communities with their most recent year's MALI data in the format(s) desired. Available formats include spreadsheet, ASCII, dBASE and paper copies. In 1997, SEMCOG provided over 130 communities with the crash data associated with their jurisdiction.

Other Data System Enhancements

Several other agencies, in addition to SEMCOG, provide tools to enhance MALI data. For example, the Traffic Improvement Association of Oakland County provides services similar to those of SEMCOG, but for Oakland County. The Detroit Police Department encodes its crash data itself and has developed a system which handles the data in a manner best suited to its needs.

Wayne State University has developed interactive software which manages citizen complaints and employee report data (Datta, 1995). Michigan Technological University has developed computer software known as RoadSoft which may be used as a crash records system.

In response to the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, in particular the section mandating Safety Management Systems, increased funding has become available for developing more efficient traffic-record/crash-management systems. These funds will assist in the further computerization and coordination of record systems at the state, county and local levels.

Figure 2-4.
Typical Response to SAAS Data Request

SEMCOG ACCIDENT ANALYSIS SYSTEM (SAAS)

INTERSECTION CHARACTERISTICS REPORT, YEAR: 1994

INTERSECTION OF: STREET 1(PR #: 1427803, mi: 1.23) AT STREET 2 (PR #: 1428902, mi: 0.69) @ 150 FEET

PRODUCED: FEBRUARY 7, 1996

DATE	DAY	TIME	WEATHER	LIGHT	PAVE-MENT	ALCO-HOL	SEVER-ITY	ACCIDENT TYPE	OFFSET FEET	UNIT #	VEHICLE TYPE	HAZARDOUS ACTION	DRIVER INTENT	DIR
JAN 8	SAT	10-11	CLOUDY	DAY	ICY	NO	DAMAGE	SWIPE-SAME	30	1	AUTO/SWGN	UNABLE STOP	SLOWING ON RD	E
										2	AUTO/SWGN	NONE	STOPPED ON RD	E
MAR 20	SUN	23-24	RAIN	ST. LGT	WET	YES	DAMAGE	ANGLE	10	1	AUTO/SWGN	NONE	GOING STRAIGHT	N
										2	AUTO/SWGN	DIS TRAF CONT	GOING STRAIGHT	E
MAR 29	TUE	15-16	SNOW	DAY	SNOWY	NO	DAMAGE	OTHER	0	1	AUTO/SWGN	FAIL TO YIELD	GOING STRAIGHT	E
										2	AUTO/SWGN	NONE	GOING STRAIGHT	N
JUL 6	WED	18-19	CLOUDY	DAY	WET	NO	INJURY	ANGLE	10	1	AUTO/SWGN	FAIL TO YIELD	LEFT TURN	W
										2	AUTO/SWGN	UNKNOWN	GOING STRAIGHT	S
SEP 27	TUE	13-14	CLOUDY	DAY	DRY	NO	DAMAGE	REAR END	20	1	AUTO/SWGN	UNABLE STOP	STOPPED ON RD	E
										2	AUTO/SWGN	NONE	START ON ROAD	E
NOV 4	FRI	16-17	CLOUDY	DAY	DRY	NO	DAMAGE	SWIPE-SAME	10	1	VAN/RV	UNABLE STOP	SLOWING ON RD	S
										2	OTHER/UNK	UNKNOWN	LEFT TURN	

**** INTERSECTION SUMMARY ****

|<----------- GENERAL CRASH STATISTICS ----------->|

TOTAL CRASHES =	6	PEDESTRIAN CRASHES =	0
FATAL CRASHES =	0	BICYCLIST CRASHES =	0
INJURY CRASHES =	1	ALCOHOL RELATED CRASHES =	1

|<--------------------- CRASH TYPE --------------------->|

HEAD-ON =	0	REAR-END =	1	SIDESWIPE-SAME =	2
HEAD-LEFT =	0	REAR-LEFT =	0	SIDESWIPE-OPP =	0
ANGLE =	2	REAR-RIGHT =	0	OTHER/UNKNOWN =	1
SINGLE VEH =	0				

CHAPTER 3

IDENTIFICATION OF HIGH-CRASH LOCATIONS

Identifying high-crash locations is a vital first step in achieving cost-effective reductions in highway crash losses. This chapter covers the selection of locations to be evaluated, number of years of crash data which should be analyzed, length considerations in defining locations and several commonly used methods for identifying high-crash locations. The methods are presented in a detailed step-by-step format and are later illustrated in the same format with an intersection example. The identification of potentially hazardous locations is also discussed briefly.

LOCATIONS EVALUATED

The methods presented in this chapter can be used to evaluate any number of suspected high-crash locations. An evaluation may entail reviewing all physically similar locations throughout a jurisdiction, comparing the crash histories of a few individual locations of concern or checking the crash history of a single troublesome location. In evaluations involving selected individual locations, those locations can come to the attention of the local traffic safety staff through:

- ongoing or periodic application of simple high-crash identification methods, such as the Spot Map or Crash Frequency Method (described below),
- citizen complaints of perceived operational and safety problems,
- complaints and concerns expressed by local elected officials and senior agency management,
- reports of questionable features and conditions filed by agency employees,
- review of maintenance records (e.g., on sign and guardrail repair),
- personal knowledge and opinions of highway and traffic engineers, police officers and emergency medical technicians,
- review of traffic citation patterns by location and operating condition, and
- review of locations associated with adverse litigation awards and settlements.

TIME AND LENGTH CONSIDERATIONS

Crash data for the most recent one- to three-year period are normally used. However, the crash frequency at a given location can fluctuate significantly from year to year, often in a statistically random manner. Thus, the use of a single year of crash data in identifying high-crash locations may yield unreliable and even misleading results. This is especially true for locations having low traffic volumes and relatively few crashes in most years. Longer analysis periods, up to four years, are generally more reliable for identifying true high-crash locations. However, if sudden changes in crash patterns are suspected due to specific causal factors, the use of both short and long analysis periods — or a year-to-year statistical profile — may be warranted. If a single time period is used, three years of data have been found to be desirable (FHWA, 1986a).

The roadway network should be divided into spots and segments. Isolated curves, bridges, railroad crossings and intersections are examples of spots. Segments are defined by a particular section length (typically in the range of one to five miles) or as the section of roadway between two spots.

Spots should be defined to include the area of influence of the feature in question. For example, driver behavior can be influenced as far as 500 feet from a curve and 250 feet from an intersection (or further with severe congestion and queuing). Using at least a 500-foot influence area either side of a non-intersection spot location also helps ensure that a larger share of relevant crashes are properly identified, given typical uncertainties and errors in reporting crash position (especially on rural roads).

METHODS FOR IDENTIFYING HIGH-CRASH LOCATIONS

The analyst is free to apply any one or more of the following methods for identifying high-crash locations:

- Spot Map Method — The geographic clustering of crashes is appraised.
- Crash Frequency Method — Locations are ranked by descending crash frequency, and above-average frequencies are tested for significance.
- Crash Rate Method — Locations are ranked by descending crash rate, and above-average rates are tested for significance (also known as Rate Quality Control Method).
- Frequency-Rate Method — High-crash locations are sorted in a frequency-rate matrix.
- Crash Severity Methods — Crash frequencies are weighted by severity in two alternative methods.
- Crash Probability Index (CPI) Method — Frequency, rate and severity results are combined.

Again, these methods may be used to review all similar locations within a jurisdiction, compare the crash histories of a few individual locations of concern or check the crash history of a single location. Regardless of the number of locations being evaluated, it is a good idea to maintain a list of locations which have been evaluated and rank the locations on the list according to measures such as crash frequency or crash rate.

Spot Map Method

The simplest method of identifying high-crash locations is to examine a map showing clusters of symbols at those spots and on those segments in the road network having the greatest numbers of total crashes (or crashes of specific types, such as those involving serious injuries and/or fatalities, pedestrians, darkness or driving under the influence of alcohol or drugs). Where the study area and/or crash frequencies are large, or when a list of high-crash locations is desired, one of the other high-crash identification methods will usually be more satisfactory (FHWA, 1986a).

Crash Frequency Method

This method ranks locations by the number of reported crashes (or crashes per mile), with frequencies listed in descending order. Locations having crash frequencies greater than or equal to a critical crash frequency are considered to be high-crash.

To apply the Crash Frequency Method, complete the following steps for each location being studied:

1. Determine the location's crash frequency. Compute the annual average number of crashes, preferably for at least three recent (and consecutive) 12-month periods; however, if three years' data are unavailable or there is a desire to examine a shorter period, as little as one year of data may be used with caution for locations having moderate to high traffic volumes.

   If a roadway segment is being studied, the crash frequency should be divided by the segment's length in miles to allow for fairer comparisons to segments of other lengths.

2. Define the location type. Categorize the location by as many of the following features as possible:

a. area type (urban/rural),

b. roadway functional class (arterial/collector/local) — for an intersection, the higher or highest functional class of the intersecting roadways, where an arterial is the highest class (meant primarily to carry through traffic) and a local is the lowest class (meant primarily to provide access to abutting properties);

c. number of lanes — for an intersection, the number of through lanes on the widest approach;

d. predominant traffic control — for an intersection, the presence or absence of signalization and for a segment, the speed limit; and

e. average daily traffic (ADT) volume (the 10,000 vehicle per day range within which the location's ADT falls; e.g., 0 to 10,000, 10,001 to 20,000, etc.) — for an intersection, the sum of the volumes on all approaches.

3. If a list of previously evaluated locations is being maintained, insert the location into the list of locations ranked in descending order by crash frequency. At a minimum, maintain separate lists for intersections, other spot locations and segments. As the number of evaluated locations grows, consider setting up and maintaining lists for increasingly specific combinations of the variables listed in Step 2 (e.g., all urban intersections with volumes between 20,001 and 30,000 vehicles per day, when five or more evaluated locations fall into such a category).

4. Determine the critical crash frequency. Take one or more of the following approaches to determine a critical crash frequency for the corresponding location type:

   a. Look up one to four regional critical crash frequencies in tables developed by SEMCOG for intersections in Southeast Michigan (Tables 3-1 to 3-4) and compute an average value. These critical crash frequencies were computed with crash data for the entire SEMCOG region using the equation described in Appendix A. Local critical crash frequencies may be calculated using the appropriate statistical method detailed in Appendix A. If a local critical crash frequency is derived, it is important to verify that the sample size is sufficient for the community.

   b. Choose a number of crashes per year (or per year per mile) which the community considers "high" and which is likely to be exceeded at only a few similar locations which the agency can reasonably be expected to study in detail. This number will be subjective and based primarily on community experience.

5. Compare the location's crash frequency to the critical crash frequency. If the crash frequency equals or exceeds the critical crash frequency, classify the location as high-crash.

The Crash Frequency Method does not take into account the differing amounts of traffic at the locations compared. Hence, the method tends to rank a high-volume location as a high-crash location, even if the location has a relatively low number of crashes for its traffic volume. Many agencies use the Crash Frequency Method to select an initial list of suspect locations, and then evaluate the crash histories of the listed locations in greater detail using other methods (FHWA, 1986a).

Crash Rate Method

The Crash Rate Method compares the number of crashes to the volume of traffic, with the latter measured either as the number of vehicles crossing a spot in a given time period, or as the number of vehicle-miles of travel along a segment in that period. To express the associated crash rates in conveniently sized numbers, the spot rate is generally stated in terms of "crashes per million vehicles" (MV) and the segment rate in terms of "crashes per million vehicle-miles" (MVM).

Table 3-1.
Regional Critical Intersection Crash Rates, Frequencies and Casualty Ratios: By Area Type

Average Daily Traffic Volume Entering Intersection	Average Crash Rate	Critical Crash Rate	Average Crash Frequency	Critical Crash Frequency	Average Casualty Ratio	Critical Casualty Ratio	Number of Intersections Sampled[1]
URBAN AREA[2]	**1.52**	**2.17**	**13.13**	**26.38**	**0.28**	**0.42**	**2,925**
1 - 10,000	3.86	6.11	4.86	9.57	0.30	0.50	307
10,001 - 20,000	1.47	2.41	7.99	15.37	0.28	0.44	677
20,001 - 30,000	1.33	2.02	12.08	23.29	0.28	0.42	683
30,001 - 40,000	1.15	1.68	14.62	26.60	0.28	0.40	497
40,001 - 50,000	1.11	1.56	17.97	33.38	0.28	0.40	331
50,001 - 60,000	1.10	1.51	21.67	39.27	0.26	0.37	190
60,001 - 70,000	1.03	1.40	24.40	43.99	0.27	0.36	103
70,001 - 80,000	0.82	1.13	22.52	40.14	0.28	0.39	55
80,001 - 90,000	0.92	1.22	28.18	46.28	0.25	0.39	48
over 90,000	0.67	0.90	24.42	40.60	0.29	0.39	34
RURAL AREA[2]	**2.37**	**3.88**	**4.74**	**9.98**	**0.29**	**0.49**	**395**
1 - 10,000	2.89	5.09	2.83	5.12	0.29	0.52	260
10,001 - 20,000	1.35	2.29	6.97	12.28	0.28	0.44	107
over 20,000	1.48	2.17	14.01	23.76	0.26	0.36	28

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995.
[2] Values on this line are volume-independent. Rates are in crashes per million vehicles and frequencies are annual averages.

Table 3-2.
Regional Critical Intersection Crash Rates, Frequencies and Casualty Ratios: By Higher Functional Class of Roadway

Average Daily Traffic Volume Entering Intersection	Average Crash Rate	**Critical Crash Rate**	Average Crash Frequency	**Critical Crash Frequency**	Average Casualty Ratio	**Critical Casualty Ratio**	Number of Intersections Sampled[1]
ARTERIAL[2]	**1.59**	**2.25**	**13.62**	**26.91**	**0.28**	**0.42**	**2,830**
1 - 10,000	4.58	6.97	5.33	10.25	0.29	0.48	265
10,001 - 20,000	1.53	2.49	8.40	15.79	0.28	0.43	667
20,001 - 30,000	1.39	2.09	12.69	24.00	0.28	0.41	656
30,001 - 40,000	1.17	1.71	14.91	26.95	0.28	0.40	486
40,001 - 50,000	1.11	1.57	18.08	33.51	0.28	0.40	328
50,001 - 60,000	1.10	1.51	21.69	39.33	0.26	0.37	189
60,001 - 70,000	1.03	1.40	24.40	43.99	0.27	0.36	103
70,001 - 80,000	.082	1.13	22.52	40314	0.28	0.39	55
80,001 - 90,000	0.92	1.22	28.18	46.28	0.25	0.32	48
over 90,000	0.69	0.93	25.14	41.01	0.28	0.38	33
COLLECTOR OR LOCAL[2]	**1.79**	**3.01**	**3.60**	**7.15**	**0.28**	**0.50**	**490**
1 - 10,000	2.39	4.43	2.70	4.82	0.30	0.53	302
10,001 - 20,000	0.97	1.79	4.70	9.06	0.25	0.45	117
20,001 - 30,000	0.63	1.14	5.33	10.55	0.27	0.46	50
30,001 - 40,000	0.46	0.82	5.98	10.73	0.25	0.44	16
over 40,000	0.40	0.62	7.27	14.58	0.32	0.48	5

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1995-1997.
[2] Values on this line are volume-independent. Rates are in crashes per million vehicles and frequencies are annual averages.

Table 3-3.
Regional Critical Intersection Rates, Frequencies and Casualty Ratios: By No. of Through Lanes on Widest Approach

Average Daily Traffic Volume Entering Intersection	Average Crash Rate	**Critical Crash Rate**	Average Crash Frequency	**Critical Crash Frequency**	Average Casualty Ratio	**Critical Casualty Ratio**	Number of Intersections Sampled[1]
ONE LANE[2]	**1.69**	**2.71**	**5.82**	**12.05**	**0.30**	**0.50**	**1161**
1 - 10,000	2.66	4.68	3.01	5.64	0.30	0.54	453
10,001 - 20,000	1.14	2.00	5.99	10.92	0.30	0.49	429
20,001 - 30,000	1.02	1.64	8.84	16.28	0.29	0.45	186
30,001 - 40,000	1.00	1.50	12.46	23.90	0.28	0.43	57
over 40,000	0.74	1.11	12.88	24.11	0.28	0.40	36
TWO LANES[2]	**1.29**	**1.87**	**11.21**	**21.77**	**0.28**	**0.43**	**1,185**
1 - 10,000	4.02	6.32	5.83	10.86	0.29	0.46	94
10,001 - 20,000	1.39	2.30	7.63	13.80	0.28	0.45	242
20,001 - 30,000	1.22	1.88	11.18	21.70	0.27	0.40	287
30,001 - 40,000	0.95	1.45	12.04	22.58	0.29	0.43	237
40,001 - 50,000	0.87	1.28	14.07	27.75	0.30	0.45	138
50,001 - 60,000	0.64	0.95	12.64	22.67	0.28	0.40	70
over 60,000	0.62	0.88	17.15	29.79	0.28	0.37	117
Three and Four or More Lanes on Next Page							

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1995-1997.
[2] Values on this line are volume-independent. Rates are in crashes per million vehicles and frequencies are annual averages.

Table 3-3.
Regional Critical Intersection Rates, Frequencies and Casualty Ratios: By No. of Through Lanes on Widest Approach (cont'd)

Average Daily Traffic Volume Entering Intersection	Average Crash Rate	**Critical Crash Rate**	Average Crash Frequency	**Critical Crash Frequency**	Average Casualty Ratio	**Critical Casualty Ratio**	Number of Intersections Sampled[1]
THREE LANES[2]	**1.65**	**2.25**	**17.84**	**32.47**	**0.31**	**0.42**	**798**
1 - 20,000	3.91	5.41	10.93	21.96	0.30	0.44	114
20,001 - 30,000	1.38	2.07	12.81	23.19	0.32	0.46	191
30,001 - 40,000	1.26	1.82	16.21	28.03	0.31	0.42	180
40,001 - 50,000	1.24	1.72	20.16	35.18	0.30	0.41	140
50,001 - 60,000	1.29	1.73	25.33	42.08	0.30	0.40	89
60,001 - 70,000	1.29	1.70	30.73	46.70	0.30	0.39	36
over 70,000	0.98	1.28	30.06	48.95	0.29	0.38	48
FOUR OR MORE LANES[2]	**1.64**	**2.21**	**22.92**	**42.49**	**0.28**	**0.39**	**176**
1 - 20,000	2.55	3.77	14.30	23.99	0.29	0.37	19
20,001 - 30,000	1.88	2.68	16.73	31.72	0.24	0.34	42
30,001 - 40,000	1.49	2.09	19.46	31.44	0.29	0.40	28
40,001 - 50,000	1.30	1.79	21.10	41.58	0.31	0.42	26
50,001 - 60,000	1.74	2.25	34.55	60.09	0.31	0.42	25
60,001 - 70,000	1.31	1.72	30.77	55.74	0.33	0.46	20
over 70,000	1.04	1.37	30.46	49.15	0.27	0.34	16

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995.
[2] Values on this line are volume-independent. Rates are in crashes per million vehicles and frequencies are annual averages.

Table 3-4.
Regional Critical Intersection Crash Rates, Frequencies and Casualty Ratios: By Presence or Absence of Signalization

Average Daily Traffic Volume Entering Intersection	Average Crash Rate	**Critical Crash Rate**	Average Crash Frequency	**Critical Crash Frequency**	Average Casualty Ratio	**Critical Casualty Ratio**	Number of Intersections Sampled[1]
SIGNALIZED[2]	**1.66**	**2.31**	**14.79**	**27.87**	**0.30**	**0.42**	**2,375**
1 - 10,000	6.13	8.88	6.42	11.36	0.33	0.49	158
10,001 - 20,000	1.70	2.70	9.38	16.56	0.30	0.43	507
20,001 - 30,000	1.43	2.13	12.95	23.54	0.29	0.42	579
30,001 - 40,000	1.21	1.75	15.38	26.69	0.30	0.42	437
40,001 - 50,000	1.14	1.60	18.52	33.62	0.30	0.42	298
50,001 - 60,000	1.18	1.61	23.37	41.08	0.29	0.38	169
60,001 - 70,000	1.06	1.43	25.03	42.93	0.30	0.39	96
70,001 - 80,000	0.83	1.14	22.85	39.60	0.30	0.38	52
80,001 - 90,000	0.89	1.19	27.25	44.64	0.26	0.32	46
over 90,000	0.69	0.92	24.99	41.24	0.29	0.40	33
Unsignalized on Next Page							

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995.
[2] Values on this line are volume-independent. Rates are in crashes per million vehicles and frequencies are annual averages.

Table 3-4.
Regional Critical Intersection Crash Rates, Frequencies and Casualty Ratios: By Presence or Absence of Signalization (cont'd)

Average Daily Traffic Volume Entering Intersection	Average Crash Rate	**Critical Crash Rate**	Average Crash Frequency	**Critical Crash Frequency**	Average Casualty Ratio	**Critical Casualty Ratio**	Number of Intersections Sampled[1]
UNSIGNALIZED[2]	**1.23**	**2.07**	**3.37**	**7.05**	**0.28**	**0.51**	**945**
1 - 10,000	2.15	4.02	2.73	6.25	0.29	0.53	409
10,001 - 20,000	0.68	1.38	3.46	6.36	0.29	0.51	277
20,001 - 30,000	0.44	0.86	3.99	7.03	0.26	0.46	127
30,001 - 40,000	0.38	0.70	4.69	11.57	0.25	0.44	65
40,001 - 50,000	0.29	0.54	4.59	7.86	0.32	0.52	33
50,001 - 60,000	0.25	0.46	4.87	9.52	0.28	0.47	21
over 60,000	0.13	0.26	3.33	4.97	0.27	0.44	13

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995.
[2] Values on this line are volume-independent. Rates are in crashes per million vehicles and frequencies are annual averages.

The Crash Rate Method as defined in this manual incorporates a technique known as the Rate Quality Control Method. This method applies an easy-to-use statistical test to determine whether the crash rate for a particular location is significantly higher than the average crash rate for other locations in the jurisdiction (or region) having similar characteristics. If it is, the location is classified as a high-crash location.

To apply the Crash Rate Method, complete the following steps for each location being studied:

1. Determine the location's crash rate. Compute the crash rate using the appropriate equation below.

   a. The equation for spot crash rate (in crashes per MV) is:

   Eq.(3-1)

   $$R_{sp} = \frac{1{,}000{,}000 x CRA}{365 x ADT}$$

   where CRA = average annual number of crashes during the study period and

   ADT = average daily traffic volume during the study period (for an intersection, the sum of the volumes on all approaches).

   b. The equation for segment crash rate (in crashes per MVM) is:

   Eq.(3-2)

   $$R_{se} = \frac{1{,}000{,}000 x CRA}{365 x ADT x L}$$

   where L = length of segment in miles and

   the other variables are as defined above.

2. Define the location type. If not already done, categorize the location in the manner described in Step 2 of the Crash Frequency Method.

3. If a list of previously evaluated locations is being maintained, insert the location into the list of locations ranked in descending order by crash rate. At a minimum, maintain separate lists for intersections, other spot locations and segments. As the number of evaluated locations grows, consider setting up and maintaining lists for increasingly specific combinations of the variables listed in Step 2 of the Crash Frequency Method (e.g. all urban intersections with volumes between 20,001 and 30,000 vehicles per day, when five or more evaluated locations fall into such a category).

4. Determine the critical crash rate. Look up one to four regional critical crash rates in tables developed by SEMCOG for intersections in Southeast Michigan (Tables 3-1 to 3-4) and compute an average value. These regional critical crash rates were computed with crash data for the entire SEMCOG region using the method described in Appendix A. Local critical crash rates may be calculated using the appropriate statistical method, also detailed in Appendix A. If a local critical crash rate is derived, it is important to verify that the sample size is sufficient for the community.

5. Compare the location's crash rate to the critical crash rate. If the crash rate equals or exceeds the critical crash rate, classify the location as high-crash.

Since the Crash Rate Method accounts for a location's traffic "exposure," it is less likely to unfairly condemn high-volume locations than when using the Crash Frequency Method. However, it tends to unfairly identify low-volume locations having relatively few crashes as high-crash locations. For example, a crash rate of two to three crashes per MVM is considered by some states to be an average rate for rural two-lane roads, exclusive of intersections (FHWA, 1986a). However, a one-mile segment with a traffic volume of only 300 vehicles per day and an average of only one crash per year would have a crash rate of 9.1 crashes per MVM. A rate more than three times the average makes the segment look unusually hazardous, even though only one crash occurred. Thus, the Crash Rate Method can yield misleading results for low-volume locations.

Crash Severity Methods

Accounting for crash severity in identifying and treating high-crash locations should result in higher system-wide loss reductions due to the more serious (as well as more frequently experienced) hazards being addressed.

There are several methods for identifying high-crash locations that account for and weight crashes based on their severity level (i.e., the most severe injury incurred). Standard crash severity levels, defined by the National Safety Council and now commonly used in police reporting of accidents, include:

- Fatal — one or more deaths,
- A-level injury — incapacitating injury preventing victim from functioning normally (e.g., paralysis, broken/distorted limbs, etc.),
- B-level injury — non-incapacitating but visible injury (e.g., abrasions, bruises, swelling, limping, etc.),
- C-level injury — probable but not visible injury (e.g., sore/stiff neck) and
- PDO — property-damage-only.

This section describes two crash severity methods, the Equivalent Property-Damage-Only (EPDO) Method and the Relative Severity Index (RSI) Method.

<u>EPDO Method</u>
For a given location, the number of crashes at each severity level is multiplied by an arbitrary weighting factor in order to transform that frequency into an "equivalent" frequency of PDO crashes.

Weighted frequencies are then summed across severity levels to yield a value called EPDO. "High-serious-crash" locations are selected from the top of a list of locations ranked in descending order by either EPDO or EPDO crash rate (i.e., EPDO crashes per MV or per MVM).

To apply the EPDO Method, complete the following steps for each location being studied:

1. <u>Determine the number of crashes which occurred at each severity level</u>. Compute five annual average crash frequencies, one for each standard severity level based on the most severe injury incurred (i.e., fatal, A-level, B-level, C-level and PDO). Due to the relatively small numbers of crashes expected at the more severe levels, longer analysis periods are typically needed to produce reliable frequencies for use in this method. From three to as many as seven years of crash data may be needed, depending on traffic volume and overall crash frequency; however, great care should be exercised when using multiple years of data to ensure that traffic and road characteristics have not changed materially during the analysis period.

2. <u>Compute the location's EPDO value</u>. Substitute the severity-specific crash frequencies from Step 1 into the following equation and solve for EPDO:

Eq.(3-3)

$$EPDO = 9.5x(F+A) + 3.5x(B+C) + PDO$$

where F = annual average number of fatal crashes,

A = annual average number of A-level injury crashes,

B = annual average number of B-level injury crashes,

C = annual average number of C-level injury crashes, and

PDO = annual average number of property-damage-only crashes.

3. Compute the EPDO crash rate **(optional)**. Substitute the result from Step 2 into the appropriate equation below and solve. Variables ADT and L are defined in Step 1 of the Crash Rate Method.

   a. The equation for spot locations is:

Eq.(3-4)

$$\frac{EPDO}{MV} = \frac{1,000,000xEPDO}{365xADT}$$

   b. The equation for segments is:

Eq.(3-5)

$$\frac{EDPO}{MVM} = \frac{1,000,000xEDPO}{365xADTxL}$$

4. Define the location type. If not already done, categorize the location in the manner described in Step 2 of the Crash Frequency Method.

5. If a list of previously evaluated locations is being maintained, insert the location into the list of locations ranked in descending order by either EPDO or EPDO crash rate. Complete this step in a manner similar to that described in Step 3 of the Crash Frequency Method.

6. Declare the location to be "high-serious-crash" if it ranks relatively high compared to locations with similar characteristics. Since SEMCOG has not determined critical EPDO values for the region, the analyst should compare the location's EPDO value to the EPDO values of other similar locations, if the data is available. It is possible for a location to have a high EPDO value when compared to other locations within the community but which does not exceed any regional critical EPDO values.

The EPDO Method provides a way of incorporating crash severity into the previously described ranking processes based only on crash frequency or crash rate.

RSI Method

This method computes the weighted average cost of a crash at a location during the analysis period. It is, therefore, best-suited for the further evaluation of locations already identified as high-crash (or high-serious-crash) by other methods. The number of crashes at each severity level is first multiplied by the average "comprehensive cost" for a crash at that severity level. These severity-specific cost subtotals are then summed, and the sum is divided by the total number of crashes.

To apply the RSI Method, complete the following steps for each location being studied:

1. Determine the number of crashes which occurred at each severity level. If not already done in applying the EPDO Method, complete this step in the manner described in Step 1 of that method.

2. Compute the location's RSI value. Substitute the crash frequencies by severity determined in Step 1 into the following equation and solve:

Eq.(3-6)

$$RSI = \frac{C_F xF + C_A xA + C_B xB + C_C xC + C_{PDO} xPDO}{F+A+B+C+PDO}$$

where C_i is the average comprehensive cost per crash for a crash of severity level i (accepted for analysis purposes) and F, A, B, C and PDO are as defined above for the EPDO Method. In lieu of locally computed unit crash costs, the 1993 values shown in Table 3-5 can be applied. (Streff and Molnar, 1994)

3. Define the location type. If not already done, categorize the location in the manner described in Step 2 of the Crash Frequency Method.

4. If a list of previously evaluated locations is being maintained, insert the location into the list of locations ranked in descending order by RSI. Complete this step in a manner similar to that described in Step 3 of the Crash Frequency Method.

5. Declare the location "high-serious-crash" if it ranks relatively high compared to locations with similar characteristics. Since SEMCOG has not determined critical RSI values for the region, the analyst should compare the location's RSI value to the RSI values of other similar locations, if the data is available. It is possible for a location to have a high RSI value when compared to other locations within the community but which does not exceed any regional critical RSI values.

The above process ranks locations by average crash cost. Locations high on an RSI list are generally those most in need of further evaluation with respect to crash severity-reducing countermeasures.

Where the number of crashes for a location is small, crash severity methods must be used with great care. A single fatal crash can move a location to the top of the high-serious-crash location rankings (especially with the RSI Method), even though the fatality or fatalities in the crash may have been due to factors unrelated to highway condition (such as the ejection of an unrestrained vehicle occupant). This could lead to large expenditures of safety improvement funds on locations where crash severities may not be sensitive to highway treatments. (FHWA, 1986a)

Crash Probability Index Method

This method combines the Crash Frequency and Crash Rate Methods with a simplified severity method. This combination reduces the sometimes misleading results for high-volume and low-volume intersections when only one method is used. The CPI Method also allows the analyst to adjust the weights assigned to each measure according to the priorities of the community. For example, SEMCOG has concluded that severity is of great concern to the agency, so severity distribution is weighted twice as heavily as crash frequency and crash rate.

Table 3-5.
Average Comprehensive Cost Per Crash, 1993

Crash Severity	Cost Per Crash
F	$3,961,000
A	$278,000
B	$66,000
C	$38,000
PDO	$2,700

When the location's crash history is significantly worse than average for crash frequency, crash rate or severity distribution, it is assigned penalty points. These points are then summed across measures to determine an overall CPI. High-crash locations are selected from the top of a list of locations ranked in descending order by non-zero CPI.

To apply the CPI Method, complete the following steps for each location studied:

1. Determine the location's crash rate, crash frequency and casualty ratio (CR). If not already done, compute the first two measures as described in the Crash Rate and Crash Frequency Methods, respectively, with segment crash frequency being expressed in crashes per mile. Compute the third measure, CR, using the following equation:

   Eq.(3-7)

   $$CR=\frac{F+A+B+C}{F+A+B+C+PDO}$$

   where all variables on the right side of the equation are defined in Step 2 of the EPDO Method.

2. Define the location type. If not already done, categorize the location in the manner described in Step 2 of the Crash Frequency Method.

3. Determine the critical crash rate, critical crash frequency and critical casualty ratio. The critical rate and critical frequency are computed as described in the Crash Rate and Crash Frequency Methods, respectively. The critical casualty ratio is determined for the corresponding location type by looking up one to four regional critical casualty ratios in tables developed by SEMCOG for intersections in Southeast Michigan (Tables 3-1 to 3-4) and computing an average value. These regional critical casualty ratios were computed with crash data for the entire SEMCOG region using the method described in Appendix A. Local critical casualty ratios may be calculated using the appropriate statistical method, also described in Appendix A. If a local critical casualty ratio is derived, it is important to verify that the sample size is sufficient for the community.

4. Compute the location's CPI value. Compare the location's crash rate, crash frequency and casualty ratio to the corresponding critical values in the following manner:

   a. If neither the crash rate, crash frequency nor CR equals or exceeds the corresponding critical value, set the CPI for the location equal to zero.

   b. If the crash rate equals or exceeds the corresponding critical crash rate, assess the location five penalty points.

   c. If the crash frequency equals or exceeds the corresponding critical crash frequency, assess the location five penalty points.

   d. If the CR equals or exceeds the corresponding critical casualty ratio, assess the location ten penalty points.

   e. Compute the location's CPI by summing the penalty points assessed in the preceding sub-steps.

   If there is a desire to assign a greater or lesser weight to any of the measures, the penalty points for equaling or exceeding the critical rate may be set equal to any value determined by the analyst. The number of points chosen for this purpose should be the same, however, for all locations studied and ranked in a given analysis.

5. If the location has been assessed a CPI of zero, remove it from the analysis.

6. If the location has a CPI greater than zero, declare the location to be high-crash and insert it into one or more lists sorted in descending order by CPI, if a list of previously evaluated locations is being maintained. Apply to the list(s) the

following three high-crash classifications based on CPI value: first-class (20 points), second-class (10-15 points) and third-class (5 points). According to the CPI method, first-class locations should receive the highest priority and third-class locations should receive less immediate attention.

EXAMPLE USING ALTERNATIVE METHODS

This section uses complete data for a sample intersection, plus limited data for five comparison intersections, to illustrate the application of several of the methods described above for identifying high-crash locations.

Sample Intersection

The intersection of Sem Road and Cog Avenue is located in an urban area. Both streets are classified as arterials, and there is a traffic signal at the intersection. There are two through lanes on the widest approach.

An evaluation of the intersection for the years 1993 to 1995 has been requested. A review of available crash data for those three years shows that 141 crashes were reported for the intersection. These 141 crashes consisted of 0 fatal crashes, 3 A-level crashes, 8 B-level crashes, 25 C-level crashes and 105 PDO crashes.

Selected crash statistics for five other similar intersections are summarized in Table 3-6.

Terms used in the table's column headings are defined in earlier sections presenting the various methods for identifying high-crash locations. The values given for annual average number of crashes have been rounded to whole numbers to simplify the presentation.

Over the same years used in the crash data retrieval, two-way ADT volumes for the four legs of the Sem-Cog intersection were 9,168, 18,403, 13,385 and 15,910 vehicles. Lacking more specific data, it is reasonable to assume that the total average daily volume entering the intersection was one half of the total of these two-way volumes, or (9,168 + 18,403 + 13,385 + 15,910) / 2 = 28,433 vehicles. Hence, the intersection's ADT falls in the range indicated in Table 3-6.

Crash Frequency Method

The results from applying this method to the sample intersection are indicated below under each of the method's steps. These steps require the analyst to:

1. Determine the location's crash frequency. There was an average of 141/3 = 47 crashes per year during the three-year analysis period.

2. Define the location type. Information defining the location type is given in the heading block of Table 3-6.

3. If a list of previously evaluated locations is being maintained, insert the location into the list of locations ranked in descending order by crash frequency. Table 3-7 is such a list and was readily constructed from data presented above.

4. Determine the critical crash frequency. Both alternative approaches are illustrated here. Note that they produce nearly identical results.

    a. Look up objectively determined regional critical crash frequencies in Tables 3-1 to 3-4 and compute an average value. For this intersection type, these tables provide critical frequencies of 21.67, 22.24, 21.70 and 23.54 crashes per year, respectively. The average of these values is 22.29 crashes per year.

    b. Assume that the community has subjectively determined 22 crashes per year to be critical.

5. Compare the location's crash frequency to the critical crash frequency. Since the intersection's 47 crashes per year exceeds the regional critical crash frequency of 22.29 crashes per year, this method identifies the Sem-Cog intersection as a high-crash location.

Table 3-6.

Crash Statistics for Comparison Intersections

Area Type Urban Functional Class Arterial Approach Lanes 2

Signalized X Unsignalized _____ Speed Limit _____ ADT Range 20,001-30,000

Analysis Period 1993-95 Analyst John Smith Date 09/04/95

Location	Annual Average No. of Crashes	Crash Rate (per MV)	EPDO Rate (per MV)	RSI ($ per Crash)	CPI
I-1	52	5.09	10.76	88,350	10
I-2	44	4.02	11.46	114,360	20
I-3	39	4.45	7.42	18,000	10
I-4	32	3.37	6.64	23,800	10
I-5	28	3.49	4.73	10,120	5

Table 3-7.
1993-1995 Annual Average Crash Frequencies for Example

Ranking	Location	No. of Crashes
1	I-1	52
2	**Sem-Cog**	**47**
3	I-2	44
4	I-3	39
5	I-4	32
6	I-5	28

Crash Rate Method

The results from applying this method to the sample intersection are indicated below under each of the method's steps. These steps require the analyst to:

1. Determine the location's crash rate. Substituting the crash frequency and ADT into Eq.(3-1) gives R_{sp} = (1,000,000 x 47)/(365 x 28,433) = 4.53 crashes per MV.

2. Define the location type. Information defining the location type is given in the heading block of Table 3-6.

3. If a list of previously evaluated locations is being maintained, insert the location into the list of locations ranked in descending order by crash rate. Table 3-8 is such a list and was readily constructed from data presented above.

4. Determine the critical crash rate. Look up objectively determined regional critical crash rates in Tables 3-1 to 3-4 and compute an average value. For this intersection type, these tables provide critical rates of 1.91, 1.98, 1.88 and 2.13 respectively, for an average of 1.98 crashes per MV.

5. Compare the location's crash rate to the critical crash rate. Since the intersection's rate of 4.53 crashes per MV exceeds the critical rate of 1.98 crashes per MV, this method identifies the Sem-Cog intersection as a high-crash location.

EPDO Method

The results from applying this method to the sample intersection are indicated below under each of the method's steps. These steps require the analyst to:

1. Determine the number of crashes which occurred at each severity level. Dividing the three-year crash totals given above by the length of the analysis period gives annual averages of 0.0 fatal crashes, 1.00 A-level crash, 2.67 B-level crashes, 8.33 C-level crashes and 35.00 PDO crashes.

2. Compute the location's EPDO value. Substituting the annual average crash frequencies by severity level from Step 1 into Eq.(3-3) gives EPDO = 9.5 x (0.0 + 1.00) + 3.5 x (2.67 + 8.33) + 35.00 = 83.0 EPDO crashes per year.

Table 3-8.
1993-1995 Crash Rates for Example

Ranking	Location	Crash Rate (per MV)
1	I-1	5.09
2	**Sem-Cog**	**4.53**
3	I-3	4.45
4	I-2	4.02
5	I-5	3.49
6	I-4	3.37

3. Compute EPDO crash rate **(optional)** Substituting the result from Step 2 into Eq.(3-4) gives EPDO/MV = (1,000,000 x 83.0) / (365 x 28,433) = 8.00 EPDO crashes per MV.

4. Define the location type. Information defining the location type is given in the heading block of Table 3-6.

5. If a list of previously evaluated locations is being maintained, insert the location into the list of locations ranked in descending order by either EPDO or EPDO crash rate. Table 3-9 is a list of the locations ranked by EPDO crash rate and was readily constructed from data presented above.

6. Declare the location "high-serious-crash" if it ranks relatively high compared to locations with similar characteristics. Considering only the EPDO rates listed in Table 3-9, the Sem-Cog intersection does not appear to be a high-serious-crash location; only I-1 and I-2 do. This conclusion can be checked by also applying the RSI Method.

RSI Method

The results from applying this method to the sample intersection are indicated below under each of the method's steps. These steps require the analyst to:

1. Determine the number of crashes which occurred at each severity level. The results for this step are shown under Step 1 of the EPDO Method.

2. Compute the location's RSI value. Substituting the severity-specific crash frequencies shown above into Eq.(3-6) gives RSI = ($3,961,000 x 0.0 + $278,000 x 1.0 + $66,000 x 2.67 + $38,000 x 8.33 + $2,700 x 35.0)/(0.0+1.0+2.67+8.33+35.0) = $18,410.

3. Define the location type. Information defining the location type is given in the heading block of Table 3-6.

4. If a list of previously evaluated locations is being maintained, insert the location into the list of locations sorted in descending order by RSI. Table 3-10 is a list of the locations ranked by RSI and was readily constructed from data presented above.

5. Declare the location "high-serious-crash" if it ranks relatively high compared to locations with similar characteristics. Considering only the RSI values listed in Table 3-10, the Sem-Cog intersection does not appear to be a high-serious-crash location; only I-1 and I-2 do. This conclusion was also reached using the EPDO Method.

Table 3-9.
1993-1995 EPDO Crash Rates for Example

Ranking	Location	EPDO Rate (per MV)
1	I-2	11.46
2	I-1	10.76
3	**Sem-Cog**	**8**
4	I-3	7.42
5	I-4	6.64
6	I-5	4.73

CPI Method

The results from applying this method to the sample intersection are indicated below under each of the method's steps. These steps require the analyst to:

1. Determine the location's crash rate, crash frequency and CR. As determined earlier in this example, the intersection's crash rate is 4.53 crashes per MV and its crash frequency is 47 crashes per year. Substituting the above-noted crash frequencies by severity into Eq.(3-7) gives a CR of (0.0 + 1.00 + 2.67 + 8.33) / (0.0 + 1.00 + 2.67 + 8.33 + 35.00) = 0.26 (i.e., 26 percent of the location's crashes involved one or more personal injuries/fatalities).

2. Define the location type. Information defining the location type is given in the heading block of Table 3.6.

3. Determine the critical crash rate, critical crash frequency and critical casualty ratio. As determined earlier in this example, the regional critical crash rate is 1.98 crashes per MV and the critical crash frequency is 22.29 crashes per year.

   Look up objectively determined regional critical casualty ratios in Tables 3-1 to 3-4 and compute an average value. For this intersection type, these tables provide critical casualty ratios of 0.43, 0.42, 0.40 and 0.42, respectively, for an average of 0.42.

4. Compute the location's CPI value. The crash rate, 4.53, exceeds the regional critical crash rate of 1.98. Also, the crash frequency, 47, exceeds the regional critical crash frequency of 22.29. However, the CR, 0.26, is less than the regional critical casualty ratio of 0.42. Given these results, assess CPI penalty points according to the previously stated rules as follows:

   a. Since two of the three measures exceed their respective critical values, realize that the CPI will not be equal to zero.

   b. Since the crash rate exceeds the regional critical crash rate, assess five penalty points.

   c. Since the crash frequency exceeds the regional critical crash frequency, assess another five penalty points.

   d. Since the CR does not exceed the critical casualty ratio, do not assess any additional penalty points.

   e. Thus, CPI = 5 + 5 + 0 = 10.

Table 3-10.
1993-1995 RSI Values for Example

Ranking	Location	RSI ($ per Crash)
1	I-2	114,360
2	I-1	88,350
3	I-4	23,800
4	**Sem-Cog**	**18,410**
5	I-3	18,000
6	I-5	10,120

5. If the location has been assessed a CPI of zero, remove it from the analysis. This is not applicable since the CPI is greater than zero.

6. If the location has a CPI greater than zero, declare the location to be high-crash and insert it into one or more lists sorted in descending order by CPI, if a list of previously evaluated locations is being maintained.

   Table 3-11 is a list of the locations sorted by CPI class and actual CPI and was readily constructed from data presented above. The first-class location deserves the highest priority of the six high-crash locations and the third-class location is of less immediate concern.

Rankings by Method

As indicated at the beginning of the chapter, the analyst is free to apply any one or more of the methods described for identifying high-crash locations. One advantage of applying several methods is that it allows a comparison of results. Table 3-12 summarizes the example results from the various methods in terms of relative hazard ranking. Fractional values for the rankings reflect ties. Note that even for those methods not producing ties, the methods produce different rankings due to the different factors taken into consideration — frequency, rate and/or severity.

IDENTIFYING LOCATIONS WITH POTENTIAL SAFETY PROBLEMS

None of the methods described here are suitable for identifying potential safety problems associated with non-high-crash locations. Such locations may appear to have safety concerns due to factors such as increasing traffic volumes or unusual geometrics, but have not yet experienced sufficiently frequent and/or severe crashes to qualify as high-crash locations. Agencies may wish to identify and possibly treat these locations before serious losses occur.

"Suspect" locations can be tentatively identified by systematically reviewing and tabulating citizen complaints and other data of the types listed at the beginning of this chapter. At a minimum, the crash histories of such locations should then be monitored more closely. Follow-up field investigations should also be conducted, if possible, by teams of two or more persons having a mix of relevant backgrounds (e.g., highway/traffic engineering, law enforcement and maintenance).

If sufficient expertise and resources can be garnered, some of the more bothersome locations might also be evaluated with an established technique such as the Hazard Index Method or the Hazardous Roadway Features Inventory. These methods are quite technical in nature and are presented in detail in other references (FHWA, 1981a).

Table 3-11.
1993-1995 CPI Values for Example

CPI Class	Location
First (20 pts)	I-2
Second (10 pts)	I-1
	I-3
	I-4
	Sem-Cog
Third (5 pts)	I-5

Table 3-12.
Comparison of Hazard Rankings by Method

Location	**Hazard Ranking by Method**				
	Crash Frequency	**Crash Rate**	**EPDO Rate**	**RSI**	**CPI**
I-1	1	1	2	2	3.5
Sem-Cog	**2**	**2**	**3**	**4**	**3.5**
I-2	3	4	1	1	1
I-3	4	3	4	5	3.5
I-4	5	6	5	3	3.5
I-5	6	5	6	6	6

CHAPTER 4

DETERMINATION OF COUNTERMEASURES, CRASH-REDUCTION FACTORS AND COSTS

Obtaining the greatest traffic safety improvement possible with limited funds requires crash countermeasures well-matched to the physical features, traffic characteristics and most troublesome crash types present at specific locations. This chapter describes a methodology for identifying a location's crash patterns and possible causes and countermeasures related to those patterns. The methodology is illustrated with a continuation of the intersection example begun in Chapter 3.

Numerous specific countermeasures are listed for consideration, generally involving traffic engineering, highway design, maintenance and law enforcement. Representative data for the benefit/cost (B/C) analysis of the traffic engineering countermeasures are also presented. These data include anticipated countermeasure crash-reduction factors, service life estimates and costs.

CRASH PATTERN IDENTIFICATION

When crashes of a particular type constitute an unexpectedly large proportion of a location's reported crashes, a significant crash pattern is said to exist. Examining the pattern can identify possible causes susceptible to correction. (Causes may be accurately characterized as "probable" only after follow-up engineering studies have tended to support suspected cause-and-effect relationships.)

SEMCOG staff has studied several commonly recurring crash patterns and linked them with their typical (and therefore possible) causes. This manual presents these linkages in a form easily applied by others in evaluating crash patterns occurring at specific locations of concern.

There are numerous crash patterns of potential interest in identifying possible causes. In a manual published by the Federal Highway Administration (FHWA, 1981a), tables relating crash patterns, causes and countermeasures covered twelve crash patterns categorized by SEMCOG as follows:

- multiple-vehicle crashes:
  - head-on and sideswipe/opposite-direction (SS/OD),
  - head-left/rear-left,
  - angle,
  - rear-left/rear-right and sideswipe/same direction (SS/SD);

- object involved:
  - train,
  - fixed object,
  - parked/parking vehicle,
  - pedestrian/bicyclist;

- driving situation:
  - driveway use,
  - running-off-road,
  - nighttime,
  - wet pavement.

Note that many of these patterns overlap each other in terms of their ability to accurately characterize a given crash; for example, a crash could involve a driver running off the road due to darkness and wet pavement. The patterns one chooses to search for in crash data depend on one's particular safety concerns regarding the location being studied. If there are concerns not addressed by the above list of patterns — such as single-vehicle rollover crashes or crashes involving alcohol and drug-influenced drivers — additional crash patterns can be defined for evaluation.

To identify significant crash patterns for a given location, use a worksheet of the type presented in Figure 4-1 to complete the following steps:

Figure 4-1.
Crash Pattern Identification and Prioritization at _______________________________

Average Daily Traffic (ADT) Range ___________________

Evaluation Criteria		Possible Crash Pattern			
		Head-On & SS/OD	**Head-Left/ Rear-Left**	**Angle**	**Rear-End/ Rear-Right & SS/SD**
Location's Crashes	No. by Type / Total No.	/	/	/	/
	Location's %				
Regional Crash % (table or computation)	4-1. Area Type:______________				
	4-2. Functional Class:_________				
	4-3. No. of Lanes: ___				
	4-4. Sig. ___ Unsig. ___				
	Computed (attach details)				
Significant Pattern?	Enter YES if Location's % Exceeds At Least One of the Above Regional %s				
Pattern Priority[1]	Average Regional % [2]				
	Over-Representation Ratio (ORR) = Location's % / Average Regional %				
	Severity Weighting (SW)				
	Pattern Priority Index (PPI) = 10 / (ORR x SW)				

[1] Complete this block only for significant patterns.
[2] Circle or highlight, and then average, only those regional %s which are less than the location's %. This is necessary to guarantee an ORR greater than 1.0.
[3]See Figure 4-6 for a completed example of worksheet.

1. Compute the location's crash percentage for each possible crash pattern. Assume for purposes of this discussion that there is a desire to evaluate a location's crash data for the multiple-vehicle crash patterns listed above and shown again as column headings in Figure 4-1. A reproducible copy of this figure can be found in Appendix F. Enter in each box of the worksheet's first row the number of crashes of the corresponding type, separated by a slash from the total number of crashes at the location. Then enter in each box of the second row the location's crash percentage (100 times the number of crashes of the corresponding type divided by the total number of crashes).

2. Define the location type. In the manner described in Chapter 3, categorize the location by as many of the following features as possible:

   a. area type (urban/rural);

   b. roadway functional class (arterial/collector/local) — for an intersection, the higher or highest functional class of the intersecting roadways, where an arterial is the highest class (meant primarily to carry through traffic) and a local is the lowest class (meant primarily to provide access to abutting properties);

   c. number of lanes — for an intersection, the number of through lanes on the widest approach;

   d. predominant traffic control — for an intersection, the presence or absence of signalization and for a segment, the speed limit; and

   e. average daily traffic (ADT) volume (the 10,000 vehicle per day range within which the location's ADT falls; e.g., 0 to 10,000, 10,001 to 20,000, etc.) — for an intersection, the sum of the volumes on all approaches.

   Enter the categorizations according to criteria "a" to "d" in the corresponding worksheet blanks labeled "4-1" to "4-4." Enter the ADT from criterion "e" in the blank provided just above the body of the worksheet.

3. Determine regional crash percentages for each possible crash pattern. Look up one to four regional crash percentages for each pattern, using tables developed by SEMCOG for intersections in Southeast Michigan (Tables 4-1 to 4-4) and enter them into the appropriate cells of the worksheet. Draw a horizontal line through the row of cells corresponding to any of the four tables not consulted for regional values.

   These regional crash percentages were computed with crash data for the entire SEMCOG region. Alternative crash percentages may be calculated for the local level using the appropriate statistical method discussed in Appendix A. If a local crash percentage is derived, it is important to verify that the sample size is sufficient for the community.

4. Compare each crash percentage computed for the location to the corresponding regional crash percentages. If the location's crash percentage exceeds one or more of the regional crash percentages entered in the same column, the location has an above-average proportion of crashes of the indicated type and can be said to have exhibited a significant crash pattern of that type. Indicate significant crash patterns by entering "YES" into the appropriate columns of the worksheet.

To prioritize a location's significant crash patterns for further evaluation, continue using the Figure 4-1 worksheet to complete the following additional steps:

Table 4-1 .
Regional Crash Percentages at Intersections by Crash Types: By Area Type

Average Daily Traffic Volume Entering Intersection	% Single-Vehicle	% Head-On & Sideswipe/ Opp.-Dir.	% Head-Left/ Rear- Left	% Angle	% Rear-End/ Rear-Right & Sideswipe/ Same-Dir.	% Other & Uncoded	Number of Intersections Sampled[1]
URBAN AREA[2]	**4.0**	**4.9**	**9.7**	**26.4**	**45.2**	**9.7**	**2,925**
1 - 10,000	9.1	5.9	9.8	31.4	32.3	11.5	307
10,001 - 20,000	6.0	5.8	10.5	27.8	39.1	10.8	677
20,001 - 30,000	4.2	5.3	11.3	26.2	42.6	10.5	683
30,001 - 40,000	3.8	5.3	11.0	26.7	42.8	10.5	497
40,001 - 50,000	3.2	4.3	10.4	26.5	46.7	8.8	331
50,001 - 60,000	2.8	4.4	8.2	26.0	50.4	8.3	190
60,001 - 70,000	2.5	4.3	6.6	26.4	52.2	8.0	103
70,001 - 80,000	3.1	3.7	6.1	24.8	54.1	8.4	55
80,001 - 90,000	3.0	3.4	5.1	21.0	59.5	8.0	48
over 90,000	3.0	2.8	2.8	22.4	61.8	7.2	34
RURAL AREA[2]	**13.1**	**5.1**	**9.1**	**27.9**	**36.2**	**8.7**	**395**
1 - 10,000	20.1	5.6	7.1	30.9	26.7	9.7	260
10,001 - 20,000	10.5	4.7	9.9	27.5	39.7	7.8	107
over 20,000	4.4	4.8	11.7	22.8	47.9	8.4	28

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995.
[2] Values on this line are volume-independent. All percentages are distributional averages.

Table 4-2.
Regional Crash Percentages at Intersections by Crash Types: By Higher Functional Class of Roadway

Average Daily Traffic Volume Entering Intersection	% Single-Vehicle	% Head-On & Sideswipe/ Opp.-Dir.	% Head-Left/ Rear- Left	% Angle	% Rear-End/ Rear-Right & Sideswipe/ Same-Dir.	% Other & Uncoded	Number of Intersections Sampled[1]
ARTERIAL[2]	**4.0**	**4.9**	**9.8**	**26.3**	**45.5**	**9.6**	**2,830**
1 - 10,000	8.8	6.0	9.8	30.3	33.9	11.3	265
10,001 - 20,000	6.2	5.7	10.6	27.4	39.7	10.4	667
20,001 - 30,000	4.2	5.3	11.4	26.0	42.7	10.4	656
30,001 - 40,000	3.8	5.3	11.1	26.5	42.9	10.5	486
40,001 - 50,000	3.2	4.3	10.4	26.5	46.7	8.8	328
50,001 - 60,000	2.9	4.4	8.1	26.0	50.4	8.3	189
60,001 - 70,000	2.5	4.3	6.6	26.4	52.2	8.0	103
70,001 - 80,000	3.1	3.7	6.1	24.8	54.1	8.4	55
80,001 - 90,000	3.0	3.4	5.1	21.0	59.5	8.0	48
over 90,000	3.0	2.8	2.9	22.5	61.8	7.1	33
COLLECTOR OR LOCAL[2]	**13.5**	**5.4**	**7.8**	**31.5**	**31.1**	**10.8**	**490**
1 - 10,000	19.7	5.6	7.3	32.9	24.4	10.2	302
10,001 - 20,000	10.3	5.5	8.5	31.5	33.6	10.7	117
20,001 - 30,000	5.8	5.0	6.4	27.6	43.2	12.0	50
30,001 - 40,000	4.3	4.3	7.5	32.3	40.5	11.1	16
over 40,000	1.8	3.7	16.5	28.4	34.9	14.7	5

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995.
[2] Values on this line are volume-independent. All percentages are distributional averages.

Table 4-3.
Regional Crash Percentages at Intersections by Crash Types:
By Number of Through Lanes on Widest Approach

Average Daily Traffic Volume Entering Intersection	% Single-Vehicle	% Head-On & Sideswipe/ Opp.-Dir.	% Head-Left/ Rear- Left	% Angle	% Rear-End/ Rear-Right & Sideswipe/ Same-Dir.	% Other & Uncoded	Number of Intersections Sampled[1]
ONE LANE[2]	**8.4**	**5.1**	**10.7**	**26.9**	**40.1**	**8.8**	**1161**
1 - 10,000	16.5	5.7	8.0	31.4	28.3	10.1	453
10,001 - 20,000	8.0	5.3	10.6	28.1	39.1	8.8	429
20,001 - 30,000	5.4	4.7	12.2	24.1	44.4	9.1	186
30,001 - 40,000	3.3	4.5	13.1	23.0	48.7	7.6	57
over 40,000	4.2	3.5	10.2	23.5	52.8	5.7	36
TWO LANES[2]	**4.4**	**5.1**	**8.3**	**27.8**	**43.1**	**11.2**	**1,185**
1 - 10,000	6.8	6.2	8.0	30.8	34.4	13.8	94
10,001 - 20,000	6.3	6.2	9.5	28.9	36.7	12.4	242
20,001 - 30,000	4.1	5.4	10.0	28.2	40.5	11.8	287
30,001 - 40,000	4.4	5.2	10.5	28.5	39.5	11.9	237
40,001 - 50,000	3.6	4.3	9.0	28.0	45.4	9.8	138
50,001 - 60,000	3.9	5.7	4.9	29.4	46.1	10.0	70
over 60,000	3.5	3.7	2.6	23.5	57.3	9.5	117

Three and Four or More Lanes on Next Page

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995.
[2] Values on this line are volume-independent. All percentages are distributional averages.

Table 4-3.
Regional Crash Percentages at Intersections by Crash Types:
By Number of Through Lanes on Widest Approach (cont'd)

Average Daily Traffic Volume Entering Intersection	% Single-Vehicle	% Head-On & Sideswipe/ Opp.-Dir.	% Head-Left/ Rear- Left	% Angle	% Rear-End/ Rear-Right & Sideswipe/ Same-Dir.	% Other & Uncoded	Number of Intersections Sampled[1]
THREE LANES[2]	**3.0**	**4.4**	**11.1**	**25.7**	**47.9**	**7.9**	**798**
1 - 20,000	3.9	5.1	12.9	27.5	41.3	9.4	114
20,001 - 30,000	3.6	5.0	13.3	24.9	44.9	8.2	191
30,001 - 40,000	3.3	5.0	11.8	25.8	45.0	9.0	180
40,001 - 50,000	2.7	4.2	11.7	26.2	47.0	8.2	140
50,001 - 60,000	2.4	3.8	10.0	25.8	50.9	7.1	89
60,001 - 70,000	1.6	3.9	9.3	26.8	52.3	6.1	36
over 70,000	2.7	2.7	6.2	23.7	58.9	5.9	48
FOUR OR MORE LANES[2]	**3.2**	**5.9**	**7.3**	**24.2**	**47.4**	**11.9**	**176**
1 - 20,000	4.1	7.8	8.6	21.8	41.9	15.7	19
20,001 - 30,000	3.6	7.3	7.9	24.5	42.1	14.7	42
30,001 - 40,000	3.5	7.6	7.1	25.6	41.7	14.6	28
40,001 - 50,000	3.4	5.7	8.2	26.5	45.2	10.9	26
50,001 - 60,000	2.9	4.4	6.8	23.4	52.9	9.7	25
60,001 - 70,000	2.8	5.7	5.8	23.3	51.4	11.0	20
over 70,000	2.6	4.3	8.2	23.9	52.5	8.5	16

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995.
[2] Values on this line are volume-independent. All percentages are distributional averages.

Table 4-4.
Regional Crash Percentages at Intersections by Crash Types:
By Presence or Absence of Signalization

Average Daily Traffic Volume Entering Intersection	% Single-Vehicle	% Head-On & Sideswipe/ Opp.-Dir.	% Head-Left/ Rear- Left	% Angle	% Rear-End/ Rear-Right & Sideswipe/ Same-Dir.	% Other & Uncoded	Number of Intersections Sampled[1]
SIGNALIZED[2]	**3.6**	**4.8**	**9.9**	**26.3**	**45.7**	**9.6**	**2,375**
1 - 10,000	6.5	5.7	9.9	30.4	35.5	11.9	158
10,001 - 20,000	5.5	5.7	11.1	27.4	39.9	10.6	507
20,001 - 30,000	3.9	5.3	11.6	26.0	42.7	10.4	579
30,001 - 40,000	3.5	5.2	11.2	27.0	42.8	10.4	437
40,001 - 50,000	2.9	4.4	10.7	26.6	46.6	8.8	298
50,001 - 60,000	2.7	4.4	8.3	25.9	50.5	8.3	169
60,001 - 70,000	2.5	4.3	6.6	26.3	52.3	7.9	96
70,001 - 80,000	2.9	3.7	6.1	24.9	54.0	8.4	52
80,001 - 90,000	2.9	3.4	5.1	21.0	59.7	8.0	46
over 90,000	3.0	2.8	2.9	22.5	61.8	7.1	33
Unsignalized on Next Page							

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995.
[2] Values on this line are volume-independent. All percentages are distributional averages.

Table 4-4.
Regional Crash Percentages at Intersections by Crash Types:
By Presence or Absence of Signalization (cont'd)

Average Daily Traffic Volume Entering Intersection	% Single-Vehicle	% Head-On & Sideswipe/ Opp.-Dir.	% Head-Left/ Rear- Left	% Angle	% Rear-End/ Rear-Right & Sideswipe/ Same-Dir.	% Other & Uncoded	Number of Intersections Sampled[1]
UNSIGNALIZED[2]	**13.2**	**5.8**	**6.8**	**28.4**	**35.4**	**10.3**	**945**
1 - 10,000	18.4	5.9	8.0	32.0	25.8	10.0	409
10,001 - 20,000	11.9	5.8	7.1	29.9	35.5	9.9	277
20,001 - 30,000	8.4	5.9	5.5	26.1	43.1	11.0	127
30,001 - 40,000	10.1	7.4	6.8	17.7	45.6	12.6	65
40,001 - 50,000	11.8	3.4	3.0	24.0	48.5	9.2	33
50,001 - 60,000	7.7	4.2	4.5	30.1	45.2	8.3	21
over 60,000	8.8	5.8	4.4	21.9	44.5	14.6	13

[1] Size of sample taken from SEMCOG crash data for Southeast Michigan, 1993-1995
[2] Values on this line are volume-independent. All percentages are distributional averages.

5. Compute the average of all regional crash percentages which are less than the location's crash percentage. Enter the computed value in the corresponding box of the worksheet row labeled "Average Regional Percentage". Circle or highlight the regional values averaged.

6. Compute an over-representation ratio (ORR). Divide the location's crash percentage by the corresponding average regional crash percentage and enter the ratio in the appropriate box of the worksheet. The ORR should be greater than 1.0.

7. Determine a severity weighting (SW). Some crash types are typically more severe than others; for example, angle crashes result in more serious personal injuries, on average, than do rear-end crashes. To reflect this difference, determine a pattern's severity weighting by taking one of the following two approaches:

   a. Use "1" for patterns predominated by rear-end or either direction of sideswipe crash and "2" for all other crash types or, in the event that different crash types are being evaluated, adopt a similar set of simple subjective severity weightings.

   b. If sufficient crash data exist, compute and use the casualty ratio for the crash type(s) in question. Refer to Step 1 of the CPI Method, in Chapter 3, for the definition and equation used to compute a casualty ratio.

   Enter the SW(s) in the appropriate row of the worksheet.

8. Determine pattern priority. Compute a pattern priority index (PPI) for each significant crash pattern by substituting the values of ORR and SW determined in Steps 6 and 7, respectively, into the following equation and solving:

Eq. (4-1)

$$PPI = \frac{10}{ORR x SW}$$

Once computed (to one decimal place) for every significant crash pattern and entered in the last row of the worksheet, the PPI values will indicate the relative priorities for further evaluating and potentially treating significant crash patterns. The pattern with the smallest value of PPI should receive the highest priority, and the pattern with the largest value of PPI, the lowest priority. PPI values will function in a manner similar to normal priority rankings, but they will not be whole consecutive numbers. (See Figure 4-6 for a completed example of worksheet.)

DETERMINATION OF POSSIBLE CAUSES

Possible causes may be determined for just one, a few or all significant crash patterns found at a location. The scheme described in the preceding section for prioritizing crash patterns will help analysts make more cost-effective use of their time. Focusing first on the more highly over-represented and severe crash patterns will speed up the process of isolating those causes responsible for the greatest crash losses occurring at a high-crash location.

Figure 4-2 presents 21 possible causes for crash patterns categorized by the multiple-vehicle crash type. Most of the causes listed deal with some aspect of the driving environment which can influence the probability of a crash. While driver error is invariably cited as the most common cause of crashes, the likelihood of an error occurring can be heavily influenced by the design, operation and maintenance of the roadway — typical responsibilities of local agencies. Other than speed limit posting and enforcement, there is relatively little that such agencies can do to directly modify driver behavior; hence, the only driver error listed here as a crash cause is Excessive Speed.

Figure 4-2.
Possible Causes for Multiple-Vehicle Crash Patterns at ____________________________

Possible Cause	Crash Pattern					
	Head-On & SS/OD	Head-Left/ Rear-Left	Angle		Rear-End/ Rear-Right & SS/SD	
			Sig	Unsig	Sig	Unsig
Pattern Priority Index (PPI)						
Excessive Speed	o	o	o	o	o	o
Restricted Sight Distance	o	o	o	o		o
Slippery Surface			o	o	o	o
Narrow Lanes	o				o	o
Inadequate Signal Change Interval		o	o			
Turning Vehicles Slowing or Stopping in Through Lanes					o	o
Unexpected Slowing and Lane Changing					o	o
Poor Visibility of Traffic Signal			o		o	
Unexpected/Unnecessary Stops Due to Signal			o		o	
Unsafe Right-Turns-on-Red			o		o	
Crossing Pedestrians					o	o
Poor Visibility of STOP/YIELD Signs				o		o
Proper Stopping Position Unclear			o	o		
Inadequate Pavement Markings	o					
Inadequate Roadway Shoulders	o					
Inadequate Maintenance	o					
Severe Curves	o					
Inadequate Gaps in Oncoming Traffic		o				
Inadequate Signalization for Left-Turn Volume		o				
Inadequate Gaps for Turning and Accelerating						o
Unexpected Cross Traffic				o		

See Figure 4-7 for a completed example of worksheet.

Figure 4-2 has been designed to be used as a worksheet in identifying and prioritizing a location's possible crash causes. A reproducible copy of this figure can be found in Appendix F. To apply it as a worksheet, fill in the location name or code in the title block and complete the following steps:

1. Highlight the columns associated with significant crash patterns. Using the results from the Figure 4-1 worksheet, highlight the columns representing significant crash patterns in the current worksheet. Ensure that the columns chosen for angle, rear-end/rear-right & sideswipe/same-direction crash patterns accurately reflect the presence or absence of signalization.

2. Enter the PPI values. Transfer these values from the last row of the Figure 4-1 worksheet to the first row of the Figure 4-2 worksheet, again accounting for the presence or absence of signalization. Indices should be available for entry only in highlighted columns. Draw a horizontal line through the PPI cells in other columns.

3. Highlight possible causes for the highest priority crash pattern. To complete this step:

   a. Locate the pattern having the smallest value of PPI.

   b. Scan the highlighted column associated with this pattern for bullets.

   c. When a bullet is encountered, highlight the possible cause directly to the left.

4. Highlight possible causes for multiple significant crash patterns. Scan all highlighted columns collectively for two or more bullets in the same row of the worksheet and whenever such a situation is found, highlight the possible cause directly to the left of the bullets (if not already highlighted in Step 3).

5. Compile a separate list of the possible causes highlighted in Steps 3 and 4 and declare them to be "higher-priority" possible causes. Use the format shown in Figure 4-3. A full-size reproducible copy of this figure can be found in Appendix F. A possible cause of multiple crash patterns should be listed separately under each related pattern. This is necessary in order to use this list to identify all possible countermeasures (appropriate countermeasures for the same cause will vary with crash pattern).

Figure 4-3.
Higher-Priority Possible Causes for Crash Patterns at ____________________________

Crash Pattern	Possible Cause	Applicable? (Step 7)		Comments
		Yes	No	
Causes Associated with Highest Priority Pattern (Step 3)				
Causes Associated with Multiple Patterns (Step 4)				

See Figure 4-8 and Figure 4-9 for completed examples of worksheet.

Addressing these higher-priority causes first should aid in the early consideration of more broadly effective crash countermeasures.

6. Highlight and/or list other possible causes. Review the Figure 4-2 worksheet for possible causes of single significant crash patterns other than the one identified in Step 3. Consider highlighting the names of these causes in the first column using a different color or shading than used in previous steps. Then compile a separate list entitled "Other Possible Causes for Crash Patterns" using the column headings shown in Figure 4-3. A reproducible copy of this form can be found in Appendix F. Your agency may want to address the possible causes on this list at a later time, after first addressing the higher-priority possible causes.

7. Review the lists compiled in Steps 5 and 6 and rule out possible causes which are inconsistent with basic location features. For example, if the travel lanes are all 11 feet or wider, "narrow lanes" should probably not be cited as a possible crash cause. Other obviously inconsistent causes, such as "severe curves" on a perfectly straight road, should also be ruled out.

   Use the "Comments" column of the listing to explain why certain possible causes are being ruled out (or ruled in). Reinforce the sorting process by highlighting causes that are not ruled out. (See Figures 4-7 through 4-9 for completed examples of worksheets.)

DETERMINATION OF POSSIBLE COUNTERMEASURES

Having identified the possible causes of a location's most troublesome crash types, the next logical step is to determine possible countermeasures. Such countermeasures can be determined for a specific multiple-vehicle crash pattern and cause by consulting one of the following tables:

- Head-on and sideswipe/opposite-direction crashes -- Table 4-5;
- Head-left/rear-left crashes: Table 4-6;
- Angle crashes -- signalized: Table 4-7 and unsignalized: Table 4-8;
- Rear-end/rear-right and sideswipe/same-direction crashes -- signalized: Table 4-9 and unsignalized: Table 4-10.

Note that two patterns, angle crashes and the combination of rear-end/rear-right & sideswipe/same-direction crashes, are each treated in a pair of tables differentiated by the form of intersection traffic control (i.e., signalized or unsignalized). Both the analysis of possible causes and the selection of appropriate countermeasures depend on whether or not the location is signalized. It is important to know not only the present form of control, but also that this form was in place throughout the crash data analysis period. For causal analysis to be meaningful and reliable, a signal should not have been added or removed during this analysis period.

Tables 4-5 to 4-10 are intended to be used as a guide in performing B/C analyses and are not to be considered all-inclusive. Users of this manual may add to the tables any crash causes and/or countermeasures unique to local conditions which they have successfully identified in past traffic safety analyses.

The code given in the last column of the tables cross-references each specific countermeasure to a more detailed table used for costing purposes (as discussed later in this chapter). Please note that not all countermeasures include benefit and cost data. Countermeasures for which such data can be obtained can be used in the analysis. Other countermeasures can be studied or researched to obtain such data for future reference. The alphabetic prefix indicates one of the following 11 countermeasure categorizations:

- Signs (SN) -- standard traffic signs for regulating, warning and guiding;
- Signals (SG) -- vehicle and pedestrian signals, intersection warning flashers;

Table 4-5.
Possible Causes and Countermeasures for Head-On and Sideswipe/Opposite-Direction Crashes

Possible Cause	Possible Countermeasure Specific Name [1]	Code
Restricted Sight Distance	Install No Passing Zones	MK-10
	Add NO PASSING ZONE Pennant Signs	SN-19
	Reduce Obstructions on Insides of Curves	MS-2
	Lower Roadbed on Hill Crests	RD-7
Inadequate Pavement Markings	Supplement Centerline with RPMs	MK-9
	Upgrade Markings (Halve Maint. Cycle)[2]	MK-1
	Add Ctr + Lanelines to Unstriped Street	MK-4
	Add Ctr + Edgelines to Unstriped Road	MK-6
	Add Centerline to Unstriped Pavement	MK-5
	Install Flush Median	CH-2
	Install Raised Median	CH-1
Narrow Lanes	Eliminate Parking	SN-14
	Widen Lanes	RD-2
Inadequate Roadway Shoulders	Upgrade Roadway Shoulders	RD-1
	Remove/Relocate Obstacles Close to Road	MS-3
Inadequate Maintenance	Repair/Replace Roadway Surface	PV-4
	Repair/Replace Shoulder Surface	PV-5
Severe Curves	Realign Opposing Intersection Legs	RD-4
	Flatten Roadway Curves	RD-6
	Provide Proper Superelevation (Banking)	RD-5
	Post Curve Warnings / Advisory Speeds	SN-20
Excessive Speed	Post/Reduce Speed Limit	SN-19
	Increase Traffic/Speed Enforcement	MS-9

[1] RPM = Reflective Pavement Marker and Ctr = Centerline.

[2] In other words, reduce the time between repainting to one half of its present value (e.g., repaint every six months instead of annually).

Table 4-6.
Possible Causes and Countermeasures for Head-Left/Rear-Left Crashes

Possible Cause	Possible Countermeasure	
	Specific Name[3]	Code
Inadequate Gaps in Oncoming Traffic	Add 2-Way STOP/YIELD at Urban I/S	SN-11
	Add 2-Way STOP at Rural I/S	SN-12
	Change from 2-Way to 4-Way STOP	SN-13
	Signalize Intersection	SG-1
Inadequate Signalization for Left-Turn (LT) Volume	Retime Traffic Signal	SG-2
	Provide Lead/Lag or Split Phasing	SG-9
	Add Pretimed, Protected LT Signals	SG-8
	Install Signal Actuation	SG-12
	Upgrade Signal Controller	SG-15
	Upgrade Signalization	SG-14
	Install Dual LT Lanes, Signs, & Signals	SG-7
	Prohibit Turns	SN-25
	Reroute Left-Turn Traffic	SN-24
	Sign One-Way Street Operation	SN-22
Inadequate Signal Change Interval	Increase Yellow Change Interval	SG-3
	Add All-Red Clearance Interval	SG-4
Excessive Speed	Post/Reduce Speed Limit	SN-19
	Increase Traffic/Speed Enforcement	MS-9
Restricted Sight Distance	Reduce Obstructions in Median	MS-1
	Favorably Offset Opposing LT Lanes	CH-5
	Move Intersection Away from Curves/Crests	RD-3
	Reduce Obstructions on Insides of Curves	MS-2
	Flatten Curves	RD-6
	Lower Roadbed on Hill Crests	RD-7

[3] I/S = Intersection

Table 4-7.
Possible Causes and Countermeasures for Angle Crashes at Signalized Intersections

	Possible Countermeasure	
Possible Cause	**Specific Name**	**Code**
Poor Visibility of Traffic Signal	Remove Signal Sight Obstructions	MS-7
	Post SIGNAL AHEAD Warning Signs/Urban	SN-3
	Post SIGNAL AHEAD Warning Signs/Rural	SN-4
	Install/Replace Signal Visors	SG-19
	Add Signal Back Plates	SG-18
	Add/Relocate Signal Head	SG-17
	Install 12-inch Signal Lenses	SG-16
	Install Advance Flasher-Signs	SG-21
	Upgrade Signalization	SG-14
Unexpected/Unnecessary Stops Due to Signal	Retime Traffic Signal	SG-2
	Upgrade Signal Controller	SG-15
	Provide Signal Progression	SG-13
	Install Signal Actuation	SG-12
Inadequate Signal Change Interval	Increase Yellow Change Interval	SG-3
	Add All-Red Clearance Interval	SG-4
Excessive Speed	Post/Reduce Speed Limit	SN-19
	Increase Traffic/Speed Enforcement	MS-9
Slippery Surface	Post SLIPPERY WHEN WET Signs / Urban	SN-9
	Post SLIPPERY WHEN WET Signs / Rural	SN-10
	Improve Drainage	PV-2
	Groove Pavement	PV-1
	Resurface Roadway	PV-3
Proper Stopping Position Unclear	Add Stop Bars/Crosswalks	MK-2
	Add/Improve Intersection Lighting	MS-8

Table 4-7.
Possible Causes and Countermeasures for Angle Crashes at Signalized Intersections (cont'd)

	Possible Countermeasure	
Possible Cause	**Specific Name**	**Code**
Unsafe Right-Turns-on-Red (RTOR)	Reduce RTOR Sight Obstructions	MS-6
	Add Right-Turn Lane Channelization	CH-3
	Provide Right-Turn Overlap (Green Arrow)	SG -6
	Prohibit RTOR	SN-23
Restricted Sight Distance	Eliminate Parking Near Intersection	SN-14
	Remove Obstructions from Sight Triangle	MS-4
	Close/Relocate Driveways Near Intersection	DY-1

Table 4-8.
Possible Causes and Countermeasures for Angle Crashes at Unsignalized Intersections

Possible Cause	Possible Countermeasure	
	Specific Name[4]	Code
Unexpected Cross Traffic	Install Intersection Warning Signs / Urban	SN-5
	Install Intersection Warning Signs / Rural	SN-6
	Move Intersection Away from Curves/Crests	RD-3
Restricted Sight Distance	Eliminate Parking Near Intersection	SN-14
	Remove Obstructions from Sight Triangle	MS-4
	Close/Relocate Driveways Near Intersection	DY-1
	Add 2-Way STOP/YIELD at Urban I/S	SN-11
	Add 2-Way STOP at Rural I/S	SN-12
	Change from 2-Way to 4-Way STOP	SN-13
	Signalize Intersection	SG-1
Poor Visibility of STOP/YIELD Signs	Remove Sign Sight Obstructions	MS-5
	Install Larger Signs	SN-17
	Install STOP/YIELD AHEAD Signs / Urban	SN-1
	Install STOP AHEAD Signs / Rural	SN-2
Excessive Speed	Post/Reduce Speed Limit	SN-19
	Increase Traffic/Speed Enforcement	MS-9
Slippery Surface	Post SLIPPERY WHEN WET Signs / Urban	SN-9
	Post SLIPPERY WHEN WET Signs / Rural	SN-10
	Improve Drainage	PV-2
	Groove Pavement	PV-1
	Resurface Roadway	PV-3
Proper Stopping Position Unclear	Add Stop Bars/Crosswalks	MK-2
	Add/Improve Intersection Lighting	MS-8

[4] I/S = Intersection

Table 4-9.
Possible Causes and Countermeasures for Rear-End/Rear-Right and Side-Swipe/Same-Direction Crashes at Signalized Intersections

Possible Cause	Possible Countermeasure	
	Specific Name [5]	**Code**
Turning Vehicles Slowing or Stopping in Through Lanes	Mark/Lengthen Exclusive Turn Lanes	MK-7
	Install Two-Way Left-Turn Lane	MK-8
	Widen Approaches to Handle Turn Lanes	CH-4
	Increase Curb/Edge-of-Pavement Radius	CH-6
	Add Pretimed, Protected LT Signals	SG-8
	Install Signal Actuation	SG-12
	Install Dual LT Lanes, Signs, & Signals	SG-7
	Provide Split Phasing	SG-9
	Prohibit Turns	SN-25
	Reroute Left-Turn Traffic	SN-24
Unexpected Slowing and Lane Changing	Install Guide Signs	SN-15
	Install Larger Signs	SN-17
	Install Lane-Use Control (Metal) Signs	SN-16
	Install Internally Illuminated Signs	SN-21
Narrow Lanes	Eliminate Parking	SN-14
	Widen Lanes	RD-2
Poor Visibility of Traffic Signal	Remove Signal Sight Obstructions	MS-7
	Post SIGNAL AHEAD Warning Signs/Urban	SN-3
	Post SIGNAL AHEAD Warning Signs/Rural	SN-4
	Install/Replace Signal Visors	SG-19
	Add Signal Back Plates	SG-18
	Add/Relocate Signal Head	SG-17
	Install 12-inch Signal Lenses	SG-16
	Install Advance Flasher-Signs	SG-21
	Upgrade Signalization	SG-14

[5] LT = Left-Turn

**Table 4-9.
Possible Causes and Countermeasures for Rear-End/Rear-Right and Side-Swipe/Same-Direction Crashes at Signalized Intersections (cont'd)**

Possible Cause	Possible Countermeasure	
	Specific Name	**Code**
Unexpected/Unnecessary Stops Due to Signal	Revise Signal Phasing/Sequence	SG-15
	Retime Traffic Signal	SG-2
	Upgrade Signal Controller	SG-15
	Provide Signal Progression	SG-13
	Install Signal Actuation	SG-12
	Remove Unwarranted Signalization	SG-20
Unsafe Right-Turns-on-Red (RTOR)	Reduce RTOR Sight Obstructions	MS-6
	Add Right-Turn Lane Channelization	CH-3
	Provide Right-Turn Overlap (Green Arrow)	SG-6
	Prohibit RTOR	SN-23
Crossing Pedestrians	Add Stop Bars/Crosswalks	MK-2
	Post Ped Xing/Advance Xing Signs / Urban	SN-7
	Post Ped Xing/Advance Xing Signs / Rural	SN-8
	Place Advance Pavement Messages	MK-3
	Install WALK-DON'T WALK Signals	SG-10
	Add/Improve Intersection Lighting	MS-8
	Reroute Pedestrians to Safer Crossing	PE-1
Slippery Surface	Post SLIPPERY WHEN WET Signs / Urban	SN-9
	Post SLIPPERY WHEN WET Signs / Rural	SN-10
	Improve Drainage	PV-2
	Groove Pavement	PV-1
	Resurface Roadway	PV-3
Excessive Speed	Post/Reduce Speed Limit	SN-19
	Increase Traffic/Speed Enforcement	MS-9

Table 4-10.
Possible Causes and Countermeasures for Rear-End/Rear-Right and Side-Swipe/Same-Direction Crashes at Unsignalized Intersections

	Possible Countermeasure	
Possible Cause	**Specific Name**	**Code**
Stopping in Through Lanes	Mark/Lengthen Exclusive Turn Lanes	MK-7
	Install Two-Way Left-Turn Lane	MK-8
	Widen Approaches to Handle Turn Lanes	CH-4
	Increase Curb/Edge-of-Pavement Radius	CH-6
	Prohibit Turns	SN-25
	Reroute Left-Turn Traffic	SN-24
Unexpected Slowing and Lane Changing	Install Guide Signs	SN-15
	Install Larger Signs	SN-17
	Install Lane-Use Control (Metal) Signs	SN-16
Narrow Lanes	Eliminate Parking	SN-14
	Widen Lanes	RD-2
Poor Visibility of STOP/YIELD Signs	Remove Sign Sight Obstructions	MS-5
	Install Larger Signs	SN-17
	Install STOP/YIELD AHEAD Signs / Urban	SN-1
	Install STOP AHEAD Signs / Rural	SN-2
Inadequate Gaps for Turning and Accelerating	Change from 2-Way to 4-Way STOP	SN-13
	Signalize Intersection	SG-1
Crossing Pedestrians	Add Stop Bars/Crosswalks	MK-2
	Post Ped Xing/Advance Xing Signs / Urban	SN-7
	Post Ped Xing/Advance Xing Signs / Rural	SN-8
	Place Advance Pavement Messages	MK-3
	Add/Improve Intersection Lighting	MS-8
	Reroute Pedestrians to Safer Crossing	PE-1
	Signalize Pedestrian Crossing	SG-11

Table 4-10.
Possible Causes and Countermeasures for Rear-End/Rear-Right and Side-Swipe/Same-Direction Crashes at Unsignalized Intersections (cont'd)

Possible Cause	Possible Countermeasure	
	Specific Name	**Code**
Slippery Surface	Post SLIPPERY WHEN WET Signs / Urban	SN-9
	Post SLIPPERY WHEN WET Signs / Rural	SN-10
	Improve Drainage	PV-2
	Groove Pavement	PV-1
	Resurface Roadway	PV-3
Excessive Speed	Post/Reduce Speed Limit	SN-19
	Increase Traffic/Speed Enforcement	MS-9
Restricted Sight Distance	Install Intersection Warning Signs / Urban	SN-5
	Install Intersection Warning Signs / Rural	SN-6
	Move Intersection Away from Curves/Crests	RD-3

- Markings (MK) -- pavement striping/markers, post delineators, chevrons;
- Channelization (CH) -- channelizing islands, median strips, turning radii;
- Pavement (PV) -- drainage, skid resistance, maintenance, rumble strips;
- Roadway (RD) -- widening lanes/shoulders, banking, realigning, flattening;
- Pedestrian (PE) -- crosswalks, signs, signals, refuge islands, lighting, routing;
- Barriers (BA) -- guardrails, median barriers, impact attenuators;
- Driveways (DY) -- definition, geometry, spacing, corner setback, turning rules;
- Railroad Crossing (RR) -- sight distance, signs, markings, flashers, gates; and
- Miscellaneous (MS) -- sight lines, object hazards, lighting, enforcement, etc.

It must be emphasized that <u>the methodology presented in this chapter for identifying crash causes and countermeasures should generally be limited in its application to the preliminary planning and budgeting of a safety improvement program</u>. This is especially important for the more costly countermeasures and those which may have unexpected or undesirable side-effects at particular locations (e.g., an unwarranted traffic signal may have a net negative effect on safety if increased rear-end crashes greatly outnumber decreased angle crashes).

Additional field surveys and engineering studies will often be necessary to properly justify and design the countermeasures preliminarily selected here (FHWA, 1981b; FHWA, 1986b). Also, any traffic control devices (i.e., signs, signals and markings) involved in proposed countermeasures should be evaluated against applicable warrants in the *Michigan Manual of Uniform Traffic Control Devices* (Michigan, 1994).

The possible countermeasures extracted from Tables 4-5 to 4-10 should be consistent with existing conditions, policies and agency capabilities. To document the systematic review of possible countermeasures, complete the following steps:

1. <u>Identify possible countermeasures</u>. Review Tables 4-5 to 4-10 for selected (higher-priority or other) pattern/cause combinations. Note all possible countermeasures associated with these combinations, regardless of individual countermeasure feasibility or duplication.

2. <u>Compile a separate list of the possible countermeasures identified in Step 1</u>. Use the format shown in Figure 4-4. A full-size reproducible copy of this figure can be found in Appendix F.

3. <u>Review the list compiled in Step 2 and rule out inapplicable countermeasures</u>. Classify as inapplicable any counter-measure that:

    a. duplicates one listed earlier,

    b. is inconsistent with basic location features, or

Figure 4-4.
Possible Countermeasures for Crash Patterns at ____________________________

Crash Pattern	Possible Cause	Possible Countermeasure (Step 1)		Applicable? (Step 3)		Comments
		Specific Name	Generic Code	Yes	No	

See Figure 4-9 for a completed example of worksheet.

c. would violate agency policy or otherwise be very difficult to implement due to legal, technical, staffing, administrative or budgetary constraints.

For example, assume that a conventionally striped and lighted urban intersection is being evaluated, and that one of the possible crash causes of interest is Inadequate Pavement Markings. Table 4-5 indicates that one of the possible countermeasures for this cause would add reflective pavement markers (RPMs), and three other possible countermeasures would add a centerline. A suitable comment to include in Figure 4-4 for the RPM countermeasure would be: "Unwarranted given existing intersection lighting." A suitable comment for each of the centerline countermeasures would be: "Inapplicable given existing centerline." The "No" column in the figure would be checked for all four inappropriate countermeasures.

Use the "Comments" column of the listing to explain why certain possible countermeasures are being ruled out (or ruled in). Reinforce the sorting process by highlighting counter-measures that are not ruled out. (See Figure 4-10 for a completed example of worksheet.)

DATA FOR B/C ANALYSIS

To compute the B/C ratios used to compare the relative economic attractiveness of alternative crash countermeasures, an interest rate and the following countermeasure-specific inputs must be determined:

- benefits in terms of overall crash-reduction potential, and
- various cost-related parameters, including:
  - implementation cost,
  - operating and maintenance (O&M) cost,
  - service life and
  - salvage value.

Crash-Reduction Potential

Chapter 5's B/C methodology estimates the benefits of a countermeasure as the monetary value of the reduced crashes expected at a location due to countermeasure implementation. A SEMCOG search for relevant technical literature produced several sources of data on countermeasure crash-reduction potential. The results of this search are synthesized in Appendix B. Judgment was applied to the synthesized data in choosing the single default value shown in Tables 4-11 to 4-13 as each countermeasure's Total Crash Reduction Factor (CRF) for the Signs, Signals, and Markings countermeasure categories. Appendix D contains tables of CRF values for these counter-measures for which no associated cost data was available — Channelization, Pavement, Roadway, Pedestrian, Driveway, and Miscellaneous countermeasure categories. These values are rough (certainly unguaranteed) estimates.

The B/C analysis worksheet presented in the next chapter allows the user or the analyst to input alternative CRFs at their discretion. If this is done, care should be exercised in documenting both the action and the basis for the action. Subsequent editions of this manual are likely to include updated values for various CRFs; hence, SEMCOG would appreciate learning about alternative values being used or proposed for use (especially in Southeast Michigan).

The CRFs given in Tables 4-11 to 4-13 and in Appendix D are for the application of a single countermeasure at a location. When a combination of countermeasures is under consideration (see next section), a combined CRF must be estimated. This combined factor is not, however, simply the sum of the individual CRFs, since the effects of multiple countermeasures often interact and overlap. Compute the CRF for a countermeasure combination by completing the following steps:

1. Express the CRF for each countermeasure in the combination as a value, CRF_i, between 0 and 1 (i.e., tabled value/100).

Table 4-11.
Countermeasure Default Values: SIGNS (SN)

Countermeasure[1]	Service Life (yrs)	Costing Unit[1]	Unit Costs ($)		Units/ Project	Project Costs ($)		Total CRF (%)
			Implementation	O&M /yr		Implementation	O&M/yr	
1-Install STOP/YIELD AHEAD Signs/Urban	7	Sign	225	0	4	900	0	30
2-Install STOP/YIELD AHEAD Signs/Rural	7	Sign	225	0	4	900	0	35
3-Install SIGNAL AHEAD Warning Signs/Urban	7	Sign	225	0	4	900	0	30
4-Install SIGNAL AHEAD Warning SIgns/Rural	7	Sign	225	0	4	900	0	35
5-Install I/S Warning Signs / Urban	7	Sign	225	0	4	900	0	30
6-Install I/S Warning Signs / Rural	7	Sign	225	0	4	900	0	35
7-Post Ped Xing/Advance Xing Signs/Urban	7	Sign	225	0	4	900	0	20
8-Post Ped Xing/Advance Xing Signs/Rural	7	Sign	225	0	4	900	0	25
9-Post SLIPPERY WHEN WET Signs/Urban	7	Sign	225	0	4	900	0	15
10-Post SLIPPERY WHEN WET Signs/Rural	7	Sign	225	0	4	900	0	20
11-Add 2-Way STOP/YIELD at Urban I/S	7	I/S	450	0	1	450	0	35
12-Add 2-Way STOP at Rural I/S	7	I/S	450	0	1	450	0	40
13-Change from 2-Way to 4-Way STOP	7	I/S	600	0	1	600	0	50
14-Eliminate Parking (w/signs @ 200 ft)	10	Sign	85	0	50	4,250	0	30

[1] I/S = Intersection

Table 4-11.
Countermeasure Default Values: SIGNS (SN) (cont'd)

Countermeasure[1]	Service Life (yrs)	Costing Unit[1]	Unit Costs ($)		Units/ Project	Project Costs ($)		Total CRF (%)
			Implementation	O&M /yr		Implementation	O&M/yr	
15-Install Guide Signs	7	Sign	225	0	4	900	0	15
16-Install Lane-Use Control Signs (Metal)	7	Sign						
17-Install Larger Signs	7	Sign	300	0	4	1,200	0	
18-Install NO PASSING ZONE Pennant Signs	7	Sign						20
19-Post/Reduce Speed Limit	7	Sign	225	0	4	900	0	25
20-Post Curve Warnings/Advisory Speeds	7	Sign	300	0	2	600	0	30
21-Install Internally Illuminated Signs	7	Sign						
22-Sign One-Way Street Operation	7	Sign						35
23-Prohibit RTOR	7	Sign	225	0	4	900	0	45
24-Reroute LT Traffic	7	Sign						45
25-Prohibit Turns (at I/S or between I/Ss)	7	Sign	225	0	4	900	0	40

[1] I/S = Intersection

Table 4-12.
Countermeasure Default Values: Signals (SG)

Countermeasure[1]	Service Life (yrs)	Costing Unit[1]	Unit Costs ($)		Units/ Project	Project Costs ($)		Total CRF (%)
			Implementation	O&M/yr		Implementation	O&M/yr	
1-Signalize Intersection	15	I/S	45,000	2,600	1	45,000	2,600	20
2-Retime Traffic Signal	1	I/S	900	0	1	900	0	10
3-Increase Yellow Change Interval	1	I/S	900	0	1	900	0	15
4-Add All-Red Clearance Interval	1	I/S	900	0	1	900	0	15
5-Revise Signal Phasing/Sequence	3	I/S	1,600	0	1	1,600	0	25
6-Provide RT Overlap (Green Arrow)	3	I/S	1,600	0	1	1,600	0	25
7-Install Dual LT Lanes, Signs and Signals		I/S						
8-Add Pretimed/Protected LT Signals	15	Street	4,500	800	1	4,500	800	25
9-Provide Lead/Lag or Split Phasing	3	I/S	1,600	0	1	1,600	0	25
10-Install WALK-DON'T WALK Signals	15	I/S	8,000	1,000	1	8,000	1,000	20
11-Signalize Pedestrian Crossing	15	Each	22,500	1,000	1	22,500	1,000	20
12-Install Signal Actuation	10	I/S	25,000	1,800	1	25,000	1,800	20
13-Provide Signal Progression (3 I/Ss)	11	I/S	1,400	0	1	1,400	0	10
14-Upgrade Signalization	15	I/S	37,500	0	1	37,500	0	20
15-Upgrade Signal Controller	15	I/S	2,500	0	1	2,500	0	20
16-Install 12-inch Signal Lenses	15	I/S	5,000	0	1	5,000	0	10
17-Add/Relocate Signal Head	15	Each	1,000	0	1	1,000	0	
18-Add Signal Back Plates	15	Appr	400	0	2	800	0	20
19-Install/Replace Signal Visors	15	Appr	500	0	1	500	0	
20-Remove Unwarranted Signalization	15	I/S	3,500	(2,500)	1	3,500	(2,500)	55
21-Install Advance Flasher-Signs	15	Each	5,000	150	2	10,000	300	25

[1] I/S=Intersection, LT=Left-Turn, and Appr=Approach

Table 4-13.
Countermeasure Default Values: MARKINGS (MK)

Countermeasure[1]	Service Life (yrs)	Costing Unit[1]	Unit Costs ($)		Units/ Project	Project Costs ($)		Total CRF (%)
			Implementation	O&M /yr		Implementation	O&M/yr	
1-Upgrade Markings (Halve Maint. Cycle)[2]	1	LF	0.04	0	13,200	525	0	15
2-Add Stop Bars/Crosswalks	3	I/S	1,200.00	0	1	1,200	0	15
3-Place Advance Pavement Messages	5	Each	200.00	0	2	400	0	15
4-Add Ctr + Lanelines to Unstriped Street	1	LF	0.04	0	13,200	525	0	35
5-Add Centerline to Unstriped Pavement	1	LF	0.04	0	1,320	50	0	35
6-Add Ctr + Edgelines to Unstriped Road	1	LF	0.04	0	11,880	475	0	40
7-Mark/Lengthen Exclusive Turn Lanes	3	Lane	400.00	0	2	800	0	30
8-Install Two-Way Left-Turn Lane	1	LF	0.04	0	13,200	525	0	35
9-Supplement Centerline with RPMs	10	RPM	27.00	1	65	1,750	65	15
10-Install No Passing Zones (33% need)[3]	6	LF	0.60	0	3,500	2,100	0	40

[1] RPM = Reflective Pavement Marker, I/S = Intersection and LF = Lineal Feet.

[2] In other words, reduce the time between repainting to one half of its present value (e.g., repaint every six months instead of annually).

[3] Assumes that passing will be prohibited over 33% of the travel distance in each direction on a representative rural two-lane highway. This requires a total of 0.33 x 5,280 feet per mile x 2 directions of travel = 3,485 (or approximately 3,500) feet of yellow striping per mile.

2. List the proposed countermeasures in the combination in order of decreasing priority. Consider basing countermeasure priority on the:

   a. crash reduction (e.g. $CRF_1 > CRF_2 > CRF_3$) or the

   b. ease and/or immediacy of implementation (logical for phased countermeasures introductions).

3. Compute the combined CRF with the following equation (FHWA, 1991):

Eq.(4-2)

$$CRF_{com} = 1 - [(1 - CRF_1) x (1 - CRF_2) x (1 - CRF_3) ...]$$

While using Eq.(4-2) guarantees that the combined factor does not exceed 1.0, judgment is still required to avoid adopting values that may be unrealistically high (e.g. > 0.75). (See page 4-37 for an example of computation.)

Cost-Related Parameters

Considering the expected geographic sensitivity of countermeasure cost and service life data, SEMCOG surveyed a variety of Southeastern Michigan sources for such data. The results of this survey are synthesized in Appendix C. Judgment was applied to the synthesized data in choosing default values for each countermeasure's "Service Life" and "Unit Costs" (Tables 4-11 to 4-13).

Unit costs for "O&M" have been set to zero for all countermeasures in the SIGNS category involving conventional sign panels (Table 4-11). This reflects the fairly common practice of simply replacing signs rather than washing or otherwise maintaining them in place.

Traffic engineering countermeasures appear to be rarely assigned a salvage value in economic analyses, and no attempt to do so occurred in the preparation of this manual. A relatively large proportion of the implementation cost of most such measures is for labor. Also, some of the more costly pieces of hardware (such as signal controllers) typically reach technological obsolescence at or before the time they are replaced due to their physical condition. These considerations notwithstanding, individual agencies may wish to adopt their own (non-zero) salvage values for countermeasures involving such items as sign blanks to be recycled or signal heads to be reused after their removal from a location where traffic controls are being upgraded.

The most difficult generalization in putting together Tables 4-11 to 4-13 was the assumed project size (i.e., "Units/Project"). Prior to starting the B/C analysis, users should carefully consider the appropriateness of each such value for the actual location(s) under study. Any adopted revisions to tabled values should be highlighted in revised tables of the same format. Currently tabled values assume that:

- For treatments not applied only at an intersection or a curve, the typical project length for planning purposes is one mile and the typical quantity of required signs is four per mile (i.e., two per direction per mile).

- Effective enforcement of a continuous No Parking zone which previously accommodated parking requires signs to be placed at intervals not exceeding about 200 feet (see countermeasure SN-14.

- While warning signs and signal back plates may be needed on only one approach to an intersection or curve due to driver expectancy and visibility problems, a common (generally inexpensive and liability-sensitive) practice is to treat both approaches on a given roadway even if only one is warranted.

- Special signal visors, on the other hand, are used to restrict the viewing of treated signal indications to a single intersection approach.

COUNTERMEASURE PACKAGING

The last step before proceeding to countermeasure B/C analysis is to consider how the individual countermeasures identified earlier might be logically combined or "packaged." Packaging countermeasures both simplifies and enhances the value of the B/C analyses. It accomplishes this by limiting the alternatives evaluated to complementary combinations of countermeasures which are practical to implement together at various stages in the long-term safety improvement of a given location.

As an example of countermeasure packaging, assume that a signalized intersection on a five-lane street suffers from excessive left-turn crashes. Preliminary observation and analysis indicate that the two leading possible crash causes are excessive speed and restricted sight distance, the latter due to the frequency of simultaneously opposing left-turns. A plausible countermeasure combination for near-term (if not immediate) implementation would be the introduction of a new speed limit and a complementary increase in speed enforcement. The most likely countermeasure for longer-term implementation would probably be the addition of protected left-turn signal phasing. However, a viable alternative or predecessor to such phasing may be the removal of on-street parking to make room on the intersection approach for the insertion of raised median channelization. The objective of such channelization would be to offset opposing left-turn lanes to the left of each other for improved visibility of oncoming through traffic. Such a channelization package may provide a cost-effective safety improvement for an extended period without the need for capacity-reducing turn phases.

The process of packaging countermeasures provides analysts a good opportunity to exercise their own discretion as to which possible countermeasures they wish to evaluate further and which ones they wish to "set aside." This is also a convenient time to check the availability of data needed for the B/C analysis. Use a checklist having the format shown in Figure 4-5 to document the preparation of countermeasure packages. A full-size reproducible copy of this figure can be found in Appendix F. (See Figure 4-11 for completed example of worksheet.)

Figure 4-5.
Countermeasure Packaging at ________________________

Countermeasure		Check Data Available				Comments
Package	**Specific Name (& Generic Code)**	**Service Life**	**Unit Costs**	**Units/ Project**	**CRF**	
Set-Asides (Explain to right)						

See Figure 4-11 for completed example of worksheet.

EXAMPLE OF PATTERN/CAUSE/ COUNTERMEASURE IDENTIFICATION

This final section continues the example problem started in Chapter 3. In that chapter, it was shown using several methods that the Sem-Cog intersection was a high-crash location for the calendar years 1993 to 1995. Now it is possible to determine the crash patterns causing that condition and the various countermeasures that might be pursued to alleviate those crash patterns. The earlier retrieval of crash data for this location revealed that of the 141 total crashes reported over the three-year analysis period, none were head-on crashes, 21 were sideswipe/opposite-direction crashes, 18 were head-left/rear-left crashes, 39 were angle crashes, 24 were rear-end/rear-right crashes and 12 were sideswipe/same-direction crashes. The remaining 27 crashes were single-vehicle crashes or other types not relevant to evaluating crash patterns categorized by multiple-vehicle crash type (the patterns for which this edition of the manual includes pattern/cause/ countermeasure tables).

Crash Patterns

The results from applying the crash pattern identification and prioritization method to the sample intersection are indicated below under each of the method's steps. These steps apply to the Figure 4-1 worksheet (repeated for the example as Figure 4-6) and require the analyst to:

1. Compute the location's crash percentage for each possible crash pattern. The numbers of multiple-vehicle crashes by type given above are entered in the appropriate boxes in the first row of Figure 4-6. The corresponding percentages are then computed to one decimal place and entered in the second row.

2. Define the location type. Information defining the location type is entered in Figure 4-6. The ADT range is indicated in the figure's title block and the area type, roadway functional class, number of lanes and predominant traffic control are indicated opposite the corresponding regional percentage value look-up table numbers.

3. Determine regional crash percentages for each possible crash pattern. The method used to complete this step is described on page 4-3 (Step 3 under CRASH PATTERN IDENTIFICATION). Four regional crash percentages for each pattern, one from each of the SEMCOG tables (Tables 4.1 to 4.4), are entered in the corresponding cells of the worksheet.

4. Compare each crash percentage computed for the location to the corresponding regional crash percentages. Note in Figure 4-6 that for each of the first three crash patterns, the location's percentage exceeds each of the corresponding four regional percentages; hence, these patterns are significant and the word "YES" is entered in the appropriate column in the "Significant Pattern?" row. For rear-end/rear-right & sideswipe/same-direction crashes, the location's percentage fails to exceed even one regional percentage. There is no significant pattern associated with these latter crash types since they are under-represented at the sample intersection.

5. Compute the average of all regional crash percentages which are less than the location's crash percentage. Averages for the three significant patterns are computed and entered in the worksheet. All values averaged are highlighted through the use of boldface type (in manually completing the worksheet, these values would be circled).

6. Compute an ORR. The location's crash percentage for each significant pattern is divided by the corresponding average regional percentage, expressed to one decimal place and entered in the ORR

row of the worksheet. The results show that head-on and sideswipe/opposite-direction crashes were over-represented by a factor of 2.8, head-left/rear-left crashes by a factor of 1.2 and angle crashes by a factor of 1.1.

7. Determine a SW. Severity weightings are used to attach higher priority to those crash patterns producing higher average losses. Weightings are determined in this example using the method described in sub-step 7a on page 4-10. Since sideswipe crashes predominate the first pattern (there were no head-on crashes), this pattern receives a SW of 1.

8. Determine pattern priority. Eq.(4-1) is applied to the values of ORR and SW determined in Steps 6 and 7, respectively, and the results are shown to one decimal place in the last row of the worksheet. The PPIs show that the combination of head-on and sideswipe/opposite-direction crashes should receive the greatest attention in identifying possible causes and counter-measures.

Possible Causes

The results from applying the above method for identifying possible causes to the sample intersection are indicated below under each of the method's steps. These steps apply to the Figure 4-2 and Figure 4-3 worksheets (repeated for the example as Figure 4-7 through Figure 4-9) and require the analyst to:

1. Highlight the columns associated with significant crash patterns. As revealed in Figure 4-6, the Sem-Cog intersection displayed significant patterns of head-on & sideswipe/opposite-direction crashes, left-turn crashes and angle crashes between 1993 and 1995. The corresponding columns are highlighted in Figure 4-7 by darkening in the previously hollow bullets (although shading the full width of the columns with highlighting ink would be a good alternative). In highlighting these columns, recognition is given to the fact that the location being evaluated is signalized (i.e., the "Angle-Sig" column is highlighted).

2. Enter the PPIs. The values of PPI for the three significant crash patterns (3.6, 4.2 and 4.5, respectively) are taken from Figure 4-6 and entered in the current worksheet.

3. Highlight possible causes for the highest priority crash pattern. With a PPI of 3.6, the combination of head-on & sideswipe/opposite-direction crashes should receive the highest priority. Scanning down this pattern column for bullets and then reading across to the left reveals seven possible causes: Excessive Speed, Restricted Sight Distance, Narrow Lanes, Inadequate Pavement Markings, Inadequate Roadway Shoulders, Inadequate Maintenance and Severe Curves. These possible causes are highlighted in Figure 4-7 using bold-face type (highlighting ink is used when done manually).

4. Highlight possible causes for multiple significant crash patterns. Scanning the highlighted columns for two or more bullets in the same row and then reading across to the left reveals three possible crash causes common to multiple patterns: Excessive Speed, Restricted Sight Distance and Inadequate Signal Change Interval. Since the first two of these possible causes were already highlighted in Step 3, only Inadequate Signal Change Interval needs to be highlighted now.

5. Compile a separate list of the possible causes highlighted in Steps 3 and 4 and declare them to be "higher-priority" possible causes. Every pattern/cause combination needs to be listed, even when this results in the same cause appearing more than once in the list. (See Figure 4-8) This is necessary in order to later identify all applicable countermeasures in pattern-specific tables.

6. Highlight and/or list other possible causes. A review of the Figure 4-7 worksheet shows that other possible causes for this location's significant crash patterns (i.e., those having a single bullet in the second or third column) are the seven listed in Figure 4-9. To simplify the completion of this example,

these possible causes and countermeasures are not discussed further.

7. Review the lists compiled in Steps 5 and 6 and rule out possible causes which are inconsistent with basic location features. As explained in the last column of Figure 4-8, three possible causes can be ruled out for head-on & sideswipe/same-direction crashes at this location: Restricted Sight Distance, Inadequate Roadway Shoulders and Severe Curves. The remaining higher-priority possible causes are shown in boldface type. Comments in the figure also describe location features expected to be important in the selection of countermeasures.

Figure 4-6.
Crash Pattern Identification and Prioritization at Sem-Cog Intersection

Average Daily Traffic (ADT) Range 20,001 - 30,000

Evaluation Criteria		**Possible Crash Pattern**			
		Head-On & SS/OD	**Head-Left Rear-Left**	**Angle**	**Rear-End Rear-Right & SS/SD**
Location's Crashes	No. by Type / Total No.	21/141	18/141	39/141	36 / 141
	Location's %	14.9	12.8	27.7	25.5
Regional Crash % (table or computation)	4-1. Area Type: Urban	**5.3**	**11.3**	**26.2**	42.6
	4-2. Functional Class: Arterial	**5.3**	**11.4**	**26**	42.7
	4-3. No. of Lanes: 2	**5.4**	**10**	28.2	40.5
	4-4. Sig. X Unsig. ___	**5.3**	**11.6**	**26**	42.7
	Computed (attach details)				
Significant Pattern?	Enter YES if Location's % Exceeds At Least One of the Above Regional %s	YES	YES	YES	NO
Pattern Priority[1]	Average Regional % [2]	5.3	11.1	26.1	---
	Over-Representation Ratio (ORR) = Location's % / Average Regional %	2.8	1.2	1.1	---
	Severity Weighting (SW)	1	2	2	---
	Pattern Priority Index (PPI) = 10 / (ORR x SW)	3.6	4.2	4.5	---

[1] Complete this block only for significant patterns.

[2] Circle or highlight, and then average, only those Regional Percentages which are less than the location's %. This is necessary to guarantee an ORR greater than 1.0.

Figure 4-7.
Possible Causes for Multiple-Vehicle Crash Patterns at Sem-Cog Intersection

Possible Cause	Crash Pattern					
	Head-On & SS/OD	Left-Turn	Angle		Rear-End & SS/SD	
			Sig	Unsig	Sig	Unsig
Pattern Priority Index (PPI)	**3.6**	**4.2**	**4.5**	-	-	-
Excessive Speed	●	●	●	o	o	o
Restricted Sight Distance	●	●	●	o		o
Slippery Surface			●	o	o	o
Narrow Lanes	●				o	o
Inadequate Signal Change Interval		●	●			
Turning Vehicles Slowing or Stopping in Through Lanes					o	o
Unexpected Slowing and Lane Changing					o	o
Poor Visibility of Traffic Signal			●		o	
Unexpected/Unnecessary Stops Due to Signal			●		o	
Unsafe Right-Turns-on-Red			●		o	
Crossing Pedestrians					o	o
Poor Visibility of STOP/YIELD Signs				o		o
Proper Stopping Position Unclear			●	o		
Inadequate Pavement Markings	●					
Inadequate Roadway Shoulders	●					
Inadequate Maintenance	●					
Severe Curves	●					
Inadequate Gaps in Oncoming Traffic		●				
Inadequate Signalization for Left-Turn Volume		●				
Inadequate Gaps for Turning and Accelerating						o
Unexpected Cross Traffic				o		

Figure 4-8.
Higher-Priority Possible Causes for Crash Patterns at Sem-Cog Intersection

Crash Pattern	**Possible Cause**	**Applicable? (Step 7) Yes**	**No**	**Comments**
Causes Associated with Highest Priority Pattern (Step 3)				
Head-On & SS/OD	**Excessive Speed**	X		A speed survey should be conducted if recent speed data are not available.
	Restricted Sight Distance		X	This pattern/cause combination deals with passing-related crashes on two-lane roads. See other patterns below for intersections.
	Narrow Lanes	X		Marked lanes (including left-turn lane) average only 10-1/2 ft wide due to on-street parking.
	Inadequate Pavement Markings	X		Both streets have conventional striping repainted annually. The intersection is lighted.
	Inadequate Roadway Shoulders		X	Both Sem Rd. and Cog Ave. are curbed urban streets without shoulders.
	Inadequate Maintenance	X		Drivers attempting to avoid frequent potholes may cause sideswipe crashes.
	Severe Curves		X	Both streets run straight through the intersection without any directional changes.
Causes Associated with Multiple Patterns (Step 4)				
Left-Turn & Angle	**Excessive Speed**	X		Recent speed survey?
	Restricted Sight Distance	X		Drivers of left-turning vehicles frequently have their view of through traffic blocked by vehicles waiting to make left-turns from the opposite direction. With respect to possible off-street causes and countermeasures, note that buildings abutting the sidewalks on all four corners preclude meaningful sight triangles. There are no driveways near any of the corners which would allow vehicles waiting to enter the street to block cross-corner viewing.
	Inadequate Signal Change Interval	X		Currently, there is a nominal yellow interval and no all-red interval.

Figure 4-9.
Other Possible Causes for Crash Patterns at __Sem-Cog Intersection__

Crash Pattern	Possible Cause	Applicable? (Step 7)		Comments
		Yes	No	
Angle	Slippery Surface			
	Poor Visibility of Traffic Signal			
	Unexpected/ Unnecessary Stops Due to Signal			
	Unsafe Right-Turns-on-Red			
	Proper Stopping Position Unclear			
Left-Turn	Inadequate Gaps in Oncoming Traffic			
	Inadequate Signalization for Left-Turn Volume			

Possible Countermeasures

Applying the above method results in the identification of possible countermeasures for the sample intersection as indicated below under each of the method's steps. These steps apply to the Figure 4-4 worksheet (repeated for the example as Figure 4-10) and require the analyst to:

1. Identify possible countermeasures. The pattern/cause/countermeasure combinations relevant to this example are found in Tables 4-5, 4-6 and 4-7. These tables are reviewed for the six higher-priority possible causes remaining after the Figure 4-8 review: Excessive Speed, Narrow Lanes, Inadequate Pavement Markings, Inadequate Maintenance, Restricted Sight Distance and Inadequate Signal Change Interval.

2. Compile a separate list of the possible countermeasures identified in Step 1. A total of 30 countermeasure "line items" are listed in Figure 4-10. This number includes some duplicate and clearly infeasible countermeasures.

3. Review the list compiled in Step 2 and rule out inapplicable countermeasures. Using the three criteria presented earlier, the 30 line items are reduced to the 11 higher-priority possible countermeasures shown in boldface type in Figure 4-10. Reasons for excluding the other 19 line items are stated briefly in the "Comments" column of the figure.

Countermeasure Packages

Figure 4-5 (repeated for the example as Figure 4-11) is used to sort the eleven higher-priority possible countermeasures for the sample intersection into two logical implementation packages and a group of so-called "set asides." Package A includes three quickly implementable, operational-type countermeasures. Package B consists of five related countermeasures of various types that may be implemented over a somewhat longer period of time. The remaining three countermeasures are duplicative or less desirable and have been set aside.

The Xs in the figure indicating data availability are limited to the information presented in this edition of the *SEMCOG Traffic Safety Manual*. Users are encouraged to develop their own data for the missing values and provide copies of such new information to the SEMCOG Transportation Department.

CRFs for countermeasure combinations must be computed using Eq.(4-2) and the related steps described earlier. This equation mathematically combines the CRFs given for individual countermeasures in Tables 4-11 to 4-13. Those countermeasures for which costing data is not available have not been included in the continuation of this analysis. Therefore, the result of the combined CRF calculation will be on the low, or conservative, side.

Package A
In order of decreasing size, the two known individual CRFs are $CRF_{SN-19} = 0.25$ (for Post/Reduce Speed Limit) and $CRF_{SG-4} = 0.10$ (for Add All-Red Clearance Interval); hence,

$$CRF_A = 1 - [\,(1 - CRF_{SN-19}) \times (1 - CRF_{SG-4})\,]$$

$$= 1 - [\,(1 - 0.25) \times (1 - 0.15)\,] = 0.363$$

Package B
The two known individual CRFs are $CRF_{SN-14} = 0.30$ (for Eliminate Parking Near Intersections) and $CRF_{MK-1} = 0.15$ (for Upgrade Markings — Halve Maintenance Cycle); hence,

$$CRF_B = 1 - [\,(1 - CRF_{SN-14)} \times (1 - CRF_{MK-1})\,]$$

$$= 1 - [\,(1 - 0.30) \times (1 - 0.15)\,] = 0.405$$

Packages A and B Combined
The combined CRF for all four countermeasures implemented simultaneously would be: $CRF_{A\&B} = 1-[(1-0.25)x(1-0.15)x(1-0.30)x(1-0.15)] = 0.621$.

Figure 4-10.
Possible Countermeasures for Crash Patterns at __Sem-Cog Intersection__

Crash Pattern	Possible Cause	Possible Countermeasure (Step 1)		Applicable? (Step 3)		Comments[1]
		Specific Name[1]	Generic Code	Yes	No	
Head-On & SS/OD (Table 4-5)	Excessive Speed	**Post/Reduce Speed Limit**	SN-3	X		
		Increase Traffic/ Speed Enforcement	MS	X		
	Narrow Lanes	Eliminate Parking	SN-1		X	See Eliminate Parking Near Inter-section (below).
		Widen Lanes	RD	X		
	Inadequate Pavement Markings	Supplement Center-line with RPMs	MK-2		X	Unwarranted given existing I/S lighting.
		Upgrade Markings (Halve Maint. Cycle)	MK-6	X		
		Add Ctr + Lanelines to Unstriped Street	MK-8		X	Inapplicable given existing centerline.
		Add Ctr + Edgelines to Unstriped Road	MK-10		X	Inapplicable given existing centerline.
		Add Centerline to Unstriped Pavement	MK-15		X	Inapplicable given existing centerline.
		Install Flush Median	CH	X		
		Install Raised Median	CH	X		
	Inadequate Maintenanc e	**Repair/Replace Roadway Surface**	PV	X		
		Repair/Replace Shoulder Surface	PV		X	No shoulder to maintain.
Left-Turn (Table 4-6)	Excessive Speed	Post/Reduce Speed Limit	SN-3		X	Duplicate.
		Increase Traffic/ Speed Enforcement	MS		X	Duplicate.
	Restricted Sight Distance	Reduce Obstructions in Median	MS		X	No median or obstructions.
		Favorably Offset Opposing LT Lanes	CH	X		

Figure 4-10.
Possible Countermeasures for Crash Patterns at Sem-Cog Intersection (cont'd)

Crash Pattern	Possible Cause	Possible Countermeasure (Step 1)		Applicable? (Step 3)		Comments[1]
		Specific Name[1]	Generic Code	Yes	No	
Left-Turn (cont'd)	Restricted Sight Distance	Move I/S Away from Curves/Crests	RD		X	Both streets are straight and level.
		Reduce Obstructions on Insides of Curves	MS		X	Both streets are straight and level.
		Flatten Curves	RD		X	Both streets are straight and level.
		Lower Roadbed on Hill Crests	RD		X	Both streets are straight and level.
	Inadequate Signal Change Interval	**Increase Yellow Change Interval**	SG-14	X		
		Add All-Red Clearance Interval	SG-14	X		
Angle (Table 4-7)	Excessive Speed	Post/Reduce Speed Limit	SN-3		X	Duplicate.
		Increase Traffic/ Speed Enforcement	MS		X	Duplicate.
	Restricted Sight Distance	**Eliminate Parking Near Intersection**	SN-1	X		Better than simply Remove Parking.
		Remove Obstructions from Sight Triangle	MS		X	Infeasible to remove buildings.
		Close/Relocate Driveways Near Intersection	DY		X	No driveways nearby.
	Inadequate Signal Change Interval	Increase Yellow Change Interval	SG-14		X	Duplicate.
		Add All-Red Clearance Interval	SG-14		X	Duplicate.

[1] RPMs = Reflective Pavement Markers, I/S = Intersection, Ctr = Centerline and LT = Left-Turn.

Figure 4-11.
Countermeasure Packaging at Sem-Cog Intersection

Countermeasure		Check Data Available				Comments
Package	**Specific Name and [Generic Code]**	**Service Life**	**Unit Costs**	**Units/ Project**	**CRF**	
A	Post/Reduce Speed Limit [SN-19]	X	X	X	X	Speed study may be required.
	Increase Traffic/ Speed Enforcement [MS-9]					May want to try before changing speed limit.
	Add All-Red Clearance Interval [SG-4]	X	X	X	X	Preferred over longer yellow.
B	Eliminate Parking Near Intersection [SN-14]	X	X		X	Sign quantity depends on parking details.
	Repair/Replace Roadway Surface [PV-4]					Resurfacing facilitates new striping pattern.
	Favorably Offset Opposing LT Lanes [CH-5]					Parking removal allows both this treatment and lane widening.
	Widen Lanes [RD-2]					Remove parking.
	Upgrade Markings (Halve Maint. Cycle) [MK-1]	X	X		X	Striping required depends on inter-section size.
Set-Asides (Explain to right)	Install Flush Median [CH-2]	There is already a median left-turn-only lane. Its narrowness may be causing SS/OD crashes.				
	Install Raised Median [CH-1]	Favorably Offset Opposing LT Lanes is a specific form of this countermeasure.				
	Increase Yellow Change Interval [SG-3]	Prevailing traffic engineering sentiment favors all-red intervals over longer yellow intervals.				

CHAPTER 5

BENEFIT/COST ANALYSIS

The benefit/cost (B/C) analysis is an economic tool for assessing and comparing possible countermeasures. For each countermeasure considered, it compares expected benefits to expected costs. "Benefits" here consist of the reduced frequency and severity of crashes. "Costs" include elements for selecting, designing, implementing, operating and maintaining a countermeasure. Both benefits and costs are expressed in dollars to facilitate the use of their ratio as a key economic performance indicator. B/C ratios indicate economic viability when they are greater than or equal to 1.0, and they reflect relative economic desirability by the degree to which they exceed 1.0.

This chapter briefly discusses the issue of crash costing, describes B/C methodology in detail with the aid of a worksheet and then illustrates the application of the methodology with a continuation of the intersection example used in Chapters 3 and 4. Also discussed is the use of benefit and cost data in project selection.

HIGHWAY CRASH COSTS

The costs of highway crashes are used for many purposes, including allocating highway safety resources to maximize safety benefits, evaluating proposed safety regulations and convincing policy makers and employers that safety programs are beneficial. Crash costs are one of the most important measures available for determining the effectiveness of highway safety improvement projects. These costs are sensitive, however, to time and the methodology used to compute them. Thus, it is essential that crash costs are current and that the underlying methodology is theoretically sound.

Many individuals and agencies are reluctant to assign a dollar value to a human life. This is an emotional issue that has been and will continue to be the subject of many debates. Nonetheless, once the costs of a proposed safety project have been estimated, a decision must be made whether to fund the project. A common method used to make (or at least influence) this decision is a B/C analysis. Such an analysis requires the quantification of expected project benefit. This quantification requires, in turn, estimates of the numbers of crashes, deaths and injuries which may be avoided by the implementation of the project. It also requires the adoption and use of average dollar values for each life saved and injury avoided.

Over the years, two methods of computing the economic value of human life have prevailed: the Human Capital Method and the Willingness-to-Pay Method (Miller, 1991). The latter method incorporates quality-of-life considerations as well as the direct and indirect costs of resources lost in a crash; hence, it is the method recommended for generating the "comprehensive crash benefits" used in the B/C analysis of proposed highway safety projects (Jacks, 1987). Table 5-1 gives rounded values of comprehensive costs predicted with this method for 1993, on both a per-crash and per-person basis (Streff and Molnar, 1994). (See Chapter 3 for more detailed crash severity level definitions.)

B/C ANALYSIS METHODOLOGY

The Federal Highway Administration publication entitled *Highway Safety Evaluation Procedural Guide* (FHWA, 1981c) describes a nine-step methodology for the B/C analysis of highway safety improvement projects (i.e., crash countermeasures or countermeasure combinations). These steps determine the following countermeasure properties and economic parameters:

Table 5-1.
Comprehensive Crash Costs, 1993

Severity	Cost Per Crash	Cost Per Person
F — Fatal	$3,961,000	$3,057,000
A — Incapacitating Injury	$278,000	$202,000
B — Non-Incapacitating Injury	$66,000	$46,000
C — Possible Injury	$38,000	$22,000
PDO — Property-Damage-Only	$2,700	$2,800

1. annual average safety benefit,
2. implementation cost,
3. net annual operating and maintenance (O&M) costs,
4. service life,
5. salvage value,
6. interest rate,
7. capital-recovery, sinking-fund and present-worth factors,
8. B/C ratio using Equivalent Uniform Annual Benefit and Cost Method, and
9. B/C ratio using Present Worth of Benefits and Costs Method.

Alternative Methods

The analyst is free to apply either or both of the methods listed in the last two steps for computing a B/C ratio. The methods produce the same result; hence, applying both provides a computational cross-check.

The Equivalent Uniform Annual Benefit and Cost Method sums costs and spreads them out over the life of a countermeasure in equal annual installments for comparison to annual benefit. Such installments are similar to car payments where the amount paid is constant throughout the loan period. B/C ratios computed by this method for alternative countermeasures can be directly compared even when the service lives of the countermeasures are not equal. This is because the method assumes that shorter-lived countermeasures will continue to be replaced throughout the service life of the longest-lived countermeasure.

The Present Worth of Benefits and Costs Method sums all benefits and costs, both present and future, and determines how much these lump sums would be in today's dollars. B/C ratios computed by this method can be directly compared only if they are based on the same length of analysis period. Special "adjustments" therefore have to be made when the countermeasures to be compared have unequal service lives. Perhaps the simplest way of making such adjustments is to assume an analysis period equal to the least common multiple of the lives of the countermeasures being compared. During this period, it is assumed that countermeasures with service lives shorter than the analysis period are renewed or replaced according to their respective service lives.

The Nine Steps

A three-page worksheet (Figure 5-1) has been developed to assist in computing the B/C ratio for a crash countermeasure or countermeasure combination. A reproducible copy of this figure can be found in Appendix F. First fill in the title block of the worksheet using the countermeasure name(s) and code(s) provided in Chapter 4. Then complete the steps described in detail below.

Figure 5-1.
B/C Analysis Worksheet

Location____

Countermeasure Name(s) & Code(s)____

____

Analyst ____ Date_______________________________

==

1. Annual Average Safety Benefit

a. *Annual Average Number of Crashes by Severity (pre-treatment)*

Determined for ___ years: 19 ___ to 19 ___ (min. is 3 yrs)

Fatal, F ___ + Non-F Injury, A+B+C _____ + PDO _____ = Total ______

b. *Crash-Reduction Factor (CRF) by Severity (*may set = CRF_T)*

CRF_F* _____ CRF_{ABC}* _____ CRF_{PDO}* _____ Total Crashes, CRF_T _____

Source: Tables 4-11 to 4-13 ___ Other (attach) ___

c. *Average Cost Per Crash by Severity (C_i)*

Source: Table 5-1 ___ Other (attach) ___ C_F $ ______________

Weighted Average for Non-F Injury:

$C_{ABC} = (C_A xA + C_B xB + C_C xC) / (A+B+C) =$

($ ___________ x _____ +

$ ___________ x _____ +

$ ___________ x _____) / _____ = C_{ABC} $ ______________

C_{PDO} $ ______________

d. *Annual Benefit =*

(F x CRF_F x C_F) +

((A+B+C) x CRF_{ABC} x C_{ABC}) +

(PDO x CRF_{PDO} x C_{PDO}) =

(_____ x ______ x $ _____________) +

(_____ x ______ x $ _____________) +

(_____ x ______ x $ _____________) = $ _____________

Figure 5-1.
B/C Analysis Worksheet (cont'd)

2. Implementation Cost

   Source: Tables 4-11 to 4-13 ___ Other (attach) ___ $ _____________

3. Net Annual Operating and Maintenance (O&M) Costs

   Source: Tables 4-11 to 4-13 ___ Other (attach) ___ $ _____________

4. Service Life

   Source: Tables 4-11 to 4-13 ___ Other (attach) ___ ____ yrs

5. Salvage Value (if not set equal to 0, explain basis below:)

   ____ $ _____________

6. Interest Rate _____ %

7. Other Economic Factors
   See Appendix E tables for service life & interest rate above:

   Capital-Recovery Factor _____________

   Sinking-Fund Factor _____________

   Present-Worth Factor _____________

   Present-Worth Factor for a Series of Payments _____________

8. B/C Ratio Using Equivalent Uniform Annual Benefit and Cost Method

   a. *Annual Cost* =

      (Implementation Cost x Capital-Recovery Factor) +
      (Net Annual Operating and Maintenance Costs) -
      (Salvage Value x Sinking-Fund Factor) =

      ($ _____________ x _____________) +

      ($ _____________) -

      ($ _____________ x _____________) = $ _____________

   b. *B/C* = (Annual Benefit / Annual Cost) =

      ($ _____________ / $ _____________) = ___:___

Figure 5-1.
B/C Analysis Worksheet (cont'd)

9. <u>B/C Ratio Using Present Worth of Benefits and Costs Method</u>

a. *Present Benefit* =

(Annual Benefit x Present Worth Factor for a Series of Payments) =

($ _____________ x _____________) = $ _____________

b. *Present Cost* =

(Implementation Cost) +
(Net Annual Operating and Maintenance Costs x Present Worth Factor for a Series of Payments) - (Salvage Value x Present Worth Factor) =

($ _____________) +

($ _____________ x _____________) -

($ _____________ x _____________) = $ _____________

c. *B/C* = (Present Benefit/Present Cost) =

($ _____________ / $ _____________) = ____:__

1. Compute the annual average safety benefit. There are four sub-steps involved:

   a. Determine the annual average number of crashes occurring at each severity level prior to countermeasure implementation ("pre-treatment"). Refer to the EPDO Method in Chapter 3 for a discussion of severity levels and the number of years of crash data required. (As indicated earlier, from three to as many as seven years of data may be needed, depending on traffic volume and overall crash frequency). Enter the specific years used in the blanks provided. Enter the annual average number of fatal (F) crashes, A-level, B-level and C-level injury (A, B, C) crashes, and property damage only (PDO) crashes in the appropriate blanks. Enter the sum of the injury (A+B+C) crashes in the appropriate blanks. Values for annual average numbers of crashes should be expressed to two decimal places.

   b. Enter crash-reduction factors (CRFs). First enter the CRF for total crashes and indicate whether this value is from a Chapter 4 Table (4-11, 4-12 or 4-13 for the Signs, Signals and Markings categories, respectively) or some other source (reference or attach relevant excerpts of other sources). Again, Appendix D contains tables of CRF values for the remaining countermeasure categories (Channelization, Pavement, Roadway, Pedestrian, Driveways, and Miscellaneous) although no costing data for these countermeasures have been included in this edition of the manual. If CRF values are also available for fatal, non-fatal injury (ABC) and PDO crashes, enter such values in the appropriate blanks and attach documentation; otherwise, assume that the value for total crashes applies across all severity levels. If entered values are for a combination of countermeasures, indicate this fact in the worksheet's title block and on a separate sheet showing the computation of the combined CRF in the manner described in Chapter 4.

   c. Determine the average cost per crash by severity. Enter the comprehensive crash costs from the middle column of Table 5-1 or other agency guidelines (to be cited and/or attached). Values for fatal and PDO crashes are entered directly in the appropriate blanks at the right margin of the worksheet; however, values for the three levels of non-fatal injury crashes are input in an equation that computes an average cost for all non-fatal injury crashes weighted by the respective numbers of A-, B- and C-level crashes. Solve the equation for C_{ABC} after double-checking to see that all the proper values have first been input.

   d. Compute the annual benefit anticipated for the countermeasure(s) being evaluated. Use the three-term equation provided in the worksheet. The terms of this equation represent the economic value of reduced fatal crashes, non-fatal injury crashes and PDO crashes, respectively. In each term of the equation, enter for the corresponding severity level(s) the pre-treatment annual average number of crashes (from Sub-Step 1a) in the first blank, CRF (from Sub-Step 1b) in the second blank and average cost per crash (from Sub-Step 1c) in the third blank. Then solve the equation for the annual benefit in dollars.

2. Determine countermeasure implementation cost. The cost of implementing a crash countermeasure will depend on many project-specific variables which are difficult to quantify at the planning stage, not the least of which is the appropriate scale of application. Tables 4-11 to 4-13 provide unit cost data for various countermeasures and, under stated assumptions regarding project size, the resulting total implementation cost. Carefully review the data and assumptions given in these tables for the

countermeasure being evaluated; if you are willing to accept them, take the corresponding total project implementation cost and enter it in the B/C analysis worksheet. If, however, you choose to use a different total cost, attach supporting documentation indicating your assumptions regarding unit cost and project size. Also note or show your computation of implementation cost for any countermeasure combination being evaluated. Normally the costs of the countermeasures in the combination are simply summed; however, some components of implementation cost (such as that for construction zone traffic control) may be shared and any assumptions in this regard should be documented. You may also wish to include those countermeasures listed in Appendix D which are applicable to the analysis and for which you have costing data available. As this manual will continue to be updated and revised, SEMCOG would appreciate receiving any additional costing data, particularly for those countermeasures for which no costing data is currently included.

3. Determine the net annual O&M costs. Enter the difference between the annual average O&M costs for the location before project implementation and those costs after implementation. If the project is expected to reduce overall annual O&M costs, the net cost entered here would be negative. As with implementation costs, agency experience may suggest values different than those provided in Tables 4-11 through 4-13; attach documentation for any alternate values used in completing the worksheet.

   This variable may also be used to account for the cost of renewing or replacing countermeasures having shorter service lives than others considered for initial implementation at the same time. For example, if a proposed countermeasure combination includes a sign countermeasure with a seven-year service life and a marking countermeasure with a one-year service life, the combination could be said to have a seven-year service life with a net annual O&M cost adequate to cover both sign maintenance and annual restriping.

4. Determine countermeasure service life. Enter the time period over which a countermeasure is expected to reduce crash rates and/or crash severity, not the physical life expectancy of the countermeasure itself. Suggested service lives are listed in Tables 4-11 to 4-13 for typical traffic engineering countermeasures; however, additional and alternative values can be found in other sources (e.g., FHWA, 1981a). Identify the source used and attach relevant excerpts from any outside sources. As indicated in Step 3, combinations of countermeasures having unequal service lives can be handled by assuming an overall service life equal to the least common multiple of the lives of the countermeasures being analyzed (for further discussion of the problem of unequal service lives, see Wohl and Martin, 1967).

5. Determine a salvage value. Figure 5-1 assumes that this value will normally be set equal to zero. Note exceptions in the space provided.

6. Select an interest rate. Enter an agency-approved interest rate to reflect the time value of money. Economic analyses are very sensitive to small variations in interest rates. The same interest rate should therefore be used in evaluating all safety improvements being considered within a given planning or budgeting cycle. The rate used should normally reflect current interest rates for government bonds and securities, as well as both past and current policies of the agency (FHWA, 1981a).

7. Determine other economic factors. First decide which method(s) will be used in completing the computation of a B/C ratio: the Equivalent Uniform Annual Benefit and Cost Method (Step 8), the Present Worth of Benefits and Costs Method (Step 9), or both. The first method requires the Capital-Recovery and Sinking-Fund factors and the second method requires the Present-Worth Factor and the Present-Worth Factor for a Series of Payments. Look up the necessary factors in compound interest tables

(Appendix E) and enter the factors in the blanks provided on the worksheet.

8. Compute the B/C ratio using the Equivalent Uniform Annual Benefit and Cost Method. First confirm that this method is desired (noting the discussion of the alternative methods at the beginning of this section). If it is not, skip to Step 9; if it is, complete the following two sub-steps:

   a. Enter in the blanks of the Annual Cost equation the corresponding quantities from the top half of the page and solve.

   b. Enter in the blanks of the B/C equation the Annual Benefit from the preceding page and the Annual Cost from the preceding sub-step and solve. Circle or highlight the resulting ratio if it is greater than or equal to 1.0.

9. Compute the B/C ratio using the Present Worth of Benefits and Costs Method. First confirm that this method is desired (noting the discussion of alternative methods at the beginning of this section). If it is not, verify that Step 8 has been completed and skip Step 9; if it is, complete the following three sub-steps:

   a. Enter in the blanks of the Present Benefit equation the two indicated quantities and solve.

   b. Enter in the blanks of the Present Cost equation the corresponding quantities from the preceding page and solve.

   c. Enter in the blanks of the B/C equation the Present Benefit from Sub-Step 9a and the Present Cost from Sub-Step 9b and solve. Circle or highlight the resulting ratio if it is greater than or equal to 1.0. If the B/C ratio was also computed in Step 8, verify that Steps 8 and 9 produced the same ratio.

EXAMPLE OF B/C ANALYSIS

This section completes the example started in Chapter 3 and continued in Chapter 4. The sample intersection was shown to be a high-crash location based on 1993 to 1995 data. Significant crash patterns included head-on & sideswipe/opposite-direction crashes, head-left/rear-left crashes and angle crashes. Eleven higher-priority countermeasures for such patterns were identified.

Three of the identified countermeasures, designated "Package A" in Figure 4-11, involve fairly simple traffic engineering and enforcement actions that could be implemented immediately. Another five of the countermeasures, designated "Package B," involve making better use of available pavement on the intersection's approaches. The likely costs and implementation phasing of Package B are not fully known at present but warrant further study. The use of the B/C Analysis Worksheet is illustrated in Figure 5-2 for the proposed simultaneous implementation of the two traffic engineering countermeasures within Package A: Post/Reduce Speed Limit (SN-19) and Add All-Red Clearance Interval (SG-4). The third countermeasure within the package, Increase Traffic/Speed Enforcement, is not included in the analysis due to the lack of cost data.

The results from applying this worksheet are indicated below under each of the steps described earlier. These steps require the analyst to:

1. Compute the annual average safety benefit. This involves four sub-steps:

   a. Determine the annual average number of crashes occurring at each severity level prior to countermeasure implementation ("pre-treatment"). The example data used to illustrate the EPDO Method in Chapter 3 are in the corresponding blanks of Figure 5-2 (for Sub-Step 1c as well as 1a).

   b. Enter CRFs. The value of CRF_T for this specific countermeasure combination is determined in Chapter 4 to be 0.363.

Since this value was not taken directly from any of that chapter's tables, the "Other" option is checked for source (computations of the type shown at the end of Chapter 4 would ordinarily be attached to the worksheet). No severity-specific values are available, so the value for total crashes is also entered in the other blanks on the same line of the worksheet.

c. Determine the average cost per crash by severity. The values of C_F and C_{PDO} given in Table 5-1 are entered directly into the blanks at the right margin. The values for A-, B- and C-level injury crashes are entered in the first blank on each line of the equation for C_{ABC}. Since other values needed in the equation have already been entered in Sub-Step 1a, the equation can now be solved.

d. Compute the annual benefit anticipated for the countermeasure(s) being evaluated. Values determined in Sub-Steps 1a to 1c are entered in the corresponding blanks of the equation for Annual Benefit and the equation is solved. The result, $314,000, is rounded to the nearest 100 dollars.

2. Determine countermeasure implementation cost. As noted on the example worksheet, the implementation costs given in the Chapter 4 tables for SN-19 and SG-4 are simply added (they each cost $900).

3. Determine the net annual O&M costs. According to Tables 4-11 and 4-12, both countermeasures have zero O&M costs.

4. Determine countermeasure service life. Table 4-11 gives a service life for SN-19 (speed limit signs) of seven years. Table 4-12 gives a service life for SG-4 (signal retiming) of one year, but this does not really apply to all-red clearance intervals which — unlike cycling green and red phases — ordinarily do not warrant an annual retiming effort. Hence, the service life being assumed here for the countermeasure Add All-Red Clearance Interval is the same seven years used for the companion signing countermeasure.

5. Determine a salvage value. Neither countermeasure in the combination has a salvage value.

6. Select an interest rate. An unusually large value (10 percent) is used here to reflect future economic uncertainty. This value is sufficiently high that it should produce a conservative or "worst-case" B/C ratio (i.e., a low ratio resulting from a high cost). The analyst may want to repeat the cost and B/C ratio computations with a lower interest rate in order to establish a range of possible B/C ratios.

7. Determine other economic factors. Both methods for completing the B/C computation are being illustrated here, so all four factors are determined using the tables in Appendix E and are entered in the appropriate blanks.

8. Compute the B/C ratio using the Equivalent Uniform Annual Benefit and Cost Method. The necessary input values for the Annual Cost and B/C equations are taken from earlier places within the worksheet and entered in the corresponding blanks. The Annual Cost is then computed to be $370 and the B/C ratio is ($314,000/$370 =) 849:1. It is immediately obvious from this example that operational, non-capital-intensive crash countermeasures can be highly cost-effective.

9. Compute the B/C ratio using the Present Worth of Benefits and Costs Method. The necessary input values for the Present Benefit, Present Cost and B/C equations are taken from earlier places within the worksheet and entered in the corresponding blanks. The Present Benefit is then computed to be $1,528,700 (rounded), the Present Cost is $1,800 and the resulting B/C ratio is — once again — 849:1. The computational cross-check has therefore succeeded.

Figure 5-2.
Example Use of B/C Analysis Worksheet

Location ____________ Intersection of Sem Road and Cog Avenue ____________

Countermeasure Name(s) & Code(s) ____ Post/Reduce Speed Limit (SN-3) and ____

____ Add All-Red Clearance Interval (SG-14) ____

Analyst ____ John Smith ____ Date ____ 09/04/97 ____

==

1. Annual Average Safety Benefit

a. *Annual Average Number of Crashes by Severity (pre-treatment)*

Determined for 3 years: 1993 to 1995 (min. is 3 yrs)

Fatal, F 0.0 + Non-F Injury, A+B+C 12.00 + PDO 35.00 = Total 47.00

b. *Crash-Reduction Factor (CRF) by Severity (*may set = CRF_T)*

CRF_F* 0.363 CRF_{ABC}* 0.363 CRF_{PDO}* 0.363 Total Crashes, CRF_T 0.363

Source: Tables 4-11 to 4-13 ___ Other (attach) X
Note: See computation of combined CRF_T at end of Chapter 4.

c. *Average Cost Per Crash by Severity (C_i)*

Source: Table 5-1 X Other (attach) ___ C_F \$ 3,961,000

Weighted Average for Non-F Injury:

$C_{ABC} = (C_A x A + C_B x B + C_C x C) / (A+B+C) =$

(\$ 278,000 x 1.00 +

\$ 66,000 x 2.67 +

\$ 38,000 x 8.33) / 12.00 = C_{ABC} \$ 64,230

C_{PDO} \$ 2,700

d. *Annual Benefit =*

($F \times CRF_F \times C_F$) +

($(A+B+C) \times CRF_{ABC} \times C_{ABC}$) +

($PDO \times CRF_{PDO} \times C_{PDO}$) =

(0.0 x 0.363 x \$ 3,961,000) +
(12.00 x 0.363 x \$ 64,230) +
(35.00 x 0.363 x \$ 2,700) = \$ 314,000

Figure 5-2.
B/C Analysis Worksheet (cont'd)

2. Implementation Cost

   Source: Tables 4-11 to 4-13 X Other (attach) ___ — $ 1,800
   Note: Costs from these tables for SN-3 and SG-14 are added.

3. Net Annual Operating and Maintenance (O&M) Costs

   Source: Tables 4-11 to 4-13 X Other (attach) ___ — $ 0

4. Service Life

   Source: Tables 4-11 to 4-13 X Other (attach) ___ — 7 yrs
   Note: All-red interval does not need annual retiming.

5. Salvage Value (if not set equal to 0, explain basis below:)

   ____ — $ 0

6. Interest Rate — 10 %

7. Other Economic Factors
   See Appendix E tables for service life & interest rate above:

   Capital-Recovery Factor 0.2054

   Sinking-Fund Factor 0.1054

   Present-Worth Factor 0.5132

   Present-Worth Factor for a Series of Payments 4.8684

8. B/C Ratio Using Equivalent Uniform Annual Benefit and Cost Method

   a. *Annual Cost* =

      (Implementation Cost x Capital-Recovery Factor) +
      (Net Annual Operating and Maintenance Costs) -
      (Salvage Value x Sinking-Fund Factor) =

      ($ 1,800 x 0.2054) +

      ($ 0) -

      ($ 0 x 0.1054) = — $ 370

   b. *B/C* = (Annual Benefit / Annual Cost) =

      ($ 314,000 / $ 370) = — **849:1**

Figure 5-2.
B/C Analysis Worksheet (cont'd)

9. B/C Ratio Using Present Worth of Benefits and Costs Method

a. *Present Benefit* =

(Annual Benefit x Present Worth Factor for a Series of Payments) =

($ 314,000 x 4.8684) = $ 1,528,700

b. *Present Cost* =

(Implementation Cost) +
(Net Annual Operating and Maintenance Costs x Present Worth Factor for a Series of Payments) - (Salvage Value x Present Worth Factor) =

($ 1,800) +

($ 0 x 4.8684) -

($ 0 x 0.5132) = $ 1,800

c. *B/C* = (Present Benefit/Present Cost) =

($ 1,528,700 / $ 1,800) = **849:1**

PROJECT SELECTION

Unfortunately, most local agencies do not have sufficient funds to complete all the safety improvements they would like to make. Therefore, countermeasures and the locations to be treated should be selected so as to maximize the amount of safety benefit per dollar spent, subject to various engineering, financial and institutional constraints.

This section briefly describes three of the simpler methods of using benefit and cost data to prioritize safety improvement projects (countermeasures or countermeasure combinations). Additional discussion and methods can be found in the *Highway Safety Improvement Program User's Manual* (FHWA, 1981a) and the *Local Highway Safety Improvement Program Users' Guide* (FHWA, 1986a).

All three methods discussed here — the Net Benefit Method, B/C Ratio Method and Incremental B/C Method — are useful in ranking alternative projects at a single location. However, only the latter two methods aid in the selection of projects tending to optimize safety benefits on a system-wide basis.

Net Benefit Method

This method is used to identify the project offering the greatest safety benefit at a given location. "Net benefit" is the difference between the equivalent uniform annual benefit and the equivalent uniform annual cost, two quantities computed above in the B/C analysis worksheet. Alternative projects having a net benefit greater than zero (or B/C ratio greater than 1.0) are ranked in descending order by value of net benefit. The project having the largest net benefit is considered by this method to be the best alternative.

The Net Benefit Method tends to identify high-cost, capital-intensive projects. Implementing only this type of project would dedicate large portions of the total safety improvement budget to a rather limited number of locations, usually to the disadvantage of other locations in the network for which low-cost countermeasures might be well-suited. As discussed below, this method should probably be used only in conjunction with other project selection methods.

B/C Ratio Method

This method ranks candidate projects based on the amount of safety benefit they offer for every dollar spent. The method can be applied at either a single location or system-wide.

In applying the method at a single location, alternative projects having B/C ratios exceeding 1.0 are first ranked in descending order by B/C ratio. The project having the largest B/C ratio is considered by this method to be the best alternative.

In applying the method system-wide, candidate projects having B/C ratios exceeding 1.0 are first ranked in descending order by B/C ratio. Project selection then begins at the top of the list and proceeds down the list until available funds are depleted. A project on the list is skipped if it would treat the same location as a project higher on the list or if the addition of its cost to cumulative program cost would result in a budget overrun. Separate project lists may be developed on the basis of such factors as district, roadway functional class and average daily traffic volume.

The B/C Ratio Method tends to favor low-cost operational safety improvements. While such improvements might offer very high benefits per dollar spent, they do not always provide reliably long-lasting reductions in both crash frequency and crash severity. Many of the most hazardous known locations should be corrected, even if the B/C ratios for the countermeasures identified for those locations are not as high as elsewhere.
There are several possible ways of offsetting the above-noted disadvantages of the Net Benefit and B/C Ratio Methods of project selection.

One way is to compile a project list by each method and then select an arbitrary number of unique projects from the top of each list. Another way is to subdivide all possible projects into low-, medium- and high-cost classes and then select a project from each list until available funds are depleted. Yet another way is to apply the Incremental B/C Method.

Incremental B/C Method

This method can be used to select projects based on whether extra increments of expenditure are justified for a particular location. It can also be used to simultaneously determine the optimal level of expenditure at multiple locations, each having more than one possible treatment alternative (FHWA, 1981a).

The Incremental B/C method assumes that the relative merit of a project is measured by its increased benefit (compared to the next-lower-cost project) divided by its increase in cost (compared to the next-lower-cost project). The increased benefit divided by the increase in cost is known as the incremental B/C ratio. To apply the Incremental B/C Method, complete the following steps for each location being studied:

1. Determine the benefit, cost and B/C ratio of each candidate project.

2. List the projects having a B/C ratio greater than 1.0 in order of increasing cost.

3. Calculate the incremental B/C ratio of the second-lowest-cost project compared to the lowest-cost project.

4. Continue, in order of increasing cost, to calculate the incremental B/C ratio for each project compared to the next-lower-cost project.

5. Stop when the incremental B/C ratio first falls below 1.0.

According to this method, the last incremental B/C ratio on the list which exceeds 1.0 identifies the most economically attractive (or best) project. This project — the higher-cost alternative of the two being compared by the ratio — is the most expensive project on the list having additional benefits in excess of additional costs.

To apply the Incremental B/C Method in system-wide project selection:

1. Use the method to identify the best project at each location studied.

2. List the resulting best projects in order of increasing cost.

3. Complete Steps 3, 4 and 5 of the Incremental B/C Method (above) for the list of best projects.

4. Identify the best system-wide project (according to the method's criterion).

5. Select projects by starting with the best system-wide project and proceeding UP the list (i.e., in the direction of decreasing cost) until available funds are depleted. Skip a project if the addition of its cost to cumulative program cost would result in a budget overrun.

If the list of projects generated by the last step fails to utilize all available safety improvement funds, the agency may want to consider adding projects suggested by the application of other methods. Alternatively, spare funds might be held in a contingency account (if law and policy allow), in order to finance future cost overruns or other projects whose need becomes more apparent later in the fiscal year.

This method reduces the impact of very-low-cost projects. It also enhances the consideration of additional projects based on their expected additional benefits. An example of the method's application at a single location can be found in the *Local Highway Safety Improvement Program User's Guide* (FHWA, 1986a).

CHAPTER 6

SUMMARY AND CONCLUSIONS

This chapter summarizes key points by chapter, highlights those elements of the methodology open to expansion and/or refinement and draws conclusions regarding the expected usefulness of the manual.

CHAPTER 1 - INTRODUCTION

A comprehensive highway safety program is needed to reduce the large and varied impacts of traffic crashes on Southeast Michigan residents. A crucial element of such a program is the collection and effective use of crash data to identify and correct safety deficiencies in the roadway system.

The shortage of traffic engineers in Southeast Michigan has resulted in many communities assigning traffic safety as a collateral duty to law enforcement and public works personnel. SEMCOG has created this manual to assist these personnel (and others) in their analysis of roadway-related traffic safety problems. The manual provides a set of user-friendly tools for checking a location's crash history, identifying possible crash causes and countermeasures and conducting benefit/cost (B/C) analyses of selected countermeasures.

CHAPTER 2 - DATA COLLECTION AND MAINTENANCE

Potentially useful in identifying and analyzing traffic safety problems are data on crashes, traffic volume and composition, traffic control devices, roadway and roadside design features, perceived operational and safety problems, maintenance of objects struck in crashes, traffic citation patterns and adverse litigation history.

Crash Data

The State of Michigan Traffic Crash Report, or UD-10, is used to code numerous details describing the crash scene, roadway conditions, persons and vehicles involved, sequence of events, type of crash and resulting injuries and property damage. One of the most important sections of the UD-10, however, is the box entitled "Crash Diagram and Remarks." Due in part to its value in diagnosing roadway-related causal factors, this section should be completed carefully and conscientiously for all crashes.

Traffic Volume and Composition

Volume data allow for the computation of exposure-based crash rates, thus preventing the potentially misleading classification of a relatively safe high-volume location as "high-crash" simply because it has experienced a relatively large number of crashes. Information on the composition of traffic can be useful in explaining differing crash histories of two otherwise similar locations.

Perceived Operational and Safety Problems

The complaints and concerns of road users are sometimes useful in identifying potential crash locations (i.e., locations where developing patterns of behavior may lead to future crashes). Also, high-crash locations experiencing unusually high numbers of user complaints may warrant more immediate attention.

Manual Location Files

These files are used to store by location the paper copies of crash reports and other traffic and roadway data. Such files are valuable in an archival sense even if computerized systems are used to facilitate data retrieval and analysis. Manual files provide important access to individual crash diagrams.

Central files should normally be kept current for at least three years. Any given crash analysis will need data for a multiple of 12 continuous months to avoid seasonal biases. The best record-retention policy from an analytical point of view is to maintain active files for the three full calendar years immediately preceding the current year.

Spot Maps

Spot maps display crash frequencies by location in the roadway network. They provide a quick visual overview of crash concentrations and typically have been used in the past to supplement manual location filing systems for small- to medium-sized networks. However, recent developments in Geographic Information Systems (GIS) are increasing the feasibility of also using spot maps with larger, computerized filing systems.

Computerized Record Systems

These systems operate by coding selected data from hard-copy reports into electronic data bases. Most computerized record systems contain several data bases to separately file crash reports, traffic volume data, traffic control device inventories and other relevant data. These data bases should be set up so that they can be linked, by location and time period, for the computation of crash rates and for analyzing correlations between crash history and roadway features of interest.

The Michigan State Police developed the Michigan Accident Location Index (MALI) system in the early 1980s as a computerized process for storing and analyzing statewide crash information. Government agencies and law enforcement personnel may use MALI to identify crash patterns and locate problem areas.

SEMCOG's Accident Analysis System (SAAS) allows SEMCOG staff to provide MALI data to its local communities in formats easy for them to use. Two basic data types are provided upon request. One type is a log of selected UD-10 crash variables for specific locations of interest. The other type consists of the most recent year's MALI data for roadways within a community's boundaries, in either paper or machine-readable form.

CHAPTER 3 - IDENTIFICATION OF HIGH-CRASH LOCATIONS

As indicated at the beginning of Chapter 2, a wide variety of sources should be considered in selecting candidate locations to be evaluated. The Spot Map and Crash Frequency Methods are often used to preliminarily identify candidate or suspect locations using crash data. Suspect locations should be further evaluated using the Crash Rate, Frequency-Rate, Crash Severity and/or Crash Probability Index (CPI) Methods.

Time and Length Considerations

For statistical reliability, high-crash locations should be identified whenever possible on the basis of a three-year rather than a one-year crash history. This is especially important for low-volume locations having relatively few crashes in most years.

In crash analyses, spot locations should be defined to include the area of influence of the feature in question. Driver behavior can be influenced as far as 500 feet from a curve and 250 feet from an intersection (or further with severe congestion). Consideration should also be given to typical crash location reporting precision and accuracy.

Crash Frequency Method

This method ranks suspect locations by crash frequency and then identifies high-crash locations as those having frequencies exceeding a critical frequency. The Crash Frequency Method has the disadvantage that it tends to rank a high-volume location as a high-crash location, even if the location has a relatively low number of crashes for its traffic volume.

Crash Rate Method

This method compares the number of crashes to the volume of traffic, with the latter measured either as the number of vehicles crossing a spot in a given time period or as the number of vehicle-miles of travel along a segment in that period. The Crash Rate Method is less likely to unfairly condemn high-volume locations; however, it does tend to unfairly condemn low-volume locations having relatively few crashes.

Crash Severity Methods

Accounting for crash severity (or injury level) in identifying and treating high-crash locations should result in higher system-wide loss reductions due to the more serious, as well as more frequently experienced, hazards being addressed. Two specific crash severity methods, the Equivalent Property-Damage-Only (EPDO) Method and Relative Severity Index (RSI) Method, are presented in Chapter 3.

Crash severity methods require crash counts by injury severity level. Due to the relatively small numbers of crashes at the more severe levels, however, longer analysis periods are typically needed to produce reliable counts for these methods. From three to as many as seven years of crash data may be needed, depending on traffic volumes and overall crash frequencies.

CPI Method

This method combines the advantages of the Crash Frequency and Crash Rate Methods with a simplified severity method. When the location's crash history is significantly worse than average for one of these measures, it is assigned penalty points. These points are then summed across measures to determine an overall CPI. High-crash locations are selected from the top of a list of locations sorted in descending order by non-zero CPI.

Tables of critical values for use in statistical significance testing are included in this manual. These tables can be used with the CPI, Crash Frequency and Crash Rate Methods.

Example Using Alternative Methods

Data for a hypothetical urban intersection are used to illustrate all of the above methods for identifying high-crash locations, with the exception of the Spot Map Method.

Identifying Locations with Potential Safety Problems

The methods just discussed are not suitable for identifying locations with potential safety problems. Such locations appear to be of concern but have not yet experienced sufficiently frequent and/or severe crashes to qualify as high-crash locations. Agencies may wish to identify and possibly treat these locations before serious losses occur.

CHAPTER 4 - DETERMINATION OF COUNTERMEASURES, CRASH-REDUCTION FACTORS AND COSTS

A methodology is presented and illustrated for identifying a location's crash patterns and possible causes and countermeasures related to those patterns. Specific countermeasures are listed, along with representative values for effectiveness and cost.

Crash Pattern Identification

When crashes of a particular type constitute an unexpectedly large proportion of a location's reported crashes, a significant crash pattern is said to exist. An eight-step, worksheet-assisted method for identifying and prioritizing crash patterns is described in this chapter.

Studies by SEMCOG and others have linked several commonly recurring crash patterns with their typical causes. This manual presents these linkages in a form easily applied by others in evaluating crash patterns occurring at specific locations of concern.

Determination of Possible Causes

Possible causes may be determined for just one, a few or all significant crash patterns found for a location. Focusing first on the more highly over-represented and severe crash patterns (in terms of injury levels) will speed up the process of isolating those causes responsible for the greatest crash losses occurring at a high-crash location.

A seven-step method is described for identifying and prioritizing a location's possible crash causes. At the core of this method is a figure listing 21 possible causes of multiple-vehicle crash patterns. By following the prescribed steps and using tools no more sophisticated than a highlighter, the analyst is able to create a list of higher-priority crash causes. Before proceeding to countermeasure determination, this list is purged of those countermeasures which are inconsistent with basic location features.

Determination of Possible Countermeasures

Possible countermeasures are determined for a specific location, crash pattern and cause by consulting the appropriate table in Chapter 4 and extracting those countermeasures consistent with existing conditions, policies and agency capabilities. Users of this manual may also wish to consider crash causes and/or countermeasures unique to local conditions which they have successfully identified in past traffic safety analyses.

<u>The recommended methodology for identifying crash causes and countermeasures should generally be limited in its application to the preliminary planning and budgeting of a safety improvement program.</u> This is especially important for the more costly countermeasures and those which may have unexpected or undesirable side-effects at particular locations. Additional studies will often be necessary to properly justify and design the countermeasures preliminarily selected here; for example, proposed traffic control devices should be evaluated against applicable warrants in the *Michigan Manual of Uniform Traffic Control Devices* (Michigan, 1994).

Data for B/C Analyses

To compute B/C ratios for crash countermeasures, data are needed on countermeasure crash-reduction potential, costs, service life and salvage value. Such data are given in Chapter 4 for many common traffic engineering actions. A method for computing the anticipated effectiveness of countermeasure combinations is also presented.

Appendix D contains lists of other common countermeasures for which SEMCOG does not currently have cost and/or crash reduction data. SEMCOG acknowledges that the local agencies often have better first-hand knowledge of such data. As the revision of this manual continues, the contribution of any such data would be greatly appreciated.

Example of Pattern/Cause/Countermeasure Identification

The earlier intersection example is continued in order to illustrate the methodology for identifying significant crash patterns and possible causes, countermeasures and countermeasure combinations. This example shows how three patterns are identified and ranked; 15 possible causes of these patterns are reduced to six feasible higher-priority possible causes; 24 possible countermeasures for these higher-priority causes are reduced to 11 feasible countermeasures; and eight of these feasible higher-priority countermeasures are combined into two logical countermeasure "packages."

CHAPTER 5 - BENEFIT/COST ANALYSIS

The B/C analysis compares a countermeasure's expected benefit (in terms of reduced crashes) to its expected cost (for selection, design, implementation, operation and maintenance). A recommended worksheet-assisted methodology for B/C analysis is presented and illustrated in this chapter.

Highway Crash Costs

The B/C analysis of proposed crash countermeasures should use comprehensive unit crash costs based on the Willingness-to-Pay Method. Such costs incorporate quality-of-life considerations as well as the direct and indirect costs of resources lost in crashes.

A Nine-Step B/C Analysis Methodology

The first seven steps for a given countermeasure determine the annual average safety benefit, implementation cost, net annual operating and maintenance costs, service life, salvage value, interest rate and other economic factors. The last two steps compute the B/C ratio by two alternative methods: the Equivalent Uniform Annual Benefit and Cost Method and the Present Worth of Benefits and Costs Method (both methods yield the same ratio).

Example of B/C Analysis

The intersection example used in Chapters 3 and 4 is continued here as a way of illustrating completion of the recommended B/C analysis worksheet.

Project Selection

Three relatively simple methods of using benefit and cost data to prioritize safety improvement projects are briefly discussed. These methods are the Net Benefit Method, B/C Ratio Method and Incremental B/C Method.

APPENDICES

Appendices to this manual include Formulas for Computing Critical Values (A), Synthesis of Crash-Reduction Data (B), Synthesis of Countermeasure Cost and Service Life Data (C) Additional Countermeasure Default Values (D), Compound Interest Tables (E), Reproducible Figures and Tables (F), References (G) and an Acronym List (H).

FUTURE ENHANCEMENTS

Although comprehensive, this first edition of the *SEMCOG Traffic Safety Manual* contains several parts open to expansion and/or refinement. Potential enhancements include, but are not necessarily limited to:

1. providing missing cost data and crash-reduction factors, where feasible, for currently listed countermeasures;

2. creating critical value tables for other spot location types and segments;

3. periodically updating critical value tables using the latest available crash and traffic volume data for Southeast Michigan;

4. computing critical crash percentages larger than simple sample averages, so as to allow testing on the basis of statistical significance;

5. providing critical crash percentages for the eight crash patterns categorized by object struck and by driving situation (listed in Chapter 4);

6. listing possible causes of crash patterns categorized by object struck and by driving situation;

7. listing possible countermeasures for crash patterns categorized by object struck and by driving situation;

8. providing cost data and crash-reduction factors, where feasible, for newly identified crash countermeasures; and

9. making other additions and changes prompted by user comments.

SEMCOG would appreciate receiving not only comments on the manual and its contents, but also additional information on the crash causes and countermeasures which are detailed in the manual. Please contact SEMCOG staff to confirm that a listed countermeasure is one for which you have additional cost or effectiveness data. Information on causes and countermeasures not listed in the manual are also welcome. Comments, questions and data should be directed to SEMCOG's Transportation Department, either by mail at 660 Plaza Drive, Suite 1900, Detroit, Michigan, 48226, or by telephone at (313) 961-4266.

SEMCOG has created a menu-driven personal computer software package based on the methods outlined in this manual. A prototype version of this software package, called the Comprehensive Analysis Safety Tool (CAST), was first demonstrated in September 1995. Additional refinements to the prototype are ongoing. Further information on CAST can be obtained by calling or writing SEMCOG at the location indicated above.

CONCLUSIONS

The tools presented in the *SEMCOG Traffic Safety Manual* will:

- assist in more thoroughly and efficiently identifying traffic safety problems, possible solutions and the relative benefits and costs of those solutions;
- facilitate a quick sketch-planning approach to developing preliminary plans and budgets for traffic safety improvements;
- enable engineers, non-engineers and others not specially trained in traffic engineering to conduct comprehensive preliminary safety analyses; and
- provide a good foundation for the further development and maintenance of user-friendly software for the personal computer.

APPENDIX A

FORMULAS FOR COMPUTING CRITICAL VALUES

FORMULAS FOR COMPUTING CRITICAL VALUES

This appendix supports analysis methods described in *Chapter 3 - Identification of High-Crash Locations*. Presented below are formulas for computing critical crash frequency, critical crash rate and critical casualty ratio.

Critical Crash Frequency

Critical crash frequency is denoted as F_{cr} and is computed with the equation:

Eq.(A-1)

$$F_{cr} = F_{av} + s_F$$

where F_{av} = average crash frequency for all locations of a given type,

s_F = standard deviation of crash frequency for all locations of this type.

Critical Crash Rate

Critical crash rate is denoted as R_{cr} and is computed with the equation:

Eq.(A-2)

$$R_{cr} = R_{av} + K\sqrt{\frac{R_{av}}{M} + \frac{1}{2M}}$$

where R_{av} = average crash rate for locations having similar characteristics;

M = (365 x YRS x ADT) / 1,000,000 (millions of vehicles) for a spot or (365 x YRS x ADT x L) / 1,000,000 (millions of vehicle-miles) for a segment, where YRS, ADT and L are as defined for Eq.(3-1); and

K = factor based on desired confidence level for the test (Table A-1).

A confidence level of 0.95 (or 95 percent) is the most commonly used in statistical testing. A smaller value (e.g., 0.90) will result in more locations being identified as high-crash, but it will also increase the probability that the crash frequencies for such locations are high by chance. The analyst may want to try alternative confidence levels and K values until a suitable number of high-crash locations are identified for further study.The confidence level for the test is the probability that a crash rate is sufficiently large that it can not be reasonably attributed to random occurrences.

A 95% confidence interval was used to calculate the regional critical crash rates found in Chapter 3.

Table A-1.
K Values Commonly Used in Computing Critical Values

Significance Level, alpha	**0.10**	**0.05**	**0.01**
Confidence Level, 1 - alpha	**0.90**	**0.95**	**0.99**
K Value	1.282	1.645	2.326

Critical Casualty Ratio

Recall from the discussion of the CPI Method in Chapter 3 that the casualty ratio is the proportion of all crashes that involve at least one fatality and/or non-fatal injury. The critical casualty ratio is denoted as CR_{cr} and is computed with the equation:

Eq.(A-3)

$$CR_{cr} = CR_{av} + s_{CR}$$

where CR_{av} = average casualty ratio for all locations of a given type,

s_{CR} = standard deviation of the casualty ratio for all locations of this type.

APPENDIX B

SYNTHESIS OF CRASH-REDUCTION DATA

Table B-1.
Synthesis of Crash-Reduction Factors

Countermeasure Description	Code	Kentucky Transportation Research Program[1]	Kentucky Transportation Center[2]	Texas DOT[3]	Michigan DOT[4]	CRF (%)
Install Raised Median	CH-1		25	25		25
Install Flush Median	CH-2		15			15
Add Right-Turn Acceleration Lane	CH-3		25	10		25
Widen Approaches to Handle Turn Lanes	CH-4		25			25
Favorably Offset Opposing LT Lanes	CH-5		30			30
Increase Curb/Edge-of-Pavement Radius	CH-6		15		15	15
Close/Relocate Driveways Near Intersection	DY-1					
Upgrade Markings (Halve Maint. Cycle)	MK-1	15				15
Add Stop Bars/Crosswalks	MK-2	15	25	10		15
Place Advance Pavement Messages	MK-3	15		20		15
Add Ctr + Lanelines to Unstriped Street	MK-4	35	35	65		35
Add Centerline to Unstriped Pavement	MK-5	30	35	65		35
Add Ctr + Edgelines to Unstriped Road	MK-6	40	25	45		40
Mark /Lengthen Exclusive Turn Lanes	MK-7	30	15	40		30
Install 2-Way Left-Turn Lane	MK-8	30	30	40	35	35
Supplement Centerline with RPMs	MK-9	5	10	25		15
Install No Passing Zone	MK-10	40	40			40
Reduce Obstructions in Median	MS-1		30	55	50	45
Reduce Obstructions on Insides of Curves	MS-2		30	55	50	45
Remove/Relocate Obstacles Close to Road	MS-3		30	55	50	45
Remove Obstructions from Sight Triangle	MS-4		30	55	50	45
Remove Sign Sight Obstructions	MS-5		30	55	50	45
Reduce RTOR Sight Obstructions	MS-6		30	55	50	45
Remove Signal Sight Obstructions	MS-7		30	55	50	45
Add/Improve Intersection Lighting	MS-8		30	75		30
Increase Traffic/Speed Enforcement	MS-9		20			20
Reroute Pedestrians to Safer Crossings	PE-1					

Table B-1.
Synthesis of Crash-Reduction Factors

Countermeasure Description	Code	Kentucky Transportation Research Program[1]	Kentucky Transportation Center[2]	Texas DOT[3]	Michigan DOT[4]	CRF (%)
Groove Pavement	PV-1		25			25
Improve Drainage	PV-2		20	30		25
Resurface Roadway	PV-3		25	42		35
Repair/Replace Roadway Surface	PV-4		25	15		20
Repair/Replace Shoulder Surface	PV-5		25			25
Upgrade Roadway Shoulders	RD-1		20	12	15	15
Widen Lanes	RD-2		25	30	25	25
Move Intersection Away from Curves/Crests	RD-3		50	50		50
Realign Opposing Intersection Legs	RD-4		40			40
Provide Proper Superelevation (Banking)	RD-5		40	65	20	40
Flatten Roadway Curves	RD-6		40	50	25	45
Lower Roadbed on Hill Crests	RD-7		50	50		50
Signalize Intersection	SG-1	20	25	20		20
Retime Traffic Signal	SG-2	10	10			10
Increase Yellow Change Interval	SG-3	10	15			15
Add All-Red Clearance Interval	SG-4	10	15			15
Revise Signal Phasing /Sequence	SG-5	25	25			25
Provide Right-Turn Overlap (Green Arrow)	SG-6		25			25
Install Dual LT Lanes, Signs & Signals	SG-7					
Add Pretimed, Protected LT Signals	SG-8	25	25	25		25
Provide Lead/Lag or Split Phasing	SG-9	25	25	25		25
Install WALK-DON'T WALK Signals	SG-10	15	25	15		20
Signalize Pedestrian Crossing	SG-11		25	15		20
Install Signal Actuation	SG-12	20				20
Provide Signal Progression (3 I/Ss)	SG-13	10	15	10		10
Upgrade Signalization	SG-14	20	20	22		20
Upgrade Signal Controller	SG-15		20	22		20

Table B-1.
Synthesis of Crash-Reduction Factors

Countermeasure Description	Code	Kentucky Transportation Research Program[1]	Kentucky Transportation Center[2]	Texas DOT[3]	Michigan DOT[4]	CRF (%)
Install 12-inch Signal Lenses	SG-16	10	10			10
Add/Relocate Signal Head	SG-17					
Add Signal Back Plates	SG-18		20			20
Install/Replace Signal Visors	SG-19					
Remove Unwarranted Signalization	SG-20	60	50			55
Install Advance Flasher-Signs	SG-21	25	25	50		25
Install STOP/YIELD AHEAD Signs /Urban	SN-1	30	30	20		30
Install STOP AHEAD Signs / Rural	SN-2	40	30	20		35
Post SIGNAL AHEAD Warning Signs/Urban	SN-3	30	30	20		30
Post SIGNAL AHEAD Warning Signs/Rural	SN-4	40	30	20		35
Install I/S Warnings Signs / Urban	SN-5	30	30	20		30
Install I/S Warning Signs / Rural	SN-6	40	30	20		35
Post Ped Xing/Advance Xing Signs/Urban	SN-7	15	30	20		20
Post Ped Xing/Advance Xing Signs/Rural	SN-8	20	30	20		25
Post SLIPPERY WHEN WET Signs/Urban	SN-9	15	20	20		15
Post SLIPPERY WHEN WET Signs/Rural	SN-10	20	20	20		20
Add 2-Way STOP/YIELD at Urban I/S	SN-11	40	35	20		35
Add 2-Way STOP at Rural I/S	SN-12	60	35	20		40
Change from 2-Way to 4-Way STOP	SN-13	50	55	20		50
Eliminate Parking Near Intersection	SN-14	30	35	32		30
Eliminate Parking	SN-15	30	35			35
Install Guide Signs	SN-16	15	15	20		15
Install Lane-Use Control (Metal) Signs	SN-17					
Install Larger Signs	SN-18					
Add NO PASSING ZONE Pennant Signs	SN-19	20				20
Post/Reduce Speed Limit	SN-20	25	20			25
Post Curve Warnings/Advisory Speeds	SN-21	30	30	20		30

Table B-1.
Synthesis of Crash-Reduction Factors

Countermeasure Description	Code	Kentucky Transportation Research Program[1]	Kentucky Transportation Center[2]	Texas DOT[3]	Michigan DOT[4]	CRF (%)
Install Internally Illuminated Signs	SN-22					
Sign One-Way Street Operation	SN-23	35				35
Prohibit RTOR	SN-24		45			45
Reroute Left-Turn Traffic	SN-25		45			45
Prohibit Turns	SN-26	40	45	40		40

[1] Creasey and Agent (1985)
[2] Agent, Stamatiadis and Jones (1996)
[3] Texas Department of Transportation (1995)
[4] Michigan Department of Transportation

APPENDIX C

SYNTHESIS OF COUNTERMEASURE SERVICE LIFE AND COST DATA

Table C-1.
Synthesis of Service Life and Cost Data: SIGNS (SN)

Countermeasure Component	Service Life (yrs)	Unit Cost ($/sign)		Comments
		Implementation	O&M/yr	
Small Sign (e.g., 12 in x 18 in - NO PARKING)	6-7	73-100		Service life of sign panel. Six-year service life from FHWA (1981a).
Medium Sign (e.g., 24 in x 30 in - Speed Limit)	6-15	200-250	6	Includes engineering, materials, labor and equipment. Maintenance includes new signs and upgrades. Six-year service life from FHWA (1981a).
Large Sign (e.g., 36 in x 36 in - Warning)	6-7	250 (or +83)		Cost in parentheses is to "increase size of sign." Six-year service life from FHWA (1981a).
Upgraded Sign	7	250 (or +83)		Cost in parentheses is to "upgrade sign" (assume panel only).
Internally Illuminated Sign	15			

Table C-2.
Synthesis of Service Life and Cost Data: SIGNALS (SG)

Countermeasure	Service Life (yrs)	Unit Cost ($/intersection, except as noted)		Comments
		Implementation	O&M/yr	
1. Signalize Intersection	10-20	12,000-80,000	2,600	$40,000-$50,000 implementation cost is typical, including engineering and project administration. FHWA (1980) gives 15-yr service life and $1,450/yr for O&M (assume 4%/yr inflation).
2. Upgrade Signalization	10-20	10,000-80,000		Includes engineering and project administration. Assume part of old signal system is salvaged.
3. Install Signal Actuation	10-20	5,000-30,000	1,800	Detector service life is limiting. $20,000-$30,000 implementation cost is typical, including engineering and project administration. FHWA (1980) gives O&M differential, pretimed v. fully actuated signals, of $1,000/yr (assume 4%/yr inflation).
4. Signalize Pedestrian Crossing		5,000-20,000 /crossing		Cost range seems too low relative to SG-1, *Signalize Intersection*.
5. Install Advance Flasher-Signs	10-20	5,000-15,000 /sign		Includes engineering and project administration. Cost is sensitive to power and communication needs (e.g., with respect to signal controller).
6. Install WALK-DONT WALK Signals		1,000-20,000 /signal		Survey asked about installing "pedestrian signal" (singular). Typical intersection has eight WALK-DONT WALK signals.
7. Install 12-inch Signal Lenses		12,000-80,000		Same cost range as SG-1 appears too high.
8. Add Pretimed/Protected Left-Turn Signals				Not surveyed. Say cost/street = two-heads (@ SG-13) + phasing (SG-11) + miscellaneous signs and markings (latter estimated at $900).

Table C-2.
Synthesis of Service Life and Cost Data: SIGNALS (SG) (cont'd)

Countermeasure	Service Life (yrs)	Unit Cost ($/intersection, except as noted)		Comments
		Implementation	O&M/yr	
9. Remove Unwarranted Signalization		12,000-80,000	-2,500	Survey asked about removal and relocation. Removal-only, estimated by inflating FHWA (1980) value of $2,000 by 4%/yr, is $3,500. Similarly, O&M is reduced by $2,500/yr.
10. Upgrade Signal Controller	15	1,000		Survey asked about a "multi-dial" controller (i.e., an electromechanical controller, now obsolete). Assume higher cost for solid-state model.
11. Revise Signal Phasing/Sequence	1-10	500-3,000		Includes data collection and analysis.
12. Provide Signal Progression		200-25,000		Assume three intersections, $1,000 each for minimum hardware + $1,200 to select timing offsets, for average cost/intersection of $1,400. Weighted average service life of hardware and timings is 11 yrs.
13. Add/Relocate Signal Head		1,000 /head		Assume hardware cost of a new head is equivalent to labor and equipment cost of deactivating, dismounting and servicing (for reuse) an existing head.
14. Retime Traffic Signal	1	700-1,200		Includes data collection and analysis.
15. Add Signal Back Plates		200 /plate		Survey asked about "back plate" (singular). Assume four/intersection, two on eastbound approach and two on westbound approach.
16. Install/Replace Signal Visors		90 /visor		Survey asked about "visor" (singular). Assume six/intersection, for six lenses of two standard signal faces on critical approach.

Table C-3.
Synthesis of Service Life and Cost Data: MARKINGS (MK)

Countermeasure	Service Life (yrs)	Unit Cost ($/lineal foot, except as noted)		Comments
		Implementation	O&M/yr	
1. Install No Passing Zones	1-15	0.60-2.00		Smaller cost assumes 3,500 ft of striping/road-mile (Table 4-13) @ $0.04 + eight signs @ $225 + $160/road-mile for layout. Weighted average service life of paint and signs is 6 yrs.
2. Supplement Centerline with Reflective Pavement Markers	3-10	18-35 /marker	1.00-3.33 /marker	Longer service life is for hardened steel casing; lens typically replaced every 3-4 yrs. Lower marker cost is for Michigan (FHWA, 1994); $1/yr O&M for two, $5 lenses in 10 yrs.
3. Add Stop Bars/Crosswalks	1-5	4.00		Assume 300 ft of 8-in tape @ $1.60 (walks) + 100 ft of 12-in tape @ $2.40 (stop bars) + $120/approach for layout and installation = $1,200/intersection.
4. Mark Exclusive Turn Lanes at Intersection	3-5	4.00		Survey item was "Install Turning Guidelines." Assume 100 ft of 6-in tape @ $1.20 + pavement message (MK-12) + $80 for layout and installation = $400/lane.
5. Stripe Parking or Bike Lanes	1	0.03		Assume cost of 4-in painted line with lateral "ticks" to show stalls = cost of 6-in painted bike lane line = $0.06/ft.
6. Upgrade Markings (Halve Maintenance Cycle)	0.5-1	0.04-2.00		Higher cost includes engineering and marking removal; survey did not say "Halve Maint. Cycle." Extra application repeated annually.
7. Install Two-Way Left-Turn Lane	0.5-2	0.04-0.09	0.03	Assume 1:3 stripe-to-gap ratio for broken line.
8. Add Centerline + Lanelines to Unstriped Street	0.5-2	0.04-0.09	0.03	Service life varies inversely with traffic volume. Assume double-yellow (continuous) centerline.

Table C-3.
Synthesis of Service Life and Cost Data: MARKINGS (MK) (cont'd)

Countermeasure	Service Life (yrs)	Unit Cost ($/lineal foot, except as noted)		Comments
		Implementation	O&M/yr	
9. Install Continuous Delineators	5-10	15 /delineator		Cost includes post.
10. Add Centerline + Edgelines to Unstriped Road	0.5-2	0.04-0.09	0.03	Service life varies inversely with traffic volume. Assume 1:3 stripe-to-gap ratio for centerline.
11. Add Edgelines to Centerlined Road	0.5-2	0.04-0.09	0.03	Service life varies inversely with traffic volume.
12. Place Advance Pavement Messages	5-15	200 /message		Service life and cost for tape, but message could be (and often is) painted.
13. Install Delineators or Chevrons on Curves	5-10	15 /delineator		Assume medium length curve requiring 20 delineators @ $15 + engineering @ $100 = $400, or the approximate cost of three posts and six chevrons (the minimum for a curve).
14. Add Lanelines to Centerlined Street	0.5-2	0.04-0.09	0.03	Service life varies inversely with traffic volume. Assume 1:3 stripe-to-gap ratio for lanelines.
15. Add Centerline to Unstriped Pavement	0.5-2	0.04-0.09	0.03	Service life varies inversely with traffic volume. Assume 1:3 stripe-to-gap ratio for centerline.
16. Convert Angle to Parallel Parking				Service life and cost not estimated at this time.

APPENDIX D

ADDITIONAL COUNTERMEASURE DEFAULT VALUES

Countermeasure Default Values: CHANNELIZATION (CH)

Countermeasure[1]	Service Life (yrs)	Costing Unit[1]	Unit Costs ($)		Units/ Project	Project Costs ($)		Total CRF (%)
			Implementation	O&M /yr		Implementation	O&M/yr	
1-Install Raised Median								25
2-Install Flush Median								15
3-Add RT Lane Channelization								25
4-Widen Approaches to Handle Turn Lanes								25
5-Favorably Offset Opposing LT Lanes								30
6-Increase Curb/Edge-of-Pavement Radius								15

[1] RPM = Reflective Pavement Marker, I/S = Intersection and LF = Lineal Feet.

Countermeasure Default Values: PAVEMENT (PV)

Countermeasure[2]	Service Life (yrs)	Costing Unit[1]	Unit Costs ($)		Units/ Project	Project Costs ($)		Total CRF (%)
			Implementation	O&M /yr		Implementation	O&M/yr	
1-Groove Pavement								25
2-Improve Drainage								25
3-Resurface Roadway								35
4-Repair/Replace Roadway Surface								20
5-Repair/Replace Shoulder Surface								25

[2] RPM = Reflective Pavement Marker, I/S = Intersection and LF = Lineal Feet.

Countermeasure Default Values: ROADWAY (RD)

Countermeasure[3]	Service Life (yrs)	Costing Unit[1]	Unit Costs ($)		Units/ Project	Project Costs ($)		Total CRF (%)
			Implementation	O&M /yr		Implementation	O&M/yr	
1-Upgrade Roadway Shoulders								15
2-Widen Lanes								25
3-Move Intersection Away from Curves/Crests								50
4-Realign Opposing Intersection Legs								40
5-Provide Proper Superelevation (Banking)								40
6-Flatten Roadway Curves								45
7-Lower Roadbed on Hill Crests								50

[3] RPM = Reflective Pavement Marker, I/S = Intersection and LF = Lineal Feet.

Countermeasure Default Values: PEDESTRIAN (PE)

Countermeasure[4]	Service Life (yrs)	Costing Unit[1]	Unit Costs ($)		Units/ Project	Project Costs ($)		Total CRF (%)
			Implementation	O&M /yr		Implementation	O&M/yr	
1-Reroute Pedestrians to Safer Crossings								

Countermeasure Default Values: MISCELLANEOUS (MS)

Countermeasure[5]	Service Life (yrs)	Costing Unit[1]	Unit Costs ($)		Units/ Project	Project Costs ($)		Total CRF (%)
			Implementation	O&M /yr		Implementation	O&M/yr	
1-Reduce Obstructions in Median								45
2-Reduce Obstructions on Insides of Curves								45
3-Remove/Relocate Obstacles Close to Road								45
4-Remove Obstructions from Sight Triangle								45
5-Remove Sign Sight Obstructions								45
6-Reduce RTOR Sight Obstructions								45
7-Remove Signal Sight Obstructions								45
8-Add/Improve Intersection Lighting								30
9-Increase Traffic/Speed Enforcement								20

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[4] RPM = Reflective Pavement Marker, I/S = Intersection and LF = Lineal Feet.

[5] RPM = Reflective Pavement Marker, I/S = Intersection and LF = Lineal Feet.

APPENDIX E

COMPOUND INTEREST TABLES

COMPOUND INTEREST TABLES

YEAR	CAPITAL RECOVERY FACTOR				SINKING FUND FACTOR			
	6%	8%	10%	12%	6%	8%	10%	12%
1	1.0600	1.0800	1.1000	1.1200	1.0000	1.0000	1.0000	1.0000
2	0.5454	0.5608	0.5762	0.5917	0.4854	0.4808	0.4762	0.4717
3	0.3741	0.3880	0.4021	0.4163	0.3141	0.3080	0.3021	0.2963
4	0.2886	0.3019	0.3155	0.3292	0.2286	0.2219	0.2155	0.2092
5	0.2374	0.2505	0.2638	0.2774	0.1774	0.1705	0.1638	0.1574
6	0.2034	0.2163	0.2296	0.2432	0.1434	0.1363	0.1296	0.1232
7	0.1791	0.1921	0.2054	0.2191	0.1191	0.1121	0.1054	0.0991
8	0.1610	0.1740	0.1874	0.2013	0.1010	0.0940	0.0874	0.0813
9	0.1470	0.1601	0.1736	0.1877	0.0870	0.0801	0.0736	0.0677
10	0.1359	0.1490	0.1627	0.1770	0.0759	0.0690	0.0627	0.0570
11	0.1268	0.1401	0.1540	0.1684	0.0668	0.0601	0.0540	0.0484
12	0.1193	0.1327	0.1468	0.1614	0.0593	0.0527	0.0468	0.0414
13	0.1130	0.1265	0.1408	0.1557	0.0530	0.0465	0.0408	0.0357
14	0.1076	0.1213	0.1357	0.1509	0.0476	0.0413	0.0357	0.0309

Notes

1. Source: FHWA (1986a).
2. Factors for other rates of annually compounding interest can be found in other references (e.g., FHWA (1981a)).
3. Factors can also be computed using equations given in various textbooks (e.g., DeGarmo and Canada (1973)).
4. Capital Recovery Factor and Sinking Fund Factor are for an equal payment series.

COMPOUND INTEREST TABLES

YEAR	CAPITAL RECOVERY FACTOR				SINKING FUND FACTOR			
	6%	8%	10%	12%	6%	8%	10%	12%
15	0.1030	0.1168	0.1315	0.1468	0.0430	0.0368	0.0315	0.0268
16	0.0990	0.1130	0.1278	0.1434	0.0390	0.0330	0.0278	0.0234
17	0.0954	0.1096	0.1247	0.1405	0.0354	0.0296	0.0247	0.0205
18	0.0924	0.1067	0.1219	0.1379	0.0324	0.0267	0.0219	0.0179
19	0.0896	0.1041	0.1195	0.1358	0.0296	0.0241	0.0195	0.0158
20	0.0872	0.1019	0.1175	0.1339	0.0272	0.0219	0.0175	0.0139

Notes

1. Source: FHWA (1986a).
2. Factors for other rates of annually compounding interest can be found in other references (e.g., FHWA (1981a)).
3. Factors can also be computed using equations given in various textbooks (e.g., DeGarmo and Canada (1973)).
4. Capital Recovery Factor and Sinking Fund Factor are for an equal payment series.

COMPOUND INTEREST TABLES

YEAR	PRESENT WORTH FACTOR							
	SINGLE PAYMENT SERIES				EQUAL PAYMENT SERIES			
	6%	8%	10%	12%	6%	8%	10%	12%
1	0.9434	0.9259	0.9091	0.8929	0.9434	0.9259	0.9091	0.8929
2	0.8900	0.8573	0.8264	0.7972	1.8334	1.7833	1.7355	1.6901
3	0.8396	0.7938	0.7513	0.7118	2.6730	2.5771	2.4869	2.4018
4	0.7921	0.7350	0.6830	0.6355	3.4651	3.3121	3.1699	3.0373
5	0.7473	0.6806	0.6209	0.5674	4.2124	3.9927	3.7908	3.6048
6	0.7050	0.6302	0.5645	0.5066	4.9173	4.6229	4.3553	4.1114
7	0.6651	0.5835	0.5132	0.4523	5.5824	5.2064	4.8684	4.5638
8	0.6274	0.5403	0.4665	0.4039	6.2098	5.7466	5.3349	4.9676
9	0.5919	0.5002	0.4241	0.3606	6.8017	6.2469	5.7590	5.3282
10	0.5584	0.4632	0.3855	0.3220	7.3601	6.7101	6.1446	5.6502
11	0.5268	0.4289	0.3505	0.2875	7.8869	7.1390	6.4951	5.9377
12	0.4970	0.3971	0.3186	0.2567	8.3838	7.5361	6.8137	6.1944
13	0.4688	0.3677	0.2897	0.2292	8.8527	7.9038	7.1034	6.4235
14	0.4423	0.3405	0.2633	0.2046	9.2950	8.2442	7.3667	6.6282

Notes

1. Source: FHWA (1986a).
2. Factors for other rates of annually compounding interest can be found in other references (e.g., FHWA (1981a)).
3. Factors can also be computed using equations given in various textbooks (e.g., DeGarmo and Canada (1973)).
4. Capital Recovery Factor and Sinking Fund Factor are for an equal payment series.

COMPOUND INTEREST TABLES

YEAR	PRESENT WORTH FACTOR							
	SINGLE PAYMENT SERIES				EQUAL PAYMENT SERIES			
	6%	8%	10%	12%	6%	8%	10%	12%
15	0.4173	0.3152	0.2394	0.1827	9.7122	8.5595	7.6061	6.8109
16	0.3936	0.2919	0.2176	0.1631	10.1059	8.8514	7.8237	6.9740
17	0.3714	0.2703	0.1978	0.1456	10.4773	9.1216	8.0216	7.1196
18	0.3503	0.2502	0.1799	0.1300	10.8276	9.3719	8.2014	7.2497
19	0.3305	0.2317	0.1635	0.1161	11.1581	9.6036	8.3649	7.3658
20	0.3118	0.2145	0.1486	0.1037	11.4699	9.8181	8.5136	7.4694

Notes

1. Source: FHWA (1986a).
2. Factors for other rates of annually compounding interest can be found in other references (e.g., FHWA (1981a)).
3. Factors can also be computed using equations given in various textbooks (e.g., DeGarmo and Canada (1973)).

APPENDIX F

REPRODUCIBLE TABLES AND FIGURES

Crash Pattern Identification and Prioritization at ______________________________

Average Daily Traffic (ADT) Range ___________________

Evaluation Criteria		Possible Crash Pattern			
		Head-On & SS/OD	**Head-Left/ Rear-Left**	**Angle**	**Rear-End/ Rear-Right & SS/SD**
Location's Crashes	No. by Type / Total No.	/	/	/	/
	Location's %				
Regional Crash % (table or computation)	4-1. Area Type:______________				
	4-2. Functional Class:_________				
	4-3. No. of Lanes: ___				
	4-4. Sig. ___ Unsig. ___				
	Computed (attach details)				
Significant Pattern?	Enter YES if Location's % Exceeds At Least One of the Above Regional %s				
Pattern Priority[1]	Average Regional % [2]				
	Over-Representation Ratio (ORR) = Location's % / Average Regional %				
	Severity Weighting (SW)				
	Pattern Priority Index (PPI) = 10 / (ORR x SW)				

[1] Complete this block only for significant patterns.
[2] Circle or highlight, and then average, only those regional %s which are less than the location's %. This is necessary to guarantee an ORR greater than 1.0.

Possible Causes for Multiple-Vehicle Crash Patterns at ____________________________

Possible Cause	Crash Pattern					
	Head-On & SS/OD	Rear-Left/ Head-Left	Angle		Rear-End Rear-Right & SS/SD	
			Sig	Unsig	Sig	Unsig
Pattern Priority Index (PPI)						
Excessive Speed	o	o	o	o	o	o
Restricted Sight Distance	o	o	o	o		o
Slippery Surface			o	o	o	o
Narrow Lanes	o				o	o
Inadequate Signal Change Interval		o	o			
Turning Vehicles Slowing or Stopping in Through Lanes					o	o
Unexpected Slowing and Lane Changing					o	o
Poor Visibility of Traffic Signal			o		o	
Unexpected/Unnecessary Stops Due to Signal			o		o	
Unsafe Right-Turns-on-Red			o		o	
Crossing Pedestrians					o	o
Poor Visibility of STOP/YIELD Signs				o		o
Proper Stopping Position Unclear			o	o		
Inadequate Pavement Markings	o					
Inadequate Roadway Shoulders	o					
Inadequate Maintenance	o					
Severe Curves	o					
Inadequate Gaps in Oncoming Traffic		o				
Inadequate Signalization for Left-Turn Volume		o				
Inadequate Gaps for Turning and Accelerating						o
Unexpected Cross Traffic						

Higher-Priority Possible Causes for Crash Patterns at ____________________________

Crash Pattern	Possible Cause	Applicable? (Step 7)		Comments
		Yes	No	
Causes Associated with Highest Priority Pattern (Step 3)				
Causes Associated with Multiple Patterns (Step 4)				

Other Possible Causes for Crash Patterns at ____

Crash Pattern	Possible Cause	Applicable? (Step 7)		Comments
		Yes	No	

Possible Countermeasures for Crash Patterns at ______________________________

Crash Pattern	Possible Cause	Possible Countermeasure (Step 1)		Applicable? (Step 3)		Comments
		Specific Name	Generic Code	Yes	No	

Countermeasure Packaging at ____________________________

Countermeasure		Check Data Available				Comments
Package	Specific Name (& Generic Code)	Service Life	Unit Costs	Units/ Project	CRF	
Set-Asides (Explain to right)						

B/C Analysis Worksheet

Location____

Countermeasure Name(s) & Code(s)____

____

Analyst ____________________________________ Date____________________________

==

1. Annual Average Safety Benefit

   a. *Annual Average Number of Crashes by Severity (pre-treatment)*

      Determined for ___ years: 19 ___ to 19 ___ (min. is 3 yrs)

      Fatal, F ___ + Non-F Injury, A+B+C _____ + PDO _____ = Total ______

   b. *Crash-Reduction Factor (CRF) by Severity (*may set = CRF_T)*

      CRF_F* _____ CRF_{ABC}* _____ CRF_{PDO}* _____ Total Crashes, CRF_T _____

      Source: Tables 4-11 to 4-13 ___ Other (attach) ___

   c. *Average Cost Per Crash by Severity (C_i)*

      Source: Table 5-1 ___ Other (attach) ___ C_F $ ______________

      Weighted Average for Non-F Injury:

      $\mathbf{C_{ABC} = (C_A xA + C_B xB + C_C xC) / (A+B+C) =}$

      ($ ___________ x _____ +

      $ ___________ x _____ +

      $ ___________ x _____) / _____ = C_{ABC} $ ______________

      C_{PDO} $ ______________

   d. *Annual Benefit* =

      $\mathbf{(F \times CRF_F \times C_F) +}$

      $\mathbf{((A+B+C) \times CRF_{ABC} \times C_{ABC}) +}$

      $\mathbf{(PDO \times CRF_{PDO} \times C_{PDO}) =}$

      (_____ x ______ x $ _____________) +

      (_____ x ______ x $ _____________) +

      (_____ x ______ x $ _____________) = $ _____________

B/C Analysis Worksheet (cont'd)

2. Implementation Cost

   Source: Tables 4-11 to 4-13 ___ Other (attach) ___ $ _____________

3. Net Annual Operating and Maintenance (O&M) Costs

   Source: Tables 4-11 to 4-13 ___ Other (attach) ___ $ _____________

4. Service Life

   Source: Tables 4-11 to 4-13 ___ Other (attach) ___ ____ yrs

5. Salvage Value (if not set equal to 0, explain basis below:)

   ____ $ _____________

6. Interest Rate _____ %

7. Other Economic Factors
   See Appendix E tables for service life & interest rate above:

   Capital-Recovery Factor _____________

   Sinking-Fund Factor _____________

   Present-Worth Factor _____________

   Present-Worth Factor for a Series of Payments _____________

8. B/C Ratio Using Equivalent Uniform Annual Benefit and Cost Method

   a. *Annual Cost* =

      (Implementation Cost x Capital-Recovery Factor) +
      (Net Annual Operating and Maintenance Costs) -
      (Salvage Value x Sinking-Fund Factor) =

      ($ _____________ x _____________) +

      ($ _____________) -

      ($ _____________ x _____________) = $ _____________

   b. *B/C* = (Annual Benefit / Annual Cost) =

      ($ _____________ / $ _____________) = ____:___

9. <u>B/C Ratio Using Present Worth of Benefits and Costs Method</u>

a. *Present Benefit* =

(Annual Benefit x Present Worth Factor for a Series of Payments) =

($ _____________ x _____________) = $ _____________

b. *Present Cost* =

(Implementation Cost) +
(Net Annual Operating and Maintenance Costs x Present Worth Factor for a Series of Payments) - (Salvage Value x Present Worth Factor) =

($ _____________) +

($ _____________ x _____________) -

($ _____________ x _____________) = $ _____________

c. *B/C* = (Present Benefit/Present Cost) =

($ _____________ / $ _____________) = ____:__

APPENDIX G

REFERENCES

REFERENCES

Agent, Kenneth R., Nikiforos Stamatiadis, and Samantha Jones (1996). *Development of Accident Reduction Factors*. Kentucky Highway Research Program, Research Report KTC-96-13. Lexington: University of Kentucky, June.

Creasey, T. and K. R. Agent (1985). *Development of Accident Reduction Factors*. Kentucky Highway Research Program, Research Report UKTRP-85-6. Lexington: University of Kentucky, March.

Datta, T. (1990). *Highway Risk Management System -- Procedural Guide*. Detroit, Michigan: Wayne State University, July.

Datta, T. (1995). *Roadway Defect Surveillance -- A Personal Computer-Based System*. ITE Journal, August.

DeGarmo, E. and J. Canada (1973). *Engineering Economy*. New York: Macmillan Publishing.

DeSmet, K. (1994). *Car Accidents Cost Residents in State More than Crime*. Detroit News, December 29.

FHWA (1980). *User Guide for Removal of Not Needed Traffic Signals*. Implementation Package FHWA-IP-80-12. Alexandria, Virginia: JHK & Associates and Wagner-McGee Associates, November.

FHWA (1981a). *Highway Safety Improvement Program (HSIP) User's Manual*. FHWA-TS-81-218. National Highway Institute, Federal Highway Administration.

FHWA (1981b). *Highway Safety Engineering Studies Procedural Guide*. National Highway Institute, Federal Highway Administration.

FHWA (1981c). *Highway Safety Evaluation Procedural Guide*. National Highway Institute, Federal Highway Administration.

FHWA (1986a). *Local Highway Safety Improvement Program (LHSIP) Users' Guide*. National Highway Institute, Federal Highway Administration.

FHWA (1986b). *Local Highway Safety Studies (LHSS) Users' Guide*. National Highway Institute, Federal Highway Administration.

FHWA (1991). *Design Risk Analysis -- Volume II -- Users' Manual*. Report No. FHWA-FLP-91-011, Federal Highway Administration.

FHWA (1994). *Roadway Delineation Practices Handbook*. Publication No. FHWA-SA-93-001, Federal Highway Administration.

ITE (1992). *Traffic Engineering Handbook*, 4th Edition. Institute of Transportation Engineers. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Jacks, M. (1987). *Motor Vehicle Accident Costs*. Accident Facts, June. Provided to National Safety Council by Federal Highway Administration.

McShane, W. R. and R. P. Roess (1990). *Traffic Engineering*. Englewood Cliffs, New Jersey: Prentice Hall, Inc.

McTrans (1995). *1995 Catalog*. Center for Microcomputers in Transportation, University of Florida, telephone number (904) 392-0378.

MDSP (1982). *Michigan Accident Location Index (MALI)*. Lansing: Michigan Department of State Police.

Michigan (1994). *Michigan Manual of Uniform Traffic Control Devices*. Lansing: Department of Transportation and Department of State Police, State of Michigan.

Miller, et al. (1991). *The Costs of Highway Crashes*. Federal Highway Administration and the Urban Land Institute, PB 92-163625, Springfield, Virginia: National Technical Information Service.

MSU (1991). *Seminar on Highway Risk Management System for Engineering and Law Enforcement Supervisors*. Presented by Highway Traffic Safety Programs, Department of Civil & Environmental Engineering, Michigan State University.

SEMCOG (1989). *Southeast Michigan Traffic Crash Profile*, November.

SEMCOG (1990). *Traffic Crashes: The Neglected Epidemic*, April.

Streff, F. and L. Molnar (1994). *Selected Costs of Traffic Crashes and Crimes in Michigan*. Report UMTRI-94-46 Ann Arbor, Michigan: University of Michigan Transportation Research Institute, December

Wohl, M. and B. Martin (1967). *Traffic Systems Analysis for Engineers and Planners*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

APPENDIX H

ACRONYMS

ACRONYMS

ADT	average daily traffic
B/C	benefit/cost
BA	barrier
CH	channelization
CPI	crash probability Index
CR	casualty ratio
CRF	crash-reduction factor
Ctr	centerline
dn	dry-night
DY	driveways
EPDO	equivalent property-damage-only
FHWA	Federal Highway Administration
GIS	Geographic Information Systems
I/S	intersection
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
LF	lineal feet
LT	left turn
MALI	Michigan Accident Location Index
MK	markings
MS	miscellaneous (countermeasure)
MV	million vehicles
MVM	million vehicle-miles
O&M	operating and maintenance
ORR	over-representation ratio
PE	pedestrian
PPI	pattern priority index
PR	physical route
PV	pavement
RD	roadway
RPM	reflective pavement marker
RR	railroad crossing
RSI	relative severity index
RTOR	right-turns-on-red
SAAS	SEMCOG Accident Analysis System
SEMCOG	Southeast Michigan Council of Governments
SG	signals
SN	signs
SS/OD	sideswipe/opposite-direction
SS/SD	sideswipe/same-direction
SW	severity weighting
wn	wet-night
Xing	crossing