Edition 4th

MISSOURI DEPARTMENT OF TRANSPORTATION

Produced by the University of Missouri

S-HAL

S-HAL: Safety Handbook for Locals

Acknowledgments

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1

CHAPTER 1:
INTRODUCTION TO S-HAL

A system for improving safety for all local communities.

The Safety Handbook for Locals (S-HAL) is intended to be a comprehensive traffic safety resource for all local communities in Missouri, be it cities or counties. The S-HAL mirrors the national Highway Safety Manual (HSM) (AASHTO, 2010) in using a systematic and data-driven approach to improving traffic safety. The HSM is expected to significantly influence local policy and engineering practice, in the same way that the Highway Capacity Manual transformed traffic impact analysis for planning and site development. It is important that the S-HAL is consistent with the principles and techniques promoted in the HSM, which was developed using a wealth of national highway safety knowledge and experience; the S-HAL takes advantage of the same wellspring of knowledge. The HSM is divided into four major parts. Part A discusses fundamentals of traffic safety, including human factors. Part B presents the safety management process, namely, network screening, diagnosis, countermeasure design, economic appraisal, project prioritization, and safety effectiveness evaluation. Part C describes predictive methods for rural highways, and urban and suburban arterials. Part D lists crash modification factors for a wide range of transportation facilities and treatments. The S-HAL covers the same topics as the HSM but not in as much detail. Also, the S-HAL focuses on facilities that are of more interest to local communities; thus freeway and expressway facilities are not covered in the S-HAL. Even though the types of topics covered in the HSM and the S-HAL are similar, the S-HAL is organized into seven chapters instead of four parts. Topics covered in the S-HAL include establishing a traffic records system, screening for problem locations, analyzing conflict and crash patterns, designing safety improvements, conducting road safety audits, and accessing national and regional safety resources. The S-HAL can be considered a gateway to HSM, since it introduces readers to the theory and techniques presented in the HSM.

Local communities are faced with very distinct needs and challenges in planning and maintaining the local transportation network for their citizens. An important goal is to improve the safety of highways and streets. Local communities in Missouri vary significantly in population, population density, land area, land use, road facilities—even

climate. For example, Missouri contains several very large counties by population, including St. Louis, Jackson, St. Charles, Greene, Clay, Jefferson, and Boone Counties (US Census, 2010). The largest, St. Louis County, holds almost one million residents. Missouri also contains several large cities by population, including Kansas City, St. Louis, Springfield, Independence, Columbia, and Lee's Summit; the largest, Kansas City, is approaching half a million residents. But the majority of Missouri's 114 counties and their corresponding cities are rural, containing much smaller populations. Local agency staffing also varies considerably. A few large cities maintain dedicated staff for transportation engineering or highway safety, but the vast majority employ city staff members that serve multiple roles related to public works. The S-HAL manual is intended to be a resource for cities of all shapes and sizes. Whether your community is large and urban or small and rural, the S-HAL can be a tool for achieving your local safety goals.

The Missouri Department of Transportation (MoDOT) works with local agencies and law enforcement to improve the safety of local streets and highways. MoDOT can offer valuable assistance and expertise toward addressing safety issues within a community's transportation network. For example, the Technology Transfer Assistance Program (TTAP) of the U.S. Department of Transportation (US DOT), as administered by MoDOT, offers advice on design and construction. Local agencies may request assistance by contacting the District Liaison Engineer at the nearest MoDOT district office. The MoDOT districts and their contact information are shown in Figure 1.1. The district office's contact and other information are also available on the MoDOT website at http://www.modot.org.

MoDOT Districts

District	Phone Number
Northwest	(816) 387-2350
Northeast	(573) 248-2490
Kansas City	(816) 622-6500
Central	(573) 751-3322
St. Louis	(314) 275-1500
Southwest	(417) 895-7600
Southeast	(573) 472-5333
Central Office	(573) 751-2840

★ District Offices
● Regional Offices
● Central Office

Missouri Department of Transportation
1-888-ASK-MODOT (275-6636)
WWW.MODOT.ORG
6/15/2011

Figure 1.1 MoDOT districts and contact information.

Changes from Previous Editions

The present 4th edition of the S-HAL contains both stylistic and content changes from the previous edition. In terms of style, a main goal was to make the manual more reader-friendly for local communities. A more contemporary style sheet was used in the present edition, accompanied by improvements in the appearance of figures, tables, headings, and labels. When numerical examples are presented, numerical analysis is employed to help the reader follow the units of each variable, providing for a better understanding of the computations. When advanced techniques are presented, the required effort is presented graphically; in this way, the reader can quickly ignore techniques that are beyond their resources.

🔔 Content Changes

Systematic vs. Blackspots

Updated Countermeasures

Economic Analysis

Technology

Modern Safety Tools

Since the publication of the 3rd edition in 1999, significant substantive advances have been achieved in the area of highway safety. These advances are reflected in the HSM and in the contents of this edition. One main advance that has taken place is a change in focus from blackspot identification to system-wide analysis. In other words, the HSM approach to safety has moved beyond the simplistic pursuit of high-crash locations—i.e., it has become proactive, rather than reactive. Traffic crashes are rare, because many circumstances must occur simultaneously to cause a crash; the possibility that the same set of circumstances will recur exactly carries only a tiny probability. This is not to say, however, that it is not important to examine the contributing circumstances of a crash. These are typically divided into three categories: human factors, vehicle factors, and roadway factors (including environmental factors). As such, the title of this manual was changed from HAL (Identification, Analysis, and Correction of High-Crash Locations) to S-HAL (Safety Handbook for Locals).

The current chapter on countermeasures has been improved significantly through incorporating the HSM approach to countermeasure effectiveness analysis. Utilizing the HSM approach, problems such as regression-to-the-mean and data randomness are increasingly being reduced. Also noteworthy is the abundance of countermeasure evaluations that have been performed over the past 20 years. The local community now possesses the experiences of other communities, translated into user-friendly quantitative measures (the primary measure being the Crash Modification Factor [CMF]). The economic analysis procedure for countermeasures has been completely re-written and expanded following the HSM. For example, three different methods—net present value, benefit/cost ratio, and cost effectiveness—are now presented.

Though this manual is aimed toward individuals who are involved in public works and transportation engineering, the current trend in safety is a movement toward a partnership-based approach, in contrast to the primarily engineering-based approach to safety in the past. This new edition encourages the formation of partnerships and coalitions for improving safety. One indispensable partner is local traffic enforcement. Local police collect vital crash data and enforce traffic laws; in some communities, it is

local police, not engineers, who are in charge of traffic safety. Another important "partner" is education. Education can refer to formal ways of improving driver education, especially among higher risk younger drivers, but can also refer to general public outreach via the media and/or news releases. For example, the success of new engineering techniques such as roundabouts and the flashing yellow arrow indication relies heavily upon the public's understanding and acceptance of these techniques. Education can also refer to the changing of behaviors and attitudes towards risky behavior like driving while intoxicated, not using seatbelts, or using improper child restraints. Emergency medical services comprise another important class of partners. How quickly the injured are transported and treated following a crash can have a significant impact on severity and the prognosis for recovery. Many additional partners have a vested interest in safety, including public schools, neighborhood associations, and pedestrian coalitions, just to name a few.

One major change in the past decade is that technology has made it easy to access electronic sources and documents. Rather than requesting, then waiting for, paper documents, electronic information can be accessed instantaneously. This 4th edition takes full advantage of the availability of safety-related information, and thereby becomes a gateway for many additional sources, many of which, e.g., publications and websites, are fully documented throughout this edition.

Many new tools have also recently been developed. A brand new chapter has been devoted to the Road Safety Audits or Assessments (RSA) tool. This new tool incorporates modern and varied perspectives that were previously unaccounted for. It reflects the new attitude of utilizing community partnerships to achieve safety-related goals.

How to Use the S-HAL System

This manual can be used as a reference for specific safety-related topics such as project prioritization, crash analysis, and countermeasure selection, to name a few. Chapters are written in a self-contained fashion; thus, the reader is able to review the table of contents and jump straight ahead to sections that will assist them with a specific issue. The greatest value to local communities, however, occurs through the use of this manual for setting up a comprehensive approach to local transportation safety. This allows a community to plan and execute a sustainable approach toward safety improvements. Figure 1.2 presents the core S-HAL system components that will lead to a long term community safety improvement plan. These core components include the development of a traffic records system, performance evaluation of the network, analysis of crashes, and the implementation and evaluation of crash-mitigating countermeasures.

Crash Reporting

Database

Data Description

Chapter 2
Developing a Crash
Record System

Safety Performance Measures

Facilities Analysis

Facilities Prioritization

Chapter 3
Network Screening

Crash
Characteristics

Physical Site
Characteristics

Traffic/Demand
Characteristics

Crash
Patterns

Physical Site
Patterns

Traffic/Demand
Patterns

Chapter 4
Tools for
Crash
Analysis

Countermeasures

Crash Modification Factors

Project Prioritization

Implementation

Evaluation

Chapter 5
Safety
Improvements

Figure 1.2 The Core S-HAL System.

Evolution of Substantive Safety

Several key concepts pertaining to highway safety have evolved over the years. One is the use of crash frequency and severity as the fundamental basis for all safety work, including analysis, prioritization, countermeasure selection, and evaluation. Crash frequency is simply the number of crashes occurring at a facility per year. Crash severity is typically categorized as fatal, incapacitating injury, non-incapacitating injury, possible injury, or property damage only (PDO). At times, all injury categories are combined. One motivation for the use of crash frequency and severity is the desire to make the safety process more objective and data-driven, rather than relying on the more subjective perceptions of stakeholders. This new emphasis does not detract from the worthy goal of making the public feel subjectively safer.

Another key concept is the inherent randomness of crashes. This leads to the problems of bias and regression-to-the-mean (RTM). Randomness implies that the number of crashes naturally rises and falls, meaning that small sample sizes and short-term observations are unreliable. RTM refers to the phenomenon in which a period of relatively high crash frequency will naturally be followed by a period of relatively low crash frequency. Making decisions without accounting for RTM can result in the mis-prioritization of safety projects and the misuse of budgets on less critical facilities.

A third key concept is that of moving away from merely describing historical numbers, and toward the prediction of expected numbers. Historical numbers summarize only what has happened previously in terms of number of crashes, crash rate, crash severity, and crash type. These numbers have a significant random component, and are of limited value in terms of prediction. Newer methods included in the 4th edition mimic the HSM in attempting to calculate the expected number of crashes by minimizing the effect of randomness.

The final key concept is the difference between nominal and substantive safety. Nominal safety refers to compliance with applicable standards, guidelines, and procedures; examples include compliance with the AASHTO Green Book's (2011) guidelines for geometric design, or the MUTCD (2009) manual for implementing traffic control devices such as signing, signals, and striping. However, achieving nominal safety requirements does not necessarily equate to achieving substantive safety, or to improvements in expected or actual crash frequencies and severities. This is due to the fact that guidelines typically address one specific area without taking into account the full, dizzying array of factors that are relevant to the substantive safety of a particular facility. Furthermore, nominal safety is an absolute threshold, while substantive safety is a continuum. Thus, improvements to a facility's safety can always be considered, irrespective of the nominal safety threshold. Figure 1.3 contrasts the nominal safety approach of meeting individual standard thresholds with the substantive safety approach of examining the complexities and trade-offs that exist when attempting to improve the actual safety performance of a particular facility. Thus, a fuller picture is obtained through the approach advocated by the S-HAL, because safety factors are not considered in isolation.
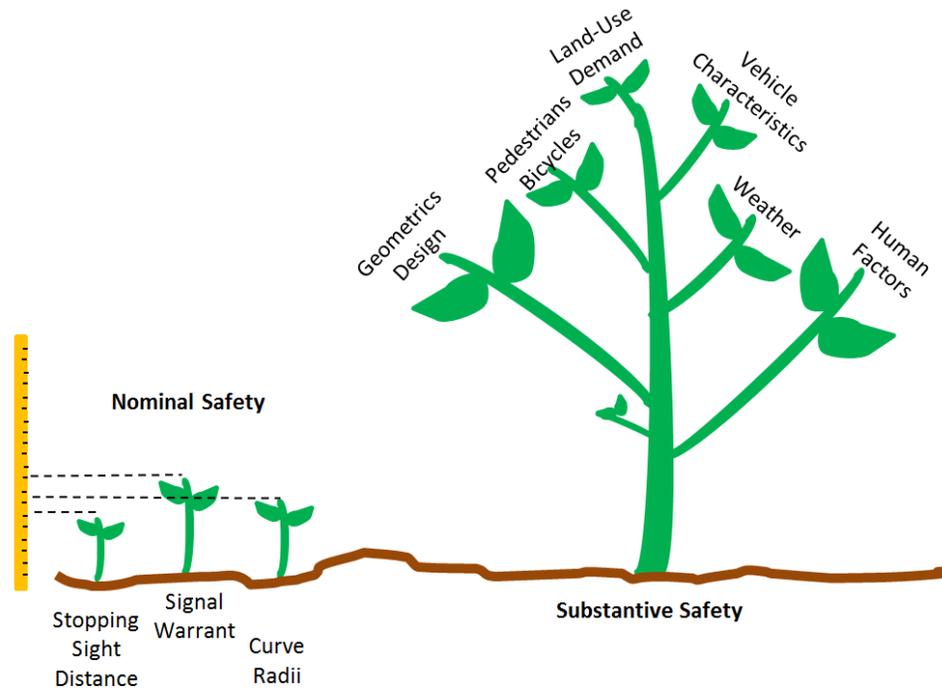
Figure 1.3 Substantive versus nominal safety.

S-HAL Organization

Each chapter of the S-HAL is followed by a bibliographic section to enable the user to explore additional resources. The S-HAL manual is organized into the following chapters:

Chapter 1: Introduction to the HAL System

Chapter 1 describes the purpose of the S-HAL and depicts the benefits that the use of this manual can produce for local communities. The chapter explains the role of S-HAL's sponsor, the Missouri Department of Transportation (MoDOT), and discusses ways in which MoDOT can assist with local highway safety. Stylistic and substantive changes from the second to the current edition are clearly outlined. An overview of the S-HAL system as a comprehensive safety approach is presented. The important concept of substantive safety is discussed.

Chapter 2: Developing a Crash Records System

The use of crash data is essential in the analysis of transportation safety. Chapter 2 introduces the Missouri Uniform Crash Report (MUCR) and the Statewide Traffic Accident Records System (STARS). Possible sources and interfaces for crash data are

presented. Modern tools for developing a local community crash database are also illustrated.

Chapter 3: Network Screening

Chapter 3 describes the process of network screening, or, the systematic process of prioritizing facilities according to potential benefits. Fundamental traffic variables such as annual average daily traffic (AADT) are reviewed. Ten safety performance measures are discussed, including crash frequency, crash rate, critical crash rate, and Empirical Bayes (EB) adjustments. The described safety performance measures are rated by effort required, and are accompanied by illustrative numerical examples.

Chapter 4: Tools for Crash Analysis

In Chapter 4, several tools for crash analysis are described, including tools for analyzing individual, as well as local, locations. Example tools include collision diagrams, site observations, condition diagrams, traffic patterns, and several tools provided by MoDOT, the Federal Highway Administration (FHWA), and the American Association of State Highway and Transportation Officials (AASHTO).

Chapter 5: Countermeasures

Chapter 5 is divided into two main sections. The first focuses on the selection of countermeasures; this involves the identification of crash contributing factors and the tailoring of solutions based upon those contributing factors. The second section focuses on the economic analysis of countermeasures. Benefit-cost analysis and cost-effectiveness analysis are presented as methods for assessing individual projects and developing a systematic, community-wide approach.

Chapter 6: Road Safety Audits

Chapter 6 presents a proven safety tool—the Road Safety Audit or Assessment (RSA). This new tool takes a proactive approach to safety, utilizing an independent and multidisciplinary safety review team. Such an audit can reveal safety issues and solutions often omitted from traditional safety analysis by local agencies. The eight steps of RSA are discussed in detail. A comprehensive example is provided to illustrate the RSA tool.

Chapter 7: Additional Resources

The final chapter presents additional resources that may be of assistance to local communities. A number of agencies and organizations exist and provide a variety of resources at both the national and local levels. FHWA is one particular agency highlighted in the current manual, being a sponsor of the Local Technical Assistance Program (LTAP) focusing on local communities. Free and publicly available resources abound, including a number of publications that address local roads.

Chapter 1 Bibliography

AASHTO (2010) *Highway Safety Manual*. American Association of State Highway and Transportation Officials. Washington, D.C.

AASHTO (2011) *A Policy on Geometric Design of Highways and Streets*. 6th Edition. American Association of State Highway and Transportation Officials. Washington, D.C.

MUTCD (2009) *Manual of Traffic Control Devices*. Federal Highway Administration. Washington, D.C.

US Census (2010) *Population Estimate Program 2012*. 2006-2010 American Community Survey. United States Bureau of the Census.

Chapter

2

CHAPTER 2: TRAFFIC RECORDS SYSTEM

Setting up a crash database.

A traffic records system is vital to the entire S-HAL process because it provides critical crash data necessary for decision making. The use of this data moves a community away from subjective safety assessments, and toward an objective, data-driven safety improvement process. Due to advances in computing and database technology, and with the support of the Missouri Department of Transportation (MoDOT) and the Missouri State Highway Patrol (MSHP), setting up a traffic records system in Missouri has become a relatively simple task. Even a small community can establish a basic traffic records system to meet its particular needs.

Crash Data

The Statewide Traffic Accident Records System (STARS) manual (MTRC, 2002) is the document that describes in detail the Missouri Uniform Crash Report (MUCR). As the name of the report implies, the STARS manual seeks to bring uniformity to accident reporting throughout the state. Such uniformity facilitates the effective analysis of traffic crashes throughout the state—even nationwide. The STARS manual provides guidelines and procedures for local law enforcement who are completing the MUCR. The four-page MUCR contains information such as the location of a crash, driver- and vehicle-related information, collision diagrams, road characteristics, and traffic conditions.

Figures 2.1-2.4 picture the four pages of the 2012 MUCR form. Figure 2.1 depicts general information about the accident, including data on severity, date, time, crash type, location, and pedestrians. A blank page for drawing a collision diagram is pictured in Figure 2.2. Figure 2.3 contains detailed information on drivers, vehicles, owners, occupants, and circumstances of the crash. Driver information includes license and insurance information. Vehicle information includes vehicle make and model, damage sustained, vehicle sequence, and commercial motor vehicle details, when applicable. Circumstances may involve driver error, impairment, traffic control, and work zones. Figure 2.4 presents the codes used on previous pages. The various codes simplify the coding of fields such as seat location, injury type, vehicle actions, event sequences,

objects, and driving distractions. Figure 2.4 also depicts space provided for the narrative description of the crash. For pre-2012 data, an earlier version of the MUCR is used to record crash information. Significant content similarities exist between the previous and current MUCR forms.

MISSOURI UNIFORM CRASH REPORT   PAGE _____ OF_____

1 - GENERAL CRASH INFORMATION   AGENCY NAME AND ORI

SPACE USED FOR BARCODE

LEFT THE SCENE	DRIVER NO.	CLEARED	CRASH	PROPERTY DAMAGE ONLY	NO. INJURED	NO. KILLED	REPORT / CASE / INCIDENT NUMBER
☐ Yes ☐ No		☐ Yes ☐ No	CLASSIFICATION ☐				

NO. VEH. INV.	CRASH DATE	CRASH TIME (MIL.)	NOTIFIED DATE	TIME NOTIFIED (MIL.)	INVESTIGATION DATE	TIME ARRIVED (MIL.)	INVEST. AT SCENE ☐ Yes ☐ No

CRASH TYPE

ROADWAY
☐ On Roadway
☐ Off Roadway

NON-COLLISION
☐ Overturning
☐ Fire / Explosion
☐ Immersion
☐ Jackknife
☐ Fell/Jumped From MV
☐ Cargo / Equip Loss / Shift
☐ Other Non-Collision

COLLISION INVOLVING
☐ Animal
☐ Pedalcycle
☐ Fixed Object
☐ Other Object
☐ Pedestrian
☐ Railway Vehicle
☐ Animal Drawn Veh / Animal Ridden Trans.
☐ Motor Vehicle in Transport ⟶
☐ Parked Motor Vehicle
☐ Working Motor Vehicle ⟶

DIRECTIONAL ANALYSIS FOR IMPACT WITH MOTOR VEHICLE
☐ Front to Front
☐ Front to Rear
☐ Rear to Rear
☐ Rear to Side
☐ Angle
☐ Sideswipe (Same Dir.)
☐ Sideswipe (Opp. Dir.)
☐ Falling / Shifting Cargo (Set in motion by MV)
☐ Other (Explain)
☐ Unknown (Explain)

COMMERCIAL MOTOR VEHICLE INVOLVEMENT CRITERIA - Answer the following to determine if the "Commercial Vehicle" fields in Section 7G must be completed.

1. Does this crash involve any of the following?
   1a. A person fatally injured; OR
   1b. A person transported for medical attention; OR
   1c. A vehicle towed due to disabling damage.
   ☐ No - No commercial vehicle fields need completion.
   ☐ Yes - Go to number 2. ⟶

2. Examine each vehicle to determine if it is a commercial vehicle based upon the following:
   2a. A truck / cargo van with GVWR / GCVWR of more than 10,000 lbs; OR
   2b. A motor vehicle with seating for 9 or more including driver; OR
   2c. A vehicle with a hazardous materials placard.
   ☐ No - No commercial vehicle fields need completion.
   ☐ Yes - Complete Section 7G for appropriate vehicle.

EVIDENTIARY PHOTOS TAKEN BY WHOM   AVAILABLE FROM ☐ Investigating Agency
☐ Yes ☐ No

RECONSTRUCTION BY WHOM   AVAILABLE FROM ☐ Investigating Agency
☐ Yes ☐ No

2 - LOCATION

COUNTY	MUNICIPALITY	BEAT / ZONE	TRP/DIST/PCT	GPS COORDINATES (DD MM SS.S FORMAT)
				LAT: N LONG: W

ON	RDWY. DIR.	DISTANCE FROM	LOCATION	INTERSECTING
		☐ NA ____ Feet ____ . ___ Miles	☐ NA ☐ After ☐ Before ☐ At	

SPEED LIMIT	ROAD MAINTAINED BY ☐ Unknown		SPEED LIMIT	INT. DIR.	GEO - CODE
	☐ State ☐ County ☐ Municipal ☐ Private Property ☐ Other				

TRAFFICWAY
☐ One-Way   ☐ Two-Way; Not Divided   ☐ Two-Way; Divided; Unprotected Median   ☐ Other
☐ Two-Way; Not Divided; Continuous Center Turn Lane   ☐ Two-Way; Divided; Positive Median Barrier   ☐ Unknown

ROAD ALIGNMENT
☐ Straight ☐ Curve
☐ Unknown (Explain)

ROAD PROFILE
☐ Level ☐ Downhill ☐ Dip
☐ Uphill ☐ Hillcrest ☐ Unknown (Explain)

INTERSECTION TYPE ☐ NA
☐ 4-way Intersection ☐ Y-Intersection ☐ 5-way / More ☐ Unknown (Explain)
☐ T-Intersection ☐ Roundabout ☐ Other (Explain)

ROAD CONDITION
☐ Dry ☐ Snow ☐ Slush ☐ Standing Water ☐ Sand / Gravel ☐ Unknown (Explain)
☐ Wet ☐ Ice / Frost ☐ Mud / Dirt ☐ Moving Water ☐ Other (Explain)

ROAD SURFACE
☐ Concrete ☐ Brick ☐ Dirt / Sand ☐ Cobblestone
☐ Asphalt ☐ Gravel ☐ Multi-Surface ☐ Unknown (Explain)

WEATHER CONDITION
☐ Clear ☐ Rain ☐ Sleet / Hail ☐ Fog / Mist ☐ Other (Explain)
☐ Cloudy ☐ Snow ☐ Freezing (Temp) ☐ Severe Crosswind ☐ Unknown (Explain)

LIGHT CONDITION
☐ Daylight ☐ Dark-Lighted ☐ Dark-Unlighted ☐ Dark-Unknown Lighting ☐ Other (Explain) ☐ Unknown (Explain)

3 - DAMAGE TO PROPERTY OTHER THAN VEHICLES ☐ None
LIST OWNER'S NAME & ADDRESS, DESCRIPTION OF PROPERTY, AND DAMAGE. ☐ MoDOT ☐ County ☐ Municipality

4 - WITNESS ☐ None Identified ☐ Additional Witnesses In Narrative

NAME	ADDRESS (Street, City, State, Zip)	PHONE NUMBER

5 - PEDESTRIAN ☐ NA ☐ Law Enforcement Officer ☐ Other Emergency Services Personnel ☐ MoDOT Worker ☐ Other Trafficway Worker ☐ Other Pedestrian

NO.	NAME (Last, First, MI) & ADDRESS (Street, City, State, Zip)	PHONE NUMBER

DATE OF BIRTH	SEX	STRUCK BY VEH #	INJ	TRANS-PORT	SAFETY DEVICES	LOCATION
						☐ On Roadway ☐ In Driveway Access ☐ On Median / Crossing Island
						☐ On Sidewalk ☐ Off Roadway ☐ Unknown

CROSSING ROAD ☐ NA
☐ With Signal
☐ Against Signal
☐ No Signal
☐ Unknown

☐ Not At Crosswalk
☐ In Marked Crosswalk
☐ In Unmarked Crosswalk
☐ Unknown

OTHER ACTIONS ☐ NA / None
☐ Getting On / Off Vehicle
☐ Standing / Lying / Sitting In Trafficway
☐ Pushing / Working On Vehicle
☐ Behind / In Front of Parked / Stopped Veh.

☐ Working In Trafficway
☐ Playing In Trafficway
☐ Walking / Running In Trafficway
☐ With Traffic ☐ Against Traffic

☐ Unknown
☐ Other (Explain)

SCHOOL INFO. ☐ NA
☐ Going To / From School
☐ Getting On / Off School Bus
☐ Both Of The Above
☐ Unknown (Explain)

PROBABLE CONTRIBUTING CIRCUMSTANCES ☐ None
☐ Failed To Yield ☐ Alcohol ☐ Vision Obstructed (Explain) ☐ Other (Explain)
☐ Distracted / Inattentive ☐ Drugs ☐ Physical Impairment (Explain) ☐ Unknown (Explain)

DISTRACTION / INATTENTION CODE(S) ☐ NA

ALCOHOL USE
☐ Yes ☐ No ☐ Unknown

DISTRIBUTION: **COPY** - AGENCY FILE; **ORIGINAL** - MISSOURI STATE HIGHWAY PATROL - TRAFFIC RECORDS DIVISION - P.O. BOX 568 - JEFFERSON CITY, MO 65102   SHP-3Q 01/12

Figure 2.1 MUCR page 1, general information, location.

REPORT #_____   PAGE _____ OF_____

6. COLLISION DIAGRAM	Compass Direction Before Crash Event(s) (Circle One)	V1 N E S W U	V2 N E S W U	V3 N E S W U	V4 N E S W U	V5 N E S W U	V6 N E S W U

INDICATE NORTH

INDICATE ROAD NAMES

DIAGRAM NOT TO SCALE

Figure 2.2 MUCR page 2, collision diagram.

REPORT #_____ PAGE _____ OF_____

7 - DRIVERS, VEHICLES, OWNERS, & OCCUPANTS

NO: **7A. DRIVER** - NAME (Last, First, MI) & ADDRESS (Street, City, State, Zip) | PHONE NUMBER

DRIVER LICENSE / ID NUMBER | STATE | LIC STATUS | ☐ Valid ☐ Susp / Rev / Denied ☐ Canceled / Oth Invalid ☐ NA | ☐ Expired ☐ Disqual CDL ☐ Unknown | LIC TYPE | ☐ Operator Class ____ ☐ CDL Class ____ ☐ Interm / Grad ☐ NA | ☐ Permit ☐ MC Only ☐ Unlicensed | ☐ Unknown (Explain) | MC ENDORSEMENT ☐ Yes ☐ No ☐ NA ☐ Unknown (Explain)

DATE OF BIRTH | SEX | SEAT LOC | INJ | TRANS-PORT | EJEC-TION | AIR BAG | SAFETY DEVICES | VISION OBSTRUCTED ☐ NA | ☐ Not Obstructed ☐ Windshield ☐ Load on Veh | ☐ Trees / Brush ☐ Building ☐ Embankment | ☐ Sign ☐ Hillcrest ☐ Parked Veh | ☐ Moving Veh ☐ Stopped Veh ☐ Glare | ☐ Other (Explain) ☐ Unknown (Explain)

PROOF OF INSURANCE ☐ Yes ☐ No ☐ Not Required | INSURANCE COMPANY ☐ Expired | PHONE NO. (Optional) | POLICY NUMBER ☐ NA | ☐ Driver ☐ Vehicle

7B. VEHICLE - OWNER NAME (Last, First, MI) & ADDRESS (Street, City, State, Zip) ☐ SAD | PHONE NUMBER ☐ SAD

YEAR | MAKE | MODEL | COLOR | VEH. TYPE | TOTAL NO. OF OCC.

LICENSE - PLATE NO. | STATE | YEAR | VIN | TOWED FROM SCENE ☐ Yes ☐ No | TOWED DUE TO DIS. DAMAGE ☐ Yes ☐ No

VEHICLE DAMAGE (Mark all damaged areas) ☐ None / No Damage

INITIAL IMPACT NO: 2│3│4│5│6│7 ☐ NA 1│15│16│17│8 14│13│12│11│10│9 | 18 - Undercarriage 19 - Windshield 20 - Burned 21 - Towed Unit | 22 - Cargo 23 - Unknown 24 - Other (Explain) | TOWED BY ☐ Unknown ☐ NA

VEHICLE BODY TYPES - Automobiles / Specialty Vehicles ☐ Vehicle Used As Public Conveyance

☐ Passenger Car
☐ Van (< 9 W/Driver)
☐ Passenger Van (9+ W/Driver)
☐ Sport Utility Vehicle
☐ Limousine (7-8 W/Driver)
☐ Limousine (9-15 W/Driver)
☐ Motorized Bicycle
☐ Pedalcycle ☐ To / From School

☐ Small Bus (9-15 W/Driver)
☐ Large Bus (16+ W/Driver)
☐ School Bus
☐ Intercity
☐ Transit / Commuter
☐ Charter / Tour
☐ Other

☐ Motorcycle
☐ ATV
☐ 2 Wh
☐ 3 Wh
☐ 4 Wh
☐ 5 Wh / More
☐ Unknown

☐ Motor Home
☐ Farm Implements
☐ Construction Equip. Heavy Mach.
☐ Other Vehicle (Code) _____
☐ Cargo Van
☐ Pickup
☐ Other Heavy Truck
☐ Unknown (Explain)

☐ Single-unit Truck; 2 axles, 6 tires
☐ Single-unit Truck; 3 or more axles
☐ Veh. Pulling Another Unit(s) (Does not apply to Truck Tractors)
☐ Truck Tractor With No Units
☐ Truck Tractor With One Unit
☐ Truck Tractor With Two Units
☐ Truck Tractor With Three Units

GVW / GCVW RATING (Not Licensed Weight) (Pickups, Cargo Vans, All Trucks, Truck Tractors, or Haz Mat Placard Veh. Only)
☐ Less than or equal to 10,000 lbs.
☐ 10,001 - 26,000 lbs.
☐ Greater than 26,000 lbs.
☐ Unknown

EMERGENCY VEHICLE INVOLVEMENT ☐ NA
☐ Police ☐ Ambulance
☐ Fire ☐ Other (Must check "A" / "B") → | ☐ A. Emergency Vehicle on Emergency Run ☐ B. Stationary With Emergency Equip. Activated

CONTRIBUTING TRAFFIC CONDITIONS ☐ NA
☐ Congestion Ahead ☐ Other Incident Ahead
☐ Crash Ahead ☐ Unknown (Explain)

7C. VEHICLE ACTION / SEQUENCE OF EVENTS CODES ☐ Additional Codes Listed in Narrative (See Codes in Section 8)

SEQUENCE OF EVENTS CODES ☐ Unknown | ANIMAL CODE(S) | FIXED OBJECT CODE(S) | ALCOHOL USE ☐ Yes ☐ Unk ☐ No ☐ NA

7D. PROBABLE CONTRIBUTING CIRCUMSTANCES ☐ None

☐ Vehicle Defects (Explain)
☐ Speed - Exceeded Limit
☐ Too Fast For Conditions
☐ Violation Signal / Sign
☐ Failed To Yield
☐ Alcohol
☐ Drugs

☐ Vision Obstructed
☐ Driver Fatigue / Asleep
☐ Improper Signal
☐ Improper Backing
☐ Improper Turn
☐ Improper Passing
☐ Improperly Parked

☐ Failed To Dim Headlights
☐ Failed To Use Lights
☐ Following Too Close
☐ Wrong Side (Not Passing)
☐ Wrong Side (One-Way)
☐ Physical Impairment (Explain)
☐ Improper Start From Park

☐ Improper Towing / Pushing
☐ Improperly Stopped On Roadway
☐ Improper Lane Usage / Change
☐ Overcorrected
☐ Improper Riding / Clinging To Veh. Exterior
☐ Failed To Secure Load / Improper Loading
☐ Animal(s) In Roadway

☐ Object / Obstruction in Roadway
☐ Distracted / Inattentive (Designate Type)
☐ Unknown (Explain)
☐ Other (Explain)

DISTRACTED / INATTENTIVE CODE(S) ☐ NA (See Codes in Section 8)

7E. WORK ZONE ☐ Yes ☐ No ☐ Unknown

TRAFFIC CONTROL ☐ None ☐ Unknown
Electric: ☐ Green/Yellow/Red ☐ Flashing Red ☐ Flashing Yellow ☐ Ramp Meter ☐ Other (Explain)

Workers Present ☐ Yes ☐ No ☐ Unknown
Other Controls: ☐ Stop Sign ☐ No Passing Zone ☐ Turn Restricted ☐ Officer / Flagman ☐ Signal On School Bus ☐ Warning Sign / Device ☐ Railway Crossing Sign / Device ☐ School Zone ☐ Yield Sign ☐ Other (Explain)

CONTROL MALFUNCTIONING / INOPERATIVE / MISSING ☐ Yes (Explain) ☐ No ☐ Unknown ☐ NA

7F. OCCUPANTS - NAME (Last, First, MI) ADDRESS (Street, City, State, Zip) | DATE OF BIRTH MM-DD-YYYY | SEX | SEAT LOC | INJ | TRANS-PORT | EJEC-TION | AIR BAG | SAFETY DEVICES | PHONE NUMBER

7G. COMMERCIAL MOTOR VEHICLE ☐ NA | Required on vehicle if "Yes" was answered to questions in parts 1 and 2 in CMV involvement criteria and vehicle meets one of the three criteria in part 2.

MOTOR CARRIER IDENTIFICATION (Lessee, etc.) - NAME & ADDRESS (Street, City, State, Zip) ☐ SAO | PHONE NUMBER ☐ SAO

COMMERCIAL / NON-COMMERCIAL | ☐ Interstate Carrier ☐ Intrastate Carrier | ☐ Not In Commerce - Government Vehicle ☐ Not In Commerce - Rental Vehicle | ☐ Not In Commerce - Other Vehicle | MC / MX / ICC NO. | USDOT NO.

CARGO BODY TYPE | ☐ Enclosed Box ☐ Cargo Tank | ☐ Flatbed ☐ Dump | ☐ Concrete Mixer ☐ Auto Transporter | ☐ Garbage / Refuse ☐ Grain / Chip / Gravel | ☐ Pole Trailer ☐ Log | ☐ Vehicle Towing Another Veh. | ☐ Intermodal Container Chassis | ☐ NA (No Cargo Body) | ☐ Other ☐ Unknown

HAZARDOUS MATERIALS | PLACARD DISPLAYED ☐ Yes ☐ No ☐ Unknown | 4-DIGIT NO. | CLASS | HM CARGO PRESENT ☐ Yes ☐ No ☐ Unknown | HM CARGO RELEASED ☐ Yes ☐ No ☐ Unknown | HAZARDOUS MATERIAL NAME

Figure 2.3 MUCR page 3, drivers, vehicles, owners, and occupants.

REPORT #_____   PAGE _____ OF_____

9 - CODES

SEAT LOCATION
XX - Not Known
B - Pedalcycle
M - Motorcycle
CP - Commercial Passenger
OE - Occupant - Enclosed Load Area
OU - Occupant - Unenclosed Load Area
RC - Rail Crew
SV - Other (Explain in Narrative)
NA - Not Applicable

FR SR TR
FC SC TC
FL SL TL

INJURY
1. Fatal
2. Disabling
3. Evident - Not Disabling
4. Probable - Not Apparent
5. None Apparent
U. Unknown
N. NA

TRANSPORTED (For Medical Treatment)
1. No
2. EMS
3. Other
U. Unknown
N. NA

EJECTION
1. NA
2. No
3. Partially
4. Totally
U. Unknown

AIR BAG
1. None / NA
3. Not Deployed
4. Removed
5. Deployed - Front
6. Deployed - Side
7. Deployed - Curtain
8. Deployed - Other (Knee, Air Belt, etc.)
9. Deployed - Combination
10. Deployment Unknown
U. Air Bag Presence Unknown

SAFETY DEVICES
1. None
2. Not Used
3. Shoulder Belt Only
4. Lap Belt Only
5. Shoulder and Lap Belt
7. DOT Compliant MC Helmet
8. No Helmet
10. Booster Seat
11. Child Restraint - Forward Facing
12. Child Restraint - Rear Facing
13. Other Helmet
14. Reflective Clothing
15. Other
U. Use Unknown
N. Not Applicable

VEHICLE ACTION / SEQUENCE OF EVENTS (items with double-asterisk (**) require additional coding)
1. Going Straight
2. Overtaking
3. Making Right Turn
4. Right Turn on Red
5. Making Left Turn
6. Making U-Turn
7. Skidding / Sliding
8. Slowing / Stopping
9. Start In Traffic
10. Start From Parked
11. Backing
12. Stopped In Traffic
13. Parked
14. Changing Lanes
15. Avoiding
16. Cross Median
17. Cross Center Of Road
18. Cross Road
19. Airborne
20. Ran Off Roadway - Right
21. Ran Off Roadway - Left
22. Overturn / Rollover
23. Fire / Explosion
24. Immersion
25. Jackknife
26. Cargo Loss / Shift
27. Equipment Failure
28. Separation Of Units
29. Returned To Roadway
30. Collision Inv. Pedestrian
31. Collision Inv. Bicycle/Pedalcycle
32. Collision Inv. Railway Veh.
33. Collision Inv. Animal (**)
34. Collision Inv. MV in Transport
35. Collision Inv. Parked MV
36. Collision Inv. Fixed Object (**)
37. Collision Inv. Other Object (Explain)
38. Other Non-collision
39. Collision Inv. Bicycle/Pedalcycle In Bicycle Lane
40. Collision Inv. Animal Drawn Vehicle / Animal Ridden For Transportation
41. Collision Inv. Working MV
42. Downhill Runaway
43. Fell/Jumped From MV
44. Thrown/Falling Object
45. Struck By Falling, Shifting Cargo, Object Set In Motion By Own MV
46. Ran Off Roadway - Other (Explain)
47. Cross Separator

ANIMAL CODES FOR VEHICLE ACTION / SEQUENCE OF EVENTS
60. Deer   61. Farm Animal   62. Dog   63. Other Animal   U. Unknown

FIXED OBJECT CODES FOR VEHICLE ACTION / SEQUENCE OF EVENTS
20. Tree / Stump (Standing)
21. Embankment / Driveway / Ground / Rock Bluff
22. Guardrail Face
23. Utility Pole
24. Fence
25. Street Light Support
26. Culvert
27. Highway Traffic Sign Post / Support
28. Bridge Pier / Abutment / Support
29. Curb
30. Mail Box
31. Concrete Traffic Barrier
32. Building
33. Traffic Signal Support
34. Impact Attenuator / Crash Cushion
35. Fire Hydrant
36. Other (Explain)
37. Bridge Parapet End
38. Bridge Rail
39. Guardrail End
40. Other Traffic Barrier
41. Overhead Sign Support
42. Ditch
43. Other Post / Pole / Support
44. Wall
45. Cable Barrier
46. Bridge Overhead Structure
47. Overhead Line / Cable
U. Unknown

DISTRACTED / INATTENTIVE CODES
1. External Distraction
2. Passengers
3. Stereo / Audio / Video Equipment
4. Navigation Device
5. Communication Device - Hand-held
6. Communication Device - Hands Free
7. Communication Device - Texting / E-mailing
8. Communication Device - Web Browsing
9. Eating / Drinking
10. Reading
11. Tobacco Use
12. Grooming
13. Computer Equipment / Electronic Games / etc.
14. Adjusting Vehicle Controls
15. Other (Explain)

VEHICLE TYPE CODES
1. Motor Vehicle In Transport
2. Parked Motor Vehicle
3. Working Motor Vehicle
4. Pedalcycle
5. Animal Drawn Vehicle / Animal Ridden For Transport Purposes
U. Unknown

OTHER VEHICLE CODES
1. Riding Mower / Garden Tractor
2. Golf Cart
3. Snowmobile
4. Forklift
5. Animal Drawn Vehicle / Animal Ridden For Transportation
6. Low Speed Vehicle
7. Other (Explain)

9. NARRATIVE / STATEMENTS (If additional room is necessary, use Section 11 - Narrative / Statements Continuation)

10. REPORTING AND REVIEWING OFFICER INFORMATION

REPORTING OFFICER NAME | DSN / BADGE NO. | BEAT / ZONE | TROOP / DISTRICT / PRECINCT

REVIEWING OFFICER NAME | DSN / BADGE NO | REVIEWING OFFICER 2 NAME | DSN / BADGE NO.

Figure 2.4 MUCR page 4, codes and narrative.

The MSHP is Missouri's lead agency in terms of providing STARS training for all police agencies. The agency partners with MoDOT to store and archive MUCR data. Since such information is comprised of standardized fields and is stored in an electronic database, it can be easily queried and manipulated using the tools that will be discussed throughout the remained of this chapter.

The STARS (2012) manual contains a thorough description of all of the fields contained in the MUCR. The following fields are highlighted, as they are frequently used in the analysis of crash patterns: Crash type refers to the first harmful event in a crash. Non-collision events include overturning, fire, and cargo loss. Collisions can involve other vehicles, fixed objects, animals, pedestrians, or trains. For vehicle-to-vehicle impacts, the nature of the impact is reported, e.g., head-on, rear-end, sideswipe, or angle. Site particulars are described in fields such as road alignment, road profile, intersection type, road condition, road surface, weather condition, and light condition. Road alignment refers to an either curved or straight horizontal alignment. Road profile refers to vertical alignment, and can be classified as level, uphill, downhill, or at the top or bottom of a hill. Intersection types include four-way, T, Y, roundabout, or multi-point. Road conditions can include dry, snow, ice, slush, mud, water, or sand. The surface layer of the road material can be coded as concrete, asphalt, brick, gravel, dirt, cobblestone, or multi-surface. Weather conditions include clear, cloudy, rain, snow, sleet, freezing, fog, and severe crosswind. Light condition includes daylight, man-made lighting, and unlighted. Probable contributing circumstances could involve driver error, vehicle defects, or other miscellaneous circumstances; common circumstances include speeding, traveling too fast for conditions, signal/signage violations, failure to yield, drugs and alcohol, vision obstruction, fatigue, various improper maneuvers, and following too closely. Crash severity can be categorized as fatal (i.e., a person died within 30 days), disabling injury, evident injury, probable injury, or property damage only (PDO).

The MUCR contains a wealth of information that can be mined for a better understanding of local crashes and possible trends among crashes. Missouri's Blueprint to Save More Lives (2012) illustrates the usefulness of the MUCR. One major piece of information obtained from the MUCR is crash severity; thus, more serious fatal and disabling injury crashes can be viewed separately from PDO crashes. The Blueprint reported the most serious crash types occurring in Missouri: run-off-road, horizontal curve, intersection, tree/pole, and head-on. The Blueprint also examined driver behavior data from the MUCR, finding that the highest crash-related risk factors were aggressiveness, unrestrained occupants, distraction, impairment, young drivers, and invalid licenses. By tracking MUCR information across multiple years, the Blueprint documented the performance of different crash areas over multiple years. Even though the Blueprint is produced at the state level, similar analyses of crash data can be conducted at the local level. Local crash type analysis is available by accessing the website at: http://www.modot.org/safety/BlueprintCrashStatistics.htm.

Crash Data Interfaces

Local communities can choose among three different methods of accessing crash data. The first is to obtain data directly from the local police department, though this may not be the preferred method since other methods have much quicker turnaround times. The two additional methods involve accessing the statewide crash database maintained by the MSHP and MoDOT. Local police departments compile and report crashes in their jurisdictions to the centralized MSHP database.

MoDOT's Transportation Management System (TMS) is designed to collect, organize, and process data to support decision making throughout the state. TMS's primary components include data inventory, report generation, and data analysis. Types of data available within TMS that are relevant to safety include crashes, travelway information, and pavement data. TMS supports various interfaces, such as desktop, web, and ODBC (Open Database Connectivity). The web-based applications can be made available to local agencies via the use of a Virtual Private Network (VPN). A VPN is a dedicated connection that grants access to MoDOT's intranet via a public network.

The web-based TMS accident browser tool allows local communities to search and obtain crash information regarding specific facilities (MoDOT, n.d.). Figure 2.5 provides an example of a query for crashes on US 50 in Cole County. This figure illustrates how crashes can be queried for any portion of US 50. The resulting list of crashes is shown in Figure 2.6. The crashes include information on the county name, travelway identifier, continuous log, crash type, crash date, severity rating, image number, and county log unit. The image number is a unique identifier that can be used to find the applicable police report to obtain additional information on a particular crash. Five options exist for display in the accident browser:

1. All approach legs of an intersection
2. Non-intersection only
3. A particular travelway only
4. Within a travelway range
5. All interchange accidents
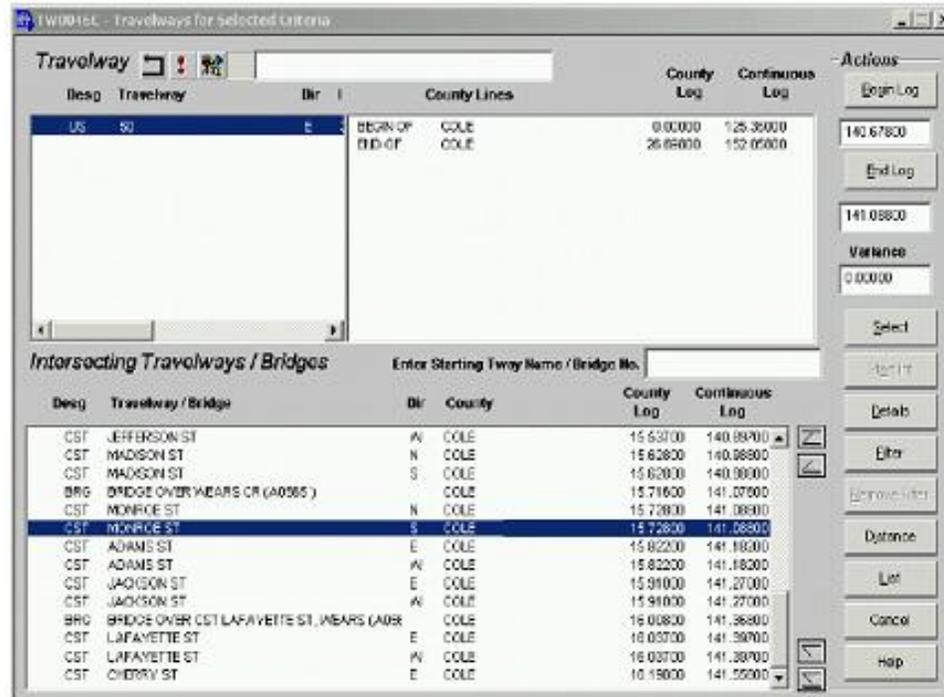
Figure 2.5 Example of an accident browser selection.
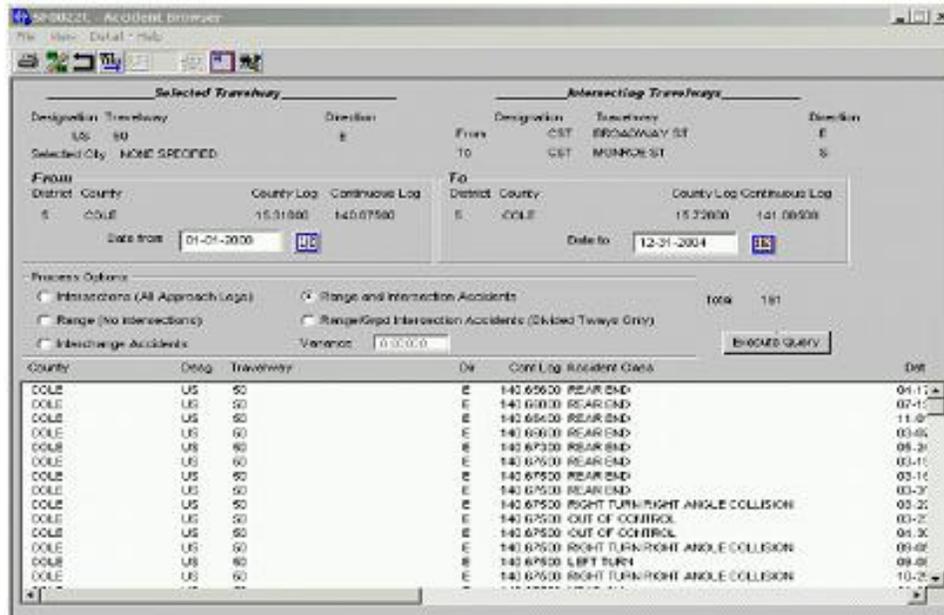
Figure 2.6 Example of a listing of crashes.

Another TMS tool is the statewide average accident rates tool from the TMS safety management system. This tool displays accident rates for segments and intersections. Accident rate is discussed in greater detail in Chapter 3.

A third method of accessing crash data is through the MSHP Accident Characteristics Summary Reports website. The website is publicly accessible at http://www.mshp.dps.missouri.gov/TR15Reports/850ReportMenu.htm. Figure 2.7 shows a screen capture of the MSHP crash report interface. Various types of reports are available, including reports by highway character, highway condition, highway classification, crash severity, day of the week, contributing circumstances, impairment, and young drivers. The user can search for crashes within a range of dates, and a location defined by county, city, or specific highway. Figure 2.7, for example, displays a Highway Characteristics Report for MO-740 (Stadium Boulevard) for dates occurring between January and December, 2013. Figure 2.8 shows the output of this query. The output row displays accident type, while the output column reports on geometric elements, such as location on the tangent and curved sections of roadways.

Figure 2.7 Example of the MSHP online traffic crash report interface.

			Straight						Curve				Unknown	Total
Accident Type	Level	Grade	Crest	Uphill	Downhill	Dip	Level	Grade	Crest	Uphill	Downhill	Dip	Unknown	Total
Animal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pedalcycle	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fixed Object	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Other Object	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pedestrian	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Train	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MV In Transport	36	0	2	3	7	1	3	0	0	0	1	0	0	53
Parked Vehicle	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Overturning	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Non-Collision	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animal Drawn/Ridden	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Working Motor Vehicle	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fire/Explosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Immersion	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jackknife	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fell/Jumped from MV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cargo/Equipment Loss/Shift	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	36	0	2	4	7	1	3	0	0	0	1	0	0	54

10/19/2013 16:48 — Agency: All — Missouri Statewide Traffic Accident Records System (STARS) — Motor Vehicle Traffic Accident Summary — Report Period: 01-2013 thru 12-2013 — Crashes, Accident Type by Highway Character — TR150850-R01 — City: COLUMBIA — Highway:MO-740

Figure 2.8 Example of an MSHP traffic crash report output.

Local Crash Database

After a local community has obtained crash data relevant to their jurisdiction, the data can be stored in a local database for further analysis and processing. A number of common computer tools exist for the creation of a local database. Three common electronic tools for maintaining a local database include spreadsheets, database software, and geographical information systems. Chapters 3 and 4 of the S-HAL manual will further discuss data analysis using a local database.

Spreadsheets

An electronic spreadsheet is a good choice for handling a moderate amount of data (defined as fewer than 65,000 lines of information) and simple queries. A query is a request for information from a database, such as "find all injury crashes occurring in Columbia from 2009 to 2011 at intersections." Each cell of a spreadsheet represents one piece of data, either numerical or text. One advantage of using a spreadsheet database is that a spreadsheet possesses data analysis capabilities. Thus, a spreadsheet can be used to perform a number of arithmetic computations, such as computing crash rates or net present values. The sort function can be used to separate crash data based on specific characteristics, such as severity. Spreadsheets have built-in statistical functions. For example, the descriptive statistics function provides a statistical overview of the data by presenting the average, median, standard deviation, minimum, and maximum values. Data can be plotted in a spreadsheet, for example, to show the percentage of crashes by crash type. The cross-tabulation function in a spreadsheet allows an agency to explore relationships among crash-related circumstances, such as the percentage of injury crashes that are head-on. But a spreadsheet is unable to easily handle queries of multiple databases. Thus, a spreadsheet would not adequately handle a simultaneous query to a crash database and an Average Annual Daily Traffic (AADT) database.

One way to organize crash data in a spreadsheet is to represent each crash as a separate row, and to use columns to capture different characteristics of a crash. Table 2.1 presents an example of a portion of a crash database that includes year, MSHP crash number, county, route designation, travelway name, direction, log mile, severity, and date.

Table 2.1 Example of a Spreadsheet Crash Database

YR	IMAGE_#	COUNTY	DES.	TWAY_NAME	DIR.	Log	SEVERITY	DATE
2009	0090010139	St. Louis	MO	340	E	2.039	Minor Inj.	1/10/2009
2009	0090011443	St. Louis	CST	Jefferson Ave.	S	2.651	PDO	1/14/2009
2009	0090012001	Jackson	CST	Langford Rd.	E	2.508	Minor Inj.	1/30/2009
2009	0090012277	Cass	US	71	N	180.685	PDO	1/23/2009
2009	0090012278	Cass	US	71	N	179.199	PDO	1/17/2009

Spreadsheets are commonly included in commercial work productivity software packages, such as Microsoft Office. In the case of Microsoft Excel (2010), the size of the worksheet is limited to 65,536 rows of crashes (Microsoft, 2013). Other commercial spreadsheets include Lotus 1-2-3 and Corel Quattro. Open source and free spreadsheets, such as Gnumeric and OpenOffice.org Calc, also exist.

Database Software
Database software is designed for database management; as such, it is much more powerful than spreadsheets. The software can define data, handle complex queries, produce reports, and maintain and update databases. Examples of database software include Microsoft Access, MySQL, and Oracle. SQL stands for "sequential querying language," and is one method of querying data. Modern software has graphical querying capabilities that are more user-friendly than is SQL.

After crash data is obtained from sources such as the MoDOT Accident Browser or the MSHP online reporting tool, it can be imported into a local database. Database software possesses an external data menu with functions to import and link a number of database formats.

GIS Databases
A geographical information system (GIS) is a spatial database, meaning that data is linked to a geographical location. GIS could be useful for crash analysis, since the data is stored according to where the crash occurred. GIS is useful for displaying spatial crash trends. Figure 2.9 shows an example of GIS mapping showing fatal crashes in Missouri. GIS uses layers of data that can be turned on or off. For example, GIS layers could include the road network, crashes, AADT, and land use. These layers can be turned on in different combinations—for example, to examine the effect of land use on crash frequency. One common reference system in GIS is the latitude/longitude coordinate system, e.g., World Geodetic System 1984 (WGS84). Though the MUCR contains fields for global positioning system (GPS) coordinates, such coordinates may

not be available for all crashes, especially crashes from previous years. The MUCR does contain the alternate log mile referencing system, which locates crashes with respect to a point from the beginning of a route. However, locating crashes using log miles instead of latitude/longitude in GIS is more challenging. Some GIS layers for local communities may be available from the planning organization related to the local agency. In the case of urban areas with populations larger than 50,000, the local metropolitan planning organization (MPO) may supply GIS basemaps and shapefiles. Examples of Missouri MPOs include the East West Gateway Coordinating Council (EWGCC), the Mid-America Regional Council (MARC), the Ozark Transportation Organization (OTO), and the Columbia Area Transportation Study Organization (CATSO).
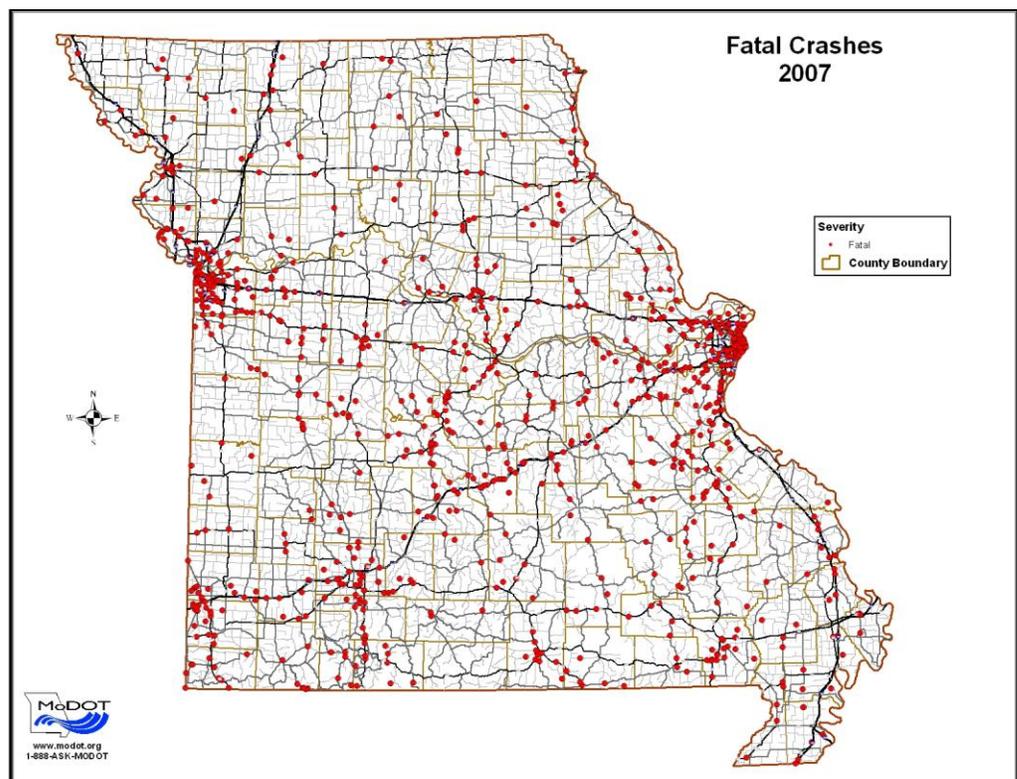
Figure 2.9 Example of GIS display of crashes (MoDOT, 2007).

Many GIS software packages are available, including those at no cost. One popular family of GIS software packages is produced by ESRI (Environmental System Research Institute). ESRI makes available a free GIS tool entitled ArcGIS Explorer. There also exist open source and free GIS tools. GRASS (Geographical Resources Analysis Support System) is a free public-domain software originally developed by the U.S. government. Chapter 4 contains additional discussions on graphical tools that can be used for analyzing crashes.

Chapter 2 Bibliography

MCRS (2012) *Missouri's Blueprint to Save More Lives*. Missouri Coalition for Roadway Safety. Jefferson City, Missouri.

Microsoft (2013) *Excel Specifications and Limits*. Microsoft Office Help. Available at http://http://office.microsoft.com/.

MoDOT (n.d.) *TMS Overview Training*. Missouri Department of Transportation. Jefferson City, Missouri.

STARS (2012) *Missouri Uniform Accident Report Preparation Manual*. (Statewide Traffic Accident Records System (STARS) Manual). Missouri STARS Committee. Available from http://epg.modot.org/files/1/11/907.4_MUARP.pdf.

Chapter

3
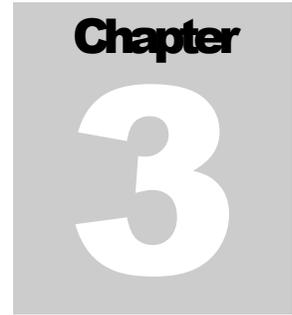
CHAPTER 3: NETWORK SCREENING

Prioritizing safety improvements and locations.

Every community has a limited quantity of time and funding available for spending on infrastructure improvements. Thus it becomes necessary to prioritize possible improvements/locations on the basis of potential benefits. The amount of benefit per dollar expended is a common measure used for such purposes. Because communities have different priorities, each community can customize the procedure described in this chapter using the community's own criteria and performance measures.

Network screening is the term given to the systematic process of examining a community's transportation network and ranking possible improvements or facilities according to their potential benefits. In previous editions of the HAL Manual, this process was referred to as "high crash location identification." However, "network screening" is now a more appropriate term, since it reflects the newer and more comprehensive approach to safety adopted by many agencies. For example, the FHWA Highway Safety Improvement Program Manual (Herbel et al., 2010) discusses the current focus on entire road segments, corridors, or systematic improvements, in lieu of chasing after high crash locations, which are often random. Note that this approach is not in conflict with the fact that some fixed locations could be problematic, such as intersections or horizontal curves.

The current chapter's techniques could be applied to both annual, city-wide analysis or early warning analysis. Both procedures are systematic ways for cities to document their safety efforts and allocate resources to achieve maximum safety benefits. Prior to this chapter's discussion of these procedures, several safety performance measures are described. The sources referenced in the discussion of safety performance measures include the Highway Safety Manual (HSM) (AASHTO, 2010), the Highway Safety Improvement Program (HSIP) Manual (Herbel et al., 2010), and research literature.

Safety Performance Measures

Safety performance measures are quantitative measures that can be used to perform network screening. Popular ways in which these measures are used include simple ranking, sliding window, and peak searching.

The following 10 safety performance measures are used in the HSM and the HSIP; they differ significantly in data requirements, ease of use, and accuracy of results. The first six measures are comparatively simpler, and are recommended for any local community, but may provide less accurate results. The latter four measures require some comprehension of advanced statistics and/or the HSM. For detailed explanations of the latter methods, the reader is referred to the HSM or the HSIP Manual, both of which are listed in the bibliography at the end of this chapter. While the complete list of 10 performance measures may seem overwhelming, a local community could simply select the one that is the best fit for its particular needs.

1. Average Crash Frequency

2. Crash Rate

3. Equivalent Property Damage Only

4. Relative Severity Index

5. Critical Crash Rate

6. Method of Moments

7. Level of Service of Safety

8. Excess Safety Performance Function Crash Frequency

9. Specific Crash Type Proportion Threshold

10. Empirical Bayes Adjustments

ICON KEY	
🖉 Numerical Example	
🕑 Effort Required (1 to 5 clocks)	

Two icons are used provide helpful information to the reader. The "Numerical Example" icon indicates a numerical example that is intended to illustrate a particular method. The "Effort Required" icon is a rough graphical representation of the amount of effort required to use a particular method; the simplest method is rated at one clock, while the most difficult is rated at five clocks. A rating of four or five clocks indicates a method that may be beyond the resources of local communities. However, some discussion of these methods is provided so that local communities can become familiar with such tools. At times, such tools are used at the regional level by organizations such as MoDOT, or a local metropolitan planning organization.

Average Crash Frequency ⏱

Average crash frequency is typically defined as the number of crashes occurring on a roadway or at an intersection over a specified time period, e.g., one year. When an adequate sample size is available, crashes can be analyzed by type (e.g., angle) and/or severity. Table 3.1 illustrates the major strength of the crash frequency measure, which is simplicity.

Table 3.1 Crash Frequency Characteristics

Data Needs	
# of crashes	
Strengths	**Limitations**
Simple	Omits other variables for more accurate forecasting.
Availability of data through HP/MoDOT.	Not account for RTM bias.
Easy way of forecasting # of crashes using traffic volumes as only variable.	Not account for exposure; can overemphasize high volume sites.
Can analyze by type and/or severity.	Requires arbitrary threshold.

Crash Frequency Numerical Example

Assume that the intersection of Main Street and Broadway Avenue experienced 21 crashes from 2009-2011. The crash frequency is 21 crashes/3 years = 7 crashes/year.

Crash Rate ⏱

Before discussing crash rates, a review of traffic data is in order. Annual Average Daily Traffic (AADT) is useful for annual safety analysis, because it averages daily and seasonal/monthly variations. The Missouri Department of Transportation (MoDOT) and other agencies often estimate and publish AADT values for all of their facilities. If AADT is not readily accessible, it can be estimated by the following formulae:

$$AADT = ADT * ACF * D * M \tag{3-1}$$

Where,

ADT = short duration traffic volume data in 24-hour periods;

ACF = axle correction factor when axle counters are used to account for multi-axle vehicles, e.g., axle tube counters;

D = daily factor to account for variability among days of the week;

M = monthly or seasonal factor to account for seasonal variability.

Figure 3.1 illustrates the concept of the daily factor, D. The horizontal line represents an AADT value of 3,400 vehicles per day. Figure 3.1 shows traffic exceeding AADT on Friday through Sunday. If the ADT is collected on Monday through Thursday, then D is greater than 1. Likewise, if the ADT is collected on Friday through Saturday, then D is less than 1.
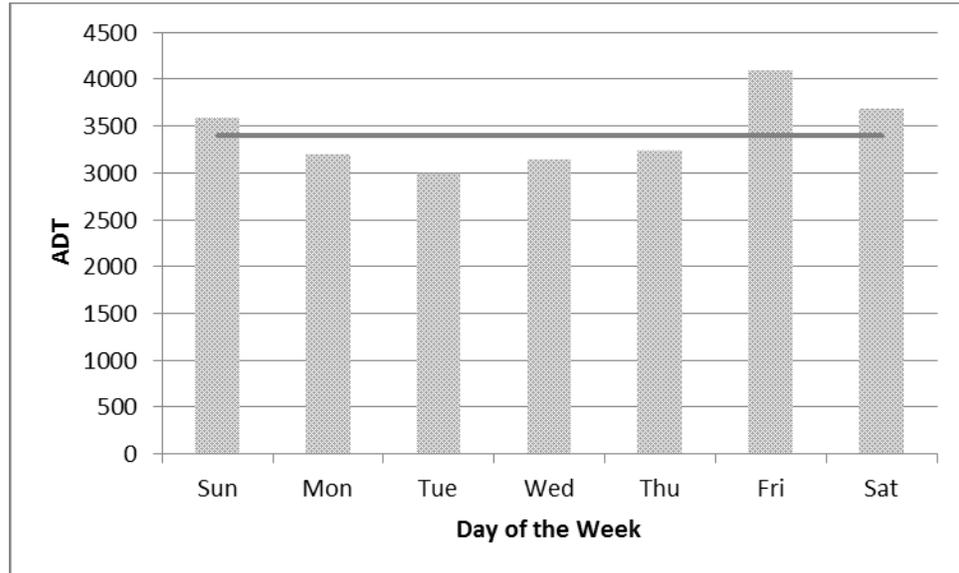
Figure 3.1 Example of daily traffic variations on a rural highway.

Figure 3.2 illustrates the concept of the monthly/seasonal factor, D. The horizontal line again shows an AADT value of 3,400 vehicles per day. Figure 3.2 shows traffic exceeding AADT during the months of May through October. If the ADT is collected from December to April, then D is greater than 1. Likewise, if the ADT is collected from May to October, then D is less than 1.
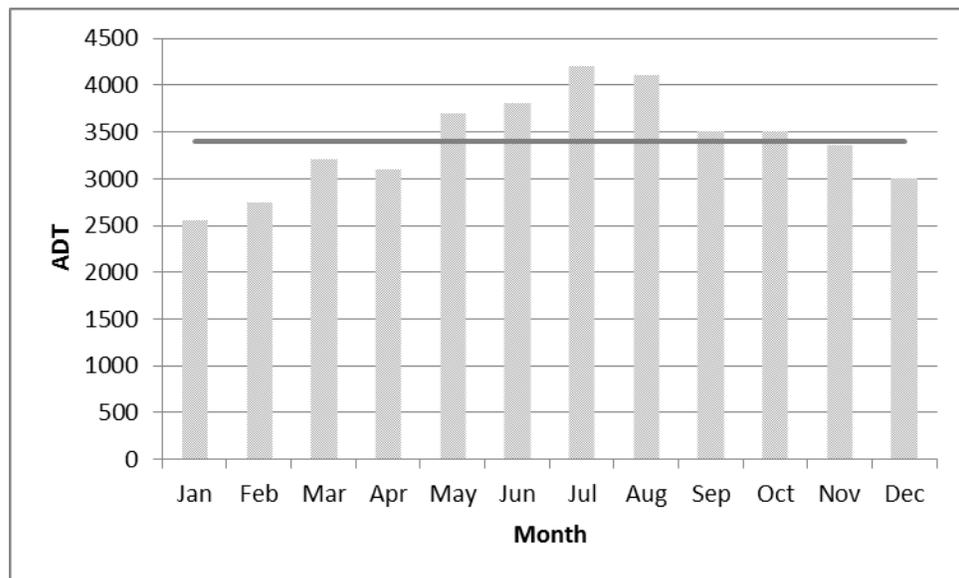
Figure 3.2 Example of monthly/seasonal traffic variations on a rural highway.

AADT Numerical Example

Assume your agency collected 48-hour ADT counts on Main Street on a Tuesday and Wednesday in July. ADT was 1,000 vehicles per day. Assume the axle correction factor, *ACF*, was 0.9 to account for multi-axle trucks. Also assume that the daily factor for Tuesday and Wednesday, *D*, was 1.2, and that the monthly factor for July, *M*, was 0.7.

$$AADT = 1000 \frac{vehicles}{day} * 0.9 * 1.1 * 0.8 = 792 \frac{vehicles}{day}$$

In terms of safety, exposure refers to how often or how long a driver is exposed to traffic risks. Thus, travelers who travel more frequently or over longer distances are exposed to greater risk. Crash rate accounts for exposure through the use of traffic volumes. Table 3.2 reveals that crash rate has similar trade-offs to those of crash frequency, but, unlike crash frequency, accounts for exposure. AADT is a measure of traffic volume commonly used to account for exposure.

Table 3.2 Crash Rate Characteristics

Data Needs	
# of crashes, traffic volumes	
Strengths	**Limitations**
Simple. Availability of data through MSHP/MoDOT. Easy way of forecasting # of crashes using traffic volumes as only variable. Can analyze by type and/or severity. Accounts for exposure.	Omits other variables for more accurate forecasting. Not account for regression-to-the-mean bias. Assumes linear relationship between traffic volume and crash frequency. Can overemphasize low volume, low crash sites. Requires arbitrary threshold. Cannot compare across sites with significant volume differences.

Crash Rate for Intersections

The following equation is used to compute the intersection (or spot) crash rate:

$$RSP = \frac{1,000,000 * C}{365 * T * V} \tag{3-2}$$

Where,

C = # of reported crashes during the analysis time frame;

T = analysis time frame in years;

V = AADT, or the sum of all entering volumes.

The resulting unit of measure of the *RSP* is crashes per million entering vehicles (MEV).

Crash Rate for Road Segments

To compute the crash rate for road segments (or sections) the following equation is used:

$$RSEC = \frac{100,000,000 * C}{365 * T * V * L}$$ (3-3)

Where,

C = # of reported crashes during the analysis time frame;

T = analysis time frame in years;

V = AADT, or the volume on the road segment;

L = length of the road segment in miles.

The resulting unit of measure of the *RSEC* is crashes per hundred million vehicle miles (HMVM).

Crash Rate Numerical Example
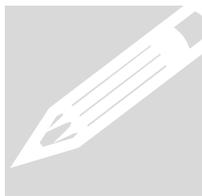
Assume that Main Street and Broadway Avenue experienced 21 crashes from 2009-2011. Also assume that the sum of the AADTs from all of the approaches was 10,000 vehicles/day.

$$RSP = \frac{1,000,000 * 21 \text{ crashes}}{365 \text{ days/year} * 3 \text{ years} * 10,000 \text{ vehicles/day}} = 1.92 \ \frac{\text{crashes}}{\text{MEV}}$$

Equivalent Property Damage Only ☺

Though Equivalent Property Damage Only (EPDO) contains "property damage only (PDO)" in its wording, it is really about combining different crash severities into a single measure with the use of weights. It is common to classify crash severity into fatal, injury, or PDO crashes. Often, the "injury" category is further divided into "disabling" or "minor." Some agencies divide injury crashes into "incapacitating," "non-incapacitating," or "possible injury." Another common classification is the KABCO scale: K-killed, A-disabling injury, B-evident injury, C-possible injury, or O-no apparent injury.

Each local community could develop their own weights for determining the relative importance of each of the severity categories. For example, a community could base the weights on crash costs. If one were to use crash costs from the AASHTO Red Book (2010), then the weights for fatal, injury, and PDO crashes would be 18,619; 543; and 1, as computed by dividing total crash costs by PDO crash cost. However, agencies often modify weights based on pure crash costs, since fatal crashes tend to dominate such weights: fatal crashes could be random in any crash sample, and the presence of even one fatal crash can disproportionately inflate crash costs at a given location (Council et al., 2005). For example, an agency might choose to assign the same weight to fatal and injury crashes by assigning each a weight of 11. Crash costs typically include both direct and indirect costs. Direct costs include property damage, insurance costs, and incident management costs (e.g., fire, police, emergency medical services). Indirect costs include pain and suffering and loss of enjoyment of life.

The following equation is used to compute EPDO:

$$EPDO = W_{fatal} * N_{fatal} + W_{injury} * N_{injury} + W_{PDO} * N_{PDO} \qquad (3\text{-}4)$$

Where,

W_{fatal} = relative weight of fatal crashes;

W_{injury} = relative weight of injury crashes;

W_{PDO} = relative weight of PDO crashes;

N_{fatal} = number of fatal crashes;

N_{fatal} = number of injury crashes;

N_{fatal} = number of PDO crashes.

Table 3.3 illustrates a major strength of EPDO, i.e., it accounts for severity.

Table 3.3 EPDO Characteristics

Data Needs	
# of crashes, crash costs by severity	
Strengths	**Limitations**
Simple Availability of data through HP/MoDOT Easy method of forecasting # of crashes using traffic volumes as only variable Considers severity	Omits other variables for more accurate forecasting Not account for RTM bias Not account for exposure Requires arbitrary threshold May overemphasize severe crashes depending on weight values

EPDO Numerical Example
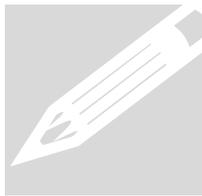
Assume that the 21 crashes at the intersection of Main Street and Broadway Avenue comprised 0 fatal, 3 injury, and 18 PDO crashes. Assume that your agency used 11; 11; and 1 for severity weights for fatal, injury, and PDO crashes, respectively.

$$EPDO = 11 * 0 + 11 * 3 + 1 * 18$$
$$= 51 \text{ equivalent PDO crashes}$$

Relative Severity Index ☺☺

As the term "relative" implies, the Relative Severity Index (RSI) compares a particular crash site against similar sites. A similar site is one displaying similar characteristics, such as traffic demand and geometry. RSI determines whether a particular site is experiencing higher or lower crash costs than an average, similar site. The average RSI for a particular site i, $\overline{RSI_i}$, can be computed as:

$$\overline{RSI_i} = \frac{\sum_{j=1}^{n_T} N_j * C_j}{\sum_{j=1}^{n_T} N_j} \tag{3-5}$$

Where,

n_T = # of different types of crashes (e.g., rear-end, angle, sideswipe);

N_j = # of crashes of a particular crash type, j;

C_j = average crash cost for a particular crash type, j.

In the absence of local data, national agency data (e.g., Federal Highway Administration [FHWA] data) can be used to estimate crash costs by crash type (Council et al., 2005). Table 3.4 shows examples of crash costs for different types of crashes in 2001 dollars. Steps for translating previous year costs to current year costs can be found in Chapter 5, under the section entitled "Economic evaluation of countermeasures."

Table 3.4 Example of Crash Cost by Crash Type[1]

Crash Type	Crash Cost
Single vehicle struck human, at intersection	$158,866
Single vehicle struck human, not at intersection	$287,917
Single vehicle struck object	$94,669
Single vehicle rolled over	$239,721
Multiple vehicles cross paths at signal (angle)	$47,333
Multiple vehicles cross paths at sign (angle)	$61,114
Multiple vehicles rear-end at all locations	$30,544
Multiple vehicle sideswipe	$34,004
Multiple vehicles, opposite direction not at intersection (head-on)	$375,075
Multiple vehicles, opposite direction at signalized intersection (head-on)	$24,069
Multiple vehicles, opposite direction at signed intersection (head-on)	$47,478

The RSI for an average, similar site, $\overline{RSI_s}$, is computed as:

$$\overline{RSI_S} = \frac{\sum_{j=1}^{n} \sum_{k=1}^{n_{j,T}} N_{j,k} * C_{j,k}}{\sum_{j=1}^{n} \sum_{k=1}^{n_T} N_{j,k}} \tag{3-6}$$

Where,

       n = # of similar sites;

       $n_{j,T}$ = # of different types of crashes for a particular site j;

       $N_{j,k}$ = # of crashes of a particular crash type k at site j;

       $C_{j,k}$ = average crash cost for a particular crash type k at site j.

Table 3.5 calls attention to the fact that RSI requires crash type information and crash cost estimates for each type of crash.

---

[1] Taken from Council et al. (2005), Table 11: Level 4 without speed limits.

Table 3.5 RSI Characteristics

Data Needs	
# of crashes by type and location, crash costs by type	
Strengths	**Limitations**
Relatively simple.	Omits other variables for more accurate forecasting.
Availability of data through HP/MoDOT.	Not account for RTM bias.
Easy way of forecasting # of crashes using traffic volumes as only variable.	Not account for exposure.
Considers severity.	Requires arbitrary threshold.
	May overemphasize locations with severe crashes.
	Requires crash and cost data by crash type.

RSI Numerical Example
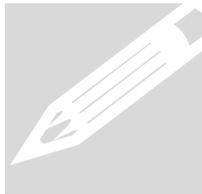
Assume that the 21 crashes at the signalized intersection of Main Street and Broadway Avenue comprised 5 angle, 10 rear-end, and 6 sideswipe crashes.

$$\overline{RSI_\iota} = \frac{5 * \$47,333 + 10 * \$30,544 + 6 * \$34,004}{5 + 10 + 6} = \$35,530$$

Assume that 10 similar sites were used for comparison against Main and Broadway. These sites totaled 198 crashes comprising 38 angle, 105 rear-end, and 55 sideswipe crashes.

$$\overline{RSI_s} = \frac{38 * \$47,333 + 105 * \$30,544 + 55 * \$34,004}{38 + 105 + 55} = \$34,727$$

Since $\overline{RSI_\iota} > \overline{RSI_s}$, Main and Broadway experienced slightly higher crash costs than did similar sites.

Critical Crash Rate ☻☹

Critical crash rate is a threshold value computed using locations with similar characteristics. If the observed crash rate at a particular location is greater than this threshold, then further analysis is recommended for the location. The agency assigns a level of confidence to the threshold value. Thus, the higher the threshold value, the less likely a location will exceed the threshold. The following critical crash rate equations assume that crashes follow a Poisson distribution.

$$OBR_i = XS + K\sqrt{\frac{XS}{V_i}} + \frac{1}{2V_i} \tag{3-7}$$

$$V_i = \frac{TEV}{1,000,000} * n * 365 \qquad (3\text{-}8)$$

Where,

OBR_i = crash rate observed at location i;

XS = mean crash rate for similar locations;

V_i = traffic volume at location i, in units of million entering vehicles;

K = level of confidence constant;

TEV = total entering volume per day;

n = number of years of crash data.

The level of confidence constant, K, is taken from the standard normal table. Table 3.6 displays popular confidence level values.

Table 3.6 Common Values for Confidence Level Constant

90 Percent	95 Percent	99 Percent
1.282	1.645	2.326

As shown in Table 3.6, critical crash rate has characteristics similar to crash rate, with the addition of a statistical threshold. The critical crash rate is also similar to the RSI in its method of comparing a specific site against similar locations.

Table 3.7 Critical Crash Rate Characteristics

Data Needs	
# of crashes, traffic volumes	
Strengths	**Limitations**
Relatively simple. Availability of data through HP/MoDOT. Easy method of forecasting # of crashes using traffic volumes as only variable. Accounts for exposure. Can analyze by type and/or severity. Considers variance in crash data. Establishes comparison threshold.	Omits other variables for more accurate forecasting. Not account for RTM bias. Cannot compare across sites with significant volume differences.

Critical Crash Rate Example
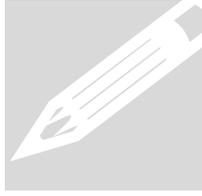
Assume that Main Street and Broadway Avenue experienced 21 crashes from 2009-2011, and that the sum of the AADTs from all approaches was 10,000 vehicles/day. The same values were used in the crash rate example. Also, assume the mean crash rate for similar locations, *XS*, to be 1.5 crashes per million entering vehicles. Use a 95% confidence level.

$$V_i = \frac{10,000 \; \frac{vehicles}{day}}{1,000,000} * 3 * 365 = 10.95 \; million \; entering \; vehicles$$

$$1.5 \; \frac{crashes}{MEV} + 1.645 \sqrt{\frac{1.5 \; \frac{crashes}{MEV}}{10.95 \; MEV} + \frac{1}{2 \; 10.95 \; MEV}} = 2.15 \; \frac{crashes}{MEV}$$

Thus, the observed crash rate at Main Street and Broadway of 1.92 crashes/MEV is less than the critical crash rate of 2.15 crashes/MEV.

Method of Moments Adjustment ☺☺

The method of moments (MEM) is a way of adjusting the observed site crash frequency using the variability of similar sites. In other words, this method assumes that a specific site value should not fall outside the natural variability of similar sites. This adjustment partially corrects the regression-to-the-mean (RTM) problem. Loosely, the term stems from the fact that the mean and variance are also called statistical moments, and such moments are estimated using a sample of similar sites.

The variance in crash frequency for all similar sites is computed as:

$$Var(N) = \frac{\sum_{i=1}^{n}\left(N_{observed,i} - N_{observed,rp}\right)^2}{n_{sites}-1} \tag{3-9}$$

Where,

   $N_{observed,i(adj)}$ = observed crash frequency at site i;

   $N_{observed,rp}$ = average crash frequency for similar sites (i.e., reference population);

   N_{sites} = number of similar sites (i.e., reference population).

The adjusted observed crash frequency is computed as,

$$N_{observed,i(adj)} = N_{observed,i} + \frac{N_{observed,rp}}{Var(N)} * \left(N_{observed,rp} - N_{observed,i}\right) \tag{3-10},$$

where the variables are the same as those previously defined in Equation 3-9. If the observed crash frequency is lower than the average crash frequency, then the observed

crash frequency is adjusted upwards. If the observed crash frequency is lower, then the crash frequency is adjusted downwards. In other words, if a particular site falls too far outside the variability of similar sites, then it is brought back "closer to the pack." In contrast to the critical crash rate method, MEM adjusts the observed crash frequency, and not the average crash frequency, of similar sites.

Table 3.8 lists MEM characteristics, and illustrates that MEM's dependence on similar sites is both a strength and a limitation. Using similar sites can establish a threshold for comparison and a measure of variability, but can also influence screening results.

Table 3.8 MEM Characteristics

Data Needs	
# of crashes by type and location	
Strengths	**Limitations**
Relatively simple.	Omits other variables for more accurate forecasting.
Availability of data through HP/MoDOT.	Partial accounting of RTM bias.
Establishes a comparison threshold.	Does not consider traffic volume.
Considers variance of similar sites.	Screening is affected by crash frequency of similar sites.

MEM Numerical Example

Assume that the intersection of Main Street and Broadway Avenue experienced 21 crashes from 2009-2011, or, a crash frequency of 7 crashes/year. Assume that 8 similar intersections with the same type of signal control and phasing averaged 5 crashes/year, with a variance of 4.9.

$$N_{observed,i(adj)} = 7\frac{\text{crashes}}{\text{year}} + \frac{5\frac{\text{crashes}}{\text{year}}}{4.9} * (5 - 7) = 4.96\frac{\text{crashes}}{\text{year}}$$

Here, the MEM adjustment reduced the observed crash frequency to near that of the average crash frequency for similar sites. Contrast this with the use of crash frequency without adjustments.

Introduction to HSM-Based Service Performance Measures

The last four safety performance measures are based on the HSM. Therefore it is important to include a discussion of HSM modeling, and to provide a specific example of an HSM model. One major benefit of HSM is that it is a national manual, like the Highway Capacity Manual or the American Association of State Highway and Transportation Officials (AASHTO) Green Book. The HSM utilizes research data from across the U.S.; therefore, it benefits from a wealth of safety research from multiple states. One major component of the HSM is its presentation of safety performance functions (SPF). SPF is not to be confused with "safety performance

measures," a term also used in this chapter. SPF predicts a "normal expected level of safety" for specific types of facilities. Thus, SPFs model the expected number of crashes at a particular facility. SPF enables the type of "what-if scenario" analysis that is impossible when using only observed data. The flexibility and usefulness of SPF comes at the cost of being labor- and data-intensive. Also, national data may not be locally applicable, and it requires calibration. Still, this relatively new manual appears to have gained widespread acceptance and use at the state level. Information on HSM spreadsheets that can aid in SPF calculations can be found in Chapter 4 on page 67.

The following example illustrates the use of HSM SPF. The example applies to rural, two-lane roadways. The base SPF expressing crash frequency is computed as follows:

$$N_{spf} = AADT * L * 365 * 10^{-6} * e^{(-0.312)} \qquad (3\text{-}11)$$

Where,

$AADT$ = annual average daily traffic;

L = length of the road segment in miles.

Equation 3-11 is easy to use. It indicates that crash frequency is proportional to exposure in terms of the amount of traffic and the length of the roadway. But each SPF has a set of associated crash modification factors (CMF) that requires extensive data to produce accurate results. The predicted crash frequency is comprised of the base SPF multiplied by the CMF, as follows:

$$N_{predicted} = N_{spf} * CMF_1 * CMF_2 * CMF_3 * ... * C \qquad (3\text{-}12)$$

The types of data required for CMF include lane width, shoulder width and type, roadside hazard rating (in terms of the number and closeness of roadside objects), driveway density, and curve geometrics for curved sections. The details of the curve geometrics include curve length and radius and the use of spiral curves.

Level of Service of Safety ☺☺☺☺
The level of service of safety (LOSS) method assigns a qualitative grade (i.e., I-IV) to a particular location. This method replicates the Highway Capacity Manual (HCM) (TRB, 2010) process of assigning a user-friendly qualitative grade based on a quantitative measure. The grade is based on the difference between observed crash frequency and the HSM-predicted average crash frequency. The LOSS grades are assigned as follows:

$$0 < \text{LOSS I} < N - 1.5\sigma < \text{LOSS II} < N < \text{LOSS III} < N + 1.5\sigma < \text{LOSS IV} \qquad (3\text{-}13)$$

$$\sigma = \sqrt{k + N^2} \qquad\qquad\qquad (3\text{-}14)$$

Where,

N = predicted average crash frequency from the HSM;

σ = standard deviation of predicted crashes;

k = SPF overdispersion parameter.

The overdispersion parameter is used in the HSM to reflect the fact that the variance exceeds the mean for crash data.

LOSS I represents a low potential for crash reduction at a particular site, while LOSS IV represents a high potential for crash reduction. Expressed verbally, Equation 3-11 says that LOSS I indicates an observed crash frequency that is less than 1.5 standard deviations from the predicted crash frequency. LOSS II indicates an observed crash frequency that is greater than LOSS I, but does not exceed the predicted crash frequency. LOSS III indicates an observed crash frequency that is greater than the predicted crash frequency but less than 1.5 standard deviations above the predicted crash frequency. LOSS IV indicates an observed crash frequency that is greater than 1.5 standard deviations above the predicted crash frequency.

The crux of the LOSS method is the computation of N using the HSM. Table 3.9 illustrates the single major issue with HSM-based measures, i.e., that they are labor- and data-intensive; not only does the HSM method require the user to be familiar with HSM models, it also necessitates extensive data collection for modeling the safety of facilities. One major benefit of LOSS is that the end product, a grade of I-IV, is user-friendly and accessible to the general public.

Table 3.9 LOSS Characteristics

Data Needs	
# of crashes by location, HSM SPF and necessary data (e.g., geometrics, traffic demand, land-use, signalization), overdispersion factor	
Strengths	**Limitations**
Establishes a comparison threshold.	Partial account for RTM bias.
Considers variance in crash data.	HSM is data and labor intensive.
Accounts for traffic volume.	Set thresholds at 1.5σ intervals.
Produces a user-friendly qualitative grade.	

LOSS Numerical Example
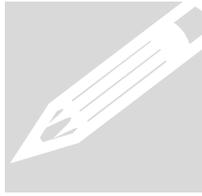
Assume that the intersection of Main Street and Broadway Avenue experienced 21 crashes from 2009-2011, or, a crash frequency of 7 crashes/year. Assume that the HSM SPF predicts the crash frequency to be 5 crashes/year, and k = 0.5.

$$\sigma = \sqrt{0.5 + 5^2} = 5.05 \text{ crashes/year}$$

$$0 < \text{LOSS I} < 5 - 1.5(5.05) < \text{LOSS II} < 5 < \text{LOSS III} < 5 + 1.5(5.05) < \text{LOSS IV}$$

Since the observed crash frequency is 7 crashes/year, LOSS III is assigned, as it includes between 5 and 12.57 crashes/year.

Excess Safety Performance Function Crash Frequency ☺☺☺☺

The excess is the difference between the observed crash frequency and the predicted crash frequency using HSM SPF. Thus, any excess means that the observed site crash frequency was higher than predicted. The excess is computed as:

$$Excess(N) = \overline{N_{observed,i}} - \overline{N_{predicted,i}} \tag{3-15}$$

Where,

$\overline{N_{observed,i}}$ = observed crash frequency for site i;

$\overline{N_{predicted,i}}$ = HSM predicted crash frequency for site i.

Table 3.10 Excess SFP Characteristics

Data Needs	
# of crashes by location, HSM SPF and necessary data (e.g., geometrics, traffic demand, land-use, signalization)	
Strengths	**Limitations**
Establishes a comparison threshold.	Partial account for RTM bias.
Accounts for traffic volume.	HSM is data- and labor-intensive.

Excess SPF Example

Assume that the intersection of Main Street and Broadway Avenue experienced 21 crashes from 2009-2011, or, a crash frequency of 7 crashes/year. Assume that the HSM SPF predicts the crash frequency to be 5 crashes/year.

$$Excess(N) = 7 - 5 = 2 \text{ crashes/year.}$$

Thus, the crash frequency is slightly higher than predicted for this example site.

Specific Crash Type Proportion Threshold ☺☺☺☺

This method estimates the probability that the true proportion of a particular crash type is greater than a threshold based on similar sites. Though the object of this method is easy to understand, its use is somewhat more complex, since it requires the estimation of mathematical distribution parameters. The reader is referred to the HSM, and to Lyon et al. (2007), for detailed explanations of this method. As illustrated by Table 3.11, the fundamental difference between this method and those based on the HSM is that this method does not require the computation of SPF. Thus the data requirement is not as great, since only enough information is required as to classify sites as a particular type. This method can be used as a diagnostic tool to identify crash types toward which treatments could be targeted.

Table 3.11 Specific Crash Type Proportion Threshold Characteristics

Data Needs	
# of crashes by type and location	
Strengths	**Limitations**
Establishes a comparison threshold.	Does not account for traffic volume.
Can be used as a diagnostic tool.	Requires distribution parameter estimation.
Not affected by RTM.	
Considers variance in crash data.	

Empirical Bayes Adjustments ☺☺☺☺☺

Empirical Bayes (EB) is a method of combining observed crash data with the safety performance of similar sites. Two main advantages of using EB include increased precision when using limited data (e.g., two or three years of crash data) and correction for RTM bias. EB adjustments can be applied to several of the previous methods, namely, average crash frequency, equivalent property damage only average crash frequency, and excess safety performance function crash frequency.

Previous measures have combined observed and predicted data, such as to compute an excess or a level of safety. EB differs by combining crash data with the expected crash frequency at similar sites in order to produce a single estimate. This combination is performed via a weighted average, as follows:

$$\textit{Estimate of the expected crashes at a site} =$$
$$\textit{weight} * \textit{crashes expected at similar sites} + (1 - \textit{weight}) *$$
$$\textit{crashes at a site} \tag{3-16}$$

The weight is based on the strength of the crash record and the reliability of the SPF. The strength of the crash record is the number of crashes expected at a site. The SPF reliability is the degree to which the safety of a specific site is expected to differ from the SPF average. The weight is computed as,

$$weight = \frac{1}{1+(\mu*Y)/\varphi}$$ (3-17)

Where,

μ = predicted crash frequency;

Y = number of years;

φ = overdispersion factor.

The standard deviation of the estimate, $\sigma(estimate)$, is computed as,

$$\sigma(estimate) = \sqrt{(1 - weight) * estimate}$$ (3-18)

The estimate in Equation 3-18 is the same as the estimate of the expected crashes at a site that was presented in Equation 3-16.

Empirical Bayes Example

Assume that the intersection of Main Street and Broadway Avenue experienced 21 crashes from 2009-2011, or, a crash frequency of 7 crashes/year. Assume that the HSM SPF predicts the crash frequency to be 5 crashes/year. Also assume $\varphi = 1.9$.

$$weight = \frac{1}{1+(5*3)/1.9} = 0.11$$

Estimate = 0.11*5+0.89*7 = 6.78 crashes per year.

$$\sigma(estimate) = \sqrt{(1 - 0.11) * 6.78} = 2.45 \text{ crashes per year}$$

Note how, in this example, the observed crash rate of 7 crashes/year was pulled toward the mean of five crashes/year, thus correcting for regression-to-the-mean bias.

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Chapter

4

CHAPTER 4: SAFETY ANALYSIS TOOLS

Maximizing use of the toolbox to improve safety.

An important part of developing a safety plan for local communities involves the analysis of locations in order to identify safety concerns. There are a variety of tools available that can be used by an analyst to evaluate safety at individual locations and multiple locations simultaneously. The analyst may elect to utilize several of these tools as part of a comprehensive evaluation of safety in a local community. For example, the analyst might utilize tools to evaluate multiple locations, in order to identify specific locations with safety concerns. The user could then use other tools to evaluate the safety of individual locations that were identified during the first stage of the analysis.

Tools for Analyzing Individual Locations

There are a number of tools that can be used by analysts to evaluate safety concerns at individual locations. Some of these tools include collision diagrams, on-site observation reports, condition diagrams, traffic data collection, spot speed studies, traffic conflict studies, sight distance evaluations, and location analysis worksheets. These tools are described in greater detail in the following sections.

Collision Diagram ☺ ☺

A collision diagram quickly reveals where crashes are occurring at each high-crash location and provides detailed information pertaining to each crash. Using the diagram, it is easy to observe any patterns in crash type that formed during the analysis period. However, since the examination of the collision diagram is a critical point in conducting a successful analysis, it is helpful to review all information pertaining to the location.

Use the following steps to prepare a collision diagram:

1. Obtain crash reports for all crashes occurring at the location during the previous one to three years. If significant changes (e.g., signals, stop signs, construction, etc.)

were made to the location in recent years, do not include reports for crashes that occurred prior to those changes.

2. Sketch a collision diagram similar to the one found in Figure 4.1. The diagram must show the general path of all vehicles involved in each crash, as well as the approximate point of each impact. The diagram need not be to scale, but it should allow for sufficient room to illustrate the paths and object(s) involved in each crash.

3. Be sure to include all of the information shown in Figure 4.1, such as the type and location of all traffic control devices. Use the symbols suggested on the form to show the type and severity of each crash. Label other basic characteristics of each crash, such as:

   • date, day, and time of crash,

   • lighting conditions (day or night),

   • pavement conditions at the time of the crash (dry, wet, icy, etc.), and

   • number of injuries or fatalities.

4. Note any special circumstances associated with a crash; particularly, any comments from a driver or investigating officer concerning glare, non-functional traffic control devices, poor pavement conditions, or sight obstructions.

5. Display any non-involved (non-contact) vehicles or pedestrians on the diagram; an example could include an incident during which a vehicle was sitting in traffic behind a left-turn vehicle and, while waiting at the end of the line, was struck in the rear by an approaching third vehicle. The vehicle making the left turn would be considered a non-involved vehicle since it was not involved in the actual collision; its intended path should be marked with a dashed line, since the vehicle affected the behavior of other vehicles that were involved in the crash.

6. Identify any crash patterns that are present. Note the types of crashes occurring on each intersection approach or along the section of street.

7. Summarize the times when crashes occurred, as well as weather and pavement conditions. These summaries will be entered in Part D of the Location Analysis Worksheet (Fig. 4.4).
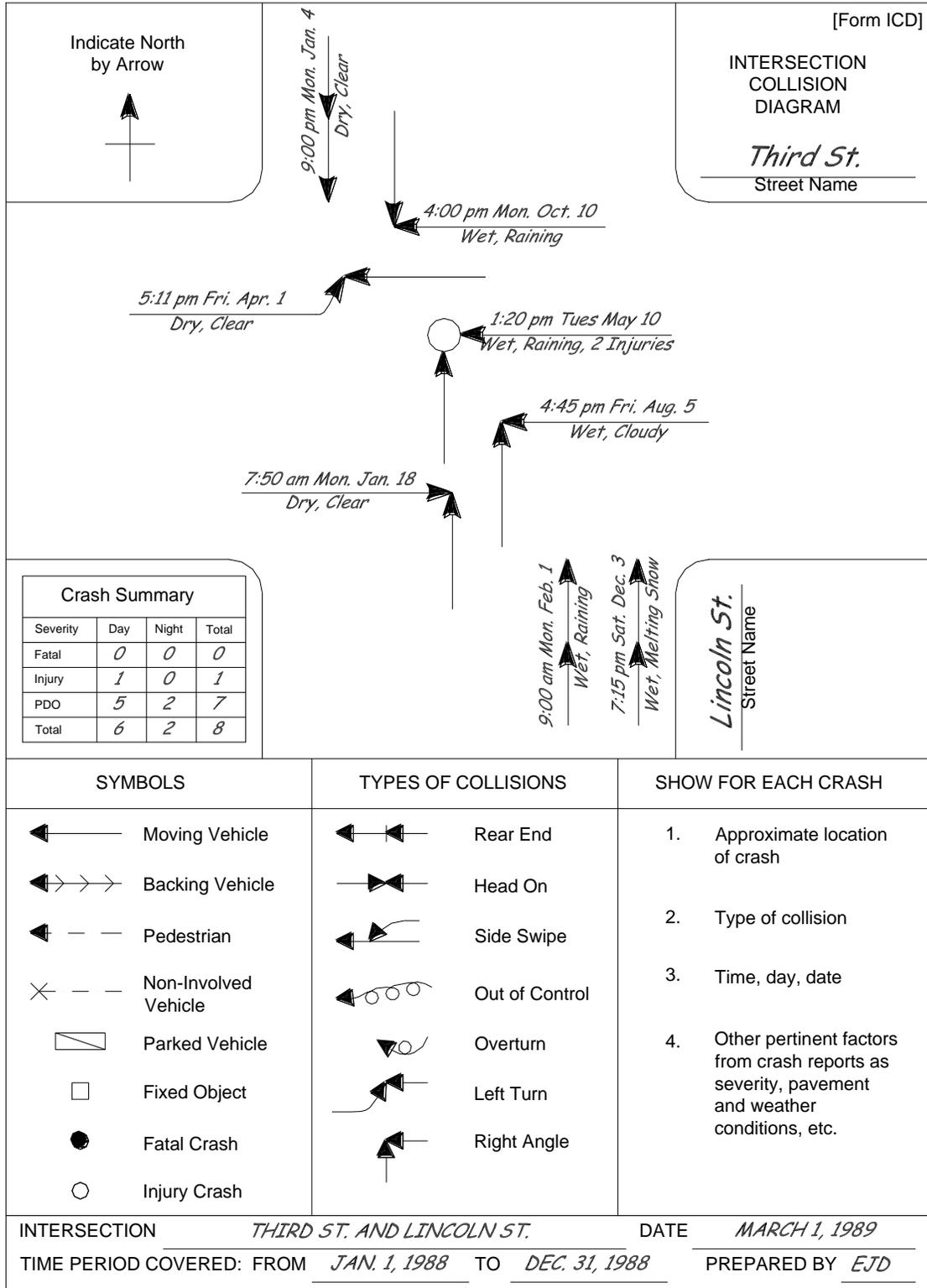
Figure 4.1 Collision diagram.

On-Site Observation Report 🕐 🕐

The on-site observation report tool can provide a useful perspective for analysis and countermeasure selection at an individual location. The on-site observation report shown in Figure 4.2 can be of great assistance in conducting inspections.

Careful preparations should be made for the on-site visit. Information concerning the site, including collision diagrams, crash summaries, and traffic counts, should be reviewed. Schedule the visit to correspond with predominant crash characteristics; for example, nighttime, peak volume, or wet pavement conditions. Be sure to fill in the first three lines of the report in advance of the field trip. Complete the observation report as follows:

1. Observation Points: Upon arriving at the site, drive through the location several times from different directions, paying close attention to how drivers might see the environment. Identify several good vantage points that provide a clear view of traffic from a safe position. Ensure that the observation points are situated so that motorists will not notice they are being observed (drivers will act differently if they suspect they are being watched).

2. Physical Checklist: Complete the "Physical Checklist" to become familiar with the features of the location and to identify potential hazards. Place a mark after the items on the list that might create problems or contribute to crashes.

3. Operational Checklist: Observe pedestrian and driver activity at the location to complete the "Operational Checklist." Note any sudden or erratic maneuvers, instances of driver or pedestrian confusion, and/or violations. Place a mark following items on the "Operational Checklist" that may be associated with confusing or hazardous site characteristics.

4. Comments: After observing traffic for approximately one hour, reconsider the items in the "Physical Checklist" to determine whether anything may have been overlooked during the original location assessment. Prior to leaving the site, list all marked items under the "Comments" section at the bottom of the second page. For each item listed, provide comments and descriptions that could be helpful in identifying any crash contributing factors. To produce useful and valuable documentation of the on-site observations, each commentary should be made as complete as possible. Use extra pages if necessary.

5. Photographs: Taking photographs of the site in order to document location characteristics is advised. Number each photograph sequentially. If there is a need to specify a physical dimension of a photographed feature (e.g., length), place markers of a known dimension next to the feature before photographing it. Another method is to take a measurement, carefully noting it on the rear of the report form along with the number of the photograph.

6. Interviews: It may also be advisable to interview individuals who live or work near the site location, recording their remarks concerning hazardous conditions or dangerous operational characteristics.

ON-SITE OBSERVATION REPORT				[Form OSOR-1]
LOCATION	*Third St. and Lincoln St.*		CONTROL DEVICES	*2-way stop*
OBSERVER *EJD*	DAY	*Tues.*	DATE	*June 5, 1999*
	TIME	*4:30 pm*	WEATHER	*Occasional Rain*

PHYSICAL CHECKLIST:	CHECK ITEM IF PROBLEM EXISTS
1. Obstructions block view of traffic control devices at or near the location?	
2. Obstructions block view of opposing or conflicting traffic?	
3. The legal parking layout restricts sight distances?	X
4. Traffic signs are satisfactory as to number, size, message, placement, reflectivity, and visibility? (see MUTCD)	X
5. Traffic signals are satisfactory as to number, lense size, placement, visibility, and timing? (see MUTCD)	
6. Pavement markings are satisfactory as to location, size, message, color, and visibility? (see MUTCD)	X
7. Channelization devices, such as islands, are adequate for:	
A. Reducing traffic conflict areas?	
B. Defining traffic movement paths?	
C. Separating traffic flows?	
8. Curb radii are adequate for turning vehicles?	
9. Roadway horizontal curves too sharp?	
10. Approach grades at intersection too steep?	
11. Pavement has proper crown and superelevation?	X
12. Lane and street widths are adequate?	
13. The pavement surface condition is satisfactory? (Consider potholes, rutting wash board, edge drop-offs, raveling, bleeding surface, cracking, and poor drainage.)	X
14. The roadside is clear of hazardous objects?	
15. Driveways are properly placed and designed?	
16. Pedestrian crosswalks are properly placed and designed?	
17. Street lighting is satisfactory?	
18. Advertising signs or lights reduce driver visual capability?	

Figure 4.2 On-site observation report – Page 1.

ON-SITE OBSERVATION REPORT - PAGE 2 [Form OSOR-2]

OPERATIONAL CHECKLIST:

CHECK ITEM IF
PROBLEM EXISTS

1. Drivers respond correctly to traffic control devices at and near the location?	
2. Repeated violations of traffic control devices or regulations?	
3. Vehicle speeds too high for existing conditions?	
4. Vehicles change speeds or stop unexpectedly?	
5. Vehicles change lanes unexpectedly?	
6. Certain traffic movements could create a hazard?	
A. Left-turning vehicles:	X
B. Straight-through vehicles:	X
C. Right-turning vehicles:	X
7. Parked vehicles or parking maneuvers create hazards?	X
8. Vehicles entering or departing from driveways create hazards?	
9. Traffic congestion and/or delays create hazards?	
10. Bicycles at the location cause confusion or conflicts?	
11. Pedestrians at the location cause confusion or conflicts?	

COMMENTS AND DESCRIPTION OF EACH PROBLEM IDENTIFIED ON CHECKLISTS:

(P = Physical with item number; O = Operational with item number)

P-3 Parking too close to corners; causes restricted view from Lincoln in all directions.

P-4 Signs for parking restrictions not in place.

P-6 Yellow curb markings faded.

P-11 No crown on Lincoln - causes ponding.

P-13 "Washboard" on Lincoln, slick patches & raveling on 3rd.

O-6 Any movement from Lincoln could be risky depending on location of parked vehicles.

O-7 Parking as close as 10 feet from corner.

(Continue comments as necessary on additional pages.)

Figure 4.2 On-site observation report – Page 2.

Condition Diagram ☺ ☺

A condition diagram, or roadway inventory, is a drawing (to scale) of the existing roadway, control device locations, and major features in the nearby environment. When prepared for a high-crash location, the diagram assists in relating crash patterns and probable causes to the physical features on and near the roadway.

A scale of 1 inch = 20 feet or 1 inch = 50 feet is typically used when drawing the condition diagram. The amount of information placed on the diagram is related to the type of improvements being considered. A location receiving only minor improvements, such as the installation of warning signs, would probably need only a few important measurements. A more detailed evaluation involving sight distance problems, possible alignment changes, or left-turn channelization might require a complete drawing with lane widths, approach grades, and distances to sight obstructions.

A completed condition diagram for a high-crash location (Fig. 4.3) should contain the following items:

- Date the diagram was prepared

- Observer's name

- Street names

- Street functional classification (arterial, collector, local)

- Traffic control devices (signs, signals, markings)

- North direction arrow

- Intersection angle

- Speed limits on all approaches

- Other traffic regulations

- Widths of all streets, lanes, medians, and parking stalls

- Parking set-backs and regulations

- Sidewalk and crosswalk locations

- Location and height of objects obstructing view (fences, shrubs)

- Location of fixed objects (buildings, utility poles, large trees, culvert headwalls, curb-side mail boxes, fire hydrants)

- Position of street lights and light poles

- Driveway locations and widths

- Road surface materials and significant surface irregularities

- Grades on all approaches

- Corner radii

- General classification of nearby land use and building use
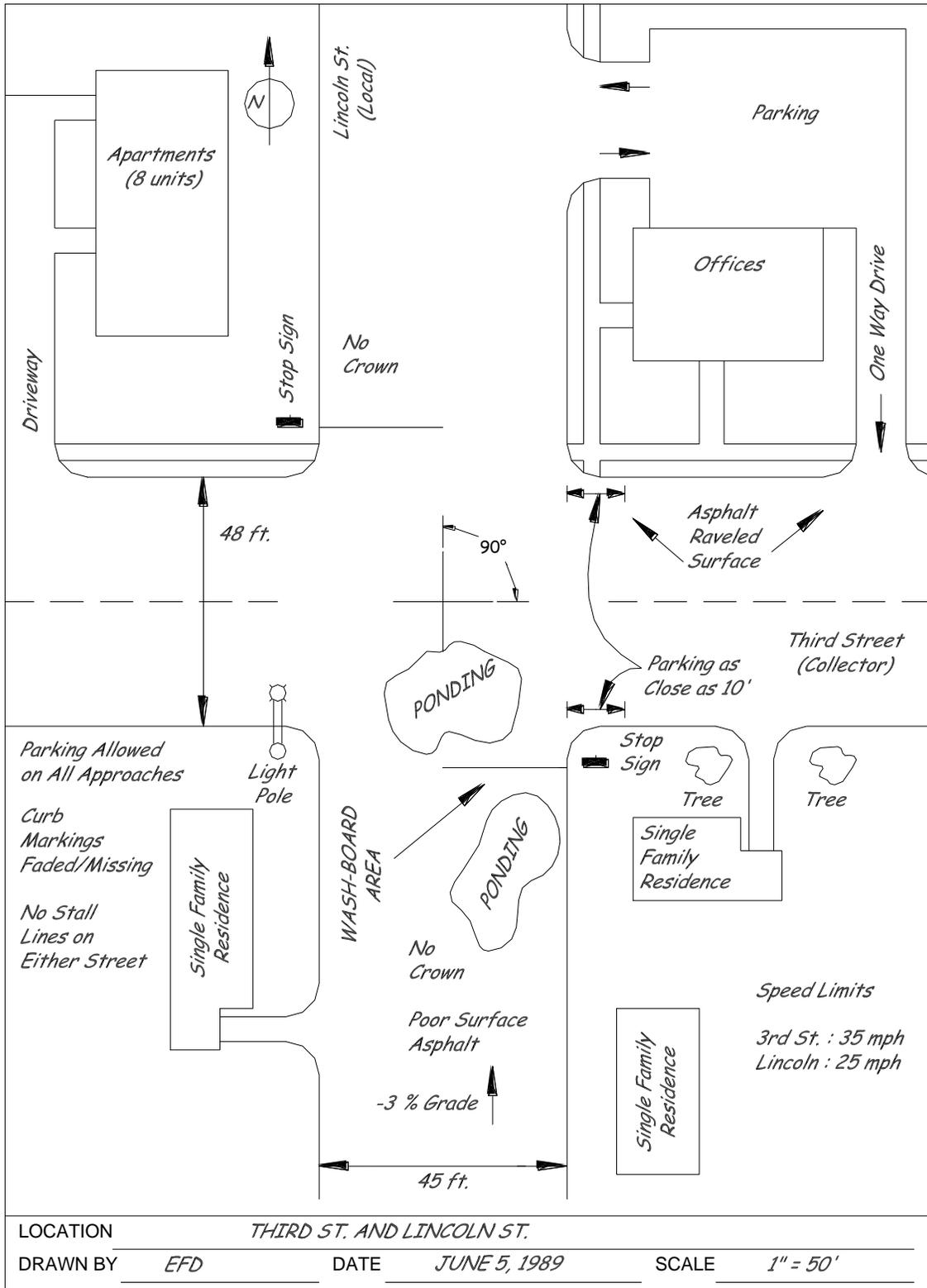
Figure 4.3 Condition diagram.

Traffic Data Collection ⏱ ⏱

A complete analysis of a high-crash location requires additional traffic data. Basic 24-hour traffic volume estimates are required in order to estimate average daily traffic (ADT). Volume counts at an intersection should show the incoming directions, turns, and departing directions for all vehicles. Counts taken at a mid-block section should specify the amount of traffic in each direction and in each lane. In urban areas, especially near schools, pedestrian and bicycle counts may be very helpful for high-crash location analysis.

Spot Speed Studies ⏱ ⏱ ⏱

Speed studies should be conducted when vehicle speed is a possible crash causal factor. Because speed is related to stopping distance, it is necessary to determine vehicle speed. The spot speed study makes it possible to properly evaluate speed regulation in the vicinity, and to check for adequate sight distances at critical locations, such as intersections and driveways.

Traffic Conflicts Studies ⏱ ⏱ ⏱ ⏱

Traffic conflicts analysis is a method for observing situations in which one driver is forced to take evasive action, such as swerving or braking, to avoid colliding with another vehicle. The frequency of the different types of conflicts is assumed to indicate the potential for crashes at the site. It is generally agreed that a traffic conflicts analysis should not be used to replace crash data analysis; however, it can be used as a supplementary tool to help identify possible countermeasures.

Sight Distance Evaluations ⏱ ⏱ ⏱

Sight distance evaluations are essential for evaluating locations in which sight distance appears to be a contributing factor to a location's crash history. It is also important for determining the type of control device to be used at an unsignalized intersection. These studies are primarily concerned with sight distances across intersection quadrants and along roads that must be crossed or entered. It is advisable to coordinate traffic control device selection with traffic characteristics and available sight distances.

Location Analysis Worksheet ⏱ ⏱ ⏱

A location analysis worksheet can be a useful tool to help identify specific safety concerns at a given location. The following steps describe how to complete the location analysis worksheet (Fig. 4.4).

1.   Location Identification: Record the location name, date, and existing traffic control devices at the top of the page.

2.   Part A: Complete this section based on the crash data for the location.

3.   Part B or Part C: If the location is an intersection, complete Part B. If it is a mid-block section, complete Part C.

4.   Part D: Complete this section with the information found in the collision diagram.

5.   Part E, "Crash Patterns Identified": Using the information in Parts B or C, the collision and condition diagrams, and the observation report, identify any single predominant crash pattern. Other patterns are classified as secondary.

6.   Part E, "Probable Causes": Determine probable causes of crashes and their general countermeasures.

7.   Part E, "Supporting Data Attached": Place a mark next to the data that will be included with the report.

8.   Part E, "General Conclusions": Using supporting data, summarize the findings of the analysis.

9.   Part E, "Specific Countermeasures": Prior to entering the specific countermeasures, determine that each is feasible and satisfies established warrants. It is essential that warrants be considered to assure the selection of appropriate countermeasures. The Manual on Uniform Traffic Control Devices (MUTCD) contains warrants for installing signals and other traffic control devices. Even if the warrants for a particular countermeasure are satisfied, alternative improvements should be compared. Finally, it may be necessary to review additional information about the site, such as right-of-way plans, to determine whether a specific improvement would require property acquisition.

10.   Part E, "Best Countermeasure, Benefit/Cost Ratio, etc.": Select the best countermeasure or combination of countermeasures from the specific countermeasures. Wait to enter the B/C ratio, costs, savings, and priority until the analysis of countermeasures has been completed.

LOCATION ANALYSIS WORKSHEET [Form LAW-1]

LOCATION   *Third Street and Lincoln Street*   DATE   *June 6, 1999*

EXISTING TRAFFIC CONTROL   *two-way stop (on Lincoln)*

PART A - CRASH NUMBER, RATE AND EPDO SUMMARY

Section Length (in miles) *mid-block only*	Year	Number of Crashes				EPDO Number	ADT	Exposure	Crash Rate	EPDO Rate
		Fatal	Injury	PDO	Total					
	1988		*1*	*7*	*8*	*13*	*3,600*	*1,314,000*	*6.088*	*9.893*
	1987	*1*	*1*	*4*	*6*	*16*	*3,550*	*1,295,750*	*4.631*	*12.348*
	1986		*1*	*3*	*4*	*9*	*3,400*	*1,241,000*	*3.223*	*7.252*
	TOTALS	*1*	*3*	*14*	*18*					
	2 OR 3 YR AVG	*0.33*	*1.00*	*4.67*	*6.00*	*12.667*	*3,517*	*1,283,583*	*4.674*	*9.868*

PART B - INTERSECTION-RELATED CRASHES

	Right Angle	Rear End	Side-Swipe		Head On	Ped.	Fixed Object	Right Turn	Left Turn	Other	TOTAL
			Meeting	Passing							
Number of Crashes	*8*	*6*				*1*		*1*	*2*		*18*
Percent of Total	*44.4%*	*33.3%*				*5.6%*		*5.6%*	*11.1%*		100%

PART C - MID-BLOCK CRASHES

	Vehicle Striking							Non-Collision		TOTAL
	Vehicle on Street	Parked Car	Vehicle at Drive	Fixed Object	Ped.	Train	Other	Over-Turn	Other	
Number of Crashes										
Percent of Total										100%

PART D - NUMBER OF CRASHES AND EXISTING CONDITIONS

Time of Day:	6:00 am - Noon	*5*		6:00 pm - Midnight	*5*		
	Noon - 6:00 pm	*7*		Midnight - 6:00 am	*1*		
Light Conditions:	Day	*13*	Night	*5*			
Surface Conditions:	Dry	*7*	Wet	*10*	Snow or Ice	*1*	
Weather:	Cloudy	*5*	Clear	*6*	Rain	*7*	Snow	Other
Other:							

Figure 4.4 Location Analysis Worksheet – Page 1.

LOCATION ANALYSIS WORKSHEET -

[Form LAW-2]

LOCATION   *Third Street and Lincoln Street*   DATE *June 6, 1999*

PART E - CRASH ANALYSIS SUMMARY

X COLLISION DIAGRAM ATTACHED

CRASH PATTERNS IDENTIFIED: Predominant   *Right Angle*

                               Secondary   *Rear End*

Probable Causes and Possible Countermeasures:

Restricted Site Distance: 1. Install 4-way
2. Remove sight obstructions
3. Restrict parking near corners
4. Reduce speed limits
5. Install overhead beacon

Slippery Pavement Surface: 1. Deslick
2. Improve drainage & crown

OPERATIONAL AND PHYSICAL DATA ANALYSIS

Supporting Data Attached: X On-Site Observation Report   X Condition Diagram
                              X Intersection Sight Distances   Spot Speed Study
                              X Volume/Turning Movement Count   Traffic Conflict Study
                                 Other:

General Conclusions from Supporting Data:

Sight distance in all directions from Lincoln is restricted by cars and vans parking too closely to corner.
Pavement has no crown on Lincoln.
Both Lincoln and Third have areas of "bleeding asphalt".
"Washboard" on Lincoln near stop line.

COUNTERMEASURE SELECTION

Specific Countermeasures:

1. Restrict parking.
2. Deslick pavement.
3. Combination of 1 and 2.

(Note: For each countermeasure, fill out a Countermeasure Analysis Worksheet)

Best Countermeasure	*3 - Combination*		
Benefit/Cost Ratio	*28.2*	Implementation Cost	*$13,300*
Average Annual Net Savings	*$62,527*	Priority Assigned	*1*

Figure 4.4 Location Analysis Worksheet – Page 2.

Tools for Analyzing Multiple Locations

In some cases, an analyst may wish to investigate many locations simultaneously. Since the publication of the previous HAL manual, many tools for the evaluation of multiple locations have been developed or enhanced, such as GIS and software packages, based on the Highway Safety Manual (HSM). Several of these tools are discussed in the following sections.

MoDOT Crash Statistics ⌚

The Missouri Department of Transportation (MoDOT) website contains a variety of crash statistics for crashes that have occurred on Missouri's highway system. The user can select from a variety of report formats based on location or type of crash. These reports can help the analyst to identify trends in the contributing factors for crashes in a specific area.

Location reports can be generated for a city, county, MoDOT region, Missouri State Highway Patrol (MSHP) troop, or the entire state. The output of the location reports includes the number of fatalities and serious injuries occurring at the selected location versus the number of crashes in the state, as well as the number of fatalities and serious injuries by target area. An example location report for Jefferson City for the years 2009-2011 is shown in Table 4.1. This report shows that 11 fatalities (0.44% of state total) and 208 serious injuries (1.14% of the state total) occurred in Jefferson City during this time period. The top three target areas associated with fatalities were horizontal curves, run-off-road crashes, and unrestrained occupants killed. The top three target areas involved in serious injuries were signalized intersection crashes, young drivers, and inattention.

In addition to reports for crash locations, reports can also be generated for different types of crashes, such as fatalities involving a horizontal curve, fatalities involving a vehicle following too closely, or fatalities involving an inattentive driver. Table 4.2 presents an example crash report for fatalities involving inattentive drivers. The output of this report reveals that 498 fatalities relating to this issue occurred between 2009-2011. The breakdown of fatalities by age group for this report shows that the 66-and-over age group comprised the largest percentage (17.3 percent) of fatalities involving an inattentive driver.

Table 4.1 Crash Report for Jefferson City (MoDOT)

City JEFFERSON CITY
Total Fatalities and Serious Injuries by Target Area
2009 - 2011

JEFFERSON CITY vs STATE

	Total Fatalities				Total Serious Injuries		
Year	Jefferson City	State	%	Year	Jefferson City	State	%
2009	5	878	0.57%	2009	46	6,540	0.70%
2010	5	821	0.61%	2010	66	6,096	1.08%
2011	1	786	0.13%	2011	96	5,643	1.70%
Total	11	2,485	0.44%	Total	208	18,279	1.14%

JEFFERSON CITY

Fatalities Involving					Serious Injuries Involving				
Description	2009	2010	2011	Total	Description	2009	2010	2011	Total
Horizontal Curves	2	3	1	6	Signalized Intersection Crashes	14	32	30	76
Run-off-Road Crashes	3	1	1	5	Young Drivers - 15-20	8	21	29	58
Unrestrained Occupants Killed	4	0	1	5	Inattention	16	10	22	48
Commercial Motor Vehicle	1	3	0	4	Unsignalized Intersection Crashes	15	12	19	46
Head-On Crashes (Non-Interstates)	0	3	0	3	Inattentive Drivers	15	9	20	44
Aggressive Driving-Speed Exceeded Limit	0	2	0	2	Unrestrained Occupants Seriously Injured	12	15	17	44
Alcohol and - or Other Drugs	0	1	1	2	Older Drivers -65-75	8	13	16	37
Young Drivers - 15-20	0	2	0	2	Run-off-Road Crashes	8	10	19	37
Aggressive Driving-Too Fast for Conditions	0	0	1	1	Older Drivers 76 or Older	4	8	12	24
Inattention	0	1	0	1	Horizontal Curves	1	9	12	22
Older Drivers 76 or Older	1	0	0	1	Aggressive Driving-Following Too Close	3	13	4	20
Pedestrians Killed	0	1	0	1	Aggressive Driving-Too Fast for Conditions	4	3	10	17
Signalized Intersection Crashes	1	0	0	1	Alcohol and - or Other Drugs	5	2	9	16
Unlicensed Drivers	0	0	1	1	Head-On Crashes (Non-Interstates)	1	9	6	16
Unsignalized Intersection Crashes	0	1	0	1	Motorcyclists Seriously Injured	2	6	8	16
Aggressive Driving-Following Too Close	0	0	0	0	Pedestrians Seriously Injured	5	1	8	14
Bicyclists Killed	0	0	0	0	Unlicensed Drivers	2	0	9	11
Collision with Tree	0	0	0	0	Commercial Motor Vehicle	3	5	1	9
Collision with Utility Pole	0	0	0	0	Bicyclists Seriously Injured	3	1	4	8
Head-On Crashes (Interstates)	0	0	0	0	Collision with Utility Pole	1	2	3	6
Inattentive Drivers	0	0	0	0	Collision with Tree	3	0	0	3
Motorcyclists Killed	0	0	0	0	Aggressive Driving-Speed Exceeded Limit	1	1	0	2
Older Drivers -65-75	0	0	0	0	Work Zones	0	1	0	1
School Buses/Bus Signal	0	0	0	0	Head-On Crashes (Interstates)	0	0	0	0
Work Zones	0	0	0	0	School Buses/Bus Signal	0	0	0	0

Table 4.2 Crash Report for Fatalities Involving Inattentive Drivers (MoDOT)

Total Fatalities by Age and Target Area
2009 - 2011

Killed Involving an Inattentive Driver

Age	Fatalities	Percent of Total Fatalities
* >= 66	86	17.27%
15-20	63	12.65%
21-25	52	10.44%
26-30	46	9.24%
41-45	42	8.43%
51-55	40	8.03%
56-60	39	7.83%
46-50	37	7.43%
61-65	30	6.02%
36-40	23	4.62%
31-35	19	3.82%
9-14	5	1.00%
5	3	0.60%
1	2	0.40%
2	2	0.40%
3	2	0.40%
6	2	0.40%
7	2	0.40%
8	2	0.40%
4	1	0.20%
** < 1	0	0.00%
UNKNOWN	0	0.00%
Total	**498**	**100.00%**

* Greater than or equal to 66   ** Less than 1

MSHP Traffic Crashes Online Mapping Tool ☺ ☺

The MSHP hosts a website that provides crash data in both graphic and tabular formats. The user can query for crashes by many different factors, such as a range of dates, city, county, crash severity, vehicle type, circumstances, gender, and level of injury. The output table of crashes that is generated provides information such as crash image number, crash report number, date, time, number of vehicles, severity, crash type, location, and light conditions. The user has the option to save the output table to a spreadsheet. The query output also includes summary statistics with the number of total crashes, number of injuries, and number of fatalities. The graphical output of the query shows a map with crash locations marked. The crashes are color coded by severity type. The user can click on the map crash icon to obtain additional information about a crash, such as date and severity. Figure 4.5 shows a sample graphical output for the number of crashes occurring in Columbia, Missouri in 2013. The summary statistics also provided in the output show that 938 crashes occurred in Columbia in 2013, with 465 injuries and four fatalities.
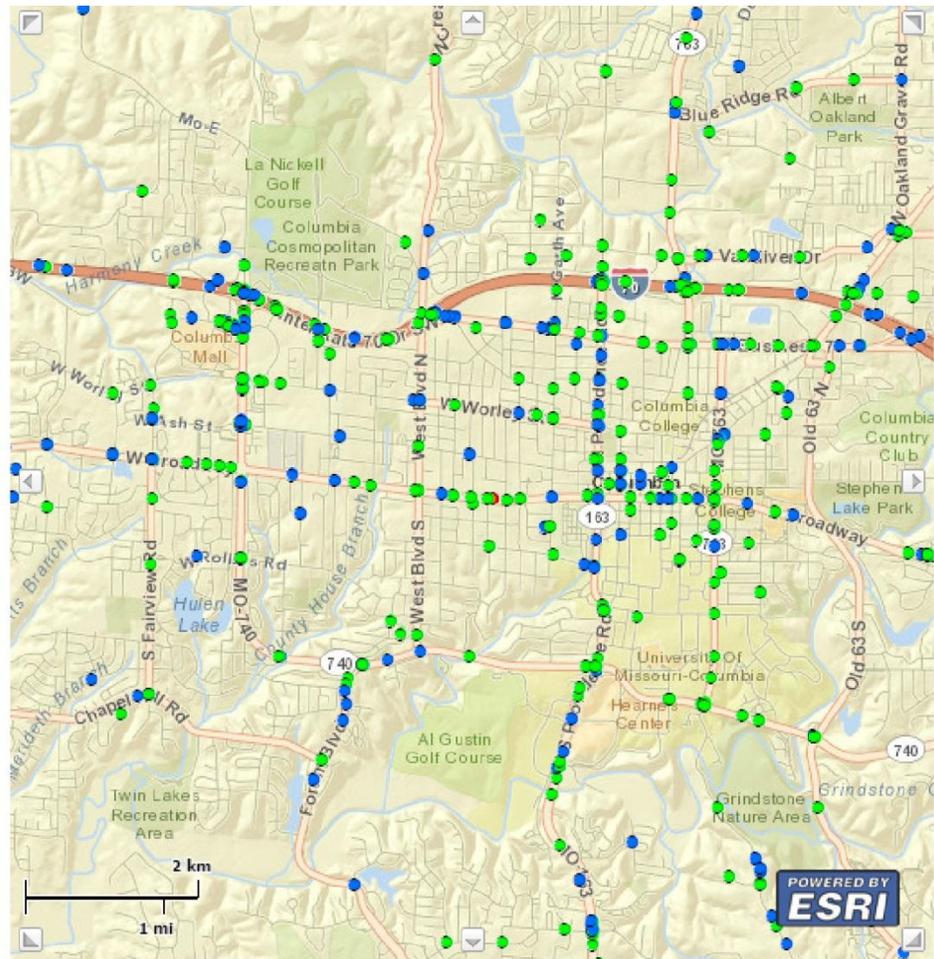
Figure 4.5 Crashes in 2013 in Columbia, Missouri from MSHP Traffic Crashes Online Mapping Tool (MSHP).

LETS ⏱ ⏱

The Law Enforcement Traffic System (LETS) was developed in cooperation with the MoDOT Traffic and Highway Safety Division. LETS provides Missouri law enforcement agencies with tools to manage crash reports, as well as citation, warning, and complaint data. LETS also allows local agencies to customize certain functions to meet their requirements. It includes optional user interfaces to retrieve driver and vehicle registration information and to create and submit crash reports electronically to the Missouri State Highway Patrol. LETS is currently the only system approved for the electronic submission of crash reports in Missouri. The electronic submission of crash reports helps to facilitate more efficient and accurate crash reporting, since reports not entered electronically must be submitted manually. LETS also has the ability to generate reports to aid in various tasks, such as the identification of problem areas and the evaluation of the effectiveness of enforcement activities. The LETS Crash Reporting function includes graphical location mapping tools, as shown in Figure 4.6. This mapping tool is available to all law enforcement agencies and can be accessed through the following website: https://www6.modot.mo.gov/hpmaps.
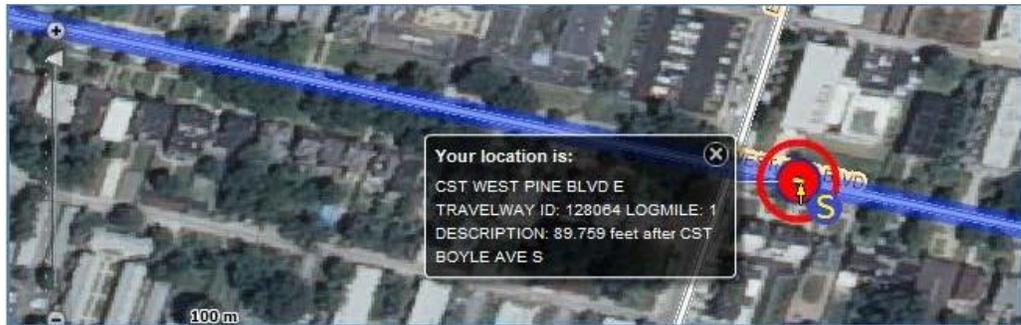
Figure 4.6 LETS Graphical Map Interface (developed by MoDOT).

Fatality Analysis Reporting System (FARS) Mapping Tool ⏱ ⏱

The Fatality Analysis Reporting System (FARS) is a database of fatal motor vehicle crashes that includes all qualifying fatalities that have occurred within the United States and Puerto Rico since 1975. To be classified as a FARS crash, the crash must involve a motor vehicle traveling on a roadway open to the public, and must result in the death of a motorist or non-motorist within 30 days of the crash. The FARS website includes documentation and raw data. The website also allows users to query crash data from the FARS encyclopedia. Queries can be made based on location and contributing factors. For example, the user could obtain crash statistics for all fatal crashes in Missouri in which alcohol was a contributing factor (Table 4.3).

Table 4.3 FARS Crash Data for Alcohol Related Crashes in 2011 (NHTSA)

Persons Killed, by STATE and Highest Driver Blood Alcohol Concentration (BAC) in Crash - State : Missouri, Year : 2011

SELECT REPORT CRITERIA:STATE: Missouri ▾ YEAR: 2011 ▾ VIEW

State	Highest Driver Blood Alcohol Concentration in Crash								Total Killed	
	BAC = .00		BAC = .01-.07		BAC = .08+		BAC=.01+			
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Missouri	479	61	40	5	258	33	299	38	784	100

The FARS encyclopedia also includes mapping tool features that allow the user to create pin maps and intensity maps from custom FARS crash database queries. Pin maps show the locations of individual crashes, while intensity maps show the tabulation of fatal crashes by county or state.

Another graphical interface for FARS crash data can be found at the SafeRoadMaps website. This website allows the user to locate fatal crashes in the vicinity of a street address. These crash locations can be displayed on a map or aerial photograph (Fig. 4.7). The user can click on the icon for an individual crash to obtain information about the crash, such as date, accident information, person information, and vehicle information. Individual layers for crashes for each year from 2001 to 2010 can be turned on and off. The graphical interface also includes tools enabling the user to measure distances or to draw annotations on the map.
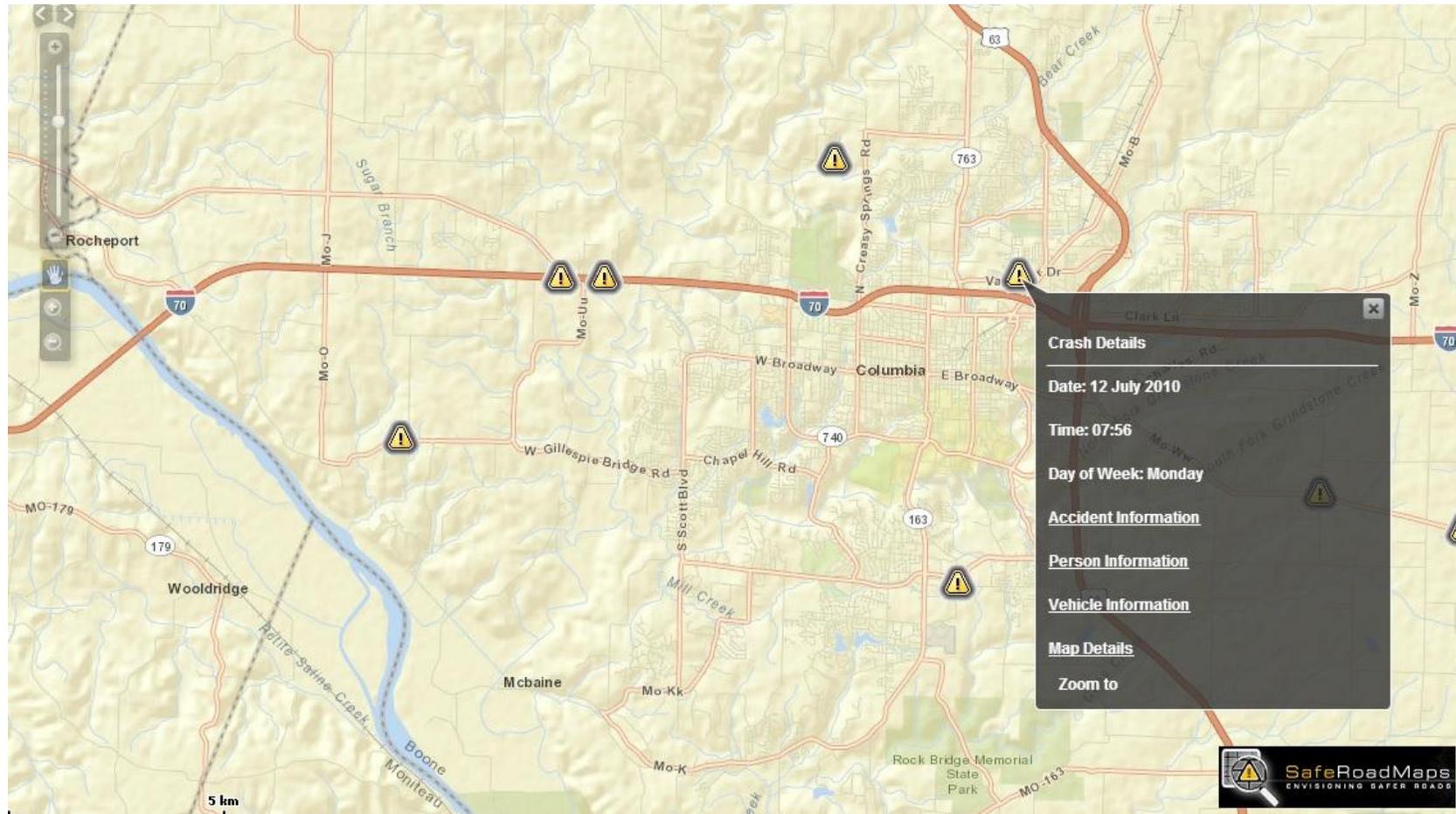
Figure 4.7 Example map from SafeRoadMaps showing locations of fatal crashes in Columbia, Missouri in 2010 (SafeRoadMaps).

Pedestrian and Bicycle GIS Safety Analysis Tools (FHWA) ⏱ ⏱ ⏱ ⏱

GIS tools from the Federal Highway Administration (FHWA) are available to facilitate the analysis of safety issues related to pedestrians and bicyclists. Three tools are available: Safe Route to School, bicycle compatible routes, and high pedestrian crash zones. The Safe Route to School tool creates a walk route and associated directions for three possible criteria: shortest route, safest route based on hazard information, or route based on user preferences. The tool for bicycle compatible routes includes two possible output options: quickest or best bicycle route to a destination or color-coded map, based on the bicycle compatibility index of a given area. The bicycle compatibility index of a street is calculated based on its characteristics. The tool for high pedestrian crash zones generates a map which provides the user with information regarding the frequency of crashes in different areas (Fig. 4.8).
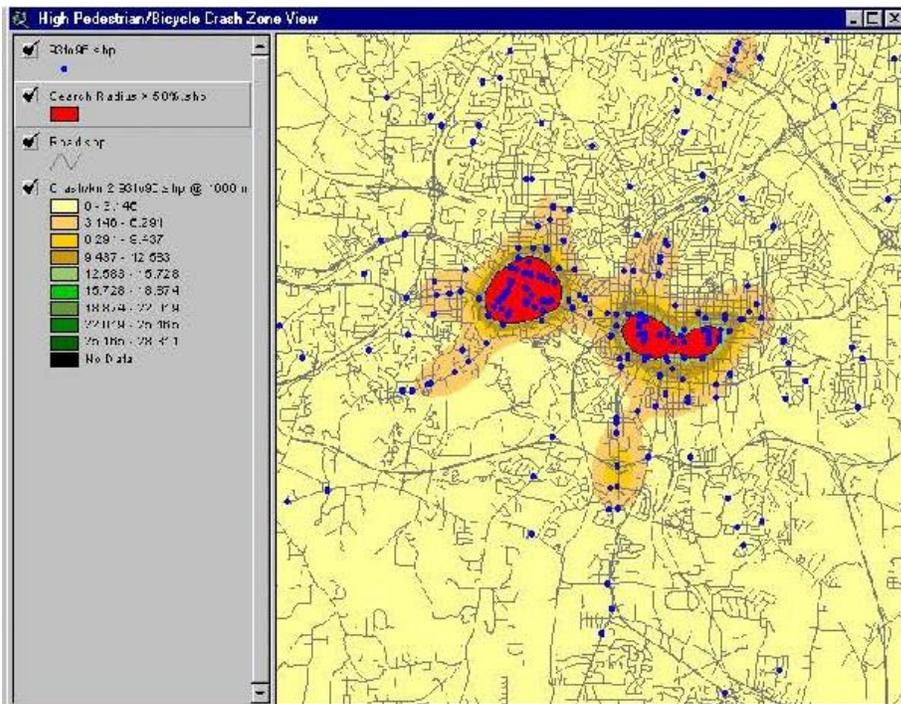
Figure 4.8 High Pedestrian Crash Zone View (FHWA).

Pedestrian and Bicycle Crash Analysis Tool (PBCAT) ⏱ ⏱ ⏱ ⏱

The Pedestrian and Bicycle Crash Analysis Tool (PBCAT) is a software package designed to help engineers, planners, and pedestrian and bicycle coordinators to address concerns related to pedestrian and bicycle crashes. PBCAT allows users to develop a database of details describing crashes between motor vehicles and pedestrians or bicyclists. The database includes crash type, and goes beyond typical crash database information, such as crash location and time, to describe the actions of motor vehicles and pedestrians or bicyclists prior to the crash. Once the database is

developed, the user can analyze the data and select appropriate countermeasures to help reduce the number of pedestrian and bicycle crashes.

Highway Safety Manual (HSM) Spreadsheets ☺ ☺ ☺ ☺

Spreadsheets have been developed to help users apply the crash predictive methods described in the HSM for three facility types: rural two-lane roads, rural multi-lane roads, and urban and suburban arterials. Two versions of these spreadsheets exist: the original spreadsheets and extended spreadsheets.

The original spreadsheets were developed by Dr. Karen Dixon as part of a volunteer effort to help support HSM training efforts. Each spreadsheet file includes a worksheet with instructions, as well as worksheets for entering segment data, worksheets for entering intersection data, and worksheets containing results. During the data inputting process, the user can either incorporate default HSM values or provide locally-derived values as needed. The input data worksheets show the results for the calculations of crash modification factors (CMF) to provide the user insight into the sensitivity of the results to the input data. The results obtained from the worksheets provide the predicted average crash frequencies by severity type for each roadway segment and intersection. The expected average crash frequencies determined by an Empirical Bayes (EB) analysis for each roadway segment and intersection are also provided in the output. One limitation of the original spreadsheets is that it they are set up for a study area having two segments and two intersections. Analysis of a study area having a different number of project elements requires additional spreadsheet manipulation, which can be time consuming and has the potential to introduce errors into the analysis. The original spreadsheets are available as a free download from the American Association of State Highway and Transportation Officials (AASHTO) HSM website.

The extended spreadsheets were developed through a project funded by the Alabama Department of Transportation in order to provide additional functionality to the original spreadsheets through the use of macros. Specifically, the extended spreadsheets provide automation for the manipulation required in the original spreadsheets to facilitate different numbers and combinations of roadway segments and intersections; they add standard reports that show results in tabular, graphical, and text formats; and they add the ability to perform multiyear analysis. The extended spreadsheets include instructions, a worksheet to enter project information, and a worksheet with a report. The user begins the analysis with this spreadsheet by entering general project information such as project description, the number of segments in the study area, the number of intersections in the study area, whether or not a multiyear analysis will be performed, and whether the analysis includes the calculation of the predicted average crash frequency only, or both the predicted and expected average crash frequencies. Upon completion of this preliminary input data, a macro generates a worksheet for each roadway segment and intersection. The user then completes the data entry for each segment and intersection in the study area. The input data worksheets show the base conditions, in addition to the actual conditions provided by the user. Once data entry is complete, a macro performs the analysis and generates reports. The worksheet with the reports summarizes the results in tabular, graphical, and text format. The

extended spreadsheets are available as a free download from the website of the Highway Safety Performance Committee of the Transportation Research Board.

HSM Spreadsheet Example

The crash frequency for a study area consisting of two segments and three intersections on an urban two-lane undivided arterial needs to be determined. Two of the intersections are four-leg signalized intersections, and one of the intersections is a four-leg unsignalized intersection.

A completed worksheet for general project information is pictured in Table 4.4. The type of traffic control for the intersections has been entered, along with other project information. Completed input data worksheets for the roadway segments and intersections are shown in Tables 4.5-4.9. Excerpts from the summary report are shown in Table 4.10. The predicted average crash frequencies for the study area are 3.5 property damage only (PDO) crashes per year, 1.7 fatal and injury crashes per year, and 5.2 total crashes per year.

Table 4.4 General Project Input Data for HSM Spreadsheet Example

PROJECT SAFETY PERFORMANCE ANALYSIS INPUT SHEET				
General Information				
Project Name	Practical Case Study		Contact Email	email
Project Description	Route A from Int. 1 to Int. 2		Contact Phone	(123) 456-7891
Reference Number	STARS Report A-1		Date Performed	05/12/11
Analyst	John Smith		Analysis Year	2011
Agency/Company	ABC Company		Multiple Year Analysis?	Yes
# of Segments in Analysis	2		Predicted/expected crashes	Predicted
# of Intersections in Analysis	3			

INDIVIDUAL PROJECT ELEMENTS	LOCATION INFORMATION		JURISDICTION	INTERSECTIONS ONLY
	Route	Location Description		Signalized or Unsignalized?
SEGMENTS				
Segment 1	Route A	From Int. 1 to Int. 2		-
Segment 2	Route A	From Int. 2 to Int. 3		-
INTERSECTIONS				
Intersection 1	Route A	First St.	State	Signalized
Intersection 2	Route A	Second St.	State	Unsignalized
Intersection 3	Route A	Third St.	State	Signalized

Table 4.5 Input Data for Segment 1 in HSM Spreadsheet Example

General Information		Location Information	
Analyst	John Smith	Roadway	Route A
Agency or Company	ABC Company	Roadway Section	From Int. 1 to Int. 2
Date Performed	05/12/11	Jurisdiction	State
Segment for Analysis	Segment 1	Analysis Year	2011

Input Data		Site Conditions	Base Conditions
Roadway type (2U, 3T, 4U, 4D, 5T)		2U	--
Length of segment, L (mi)		0.25	--
AADT (veh/day) is within range	$AADT_{MAX}$ = 32,600 (veh/day)	8,500	--
Type of on-street parking (none/parallel/angle)		None	None
Proportion of curb length with on-street parking		0	--
Median width (ft) - for divided only			15
Lighting (present / not present)		Present	Not Present
Auto speed enforcement (present / not present)		Not Present	Not Present
Major commercial driveways (number)		1	--
Minor commercial driveways (number)		2	--
Major industrial / institutional driveways (number)		1	--
Minor industrial / institutional driveways (number)		1	--
Major residential driveways (number)		0	--
Minor residential driveways (number)		4	--
Other driveways (number)		0	--
Speed Category		Posted Speed Greater than 30 mph	--
Roadside fixed object density (fixed objects / mi)		27	0
Offset to roadside fixed objects (ft) [If greater than 30 or Not Present, input 30]		15	30
Calibration Factor, Cr		1.00	1.00

Table 4.6 Input Data for Segment 2 in HSM Spreadsheet Example

General Information		Location Information	
Analyst	John Smith	Roadway	Route A
Agency or Company	ABC Company	Roadway Section	From Int. 2 to Int. 3
Date Performed	05/12/11	Jurisdiction	State
Segment for Analysis	Segment 2	Analysis Year	2011

Input Data		Site Conditions	Base Conditions
Roadway type (2U, 3T, 4U, 4D, 5T)		2U	--
Length of segment, L (mi)		0.94	--
AADT (veh/day) is within range	AADT$_{MAX}$ = 32,600 (veh/day)	5,500	--
Type of on-street parking (none/parallel/angle)		None	None
Proportion of curb length with on-street parking		0	--
Median width (ft) - for divided only			15
Lighting (present / not present)		Not Present	Not Present
Auto speed enforcement (present / not present)		Not Present	Not Present
Major commercial driveways (number)		0	--
Minor commercial driveways (number)		9	--
Major industrial / institutional driveways (number)		0	--
Minor industrial / institutional driveways (number)		2	--
Major residential driveways (number)		0	--
Minor residential driveways (number)		2	--
Other driveways (number)		0	--
Speed Category			--
Roadside fixed object density (fixed objects / mi)		43	0
Offset to roadside fixed objects (ft) [If greater than 30 or Not Present, input 30]		12	30
Calibration Factor, Cr		1.00	1.00

Table 4.7 Input Data for Intersection 1 in HSM Spreadsheet Example

General Information		Location Information	
Analyst	John Smith	Roadway	Route A
Agency or Company	ABC Company	Location Information	First St.
Date Performed	5/12/2011	Jurisdiction	State
Intersection	Intersection 1	Analysis Year	2011
Signalized/Unsignalized	Signalized	Ped Volume (after Intx Type)	Known ▼

Input Data				Site Conditions	Base Conditions
Intersection type (3ST, 3SG, 4ST, 4SG)				4SG	--
AADT $_{major}$ (veh/day) (total entering on major approaches)*	AADT$_{MAX}$ =	67,700	(veh/day)	12,000	--
AADT $_{minor}$ (veh/day) (total entering on minor approaches)*	AADT$_{MAX}$ =	33,400	(veh/day)	5,500	--
Intersection lighting (present/not present)				Not Present	Not Present
Calibration factor, C$_i$				1.00	1.00
Data for unsignalized intersections only:					
Number of major-road approaches with left-turn lanes (0,1,2)				0	0
Number of major-road approaches with right-turn lanes (0,1,2)				0	0
Data for signalized intersections only:					
Number of approaches with left-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]				4	0
Number of approaches with right-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]				4	0
Number of approaches with left-turn signal phasing [for 3SG, use maximum value of 3]				4	--
Type of left-turn signal phasing for Leg #1				Protected	Permissive
Type of left-turn signal phasing for Leg #2				Protected	--
Type of left-turn signal phasing for Leg #3				Protected	--
Type of left-turn signal phasing for Leg #4 (if applicable)				Protected	--
Number of approaches with right-turn-on-red prohibited [for 3SG, use maximum value of 3]				0	0
Intersection red light cameras (present/not present)				Not Present	Not Present
Sum of all pedestrian crossing volumes (PedVol) -- Signalized intersections only				700	--
Maximum number of lanes crossed by a pedestrian (n_{lanesx})				3	--
Number of bus stops within 300 m (1,000 ft) of the intersection				0	0
Schools within 300 m (1,000 ft) of the intersection (present/not present)				Not Present	Not Present
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection				1 to 8	0

Table 4.8 Input Data for Intersection 2 in HSM Spreadsheet Example

General Information		Location Information			Site Conditions	Base Conditions
Analyst	John Smith	Roadway	Route A			
Agency or Company	ABC Company	Location Information	Second St.			
Date Performed	5/12/2011	Jurisdiction	State			
Intersection	Intersection 2	Analysis Year	2011			
Signalized/Unsignalized	Unsignalized					▼
Input Data					**Site Conditions**	**Base Conditions**
Intersection type (3ST, 3SG, 4ST, 4SG)					4ST	--
AADT $_{major}$ (veh/day) (total entering on major approaches)*	AADT$_{MAX}$ =	46,800	(veh/day)		3,700	--
AADT $_{minor}$ (veh/day) (total entering on minor approaches)*	AADT$_{MAX}$ =	5,900	(veh/day)		310	--
Intersection lighting (present/not present)					Present	Not Present
Calibration factor, C$_i$					1.00	1.00
Data for unsignalized intersections only:						
Number of major-road approaches with left-turn lanes (0,1,2)					0	0
Number of major-road approaches with right-turn lanes (0,1,2)					0	0
Data for signalized intersections only:						
Number of approaches with left-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]					0	0
Number of approaches with right-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]					0	0
Number of approaches with left-turn signal phasing [for 3SG, use maximum value of 3]					0	--
Type of left-turn signal phasing for Leg #1					Permissive	Permissive
Type of left-turn signal phasing for Leg #2						--
Type of left-turn signal phasing for Leg #3						--
Type of left-turn signal phasing for Leg #4 (if applicable)						--
Number of approaches with right-turn-on-red prohibited [for 3SG, use maximum value of 3]					0	0
Intersection red light cameras (present/not present)					Not Present	Not Present
Sum of all pedestrian crossing volumes (PedVol) -- Signalized intersections only						--
Maximum number of lanes crossed by a pedestrian (n$_{lanesx}$)						--
Number of bus stops within 300 m (1,000 ft) of the intersection					0	0
Schools within 300 m (1,000 ft) of the intersection (present/not present)					Not Present	Not Present
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection					0	0

Table 4.9 Input Data for Intersection 3 in HSM Spreadsheet Example

General Information		Location Information			
Analyst	John Smith	Roadway	Route A		
Agency or Company	ABC Company	Location Information	Third St.		
Date Performed	5/12/2011	Jurisdiction	State		
Intersection	Intersection 3	Analysis Year	2011		
Signalized/Unsignalized	Signalized	Ped Volume (after Intx Type)	Known		▼
Input Data				**Site Conditions**	**Base Conditions**
Intersection type (3ST, 3SG, 4ST, 4SG)				4SG	--
AADT $_{major}$ (veh/day) (total entering on major approaches)*	AADT$_{MAX}$ =	67,700	(veh/day)	8,700	--
AADT $_{minor}$ (veh/day) (total entering on minor approaches)*	AADT$_{MAX}$ =	33,400	(veh/day)	1,500	--
Intersection lighting (present/not present)				Not Present	Not Present
Calibration factor, C$_i$				1.00	1.00
Data for unsignalized intersections only:					
Number of major-road approaches with left-turn lanes (0,1,2)				0	0
Number of major-road approaches with right-turn lanes (0,1,2)				0	0
Data for signalized intersections only:					
Number of approaches with left-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]				2	0
Number of approaches with right-turn lanes (0,1,2,3,4) [for 3SG, use maximum value of 3]				1	0
Number of approaches with left-turn signal phasing [for 3SG, use maximum value of 3]				0	--
Type of left-turn signal phasing for Leg #1				Permissive	Permissive
Type of left-turn signal phasing for Leg #2				Permissive/Protected	--
Type of left-turn signal phasing for Leg #3				Protected	--
Type of left-turn signal phasing for Leg #4 (if applicable)				Protected	--
Number of approaches with right-turn-on-red prohibited [for 3SG, use maximum value of 3]				0	0
Intersection red light cameras (present/not present)				Not Present	Not Present
Sum of all pedestrian crossing volumes (PedVol) -- Signalized intersections only				700	--
Maximum number of lanes crossed by a pedestrian (n_{lanesx})				3	--
Number of bus stops within 300 m (1,000 ft) of the intersection				0	0
Schools within 300 m (1,000 ft) of the intersection (present/not present)				Not Present	Not Present
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection				1 to 8	0

Table 4.10 Results Report for HSM Spreadsheet Example

PROJECT SUMMARY

Summary of Anticipated Safety Performance of the Project (average crashes/yr)

Bar chart values:
- Fatal and injury (KABC): 1.7, 0.0, 0.0
- Property damage only (PDO): 3.5, 0.0, 0.0
- Total (KABCO): 5.2, 0.0, 0.0

Legend:
- Predicted average crash frequency - Average safety performance of projects consisting of similar elements (anticipated average crashes/yr)
- Expected average crash frequency - Actual long-term safety performance of the project (anticipated average crashes/yr)
- Potential for Safety Improvement (anticipated average crashes/yr)

Project Element	Total Crashes/yr (KABCO)			Fatal and Injury Crashes/yr (KABC)			Property Damage Only Crashes/yr (PDO)		
	Predicted average crash frequency $N_{predicted\ (KABCO)}$	Expected average crash frequency $N_{expected\ (KABCO)}$	Potential for Improvement	Predicted average crash frequency $N_{predicted\ (KABC)}$	Expected average crash frequency $N_{expected\ (KABC)}$	Potential for Improvement	Predicted average crash frequency $N_{predicted\ (O)}$	Expected average crash frequency $N_{expected\ (O)}$	Potential for Improvement
INDIVIDUAL SEGMENTS									
Segment 1	0.7	0.0	0.0	0.2	0.0	0.0	0.5	0.0	0.0
Segment 2	1.3	0.0	0.0	0.4	0.0	0.0	0.9	0.0	0.0
INDIVIDUAL INTERSECTIONS									
Intersection 1	1.4	0.0	0.0	0.5	0.0	0.0	0.9	0.0	0.0
Intersection 2	0.6	0.0	0.0	0.2	0.0	0.0	0.4	0.0	0.0
Intersection 3	1.2	0.0	0.0	0.4	0.0	0.0	0.8	0.0	0.0
COMBINED (sum of column)	5.2	0.0	0.0	1.7	0.0	0.0	3.5	0.0	0.0

Interactive Highway Safety Design Model (IHSDM) Software 🕐 🕐 🕐 🕐

The Interactive Highway Safety Design Model (IHSDM) software is a suite of software tools used to assist in the evaluation of the safety and operational effects of geometric and design decisions. The IHSDM software provides decision-makers with information regarding the expected operational and safety performance of a highway facility. The IHSDM software includes six prediction modules: Crash Prediction, Policy Review, Design Consistency, Traffic Analysis, Driver/Vehicle, and Intersection review.

The IHSDM crash prediction module incorporates the HSM methodology for both intersections and segments on rural two-lane roads, rural multi-lane roads, and urban and suburban arterials. A module for crash prediction on freeway segments is also included. The crash prediction module guides the user through the process of entering data for the intersections and segments on the highway being evaluated. Figure 4.9 shows an input data panel from the IHSDM for average annual daily traffic (AADT).
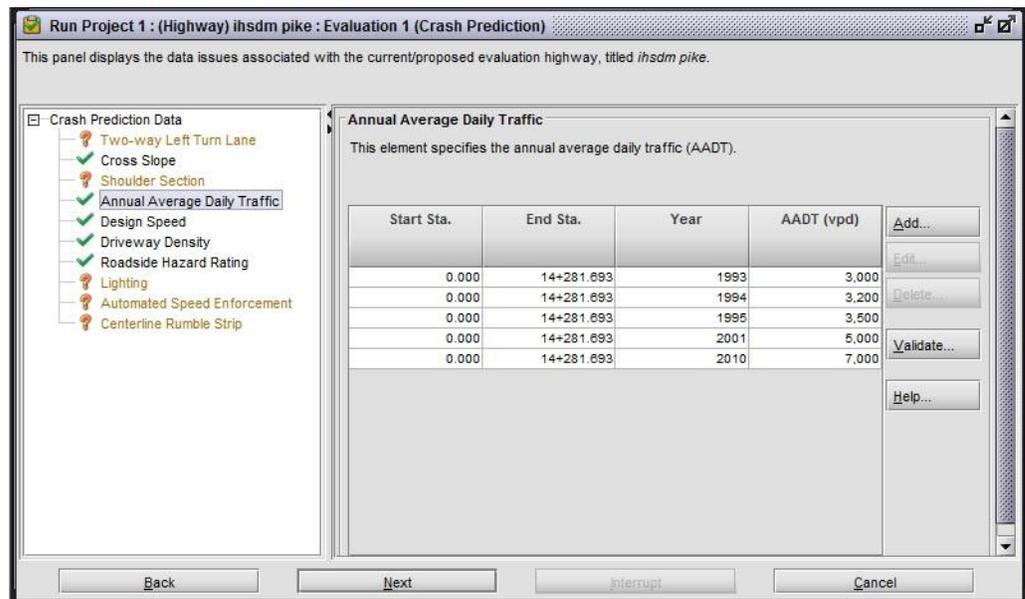
Figure 4.9 Sample input screen from IHSDM software (FHWA).

After the user enters the required data, IHSDM processes the data and generates an output report. The report opens automatically in an html browser, and includes information in both tabular and graphic format. The graphic report includes information regarding the location of intersections, horizontal and vertical curvature, and segment and intersection crashes, as shown in Figure 4.10. The tabular output includes the predicted crash frequencies for the entire study area, as well as for individual segments and intersections. Example tabular output from the IHSDM is provided in Table 4.11.

The IHSDM software includes tutorials to help the user become familiar with the various modules. The tutorial for the crash prediction module walks the user through the process of estimating crash frequencies for rural two-lane highways, rural multi-lane highways, urban arterials, and freeway segments.
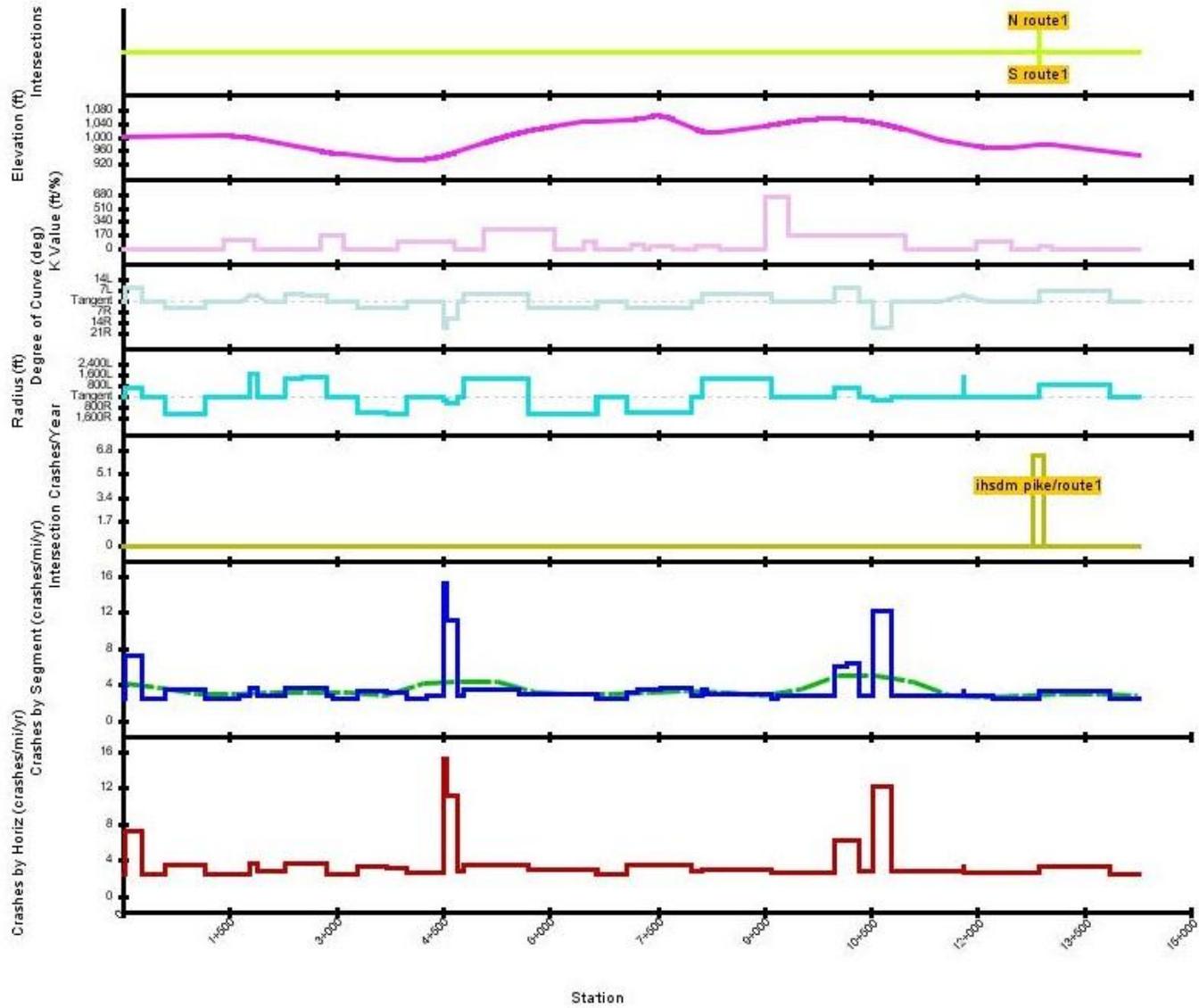
Figure 4.10 Sample graphic output from IHSDM (FHWA).

Table 4.11 Sample Tabular Output from IHSDM (FHWA)

First Year of Analysis	2013
Last Year of Analysis	2018
Evaluated Length (mi)	2.7049
Average Future Road AADT (vpd)	7,000
Expected Crashes	
Total Crashes	94.20
Fatal and Injury Crashes	30.98
Fatal and Serious Injury Crashes	14.99
Property-Damage-Only Crashes	63.23

SafetyAnalyst ⊕ ⊕ ⊕ ⊕ ⊕

SafetyAnalyst is a set of software tools that can be used by state and local highway agencies for highway safety management. SafetyAnalyst is the result of a cooperative effort between FHWA and participating state and local agencies. Distribution and technical support for SafetyAnalyst is handled by AASHTO. The package is intended for the evaluation of countermeasures related to physical modifications to the highway system. It does not apply to non-site-specific highway safety programs, such as education or enforcement programs.

SafetyAnalyst helps to identify sites with specific safety concerns by analyzing crash patterns at specific sites, and can be used to aid in the development of countermeasures to help address these safety concerns. It includes automation of the statistical methodologies described in the HSM. SafetyAnalyst consists of six analytical tools:

- The *Network Screening Tool* uses network screening algorithms to help identify sites that have the potential for safety improvement. These include sites with crash frequencies that are higher than expected, as well as additional sites with a significant number of crashes which have the potential to be addressed with cost-effective improvements.

- The *Diagnosis Tool* facilitates the identification of safety concerns at specific locations. It includes utilities for generating crash summary statistics and collision diagrams. It also has the ability to interface with other collision diagramming software packages.

- The *Countermeasure Selection Tool* helps the user to select countermeasures to reduce the frequency and severity of crashes at specific sites. The tool provides a list of suggested countermeasures based on site characteristics, crash history, and safety concerns identified by the diagnosis tool. An example countermeasures report from SafetyAnalyst is shown in Table 4.12.

- The *Economic Appraisal Tool* facilitates the economic analysis of specific countermeasures that are under consideration for a given site based on cost effectiveness (cost of countermeasure per crash reduced), benefit-cost ratio (ratio of monetary benefits to countermeasure costs), or net benefits (monetary benefits minus countermeasure costs).

- The *Priority Ranking Tool* utilizes the estimates of benefits and costs developed by the economic analysis tool to develop a prioritized list of projects. The tool can also be used to determine the optimal set of projects that will maximize the net safety benefits to the system.

- The *Countermeasure Evaluation Tool* enables the user to perform before-and-after evaluations of safety improvements that have been implemented.

Table 4.12 Example Countermeasures Report from SafetyAnalyst (FHWA 2006)

Countermeasure	Contraindication	Recommended by *	Accident pattern(s)	Implemented
Provide signal coordination	Only aids mainline	16	Rear-end	no
Add advanced detection	May increase delay	16	Rear-end	no
Install dilemma detection system		16	Rear-end	no
Improve change plus clearance interval	May increase delay	16	Rear-end	no
Narrow cross section by reducing number of approach lanes	Reduced capacity	18	Rear-end	no
Reduce speed limit on approaches		18	Rear-end	no
Increase enforcement to reduce speed on intersection approach		18	Rear-end	no
Narrow cross section by physically narrowing lanes		18	Rear-end	no
Change streetscape to increase stimulation of peripheral vision		18	Rear-end	no
Restrict movements to right-in and right-out at the access using channelizing island	Accidents may migrate with changes in volume patterns	18	Rear-end	no
Improve sight distance to intersection		User	user-selected CM	no
Improve sight distance to traffic signal		User	user-selected CM	no

* A scenario ID ending in 'u' indicates the countermeasure was user-selected and is not a result of the diagnosis.

Surrogate Safety Assessment Module (SSAM) ☺ ☺ ☺ ☺ ☺

The Surrogate Safety Assessment Module (SSAM) uses traffic conflicts as a surrogate measure of crashes to evaluate the safety of a facility. A conflict is a situation in which two road users will likely collide unless evasive action is taken. For example, Figure 4.11 depicts a conflict situation in which a collision between two vehicles could occur unless evasive action such as braking is taken; one of the vehicles has angled across two lanes and cut in front of another vehicle. SSAM works with simulation packages such as VISSIM, AIMSUN, Paramics, and TEXAS to process vehicle trajectory data that provide information regarding the location and dimensions of each vehicle approximately every 10th of a second. SSAM identifies and catalogs conflict events based on analysis of the interactions between vehicles. SSAM provides surrogate measures such as minimum time to collision, maximum deceleration rate, maximum speed differential, and conflict time for each conflict event.
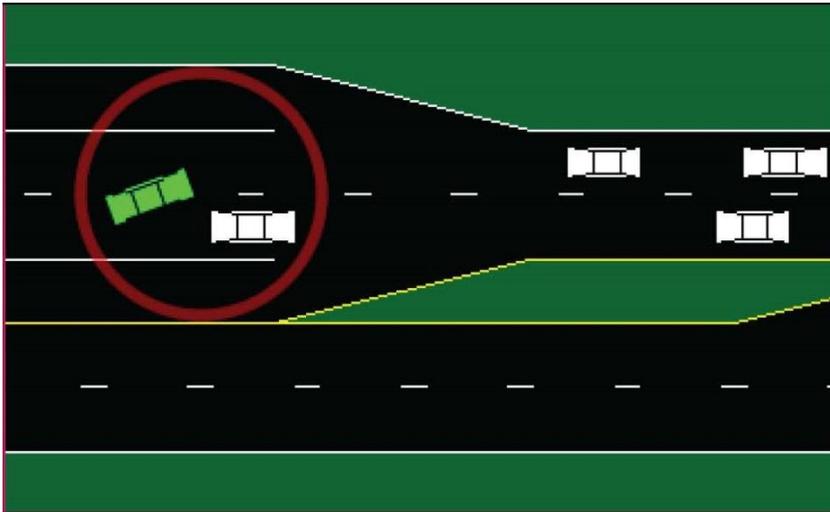
Figure 4.11 Conflict between two vehicles (FHWA).

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Chapter

5

CHAPTER 5: SAFETY IMPROVEMENTS

Matching countermeasures with contributing circumstances.

C ountermeasures are intended to improve safety by lowering the frequency of crashes and/or crash severity. An important precursor to selecting countermeasures is to identify all possible contributing factors to crashes occurring at the site. The Highway Safety Manual (HSM) groups crash contributing factors into roadway factors, vehicle factors, and human factors (driver). Roadway factors include pavement characteristics such as wet pavement, low friction, sight distance issues, signage problems, and others. Vehicle factors include vehicle operating characteristics such as wear on tires, brakes, safety features, and others. Human factors involve anything related to the driver; factors such as driver distraction, fatigue, age, and gender are all included as human factors.

The HSM recommends the use of the *Haddon matrix*, a tabular listing different contributing factors that occurred before, during, and after a crash. Table 5.1 displays an example of a Haddon matrix, showing a right-angle crash at a signalized intersection. As shown in the table, roadway factors, human factors, and vehicle factors could all contribute to the different time periods within a crash.

Table 5.1 Haddon Matrix of Contributing Factors for a Right-Angle Crash at a Signalized Intersection

Period	Roadway factors	Human factors	Vehicle factors
Before the crash (causal factors)	Poor visibility of signals Inadequate signal timing Slippery pavement Inadequate sight distance	Distraction Fatigue Age Speeding Drivers running red light Alcohol influence	Worn tires Worn brakes
During the crash (causes of severity)	Excessive speed Pavement friction Grade	Age Seat belt use Alcohol influence	Bumper height Headrest design Airbag design
After the crash (crash outcome)	Emergency response	Age Gender	Ease of removal of injured passengers

Among the three groups of factors, local agencies often have the most control over selecting countermeasures that address roadway factors. For example, inadequate lighting at a roadway intersection can be addressed with additional lighting, whereas driver distractions, such as cell phone use, may be harder to address. Thus, roadway factors will be discussed in greater detail in this chapter in order to aid in countermeasure selection. Comprehensive guidance on driver factors can be found in a recent National Highway Traffic Safety Administration (NHTSA) report (Hedlund et al., 2008), and vehicle factors are available in a (1998) National Cooperative Highway Research Program (NCHRP) report. The NHTSA report addresses driver factors such as alcohol and drug impairment, seat belts and child restraints, aggressive driving, distracted and drowsy driving, motorcycles, young and older drivers, and bicycles and pedestrians.

Roadway factors contributing to crashes at different facilities are described in the HSM. The major factors are presented in graphical form in Figures 5.1-5.5. Figure 5.1 lists the contributing factors for a roadway segment by the most prevalent types of crashes: fixed-object, rollover, run-off-the-road, nighttime, and head-on or sideswipe. The most prevalent types of crashes at signalized intersections are right angle, nighttime, and rear-end/sideswipe. Figure 5.2 displays the applicable contributing factors. Figure 5.3 shows the contributing factors related to the most prevalent types of crashes at unsignalized intersections: angle, driveway, nighttime, and rear-end. Crash contributing factors for pedestrians and bicycles are shown in Figure 5.4. At the state level in Missouri, areas of focus for serious crash types include run-off-the-road, horizontal curve, intersection, trees or utility poles, and head-on crashes (MCRS, 2012).
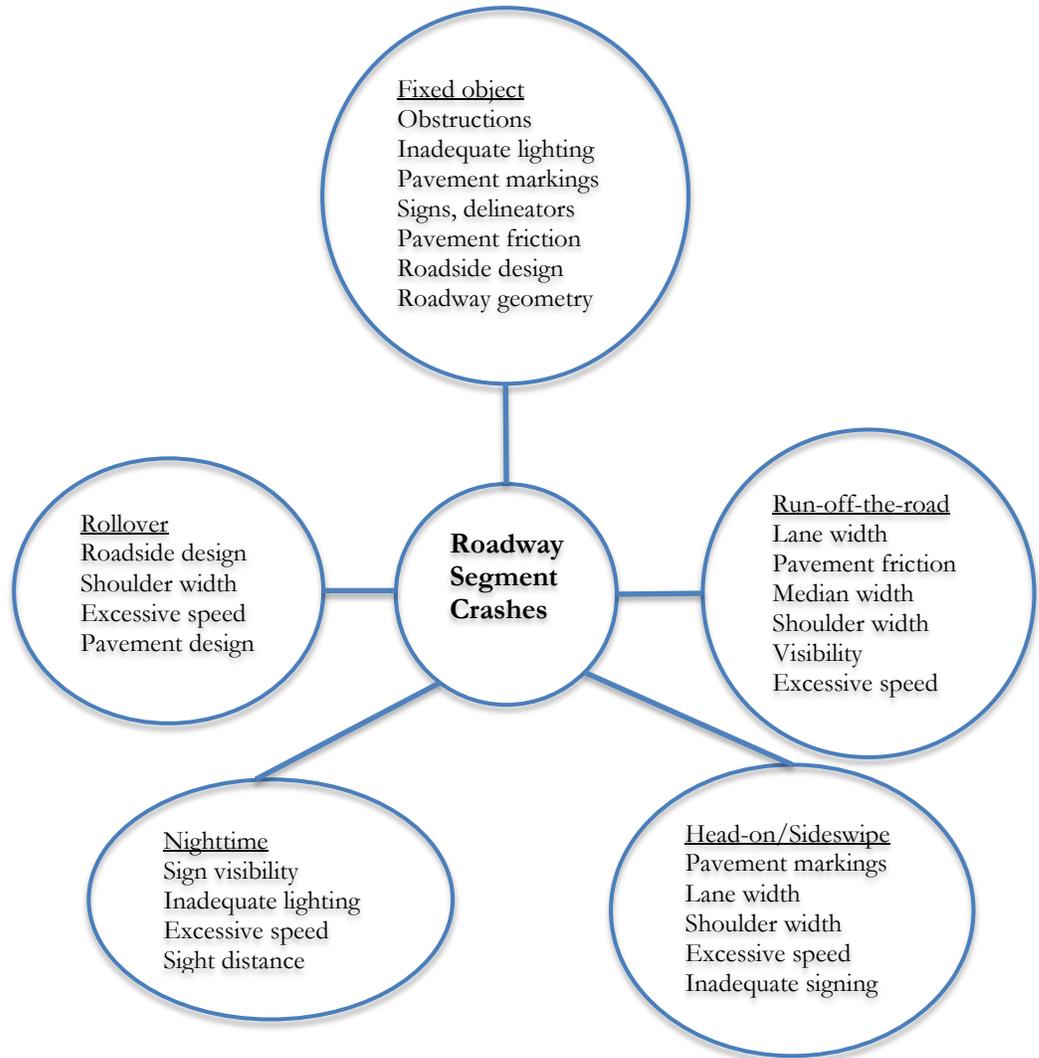
Figure 5.1 Contributing factors to roadway segment crashes.

Right angle
Signal visibility
Signal timing
Sight distance
Red light running
Excessive speed
Pavement friction

Signalized Intersections

Nighttime
Sign visibility
Inadequate lighting
Excessive speed
Sight distance

Rear-end/Sideswipe
Approach speeds
Signal visibility
Narrow lanes
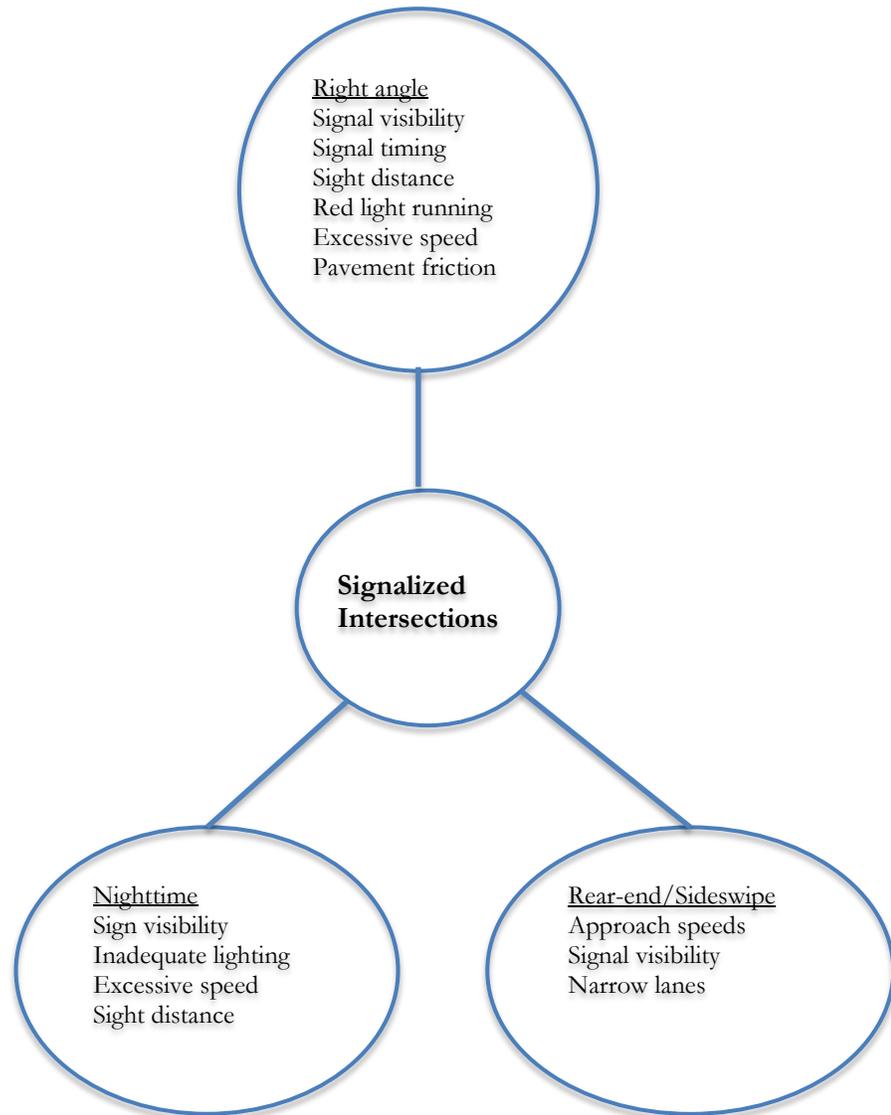
Figure 5.2 Contributing factors to crashes at signalized intersections.

Angle
Heavy traffic
Sight distance
Stop sign running
Approach speed
Unexpected- crossing traffic
Gap availability

Driveway collisions
Turning vehicles
Heavy traffic
Sight distance
Excessive speed
Heavy driveway traffic
Improper driveway location

Unsignalized Intersections

Nighttime
Sign visibility
Inadequate lighting
Excessive speed
Sight distance

Rear-end
Narrow lanes
Excessive speed
Pedestrian crossing
Pavement friction
Turning volume
Sight distance
Gap availability

Figure 5.3 Contributing factors to crashes at unsignalized intersections.

Pedestrians
Inadequate signs
Inadequate signal phasing
Limited sight distance
Excessive speed
Proximity to nearest crosswalk
Sidewalk proximity to roadway
School crossing
Insufficient crossing opportunities
Inadequate lighting

Bicyclists
Inadequate sight distance
Inadequate signs
Pavement markings
Inadequate lighting
Excessive speed
Bike path close to roadway
Narrow bike lane

Figure 5.4 Contributing factors to pedestrian and bicyclist crashes.

Selection of Countermeasures to Address Contributing Factors

After the contributing factors are identified for crashes occurring at a facility, the next step is to select one or more countermeasures to address the problem(s). The HSM provides a comprehensive list of countermeasures, and their associated crash modification factors (CMF). Additional countermeasures that may as of yet lack established CMFs are also included in the HSM. For the current document, HSM countermeasures were reviewed, and two condensed lists of countermeasures were generated for roadway segments and intersections, as presented in Tables 5.2 and 5.3, respectively. These tables include treatments that are of the most interest to local agencies. It is important to note, CMFs < 1 will indicate a reduction in crashes and CMFs > 1 will indicate an increase in crashes.

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Table 5.2 Countermeasures for Reducing Roadway Segment Crashes (Based on Chapter 13 of HSM)

Roadway elements	Roadside elements	Alignment elements	Roadway signs	Pedestrians and Bicyclists	Others
Widen lanes Road diets (4 to 3) Add or widen shoulder Modify shoulder type Add raised median Increase median width	Flatten sideslope Increase distance to roadside barriers Less rigid roadside barriers Add median barrier Add crash cushions	Increase horizontal curve radius Add spiral transitions on curves Increase superelevation Decrease vertical grade	Add advisory speeds for horizontal curves Use dynamic message signs to display incidents, queue, other warnings Add individual dynamic speed warning signs	Add sidewalk Add shoulder Add raised pedestrian crosswalk Widen median Add bicycle lanes Use shared bike lanes Pave existing shoulder and use as bike lane	Add edgeline/centerline marking Add shoulder/centerline rumble strips Add speed bumps for calming Add traversable rumble strips for calming Add lighting Reduce access point density

Table 5.3 Countermeasures for Intersections (Based on Chapter 14 of HSM)

Intersection types	Intersection design	Traffic control and operations
Convert signalized intersection to roundabout Convert stop sign to roundabout Convert minor road stop to all-way stop Remove unwarranted signals Convert stop sign to signal control Close or relocate access points in intersection functional area Increase distance between intersection and driveways	Decrease intersection skew angle Add left-turn lane on one or more approaches Add channelized left-turn lanes Add right turn lanes Add lighting	Add signs prohibiting left turns and/or U-turns at a signal Add "Stop Ahead" pavement markings Add flashing beacons at stop signs Change permissive to protected phasing for left turns Change permissive to protected/permissive or permissive/protected Replace direct left turns with right turn plus U-turn combination Prohibit right turn on red

The process of crash type analysis and countermeasure identification is best illustrated using an example. The following is an example of an S-HAL safety evaluation of a high-crash signalized intersection.

Example 1: Countermeasure Identification

A four-leg signalized intersection in an urban area is experiencing a high number of injury crashes, and the City wants to identify countermeasures that will address this problem. The average annual daily traffic (AADT) on the major road and minor road are 25,000 vehicles per day (vpd) and 9,000 vpd, respectively. Both major road approaches contain one left-turn lane each, while the minor road approaches do not contain a turn lane. The signal is currently operating in three phases – phase 1: protected left on major road; phase 2: through movement on the major road; phase 3: through movement with permissive left on the minor road. Crash analysis revealed the following proportions for different crash severities: 0.64% fatal, 25.5% injury, and 73.86% property damage only (PDO) crashes.

A traffic study reported long delays for minor road vehicles during the peak period, with minor road turning vehicles becoming impatient and accepting short, risky gaps. Vehicles running the red light were also a regular occurrence during the peak period. During off-peak hours, mainline vehicles were found to significantly exceed the posted speed limit of 50 mph. There were no concerns regarding sight distance, unexpected crossing traffic, or pavement friction.

Based on the traffic study, it was concluded that the contributing factors for the crashes were high traffic volume, high approach speed, low speed limit compliance, and red-light-running. The following countermeasures were identified to address the crash problem at the intersection:

> 1) Add turn lanes on the minor road and convert phasing for the minor road from permissive to protected left turns. The CMF value for this countermeasure from the HSM is 0.01 for left-turn crashes, with no significant changes for all severities. Rather than protected phasing, the minor road left-turn phasing could be protected/permissive or permissive/protected, with a CMF of 0.84 for left-turn injury crashes and 0.99 for all severities.

> 2) Replace the signal with a roundabout. The HSM presents a CMF value of 0.99 for all severities, and 0.40 for injury crashes.

> 3) Install red-light-running cameras. The HSM presents a CMF value of 0.74 for right angle and left-turn crashes, 0.84 for right angle left-turn injury crashes, 1.18 for rear-end crashes (all severities), and 1.24 for rear-end injury crashes.

The following section presents methods for performing economic analysis of countermeasures to rank and select from the best possible.

Economic Evaluation of Countermeasures

After identifying one or more countermeasures that address the crash problem, an economic evaluation is conducted to assess the benefits resulting from the countermeasures, as well as the costs of their implementation. The reduction in crash frequency or severity resulting from a countermeasure is used to compute its benefits. Implementation costs are always monetized, while benefits may or may not be monetized. A benefit-cost analysis monetizes benefits, whereas a cost-effectiveness analysis does not. The HSM recommends two types of benefit-cost analysis: net present value (NPV) analysis and benefit-cost ratio (b/c) analysis. NPV analysis quantifies the difference between the present value of the benefits resulting from a countermeasure and the project's costs. A positive NPV value indicates that the benefits exceed the costs of the project. The b/c value is the ratio of the present value of benefits to the project costs. A b/c value greater than 1.0 indicates that the benefits outweigh the project's costs. The goal of cost-effectiveness analysis is to determine the annual cost of achieving a unit reduction in crash frequency, also known as the cost-effectiveness index. Cost-effectiveness analysis is often used to avoid the monetization of benefits.

The NPV, b/c, and cost-effectiveness index values are used to rank all potential countermeasures. Although these three measures are recommended for ranking, an agency may use other measures to rank countermeasures. Measures such as project costs, monetized benefits, total crash frequency reduction, and fatal and injury crash frequency reduction are included in the HSM as alternatives.

The ability to quantify the benefits resulting from a countermeasure is predicated upon the computation of the expected reduction in crash frequency due to that countermeasure. The HSM provides a state-of-the-practice method to predict changes in crash frequency. The HSM predictive methodology uses CMFs to quantify the impact of countermeasures toward reducing crash frequency. Part D of the HSM includes CMFs for a variety of countermeasures for different facility types, such as roadway segments, signalized intersections, unsignalized intersections, and others. Additional sources, such as the CMF Clearinghouse (HSRC, n.d.), provide up-to-date information and a larger number of CMFs than does the HSM. The CMF Clearinghouse compiles existing research on countermeasures, provides a quality rating of the CMF, and links to the original research report. Table 5.4 provides 76 examples of some of the proven safety countermeasures, including countermeasures promoted by the Federal Highway Administration (FHWA) Office of Safety. The CMFs in Table 5.4 are examples of countermeasures that are frequently considered by local communities, and they are listed in alphabetical order.

The columns of Table 5.4 are described as follows. Column 1 presents the general category of the countermeasure. Column 2 provides a short description of the countermeasure. For more details on a particular countermeasure, please consult the

CMF Clearinghouse using the CMF Clearinghouse ID listed on the last column or by searching the Clearinghouse using a description of the countermeasure. Column 3 presents the CMF value or the anticipated crash reduction (or increase on rare occasions) that is expected from the implementation of the countermeasure. Some countermeasures have values greater than 1 indicating they can negatively impact safety. Column 4 describes the type(s) of crashes that are applicable to the particular CMF value. Column 5 lists the types of crash severities that are pertinent. For some countermeasures, only CMFs for certain crash severities are shown. It is common to evaluate a countermeasure based on its effect on the more severe crashes such as fatal or injury crashes or on all types of crash severities.

All the countermeasures presented in Table 5.4 are familiar to most local agencies and are commonly used to improve safety at the local level. One type of countermeasure is to change or implement traffic control at an intersection. The CMFs vary widely depending on the specific countermeasure. For example the removal of an unwarranted signal could result in a CMF value of 0.76, and the permitting of right-turn-on-red could result in an increase in crash frequency by 43%. And a retiming of the clearance interval could reduce the overall crash frequency but increase slightly the number of read-end crashes. Another type of countermeasure is to provide greater delineation by installing markings, delineators, or rumble strips, or to widen markings. The CMFs for such treatments range from 0.55 to 1.04. The slight increase in total crashes from the installation of post-mounted delineators is possibly due to an increase in the number of minor PDO crashes from vehicles striking the delineators. However, the delineators could still help to reduce the more serious run-of-the-road type crashes. There has been an increase in the use of roundabouts in the United States in the last decade. Depending on the type of conversion, a roundabout could result in CMFs ranging from 0.26 to 1.03. The CMFs for some controversial countermeasures are also presented. For example, the use of red-light cameras results in a CMF of 0.80 for all crashes.

Table 5.4 Countermeasure Examples

Countermeasure Category	Countermeasure	CMF	Crash Type	Crash Severity	CMF Clearing-house ID
Access management	Provide a raised median	0.61	All	Fatal, Serious Injury, Minor Injury	21
Access management	Increase intersection median width by 3 ft increments	0.96	Multiple vehicle	All	298
Access management	Replace direct left-turn with right-turn/U-turn	0.80	All	All	351
Advanced technology and ITS	Install red-light cameras	0.80	All	All	2426
Advanced technology and ITS	Implement automated speed enforcement cameras	0.46	All	All	2915
Alignment	Increase in horizontal curvature by one degree	1.05	Run off road	All	60
Alignment	Increase vertical grade by 1%	1.04	Run off road, Single vehicle	All	61
Alignment	Flatten crest vertical curve	0.49	All	Fatal, Serious injury, Minor injury	721
Bicyclists	Install bicycle lanes	1.05	All	All	2159
Bicyclists	Install bicycle boulevard	0.37	Vehicle/bicycle	All	3092
Delineation	Install post-mounted delineators	1.04	All	Serious Injury, Minor Injury	80
Delineation	Place standard edgeline marking (4-6 in)	0.97	All	Serious Injury, Minor Injury	83
Delineation	Place centerline markings	0.99	All	Serious Injury, Minor Injury	87
Delineation	Add lane lines on multilane roadway segments	0.82	All	All	89
Delineation	Install edgelines and centerlines at sites with higher incidences of crashes	0.87	All	All	100
Delineation	Place edgeline and centerline markings	0.76	All	Serious Injury, Minor Injury	101
Delineation	Install edgelines, centerlines, and post-mounted delineators	0.55	All	Serious Injury, Minor Injury	102

Table 5.4 Continued

Countermeasure Category	Countermeasure	CMF	Crash Type	Crash Severity	CMF Clearinghouse ID
Delineation	Provide "Stop Ahead" pavement markings	0.69	All	All	397
Delineation	Install wider edgelines (4 in to 6 in)	0.83	All	All	4736
Delineation	Install wider markings and edgeline rumble strips with resurfacing	0.76	All	Fatal, Serious injury, Minor injury	4778
Highway lighting	Provide intersection illumination	0.62	Nighttime	Serious Injury, Minor Injury	433
Intersection geometry	Convert four-leg intersection into two three-leg intersections	1.35	All	Serious Injury, Minor Injury	200
Intersection geometry	Conversion of stop-controlled intersection into single-lane roundabout	0.28	All	All	206
Intersection geometry	Conversion of signalized intersection into single- or multi-lane roundabout	0.26	All	Serious injury, Minor injury	212
Intersection geometry	Convert intersection with minor-road stop control to modern roundabout	0.56	All	All	227
Intersection geometry	Convert all-way, stop-controlled intersection to roundabout	1.03	All	All	242
Intersection geometry	Provide a channelized left-turn lane on both major- and minor-road approaches	0.73	All	Serious Injury, Minor Injury	249
Intersection geometry	Painted channelization of left-turn lane on major road	0.78	All	Serious injury, Minor injury	251
Intersection geometry	Provide a left-turn lane on one major-road approach	0.56	All	All	253
Intersection geometry	Provide a left-turn lane on both major-road approaches	0.52	All	All	268
Intersection geometry	Provide a right-turn lane on one major-road approach	0.86	All	All	285

Table 5.4 Continued

Countermeasure Category	Countermeasure	CMF	Crash Type	Crash Severity	CMF Clearinghouse ID
Intersection traffic control	Convert minor-road stop control to all-way stop control	0.25	Angle	All	310
		0.82	Rear-end	All	311
		0.52	All	All	315
Intersection traffic control	Install a traffic signal	0.86	All	Fatal, Serious Injury, Minor Injury	316
		0.33	Angle	Fatal, Serious Injury, Minor Injury	320
Intersection traffic control	Remove unwarranted signal (one-lane, one-way streets, excluding major arterials)	0.76	Angle, Left turn, Right turn	All	329
		0.76	All	All	332
Intersection traffic control	Change from permitted or permitted-protected to protected	0.01	Angle	All	333
		0.99	All	All	334
Intersection traffic control	Permit right-turn-on-red	1.43	Vehicle/pedestrian	All	369
Intersection traffic control	Modify change plus clearance interval to ITE 1985 Proposed Recommended Practice	0.92	All	All	380
		1.12	Rear-end	All	381
Intersection traffic control	Replace Night-Time Flash with Steady Operation	0.66	Angle, Nighttime	All	388
		0.65	Nighttime	All	389
Intersection traffic control	Prohibit left-turns with "No Left Turn" sign	0.36	Left turn	All	390
		0.32	All	All	391

Table 5.4 Continued

Countermeasure Category	Countermeasure	CMF	Crash Type	Crash Severity	CMF Clearinghouse ID
On-street parking	Prohibit on-street parking	0.58	All	All	155
On-street parking	Implement time-limited parking restrictions	0.89	All	All	161
On-street parking	Convert angle parking to parallel parking	0.65	All	All	163
		0.78	All	Fatal, Serious injury, Minor injury	4574
On-street parking	Prohibit on-street parking	0.72	All	Property damage only (PDO)	4575
Pedestrians	Raised median with marked crosswalk (uncontrolled)	0.54	Vehicle/pedestrian	All	175
Pedestrians	Installation of a High intensity Activated crossWalK (HAWK) pedestrian-activated beacon at an intersection	0.71	All	All	2911
Pedestrians	Install crosswalk on one minor approach	0.35	All	All	3019
Pedestrians	Convert Pelican crossing or farside pedestrian signal to Puffin crossing	0.81	All	Fatal, Serious injury, Minor injury	3886
Roadside	Flatten sideslope from 1V:3H to 1V:4H	0.58	All	Serious injury, Minor injury	26
Roadside	Increase distance to roadside features from 3.3 ft to 16.7 ft	0.78	All	All	35
Roadside	New guardrail along embankment	0.93	Run off road	All	39
Roadway	Decrease lane width from 11 feet to 10 feet	1.09	All	All	2
Roadway	Increase lane width from 11 feet to 12 feet	0.95	All	All	3
Roadway	Install centerline rumble strips	0.86	All	All	124
Roadway	Road diet (Convert 4-lane undivided road to 2-lanes plus turning lane)	0.71	All	All	199

Table 5.4 Continued

Countermeasure Category	Countermeasure	CMF	Crash Type	Crash Severity	CMF Clearinghouse ID
Roadway	Introduce TWLTL (two-way left turn lanes) on rural two lane roads	0.64	All	All	583
Roadway	Convert 12-ft lanes and 6-ft shoulders to 10-ft lanes and 3-ft shoulders	1.13	Run off road	All	2002
Roadway	Install transverse rumble strips on stop controlled approaches in rural areas (minor arterial)	1.22	All	All	2698
Roadway	Install edgeline rumble strips	0.71	Run off road	Fatal, Serious injury, Minor injury	3388
Shoulder treatments	Widen paved shoulder from 3 ft to 4 ft	0.97	All	All	10
Shoulder treatments	Pave a 3 to 4 ft sod shoulder	0.81	All	All	18
Shoulder treatments	Install curb and gutter	0.89	All	All	2375
Shoulder treatments	Installation of safety edge treatment	0.92	All	All	4303
Signs	Install signs to conform to MUTCD	0.85	All	Serious injury, Minor injury	62
		0.93	All	Property Damage Only (PDO)	63
Signs	Install combination horizontal alignment/ advisory speed signs	0.87	All	Serious Injury, Minor Injury	73
		0.71	All	Property Damage Only (PDO)	74
Signs	Install chevron signs and curve warning signs	0.59	All	All	1905
		0.66	Nighttime	All	1906
Speed management	Apply converging chevron pattern markings on roadway segments	0.68	All	All	112

Table 5.4 Continued

Countermeasure Category	Countermeasure	CMF	Crash Type	Crash Severity	CMF Clearinghouse ID
Speed management	Traffic calming	0.68	All	All	128
Speed management	Install speed humps	0.60	All	Serious injury, Minor injury	132
Speed management	Install transverse rumble strips as traffic calming device	0.66	All	All	138
Speed management	5% reduction in mean speed	0.83	All	Fatal	141
Speed management	Area-wide or corridor-specific traffic calming	0.89	All	Serious Injury, Minor Injury	586
	Lower posted speed by 5 mph	1.17	All	All	1238
	Lower posted speed by 10 mph	0.96	All	All	1239
Speed management	Lower posted speed by 15-20 mph	0.94	All	All	1240
	Raise posted speed by 5 mph	0.92	All	All	1252
Speed management	Raise posted speed by 10-15 mph	0.85	All	All	1253

Annual reduction in crash frequency is monetized using the severity-based societal costs of crashes. One (2005) FHWA report determined the comprehensive societal costs of crashes for various severities. These costs are reported in the HSM, and are reproduced below (Table 5.5).

Table 5.5 Societal Costs of Crashes by Severity*

Crash type	Crash costs
Fatal	$4,008,900
Disabling injury	$216,000
Evident injury	$79,000
Fatal/injury	$158,200
Possible injury	$44,900
PDO	$7,400

* This table is based on FHWA (2005) and HSM (2010)

Since fatal crash costs are so high, and because fatal crashes are infrequent, an alternative approach to using fatal crash cost is to combine the fatal and injury crash categories into one "fatal/injury" category. This combined category could prevent a single fatal crash from overwhelming the economic analysis. A city can choose to use the fatal/injury value from the HSM, as shown in Table 5.5, or to develop the value using local data, as follows:

$$F + I \ Cost = \frac{F\% * F_{cost} + I\% * I_{cost}}{F\% + I\%}$$

Where,

F% is the percentage of fatal crashes;

F_{cost} is the cost of a fatal crash;

I% is the percentage of injury crashes;

I_{cost} is the cost of an injury crash.

For example, according to Missouri State Highway Patrol (MSHP) data, 0.64% of all crashes in 2005 were fatal, and 25.5% were physical injury. Thus, the cost of *F+I* for 2005 is (0.64%*$4,008,900+25.5%*$79,000)/100% = $174,876.

The concept of *time value of money* refers to the difference in buying power between money in the present and money in the future. This concept is based on the notion that money in the present can both earn interest and be affected by inflation, and is thus different than its future value. Therefore, future benefits and costs should be discounted relative to their present value. According to the AASHTO Red Book, i.e., User and Non-User Benefit Analysis for Highways, a good rule of thumb for the

discount rate is to use three percent per year, or a riskless treasury bond yield, such as the 10-year treasury bond (AASHTO, 2010).

Because information is sometimes gathered from different years, the dollar amount from such years cannot be compared directly. It is typical to translate all dollar amounts to present values, or to those of the year during which the safety analysis was undertaken. Economic tools such as discounting and compounding are used to manipulate monetary time units. Compounding converts monetary time units forward in time, while discounting converts monetary time units back in time to find present values given future benefits; for example.

The equation for compounding is:

$$FV = PV(1 + i)^n$$

Where,

FV is the future value;

PV is the present value;

i is the discount rate;

n is the number of years.

As an example of compounding, assume that fatal crash costs are needed for the year 2013. Table 5.5 gives the fatal crash cost as $4,008,900 in terms of 2005 dollars. Assume that FV represents the year 2013, and PV represents the year 2005; then, n = 2013-2005 = 8. In this example, PV might be more aptly termed the "older value," and FV the "newer value" in the classic compounding equation. Assuming a discount rate, i, of 3%, or, 0.03, then,

$$FV = \$4{,}008{,}900\,(1 + 0.03)^8 = \$5{,}078{,}355$$

Once the annual crash reduction benefits are quantified using the crash costs shown in Table 5.5, the present value of benefits is estimated as,

$$PV_B = \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] A$$

Where,

PV_B is the present value of benefits;

A is the uniform annual monetary benefits;

i is the discount rate;

n is the service life of the countermeasure.

The NPV, b/c, and cost-effectiveness index are computed as:

$$NPV = PV_B - PV_C$$

$$b/c = \frac{PV_B}{PV_C}$$

$$cost - effectiveness\ index = \frac{PV_C}{N_P - N_O}$$

Where,

PV_C is the present value of costs;

N_P is the predicted crash frequency per year (with countermeasure);

N_O is the observed crash frequency per year (without countermeasure).

The present value of project costs is determined using the same discounting method as that used for projected benefits, demonstrated above. The AASHTO Redbook (AASHTO, 2010) provides guidance for quantifying project costs. Several cost elements are taken into consideration when determining project costs. These include right-of-way acquisition costs, planning and design costs, material and equipment costs, environmental impact costs, maintenance costs, and traffic control costs. Many cost elements, such as right-of-way acquisition and project design cost, are based on the current year, and are therefore currently at their present values. Few costs that occur in the future, such as maintenance, need to be discounted to the current year to determine present value.

Example 2: Economic Analysis of Adding Traffic Signals

A local agency conducted an analysis of crashes occurring at a two-way stop control (TWSC) intersection on a high-speed rural segment with stop control on the two minor road approaches only. The major road AADT was 14,500, and the minor road AADT was 3,200. Based on the analysis, the agency is considering replacing the TWSC intersection with a traffic signal. An economic analysis is conducted to determine the net present value, benefit-cost ratio, and cost-effectiveness index values. Assume the analysis was conducted in 2005:

The following notations will be used in this example.

$AADT_{major}$: -major road AADT

$AADT_{minor}$ -minor road AADT

N_{TWSC} -expected crash frequency for the TWSC

N_{Sig} -expected crash frequency after signalization

CMF_{Sig} -modification factor for converting a TWSC to a signalized intersection

ΔN_{Sig} -reduction in crash frequency due to signalization

ΔN_{Sig}^{fatal} -reduction in the frequency of fatal crashes

ΔN_{Sig}^{injury} -reduction in the frequency of injury crashes

ΔN_{Sig}^{PDO} -reduction in the frequency of PDO crashes

A_{Sig} -annual benefits resulting from the reduction in crash frequency due to signalization

PV_B^{Sig} -present value of benefits due to signalization

PV_C^{Sig} -present value of costs of signalization

M_{Sig} -annual costs for maintaining traffic signal

Step 1: Calculate the expected crash frequency without the countermeasure in place (i.e., for the TWSC).

The HSM safety performance function for the rural arterial intersection is used to calculate the expected crash frequency. It is found in Section 10.6.2 of the HSM as:

$$N_{TWSC} = e^{\left[a + b\ln(AADT_{major}) + c\ln(AADT_{minor})\right]}$$

For a four-leg rural intersection with minor road stop control,

$$N_{TWSC} = e^{\left[-8.56 + 0.60\ln(AADT_{major}) + 0.61\ln(AADT_{minor})\right]}$$

Inputting the volumes for the major and minor approaches,

$N_{TWSC} = e^{[-8.56 + 0.60\ln(14500) + 0.61\ln(3200)]} = 8.27$ crashes/year.

Step 2: Calculate the expected crash frequency with the countermeasure:

The CMF for the signalization countermeasure is available in Part D of the HSM. According to Section 14.4.2.6 of the HSM, installing a traffic signal at a TWSC (base condition) in a rural area has a CMF of 0.56 for all types of crashes (includes all severities). There are no separate CMF values for fatal and/or injury crashes. The expected crash frequency, N$_{Sig}$, if a traffic signal replaced the stop control is computed as,

$N_{Sig} = CMF_{Sig} \cdot N_{TWSC} = 0.56*8.27 = 4.63$ crashes/year.

Step 3: Calculate the reduction in crash frequency due to the countermeasure:

$\Delta N_{Sig} = N_{TWSC} - N_{Sig}$ = 8.27 - 4.63 = 3.64 crashes/year.

Step 4: Based on 2005 Missouri crash severity data, the proportions of different crash severities were 0.64% fatal, 25.5% injury, and 73.86% PDO. Since separate CMF values based on crash severities are not currently available for the conversion of TWSC to traffic signal control, the reduction in crash frequency by severity can be computed using the total crash reduction frequency calculated in step 3, and the crash severity proportions, as:

$\Delta N_{Sig}{}^{fatal} = \Delta N_{Sig} * 0.0064$ = 3.64*0.0064 = 0.0233 crashes/year,
$\Delta N_{Sig}{}^{injury} = \Delta N_{Sig} * 0.255$ = 3.64*0.255 = 0.928 crashes/year,
$\Delta N_{Sig}{}^{PDO} = \Delta N_{Sig} * 0.7386$ = 3.64*0.7386 = 2.69 crashes/year.

Step 5: Calculate the annual benefits, A_{Sig}, resulting from the reduction in crashes:

A_{Sig} = 0.0233*\$4,008,900 + 0.928*\$79,000+2.69*\$7,400 = \$186,614/year.

Step 6: Calculate the present value of benefits, $PV_B{}^{Sig}$, assuming a 4% discount rate and 10 years of service life for the countermeasure:

$PV_B{}^{Sig} = \left[\frac{(1+i)^n-1}{i(1+i)^n}\right] A_{Sig} = \left[\frac{(1+0.04)^{10}-1}{0.04(1+0.04)^{10}}\right] \$186,614 = \$1,513,607.$

Step 7: Calculate the present value of signalization costs, $PV_C{}^{Sig}$. For simplicity, in this example it is assumed that the only costs involved with signalization are the initial capital costs of the traffic signal and a fixed annual maintenance fee. In reality, signalization may involve additional costs, such as right-of-way acquisition, channelization, and others. The US DOT ITS Joint Program Office website provides the average capital and maintenance costs of adding signals at a four-leg intersection. Adjusting the costs to the current year using a 4% discount rate, the capital costs are about \$70,000, and annual maintenance costs equate to \$1,500. The present value of annual maintenance costs over the 10-year service life of the signal is computed as,

$$PV_C{}^{Sig} = Capital\ cost + \left[\frac{(1+i)^n-1}{i(1+i)^n}\right] M_{Sig}$$
$$= \$70,000 + \left[\frac{(1+0.04)^{10}-1}{0.04(1+0.04)^{10}}\right] \$1,500 = \$82,166$$

Step 8: Calculate the NPV, b/c, and cost-effectiveness index values:

$NPV_{Sig} = PV_B{}^{Sig} - PV_C{}^{Sig}$ = \$1,513,607 - \$82,166=\$1,431,441
$b/c_{Sig} = \frac{PV_B{}^{Sig}}{PV_C{}^{Sig}} = \frac{1,513,607}{82,166} = 18.4:1$

$$cost - effectiveness\ index_{Sig} = \frac{PV_C{}^{Sig}}{\Delta N_{Sig}} = \frac{\$82,166}{3.64} = \frac{\$22,573}{\text{crash}}.$$

The results of the economic analysis showed that the benefits significantly outweighed the costs in this instance. The net present value is $1,431,441 over 10 years. For every dollar invested in safety improvement, approximately 18 times that amount is returned in benefits. Per crash savings are $22,573.

Example 3: Economic Analysis of Adding Left Turn Lanes at a Signalized Intersection

A four-leg signalized intersection in an urban area is experiencing significant numbers of rear-end crashes. The major road AADT is 55,000 while the minor road ADT is 2,500. An investigation into the crash problem revealed that the rear-end crashes were occurring due to some vehicles going through on major road approaches rear-ending vehicles turning left from the major road to the minor road. Both major road approaches do not have a left turn lane and have permissive left-turn signal phasing. Based on the investigation, the local agency is considering adding left turn lanes on both major road approaches. An economic analysis is conducted to determine the net present value, benefit-cost ratio, and cost-effectiveness index values. Assume the analysis was conducted in 2005:

The following notations will be used in this example.

$AADT_{major}$:	-major road AADT
$AADT_{minor}$	-minor road AADT
$N_{existing}$	-expected crash frequency for the existing signalized intersection without left turn lanes on the major road
N_{after}	- expected crash frequency after adding left turn lanes on both major road approaches
CMF_{LT}	- crash modification factor for adding left turn lanes on major road approaches
ΔN	-reduction in crash frequency due to adding left turn lanes
ΔN^{fatal}	-reduction in the frequency of fatal crashes
ΔN^{injury}	-reduction in the frequency of injury crashes
ΔN^{PDO}	-reduction in the frequency of PDO crashes
A_{LT}	-annual benefits resulting from the reduction in crash frequency
PV_B	-present value of benefits
PV_C	-present value of costs of adding left turn lanes

Step 1: Calculate the expected crash frequency without the countermeasure in place (i.e., for the existing signalized intersection without left turn lanes).

The HSM safety performance function for the urban arterial intersection is used to calculate the expected crash frequency. It is found in Section 12.6.2 of the HSM as:

$$N_{existing} = e^{[a+b\ln(AADT_{major}) + c\ln(AADT_{minor})]}$$

Given the context of the crash problem involving two or more vehicles, only multiple-vehicle collisions will be analyzed in this example. Similar procedure can be repeated for single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions, if needed.

The regression coefficients, a, b, and c, for multiple-vehicle collisions are obtained from Table 12-10 of the HSM,

$$N_{existing} = e^{[-10.99 + 1.07\ln(AADT_{major}) + 0.23\ln(AADT_{minor})]}$$

Inputting the volumes for the major and minor approaches,

$$N_{existing} = e^{[-10.99 + 1.07\,ln(55000) + 0.23\,ln(2500)]} = 12.05 \text{ crashes/year.}$$

Step 2: Calculate the expected crash frequency with the countermeasure (i.e., addition of left turn lanes on both major road approaches):

The CMF for the countermeasure is available in Table 12-24 of the HSM. It is equal to 0.81 for all crash severities. The expected crash frequency, N_{after}, is computed as,

$$N_{after} = CMF_{LT} \cdot N_{existing} = 0.81*12.05 = 9.76 \text{ crashes/year.}$$

Step 3: Calculate the reduction in crash frequency due to the countermeasure:

$$\Delta N = N_{existing} - N_{after} = 12.05 - 9.76 = 2.29 \text{ crashes/year.}$$

Step 4: Based on 2005 Missouri crash severity data, the proportions of different crash severities were 0.64% fatal, 25.5% injury, and 73.86% PDO. Since separate CMF values based on crash severities are not currently available for the conversion of TWSC to traffic signal control, the reduction in crash frequency by severity can be computed using the total crash reduction frequency calculated in step 3, and the crash severity proportions, as:

$$\Delta N^{fatal} = \Delta N * 0.0064 = 2.29*0.0064 = 0.015 \text{ crashes/year,}$$
$$\Delta N^{injury} = \Delta N * 0.255 = 2.29*0.255 = 0.584 \text{ crashes/year,}$$
$$\Delta N^{PDO} = \Delta N * 0.7386 = 2.29*0.7386 = 1.690 \text{ crashes/year.}$$

Step 5: Calculate the annual benefits, A_{LT}, resulting from the reduction in crashes:

$A_{LT} = $ 0.015*\$4,008,900 + 0.584*\$79,000+1.69*\$7,400 = \$117,332/year.

Step 6: Calculate the present value of benefits, PV_B, assuming a 4% discount rate and 10 years of service life for the countermeasure:

$$PV_B = \left[\frac{(1+i)^n-1}{i(1+i)^n}\right] A_{LT} = \left[\frac{(1+0.04)^{10}-1}{0.04(1+0.04)^{10}}\right] \$117,332 = \$951,663.$$

Step 7: Calculate the present value, PV_C, of adding left turn lanes on both major road approaches. The average cost of adding a left turn lane of 300 ft on an intersection approach was obtained from MoDOT as \$50,000. Thus, for two approaches the total cost is \$100,000. For simplicity, we assume that these initial capital costs are the only costs involved with adding turn lanes.

Step 8: Calculate the NPV, b/c, and cost-effectiveness index values:

$$NPV = PV_B - PV_C = \$951,663 - \$100,000 = \$851,663$$
$$b/c_{Sig} = \frac{PV_B}{PV_C} = \frac{951,663}{100,000} = 9.52:1$$
$$cost-effectiveness\ index = \frac{PV_C}{\Delta N} = \frac{\$100,000}{2.29} = \$43,668/crash$$

In summary, the economic analysis showed that the benefits significantly outweighed the costs of adding left turn lanes on major road approaches. The net present value is \$851,663 over 10 years. For every dollar invested in safety improvement, approximately 9.5 times that amount is returned in benefits. Per crash savings are \$43,668.

Example 4: Economic Analysis of Paved Shoulders and Lane Width Reduction

A rural two-lane road with sod shoulders is experiencing a high number of run-off-the-road crashes. The local agency is considering the installation of paved shoulders. Due to right-of-way restrictions, the lane width will have to be reduced from 12 ft to 11 ft, in order to accommodate the 2 ft paved shoulders. An economic analysis is conducted to determine the net present value, benefit-cost ratio, and cost-effectiveness index values. Assume the analysis was conducted in 2005 and assume the road AADT is 3,000 and the length is 2 miles. Also assume that there is no horizontal or vertical curvature, centerline rumble strips, passing lanes, two-way left-turn lanes, lighting, or automated enforcement.

The following notations will be used in this example.

$AADT$ - annual average daily traffic volume (vehicles per day)
L - length of roadway segment (miles)
$N_{existing}$ - expected crash frequency for the existing two-lane rural road without paved shoulders

N_{after} — expected crash frequency after adding 2 ft paved shoulders but with the lane width reduced to 11 ft

CMF_{1r} — crash modification factor for lane width

CMF_{2r} — crash modification factor for shoulder width and type

ΔN — reduction in crash frequency due to adding paved shoulders, but with reduced lane width

ΔN^{fatal} — reduction in the frequency of fatal crashes

ΔN^{injury} — reduction in the frequency of injury crashes

ΔN^{PDO} — reduction in the frequency of PDO crashes

A_{LT} — annual benefits resulting from the reduction in crash frequency

PV_B — present value of benefits

PV_C — present value of costs of adding left turn lanes

Step 1: Calculate the expected crash frequency without the countermeasure in place (i.e., for the existing two-lane road without paved shoulders).

The HSM safety performance function for rural two-lane road base condition is used to calculate the expected crash frequency. It is found in Section 10.6.1 of the HSM as:

$$N_{spf\ rs} = AADT * L * 365 * 10^{-6} * e^{(-0.312)}$$

Inputting the volume and length of the road,

$N_{spf\ rs} = 3000 * 2 * 365 * 10^{-6} * e^{(-0.312)} = 1.069$ crashes/year

The CMFs for shoulders is available in Section 10.7.1 of the HSM. Table 10-9 of the HSM shows the CMF_{wra} as 1.50 for 0 ft shoulder (i.e. no shoulder) for AADT greater than 2000. Table 10-10 of the HSM shows the CMF_{tra} as 1.00 for 0 ft shoulders. The CMF is adjusted for the percentage of crashes that are most likely affected by shoulders using a proportion of total crashes, p_{ra}. Assume p_{ra} is 0.574 for this jurisdiction. The resulting CMF after adjusting for the shoulder-related crashes is:

$CMF_{2r} = (CMF_{wra} x CMF_{tra} - 1.0) x p_{ra} + 1.0 = 1.287$

The expected crash frequency, $N_{existing}$, is computed as,

$N_{exsiting} = CMF_{2r} \cdot N_{existing} = 1.287*1.069 = 1.375$ crashes/year.

Step 2: Calculate the expected crash frequency with the countermeasure (i.e., addition of 2 ft paved shoulders but with a lane reduction down to 11 ft):

The CMFs for lane width and shoulders is available in Section 10.7.1 of the HSM. Table 10-8 of the HSM shows the CMF_{ra} as 1.05 for 11 ft lane width for AADT greater than 2000. This CMF is adjusted for the percentage of crashes that are most likely affected by lane width using a proportion of total crashes, p_{ra}. Assume p_{ra} is 0.574 for this jurisdiction. The resulting CMF after adjusting for the lane-width-related crashes is:

$$CMF_{1r} = (CMF_{ra} - 1.0)xp_{ra} + 1.0 = 1.029$$

Table 10-9 of the HSM shows the CMF_{wra} as 1.30 for 2 ft shoulder width for AADT greater than 2000. Table 10-10 of the HSM shows the CMF_{tra} as 1.00 for paved shoulders. The CMF is adjusted for the percentage of crashes that are most likely affected by shoulders using a proportion of total crashes, p_{ra}. Assume p_{ra} is 0.574 for this jurisdiction. The resulting CMF after adjusting for the shoulder-related crashes is:

$$CMF_{2r} = (CMF_{wra} x CMF_{tra} - 1.0)xp_{ra} + 1.0 = 1.172$$

The expected crash frequency, N_{after}, is computed as,

$$N_{after} = CMF_{1r} \cdot CMF_{2r} \cdot N_{existing} = 1.029*1.172*1.069 = 1.289 \text{ crashes/year.}$$

Step 3: Calculate the reduction in crash frequency due to the countermeasure:

$$\Delta N = N_{existing} - N_{after} = 1.375 - 1.289 = 0.0867 \text{ crashes/year.}$$

Step 4: Based on 2005 Missouri crash severity data, the proportions of different crash severities were 0.64% fatal, 25.5% injury, and 73.86% PDO. The reduction in crash frequency by severity can be computed using the total crash reduction frequency calculated in step 3, and the crash severity proportions, as:

$$\Delta N^{fatal} = \Delta N * 0.0064 = 0.0867*0.0064 = 0.000555 \text{ crashes/year,}$$
$$\Delta N^{injury} = \Delta N * 0.255 = 0.0867*0.255 = 0.0221 \text{ crashes/year,}$$
$$\Delta N^{PDO} = \Delta N * 0.7386 = 0.0867*0.7386 = 0.0640 \text{ crashes/year.}$$

Step 5: Calculate the annual benefits, A_{LT}, resulting from the reduction in crashes:

$$A_{sh} = 0.000555*\$4,008,900 + 0.0221*\$79,000+0.0640*\$7,400 = \$4447/\text{year.}$$

Step 6: Calculate the present value of benefits, PV_B, assuming a 4% discount rate and 10 years of service life for the countermeasure:

$$PV_B = \left[\frac{(1+i)^n-1}{i(1+i)^n}\right] A_{LT} = \left[\frac{(1+0.04)^{10}-1}{0.04(1+0.04)^{10}}\right] \$4447 = \$36,066$$

Step 7: Calculate the present value, PV_C, of adding 2 ft paved shoulder but reducing lane width. The average cost of adding 2 foot shoulders was \$30,000/mile. Thus, for two miles the total cost is \$60,000. For simplicity, we assume that these initial capital costs are the only costs involved with adding turn lanes.

Step 8: Calculate the NPV, b/c, and cost-effectiveness index values:

$$NPV = PV_B - PV_C = \$36,066 - \$60,000 = -\$23,934$$
$$b/c_{Sig} = \frac{PV_B}{PV_C} = \frac{36,066}{60,000} = 0.60$$
$$cost - effectiveness\ index = \frac{PV_C}{\Delta N} = \frac{\$60,000}{0.0867} = \$691,779/crash$$

In summary, the economic analysis showed that the benefits do not outweigh the costs of adding 2 ft paved shoulder if the lane width were to be reduced. The net present value is negative and the benefit to cost ration is less than 1.

Chapter 5 Bibliography

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Chapter

6

CHAPTER 6: ROAD SAFETY AUDITS

A proactive approach to safety.

There are a variety of tools available to local communities to assist in the improvement of highway safety. One low-cost, proactive tool that can be very beneficial for improving safety is the Road Safety Audit (RSA). If a community dislikes the word "audit," then an alternate title, "Road Safety Assessment," can be used. This chapter provides a general overview of RSAs, and describes the eight-step RSA process. The chapter also includes a list of resources on RSAs for the benefit of practitioners.

Introduction
Overview of RSAs

An RSA (FHWA, 2006) is a formal safety examination of an existing or proposed road segment or intersection conducted by an independent, multidisciplinary review team. The goals of an RSA are to identify safety concerns, generate a list of possible countermeasures to address those concerns, and present findings to the project owner or designer for considered implementation. The objective of an RSA is not to redesign the project, but rather to identify proactive ways to enhance the safety of the facility. An RSA considers the safety of all road users, including automobiles, pedestrians, bicyclists, and trucks. An RSA can address concerns related to geometry, operations, and user characteristics and interactions. An RSA is not just a check of the design against design standards, although design standards can be a useful starting point for evaluating safety.

There are some key differences between an RSA and traditional safety reviews. The RSA process encourages the development of a broad coalition for safety. The composition of the RSA team is independent and multidisciplinary, whereas team members in traditional reviews are affiliated with the owner, and specialize in design or safety only. An RSA typically considers a broader set of users beyond motorized traffic alone. An RSA attempts to emphasize human factors issues and road user limitations, while a traditional safety examination may or may not include such concerns. Further, a formal response report is considered to be an essential element of the RSA process.

One concern that has been raised with respect to the RSA process is the possibility of the RSA increasing tort liability. For example, the RSA report could be used to show that a particular facility was unsafe and that the agency had notice of the unsafe facility and did not address the issue. The national research project NCHRP 336 (Wilson and Lipinski, 2004), and Owers and Wilson (2001), both examined such RSA legal issues. Counterbalancing this increase in liability argument, the following issues should be considered: First, the legal doctrines of sovereign immunity and rules of discovery could potentially protect an agency from liability, or exclude RSA evidence from being used in litigation. NCHRP 336 found that there was no correlation between the application of RSA and sovereign immunity. To assist states in developing highway safety improvement projects and programs, 23 U.S.C. §409 forbids the discovery or admission into evidence or reports, data or other information compiled or collected for activities required pursuant to Federal highway safety programs such as Sections 130, 144 and 148 (Hazard Elimination Program). *In Pierce County, Washington v. Guillen*, 537 U.S. 129 (2003), the Supreme Court upheld the constitutionality of Section 409 by indicating that it protects "all reports, surveys, schedules, lists, or data actually compiled or collected for §152 [now §148]." However, this prohibition from use in litigation is not a prohibition against public disclosure. Some states, such as Kansas, limit their RSA report to internal staff use only.

Second, the general policy of promoting public safety could stand in opposition to a plaintiff's interest in a lawsuit. Some states have actually found that RSAs could aid in tort defense by demonstrating an agency's proactive approach to safety and by documenting an agency's financial limitations and timelines for addressing various issues. Thus, an RSA could be used to counter the findings of an expert witness safety review. The reader is cautioned that the aforementioned national perspectives offer examples only from other states; tort laws are specific to a particular state, therefore examples from other states may or may not fully apply to Missouri.

When to Conduct RSAs

RSAs can be performed during any stage of a project's life, including pre-construction, construction, and post-construction. RSAs during the pre-construction phase could occur at various phases of the design process, including the planning, preliminary design, and detailed design stages. There is greater flexibility in the range of countermeasures that can be considered for a project during its early stages of design. As the design of the project progresses and right-of-way for the project is purchased, options for countermeasure-based safety improvement become more limited. A construction RSA can be performed while a project is under construction to attempt to improve the safety of the work zone. A pre-opening RSA can be undertaken following the completion of road construction, before the road facility is opened to the public. Finally, a post-construction RSA can be performed for an existing road segment or intersection. The RSA for an existing facility can incorporate crash history to help identify safety concerns and countermeasures. However, implementation costs for countermeasures at an existing facility are typically higher than implementation costs for countermeasures at a proposed facility. This increase in countermeasure cost as the project progresses is illustrated in Figure 6.1.
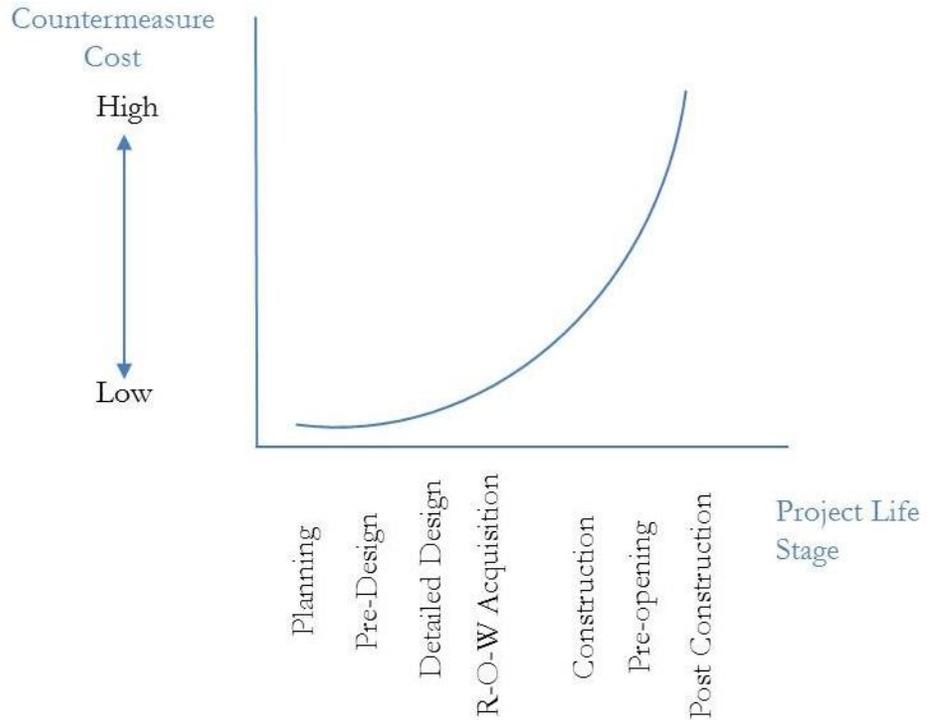
Figure 6.1 Safety implementation cost versus stage of project life.

Benefits of RSAs

RSAs are highly beneficial for aiding the discovery and mitigation of safety concerns that may not have been identified by other means. For example, the New York State DOT reported a 20% to 40% reduction in crashes at 300 high-crash locations due to the introduction of low-cost safety improvements implemented as a result of RSA findings (FHWA, 2006). RSAs also help to promote the awareness of safe practices, and create a proactive culture for addressing safety. RSAs are also relatively low cost: the typical cost for conducting an RSA and implementing countermeasures in the design stage is estimated as 5% of engineering fees (FHWA, 2006). RSAs also help to identify multimodal user interactions and human factors that contribute to crashes; they bring together perspectives from multiple stakeholders, thus revealing safety concerns and solutions that are often unperceived by a single party.

RSA Process

The RSA process includes eight steps, during which safety concerns and countermeasures are identified and presented to the project owner or designer for possible implementation (FHWA, 2006). The RSA team, project owner, and project design team have different levels of responsibility during each stage of the RSA process.

> *RSA Process*
> 1. *Identify Project*
> 2. *RSA Team*
> 3. *Start-Up Meeting*
> 4. *Field Reviews*
> 5. *RSA Analysis*
> 6. *RSA Findings*
> 7. *Formal Response*
> 8. *Incorporate Findings*

Step 1: Identify Project

The RSA process begins with the design team and project owner, who identify the facility to be evaluated in the RSA. The facility can be an extant facility or one that is in the design stage. Agencies can use a variety of criteria to determine which road segments or intersections could benefit from an RSA. For example, a road intersection or segment that does not meet current design standards and has a significant crash history would be a good candidate for an RSA. Stakeholder concerns can also help to identify sites that would be good candidates for RSAs. Other criteria, such as the minimum threshold of construction costs, could also be utilized to identify sites for RSAs.

Step 2: Select RSA Team

The design team and project owner are responsible for selecting the multidisciplinary team to conduct the RSA. The size of the RSA team varies based on the scope and stage of the project, as well as on the need for input from specialists, such as signing or bridge specialists. The RSA team should encompass core skills related to geometry, operations, and human factors. An RSA team should include a representative with local knowledge of the project area. It is also helpful to have a representative from law enforcement. The members of the RSA team should be independent from the design team and project owner. The RSA team should include a leader who is knowledgeable of the RSA procedure and who can work with the design team and project owner.

Step 3: Conduct Start-Up Meeting

After selecting the RSA team, the project owner and design team meet with the RSA team to familiarize the team with the project. The project owner and design team should provide the RSA team with as much information as possible to help them identify safety concerns and countermeasures. Information that should be provided if available includes traffic data, design criteria, and traffic signal timing plans. Other information pertinent to the project stage should also be delivered. For a pre-construction RSA, design drawings should be provided to the RSA team. The design drawings should be of a scale sufficiently large to allow the RSA team to easily review them. The plan drawings should include horizontal and vertical design information, as well as typical cross sections. For a construction RSA, if the evaluation includes work zone traffic control plans, then the maintenance of traffic plans should be provided.

For a post-construction RSA, as-built design drawings should be delivered, along with copies of any previous audits that may have been undertaken.

Step 4: Perform Field Reviews

A field review should always be performed, regardless of the type of RSA. For a pre-construction RSA, the RSA team should look at the project site in the context of the proposed design to try to visualize potential safety concerns. For a post construction RSA, the RSA team will have the benefit of observing facility geometry, operations, and user interactions. The field review should consider the viewpoints of all users of the facility, such as pedestrians, bicyclists, children, trucks, farm vehicles, and older drivers. Prompt lists, such as those provided in *FHWA Road Safety Audit Guidelines* (FHWA, 2006) can help the RSA team to identify potential safety concerns in the field. Some of the items that should be reviewed in the field include sight distance, roadside safety, pavement drop-offs, pavement conditions, pavement markings, signs, drainage, traffic signals, and accommodations for pedestrians and bicyclists.

Step 5: Conduct RSA Analysis

During this stage, the RSA team finalizes the list of safety concerns and identifies possible countermeasures to address them. Safety concerns can originate from any of the previous RSA steps. Crash history, crash diagrams, road condition diagrams, or design conditions not meeting current design standards could all be utilized from Step 1. From Steps 2 and 3, the RSA team could raise concerns stemming from personal knowledge, interaction with the public, and/or plans and drawings. Most importantly, the field review from Step 4 will identify concerns as they appear through the eyes of a diverse range of team members. It may be important to prioritize or rank safety concerns and countermeasures to outline a pathway to safety improvements. The RSA team prepares a written report to document their findings. The RSA report is submitted to the project owner and design team.

Step 6: Present RSA Findings to Owner and Design Team

The RSA team meets with the project owner and design team to present specific safety concerns and suggest possible countermeasures. This meeting allows the project owner, design team, and RSA team the opportunity to discuss the findings of the RSA in an informal setting. The RSA team should be sensitive to the fact that agencies have limited budgets and a large number of facilities to maintain. Likewise, the project owner and design team should be mindful that the RSA team has devoted significant effort to developing recommendations. It is important to undertake a team approach toward advocating safety.

Step 7: Prepare Formal Response

A joint written response to the findings should be prepared by the project owner and design team. This response should contain documentation regarding the implementation of countermeasures suggested by the RSA team. Possible responses from the project owner and design team include:

- Agree with the suggested countermeasure and outline a plan for its implementation.
- Disagree with the suggested countermeasure and suggest an alternative. The owner and design team should document the reasons for not implementing the suggested countermeasure.
- Agree with the suggested countermeasure but provide documentation for constraints that prevent the countermeasure from being implemented (such as cost, environmental impacts, or right-of-way constraints).

Step 8: Incorporate Findings

The project owner and design team should then implement the countermeasures based on the plan outlined in the formal response. The work of the owner and designer does not end with the implementation of countermeasures. An attentive owner or designer verifies that the intended safety improvements were indeed realized with the implemented countermeasures. The RSA constitutes an ongoing process, since transportation demand, land-use, and engineering practices change over time.

RSA Field Examples

As presented in Figures 6.2-6.7, the following are examples of safety concerns that could be identified during an RSA. Figure 6.2 illustrates a situation where the intersection sight distance at a stop-controlled approach was limited by a hill on the mainline. In this case, a project was undertaken to improve sight distance at the intersection by cutting from the hill to change the profile of the mainline. As seen in Figure 6.3, utility poles and trees were located adjacent to the roadway on the inside of a horizontal curve. Possible countermeasures that were identified in this case included tree removal, relocation of the utility poles, and/or installation of a guardrail. Figure 6.4 shows a tree adjacent to the roadway that was marked with a delineator sign. Roadside safety in this situation could be improved by removing the tree. In Figure 6.5, the stop sign is obscured by foliage. Trimming the foliage would greatly improve the visibility of the sign, and thereby improve safety. In Figure 6.6, the two sets of overlapping pavement markings could confuse drivers. The superfluous pavement markings should be removed. Figure 6.7 shows an example of the effects of operations on safety. In this example, the truck stopped in the median is blocking one direction of through traffic. Possible countermeasures for this situation could include signalizing the intersection, re-routing truck traffic to an alternate route, or installing a J-turn intersection that would require traffic to turn right before making a U-turn, instead of turning left.

Figure 6.2 Intersection sight distance obstructed by hill.

Figure 6.3 Utility poles and trees on inside of horizontal curve.

Figure 6.4 Tree adjacent to roadside.

Figure 6.5 Stop sign obscured by foliage.

Figure 6.6 Overlapping sets of pavement markings.

Figure 6.7 Truck in median blocking highway.

Example RSA

This section describes an example RSA that was conducted on St. Charles Road and Lake of the Woods Road in Columbia, Missouri in 2008 (Rossy et al., 2009). The example is described in the context of the eight-step RSA process.

Step 1: Identify Project

The City of Columbia and Boone County requested that the University of Missouri (MU) perform an RSA for a study area consisting of two roads in Columbia. The City of Columbia and Boone County share maintenance responsibilities for these facilities. The study area (Fig. 6.8) included the entire length of Lake of the Woods Road from Route PP to St. Charles Road (1.5 miles) and a segment on St. Charles Road from Lake of the Woods Road to Route Z (2.5 miles). The primary factor contributing to the

selection of this site for an RSA related to concerns regarding the construction of a new high school on St. Charles Road.

Both roads consisted of asphalt pavement, and were classified as rural minor arterial collectors. The approximate average daily traffic (ADT) values were 4,000 vehicles per day (2006) for Lake of the Woods Road and 2,000 vehicles per day (2007) for St. Charles Road. There was a fire station located at the intersection of these two roads, and a golf course was located approximately a half mile to the east of their intersection. The study area included three stop-controlled intersections: St. Charles Road and Route Z, St. Charles Road and Lake of the Woods Road, and Lake of the Woods Road and Route PP. The study area experienced 23 vehicular crashes from 2003 to 2008, including one disabling injury crash. Most crashes occurred at stop-controlled intersections, while many of the other crashes involved private property entrances or collisions with roadside objects.
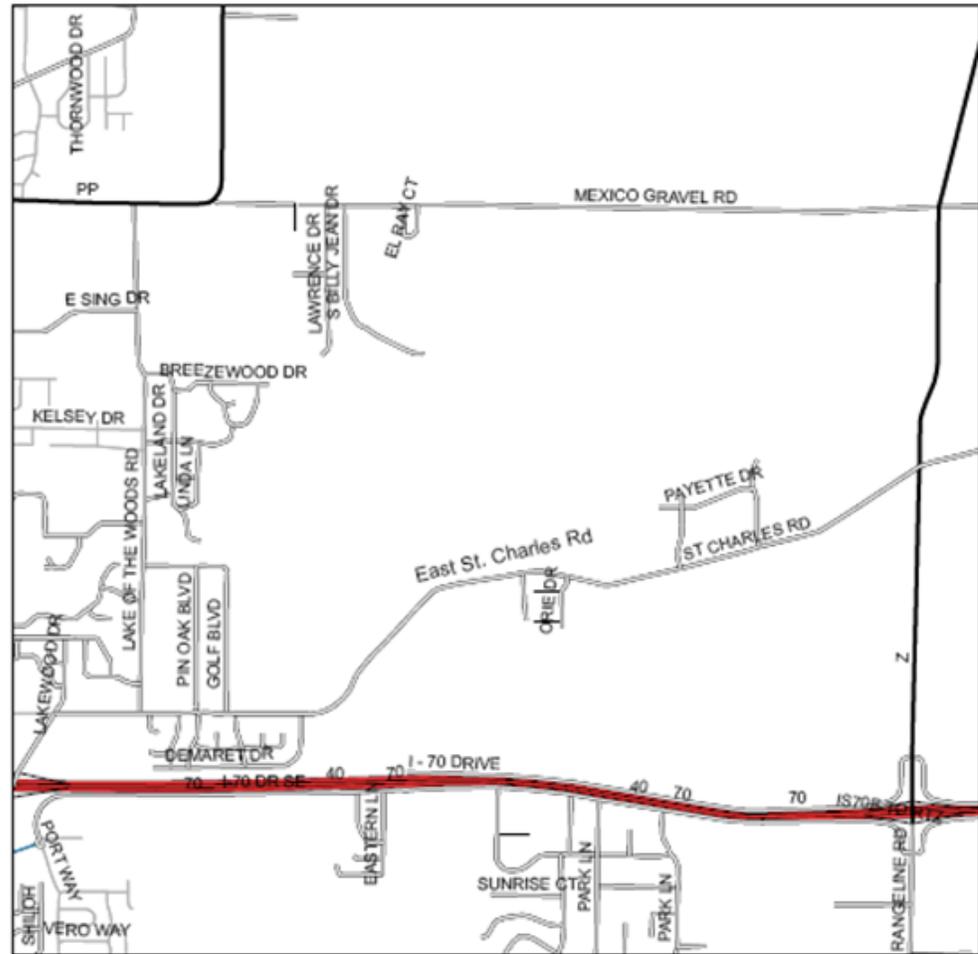
Figure 6.8 Study area for RSA example (Rossy et al., 2009).

Step 2: Select RSA Team

Due to concerns related to the construction of a new high school, a relatively large RSA team of 11 members was selected. The RSA team included representatives from the Federal Highway Administration (FHWA), the Missouri Department of Transportation (MoDOT), the City of Columbia Police Department, the Columbia Public Schools Board, Jefferson City Public Works, Linn State Technical College, and MU. Representatives from the City of Columbia and Boone County Public Works were not included on the team, since they were the clients and primary stakeholders.

Step 3: Conduct Start-Up Meeting

The start-up meeting, field inspection, and post-audit meeting for the RSA analysis were all conducted on April 10, 2008. During the start-up meeting, the team members were provided with background information on the project, including a sketch of the study area and a summary of crash reports. A question and answer session was also held. The RSA team members were also given a prompt list developed by the National Cooperative Highway Research Program (Wilson and Lipinski, 2004) to help provide guidance for the field review.

Step 4: Perform Field Reviews

The RSA team visited the study area for approximately one hour to identify potential safety concerns. Weather conditions were clear during the time of the field visit, although a heavy rainfall had ended a few hours prior. The team inspected the entire study area and paused at some locations for a more detailed review. A few example pictures illustrating concerns identified during the field review are shown in Figures 6.9-6.12.
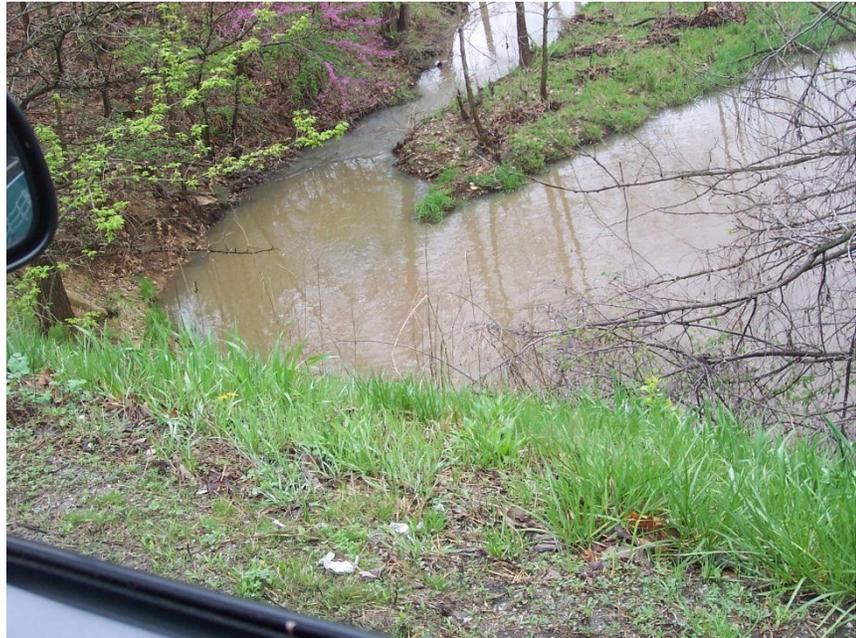
Figure 6.9 Steep dropoff at creek crossing (Rossy et al., 2009).

Figure 6.10 Driveway locations difficult to discern due to heavy foliage (Rossy et al., 2009).

Figure 6.11 Pavement rutting on St. Charles Road (Rossy et al., 2009).

Figure 6.12 Drainage problem at the intersection of St. Charles Road and Route Z (Rossy et al., 2009).

Step 5: Conduct RSA Analysis

Upon completion of the site visit, the RSA team met to discuss their observations. The discussion included the identification of safety concerns and possible countermeasures. A list of some of the concerns and suggestions identified during the analysis is shown in Table 6.1.

Table 6.1 Partial Listing of Concerns and Countermeasures in RSA example (Rossy et al., 2009)

Concern	Suggestions
Intersection of Lake of the Woods Road and St. Charles Road	
Pavement rutting	Mill and repave pavement
Limited sight distance on southbound approach	Stop ahead sign, lighting, rumble strips
Other improvements	Replace intersection with roundabout
St. Charles Road	
View of driveways limited by vegetation	Trim and remove vegetation
Lack of pavement markings or shoulders	Add edgeline and pedestrian markings, add shoulder
Horizontal curves	Add chevron sign for sharp curves
Intersection of St. Charles Road and Route Z	
Improper drainage	Improve drainage
Dense vegetation limits visibility of stop sign	Trim and remove vegetation
Limited sight distance on northbound and southbound approaches	Consider signal, roundabout, flashing yellow, or intersection ahead signing
Lake of the Woods Road	
Steep drop at culvert creek crossing	Add guardrail, delineate drop-off
Fixed objects close to pavement edge	Relocate mailboxes, relocate or remove trees
Intersections with minor roads	Install intersection ahead signs, install stop signs on minor roads
Intersection of Lake of the Woods Road and Route PP	
Faded signs	Replace signs
Pavement damage	Improve drainage
Other improvements	Provide lighting, implement mowing policy

Step 6: Present RSA Findings to Owner and Design Team

A preliminary report of the RSA findings was submitted to both the Boone County Office of Public Works and the City of Columbia Public Works Department.

Step 7: Prepare Formal Response

The City of Columbia Public Works Department and the Boone County Office of Public Works both prepared responses in which they acknowledged the validity of the findings. The independent nature of the RSA process helped the City of Columbia provide the necessary justification to request additional funding for safety improvements. The Boone County Office of Public Works expressed concerns regarding some of the challenges to implementing the low-cost improvements, arising from potential conflicts with other state and federal agencies. For example, requests for residents to relocate mailboxes further from the road could create conflicts with the United States Postal Service.

Step 8: Incorporate Findings

Within one year of the RSA's completion, the following improvements were implemented on Lake of the Woods Road:

- Re-establishment of drainage ditches

- Cleaning of culvert inlets

- Regular mowing of grassy areas adjacent to the pavement.

The following improvements were implemented at the intersection of St. Charles Road and Route Z:

- Trimming of trees to improve visibility

- Drainage treatments (Fig. 6.13)

Figure 6.13 Drainage improvements at the intersection of St. Charles Road and Route Z (Rossy et al., 2009).

RSA Case Studies

This section describes a few RSA case studies from different areas of the country. These case studies demonstrate the use of RSAs for a variety of applications, including safety improvements to existing highway sections, Bicycle Road Safety Audits (BRSA), design visualization projects in the conceptual stage, and safety improvements for routes to schools.

Case Study 1: Arizona Bullhead Parkway

In 2007, an RSA was conducted on a 10.2-mile section of Bullhead Parkway in Bullhead City, Arizona (Nabors et al., 2012). The RSA was requested by the Bullhead City Department of Public Works because the segment was one of the City's top priorities for safety improvements, being listed as a high crash location in the state of Arizona. Bullhead Parkway is a four-lane, divided rural roadway with four signalized intersections, 13 unsignalized intersections, and a posted speed limit of 50 mph. The RSA team consisted of five members from the Arizona Department of Transportation (ADOT) Traffic Safety, ADOT Traffic Design, ADOT Kingman District, FHWA, and the City of Yuma.

Several key findings and suggestions were implemented shortly after the completion of the RSA. The sole suggestion not considered or evaluated further due to cost and right-of-way constraints was the flattening of roadside slopes. Some of the key countermeasures that were implemented included:

- Installation of guardrail at locations where embankment slopes were steeper than 4:1.

- Paving inside and outside shoulders with rumble strips.

- Raising center storm drains to grade.

- Extending guardrail in some locations.

- Decreasing spacing of flexible delineators in curves from 300 ft to 150 ft.

- Moving signs in the shoulders to at least 8 ft from the travel lane.

This RSA produced a number of benefits. An analysis of crash data (Nabors et al., 2012) estimated a 54% reduction in total crashes resulting from implementation of the aforementioned improvements. The RSA benefited the City in terms of education by providing an increased awareness of best practices for roadway and roadside hazard safety. This increased awareness led the City to revisit its practices for installing trees along the roadway for landscaping. The City has appreciated the benefits of the RSA process, and has conducted two additional RSAs since the completion of the Bullhead Parkway RSA.

Case Study 2: Bicycle Road Safety Audit (BRSA) in Grant Teton National Park

In September 2012, a BRSA was held in Grand Teton National Park (Goughnour, 2013). The BRSA was a joint effort between Grand Teton National Park staff, the National Park Service Intermountain Regional Office, the Wyoming Department of Transportation, FHWA, and the Western Federal Lands Highway Division. The BRSA team included members with backgrounds in law enforcement, engineering, sustainability, and landscape architecture. The study area for the BRSA was a bicycle crossing at the intersection of

Gros Ventre Road and US Highway 26/89/191. The crossing was part of a 20-mile shared use path from Jackson to Jenny Lake. The BRSA was requested by Grand Teton National Park in response to concerns by intersection users who witnessed many near-misses between cyclists and motor vehicles. The BRSA team developed suggestions for short-term, intermediate, and long-term improvements. Suggested short-term improvements included increased signage and pavement markings for the roadways and shared use path. Suggested intermediate and long-term improvements included the relocation of the shared use path crossing, the construction of a tunnel at the crossing, and the construction of a roundabout, among others.

Case Study 3: Design Visualization for Conceptual Corridor in Rhode Island

In this example, design visualization was utilized to evaluate two alternatives at the conceptual design stage (FHWA, 2011a). This project was located on Aquidneck Island near Newport, Rhode Island. Due to concerns about increasing congestion from driveway access points and traffic signals, the conceptual alignment for a new limited-access roadway along the Burma Road South corridor was studied. A field review was not possible since the alignment was only a concept. The RSA team conducted the RSA by utilizing a detailed 3D model of the proposed road. The RSA included the evaluation of two alternatives: the use of signalized intersections at the limits of the alignment, and the use of roundabouts at the limits of the alignment. The roundabout (Fig. 6.14) was the preferred option due to its aesthetic appeal, its elimination of left-turn conflicts at intersections, and the resulting decreased traffic delay. The RSA team provided recommendations for the conceptual design that included the use of lighting, the use of sufficient radii to accommodate large vehicles, and the extension of left-turn lanes for additional storage space at intersections.

Figure 6.14 Design visualization for Burma Road South Corridor (FHWA, 2011a).

Case Study 4: Safe Routes to School in Albany, Georgia

In Albany, Georgia, RSAs have been conducted to improve safety for pedestrians walking to neighborhood elementary schools (FHWA, 2011b). The RSA team included representatives from the City of Albany Engineering Department, the Georgia Department of Transportation, the Dougherty County Board of Education, and the Parent/Teacher Association. A consultant was provided by the Georgia Safe Routes to School Resource Center to facilitate the RSA process. Recommendations from the RSA process included improvements to traffic signs and pavement markings on streets near schools, installation of sidewalk around the boundaries of school grounds, and the addition of a High-Intensity Activated Crosswalk (H.A.W.K) signal to supplement an intersection school crossing guard. This example demonstrates that RSAs can be very effective at the local level.

RSA Resources

Federal Highway Administration (FHWA) RSA Website

FHWA maintains a website containing helpful information and resources regarding RSAs. Some of the resources on the website include RSA guidelines, sample RSA reports, RSA software, and RSA case studies. Visitors to the website can also order an RSA Toolkit CD containing additional materials such as RSA videos and RSA training information.

FHWA (accessed 8/14/2013). *Road Safety Audits.* Washington, D.C. Available at http://safety.fhwa.dot.gov/rsa/.

RSA Newsletters

FHWA also publishes a quarterly newsletter that is available on the FHWA website. The newsletter includes information on state RSA programs, news stories discussing RSAs, and other resources related to RSAs.

FHWA (accessed 8/14/2013). *Road Safety Audits: Newsletters.* Washington, D.C. Available at http://safety.fhwa.dot.gov/rsa/newsletter/.

Transportation Safety Resource Center

This website includes links to many RSA resources, including an RSA brochure, a sample RSA checklist, a sample RSA response letter, and a sample RSA report.

Transportation Safety Resource Center (accessed 8/14/2013). *Road Safety Audit Resources.* Washington, D.C. Available at http://cait.rutgers.edu/tsrc/road-safety-audit-resources.

Chapter 6 Bibliography

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Federal Highway Administration. (accessed October 3, 2013b). *RSAs Lead to Safe Routes to School*. RSA Newsletter. Spring/Summer 2011. Volume 3, Number 2. Washington, D.C. Available at http://safety.fhwa.dot.gov/rsa/newsletter/2011/sprsum/.

Gibbs, M., Zein, S., Nabors, D., McGee, H., Eccles, K. (2006). *Road Safety Audits: Case Studies*. Office of Safety. Federal Highway Administration. Washington, D.C.

Goughnour, E.. (accessed October 3, 2013). *Grand Teton National Park Conducts Bike RSA to Improve Intersection Safety*. RSA Newsletter. Winter 2013. Volume 4, Number 2. Federal Highway Administration. Washington, D.C. Available at http://safety.fhwa.dot.gov/rsa/newsletter/2013/winter/.

Nabors, D., Goughnour, E., Thomas, L., DeSantis, W., and Sawyer, M. (2012). *Bicycle Road Safety Audit Guidelines and Prompt Lists*. Office of Safety. Federal Highway Administration. Washington, D.C.

Nabors, D., Gross, P., Kevin Moriarty, K., Sawyer,M., and C. Lyon. (2012). *Road Safety Audits: An Evaluation of RSA Programs and Projects*. Report FHWA-SA-12-037. Federal Highway Administration. Washington, D.C.

Owers, R. and Wilson, E. (2004). *Safety Analysis Without the Legal Paralysis: the Road Safety Audit Program*. Department of Civil and Architectural Engineering, University of Wyoming. Laramie, Wyoming.

Rossy, G., Edara, P., Nemmers, C., *Evaluation of a Road Safety Audit Pilot Project in Missouri: Case Studies of Two Roads in Boone County*. Missouri DOT and City of Columbia Research Report. 2009. (also presented at TRB annual meeting 2010).

Wilson, E., and Lipinski, M. (2004). *Road Safety Audits: A Synthesis of Highway Practice*. NHCRP 336. National Cooperative Highway Research Program. Transportation Research Board. Washington, D.C.

Chapter

7
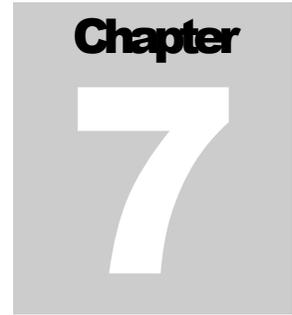
CHAPTER 7: ADDITIONAL RESOURCES

Utilizing the collective wisdom of others.

A local community is not alone in its quest to improve safety. According to the U.S. Census Bureau (2007), there are approximately 36,000 local municipalities and townships in the United States. Even though there is great diversity among these local communities in terms of population, land area, revenue, driver population, and land use, many communities share similar safety concerns and experiences. The collective wisdom of these communities can help to improve the situation in your local community. This chapter documents useful resources that capture experiences and tools from across the United States. Many of the resources discussed in this chapter are free, and some can be easily downloaded or viewed on the Internet.

> S-HAL Supports the data-driven approach required of grant funding

One principal source of assistance is the Federal Government. Several agencies from the U.S. Department of Transportation exist that can offer expertise, support, and even funding for local communities. S-HAL itself could be a key to successful Federal or other types of grant applications, in light of the recent trend requiring data-driven evidence for securing grants. For example, §31102 of MAP-21 (Moving Ahead for Progress in the 21st Century) continues the data-driven approach of the Federal Highway Safety Improvement Program. Though transportation funding legislation will continue to change, the principles discussed in S-HAL should have relevance for the foreseeable future.

FHWA is a central figure in coordinating safety resources for local communities. The FHWA Office of Safety and the Local Technical Assistance Program (LTAP) are two resources that could be the first stops for any local communities requiring assistance with safety matters.

Agencies and Organizations

There exist many agencies and organizations that are involved in improving safety for local communities. The following is a list of the most prominent safety organizations at the national level. Even though some of these organizations are national, they often operate state divisions or chapters that work more closely with each state.

American Association of State Highway and Transportation Officials (AASHTO)

AASHTO is comprised of all state and highway transportation departments in the United States (AASHTO, 2013). Though its board is composed only of state officials, the organization is concerned with all aspects of transportation, including highway safety, at the local level. AASHTO publishes several resources related to local highway safety, and is the publisher of the Highway Safety Manual and the Green Book (A Policy on Geometric Design of Highways and Streets).

AASHTO (accessed 6/26/2013) *AASHTO Overview.* American Association of State Highway and Transportation Officials. Washington D.C. Available at http://www.transportation.org.

American Public Works Association (APWA)

The APWA is an international professional organization for individuals who are involved in public works (APWA, 2013). It consists of individuals from both the public and private sectors, and includes all levels of government. One of APWA's goals is to improve the quality of life in all communities.

APWA (accessed 6/26/2013) *APWA: Who We Are.* American Public Works Association . Kansas City, Missouri. Available at http://www.apwa.net.

American Traffic Safety Services Association (ATSSA)

ATSSA is an international trade association representing the traffic control and roadway safety industries (ATSSA, 2013). ATSSA members produce products that could be deployed for use as safety countermeasures. Such products include markings, road signs, temporary traffic control devices, and guardrails. The core purpose of ATSSA is to advance roadway safety.

ATSSA (accessed 6/26/2013) *ATSSA: About Us.* American Traffic Safety Services Association. Fredericksburg, Virginia. Available at https://www.atssa.com.

Center for Excellence in Rural Safety (CERS)

The national Center for Excellence in Rural Safety, based out of the University of Minnesota and sponsored by FHWA, assists in research and training in rural transportation safety (CERS, 2013). CERS sponsors the Rural Highway Safety Clearinghouse, which is intended to be a starting point for all rural safety resources (RHSCH, 2013).

CERS (accessed 6/26/2013) *About the Center for Excellence in Rural Safety.* Center for Excellence in Rural Safety. Minneapolis, Minnesota. Available at http://www.ruralsafety.umn.edu.

RHSCH (accessed 6/26/2013) *Rural Highway Safety Clearinghouse.* University of Minnesota. Minneapolis, Minnesota. Available at http://www.ruralsafety.umn.edu/clearinghouse.

Governors Highway Safety Association (GHSA)

The GHSA focuses on behavioral highway safety issues such as teen driving, occupant protection, impaired driving, and speeding (GHSA, 2013). The name stems from the fact that the state governor selects the highway safety representative to administer the state's highway safety office created by the State and Community Highway Safety Grant Program (U.S.C. Title 23, Section 402).

GHSA (accessed 6/26/2013) *What is GHSA?* Governors Highway Safety Association. Washington, D.C. Available at http://www.ghsa.org.

Federal Highway Administration (FHWA)

Out of all the organizations here listed, FHWA is arguably the most important resource for local transportation safety. FHWA is an agency within the U.S. Department of Transportation that supports the design, construction, and maintenance of U.S. highways at all levels including the local level (FHWA, 2013a). Specifically, the Office of Safety works to promote safety at the local level (FHWA, 2013b). The Office emphasizes the "four E's": engineering, education, enforcement, and emergency medical services. It sponsors the local and rural road safety program, which provides a host of resources to the local community. Examples include funding and policy guidance, as well as training and countermeasure information.

FHWA also sponsors the Local Technical Assistance Program (LTAP), which provides support for local counties and cities in terms of roads and bridges. The four focus areas of LTAP's Strategic Plan include safety, workforce development, infrastructure management, and organizational excellence. The following are examples of each area: the area of safety could involve work zones, intersection design, heavy equipment, road safety audits, and worker safety. Pavement maintenance and heavy equipment operation are examples of infrastructure management. Workforce development could involve leadership and management training, succession planning, and career day and school outreach. An example of organizational excellence is promoting involvement in professional organizations such as the National Local Technical Assistance Program Association, the Transportation Research Board, and local government associations. LTAP provides training programs, a Clearinghouse website, technology updates, and technical assistance. The Clearinghouse is operated under contract by the American Road & Transportation Builders Association (ARTBA). There is a physical LTAP center in each of the states (LTAP, 2013).

FHWA (accessed 6/26/2013a) *About FHWA.* Federal Highway Administration. Washington, D.C. Available at http://www.fhwa.dot.gov.

FHWA (accessed 6/26/2013b) *FHWA Safety*. Federal Highway Administration. Washington, D.C. Available at http://safety.fhwa.dot.gov.

LTAP (accessed 6/26/2013b) *About the National Program*. Local Technical Assistance Program. Federal Highway Administration. Washington, D.C. Available at http://www.ltap.org.

Institute of Transportation Engineers (ITE)

ITE is a professional organization for transportation engineers who are involved in the areas of safety and mobility. ITE supports professional development in the areas of research, planning, functional design, implementation, operation, policy, and management. Ground transportation is the focus of ITE. ITE accomplishes its goals through its headquarters, regional chapters, and local chapters. Examples of ITE resources include design manuals, annual meetings, seminars, research publications, and local meetings. Missouri ITE is associated regionally with the 11-state Midwestern District, the four-state Missouri Valley Section, and the local chapters of Central Missouri, Kansas City, Ozark, and St. Louis.

ITE (accessed 7/5/2013) *About ITE*. Institute of Transportation Engineers. Washington, D.C. Available at http://www.ite.org.

Insurance Institute for Highway Safety (IIHS)

The IIHS was originally founded by insurance associations to support highway safety (IIHS, 2013). It then became an independent research organization dedicated to the reduction of crashes and crash severity. IIHS provides information on human factors, crash avoidance and crashworthiness, and road design and hazards.

IIHS (accessed 6/26/2013b) *About the Institutes*. Insurance Institute for Highway Safety. Arlington, Virginia. Available at http://www.iihs.org.

Missouri Coalition for Roadway Safety

The Missouri Coalition for Roadway Safety (MCRS, 2013) is composed of a large and diverse number of coalition partners, including law enforcement, educators, emergency responders, and engineers. The Coalition publishes Missouri's Blueprint to Save More Lives, which is the state's strategic highway safety plan. The Blueprint provides a framework to reduce roadway fatalities and serious injuries. The eight guiding principles behind the Blueprint include:

- Focus on fatalities and serious injuries
- Consider education, enforcement, emergency response, engineering and public policy strategies
- Collaborate with all safety partners
- Use evidence-based strategies
- Support system-wide safety enhancements
- Implement countermeasures at both state and regional levels
- Monitor and evaluate progress
- Apply to all roadways.

MCRS (accessed 6/26/2013) *Missouri's Blueprint to Save More Lives.* Missouri Coalition for Roadway Safety. Jefferson, City. Available at http://savemolives.org.

National Association of Counties (NACo)

NACo represents the 3,069 counties in the U.S., and assists them with issues including highway safety (NACo, 2013).

NACo (accessed 6/26/2013) *About NACo – The Voice of America's Counties. National* Association of Counties. Washington, D.C. Available at http://www.naco.org.

National Association of County Engineers (NACE)

NACE is the national voice for county road officials (NACE, 2013). The major objectives of NACE are to advance county engineering and management, to stimulate the growth of county engineers and officials, to improve cooperation among counties, and to monitor national legislation affecting counties.

NACE (accessed 6/26/2013) About NACE. National Association of County Engineers. Washington, D.C. Available at http://www.countyengineers.org.

National Association of Development Organizations (NADO)

NADO provides education, research, training, and advocacy for regional development organizations (RDOs) (NADO, 2013). RDOs perform multi-jurisdictional and cooperative planning so that local communities within a region can work together to improve the entire region. RDOs are known by various names, such as area development districts, planning and development councils, and regional councils. NADO provides resources to improve upon rural transportation safety.

NADO (accessed 6/26/2013) *About NADO.* National Association of Development Organizations.

National Association of Towns and Townships (NATaT)

NATaT represents smaller communities, towns, and townships in the U.S. Eighty-five percent of NATaT communities have fewer than 10,000 people, and around fifty percent have fewer than 1,000 people (NATaT, 2013).

NATaT (accessed 6/26/2013) NADO: About Us. National Association of Towns and Townships. Washington, D.C. Available at http://www.natat.org.

National Highway Traffic Safety Administration (NHTSA)

One NHTSA program of special interest to local communities is Safe Communities (NHTSA, 2013). This program uses a shared community approach to improving transportation safety. The main characteristics of Safe Communities are:

- Crash data analysis
- Partnerships, including medical and businesses
- Public involvement and input
- Integrated and comprehensive injury control system

NHTSA (accessed 6/26/2013) *Safe Communities.* National Highway Traffic Safety Administration. Available at http://www.nhtsa.gov

Roadway Safety Foundation (RSF)

RSF is a nonprofit organization with the mission of reducing the frequency and severity of motor vehicle crashes. Their goals include investing in cost-effective safety programs, facilitating public and private sector cooperation in safety initiatives, and increasing awareness of safety programs.

RSF (accessed 6/26/2013) About Us. Roadway Safety Foundation. Washington, D.C. Available at http://www.roadwaysafety.org.

Transportation Research Board (TRB)

TRB is an organization under the National Academies of Sciences that promotes research and innovation in all areas of transportation (TRB, 2013). TRB produces and provides much information that is relevant to local community safety. One specific TRB program is the National Cooperative Highway Research Program, which has produced significant research on specific safety topics relevant to local communities.

TRB (accessed 6/26/2013) *The Transportation Research Board.* Washington, D.C. Available at http://www.trb.org.

Publications

Roadway Safety Information Analysis: A Manual for Local Rural Road Owners

This manual promotes a data-driven approach to improving local roadway safety, since federal funding mechanisms often require such an approach (Bolembiewski and Chandler, 2011a). For example, the High Risk Rural Roads Program (HRRRP) maintains a funding pre-requisite, in that roads are expected to experience a higher than average number of crashes. Several approaches to countermeasure selection are presented, including systematic, spot location, and comprehensive.

Intersection Safety: A Manual for Local Rural Road Owners

More than 80 percent of rural intersection fatalities occur at unsignalized intersections. If available, local agencies are encouraged to consult with their state's safety implementation plan. Three main safety approaches are discussed in this manual: systematic, spot location, and comprehensive (Bolembiewski and Chandler, 2011b). A data driven approach involving law enforcement crash reports and other roadway and traffic data is recommended. Countermeasures, such as signage and markings, are described. Funding mechanisms are also discussed.

Roadway Safety Departure: A Manual for Local Rural Road Owners

Road departure crashes are often serious, and account for 53 percent of all traffic fatalities. This manual provides a way for local agencies to tie into their state's Roadway Departure Safety Implementation Plan (Bolembiewski and Chandler, 2011c). Three main safety approaches are discussed: systematic, spot location, and comprehensive. The field review process is outlined. Various countermeasures, especially low cost countermeasures, are described. Case studies in Georgia, California, and New Jersey are also presented.

Developing Safety Plans: A Manual for Local Rural Road Owners

This manual describes the Local Road Safety Plan (LRSP) which is the process of building consensus and identifying key emphasis areas and strategies that will enhance local road safety (Ceifetz et al., 2012). Proactive safety planning allows local communities to leverage resources from all levels of government and to build successful safety partnerships.

Low-Cost Treatments for Horizontal Curve Safety

Horizontal curves account for nearly 25 percent of all fatal crashes, and contribute significantly to road departure crashes. This publication focuses on six types of local treatments (McGee and Hanscom, 2006). They include basic MUTCD signs and markings, enhanced traffic control devices, MUTCD-complementary traffic devices, rumble strips, minor roadway treatments, and innovative treatments. Basic MUTCD components could be related to centerlines, edge lines, horizontal curve segments, speed advisories, delineators, and chevrons. Enhanced devices could include larger devices, doubling-up on devices, increasing retroreflectivity, flashing beacons, and raised pavement markers. Reflective barrier delineation, roadside object delineation,

dynamic curve warning systems, and speed limit advisory in lane markings are examples of MUTCD-complementary techniques. Minor improvements could involve paving shoulders, adding surface skid resistance, and eliminating shoulder drop-offs. Two examples of innovative treatments include optical speed bars and PennDOT curve advance markings.

Noteworthy Practices: Addressing Safety on Locally Owned and Maintained Roads

This 2010 publication documents successful practices from the following seven states: Alabama, Georgia, Illinois, Michigan, Minnesota, New Jersey, and Washington (Anderson et al., 2010). The focus is on identifying best practices in funding, coordination, and technical assistance between state departments of transportation (DOTs) and local agencies. These best practices share the themes of crash data collection and analysis, project prioritization/identification, project administration, funding distribution and streamlining, training, technical assistance, outreach and partnerships, and integration with state safety programs.

Guidance Memorandum on Consideration and Implementation of Proven Safety Countermeasures

The following are some of the proven safety countermeasures promoted and discussed by the FHWA in this memorandum (Lindley, 2008). A *road safety audit* is an examination of the safety performance of a facility by an independent, multi-disciplinary team. *Rumble strips and stripes* are raised or grooved pavement treatments that provide audible and physical warnings. *Median longitudinal barriers* reduce cross-median frequency and severity, and redirect vehicles. The *safety edge* is an angled pavement treatment that minimizes drop-offs and improves road recovery. The *modern roundabout* improves safety through offset, deflection, reverse superelevation, and channelization.

Funding Resources

Highway Safety Improvement Program (HSIP)

HSIP was established by SAFETEA-LU (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users) in 2005, and continued with MAP-21 through 2013 (FHWA, 2013). HSIP is a core federal aid program that seeks to significantly reduce traffic fatalities and injuries. HSIP is an umbrella program that covers several programs potentially affecting local communities.

FHWA (accessed 6/27/2013) *HSIP History.* Office of Safety. Federal Highway Administration. Available at http://safety.fhwa.dot.gov.

Strategic Highway Safety Plan (SHSP)

SHSP is a principal component of the HSIP, and requires states to develop a coordinated and comprehensive highway safety plan (FHWA, 2013a). Such a plan identifies safety needs and prioritizes safety investments. This state-level plan covers all public roads,

⌂ **A l i g n i n g   L o c a l   E f f o r t s   w i t h   M i s s o u r i ' s   B l u e p r i n t**

including local roads; thus, it is to the advantage of local communities to align their own safety goals with this plan. In fact, MAP-21 requires that SHSP involve the participation of local road jurisdictions (FHWA, 2013b). The local municipality is encouraged to review Missouri's SHSP, the Blueprint to Save More Lives, and to explore ways in which the municipality can further the goals of the Blueprint.

FHWA (accessed 6/27/2013a) *Strategic Highway Safety Plan*. Office of Safety. Federal Highway Administration. Available at http://safety.fhwa.dot.gov.

FHWA (accessed 6/27/2013b) *Strategic Highway Safety Plan (SHSP) Questions & Answers*. Office of Safety. Federal Highway Administration. Available at http://safety.fhwa.dot.gov.

High Risk Rural Road Program (HRRRP)

As defined in MAP-21, a high-risk rural road refers to any "roadway functionally classified as a rural major or minor collector or a rural local road with significant safety risks, as defined by a State in accordance with an updated State strategic highway safety plan" (23 USC 148(a)(1)). This definition emphasizes the need for local municipalities to coordinate their safety efforts and needs with Missouri's Blueprint in order to take advantage of federal funds through the state. MAP-21 obligates Missouri to expend safety funds if the "fatality rate on rural roads increases over the most recent 2-year period." Such fatality rates are computed according to the method described in Chapter 3 of S-HAL, and are rounded to the nearest tenth. For example, if a rural road experienced a five-year average fatality rate increase from 2.3 to 2.4 100 MVMT (million vehicle miles traveled), then the municipality would be eligible to receive HRRR funds to improve safety on that road.

State and Community Highway Safety Grant Program (Section 402)

The Section 402 program is jointly administered by the FHWA and the NHTSA, with the goal of improving driver behavior and reducing fatal and injury crashes (GHSA, 2013). This program has been in place since 1966, and has been continued under various transportation legislations, including MAP-21. The areas addressed by this program include impaired driving, speeding, occupant protection, motorcycle safety, pedestrian and bicycle safety, school bus safety, unsafe driving, traffic enforcement, driver performance, traffic records, emergency services, and teen driving. Missouri's program must be coordinated with Missouri's Blueprint. Under this program, Missouri received slightly less than $5 million each year from 2006 to 2012.

GHSA (accessed 7/3/2013) *Section 402 State and Community Highway Safety Grant Program*. Governors Highway Safety Association. Washington, D.C. Available at http://www.ghsa.org.

The following is a sample list of specific issues or conditions for which funding could be available to local communities. This list is related to the aforementioned HSIP, SHSP, HRRRP, and HEF programs.

Highway Lighting

Funding under 23 U.S.C. 148, the Highway Safety Improvement Program, could be used for the purpose of reducing traffic fatalities and serious injuries on public roads. According to FHWA (Alicandri, 2005), highway lighting is covered under "traffic lights," and is eligible for 100% federal funding.

Alicandri, E. (2005) *Eligibility of 23 USC 120(c) for Highway Lighting*. Office of Safety. Federal Highway Administration. December 1.

Sign Retroreflectivity and Replacement

FHWA allows the use of HSIP funds for sign replacement, but there are several requirements (Lindley, 2008). The replacement has to arise from a demonstrated safety benefit and need that is supportable by data. Such a replacement has to be consistent with the SHSP. Such replacement should not be funded by the safety program if it is part of a routine, broader project.

According to the FHWA guidance on sign retroreflectivity (FHWA, 2013), public agencies have until June 14, 2014 to implement and continue to use an assessment or management method to maintain regulatory and warning sign retroreflectivity. NATaT lists several programs that could fund sign replacement (NATaT, 2013). These include the Interstate Maintenance Program, the Surface Transportation Program, the Highway Safety Improvement Program, the High Risk Rural Roads Program, and the State Planning and Research Program.

Lindley, J. (2008) *Eligibility of HSIP Funds for Sign Replacement*. Office of Safety. Federal Highway Administration. February 27.

FHWA (2013) Maintaining Traffic Sign Retroreflectivity. FHWA-SA-07020. Federal Highway Administration. Washington, D.C.

NATaT (accessed 7/3/2013) *Sign Retroreflectivity Update and Funding Assistance*. National Association of Towns and Townships. Available at http://safety.fhwa.dot.gov.

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