Highway Safety Improvement Program Manual

The Focus is Results

Foreword

The Highway Safety Improvement Program (HSIP) Manual updates the 1981 HSIP User's Manual (FHWA-TS-81-218) to reflect current law, regulations and new and emerging technologies and noteworthy practices regarding state and local highway safety improvement programs and related activities. The HSIP consists of three main components that are essential to the success of the program: planning, implementation and evaluation.

The process and procedures outlined in the Manual can be used by state agencies to administer the HSIP, as required by 23 CFR 924. In addition, transportation planning organizations, as well as county and local government agencies can use the HSIP Manual to plan, implement, and evaluate highway safety improvement programs and projects that best meet their capabilities and needs.

For additional information, please contact the HSIP Team in the Office of Safety. We wish you continued success in implementing programs and projects to reduce the number of fatalities and serious injuries on our nation's roadways.

Joseph S. Toole
Associate Administrator
Office of Safety

Notice

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Technical Report Document Page

1. Report No. FHWA-SA-09-029	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Highway Safety Improvement Program (HSIP) Manual		5. Report DateJanuary 2010
		6. Performing Organization Code
7. Author(s) Susan Herbel, Lorrie Laing, Colleen McGovern		8. Performing Organization Report No.
9. Performing Organization Name and Address **Cambridge Systematics, Inc.** **100 Cambridge Park Drive, Suite 400** **Cambridge, MA 02140**		10. Work Unit No.
		11. Contract or Grant No. DTFH61-05-D-00026
12. Sponsoring Agency Name and Address Department of Transportation Federal Highway Administration Office of Safety 400 Seventh Street S.W. Washington, DC 20590		13. Type of Report and Period Covered Technical Manual
		14. Sponsoring Agency Code HSSP

15. Supplementary Notes
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16. Abstract

This HSIP Manual describes the overall Highway Safety Improvement Program and provides a roadway safety management process which focuses on results by emphasizing a data-driven, strategic approach to improving highway safety through infrastructure-related improvements. Current laws and regulations, new and emerging technologies, and noteworthy practices are presented for each of the HSIP's four basic steps – analyze data, identify potential countermeasures, prioritize and select projects and determine effectiveness.

This comprehensive highway reference is intended for state and local transportation safety practitioners working on HSIPs and safety projects.

17. Key Words Highway Safety Improvement Program (HSIP), safety management, countermeasure identification, project prioritization, Safety Performance Functions (SPF), Crash Modification Factors (CMF).	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 161	22. Price

Form DOT F 1700.7 (8-72)   **Reproduction of completed pages authorized**

Highway Safety Improvement Program Manual

Report No. FHWA- SA-09-029

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Federal Highway Administration

U.S. Department of Transportation

January 2010

U.S. Department of Transportation
Federal Highway Administration

Preface

The Safe, Accountable, Flexible, Efficient Transportation Equity Act – a Legacy for Users (SAFETEA-LU) established the Highway Safety Improvement Program (HSIP) as a core Federal-aid highway program. SAFETEA-LU reinforced the need for strategic planning and data-driven decisions. The Federal Highway Administration (FHWA) provided clarifying guidance to the States via updates to the Federal regulation that supports the HSIP (23 CFR 924). However, these actions require additional guidance for state departments of transportation and local government agencies to implement programs that will achieve a significant reduction in traffic fatalities and serious injuries on public roads.

The Highway Safety Improvement Program (HSIP) Manual provides an overview of the HSIP and outlines procedures and tools to assist transportation professionals with the planning, implementation and evaluation phases of the HSIP. The HSIP Manual was developed based on the latest research, as well as state and local practices, pertaining to roadway safety management processes. Hyperlinks throughout the document connect the user to valuable resources to assist with their decision-making processes. The HSIP Manual is a valuable tool and a comprehensive reference for state and local transportation safety practitioners working to advance the HSIP and other safety projects.

A technical oversight working group, consisting of Federal and state representatives, guided the development of the HSIP Manual. The primary role of the working group was to review various aspects of the HSIP Manual for technical accuracy and recommend best practices and procedures to ensure the Manual meets practitioner needs. Their gracious contributions and expertise will support the development of many life-saving programs resulting in fewer fatalities and serious injuries on our nation's roadways.

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[1] All hyperlinks in this document were tested and operational in October 2009.

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Abbreviations

AADT – Annual Average Daily Traffic

AASHTO – American Association of State Highway Transportation Officials

ADT – Average Daily Traffic

ATSSA – American Traffic Safety Services Association

BAC – Blood Alcohol Concentration

BCR – Benefit/Cost Ratio

CFR – Code of Federal Regulations

CMAQ – Congestion Mitigation and Air Quality Improvement Program

CMF – Crash Modification Factors

CMV – Commercial Motor Vehicle

CODES – Crash Outcome Data Evaluation System

CRF – Crash Reduction Factor

CVSP – Commercial Vehicle Safety Plan

DMV – Department of Motor Vehicles

DOT – Department of Transportation

DUI – Driving Under the Influence

EB – Empirical Bayes

EMS – Emergency Medical Services

EPDO – Equivalent Property Damage Only

FARS – Fatality Analysis Reporting System

FHWA – Federal Highway Administration

FMCSA – Federal Motor Carrier Safety Administration

FTA – Federal Transit Administration

FTYROW – Failed to Yield Right-of-way

FY – Fiscal Year

GAO – Government Accountability Office

GES – General Estimates System

GHSA – Governors Highway Safety Association

GIS – Geographic Information System

GPS – Global Positioning Systems

GR – Governors Representative for Highway Safety

HPMS – Highway Performance Monitoring System

HRRRP – High-Risk Rural Roads Program

HSIP – Highway Safety Improvement Program

HSM – Highway Safety Manual

HSP – Highway Safety Plan

IDIQ – Indefinite Delivery/Indefinite Quantity

IHSDM – Interactive Highway Safety Design Model

ISTEA – Intermodal Surface Transportation Efficiency Act

ITS – Intelligent Transportation System

LOSS – Level of Service of Safety

MAIS – Maximum Abbreviated Injury Scale

MCMIS – Motor Carriers Management Information System

MCSAP – Motor Carrier Safety Assistance Program

MIRE – Model Inventory of Roadway Elements

MMUCC – Model Minimum Uniform Crash Criteria

MOE – Measure of Effectiveness

MPO – Metropolitan Planning Organization

MUTCD – Manual on Uniform Traffic Control Devices

MVMT – Million Vehicle Miles Traveled

NACE – National Association of County Engineers

NCHRP – National Cooperative Highway Research Program

NEMSIS – National Emergency Medical Services Information System

NEPA – National Environmental Policy Act

NHS – National Highway System

NHTSA – National Highway Traffic Safety Administration

NPV – Net Present Value

NPW – Net Present Worth

NSC – National Safety Council

OST – Office of the Secretary of Transportation

PDO – Property Damage Only

RHGCP – Railway-Highway Grade Crossing Program

RITA – Research and Innovative Technology Administration

RSA – Road Safety Audit

RSI – Relative Severity Index

RTM – Regression to the Mean

SAFETEA-LU – Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users

SHSO – State Highway Safety Office

SHSP – Strategic Highway Safety Plan

SMS – Safety Management System

SPF – Safety Performance Function

SRTS – Safe Routes to School

STIP – Statewide Transportation Improvement Program

TEA-21 – Transportation Equity Act for the 21st Century

TEV – Total Entering Volume

TIP – Transportation Improvement Program

TRCC – Traffic Records Coordinating Committee

TTI – Texas Transportation Institute

U.S.C. – United States Code

VMT – Vehicle Miles Traveled

VSL – Value of Statistical Life

1.0 HSIP Foundations

Unit 1 of the Highway Safety Improvement Program (HSIP) Manual lays the foundation for understanding road safety and HSIP. The unit explores the costs of motor vehicle crashes to our society and provides the building blocks for understanding road safety as a discipline. The background, history, purpose, and contents of the Highway Safety Improvement Program are described. The unit also introduces the HSIP legislative requirements and guidance documents, the HSIP's relationship to other safety plans, and the relationship between the HSIP and the project development process within a department of transportation (DOT), including transportation planning, design, construction, maintenance, and operations.

1.1 HSIP MANUAL PURPOSE AND CONTENTS

The purpose of the HSIP Manual is to provide an overview of the HSIP and present state and local agencies with tools and resources to implement the HSIP. The manual provides information related to planning, implementation, and evaluation of state and local HSIPs and projects.

The manual's first unit provides a foundation for understanding the HSIP. Basic concepts in road safety; the history of the HSIP and current legislation and guidelines; addressing road safety within all phases of the project development process; setting safety goals, objectives, and performance measures; and identifying available resources and technologies that support the HSIP process, provide the context to study the various components of the HSIP detailed in the remainder of the manual.

Figure 1.1 illustrates the various components of the HSIP process: planning, implementation and evaluation. The planning component consists of processes for problem identification, countermeasure identification, and project prioritization. Once projects are identified and funding secured, HSIP projects are designed and constructed as part of the implementation component. Finally, HSIP projects and programs are evaluated to determine the effectiveness of highway safety improvements.

While the HSIP is a Federally funded, state-administered program, the HSIP components shown in Figure 1.1 are applicable to road safety management processes at all levels of government.

Figure 1.1 Highway Safety Improvement Program Components
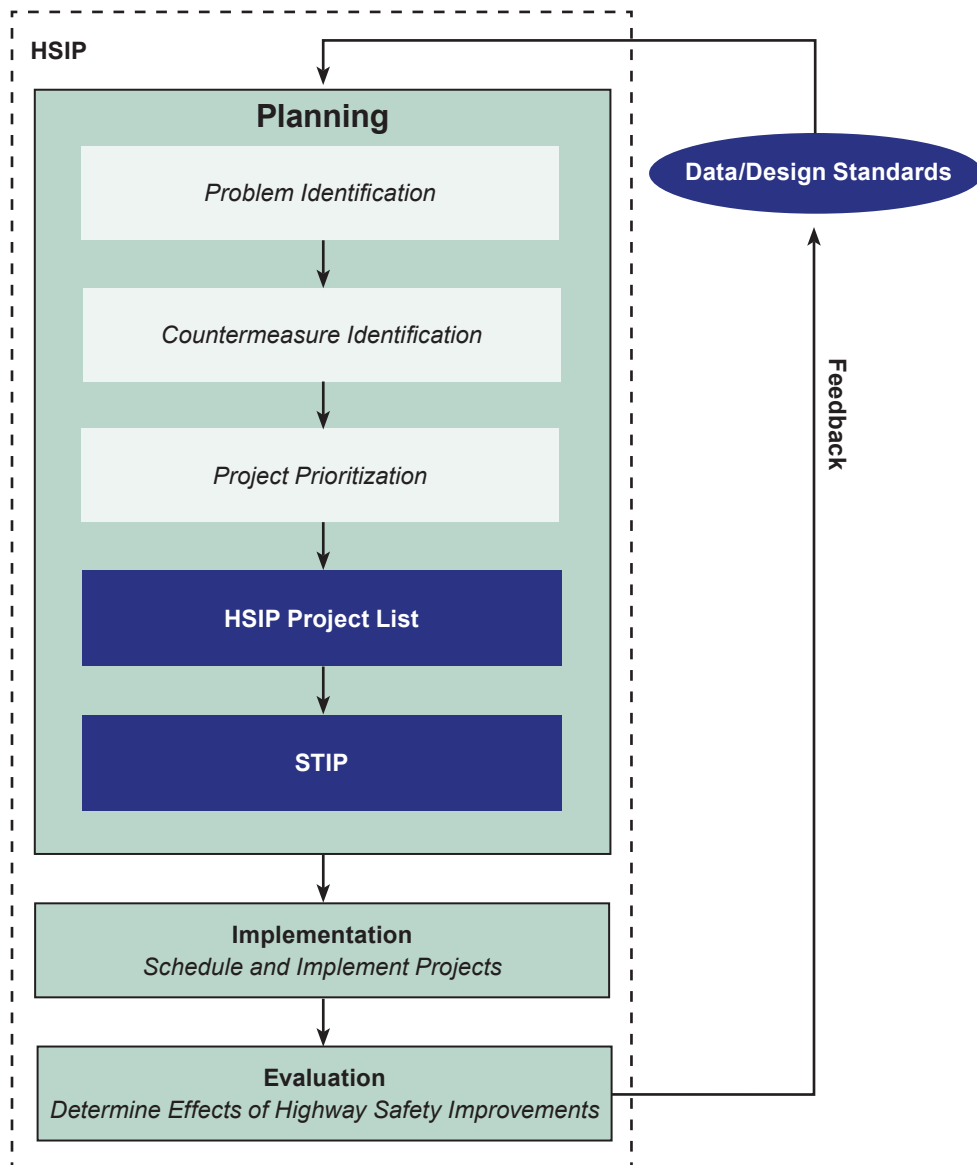
The remaining sections of the HSIP Manual address these components, as follows:

- **Planning:**

  - **Unit 2: Problem Identification –** Examines the processes for collecting and managing crash and other data needed for identifying highway safety problems.

  - **Unit 3: Countermeasure Identification –** Describes how to identify the factors or variables which contribute to crashes, and countermeasures for preventing those crashes and mitigating crash severity.

- **Unit 4: Project Prioritization –** Addresses the application of project prioritization processes to identified locations with safety improvement potential. It also demonstrates how to calculate the benefit/cost ratio for projects using Crash Modification Factors (CMF) and other information.

- **Implementation:**

  - **Unit 5: Implementation –** Addresses funding sources, allocation issues and solutions states have implemented to address funding challenges. Project programming and the development of evaluation plans is also discussed.

- **Evaluation:**

  - **Unit 6: Evaluation –** Provides information for conducting project evaluations and developing CMFs. It addresses program evaluation and the importance of inputting evaluation results back into the HSIP and Strategic Highway Safety Plan (SHSP) planning processes to aid future decision-making.

The following section defines road safety and discusses the use of actual numbers versus rates to measure road safety. These basic concepts of road safety provide a foundation for the overall Highway Safety Improvement Program.

1.2 THE NATURE OF ROAD SAFETY

Although the United States and other industrialized nations have made substantial progress over the past 30 years, the United States has experienced more than 40,000 motor vehicle-related deaths, and more than two million injuries annually between 1993 and 2006. These deaths are the leading cause of unintentional injury deaths in the United States for ages 1 year through 34 years (CDC WISQARS web site). Motor vehicle crashes place millions of people at risk for death or injury, disproportionately strike the young, and are the leading cause of lost years of productive life.

In addition to the resulting injuries and lives lost, crashes also result in significant economic consequences. In 2000, the National Highway Traffic Safety Administration (NHTSA) estimated traffic crashes in the United States accounted for over $230 billion in economic losses (Blincoe et al., 2002).

Two intertwined issues that transportation officials must deal with are safety and congestion. For example, a heavily congested highway may present little risk of high-speed crashes; however, to avoid congestion drivers often seek alternative routes, such as local roads which present much higher risks to drivers. Likewise, poor incident management can often cause unnecessary delay and congestion on our roads. The 2008 AAA study, *Crashes versus Congestion: What's the Cost to Society?* sheds light on the relationship between congestion and safety by examining the relative economic impact. It begins with the Urban Mobility Report published each year by the Texas Transportation Institute (TTI).

The authors for AAA calculated the cost of crashes for the same urban areas included in the TTI report. The AAA study findings suggest congestion costs are not nearly as great as the costs and consequences of motor vehicle crashes.

Figure 1.2 shows in the urban areas studied the cost of fatal and injury traffic crashes is more than two and one-half times the cost of congestion – $164.2 billion for traffic crashes and $67.6 billion for congestion. The study concludes that improving safety may also improve congestion because, while it varies from community to community, 40 to 50 percent of all nonrecurring congestion may be associated with traffic incidents.

Figure 1.2   Per Person Cost of Crashes versus Congestion
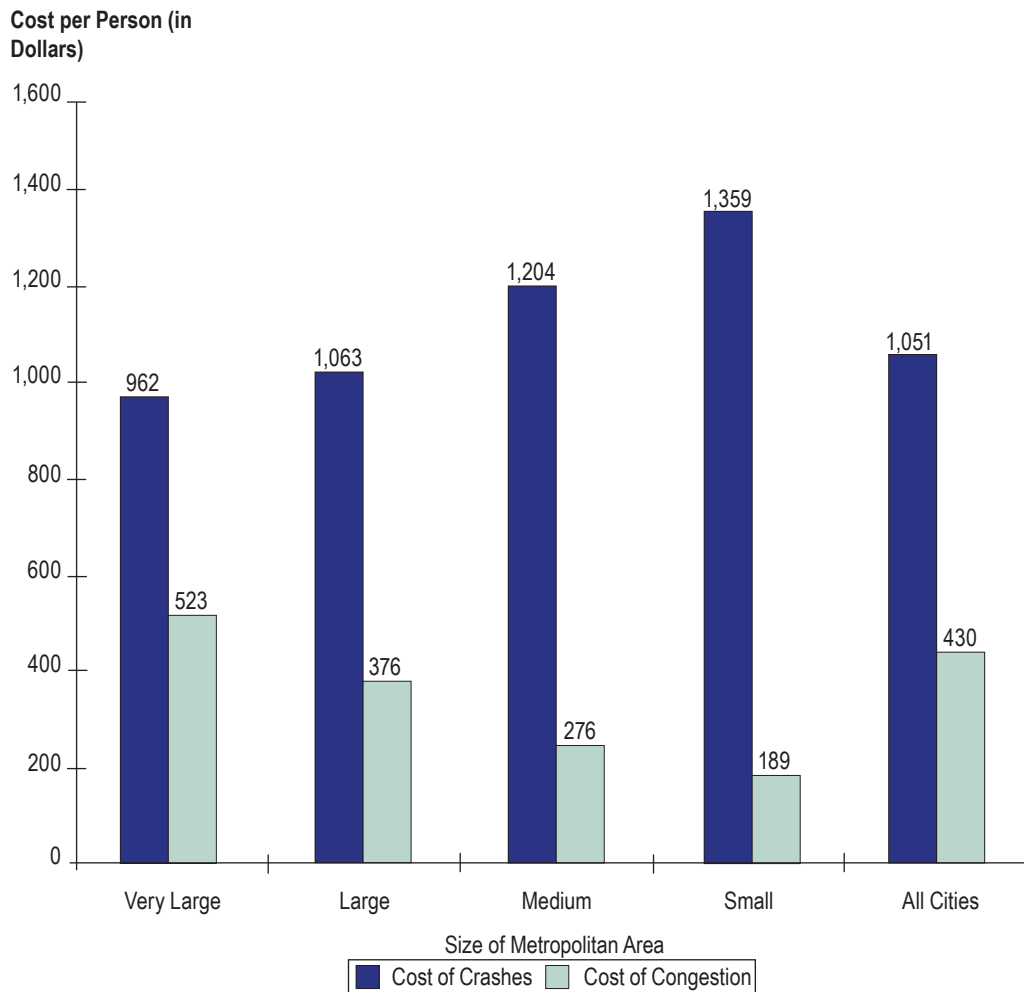
Source: Adapted from AAA, *Crashes versus Congestion: What's the Cost to Society?*, 2008.

Both congestion and safety pose a substantial cost to the public, with safety estimated as over two and half times more than the cost associated with congestion. Designers and planners need to recognize these costs and define solutions that do not inadvertently adversely impact the other.

Defining Road Safety

Road safety is typically defined in terms of the injuries and fatalities that occur on the roadway system. Therefore, definitions of road safety are often based on crash outcomes such as "…the number of accidents (crashes),[2] or accident consequences, by kind and severity, expected to occur on the entity during a specific period" (Hauer, 1997).

The science of safety has evolved over the past several years and is focusing more on data and analysis, rather than solely adhering to standards. For example, it was commonly assumed when road safety improvements met the standards contained in the Manual of Uniform Traffic Control Devices (MUTCD) and the American Association of State Highway Transportation Officials (AASHTO) – A Policy on Geometric Design of Highway and Streets (also known as the "Green Book") they were considered safe. However, most of those standards have not been evaluated specifically for their impact on safety. Crashes may occur on a roadway designed to meet standards, and this does not necessarily mean the roadway is unsafe.

Science-based road safety management is referred to as data-driven or evidence-based. This approach to road safety emphasizes estimates of the effect on safety (data and analysis), rather than adherence to standards based on personal experience, beliefs, and intuition. The safety metrics (e.g., fatalities and serious injuries) of a roadway are compared to roadways with similar characteristics to evaluate its safety performance. The goal of the evidence-based approach is to understand and quantify the expected consequences and outcomes of our actions (e.g., changes in the expected number of crashes/injuries/fatalities); the resulting calculations become the experience or evidence on which future decisions are made.

Measuring Road Safety

Road safety is usually measured in terms of fatalities and injuries involving motor vehicles and roadway users (i.e., pedestrians and bicycles) on the road system. Outcome measures should be used whenever possible to quantify safety. Some competing metrics for measuring safety, as well as the pros and cons of each are outlined below:

- **Fatalities –** Safety can be measured by tracking the number of fatalities on the roadway system. This number emphasizes lives lost, but does not address the loss in quality of life and medical costs associated with serious injuries. The definition of fatality can vary between states and/or the Federal government, from a death within 30 days of the crash to a death within one year of the crash. These discrepancies often result in variances of the number of reported fatalities. However, the fatal crash report dataset is almost always complete and often provides the greatest amount of crash detail.

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[2] Many safety professionals and some in the media believe we should consistently use the term "crash" which implies these events are preventable as opposed to "accident" which implies the incidents are unintentional.

- **Fatalities and Serious Injuries –** Safety can be measured by tracking the number of fatalities and serious or incapacitating injuries. This number is more comprehensive but is more difficult to measure because definitions of "serious injury" vary from state to state and even among crash investigators. The designation of what constitutes a "serious injury" is most likely made by a police officer who is not medically trained.

- **Fatalities and All Injuries –** This is a comprehensive measure but is difficult to track, since minor injuries are not always recorded by law enforcement.

- **Crashes –** The most inclusive measure encompasses all crashes, even those where no injury or fatality occurred (property damage-only crashes). This metric does not emphasize the human toll and is difficult to track, since crashes where no injury or fatality occurred may not be reported. Additionally, including property damage-only crashes may result in diverting scarce safety resources to areas where the safety problem is minimal compared to other sites. The metrics listed above are not always adequate to measure changes in safety, since traffic crashes are relatively rare events, and changes in their numbers over time may be due to a wide range of factors, including statistical randomness. To address this issue, surrogates are sometimes used to measure safety. Some examples of surrogate measures include the following:

  - **Number of Near-Misses[3] –** Near-misses are conflicts which occur between road users but do not result in a crash. The frequency of near-misses is sometimes used as a rough proxy for safety. The advantage of this metric is it allows for analysis of a large number of events, since near-misses are much more frequent than crashes. On the other hand, collecting near-miss data is labor-intensive, and usually is collected only at select locations. Moreover, near-misses do not reflect fatality and injury outcomes.

  - **Evidence of Unreported Crashes –** Many fixed object collisions with property damage only are not reported to the police. These crashes can be identified by physical evidence at the site (e.g., car parts in grass near curves, utility poles, trees, or median barriers; damaged sign posts, mailboxes, or fences) and through maintenance records. Repeat evidence of unreported crashes could be used to identify existing safety problems and sites for potential safety enhancement. Similar to near-misses, observation of

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[3] Although these incidents are near-collisions, the incidents are commonly referred to as "near-misses."

vehicle debris associated with unreported crashes does not reflect fatality and injury outcomes.

– **Safety Belts Use –** This measure includes the percent of motor vehicle drivers and passengers wearing safety belts in general, by time of day, and/or for those involved in crashes. Safety belt use is highly correlated with the likelihood of surviving a crash, and is a general indicator of one important dimension of safety. However, it does not capture many other influences on safety such as engineering countermeasures, vehicle safety improvements, and so forth.

– **Number of Driving Under the Influence (DUI) Arrests –** Because impaired driving is a factor in many fatal crashes, the number of DUI arrests is sometimes used as an early indicator of safety, since a greater number of DUI arrests should result in fewer traffic crashes. However, this is an output measure and used primarily to track level of effort rather than safety outcomes.

Rates versus Numbers

Safety can be measured over time by tracking the raw **number** of fatalities, injuries, or crashes. It can also be measured by calculating injury, fatality, or crash **rates**, (e.g., fatalities per million miles of travel, per 100,000 population, per number of licensed drivers, etc.), which are normalized for exposure to crash risk. For example, crash rates can control for general increases in incidents at locations where people drive more often and travel more miles.

Important tradeoffs exist when selecting whether to use rates or numbers. Numbers have the advantage of conveying the magnitude of the crash problem, and the fact that every fatality or injury is important. Numbers also are better understood by the public.

Crash rates are better for identifying crash risk, but can be misleading. The assumption behind crash rates is that the number of collisions at a site is directly proportional to the amount of exposure. In other words, as vehicle, pedestrian, or bicycle volumes increase, the number of collisions increases proportionally. However, research has consistently shown the relationship between collisions and volumes to be nonlinear. As vehicle, pedestrian, or bicycle volumes increase, the number of crashes may increase, but in a nonlinear fashion.

Safety Performance Functions (SPFs) can be used to better portray the expected safety of a site. SPFs estimate the average crash frequency for a specific site type as a function of annual average daily traffic (AADT). SPFs are described in more detail in Unit 2.

An understanding of road safety builds the foundation for the HSIP. The background and history of the HSIP are summarized in the following section.

1.3 BACKGROUND AND HISTORY OF THE HSIP

While safety has long been a consideration in transportation project development, the role and significance of safety in transportation policy has evolved over time. One of the first major efforts at the Federal level to reduce the number and severity of highway-related crashes was the *1966 Highway Safety Act* (23 U.S. Code (U.S.C.) 402). Passed by Congress on September 9, 1966, the Act required states to develop and maintain a highway safety program in accordance with uniform standards established by the Secretary of Transportation. The primary purpose of this legislation was to provide for a coordinated national highway safety program through financial assistance to the states to accelerate highway traffic safety programs. The Act established 18 standards with responsibility for implementing these standards divided between the FHWA and the NHTSA. These standards were later replaced by priority program areas in the 1973 Act.

The *Highway Safety Act of 1973* (Title II of Public Law No. 93-87) established categorical funding for the following five safety improvement program areas:

1. Rail-highway grade crossing;

2. Pavement marking demonstration programs;

3. High-hazard locations;

4. Roadside obstacle elimination; and

5. Federal-aid safer roads demonstration.

These five programs were eventually consolidated by the *Surface Transportation Assistance Act of 1978* (Public Law No. 95-599) into the Railway-Highway Grade Crossing and Hazard Elimination Programs.

The Railway-Highway Grade Crossing Program was intended to reduce the number and severity of train collisions with vehicles and pedestrians at public highway-rail grade crossings and established Federal funding for projects aimed at improving rail-highway crossing safety. Typical projects eligible for this program include (but are not limited to):

- Installation or upgrade of new/additional signing and pavement markings at crossings;

- Installation or upgrade of active warning devices (i.e., lights and gates);

- Crossing surface improvements;

- Sight distance improvements;

- Geometric improvements to the roadway approaches;

- Grade separations; and

- Closing and/or consolidating crossings.

The Hazard Elimination Program was intended to reduce the number and severity of fatalities and serious injuries resulting from crashes on all public roads and provide funding for projects to mitigate or eliminate hazardous sections, locations, or elements on any public road. Typical projects include, but are not limited to:

- Intersection improvements (channelization, traffic signal installation, sight distance increases);
- Pavement and shoulder widening;
- Guardrail and barrier improvements;
- Crash cushion installation;
- Roadway alignment modification;
- New/additional signing, pavement marking and delineation installation;
- Breakaway utility poles and sign posts installation;
- Pavement grooving and skid-resistant overlays;
- Shoulder rumble strip installation; and
- Minor structure replacements or modifications.

The evolution of highway safety continued with passage of the *Intermodal Surface Transportation Efficiency Act* (ISTEA) of 1991. ISTEA required states to develop and implement a series of management systems, including a safety management system (SMS). SMS was envisioned to be a systematic process designed to assist a broad-based coalition of safety stakeholders in selecting effective strategies to improve the efficiency and safety of the transportation system. A comprehensive crash database was to serve as the basis for these decisions, and safety performance measures were to be defined and used to monitor safety progress over time. SMS resulted in the improvement of crash databases in many states. Only a few states maintained or expanded their collaborative interagency efforts when the requirement was made optional in 1995.

In 1998, the *Transportation Equity Act for the 21st Century* (TEA-21) provided more focus by including "safety and security" as a transportation planning priority. Prior to TEA-21, safety may have been incorporated into the vision or goals of a state or metropolitan transportation planning organization (MPO) long-range transportation plan, but specific strategies to increase safety were seldom included in statewide and metropolitan planning processes or documents. More than two dozen states participated in safety conscious planning forums which, in most cases, started a dialogue between transportation planners and safety stakeholders.

TEA-21 also provided guidance on a wide range of planning, policy and safety issues affecting bicycling and walking. Bicyclists and pedestrians were to be given due consideration in state and MPO long-range transportation plans. Bicycle and pedestrian projects were to be considered, where appropriate, in conjunction with all new construction and reconstruction of transportation facilities (except where bicycle and pedestrian use is not permitted). Additionally, transportation plans

and projects were to provide consideration for safety and contiguous routes for bicyclists and pedestrians.

1.4 CURRENT LEGISLATION AND AGENCY GUIDELINES

In 2005, the *Safe, Accountable, Flexible, Efficient Transportation Equity Act – A Legacy for Users* (SAFETEA-LU) established the HSIP as a core Federal-aid program under 23 U.S.C. 148. SAFETEA-LU nearly doubled the funds for infrastructure safety, allowed increased flexibility in program funding, and required a focus on results. In addition, SAFETEA-LU elevated the highway safety program even further by separating safety and security into individual planning factors.

The specific purpose of the HSIP is to achieve a significant reduction in traffic fatalities and serious injuries on public roads. This is to be accomplished through the development and implementation of Strategic Highway Safety Plans (SHSP). SHSPs are intended to drive states' HSIP investment decisions. In addition to the Railway-Highway Grade Crossing Program (23 U.S.C. 130), SAFETEA-LU also established the High-Risk Rural Roads Program (HRRRP). Figure 1.3 diagrams the relationship among the various HSIP programs as presented in the Code of Federal Regulations, Title 23, Part 924 (23 CFR 924).

Figure 1.3   Relationships of HSIP Programs
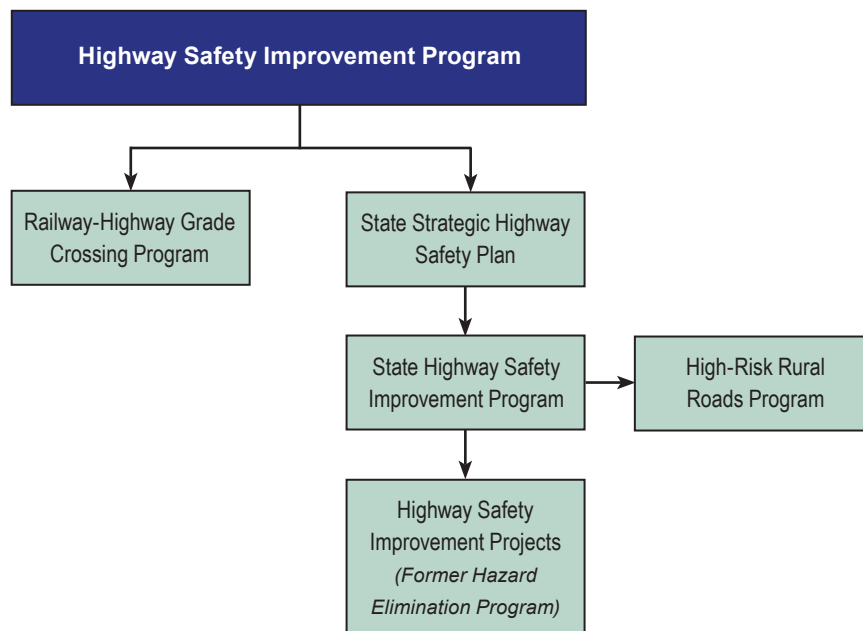
Details on each of the programs, the relationship among them, and the new reporting requirements established under SAFETEA-LU are provided below.

Strategic Highway Safety Plans

23 U.S.C. 148 requires states to develop and implement a SHSP. The state SHSP is required to be:

- Data-driven, i.e., the use of crash and other data analyses on all public roads to identify safety issues;

- Developed in collaboration with a broad range of stakeholders, including Governors Representatives for Highway Safety (GR), MPOs, major transportation modes, state and local law enforcement, Operation Lifesaver, Motor Carrier Safety Assistance Program (MCSAP) personnel, Departments of Motor Vehicles (DMV), emergency response personnel, and others;

- Multidisciplinary addressing the 4Es of Safety – engineering, enforcement, education, and emergency medical services (EMS);

- Performance-based with the adoption of strategic and performance goals which focus resources on the areas of greatest need; and

- Coordinated with other state highway safety programs.

State Highway Safety Improvement Program

The state HSIP should be consistent with the SHSP emphasis areas and strategies. Requirements for an HSIP are defined in 23 CFR 924. While states may develop their HSIPs to best serve their needs, it must include the following components:

- **Planning –** Collect and maintain data, identify hazardous locations and elements, conduct engineering studies, and establish priorities;

- **Implementation –** Schedule and implement projects; and

- **Evaluation –** Determine the effectiveness of safety improvements.

The remainder of the HSIP Manual addresses the various processes associated with HSIP planning, implementation and evaluation efforts.

Relationship between the SHSP and HSIP

Figure 1.4 illustrates the relationship between the HSIP and the SHSP.

The SHSP influences decisions made during each step of the state HSIP process. SHSP emphasis areas influence problem identification in the HSIP. The SHSP action plans, which detail the strategies the state will implement to address its motor vehicle-related fatalities and injuries, link directly to the HSIP countermeasure identification process. Projects prioritized during HSIP planning align with the SHSP priorities and action plans. Many of the infrastructure-related elements of the SHSP can be implemented via the state's HSIP. Evaluation of highway safety improvement projects informs tracking and updating of the SHSP. The results of HSIP evaluations feed back into both the SHSP and the HSIP planning processes.

Figure 1.4   Relationships between the SHSP and HSIP
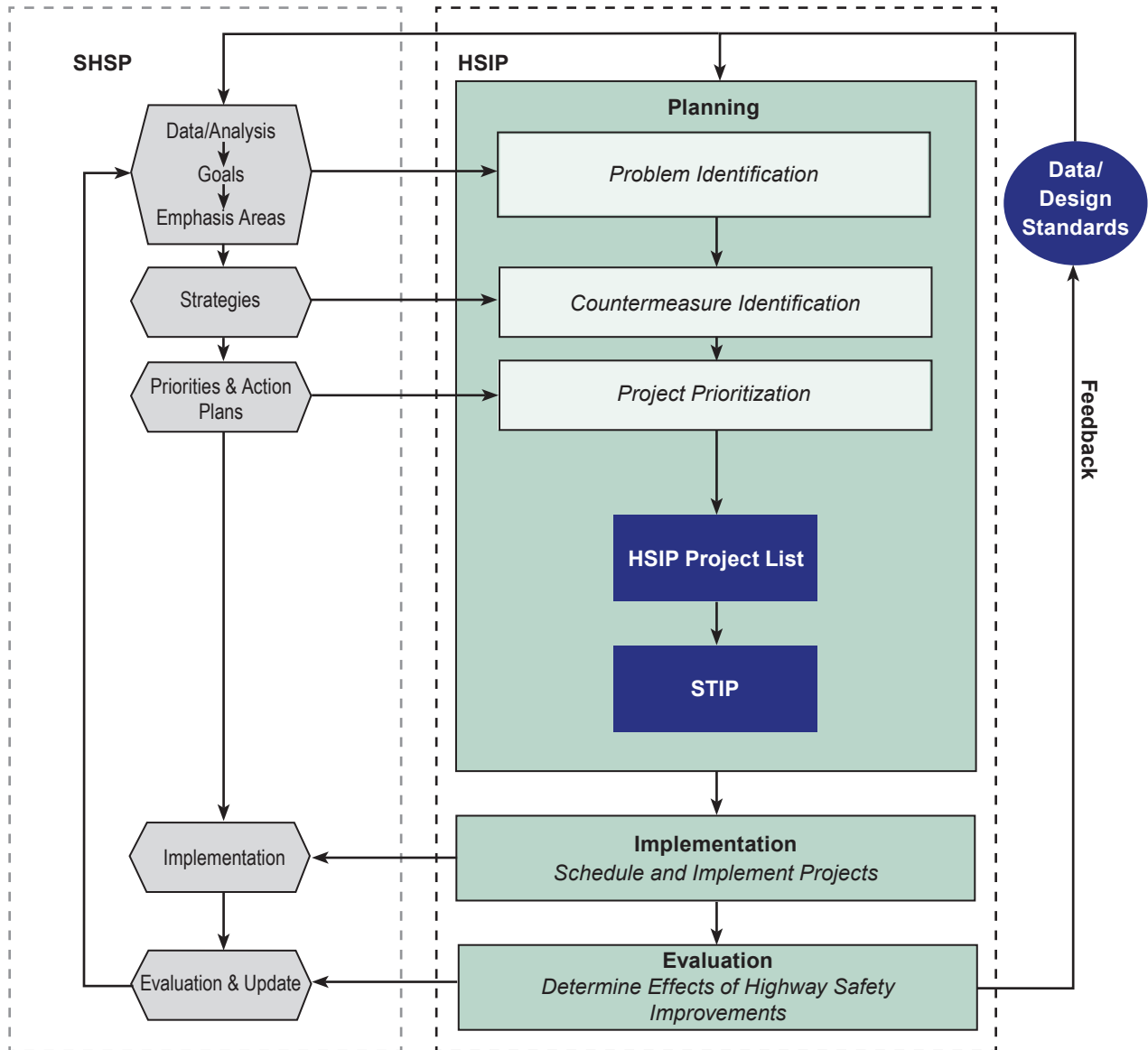
High-Risk Rural Roads Program

The High-Risk Rural Roads Program (HRRRP) provides set aside funds for construction and operational improvements on high-risk rural roads. High risk rural roads are defined as roadways with crash rates for fatalities and incapacitating injuries exceeding the statewide average on rural major or minor collectors, or rural local roads, *or* roadways likely to have increases in traffic volume which are likely to create a crash rate above the statewide average for the respective roadway functional classes. Implementation of the HRRRP requires comprehensive crash data for all public roads.

Railway-Highway Grade Crossing Program

SAFETEA-LU continued the Railway-Highway Grade Crossing Program (RHGCP) essentially intact, with the primary changes involving program funding. The program reduces the number of fatalities and injuries at public railway-highway grade crossings through the elimination of hazards and/or the installation/upgrade of protective devices at crossings. Each state is required to conduct and systematically maintain a survey of all highways to identify those railroad crossings which may require separation, relocation, or protective devices, and establish and implement a schedule of projects for this purpose. At a minimum, this schedule is to provide standard signing for all railway-highway crossings.

Reporting Requirements

State DOTs are required to submit reports to the FHWA on several elements of the HSIP. Reporting requirements include:

- Annual assessments of the progress and effectiveness of HSIP and HRRRP;

- Progress on implementing the RHGCP; and

- A *Transparency Report* (*Five Percent Report*) which includes a description of not less than five percent of locations exhibiting the most severe safety needs, an assessment of potential remedies for these locations, estimated costs associated with remedies, and impediments to implementation other than cost.

Reporting guidance for the HSIP, RHGCP and the 5% reports are provided on the [FHWA Office of Safety web site](#). Direct links to the guidance documents can be found in the References appendix.

Other Federal Safety Programs

In addition to the funding in 23 U.S.C. 148, SAFETEA-LU increased funds for highway safety grants (23 U.S.C. 402) and several other behavior-oriented grant programs through the NHTSA; established new programs, including traffic records systems improvements (23 U.S.C. 408) and Safe Routes to School; and continued to emphasize truck and transit safety through the Federal Motor Carrier Safety Administration (FMCSA) and the Federal Transit Administration (FTA), respectively.

1.5 INTEGRATING SAFETY INTO THE PROJECT DEVELOPMENT PROCESSES

States and local agencies are working to coordinate the various transportation and safety planning documents to ensure a systematic (collaborative) approach to addressing highway safety. Achieving this goal requires a fundamental change in the transportation culture which entails reaching out to other safety planning

entities and working with all phases of the transportation project development process, including planning, design, construction, operations, and maintenance. While this manual is focused on the HSIP, there are many ways to incorporate safety into an agency's overall project development processes.

In a January 7, 2005 memorandum, the FHWA Associate Administrator for Safety said reaching the national safety goal requires safety consideration:

> "… in every aspect of our business, from planning and programming, environmental analysis, project design, construction, to maintenance and operations. We must use data-driven decision-making and assure that safety is a key input in any decision made in the project development process."

Safety in Planning

Figure 1.5 shows, in theory, how the various safety plans influence and affect each other. The diagram shows the relationship flowing from the Metropolitan Transportation Plans and the Statewide or Long-Range Transportation Plans to the Transportation Improvement Programs (TIP) at the metropolitan and state level. It also demonstrates how the individual safety plans such as the HSIP the Highway Safety Plan (HSP), the Commercial Vehicle Safety Plan (CVSP), and other plans and programs, such as freight and the pedestrian/bicycle plan, are interrelated. Coordinating all of these efforts is the Strategic Highway Safety Plan, out of which come the types of projects to be incorporated into the HSIP and statewide TIP (STIP). Likewise, these safety plans influence the strategies and action plans contained in the SHSP.

Figure 1.5   Coordinated Transportation Safety Planning
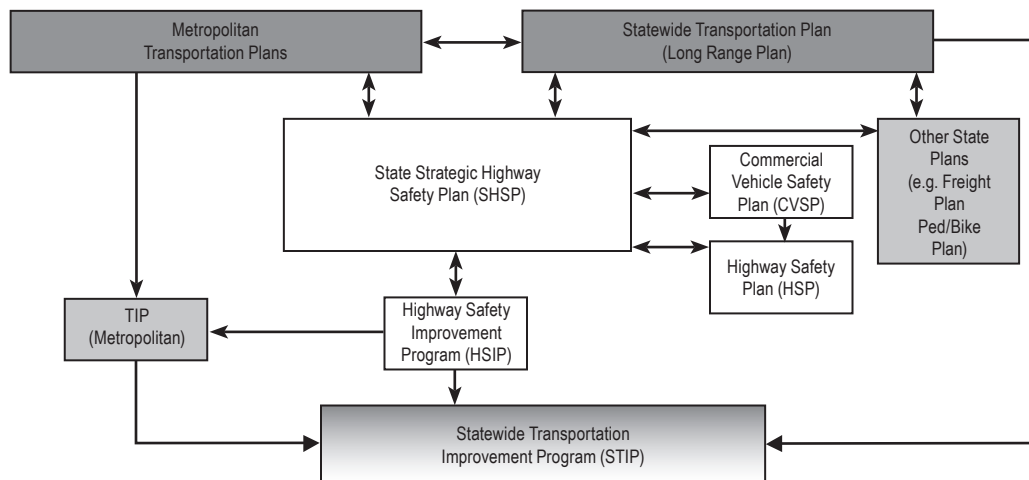
Aligning safety plans provides a more unified process which can reduce administrative burden, ensure common data and analysis methods, and align scarce resources to more effectively produce safety improvements.

Safety in Design

In addition to considering safety in identifying strategies and projects, safety should be considered in the preliminary design phase of all highway improvement projects as project options are being evaluated and environmental analysis is underway. Table 1.1 identifies potential safety tasks in the preliminary design process.

Table 1.1   Potential Safety Tasks in the Preliminary Design Process

Step	Potential Safety-Related Task
Preliminary Design Conference	Document safety needs and identify atypical conditions, complex elements, and high-cost components.
Data Collection/ Preliminary Design Preparation	Diagnose safety data to identify crash patterns and refine project scope, if necessary.
Preliminary Schematic	Perform preliminary level of safety analysis for "key" design elements.
Geometric Schematic	Perform detailed level of safety analysis for "key" design elements.
Value Engineering	Compare cost of specific elements and overall roadway with safety and operational benefits.
Geometric Schematic Approval	Document safety of design choices (use results for design exception request, if necessary).

Source: Adapted from Bonneson et al. 2005.

"Key" design elements are those associated with the 13 controlling criteria which dictate the need for a design exception or have a known impact on safety. The 13 controlling criteria include: design speed, lane width, shoulder width, horizontal alignment, vertical alignment, grades, stopping sight distance, cross slope, super-elevation, and horizontal clearance; and for bridges: lane and shoulder width, structural capacity, and vertical clearance.

The following recommendations are applicable to the design phase:

- Consider safety when design exceptions are being considered for any of the 13 controlling criteria. Several low-cost safety countermeasures (additional information on low-cost safety improvements can be found in Unit 3) can be used to mitigate potential impacts of a design exception.

- Ensure safety is not compromised when considering Context-Sensitive Solutions. Low-cost safety enhancements should be considered and incorporated in those locations where design standards cannot be met.

- Use crash data to create a quantifiable basis for enhancing safety on all projects, especially when safety is identified in the Purpose and Need statement of an environmental document.

- Emphasize safety when evaluating alternatives. Safety benefits should be quantified for each alternative during the alternatives selection process. Although right-of-way costs or other constraining factors may play a significant role in the project alternatives selection process, the safety benefits associated with each alternative should be considered in the overall evaluation. Texas Transportation Institute (Bonneson et al., 2005) developed the Interim Road Safety Design Workbook to assist engineers with evaluating potential safety tradeoffs associated with various design alternatives.

- Conduct Road Safety Audits (RSA) during the design phase of new and existing facilities, especially if crash data suggest a significant safety problem exists.

- Address safety at public outreach meetings to ensure the public understands safety issues in the context of overall needs. Since perceptions of safety may vary, quantifiable information should be used to differentiate the safety impacts of various alternatives to give the public a better understanding of the issue.

- Assure current analysis methods use crash and traffic data to demonstrate potential adverse safety impacts when considering operational performance and improvements, and ensure the action will not compromise safety.

For example, a state proposes a design exception for a horizontal curve because of excessive right-of-way costs. The safety solutions considered for the design exception include strategies to mitigate potential safety effects (e.g., raised pavement markers, high-performance pavement markings, paved shoulders, milled rumble strips, flattened fore slopes, larger and brighter warning signs and chevrons, and remediation of fixed objects) and/or adding high type skid resistance pavement overlay.

In addition, the Interactive Highway safety Design Model (IHSDM) is a suite of software analysis tools for evaluating safety and operational effects of geometric design decisions on highways. IHSDM evaluates existing and proposed alternative highway geometric designs and provides quantitative information on their expected safety and operational performance. Decision-makers can use the IHSDM quantitative information to help make, justify, and defend geometric design decisions throughout the highway design process.

Safety in Construction and Maintenance

Safety should be a key factor in any decision made during construction and maintenance. Agencies can use the following strategies to incorporate safety into the construction and maintenance phases:

- Incorporate low-cost safety improvements into resurfacing, restoration, or rehabilitation (also known as "3R") projects;

- Conduct RSAs during the construction phase to examine temporary traffic management plans, changes in design during construction, or before a roadway is opened to traffic;

- Use contract options to allow for accelerated completion or full closure to improve safety;

- Use Intelligent Transportation System (ITS) technologies for work zones to improve safety;

- Ensure safety features remain operative and/or are upgraded during construction, utility, and maintenance activities;

- Train construction, maintenance, and utility personnel to understand safety concepts such as recovery areas and breakaway devices;

- Ensure construction, maintenance, and utility personnel do not make field changes which might adversely affect safety;

- Advise maintenance of the special importance of insuring proper drainage, snow and ice removal, signing and markings, and shoulder and pavement maintenance; and

- Implement timely application of preventive maintenance treatments to extend the service life of roadways and bridges, help maintain skid-resistant properties of pavements and bridges, and reduce motorist exposure to work zones.

One state DOT incorporates safety projects into its daily business through a policy to include low-cost safety improvements into all resurfacing projects using other highway funds.

Safety in Operations

Agencies are increasingly finding ways to incorporate safety into their traffic operations. To include safety in traffic operations an agency can:

- Use advanced traveler information systems to warn drivers of upstream hazards (e.g., obstruction in road, adverse weather conditions);

- Use dynamic or variable message signs to warn drivers of upstream hazards;

- Provide uniform traffic control (e.g., signage, signal phasing) to reduce driver confusion;

- Install variable speed limit signs to adjust based on traffic conditions;

- Provide emergency vehicle preemption at signalized intersections to improve response times;

- Implement a Speed Management Program;

- Coordinate signal timing and travel speeds; and

- Utilize emergency service patrols.

In some states, various state and local representatives collaborate regularly to keeps safety in focus as other activities progress. Networking opportunities raise visibility and awareness of safety issues, educate state and local employees about

safety issues and programs, and provide reinforcement as to how their jobs are related to safety.

HSIP program managers and state safety engineers each play a critical role and must work together to integrate safety into the project development process. Transportation professionals may not be familiar with safety data location and availability; safety data analysis and forecasting techniques; organizational and collaboration structures; or safety stakeholders and networks. Safety engineers should communicate with transportation professionals to ensure they are aware of the expertise and experience available to them both within and outside their own agencies.

1.6 SAFETY GOALS, OBJECTIVES, AND PERFORMANCE MEASURES

Safety goals, objectives, and performance measures provide details on desired outcomes and measures of performance for HSIPs. Goals and objectives should be clear, concise, and quantifiable.

Goals

A goal is a general statement of a desired state or ideal function of a transportation system. Strategic Highway Safety Plans identify state transportation safety goals and provide a comprehensive framework for reducing highway fatalities and serious injuries on all public roads. The goals are generally based on number, proportion, or rate of crashes, fatalities, and/or serious injuries.

Examples of state safety goals include the following:

- Reduce the number of highway fatalities by 20 percent by 2015; and

- Reduce the fatal crash rate per 100 million vehicle miles traveled to 0.75 by December 31, 2014.

Objectives

An objective is a concrete step toward achieving a goal, stated in measurable terms. Objectives may have specific performance targets which set out in clear, numerical terms a desired or required degree of achievement. Examples of objectives include:

- Reduce serious (fatal/incapacitating injury) fixed-object crashes by 15 percent by 2010; and

- Reduce roadway departure-type crashes by 12 percent by 2015.

Clearly defining the goals and objectives is critical for identifying the different types of performance measures to incorporate into the planning process.

Safety Performance Measures

Performance measures communicate the priorities, results, and value to society of various transportation safety programs and activities. Clearly defining goals and objectives is critical for identifying the different types of performance measures to incorporate into the planning process.

Performance measures are used for several different purposes. They are used to connect goals to actions, allocate resources, and to monitor and evaluate progress. Most importantly, performance measures determine the effectiveness of safety policies and countermeasures and how changes in the system may affect performance.

Output performance measures identify the progress in utilizing resources, such as the total number of projects, total funding, and related output measures (e.g., the number of traffic signals installed, the number of intersections with improved pavement markings, etc.). Outcome performance measures are focused on the intended results of the program. General statistics (e.g., the number of crashes and crash rates), trend analysis, and benefit/cost analysis are used to measure performance outcomes.

Safety performance measures should be:

- Important, valid, and ensure the quantity measured substantially impacts traffic safety;

- Sensitive to actual trends (a change in the measure will provide useful and meaningful traffic safety information);

- Measurable for many years;

- Accurate, reliable, and repeatable over time;

- Understandable and easily communicated to decision-makers and the public;

- Timely; and

- Cost reasonable for the value of information obtained.

When incorporating safety into system performance measures, a number of issues should be considered. Performance measures must be sensitive enough to assess changes in safety performance after strategies are implemented. Agencies also should be capable of collecting or accessing timely and accurate data relevant to the performance measures. Finally, the safety performance measures should be linked to evaluation criteria for assessing the relative benefits of one project or strategy over another.

Following are examples of performance measures used for various safety improvements:

- The number of fatal or serious injuries resulting from a particular crash type;

- The number of fatal or serious injury crashes occurring on a particular facility type;

- The number of intersections with improved pavement markings;

- The number of intersections with enhanced signal head visibility;

- The number of rural intersections upgraded with sight distance improvements;

- The number of rural intersections upgraded with access improvements;

- The number of medians installed or upgraded;

- Miles of median cable barriers installed;

- Miles of rumble strips or stripes installed;

- Miles with new or upgraded installation of raised pavement markers (RPM) to improve nighttime visibility;

- The number of rural intersections with post mounted delineation signage upgrades; and The number of intersections with upgraded sign replacement.

The following example demonstrates how goals, objectives, and performance measures are used. A state selects a goal to reduce the number of motor vehicle fatalities by 20 percent by 2015. To reach this goal, one objective the state will aggressively pursue is to reduce fatal rural intersection crashes by 15 percent by 2012. As a result, the state designs a five-year program to increase visibility of roadway signs, signals, and markings. To assess progress and evaluate success of the rural intersection program the performance measures will include:

- The number of fatal rural intersection crashes each year;

- The number of fatal nighttime rural intersection crashes each year;

- The number of angle collision fatalities at rural intersections each year;

- The number of barrier reflectors upgraded in the entire district system over five years;

- The number of sign post/drive post delineators installed to 100 percent of all applicable sign posts within one year;

- The number of dual stop and "stop ahead" signs installed in the entire district system within two years; and

- The number of flashing LED stop signs installed in the entire district system within two years.

1.7 RESOURCES AND TECHNOLOGIES

As technology and safety research continue to advance, so will the available resources to support HSIP implementation. This section identifies the tools available to support the HSIP process.

Highway Safety Manual[4]

The [Highway Safety Manual (HSM)](#) provides practitioners with the best factual information and tools to facilitate roadway design and operational decisions based on explicit consideration of the safety consequences. The HSM serves as a resource for information related to the fundamentals of road safety, road safety management processes, predictive methods, and CMFs. The road safety management process outlined in the HSM aligns very closely with the HSIP process. Related to the HSIP, the HSM guides safety practitioners in several applications, including: identifying sites with potential for safety improvement, identification of contributing factors and potential countermeasures; economic appraisals and prioritization of projects; and evaluation of implemented improvements.

SafetyAnalyst

[SafetyAnalyst](#) provides a set of software tools used by state and local highway agencies for highway safety management. *SafetyAnalyst* incorporates state-of-the-art safety management approaches into computerized analytical tools for guiding the decision-making process to identify safety improvement needs and develop a systemwide program of site-specific improvement projects. *SafetyAnalyst* includes modules for identifying locations for potential safety improvement, diagnosis and countermeasure selection, economic appraisal and priority ranking, and evaluation of implemented improvements.

1.8 SUMMARY

Unit 1 serves as a foundation for the remainder of the HSIP manual. The cost of motor vehicle crashes to our society and the building blocks of road safety were discussed to provide a basic understanding of the transportation safety discipline. The relationship between the HSIP and other programs, and integrating safety into the planning, design, construction, operations, and maintenance processes, is critical to maximizing resources and the potential to impact motor vehicle crashes.

One challenge in reducing crashes and injuries is clearly understanding the crash problem(s). Unit 2 begins the HSIP planning process by addressing the importance of quality data, as well as data collection and problem identification processes.

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[4] The HSM referenced herein refers to Draft 3.1 of the First Edition of the Highway Safety Manual (April 2009), as developed under NCHRP Project 17-36: Production of the First Edition of the Highway Safety Manual.

2.0 Planning: Problem Identification

Unit 2 addresses the problem identification step in the HSIP planning process. It begins by clarifying the difference between nominal safety (based on design standards) and substantive safety (based on roadway safety performance). Since the state HSIP is data driven, quality data and data collection processes are important aspects of the problem identification process. This unit identifies potential data challenges and methods for addressing them. It also outlines how to apply safety data in the network screening process to identify safety issues to address with systemic improvements or sites with potential for safety improvement. Several alternative methods are presented to identify locations or roadway segments with potential for safety improvement.

2.1 NOMINAL AND SUBSTANTIVE SAFETY

Roadway safety can be characterized as nominal or substantive. Nominal safety is based on design standards, while substantive safety is based on roadway safety performance.

Nominal Safety

Nominal safety refers to whether or not a design (or design element) meets minimum design criteria based on national or state standards and guidance documents such as the AASHTO Green Book and the MUTCD. If a roadway meets minimum design criteria, it can be characterized as nominally safe. However, nominal safety does not characterize the actual or expected safety of a roadway.

Substantive Safety

Conversely, substantive safety refers to the actual or expected safety on a roadway. Substantive safety may be quantified in terms of:

- Crash frequency (number of crashes for a given road segment or intersection over a specified time period);

- Crash rate (normalized to account for exposure);

- Crash type; and/or

- Crash severity (i.e., fatality, injury, or property damage only).

A roadway can be characterized by its safety performance relative to an expected value for the facility type; this could include regional, state, or national averages, or some other measurement. It is important to compare a road to similar roads because the expected safety performance of the road is strongly related to its context (e.g., traffic volume, location, design type, terrain, etc.). If the roadway in question has a significantly higher incidence or severity of crashes than other roads of its kind, it may have a substantive safety problem. Also, unusual crash patterns, such as more angle or nighttime crashes than on other facilities with similar characteristics, may indicate a problem, such as insufficient signage or lighting.

Relating Nominal and Substantive Safety

A direct correlation does not exist between nominal and substantive safety. A roadway may be characterized as nominally safe (meets minimum design criteria), while having higher than expected crash experience. Similarly a roadway not meeting minimum design criteria may still function at a high level of substantive safety.

Substantive safety requires an evidence-based approach to estimate the expected safety of a roadway through data and analysis rather than focusing solely on standards. This requirement creates a need for quality data and data systems.

Since the state HSIP is data-driven, quality data and data collection processes are important. The next section focuses on the data collection process and sources, data issues and challenges, and methods for overcoming those challenges.

2.2 DATA COLLECTION

Crash data systems are used by local, state, and Federal agencies as the basis of road safety and injury prevention programs. However, other data systems are important for managing road safety, including roadway, emergency medical services (EMS), hospital outcome, and enforcement data (e.g., citations, convictions, and sentencing outcomes). The data are used by transportation design, operations, and maintenance personnel as well as safety professionals in enforcement, education, emergency medical services, and public health communities to identify problem areas, select countermeasures, and monitor countermeasure impact.

This section outlines the data collection process as well as current and potential deficiencies in the data. It concludes with methods for addressing data challenges.

Data Collection and Management Methods

The path of crash data from the point of collection to analysis is complicated and varies from state to state and even within local governments. Crash data are originally collected either by state or local law enforcement officers in the field or are self-reported by vehicle owners.

When crashes occur, state or local law enforcement is called to the scene. The officer completes a crash report (commonly referred to as police accident reports or PAR) documenting the specifics of the crash. The contents of the crash report are predetermined by the local or state government. The report documents information related to the location of the crash, vehicles involved, and drivers and passengers in the vehicles. (NHTSA maintains a catalog of state crash forms.)

While some states are collecting crash reports electronically, most data are entered into a state crash database manually or through a scanning process. Typically the state agency responsible for maintaining the crash database uses the crash report to identify and record the crash location. Reports with missing or unclear information are handled manually to determine if the information can be recovered. The time from which crash data are collected until they are available for analysis varies depending on the type of crash reporting system, and state and local government database capabilities. While some states are close to providing data with a very short turnaround (e.g., real time to a month); others may not have complete data available for up to two years.

The state crash database usually is maintained by the state DOT, state law enforcement agency or the Department of Motor Vehicles (DMV). Various programs and departments, such as local governments, metropolitan planning organizations (MPO), advocacy groups, and private consultants request state crash data to conduct various planning activities and analyze projects. The agency maintaining the database generally fills the requests by providing raw or filtered datasets.

Additional Data Sources

In addition to state-level crash data systems, agencies frequently use information from the following national databases: Fatality Analysis Reporting Systems (FARS), the Motor Carriers Management Information System (MCMIS), and in some states, the Crash Outcome Data Evaluation System (CODES).

Crashes involving fatalities are reported to NHTSA and further investigated for inclusion in FARS, which contains annual data on a census of fatal traffic crashes within the 50 states, the District of Columbia, and Puerto Rico. According to NHTSA, "…to be included in FARS, a crash must involve a motor vehicle traveling on a traffic way customarily open to the public, and must result in the death of an occupant of a vehicle or a nonmotorist within 30 days of the crash." FARS data are available annually back to 1975. FARS contains more than 100 data elements related to the driver, vehicle, involved persons, and the crash itself. The FARS web site allows users to run national or state-specific reports on multiple factors related to trends, crashes, vehicles, people, and states. It also provides a query tool which allows users to download raw data for individual analysis. FARS is a widely used information source for research and program evaluation focusing on fatal crashes.

NHTSA's State Traffic Safety Information (STI) web site provides quick and easy access to state traffic facts, including: fatalities for years 2004-2008; by the various performance measures; by county; and economic impact of motor vehicle crashes. The STSI web site now has FARS-based GIS fatal traffic crash maps.

MCMIS is the U.S. DOT Federal Motor Carrier Safety Administration's (FMCSA) central repository of data concerning the safety and operation of Interstate, and some intrastate, commercial motor vehicles on the nation's highways. MCMIS data are the primary safety data used by FMCSA and state motor carrier safety staff in all safety-related efforts. State-based crash tables can be used to look at major factors associated with truck crashes, and comparisons can be made among states.

CODES links statewide crash and injury data that match vehicle, crash, and human behavior characteristics to their specific medical and financial outcomes. As a minimum, states must have computerized statewide crash, hospital, and either EMS or emergency department data that have sufficient information to discriminate among the crash events and persons involved in each event. Medical information is linked to crash and driver data through probabilistic linkage technology since direct linkage often is not possible due to missing personal information and privacy concerns.

Additional data sources for use in safety planning include:

- State Roadway Inventory Data Files;
- Aerial Photography;
- Asset Management Databases;
- Driver History Files;
- Vehicle Registration Databases;
- Traffic Volume Data;
- Highway Performance Monitoring System (HPMS);
- Maintenance Databases;
- Statewide Injury Surveillance Data;
- Crash Reports from Local Law Enforcement;
- Occupant Protection Use Surveys;
- Citation and DUI Tracking;
- Court Records;
- National Emergency Medical Services Information System (NEMSIS);
- National Driver Register;

- General Estimates System; and

- Population Census.

Linking the crash data to these other data sources can supplement the crash database with additional information on the characteristics of the roadway, vehicle, driver experience, or medical consequences.

Data Quality Measures

Highway safety analysts need to be aware of several quality measures when working with data. These measures, commonly referenced as the "six pack," include timeliness, accuracy, completeness, uniformity, integration, and accessibility and can be used to identify data issues and deficiencies.

Timeliness

Timeliness is a measure of how quickly an event is available within a data system. Available technologies allow automated crash data collection and processing of police crash reports; however, many agencies rely on traditional methods of data collection (i.e., paper reports) and data entry (i.e., manual entry). The use of traditional data collection and entry methods can result in significant time lags. By the time data are entered in the data system, they may be unrepresentative of current conditions. If this is the case, project development is responding to historical crashes which may be out of date. Many states are moving closer to real-time data through the use of technology.

Accuracy

Accuracy is a measure of how reliable the data are, and if the data correctly represent an occurrence. Crash data are reported by various agencies within a state and various officers within an agency. Aside from inconsistencies due to multiple data collectors, some error in judgment is likely to occur. The description of the crash and contributing factors are based on the reporting officer's judgment. Since the reporting officer typically does not witness the crash, the officer must rely on information gathered from the scene of the crash and those persons involved or nearby. Witness accounts may not be consistent (or available in the event of a serious injury or fatality) and vehicles or people may have been moved from the original location of the crash. In addition, without use of advanced technologies (e.g., global positioning systems (GPS), it is uncertain how the officer determines the location of the crash. All of these factors contribute to inaccuracies in the data.

Completeness

Completeness is a measure of missing information, including missing variables on the individual crash forms, as well as underreporting of crashes. Underreporting, particularly of noninjury crashes (i.e., property damage only (PDO) crashes) presents another drawback to current crash data. Each state has a specific

reporting threshold where fatal and injury crashes are required to be reported, but PDO crashes are reported only if the crash results in a certain amount of damage (e.g., $1,000) or if a vehicle is towed from the scene. Underreporting PDO crashes hinders the ability to measure the effectiveness of safety countermeasures (e.g., safety belts, helmets, and red light cameras) or change in severity.

Uniformity

Uniformity is a measure of how consistent information is coded in the data system, and/or how well it meets accepted data standards. Numerous agencies within each state are responsible for crash data collection, some of which are not the primary users of the crash data. In some states, little consistency exists in how the data are collected among agencies. Lack of consistency includes both the number and types of variables collected and coded by each agency as well as the definitions used to define crash types and severity. Data collection managers should continually work with their partners in other state and local agencies to improve data uniformity. This may require some negotiation but, in some cases, training may prove to be the only solution needed.

Integration

Data integration is a measure of how well various systems are connected or linked. Currently, each state maintains its own crash database to which the local agencies submit their crash reports. However, crash data alone do not typically provide sufficient information on the characteristics of the roadway, vehicle, driver experience, or medical consequences. If crash data are linked to other information databases such as roadway inventory, driver licensing, vehicle registration, citation/conviction, EMS, emergency department, death certificate, census, and other state data, it becomes possible to evaluate the relationship among the roadway, vehicle, and human factors at the time of the crash. Linkage to medical information helps establish the outcome of the crash. Finally, integrating the databases promotes collaboration among the different agencies, which can lead to improvements in the data collection process.

Accessibility

Accessibility is a measure of how easy it is to retrieve and manipulate data in a system, in particular by those entities that are not the data system owner. Safety data collection is a complex process requiring collaboration with a range of agencies, organizations, modes of transportation, and disciplines. Successful integration of safety throughout the transportation project development process (planning, design, construction, operations, and maintenance) and meaningful implementation of safety improvements demand complete, accurate, and timely data be made available to localities, MPOs, and other safety partners for analysis.

Liability

Liability associated with data collection and data analysis is an issue which is often a concern of practitioners. 23 U.S.C. 409 in its entirety states "Notwithstanding any other provision of law, reports, surveys, schedules, lists, or data compiled or collected for the purpose of identifying, evaluating, or planning the safety enhancement of potential accident sites, hazardous roadway conditions, or rail-way-highway crossings, pursuant to sections 130, 144, and 148 [152] of 23 U.S.C. or for the purpose of developing any highway safety construction improvement project which may be implemented utilizing Federal-aid highway funds shall not be subject to discovery or admitted into evidence in a Federal or state court proceeding or considered for other purposes in any action for damages arising from any occurrence at a location mentioned or addressed in such reports, surveys, schedules, lists, or data."

In 2003, the U.S. Supreme Court upheld the Constitutionality of 23 U.S.C. 409, indicating it "protects all reports, surveys, schedules, lists, or data actually compiled or collected for Section 152 purposes" (Pierce County, *Washington v. Guillen*). Some states consider information covered by 23 U.S.C. 409 as an exemption to its public disclosure laws.

States have developed procedures for managing the risk of liability. For example, many states have developed some form of a release agreement which is required to obtain data. *NCHRP Research Results Digest 306: Identification of Liability-Related Impediments to Sharing Section 409 Safety Data among Transportation Agencies and Synthesis of Best Practices* documents multiple examples of risk management practices states have incorporated to reduce the risk of liability.

Overcoming Data Challenges

Congress' greater focus on safety has given rise to institutional and technical crash data collection and management innovations.

Funding and Institutional Support

Improving the timeliness, accuracy, completeness, uniformity, integration, and accessibility of data requires adequate funding and institutional support. Funding mechanisms may require the support of several agencies. Program managers should market improved safety data to other agencies to demonstrate the benefits of greater accessibility to reliable safety data. Asset management, maintenance, planning, emergency management, and legal departments may need access to safety data, and these groups may be able to provide resources.

SAFETEA-LU authorized funding through the 23 U.S.C. 408 State Traffic Safety Information System Improvement Grants. 23 U.S.C. 408 is a data improvement incentive program administered by NHTSA and the state highway safety offices. The 23 U.S.C. 408 grant program encourages states to improve the timeliness, accuracy, completeness, uniformity, integration, and accessibility of their state

safety information; link their data systems; and improve the compatibility of state and national data. To receive 23 U.S.C. 408 grant funds, states must establish a Traffic Records Coordinating Committee (TRCC), participate in a traffic records assessment at least once every five years, develop a strategic data improvement plan, and certify it has adopted and uses the model data elements contained in the Model Minimum Uniform Crash Criteria (MMUCC) and the National Emergency Medical Services Information Systems (NEMSIS) or will use 23 U.S.C. 408 grant funds to adopt and use the maximum number of model data elements.

NHTSA encourages states to establish a two-tiered TRCC: an executive TRCC with policy and funding authority and a working-level TRCC to implement the tasks associated with the strategic data improvement plan. The TRCC plays a key role in identifying the appropriate data improvement methods based on an agency's available resources. The TRCC is a source for identifying actions to improve the data system.

States can take advantage of a NHTSA's Traffic Records Assessment process (State Assessments) where a team of national highway safety data experts reviews all components of a state traffic safety data program and compares it to NHTSA guidelines. The team provides the state with a report detailing the status of the state's traffic records program, identified deficiencies in the system, and recommendations for program improvements. States can use the report to develop a plan of action and identify traffic records improvement projects that correspond to their needs.

Guidance on the State Traffic Safety Information Systems Improvement grants may be obtained on-line. Detailed information on all projects contained in the strategic data improvement plans submitted by the states and U.S. territories for 23 U.S.C. 408 grants to help fund the improvement of their safety data systems can be found within NHTSA's Traffic Records Improvement Program Reporting System (TRIPRS). The web site is intended to provide a clearinghouse for information on traffic safety data system improvement efforts and may provide useful information for agencies desiring to improve their traffic data systems.

To aid states with data deficiencies, additional funding sources for traffic safety data initiatives beyond the 408 grants have been identified by the Federal TRCC. The goal of the Federal TRCC is to "ensure that complete, accurate, and timely traffic safety data are collected, analyzed, and made available for decision-making at the national, state, and local levels to reduce crashes, deaths, and injuries on our nation's highway." The Federal TRCC includes members from OST, NHTSA, FHWA, FMCSA, and the Research and Innovative Technology Administration (RITA).

Uniform Data Elements

Uniform coding and definition of data elements allows states to compare their crash problems to other states, regions, and the nation; Interstate information

exchange; and multiyear data analysis to detect trends, and identify emerging problems and effective highway safety programs.

States are incorporating MMUCC into the data review process. It is a voluntary set of guidelines developed by a team of safety experts to promote consistency in crash data collection. It describes a minimum, standardized dataset for describing motor vehicle crashes which generate the information necessary to improve highway safety. MMUCC helps states collect consistent, reliable crash data effective for identifying traffic safety problems, establishing goals and performance measures, and monitoring the progress of programs.

A national effort currently is underway to standardize the data collected by EMS agencies through the NEMSIS, which is the national repository used to store EMS data from all states. Since the 1970s, the need for EMS information systems and databases has been well established, and many statewide data systems have been created. However, these EMS systems vary in their ability to collect patient and systems data and allow analysis at a local, state, and national level. For this reason, the *NEMSIS* project was developed to help states collect more standardized elements and eventually submit the data to a national EMS database.

Roadway inventory and traffic data are essential for the next generation of safety analysis tools. The Model Inventory of Roadway Elements (MIRE) is being developed to define the critical inventory and traffic data elements needed by agencies to meet current safety data analysis needs as well as the data needs related to the next generation of safety analysis tools.

Technology and Training

Any agency wanting to improve the accuracy and reliability of its crash data should consider implementing strategies that offer training, funding, collaboration, and policy revisions to support electronic data collection, transfer, and management.

Data collection technologies offer improvements in the collection process and range from electronic crash report systems to barcode or magnetic strip technologies used to collect vehicle and license data. *NCHRP Synthesis 367 Technologies for Improving Safety Data* provides a comprehensive summary of crash data collection innovations.

The *National Model for the Statewide Application of Data Collection and Management Technology to Improve Highway Safety* has been developed for states who have not yet implemented a statewide electronic data collection system. As an outgrowth of Iowa's TraCS integrated system, the model demonstrates how new technologies and techniques can be cost-effectively used in a statewide operational environment to improve the safety data collection and management processes. The model provides tools by which information is quickly, accurately, and efficiently collected, and is subsequently used for analysis, reporting, public and private dissemination, and data-driven decision-making.

Many states provide frequent training to law enforcement as a means to improve the accuracy and integrity of crash data, which is most vulnerable at the crash site.

Law enforcement officers benefit from training on the importance of the crash data and techniques to ensure accurate data collection. Alternatively, the importance of crash data collection and issues can be provided through a series of short roll-call videos. When new equipment is provided, such as GPS devices, training should be provided on proper use.

The review and processing of crash reports provides opportunities for errors and inaccuracies. Training crash report system administrators to properly handle reports with inaccurate or missing information can result in more accurate data. Proper protocols should be developed to address crash reports that need additional investigation. In addition, some agencies are beginning to explore the possibility of using insurance data as often the companies have a larger database of crashes.

An incentive program could encourage agencies to collect and submit their data in a timely fashion to a central repository. The program might provide funding to a department or agency to improve an existing data collection platform so additional data can be collected with a minimal increase in expenses. In some cases, incentives may appear to be unrelated to crash data improvement (e.g., radars, DUI training, etc.); however, if law enforcement is willing to participate in the program and it accomplishes the desired objectives, it may be considered an appropriate technique.

The state TRCC provides leadership for addressing traffic safety data issues through coordination between agencies and stakeholders. The TRCC provides a forum for review and endorsement of programs, policy recommendations, funding, projects, and methodologies to implement improvements for the traffic safety data or systems.

Data for Local Roads

Often crash data are not available for local (nonstate-owned and operated) roads. Even when crash data are available, some road safety issues cannot be identified using crash data due to low exposure. In rural areas, potential safety improvement locations may not be identified through the data analysis process because low-traffic volumes lead to low-crash frequencies. For these specific situations, local engineers, police officers, and maintenance staff may be aware of high-risk locations not revealed by data analysis. Physical evidence at the site and maintenance records could be used to identify existing safety problems and sites for potential safety enhancement. System users may report problem locations to the local engineer and public officials can identify locations based on citizen complaints. Road safety audits can be used to identify and correct the issues identified by these special circumstances. While it may take more effort to collect data

from the aforementioned sources, methods exist to address lack of complete data. Although the data may not achieve the preferred "data-driven" level of analysis, waiting for "state" data may not be necessary to identify safety problems on local roads.

Data Collection Considerations

Data sharing and collaboration will become easier as more agencies adopt standard data elements and practices. It may be necessary to change policies and procedures to promote more accurate and timely safety data collection. Specific activities that states should consider for improving their data system include developing several elements:

- Policies to make it easier to collect, manage, and use data. With so many agencies involved in the process, a standard set of procedures can provide a clear expectation of each agency's roles and responsibilities.

- A data standards manual to identify data streams, data definitions, and the agencies responsible for data collection and management.

- Data submission protocols for all agencies providing data to the management system.

- A schedule for data dissemination that includes a standard procedure for handling data requests.

Quality data and data collection support the network screening element of the HSIP problem identification process. These data are used by agencies to identify sites with potential for safety improvement. Basic data analysis concepts are summarized in the next section to prepare agencies for this phase of the problem identification process.

2.3 DATA ANALYSIS CONCEPTS

The network screening process requires basic knowledge of key concepts associated with safety data analysis. Key concepts range from the analysis period and defining a site, to more advanced statistical concepts such as regression to the mean, safety performance functions, and Empirical Bayes theory.

Analysis Period

Crashes are random events that naturally fluctuate over time at any given site. Figure 2.1 illustrates how over a span of several years crash data fluctuates between several high and low points around an expected average crash frequency. If you consider a short-term average crash frequency, it may be significantly higher or lower than the long-term average crash frequency. The crash fluctuation over time can make it difficult to determine whether changes in observed crash frequency are due to changes in site conditions or natural fluctuations.

Figure 2.1   Variations in Crash Frequency

Observed Crash Frequency
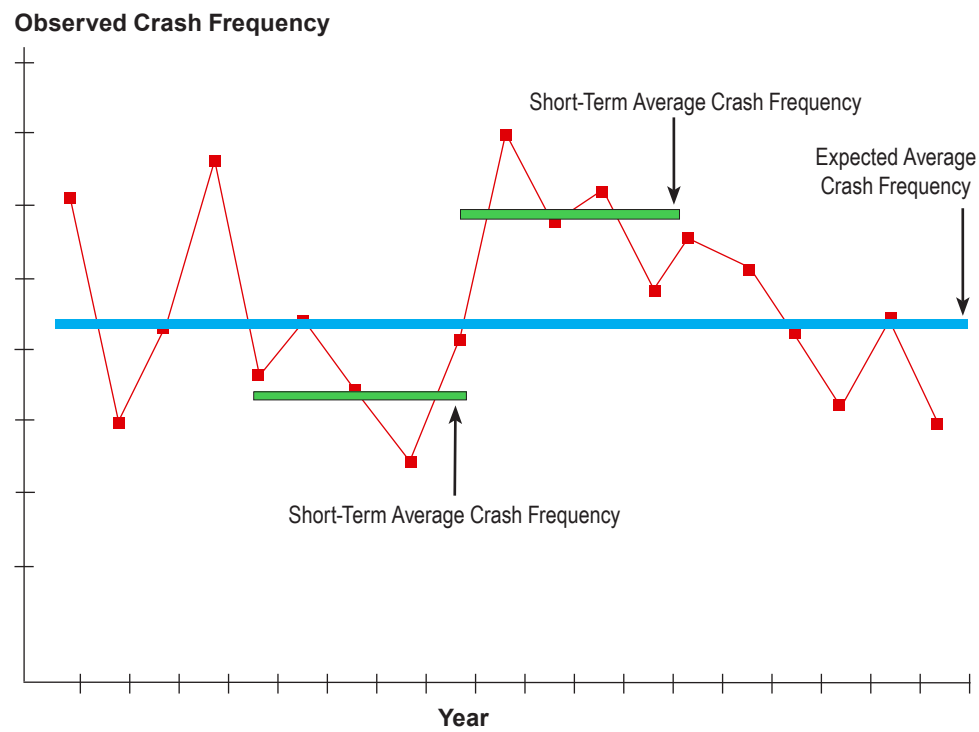
Regardless of the problem identification method used to identify locations or road segments with potential for improvement, an appropriate time period needs to be defined for the analysis. As discussed, crash experience can vary at a location from year to year, so it is important that more than one year of data is used for the analysis.

Typically a minimum of three years of crash data is used for analysis. Multiple years of data are preferable to avoid the regression to the mean phenomenon. However, the use of multiple years of data can be misguided because the facility itself may have changed (e.g., adding a lane), the travel volume may have increased, or some other change has taken place that skews the analysis. In addition, it is sometimes difficult to obtain adequate multiple years of data; therefore, it is often necessary to use a method for enhancing the estimate for sites with few years of data. The problem can be addressed by supplementing the estimation for a site with the mean (and standard deviation) for comparable sites using safety performance functions and empirical bayes.

Regression to the Mean

When identifying potential safety issues, the analyst must be aware of the statistical phenomenon of regression to the mean (RTM). RTM describes a situation in which crash rates are artificially high during the before period and would have been reduced even without an improvement to the site. Programs focused on

high-hazard locations, such as the HSIP, are vulnerable to the RTM bias which is perhaps the most important cause of erroneous conclusions in highway-related evaluations. This threat is greatest when sites are chosen because of their extreme value (e.g., high number of crashes or crash rate) in a given time period.

When selecting high-hazard locations; the locations chosen are often those with the worst recent crash record. It is generally true that crash frequency or rate at a given location, all things remaining equal, will vary from year to year around a fairly consistent mean value. The mean value represents a measure of safety at the location. The variations are usually due to the normal randomness of crash occurrence. Because of random variation, the extreme cases chosen in one period are very likely to experience lower crash frequencies in the next period, and vice versa. Simply stated; the highest get lower and the lowest get higher.

The specific concern in road safety is that one should not select sites for treatment if there is a high count in only one year because the count will tend to "regress" back toward the mean in subsequent years. Put more directly, what happens "before" is not a good indicator of what might happen "after" in this situation.

Figure 2.2 shows an example to demonstrate this concept. It shows the history of crashes at an intersection, which might have been identified as a high-hazard location in 2003 based upon the rise in crashes in 2002.

Figure 2.2   Data Series for Example Intersection

Number of Crashes
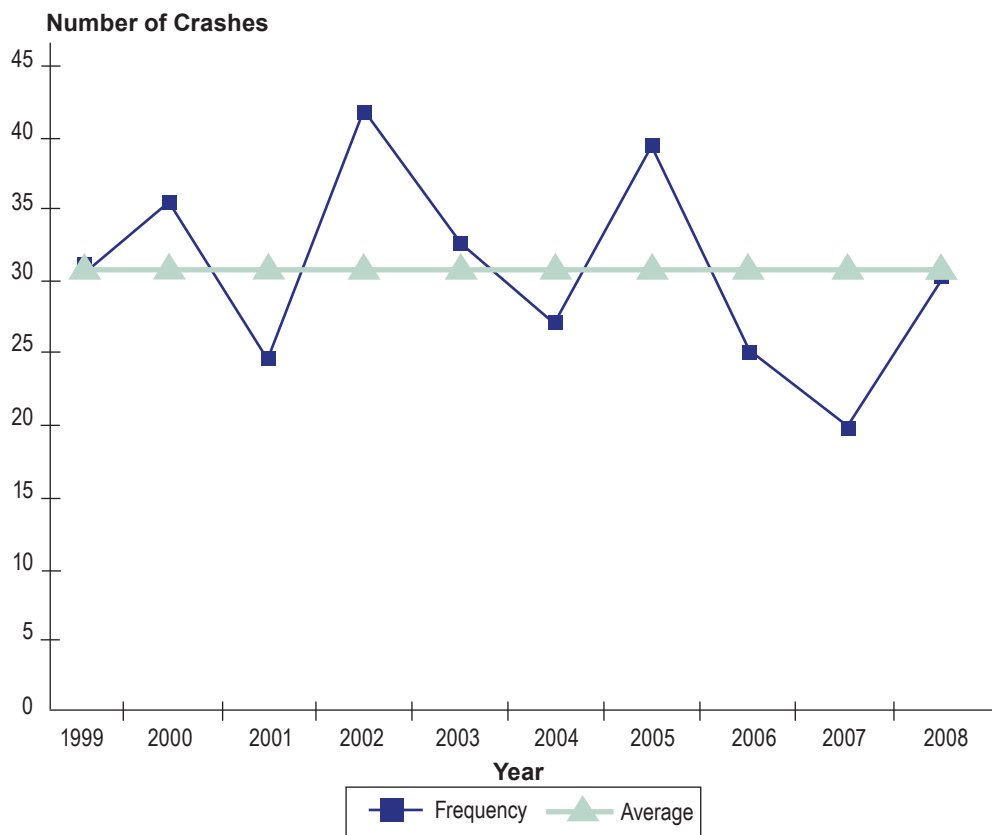
Even though a treatment may have been introduced early in 2003, any difference between the frequencies of crashes in 2002 and those in 2003 and 2004 (see Figure 2.3 would, to some unknown degree, not be attributed to the treatment, but to the RTM phenomenon. The RTM phenomenon may cause the perceived effectiveness of a treatment to be overestimated. Thus, there would be a "threat to validity" of any conclusions drawn from a simple comparison of conditions before and after a change at a site.

Figure 2.3 Example of Regression to the Mean

Number of Crashes
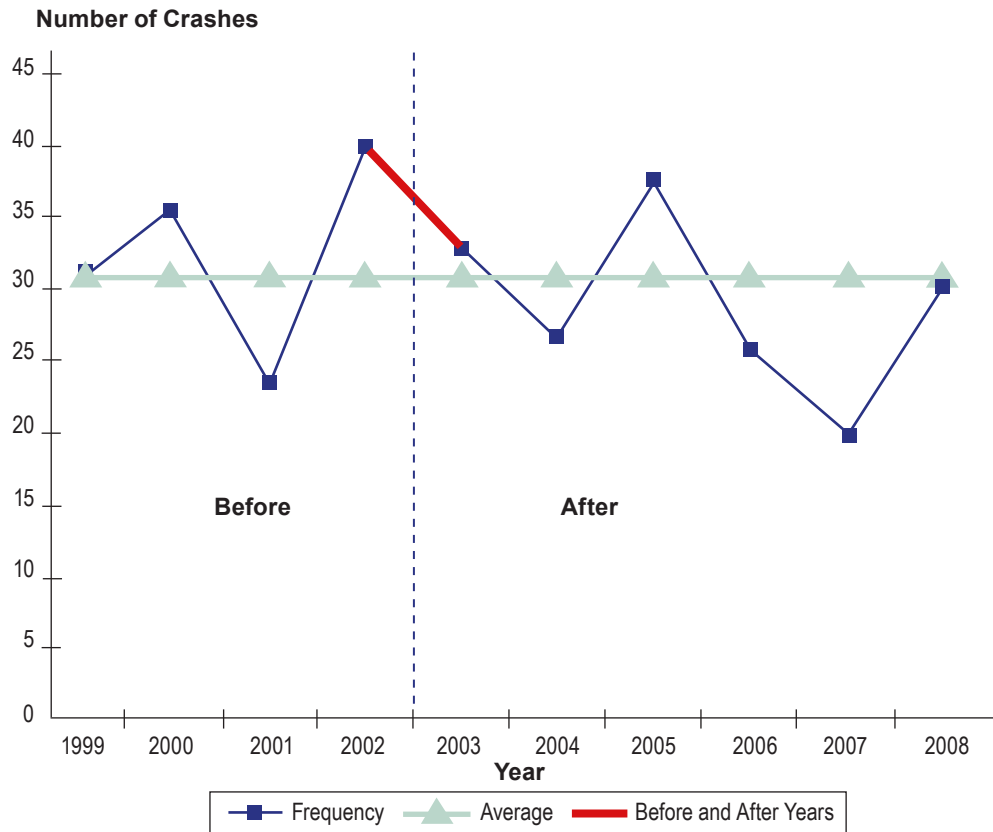
In fact, if a decision is made to forgo safety improvements at the site (e.g., due to lack of funds), the site would still be likely to show a reduction in crashes due to the natural variation in crash frequency. However, one would not be inclined to conclude doing nothing is beneficial where a safety problem truly exists.

Safety Performance Functions

Safety performance functions (SPFs) are frequently used in the network screening and evaluation processes and can be used to reduce the effects of RTM. They can be used to estimate the expected safety of a roadway segment or location based on similar facilities.

SPFs represent the change in mean crash frequency as ADT (or other exposure measure) increases or decreases. The sites contained in an SPF are called comparable sites, because they are sites that are generally comparable to the site of interest.

SPFs are constructed using crash and exposure data from multiple comparable sites. SPFs are constructed by plotting the crash and exposure data and then fitting a curve through the data using a negative binomial regression formula. The resulting curve (or equation) is the SPF.

Numerous studies have been conducted to estimate SPFs for different types of facilities. These SPFs have been compiled into safety analysis tools, such as *SafetyAnalyst* and the Highway Safety Manual (HSM). However, since crash patterns may vary in different geographical areas, SPFs must be calibrated to reflect local conditions (e.g., driver population, climate, crash reporting thresholds, etc.). Different entities have SPFs with different curves and use differing measures to represent exposure (e.g., annual average daily traffic, total entering vehicles, etc.).

Figure 2.4 depicts a typical SPF and shows crashes per mile per year for three data points (using triangles, squares, and diamonds as icons). The small icons represent values for individual years while the large comparable icon represents the mean for several years. Only three "sites" are shown in the figure, but a typical SPF may have from 100 to thousands of sites involved in its estimation. One of the advantages of displaying data in this way is to show sites that exceed the mean crash frequency for comparable sites at the same level of exposure (AADT in this case). One can think about sites with mean risk above the SPF as those with higher than average risk and those below the line as those with lower than average risk.

Figure 2.4   SPF with Individual Site Data

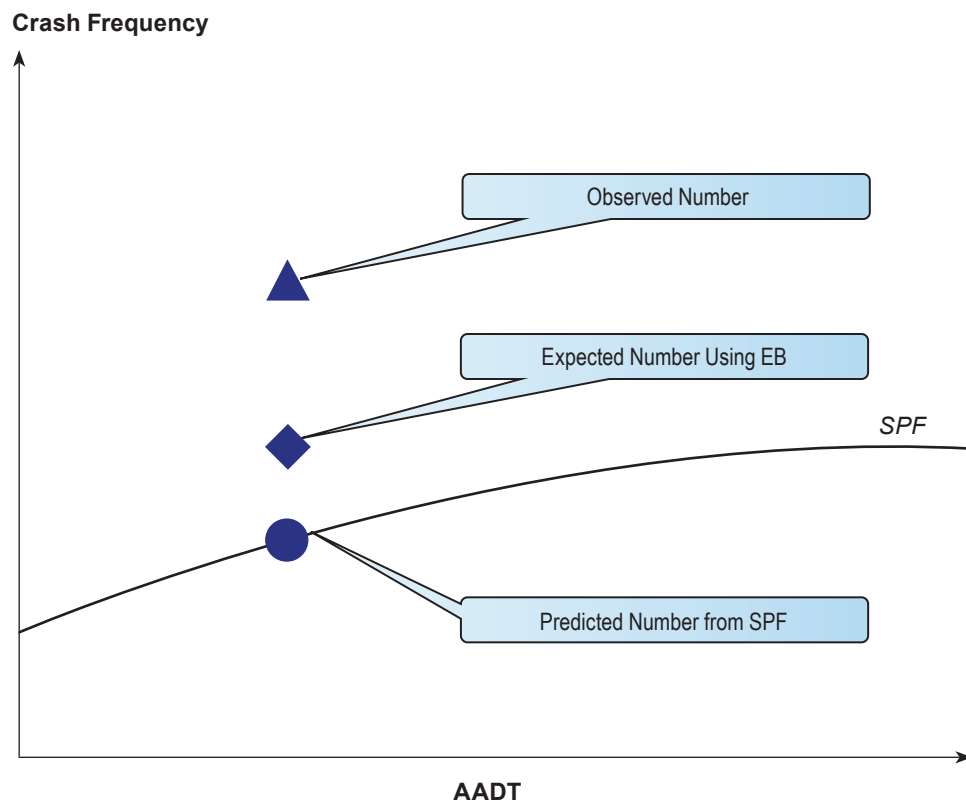**Expected Crash Frequency per Mile per Year**

AADT

Note that the large triangle and large square lie above the SPF indicating mean expected crash frequency in excess of the average for comparable sites. The large diamond lies directly on the SPF so for this site the expected crash frequency is virtually the same as the comparable sites.

Empirical Bayes

The Empirical Bayes (EB) method is a statistical method that combines the observed crash frequency with the predicted crash frequency using the SPF to calculate the expected crash frequency for a site of interest. The EB method pulls the crash count towards the mean, accounting for the RTM bias.

The EB method is illustrated in Figure 2.5, which illustrates how the observed crash frequency is combined with the predicted crash frequency based on the SPF. The EB method is applied to calculate an expected crash frequency or corrected value, which lies somewhere between the observed value and the predicted value from the SPF. The EB method is discussed in more detail in Section 6.1.

Figure 2.5   Empirical Bayes Method

Crash Frequency

AADT

Defining a Site

Caution: A small denominator (very short section length or little traffic) can lead to extremely high rates even if the actual crash frequency is low.

Sites identified for safety improvements are either intersections or segments of roads; however, there is no clear definition of what length of a road segment should be considered as a site. Typically roadways are sectioned off into segments of a fixed length, which varies from agency to agency. The segment length used to identify potential sites for safety improvement is left to the agency's discretion and does not need to be consistent for the entire data set, as long as the analysis accounts for segment length. Many states are now implementing systemic improvements, which identify sites based on roadway characteristics, rather than individual sites.

2.4 NETWORK SCREENING PROCESS

Network screening is conducted to identify key crash types to address with systemic improvements or to identify specific sites with potential for safety improvement. The process will vary depending on whether the network screening is being conducted to identify systemic improvements or to identify sites with potential for improvement.

Identifying Safety Issues to Address with Systemic Safety Improvements

Analysis now focuses more on road segments, corridors, and even entire networks. Analysts look beyond a particular location and concentrate on surrounding road segments for more efficient and effective countermeasure implementation. Some states are implementing systemic improvements using countermeasures known to be effective.

A systemic highway safety improvement is a particular countermeasure, or set of countermeasures, implemented on all roadways or roadway sections where a crash type is linked with a particular roadway or traffic element. Locations for implementing improvements are NOT based on the number or rate of crashes at particular locations, but on an analysis of what roadways share the "dangerous" elements that may be mitigated by the improvement.

The process for identifying potential safety issues to address with systemic improvements should build on the analysis used to develop the emphasis areas in the state Strategic Highway Safety Plan (SHSP). The actual identification process may vary among states but typically involves the following three steps:

1. First, identify key crash types to address (e.g., run-off-road, median cross-over), which is similar to selecting emphasis areas in the SHSP. Typically the key crash types are selected based on the number and severity of crashes.

2. Next, identify characteristics of the facilities on which key crash types occur (e.g., rural versus urban, two-lane versus four-lane, divided versus undivided, on curve versus on tangent, type of intersection control, etc.).

3. Finally, set thresholds that further define the "high-risk" facilities on which to implement the countermeasures (e.g., AADT greater than 20,000 vehicles per day, horizontal curves greater than 7 degrees, median widths less than 50 feet, etc.).

As an example, a state that has identified run-off-the-road crashes as an emphasis area in their SHSP, Should consider incorporating a systemic improvement project in their HSIP to address this crash type.

As an example, through data analysis one state has identified a significant number of severe run-off-the-road crashes occurring on their rural two-lane roadways with horizontal curves. After further looking into the analysis, they discovered most of these crashes were occurring on horizontal curves greater than seven degrees. Based on their findings, they decided to look into proven effective countermeasures on horizontal curves and to implement them on all two-lane rural roadways with horizontal curves greater than seven degrees.

States should use the SHSP to guide or influence systemic improvements in their HSIP project selection process. The emphasis areas identified in the SHSP can help states identify systemic improvements to include in the HSIP project selection process and, in some cases, address safety problems before they occur.

Once the key crash types and key characteristics are identified, the next step is to identify the appropriate countermeasure(s) for systemic improvements. This step will be discussed in Unit 3.

Identifying Sites with Potential for Safety Improvement

The network screening process for identifying sites with potential to benefit from a safety improvement involves a comprehensive review of a selected roadway network to identify locations with a potential safety problem. This process is typically conducted in four steps:

1. Identify and group the network elements;

2. Select problem identification methodology;

3. Select screening method; and

4. Screen and evaluate results.

The remainder of this section provides more detail on each of the four steps in the site identification process.

Identify and Group the Network Elements

The first step is to identify the network elements to be screened and group them into reference populations. Elements that might be considered for the screening process include: intersections, segments, facilities, ramps, ramp terminals, or

at-grade crossings which are then grouped by reference population or sites with similar characteristics.

By establishing a reference population, the performance at a particular site is compared to the expected safety of the reference population, yielding a relative measure of comparison for determining sites with potential for improvement. Reference populations can be established based on several characteristics.

Intersections potentially may be grouped into reference populations based on:

- Traffic control (signalized, two-way or all-way stop control, yield control, roundabout);
- Number of approaches (three-leg, four-leg intersection);
- Cross-section (number of through and turning lanes);
- Functional classification (arterial, collector, local);
- Area type (urban, suburban, rural);
- Traffic volumes (million entering vehicles (MEV), peak hour volumes, or average daily traffic; including pedestrian, bicycle, trucks, bus volumes);
- Terrain (flat, rolling, or mountainous); and
- Turning movements.

Similarly, roadway segments may be grouped into reference populations based on:

- Area type (urban, suburban, rural);
- Number of lanes per direction;
- Functional classification (arterial, collector, local);
- Area type (urban, suburban, rural);
- Access density (driveway or intersection spacing);
- Traffic volumes (peak hour traffic, average annual daily traffic (AADT); including pedestrian, bicycle, trucks, bus volumes);
- Median type and/or width of median;
- Operating or posted speed; and
- Terrain (flat, rolling, or mountainous).

Intersections and roadways may be grouped based on multiple reference populations, which will depend on the available data. For example, intersections might be grouped as urban signalized intersections of two arterials or urban signalized intersections of an arterial with a collector roadway. Once the network elements have been grouped by reference populations, problem identification methods are selected to use in the evaluation.

Select Problem Identification Methodology

Selecting a problem identification methodology to use for the analysis of the network elements is the second step in the network screening process. The evaluation can be based on one or multiple problem identification methods. The use of multiple problem identification methods may provide more certainty in the evaluation, if the same sites are ranked among the top sites with multiple methods.

Several problem identification methodologies can be used to identify sites for safety improvements, and the specific problem identification method used varies from agency to agency. Agencies should use problem identification methods in the network screening process that suit their specific purpose and available data.

The following are the 13 problem identification methods[5] identified in the Highway Safety Manual (HSM); however, states are using additional methods not included in the HSM:

1. **Average Crash Frequency –** Sites are ranked based on the total number of crashes or by a particular crash severity or type during a given time period. The site with the highest number of crashes is ranked first.

2. **Crash Rate –** The crash rate normalizes the crash frequency based on exposure.

3. **Equivalent Property Damage Only (EPDO) Average Crash Frequency –** Each crash is weighted based on the crash severity and the equivalent property damage only crash cost.

4. **Relative Severity Index –** Average monetary crash costs are assigned to each crash at a site, and the total average crash cost for a site is compared to the average crash cost for the reference population.

5. **Critical Crash Rate –** A critical crash rate or threshold value is calculated for each site and compared to the observed crash rate. Sites with an observed crash rate greater than their critical crash rate are flagged for further investigation.

6. **Excess Predicted Average Crash Frequency Using Method of Moments –** With this method, the observed crash frequency for a site is adjusted based on the variance in the crash data and the average crash counts for a site's reference population, which is then compared to the average frequency of crashes for the reference population.

7. **Level of Service of Safety (LOSS) –** This method compares the observed crash frequency and/or severity to the mean value predicted for the reference population using a SPF. The difference between the two values yields a performance measure that ranges between LOSS I and LOSS IV, with LOSS I indicating a low potential for crash reduction and LOSS IV indicating a high potential for crash reduction.

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[5] Referred to as performance measures in the HSM.

8. **Excess Predicted Average Crash Frequency Using SPFs –** This method represents the difference between the observed crash frequency for the site and the predicted crash frequency based on the SPF with information specific to the site.

9. **Probability of Specific Crash Types Exceeding Threshold Proportion –** This method is based on the probability that the long-term proportion of a specific crash type exceeds a threshold proportion for the site's reference population.

10. **Excess Proportion of Specific Crash Types –** This is the difference between the observed proportion of a specific crash type for a site and the threshold proportion for the reference population.

11. **Expected Average Crash Frequency with EB Adjustment –** The expected crash frequency is calculated using a calibrated SPF, which is then weighted with the observed crash frequency using the EB method. The EB method accounts for regression to the mean bias and is discussed in detail in Unit 6.

12. **EPDO Average Crash Frequency with EB Adjustment –** This method combines the expected crash frequency method with EB adjustments and the EPDO crash frequency method. The expected crash frequency is calculated using a calibrated SPF and weighted with the observed crash frequency using EB, which is then weighted based on crash severity and the equivalent property damage only cost.

13. **Excess Expected Average Crash Frequency with EB Adjustment –** The expected crash frequency determined from a SPF is weighted with the observed crash frequency using the EB method. The resulting weighted crash frequency is then compared to the expected crash frequency using the SPF to determine the difference between the two values.

Each of these problem identification methodologies has different data needs, strengths, and weaknesses. Table 2.1 summarizes the data needs, strengths, and weaknesses of the 13 problem identification methods.

Once the problem identification method(s) has been chosen for the evaluation, the next step is to select the screening method.

Table 2.1   Summary of Problem Identification Methodologies

Problem Identification Method	Data Inputs and Needs	Strengths	Weaknesses
Average Crash Frequency	• Crashes by type and/or severity and location.	• Simple; and • May be applied to crashes by type and severity.	• Does not account for RTM bias; • Does not account for exposure; • May overlook low-volume sites and overemphasize high-volume sites; and • Does not identify a performance threshold.
Crash Rate	• Crash counts and location; and • Average Daily Traffic Volumes (ADT), Total Entering Volume (TEV), or Annual Average Daily Traffic Volumes (AADT).	• Simple; and • Can modify to account for severity if EPDO or RSI-based crash count is used.	• Does not account for RTM bias; • Does not identify a performance threshold; • May overemphasize sites with low volumes; and • Comparisons cannot be made across sites with significantly different volumes.
Equivalent Property Damage Only (EPDO) Average Crash Frequency	• Crashes by severity and location; and • Fatal, injury, and PDO crash weighting factors.	• Simple; and • Considers crash severity.	• Does not account for RTM bias; • May overemphasize locations with a small number of severe crashes; • Does not identify a performance threshold; and • Does not account for traffic volume.
Relative Severity Index (RSI)	• Crashes by type and location; and • Crash costs by type.	• Simple; and • Considers crash type and crash severity.	• Does not account for RTM bias; • May overemphasize locations with small number of severe crashes; and • Does not account for traffic volumes.
Critical Crash Rate	• Crash counts and location; and • Annual Average Daily Traffic Volumes (AADT).	• Reduces exaggerated effect of sites with low volumes; • Considers variance in crash data; • Establishes a threshold for comparison; and • Can be applied to specific crash type or severity.	• Does not account for RTM bias.
Excess Predicted Average Crash Frequency Using Method of Moments	• Crashes by type and location; and • Traffic volume (AADT or ADT).	• Establishes a threshold of expected performance for a site; • Considers variance in crash data; and • Allows sites of all types to be ranked in one list.	• Does not account for RTM bias; • Does not account for traffic volumes; and • Ranking results are influenced by reference populations.

Problem Identification Method	Data Inputs and Needs	Strengths	Weaknesses
Level of Service of Safety	- A minimum of three years crash data; - Crashes by location; and - SPF, overdispersion parameter, and all variable required for SPF.	- Considers variance in crash data; - Accounts for volume; and - Establishes a threshold for comparison.	Effects of RTM bias may still be present.
Excess Predicted Average Crash Frequency Using SPFs	- A minimum of three years crash data; - Crashes by type, severity, and location; and - Calibrated SPF.	- Accounts for volume; and - Establishes a threshold for comparison.	- Requires calibrated SPF; and - Effects of RTM may still be present in the results.
Probability of Specific Crash Types Exceeding Threshold Proportion	Crashes by type, severity, and location.	- Also can be used as a diagnostic tool; - Not affected by RTM bias; and - Considers variance in crash data.	- Does not account for traffic volumes; and - Some sites may be identified for unusually low numbers of nontarget crash types.
Excess Proportion of Specific Crash Types	Crashes by type, severity, and location.	- Also can be used as a diagnostic tool; - Not affected by RTM bias; and - Considers variance in crash data.	- Does not account for traffic volumes; and - Some sites may be identified for unusually low numbers of nontarget crash types.
Expected Average Crash Frequency with EB Adjustment	- A minimum of three years crash data; - Crashes by type, severity, and location; and - Calibrated SPFs and overdispersion parameters.	Accounts for RTM.	- Requires locally calibrated SPF; - Requires rigorous analysis; and - Data intensive.
EPDO Average Crash Frequency with EB Adjustment	- A minimum of three years crash data; - Crashes by type, severity, and location; - Calibrated SPFs and overdispersion parameter; and - Fatal, injury, and PDO crash weighting factors.	- Accounts for RTM; and - Considers crash severity.	- May overemphasize locations with a small number of severe crashes depending on weighting factors used. - Requires rigorous analysis; and - Data intensive.
Excess Expected Average Crash Frequency with EB Adjustment	- A minimum of three years crash data; - Crashes by type, severity, and location; and - Calibrated SPF and overdispersion parameter.	- Accounts for RTM; and - Establishes a threshold for comparison.	- Requires locally calibrated SPF; - Requires rigorous analysis; and - Data intensive.

Source: Highway Safety Manual, First Edition, Draft 3.1, April 2009.

Select Screening Method

Three screening methods can be used in the third step of the network screening process, including simple ranking, sliding window, or peak searching. The method chosen is dependent on the reference population and the selected problem identification methodology. Table 2.2 provides a summary of when each method is applicable.

Table 2.2   Screening Method Applications

Problem Identification Method	Segments			Nodes	Facilities
	Simple Ranking	Sliding Window	Peak Searching	Simple Ranking	Simple Ranking
Average Crash Frequency	Yes	Yes	No	Yes	Yes
Crash Rate	Yes	Yes	No	Yes	Yes
Equivalent Property Damage Only (EPDO) Average Crash Frequency	Yes	Yes	No	Yes	Yes
Relative Severity Index (RSI)	Yes	Yes	No	Yes	No
Critical Crash Rate	Yes	Yes	No	Yes	Yes
Excess Predicted Average Crash Frequency Using Method of Moments	Yes	Yes	No	Yes	No
Level of Service of Safety	Yes	Yes	No	Yes	No
Excess Predicted Average Crash Frequency Using SPFs	Yes	Yes	No	Yes	No
Probability of Specific Crash Types Exceeding Threshold Proportion	Yes	Yes	No	Yes	No
Excess Proportion of Specific Crash Types	Yes	Yes	No	Yes	No
Expected Average Crash Frequency with EB Adjustment	Yes	Yes	Yes	Yes	No
EPDO Average Crash Frequency with EB Adjustment	Yes	Yes	Yes	Yes	No
Excess Expected Average Crash Frequency with EB Adjustment	Yes	Yes	Yes	Yes	No

Source: Highway Safety Manual, First Edition, Draft 3.1, April 2009.

Simple Ranking

As the name suggests, simple ranking is the simplest of the three screening methods and may be applicable for roadway segments, nodes (intersections, at-grade rail crossings), or facilities. The sites are ranked based on the highest potential for safety improvement or the greatest value of the selected problem identification methodology. Sites with the highest calculated value are identified for further study.

The sliding window and peak-searching methods are only applicable for segment-based screening. Segment-based screening identifies locations within a roadway

segment that show the most potential for safety improvement on a study road segment, not including intersections.

Sliding Window

With the sliding window method, the value of the problem identification methodology selected is calculated for a specified segment length (e.g., 0.3 miles), and the segment is moved by a specified incremental distance (e.g., 0.1 miles) and calculated for the next segment across the entire segment. The window that demonstrates the most potential for safety improvement out of the entire roadway segment is identified based on the maximum value. When the window approaches a roadway segment boundary in the sliding window method, the segment length remains the same and the incremental distance is adjusted. If the study roadway segment is less than the specified segment length, the window length equals the entire segment length.

Peak Searching

Similar to the sliding window method, the peak-searching method subdivides the individual roadway segments into windows of similar length; however, the peak-searching method is slightly more meticulous. The roadway is first subdivided into 0.1-mile windows; with the exception of the last window which may overlap with the previous window. The windows should not overlap. The problem identification method is applied to each window and the resulting value is subject to a desired level of precision, which is based on the coefficient of variation of the value calculated using the problem identification method. If none of the 0.1-mile segments meet the desired level of precision, the segment window is increased to 0.2 miles, and the process is repeated until a desired precision is reached or the window equals the entire segment length. For example, if the desired level of precision is 0.2, and the calculated coefficient of variation for each segment is greater than 0.2, then none of the segments meet the screening criterion, and the segment length should be increased.

Screen and Evaluate Results

Finally, the selected problem identification method(s) and screening method(s) are applied to the study network. The result will be a list of sites identified with potential for safety improvement with the sites most likely to benefit at the top of the list. These sites should be studied further to determine the most effective countermeasures (discussed in Unit 3).

As mentioned previously, applying multiple problem identification methods to the same data set can improve the certainty of the site identification process. Sites listed at the top of the list based on multiple problem identification methods should be investigated further. To provide a better understanding of the network screening process, two example applications are provided.

Network Screening Applications for Identifying Sites

This section provides two example applications of the network screening process for identifying sites with potential for safety improvement using the EPDO average crash frequency and the excess predicted average crash frequency using SPFs. The EPDO average crash frequency is included because it is a method currently used by many states in their screening process, and the excess predicted average crash frequency using SPFs was included because more states are starting to utilize SPFs in their screening process. The HSM will provide greater detail and several examples of all the problem identification and screening methods.

For the sample applications, it is assumed that the network elements have been identified and grouped into reference populations. All numbers used in the following examples are fictitious and provided for illustrative purposes only. We begin with an explanation of how to apply the EPDO crash frequency to screen and evaluate the network.

Equivalent Property Damage Only (EPDO) Average Crash Frequency

The EPDO average crash frequency identifies sites with potential for safety improvement for all reference populations. This method weights the frequency of crashes by severity to develop a score for each site. The weighting factors are calculated based on the crash cost by severity relative to the cost of a property damage only crash. The crash

A limitation of the EPDO average crash frequency method is that it does not provide a threshold for comparing the crash experience with expected crash experience at similar sites.

costs should include both direct (e.g., EMS, property damage, insurance, etc.) and indirect (e.g., pain and suffering, loss of life). This method provides a ranking of sites based on the severity of the crashes.

1. The first step is to calculate the weighting factors for fatal, injury, and PDO crash severities using local data (if local data sources are not available, references have been provided in Section 4.3). In some cases, fatal and injury crashes may be combined to avoid overemphasizing fatal crashes. The weighting factors are calculated as follows:

$$Fatality\ Weighting\ Factor = F_w = \frac{Average\ Fatal\ Crash\ Cost}{Average\ PDO\ Crash\ Cost}$$

$$Injury\ Weighting\ Factor = I_w = \frac{Average\ Injury\ Crash\ Cost}{Average\ PDO\ Crash\ Cost}$$

$$PDO\ Weighting\ Factor = P_w = 1.0$$

2. The weighting factors are applied to the sites based on the most severe injury for each crash to develop a score:

$$EDPO_i = K_{F,i}(F_w) + K_{I,i}(I_w) + K_{PDO,i}(P_w)$$

Where:

$K_{F,i}$ = crash frequency of fatal crashes on segment i;

$K_{I,i}$ = crash frequency of injury crashes on segment i; and

$K_{PDO,i}$ = crash frequency of PDO crashes on segment i.

3. The sites are then ranked from highest to lowest.

Example

The following is a short example applying the EPDO average crash frequency to a roadway segment using the sliding window method. The study roadway already is divided into segments of equal length. The average crash costs and segment crash information is as follows:

- Average fatal crash cost = $6,800,000;
- Average injury crash cost = $390,000; and
- Average PDO crash cost = $12,000.

Segment	Crash Count		
	Fatal	Injury	PDO
1a	0	22	8
1b	1	8	3
1c	0	16	5
1d	1	14	2
1e	0	19	6
1f	0	20	3

1. The first step is to calculate the weighting factors based on the given crash cost:

$$F_w = \frac{\$6,800,000}{\$12,000} = 566.7$$

$$I_w = \frac{\$390,000}{\$12,000} = 32.5$$

$$P_w = 1.0$$

2. Now the weighting factors are applied to each segment. For Segment 1a:

$$EDPO_1 = (0)(566.7) + (2\ )(32.5) + 8(1) = 723$$

The scores for the remaining segments are shown below.

Segment	Fatal		Injury		PDO		EPDO Score	Total Crashes
	Crash Count	Weighted Value	Crash Count	Weighted Value	Crash Count	Weighted Value		
1a	0	0	22	715	8	8	723	30
1b	1	567	8	260	3	3	830	12
1c	0	0	16	520	5	5	525	21
1d	1	567	14	455	2	2	1,024	17
1e	0	0	19	618	6	6	624	25
1f	0	0	20	650	3	3	653	23

3. For this study roadway, Segment 1d is ranked first.

Alternatively, a weighted average of the fatal and injury crashes could be used so that sites with fatal injuries are not overemphasized in the analysis. If these crashes are weighted using the injury factor only, Segment 1a is ranked first as shown below.

Segment	Fatal and Injury		PDO		EPDO Score	Total Crashes
	Crash Count	Weighted Value	Crash Count	Weighted Value		
1a	22	715	8	8	723	30
1b	9	293	3	3	296	12
1c	16	520	5	5	525	21
1d	15	488	2	2	490	17
1e	19	618	6	6	624	25
1f	20	650	3	3	653	23

It should be noted this method does not account for RTM or provide a threshold for comparing the crash experience with expected crash experience at similar sites.

Excess Predicted Average Crash Frequency Using SPFs

The excess predicted average crash frequency using SPFs is another problem identification method that can be used in the network screening process to compare a site's observed crash frequency to the predicted crash frequency from a SPF. The difference between the two values is the excess predicted average crash frequency. It is once again assumed the focus has been established as identifying sites with potential for safety improvement and the network has been identified and grouped into reference populations. In addition, it is assumed the appropriate calibrated SPFs have been obtained (SPFs can be obtained from the HSM and other research documents, but they should be calibrated to local conditions).

1. The first step is to tabulate the crashes by type, severity, and total each site for each reference population being screened:

   a. The crash counts are summarized as crashes per year at nodes; and

   b. The crashes are tabulated on a per mile per year basis for segments, either for the entire site or for the window of interest.

2. Use the appropriate SPF to calculate the estimated number of crashes (N_y), for each year (y), for the analysis period (y = 1, 2, …, Y). For segments, the crashes should be expressed on a per mile basis (calculated for the entire site or the window of interest). The number of estimated crashes for each year should then be summed together and divided by the number of years to summarize the crashes by year (or crashes per mile per year for segments).

3. The next step is to calculate the excess average crash frequency *(Excess(K))* based on all the years of data:

$$Excess(K) = Avg(K_i) - Avg(N)$$

   Where:

   Avg(Ki) = Average observed crash frequency for site (or window); and

   Avg(N) = Average estimated crash frequency from SPF for site (or window).

4. The final step is to rank all of the sites in each reference population based on excess predicted average crash frequency.

Example

A numerical example is provided below using the excess predicted average crash frequency using SPFs as a problem identification method. The given reference population is signalized four-legged intersections with the following three years of AADT and crash data.

	Year 1			Year 2			Year 3		
	AADT		Total Observed Crashes	AADT		Total Observed Crashes	AADT		Total Observed Crashes
Intersection	Major Street	Minor Street		Major Street	Minor Street		Major Street	Minor Street	
A	25,000	10,000	8	25,400	11,000	6	26,000	11,200	10
B	30,600	12,000	9	31,100	12,100	12	31,800	12,500	11
C	28,800	13,000	10	30,000	13,500	9	30,500	13,800	8
D	27,600	11,500	11	28,100	11,800	13	28,600	12,200	12

The calibrated SPF for signalized four-legged intersections in the area is:

$$N_{TOT}=e^{-3.47}(AADT_{maj})^{0.42}(AADT_{min})^{0.14}$$

Where:

N_{TOT} = The SPF predicted number of total crashes;

$AADT_{maj}$ = Average annual daily traffic on major roadway; and

$AADT_{min}$ = Average annual daily traffic on minor roadway.

1. The first step is to total the crashes at each intersection during the study period and divide by the number of years. For intersection A:

   » Observed crashes per year = (8 + 6 + 10) crashes/3 years = 8 crashes per year.

2. The SPF is used to calculate the estimated number of crashes for each year at each site. The estimated crashes for each year at a site are then added together and divided by the number of years. For intersection A:

   Year 1:

$$N_{TOT}=e^{-3.47}(AADT_{maj})^{0.42}(AADT_{min})^{0.14} = e^{-3.47}(25,000)^{0.42}(10,000)^{0.14} = 7.95$$

   Year 2:

$$N_{TOT}=e^{-3.47}(25,400)^{0.42}(11,000)^{0.14} = 8.11$$

   Year 3:

$$N_{TOT}=e^{-3.47}(26,000)^{0.42}(11,200)^{0.14} = 8.21$$

   Estimated crashes per year = (7.95 + 8.11 + 8.21) crashes/3 years = 8.09 crashes per year.

3. The excess is then calculated for each intersection. For intersection A: *Excess(K)=Avg(K_i) - Avg(N)* = 8.00 - 8.09 = -0.09

The first three steps are repeated for the remainder of the reference population, which is summarized in the following table.

Intersection	Year 1		Year 2		Year 3		Three-Year Total		Observed Crashes per Year	Predicted Crashes per Year	Excess Crash Frequency
	Observed Crashes	Predicted Crashes with SPF	Observed Crashes	Predicted Crashes with SPF	Observed Crashes	Predicted Crashes with SPF	Observed Crashes	Predicted Crashes with SPF			
A	8	7.95	6	8.11	10	8.21	24	24.26	8.00	8.09	-0.09
B	9	8.87	12	8.94	11	9.07	32	26.89	10.67	8.96	1.70
C	10	8.75	9	8.95	8	9.04	27	26.73	9.00	8.91	0.09
D	11	8.45	13	8.54	12	8.64	236	25.63	12.00	8.54	3.46

4. Finally the sites are ranked based on their excess predicted average crash frequency.

Intersection	Excess Crash Frequency
D	3.46
B	1.70
C	0.09
A	-0.09

Sites with an excess crash frequency greater than zero experience more crashes than expected, while sites with a value less than zero experience fewer crashes than expected. Based on this method, intersection D has the greatest potential for safety improvement.

This section described the network screening process and many problem identification methodologies for use in identifying sites with potential for safety improvement, including example applications. The HSM and SafetyAnalyst are tools that can assist the safety practitioner in identifying sites with improvement potential.

2.5 SUMMARY

In this unit, we discussed the importance of quality data in safety planning and outlined resources and methods for improving data. In addition, we addressed the network screening process for identifying potential safety issues to address with systemic improvements and for sites with potential for safety improvements. Once the system problems or sites with potential for safety improvement have been identified, the next step is identifying contributing crash factors and countermeasures for addressing the problem – the focus of Unit 3.

3.0 Planning: Countermeasure Identification

Identifying high-risk corridors, road segments, locations, etc., is a critical part of the road safety improvement analysis process; however, the analysis task is not complete until contributing crash factors are identified and appropriate, effective countermeasures are selected and prioritized. The purpose of Unit 3 is to describe how to identify the factors or variables that contribute to crashes and countermeasures for preventing crashes and mitigating crash severity.

A common practice is to identify contributing crash factors through a post hoc analysis of all events, behaviors, and conditions preceding a crash to determine which specific events, behaviors, or conditions made the crash inevitable. Another approach is to search a crash database to determine if certain factors, variables or sites are more prevalent in the crash data than in the normal driving population or in other locations. An emerging approach is "naturalistic" studies where drivers and vehicles are monitored continuously to obtain objective information of the conditions preceding a crash.

For practical purposes, the analysis is typically conducted through an engineering study which may be supplemented by a road safety audit (RSA). Engineering studies review recent crash data and existing roadway/intersection characteristics (i.e., geometry, control, sight distance, travel speeds, lane widths, etc.) to characterize crash data specific to the location of interest. The studies are designed to accomplish four essential steps: 1) examine the crash data to develop an in-depth analysis of the contributing crash factors; 2) conduct a field review; 3) identify alternative solutions or countermeasures; and 4) assess the effectiveness of individual and groups of countermeasures. The unit describes these steps in more detail and concludes with a case study to demonstrate an application of the engineering study process.

3.1 STEP 1 – ANALYZE THE DATA

A careful examination of the crash data will reveal contributing factors and patterns at sites and segments. The review may examine individual crash reports or an aggregate of all the data. It should result in:

- A list of crashes by crash type;
- A list of contributing crash factors;
- Crash pattern descriptions; and
- Collision diagrams.

Crash Type

After the unit of analysis (e.g., hot spot, road segment, corridor, etc.) has been identified, the data are further examined to determine the types of crashes occurring at those locations. In some cases, a single crash type might be identified, such as rear-end collisions at specific intersections. Other types of crash types include side-swipe, run-off-road, head-on, right-angle, left-turn, etc.

Figure 3.1 demonstrates an example of crash types for an intersection collision study. It is obvious turning maneuvers and rear end crashes are important issues which need to be addressed at this particular intersection.

Figure 3.1 Crash Types at an Intersection

Rear End
33
32%

Approach Turn
54
52%

Broadside
9
9%

Sideswipe
6
6%

Fixed Object
1
1%
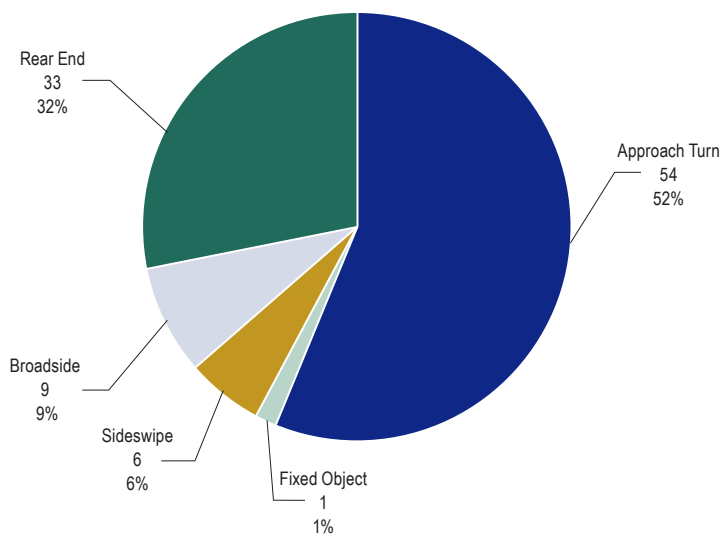
Just as identifying the high-risk locations does not complete the picture, focusing on solely the crash type may also be misleading. For example, a large number of rear-end crashes may be due to misleading signage or short sight distance, but it also could be related to driver behavior. Drivers may be distracted by a mixture of signs, billboards, etc., outside the vehicle or multitasking inside the vehicle (e.g., talking on cell phones, eating and drinking, etc.). Also, drivers may not be giving a clear signal of their intent, such as when they approach a light and then slam on the brakes at the last second.

Contributing Crash Factors

Crash factors may be related to roadway geometrics, condition, etc.; human factors, such as driver/pedestrian/motorcyclist behavior; vehicle factors which contribute to crash avoidance and survivability; and environmental conditions such as snow, ice, rain, and wind. Figure 3.2 illustrates an overall analysis of crash factors. While these percentages may not hold true for any specific situation; they generally show human factors are a significant component in all crashes, but other factors, such as roadway factors, are related as well. Engineers examine all crash factors to determine how human behavior and attributes can be affected by signage, roadway design, etc., to reduce crash risk.

Figure 3.2 Crash Factors
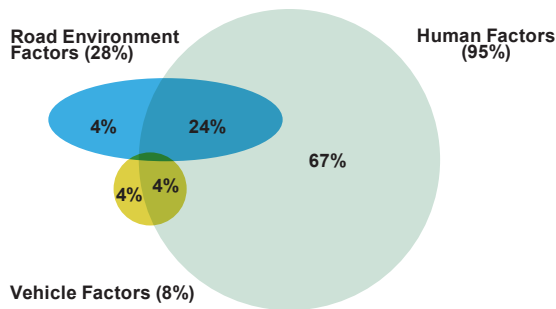
Source: NSW Roads and Traffic Authority, 1996.

The Road Environment Factors in Figure 3.2 represent the surrounding environment, which includes both roadway factors and environmental factors.

The HSIP Manual focuses on addressing issues associated with roadway factors, but the others are important for developing a thorough understanding of the circumstances surrounding a crash.

Roadway Factors

The HSIP is focused primarily on roadway factors which may contribute to help avoid or mitigate the severity of crashes. However, other factors may interact with roadway factors. Figure 3.2 shows this interaction effect. For example, 24 percent of crashes involve factors associated with both the roadway and road user behavior.

Roadway factors generally are grouped by the type of facility, including (but not limited to) interstates, freeways, intersections, rural highways, local roads, pedestrian facilities, and bicycle facilities. Safety on different facilities varies because they are built to different standards and different types of activities occur on them. Often simply knowing the type of facility provides an important safety indicator. For example, intersections may involve a large number of conflicting vehicle movements, which increases the opportunity for incidents to occur.

Some of the roadway factors which may impact the safety of a particular facility include:

- **Access Control –** Facility types are commonly classified based on the number of access points. Improving the access control reduces the number of potential conflict points.

- **Speed –** While, interstates and freeways have fewer conflict points because of controlled access, these facilities are associated with higher travel speeds, which may result in more severe injuries.

- **Roadway Cross-Section –** Roadways are designed to a minimum standard based on the facility type. The lane width, shoulder width, roadside clearance, cross-slopes, etc., may all impact the safety of a facility. For example, rural roads may be characterized by a lack of shoulders and unforgiving roadside environments.

- **Traffic Volumes –** One factor contributing to crashes on any road is the amount of exposure to risk for a given time period. Exposure relative to traffic volumes generally results in more crashes but they may be less severe due to slower speeds associated with congestion.

- **Pavement Condition –** Pavement resurfacing can improve skid resistance in locations where a high percentage of crashes occur on wet pavements or curves in the roadway. This action also may improve safety by eliminating ruts, potholes, and bumps which contribute to crashes.

Human Factors

As Figure 3.2 shows, most crashes involve one or more human factors. A host of behavioral factors are known to contribute to crashes. Some factors are attributes of drivers themselves, while others are related to the behavior of drivers. For example, advancing age is an unavoidable driver attribute, while driver intoxication is a behavioral choice. Some of the human factors that contribute to crashes include:

- **Age –** Older and younger drivers typically fall into higher crash risk groups. Older drivers frequently suffer from reduced reaction and perception times, reduced vision and flexibility (e.g., neck and back flexibility), and increasing fragility. Younger drivers lack experience and may be immature. This combination leads to excessive risk-taking and poor judgment.

- **Gender –** Men are more likely than women to be involved in fatal crashes, but women experience significant numbers of serious crashes as well and often for different reasons. In comparable crashes, some studies have shown women are more likely to be injured.

- **Aggressive Driving –** Various manifestations of aggressive driving include behaviors such as driving too fast for conditions, following too closely, inappropriate weaving in and out of traffic, and passing under unsafe conditions.

- **Impaired Driving –** Driving while intoxicated, under the influence of drugs (illegal, over-the-counter, and prescription), or fatigued are known to contribute to crashes.

- **Occupant Protection –** Drivers and passengers who choose not to use safety restraints and motorcyclists who choose not to use protective gear are at higher risk for injury and death.

- **Driver Inattention –** Distracted drivers do not give sufficient attention to the driving task. Distractions include factors both inside and outside the vehicle. Drivers may be distracted by billboards, other cars, people, noises, etc., outside the vehicle. Inside the vehicle, drivers are likely to multitask, e.g., talking or text messaging on cell phones, conversing with passengers, eating meals or snacks, changing the radio station or CD, shaving or putting on make-up, reading maps, etc.

Vehicle Factors

Vehicle design is a significant factor in road safety. Tradeoffs between large and small vehicles are complex and not well understood because we typically only observe crashes after they happen (and not crashes which are avoided). In general,

newer vehicles have better safety equipment and performance characteristics than older vehicles, and larger vehicles afford more protection in a crash.

Motorcycles and large displacement vehicles (e.g., trucks and buses) involve crash factors different from passenger vehicles. In both cases, crashes involving these vehicles tend to be more severe. Although motorcycles are highly maneuverable, crashes involving motorcycles tend to be more severe due to the lack of protection and, in some cases, the operator's behavior. Trucks, on the other hand, have far less maneuverability, but provide a high degree of protection. Crashes between a passenger vehicle and a large truck tend to result in injury to the passenger vehicle occupants rather than the truck driver. The majority of these crashes are often attributable to driver error on the part of the passenger vehicle driver and not to the trucks' maneuverability limitations.

Vehicle safety is generally approached from two perspectives:

1. **Crash Avoidance –** Numerous factors are incorporated into vehicles to avoid crashes. In general, the more maneuverable and agile a vehicle is the more likely it can avoid a crash. Also light, compact, and low vehicles offer superior maneuverability compared to heavy, large, and tall vehicles.

2. **Crash Protection –** Once a crash occurs, different vehicle factors become important (e.g., vehicle safety equipment, ability to absorb energy, etc.).

Environmental Factors

Environmental crash factors are usually weather-related and typically contribute to crashes through interactions with vehicle or driver-related factors, but sometimes these factors are responsible for crash occurrence. The following environmental factors contribute to crashes.

> *Typically, crashes are the result of multiple crash factors. The engineering study must carefully analyze all possible crash factors to identify the most effective solution.*

- **Rain –** Wet pavement has lower friction than dry pavement, so traction is reduced. Also, pooling of water can lead to hydroplaning and loss of vehicle control. Finally, rain reduces visibility. In most wet conditions, drivers can accommodate the reduced visibility; however, often a crash occurs in wet conditions due to drivers not accommodating sufficiently for the reduced friction between tires and pavement.

- **Snow, Sleet, and Ice –** Snow and ice can be hazardous due to extreme loss of traction. Ice is often more hazardous because it cannot be seen and anticipated. Also, ice often forms sporadically and catches drivers by surprise.

- **Fog –** Fog can reduce visibility to several feet, rendering a driver virtually blind.

- **Wind –** Windy conditions contribute to crashes, especially for large trucks, motorcycles and other small vehicles.

- **Sun –** The sun contributes to crashes because of glare and reduced visibility during periods of high glare.

In summary, crashes rarely involve a single crash factor; hence, careful analysis of all possible crash factors is imperative. The analysis is necessary for not only identifying all factors that contribute to a crash, but also to identify the most cost-effective countermeasures.

Crash Pattern Analysis

Crash patterns should be identified through an analysis of the crash data for specific locations. The crash patterns can be identified using a collision diagram, collision summary, field reviews, input from other disciplines, and other information.

When conducting a crash analysis, it is useful to create a summary table of the crashes that occurred during the study period. The table could include a summary of the pavement conditions, crash type, lighting conditions, number of injuries or fatalities, and any other relevant information, such as driver-related facts (i.e., age, gender, restraint use). The summary table can provide insight for identifying crash patterns. An example collision summary is shown in Table 3.1.

Table 3.1 summarizes the date and time of each collision, the crash type, injuries, time of day (day or night), and the contributing cause reported by the law enforcement officer. This summary can help identify any dominant crash types or prevailing conditions. It may also be beneficial to summarize driver-related information such as age, gender, restraint use, level of impairment, etc.

As shown in Table 3.1, left turn collisions appear to be a significant problem at this intersection, comprising 60 percent of the crashes during the one-year time period shown. In addition, it is sometimes helpful to compare site specific crash summaries to statewide averages to identify trends or overrepresentation. In this case, there were no apparent trends in crashes occurring at night (27 percent) or on wet pavement conditions (13 percent).

Although a crash summary provides some insight on potential issues, the next step is to develop a collision diagram to better understand what is occurring on a study roadway segment or intersection.

Table 3.1 Intersection Collision Summary

STUDY PERIOD: 1/1/08-12/31/08								CITY: Springfield		
ROADWAY: Center Street								COUNTY: Orange		
INTERSECTION: Main Street								SOURCE OF DATA: Local Law Enforcement		

No.	Date	Time	Type	Ped Bike	Fatal	Injuries	Property Damage	Day/ Night	Wet/ Dry	Contributing Cause
1	1/6/2008	7:30 p.m.	Left Turn	0	0	1	$2,500	Night	Dry	FTYROW*
2	1/21/2008	12:15 p.m.	Rear End	0	0	2	$1,500	Day	Dry	Followed too Closely
3	2/6/2008	2:30 p.m.	Left Turn	0	0	1	$3,000	Day	Dry	FTYROW
4	4/1/2008	4:50 p.m.	Angle	0	0	0	$2,000	Day	Dry	FTYROW
5	4/20/2008	8:25 p.m.	Left Turn	0	0	0	$2,500	Night	Dry	FTYROW
6	5/16/2008	5:30 p.m.	Rear End	0	0	2	$1,000	Day	Wet	Followed too Closely
7	5/26/2008	9:00 p.m.	Angle	0	0	1	$2,500	Night	Dry	FTYROW
8	6/9/2008	6:10 p.m.	Left Turn	0	0	0	$3,000	Day	Dry	FTYROW
9	7/19/2008	5:00 p.m.	Left Turn	0	0	1	$2,000	Day	Dry	FTYROW
10	9/1/2008	10:00 a.m.	Left Turn	0	0	0	$2,500	Day	Dry	FTYROW
11	9/8/2008	4:45 p.m.	Left Turn	0	0	2	$2,500	Day	Dry	FTYROW
12	10/30/2008	3:25 p.m.	Rear End	0	0	1	$1,000	Day	Dry	Followed too Closely
13	11/11/2008	6:30 p.m.	Rear End	0	0	0	$1,500	Night	Wet	Followed too Closely
14	1/21/2008	5:00 p.m.	Left Turn	0	0	0	$3,000	Day	Dry	FTYROW
15	12/19/2008	4:55 p.m.	Left Turn	0	0	3	$2,000	Day	Dry	FTYROW

Total No.	Ped/ Bike	Fatal	Injuries	Angle	Left Turn	Rear End	Side Swipe	Out of Control	Night	Wet
15	0	0	9	2	9	4	0	0	4	2
100%	0%	0%	60%	13%	60%	27%	0%	0%	27%	13%

* FTYROW – Failed to Yield Right-of-Way.

Collision Diagram

Transportation professionals prepare collision diagrams to demonstrate the flow and direction of travel to further illuminate the circumstances surrounding crashes. The collision diagram provides a visual representation of the crash data and can help identify crash patterns. Figure 3.3 shows an example collision diagram.

Figure 3.3   Collision Diagram
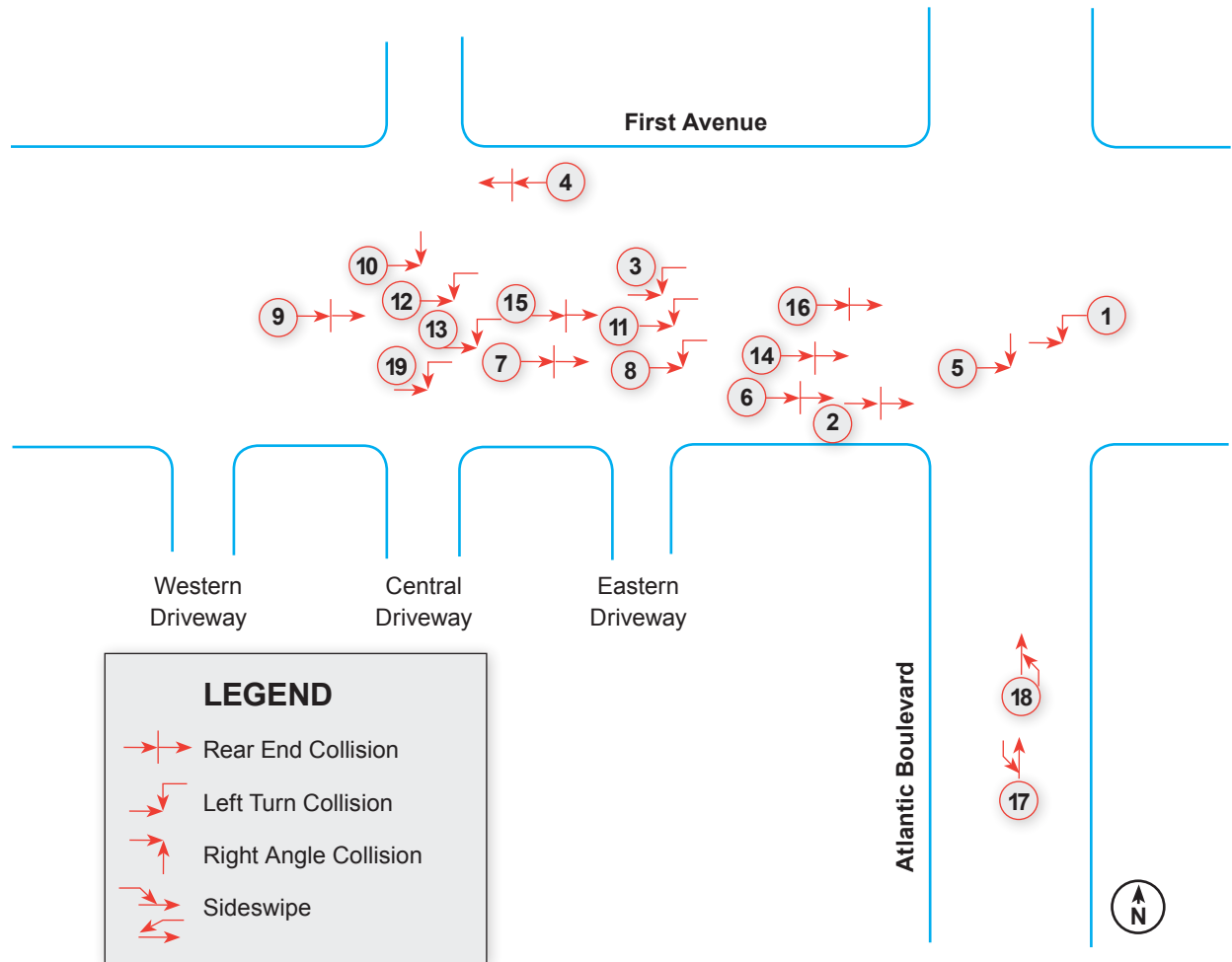
Figure 3.3 illustrates 19 crashes occurring during the study time period. The diagram shows the location of each crash, as well as the crash type. The crashes are numbered in sequential order, starting with the most recent.

As shown in Figure 3.3, there are multiple driveways on the south side of the study roadway (First Avenue). The collision diagram identifies the majority of the crashes are rear end collisions or left turn collisions with vehicles entering the driveways.

The collision diagram helps with identifying patterns, but it may not provide enough information to identify the contributing factors. The next step is to conduct a field investigation to determine what might be causing these crashes.

3.2 STEP 2 – ASSESS SITE CONDITIONS

After thorough analyses of the data, transportation professionals generally conduct a field or on-site review of the identified crash sites. The purpose of this review is to confirm the previous analysis as well as to identify additional conditions which may have contributed to the crash and to begin the process of identifying countermeasures. The site is visited during the time of day representative of the safety problem to gather information. At this stage, additional partners may be involved, such as law enforcement, local officials and citizens, etc. The data gathered during the site visit includes, but is not limited to:

- Geometry, control, lane widths, etc.;

- Traffic counts (classification counts on roadways or turning movement counts at intersections);

- Sight distance at intersections and driveways;

- Segments/intersections from the point of view of users exiting and entering;

One state found the value of digging deeper when a review of the crash diagrams in combination with a field visit discovered the crashes were not occurring on the Interstate exit ramp, but were actually occurring at an off-system road in close proximity to the exit ramp.

- Connections to existing infrastructure beyond the project limits;

- Land use activities in the vicinity (e.g., the presence of driveways, schools, shopping malls, etc.);

- Operations and road user interactions;

- Evidence of unreported crashes; and

- Future safety problems which might occur, especially under different weather, lighting, and traffic conditions

RSAs can be integrated into Safety Circuit Rider programs which are aimed at improving safety on rural roads. This approach has proven successful for improving safety at low cost.

Viewing aerial photography prior to the site visit also can help assess the field conditions. In some cases, it may help identify a recent change in land use conditions or a potential issue to investigate further in the field.

Road safety audits (RSA) can be used to supplement the engineering study and provide a broader and more complete picture of the crash problem. The FHWA defines an RSA as "a formal and independent safety performance review of a road transportation project by an experienced team of safety specialists, addressing the safety of all road users." RSAs provide an opportunity to improve safety by taking a detailed look at an existing or planned intersection or roadway segment and suggesting specific safety improvements. They are performed by a team of at least three people who represent different areas of expertise, such as engineering (e.g., design, traffic, maintenance, etc.),

law enforcement, public officials, community traffic safety advocates, and others. Interdisciplinary groups provide a more comprehensive view of road safety while the perspectives of individual disciplines may be more limited.

3.3   STEP 3 – IDENTIFY POTENTIAL COUNTERMEASURES

Once the crash experience and site conditions have been characterized, the next step is to identify potential countermeasures. This is accomplished by identifying factors among the roadway, roadside, and operational features that are contributing to the crashes identified on the collision diagram. However, the process of identifying countermeasures is more complex and often involves engineering judgment. For each type of crash identified, you should ask these three questions:

1. What road user actions lead to the occurrence of crashes?

2. What site conditions contribute to these driver actions?

3. What can be done to reduce the chances of such actions or what are the potential countermeasures?

The words countermeasure or intervention are largely synonymous for a device, engineering improvement, program (e.g., law enforcement, public education and awareness, coalition building, etc.; Appendix B provides a case study on multidisciplinary approaches), policy, or investment intended to improve safety.

While diagnosing the problem and identifying countermeasures is a skill developed through experience, there are several resources available to assist in identifying appropriate countermeasures. The Resources section of this manual (Appendix E) outlines several of these resources and some of the documented best practices. New knowledge is continuously generated relative to the effectiveness of countermeasure approaches; hence, it is important to keep abreast of the available resources and tools.

Countermeasures may be identified during a field study, an RSA, a search of the literature on effective countermeasures, by agency policy, etc. It may prove fruitful to engage safety stakeholders and other partners when selecting potential solutions as they may provide unique perspectives. Involving local officials and citizens, as well as the safety partners will result in more comprehensive and potentially more effective multidisciplinary solutions as well as more practical and cost-effective approaches. For example, one study found a multimillion dollar engineering fix could be replaced with a few thousand dollars of law enforcement overtime and community education and achieve the same result.

Some states have initiated "fatality review committees." They are typically comprised of multidisciplinary members from various agencies which may include metropolitan planning organization (MPO) officials, elected officials, highway safety practitioners, law enforcement, etc. The committees analyze the crash data for all traffic fatalities occurring in the jurisdiction and identify contributing crash factors and/or trends. The committees use their findings to offer recommendations for traffic safety improvements.

Another tool that may support the countermeasure identification process is the Haddon Matrix. The Haddon Matrix is a two-dimensional model that applies basic principles of public health to motor vehicle-related injuries. It is widely used by the public health community and by some in the road safety community. Each cell of the matrix represents a different area in which countermeasures can be implemented to improve traffic safety. Those that apply to the pre-crash phase are designed to reduce the number of crashes, while on the other hand countermeasures that apply to the crash phase would not stop the crash, but could reduce the number or severity of injuries that occur as a result. Countermeasures focusing on the post-crash phase optimize the outcome for people with injuries, and prevent secondary events. (See Appendix C for more information on the Haddon Matrix.)

3.4   STEP 4 – ASSESS COUNTERMEASURE EFFECTIVENESS

Countermeasure selection involves setting priorities. Step 4 of the engineering study process assesses the effectiveness of individual and groups of countermeasures. Once a set of countermeasures or potential solutions are identified, the list must be prioritized and pared to meet existing resources. Engineers generally accomplish this task by examining benefit/cost ratios (e.g., the amount of safety benefit gained compared to the cost of the improvement), which is discussed in great detail in Unit 4.

Crash Modification Factors (CMFs) are an excellent tool that can be used to estimate the expected safety benefits of various countermeasures and are available for many engineering improvements; however, the benefit/cost science concerning behavioral countermeasures is in its infancy. *NCHRP 17-33 Effectiveness of Behavioral Highway Safety Countermeasures* (see Resources, Appendix E) is helpful for assessing the effectiveness of behavioral countermeasures.

Crash Modification Factors

Crash Modification Factors (CMF) and Crash Reduction Factors (CRF) provide agencies with a method for estimating the expected crash reduction and/or benefits associated with various countermeasures and may be useful in identifying appropriate countermeasures. These terms are different methods for expressing the expected effectiveness of various countermeasures. A CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site, while a CRF is the percentage crash reduction that might be expected after implementing a given countermeasure. The relationship between a CMF and CRF is quite simple. The CMF is the difference between 1.0 and the CRF divided by 100 (e.g., CRF = 20 percent has a CMF equal to (1.0 -20/100) or 0.8).

CMFs are developed based on research studies and program evaluations (e.g., before/after studies and cross-sectional studies). They can be used to compare safety conditions with or without a particular treatment, or they can be used to compare the safety outcomes of alternative countermeasures or treatments.

Generally, a CMF is determined by the ratio of the expected number of crashes with a countermeasure to the expected number of crashes under identical conditions without a countermeasure.

$$CMF = \frac{Expected\ accident\ frequency\ with\ treatment\ 't'}{Expected\ accident\ frequency\ with\ conditions\ 'a'} = \frac{E_t}{E_a}$$

Where,

CMF = CMF for treatment 't' implemented under conditions 'a';

E_t = the expected crash frequency with the implemented treatment;

E_a = the expected crash frequency under identical conditions but with no treatment. In a simple before-after study, the conditions before the treatment are used.

This comparison with and without a treatment is traditionally conducted at one location and then aggregated across several locations to obtain a CMF estimate. The ratio involves expected values not counts. One method for developing CMFs uses Empirical Bayes (EB) analysis which determines the expected number of crashes which would have occurred at the site with no treatment. The expected value may be derived from the Safety Performance Function (SPF) value for a particular facility type and the average annual daily traffic (AADT) count. CMFs start with a 1.0 number which indicates no change occurred; CMFs greater than 1.0 indicate an increase in the number of crashes and those less than 1.0 indicate a reduction in crashes can be expected.

In many cases, more than one treatment is implemented at the same time. CMFs are assumed to be multiplicative ($CMF_{combined} = CMF_1$ x CMF_2 x CMF_3 x …x CMF_i), meaning that you simply multiply them by each other to calculate a combined CMF. However, it is important to realize CMFs multiplied together, assumes the effects of each CMF are independent. It is possible to overestimate the combined effect of multiple treatments, especially when more than one treatment is expected reduce the same crash type (e.g., widen lanes, widen shoulder). When using CMFs to estimate the effectiveness of multiple countermeasures, engineering judgment must be used to assess the interrelationship and/or independence of the various countermeasures, especially if more than three CMFs are considered.

The following example demonstrates how to use CMFs to estimate the expected crash reduction associated with implementing two countermeasures:

Given a rural two-lane roadway segment with 19 single vehicle crashes in the last year, identify the expected crash reduction associated with increasing the pavement friction (CMF = 0.7) and installing shoulder rumble strips (CMF = 0.79).

1. The first step is to calculate the combined CMF:

   $CMF_{combined}$ = 0.7 x 0.79 = 0.55

2. Next, calculate the estimated reduction in single vehicle crashes:

   Crash reduction = (19 crashes/year) x (1 – 0.55) = 8.55 crashes/year

Several states and local jurisdictions use CMFs, but the value of the CMF used for a particular countermeasure may vary by agency. In many cases, multiple CMFs exist for the same countermeasure, which may provide varying levels of effectiveness in improving safety. Multiple resources are available from which widely accepted CMFs can be obtained to provide safety practitioners with an estimate of countermeasure effectiveness (resources are presented later in this section). Even when using published CMFs, practitioners should make every effort to use a CMF applicable to their state and local roadway conditions.

Agencies can incorporate CMFs into safety tools to estimate the safety benefits associated with various countermeasures and to identify which countermeasure will provide the greatest return on the investment. However, agencies should use caution in selecting CMFs, as not all CMFs are equally reliable.

CMF Considerations

Several of the underlying problems with the reliability of CMFs can be attributed to the following issues (Harkey et al., 2008):

- **Origins/Transferability –** The origins of CMFs are not always known by the end user; some states develop their own based on crash data, while others simply adopt CMFs developed by other states. This transfer of CMFs may reduce their validity based on differences in crash investigation techniques as well as roadway, traffic, weather, drivers, and other characteristics.

- **Methodological Issues –** Many existing CMFs are derived from a before/after analysis of actual implemented countermeasures. Deriving CMFs from before/after analysis produces the best estimates if the study is conducted properly. Issues related to the methodology include:

  – Use of a site with an unusually high-crash incidence in the before-treatment can yield significantly exaggerated CMF estimates due to the phenomenon of regression to the mean. (Discussed in Unit 2).

  – Failure to properly separate the safety effects of other changes such as traffic volumes, impacts of other simultaneously implemented treatments, crash reporting differences, or underlying crash trends across time.

- – Use of a sample size too small for valid analysis (a large number of sites with the same combination of countermeasures are needed for a valid analysis). It is best to use a minimum of 10 to 20 sites.

- – Comparison of unsuitable groups.

- – Incorrect interpretation of estimates' accuracy or presentation of results without statements of accuracy.

- **Variability –** CMFs may be dependent on a variety of factors such as traffic volumes, crash experience, and site characteristics which may limit the applicability of a single CMF value.

Some CMFs were developed based on the reduction of all crash types and do not isolate the specific crash type being addressed with the selected countermeasure. These CMFs will generally result in a smaller reduction in crashes compared to one that isolates a particular crash type. Additionally, a specific counter-measure may have varying degrees of effectiveness based on severity. For example, installing a cable median barrier may be effective at preventing across median fatal and serious injury crashes, but PDO run-off the road crashes may increase.

- **Crash Migration and Spillover Effects –** Some countermeasures may cause crashes to migrate to adjacent locations. For instance, converting a two-way stop-controlled intersection to all-way stop may increase crash frequency at nearby two-way stop-controlled intersections due to driver confusion and expectation. This phenomenon is rarely accounted for in existing CMFs.

- **Lack of Effectiveness Information –** CMFs have not been developed for many Intelligent Transportation System (ITS) improvements and operational strategies. While many of these strategies are focused on improving traffic flow, they also may benefit traffic safety. For example, improving traffic signal coordination on a corridor may not only improve traffic flow, it also might reduce the number of rear end collisions.

- **Combination of Improvements –** When a facility is rebuilt, multiple improvements are typically implemented; yet CMFs were developed for individual improvements. Typically the CMFs are assumed to be multiplicative ($CMF_{combined} = CMF_1 \times CMF_2 \times CMF_3 \times \dots \times CMF_i$); however, very little sound research exists on the combination of treatments which leads to uncertainty in the accuracy of combining individual CMFs to capture a true combined effect.

- **Publication/Citation Issues –** Another potential weakness is a tendency to publish studies which produce favorable results for the treatment being evaluated, as well as a tendency to ignore the negative aspects of results (i.e., declining effects over time or unintended consequences leading to increases in other crash types).

It is important to recognize the potential limitations and vulnerabilities associated with CMFs. Engineering judgment should always be applied when using CMFs. Despite the potential weaknesses, valid CMFs are a key component of existing safety tools and resources used to prioritize safety programs.

Countermeasure Research

Staying current on effective countermeasures requires research, continuing education, and peer networking. The research and literature are constantly changing as policies, procedures, engineering judgment, conventional wisdom, etc., are constantly evaluated to determine new and improved methods for improving road safety. The Resources section of this manual (Appendix E) provides several tools and references related to CMFs.

The CMF Clearinghouse is an example of an available tool to assist transportation professionals with assessing countermeasure effectiveness. It is a web site that contains a searchable database of CMFs. Users can search by countermeasure, crash type and severity, and other variables. Transportation professionals also can submit their own CMF studies to the Clearinghouse.

The four steps of the engineering study process (analyze the data, assess site conditions, identify potential countermeasures and assess countermeasure effectiveness) are demonstrated using a case study in the next section.

3.5 ENGINEERING CASE STUDY

This example case study is presented to provide a more thorough understanding of steps involved in an engineering study.

In this case study, a particular intersection already has been identified as having a greater than normal crash experience, compared to intersections on similar roadways in the state. To identify any potential safety problems, as well as potential countermeasures, the first step is further analysis of the intersection crash data.

When obtaining crash data, it is important to realize roadways may be referenced by several different names, depending on the reporting officer. They may be referred to by the state route number or by the local street name; additionally, abbreviations may be used to identify the roadway (e.g., State Road 400, SR 400, Center Street, Center St, Ctr St). The engineer should search for crash reports using all possible references for the desired location.

Step 1 – Analyze the Data

Two years of crash reports were obtained from local law enforcement for the intersection. The major route in this study is State Road 400; however, this roadway is referenced locally as Center Street. Both roadway names and any variations should be used in the crash records search.

During the two-year study period a total of 17 crashes occurred at the intersection which is summarized in Table 3.2.

Table 3.2   Collision Summary

STUDY PERIOD: 1/1/07-12/31/08   **CITY:** Smithville

ROADWAY: State Road 400   **COUNTY:** Red River

INTERSECTION: Shopping Center Drive   **SOURCE OF DATA:** Local Law Enforcement

No.	Date	Time	Type	Ped Bike	Fatal	Injuries	Property Damage	Day/Night	Wet/Dry	Contributing Cause
1	1/6/2007	3:25 p.m.	Angle	0	0	0	$2,000	Day	Dry	FTYROW
2	1/21/2007	5:15 p.m.	Rear End	0	0	0	$1,500	Day	Dry	Followed too Closely
3	2/6/2007	6:40 p.m.	Angle	0	0	1	$3,000	Night	Dry	FTYROW
4	4/1/2007	4:50 p.m.	Angle	0	0	0	$2,000	Day	Dry	FTYROW
5	4/20/2007	4:00 p.m.	Left	0	0	2	$2,500	Day	Dry	FTYROW
6	6/9/2007	5:30 p.m.	Angle	0	0	0	$1,500	Day	Wet	FTYROW
7	7/19/2007	7:00 p.m.	Angle	0	0	0	$2,000	Night	Dry	FTYROW
8	10/30/2007	6:10 p.m.	Angle	0	0	1	$3,000	Day	Dry	FTYROW
9	12/1/2007	5:00 p.m.	Angle	0	0	0	$1,500	Day	Dry	FTYROW
10	12/19/2007	10:00 a.m.	Rear End	0	0	0	$1,000	Day	Dry	Followed too Closely
11	1/2/2008	4:45 p.m.	Rear End	0	0	1	$1,500	Day	Dry	Followed too Closely
12	1/9/2008	5:25 p.m.	Rear End	0	0	0	$1,000	Day	Dry	Followed too Closely
13	2/19/2008	6:30 p.m.	Rear End	0	0	0	$1,500	Night	Wet	Followed too Closely
14	4/27/2008	5:00 p.m.	Angle	0	0	3	$3,000	Day	Dry	FTYROW
15	6/21/2008	4:55 p.m.	Angle	0	0	1	$2,000	Day	Dry	FTYROW
16	10/9/2008	6:15 p.m.	Angle	0	0	0	$2,000	Day	Dry	FTYROW
17	11/23/2008	5:30 p.m.	Angle	0	0	0	$1,500	Night	Dry	FTYROW

Total No.	Ped Bike	Fatal	Injuries	Angle	Left Turn	Rear End	Side Swipe	Out of Control	Night	Wet
17	0	0	6	12	0	5	0	0	4	2
100%	0%	0%	35%	71%	0%	29%	0%	0%	24%	12%

As shown in Table 3.2, angle collisions appear to be a significant problem at this intersection, comprising 71 percent of the crashes during the two-year time period. In this case, no apparent trends in crashes occurred at night (24 percent) or on wet pavement (12 percent); however, further analysis of this crash data reveals the majority of these collisions occur during the evening peak period.

To better understand the crash experience at this intersection, the next step is to develop a collision diagram. In most cases, the crash reports will provide sufficient information to develop the collision diagram; however, if the engineer is unfamiliar with the area or if the intersection is complex, a preliminary field visit may be required to determine the layout of the intersection.

The collision diagram for the study intersection is shown in Figure 3.4. The diagram shows the location of each crash, as well as the crash type (the crash numbers on the diagram correspond to the crash number in Table 3.2).

Figure 3.4 Intersection Collision Diagram
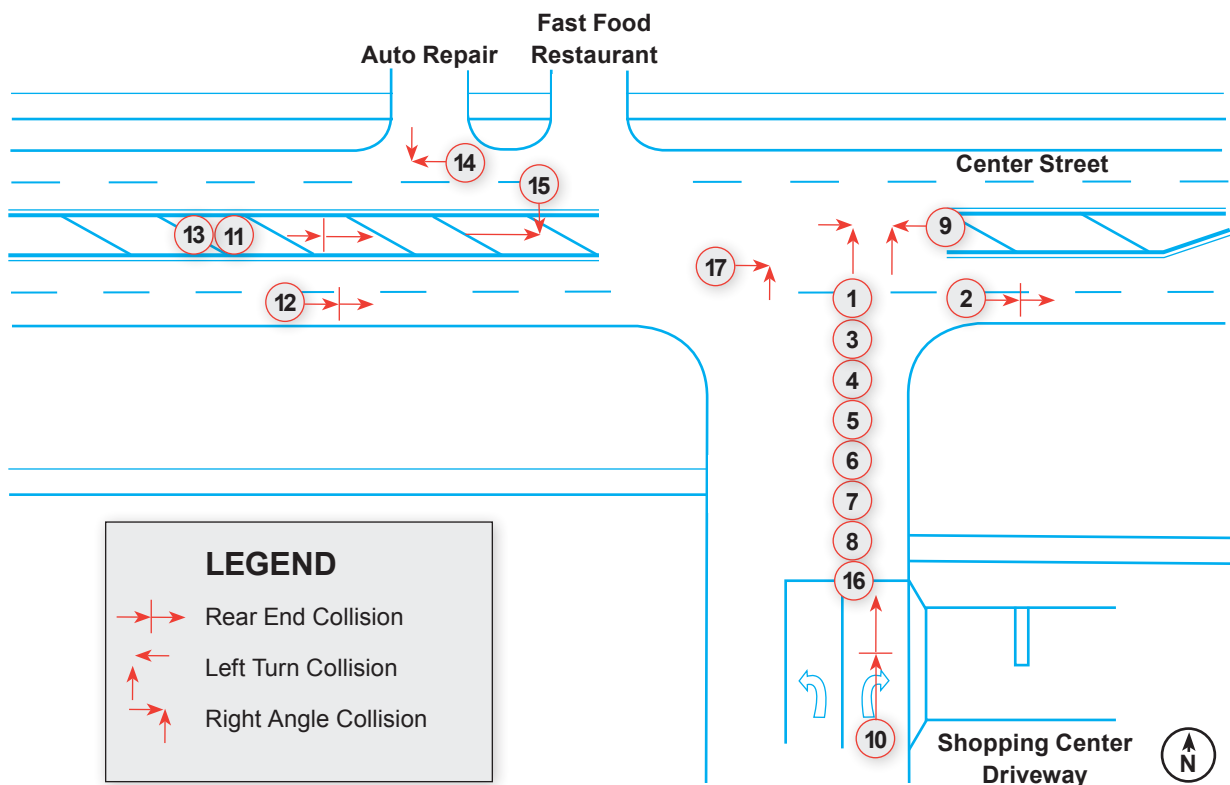
The collision diagram identifies the majority of angle collisions occur in median of this intersection, but based on the data, it is unclear why so many collisions are occurring in the median. The next step is to conduct a field investigation to determine what might be causing these crashes.

Step 2 – Assess Site Conditions

The study intersection is unsignalized and located in a suburban area. The intersection is at the connection of a shopping center with Center Street (State Road 400), which is an east-west four-lane divided roadway with a striped median. The shopping center driveway connects on the south side of Center Street (State Road 400) and has a two-lane approach – one left turn lane and one right turn lane. A major signalized intersection is located approximately 500 feet east of the study intersection.

As part of the field review, the following data were collected by the study engineer:

- A.M. and p.m. peak hour turning movement counts and 72-hour approach counts;
- Lane geometry and traffic control;
- Site distance (found to be adequate); and
- Surrounding land use.

Since the majority of the crashes occurred during the p.m. peak hour, the site was observed during this time period to identify operational issues. The field observations revealed significant vehicle queues resulting from the major signalized intersection located to the east. The queues extended almost a mile beyond the intersection. Several drivers were observed using the striped median as a travel lane to bypass the queue and enter the left-turn lane at the adjacent intersection. The site visit also revealed several near-misses between vehicles exiting the shopping center driveway to turn left and vehicles driving in the median.

No sight distance issues were identified based on the roadway alignment at the intersection, but the vehicle queues limit the sight distance of the vehicles turning left out of the shopping center driveway. The limited sight distance, in combination with illegal use of the median as a travel lane, were identified as factors contributing to crashes occurring at the intersection.

Now that the problem has been identified, the next step is to identify countermeasures to address the safety issue.

Step 3 – Identify Potential Countermeasures

A number of countermeasures could be selected to improve safety at this intersection. Some options include:

- Prohibit left turns out of the shopping center driveway. This could be accomplished by adding a raised or striped median to the driveway and signage.

- Install a raised median in place of the striped median on the major roadway to completely remove the potential conflict by prohibiting left turns out of the driveway and restricting vehicles from driving in the median; however, it will limit access to the adjacent businesses.

- Add signage restricting vehicles from traveling in the median.

- Implement enforcement campaign(s) targeting drivers illegally driving in median.

- Develop and conduct a public awareness campaign, including partnering with local businesses, to educate drivers on the dangers of driving in a designated median.

Each of these countermeasures would have a different impact. The next step is to assess their effectiveness.

Step 4 – Assess Countermeasure Effectiveness

CMFs can be used to estimate the expected safety benefits of various countermeasures. The countermeasure with the lowest CMF will be the most effective; however, when CMFs are not available, engineering judgment should be used.

In this case study, locally calibrated CMFs were not available, so engineering judgment was used to assess the effectiveness of the various countermeasures. Since installing a raised median completely removes the potential conflict, it is the most effective alternative for addressing the problem. The next best option is to prohibit left turns from the driveway by adding channelization and signage; however, since access is not restricted in the median, some vehicles will still try to make the turn. Increased enforcement is likely to work when law enforcement is observed but will be less likely to address the problem long term. Finally, adding signage to restrict vehicles from the median or implementing a public awareness campaign will have less of an impact on addressing the issue compared to the other options, since both of these options are reliant on driver decisions.

Although installing the raised median is the most effective option in this case in terms of reducing crashes, the most effective countermeasure may not always be feasible because of funding limitations or political constraints. The next unit demonstrates how to prioritize countermeasures and projects based on available resources.

3.6 SUMMARY

In this unit, we learned how to identify contributing crash factors, as well as potential countermeasures for preventing crashes and mitigating crash severity. An engineering case study illustrated the process. This unit also described how CMFs can be used to assess the effectiveness of various countermeasures; however, other factors need to be considered, such as costs and available funding. Unit 4 provides guidance on how to establish priorities for project implementation based on available resources.

4.0 Planning: Project Prioritization

After contributing crash factors and potential countermeasures have been identified, the next step is to prioritize countermeasures and projects for implementation. Unit 4 focuses on project prioritization processes and applying them to the locations identified with potential for safety improvement. A variety of methods for prioritizing safety projects are presented, including benefit/cost analysis, ranking, and optimization approaches.

4.1 THE OBJECTIVE APPROACH

Once locations with potential for safety improvement and potential counter-measures have been identified, the next step is to establish priorities for implementing these projects.

Safety is a complex issue and usually no single solution can completely solve an identified road safety problem. Solutions may vary in cost; involve an educational, engineering, or enforcement approach; or be categorized as a "quick fix" or a long-term strategy. Safety professionals are constantly challenged to weigh the menu of possible solutions and prioritize those which best address the problem given existing constraints and resources.

Quantitative analysis should be used whenever possible in the prioritization process, which typically involves identifying and comparing cost, effectiveness, and resilience (i.e., length of effectiveness) for each countermeasure or program based on the latest research.

Quantitative information lends objectivity to a decision-making process which might otherwise be dominated by subjective judgment or political considerations. It helps ensure the maximum safety benefit will be obtained for the amount of funds invested.

Various quantitative project prioritization methods (or project selection methods) can be used to compare alternative projects for a single site, across multiple sites, or for an entire network. Projects can be prioritized by simply ranking them based on specified factors (e.g., project cost, total number of crashes reduced, etc.) or a project's benefit/cost ratio (discussed later in this unit). Alternatively, projects can be prioritized using an optimization process which maximizes the safety benefits based on budget and other constraints.

Challenges to the Objective Approach

Many considerations may enter into project selection beyond safety. These considerations, some of which may be quantified, play an important role in the project selection process and include the following:

- **Design Standards –** Some safety countermeasures, especially untested or innovative ones, may conflict with established design standards. Decision-makers may avoid these countermeasures due to liability concerns.

- **Project Programming –** In some instances, higher priority projects may require more effort in project development (i.e., NEPA, right-of-way, design). This delay may promote projects of lesser priority through to implementation earlier than may have been warranted through a quantitative analysis.

- **Tradeoffs –** In transportation organizations, safety must compete with other concerns and priorities, such as improving mobility or reducing the environmental impact of transportation systems. Resistance to countermeasures perceived to conflict with other priorities may exist. For example, opposition to installation of a protected left-turn signal arrow may appear because it increases the time drivers wait at an intersection; hence, it may be perceived to hamper mobility.

- **Familiarity –** Some individuals or organizations may oppose implementation of certain countermeasures simply because they are unfamiliar with them. Decision-makers and stakeholders often have different perspectives on solving problems, and may have a vested interest in a specific solution. For example, maintenance engineers might oppose cable barriers because they are unsure how much effort is needed to maintain them.

- **Constituent Concerns –** Elected officials may favor or oppose certain countermeasures because of constituent concerns or demands. If constituents demand a particular solution to a safety problem, politicians may support it regardless of cost-effectiveness. Most transportation decisions are ultimately political in nature. For this reason, it is imperative to provide information derived from data-driven, quantitative analysis to officials so they have the facts to make an informed decision.

All these factors may play a role in project prioritization, but transportation safety professionals generally prioritize projects based on what will achieve the greatest results within the available funding constraints. Some safety investment outcomes are more easily measured than others. As an example, a reduction in the number of crashes with an intersection improvement is more easily measured than a public awareness campaign focused on deterring driving under the influence of alcohol. In any event, every attempt should be made to establish the quantitative benefit of expected outcomes and these metrics should at least provide weight, if not determine, project selection.

Quantifying these benefits can be accomplished as part of a benefit/cost analysis. Benefit/cost analysis is a quantitative measure commonly used in prioritizing projects and countermeasures. The next section provides guidance on how to estimate project costs and benefits.

4.2 BENEFIT/COST ANALYSIS

A benefit/cost analysis compares all of the benefits associated with a counter-measure (e.g., crash reduction, etc.), expressed in monetary terms, to the cost of implementing the countermeasure. A benefit/cost analysis provides a quantitative measure to help safety professionals prioritize countermeasures or projects and optimize the return on investment.

Some safety countermeasures have a higher-cost value than others. Geometric improvements to the road, such as straightening a tight curve to reduce run-off-road crashes, tend to be very expensive. Installing a "curve warning" sign and in-curve delineation addresses the same problem, but at a much lower cost. Although both countermeasures address the same problem, the actual safety benefit will not be the same. Straightening the curve would be expected to provide a greater benefit compared to installing the sign and delineation, since it is removing the potential hazard. While the sign provides the driver with advanced warning of the curve and delineation can help the driver recognize and negotiate through the curve, it is still up to the driver to reduce speed. Safety professionals take the relative costs and benefits into consideration when prioritizing among countermeasures.

Part of calculating the cost of a countermeasure is considering how those costs vary over time, including any maintenance costs, as well as the relative resilience or "lasting power" of the countermeasure. One countermeasure may be just as effective as another in the short term, but less cost-effective over a longer time period. For example, installing speed cameras along a corridor requires significant up-front cost, but over time may be less expensive than an aggressive law enforcement program. Formal benefit/cost analysis takes resilience into account by calculating all of the project benefits and costs over a given time period. This allows comparison of countermeasures even though the timing of their impact varies.

Safety countermeasures have many direct safety benefits, including reductions in injuries, fatalities, and damage to personal property. Other direct benefits may occur, such as reduced queuing through signal synchronization.

Converting Benefits to a Monetary Value

A benefit/cost analysis expresses benefits in monetary terms, which requires an estimate of the number of crashes avoided as a result of the countermeasure, and the monetary value of each avoided crash. When available, CMFs should be used to determine the expected reduction in crashes. When CMFs from a quality study are not available, especially for nonengineering countermeasures such as educational or enforcement strategies or for experimental engineering treatments, safety professionals should use their subjective judgment and research evaluations when selecting countermeasures. Proven treatments should be considered along with experimental/untried treatments.

One limitation to using benefit/cost analysis is fewer crashes may not always result in a positive outcome. For instance, cable median barriers are an accepted strategy for reducing the incidence of head-on collisions in run-off-road crashes. They do not necessarily reduce the number of run-off-road crashes, but do improve safety by reducing crash severity. Safety practitioners should consider both the likely change in number of crashes and the likely change in crash severity when calculating the benefits of a safety countermeasure.

The monetary value of crashes avoided is based on a dollar value of crashes by type and severity which many states and local agencies have developed. Costs can also vary by the type of vehicle involved (motor carrier versus personal vehicle).

Another way to determine the cost of a crash is to use the U.S. DOT's Value of Statistical Life (VSL). In 2009, the U.S. Office of the Secretary of Transportation (OST) issued a memorandum updating the cost to avert a fatality to $6.0 million. VSL provides fractional values for use when assessing the benefit of preventing an injury crash based on the Maximum Abbreviated Injury Scale (MAIS) developed by the Association for the Advancement of Automotive Medicine as shown in Table 4.1. The injuries are ranked on a scale of one to six, with one being minor and six being fatal.

Table 4.1   Relative Disutility Factors by Injury Severity Level (MAIS)

MAIS Level	Severity	Fraction of VSL
MAIS 1	Minor	0.0020
MAIS 2	Moderate	0.0155
MAIS 3	Serious	0.0575
MAIS 4	Severe	0.1875
MAIS 5	Critical	0.7625
MAIS 6	Fatal	1.0000

Source: Office of the Secretary of Transportation (2009).

Using the MAIS scale in combination with the VSL will result in an injury cost for the different severity levels. However, these injury costs must be converted to a crash cost. Usually more than one injury and/or severity is associated with a crash. Typically an average number of injuries and severities are weighted to determine an average crash cost. For example, in a fatal crash there will typically be other injuries associated with the crash which may not be fatal; therefore, an average cost must be developed to account for the other injuries.

The "KABCO" injury scale also can be used for establishing crash costs. This scale was developed by the National Safety Council (NSC) and is frequently used by law enforcement for classifying injuries:

- **K –** Fatal;

- **A –** Incapacitating injury;

- **B –** Nonincapacitating injury;

- **C –** Possible injury; and

- **O –** No injury.

The 2005 FHWA study, *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, provides crash cost estimates for several combinations of KABCO injury severities for 22 injury crash types. The NSC is another source for obtaining crash cost information by severity.

Crash costs by severity level were estimated as part of the development of the HSM. These costs were developed based on the KABCO scale and are shown in Table 4.2. If a state has not developed their own crash costs, these costs could be used to calculate safety benefits.

Table 4.2 Crash Costs by Injury Severity Level

Injury Severity Level	Comprehensive Crash Cost
Fatality (K)	$4,008,900
Disabling Injury (A)	$216,000
Evident Injury (B)	$79,000
Fatal/Injury (K/A/B)	$158,200
Possible Injury (C)	$44,900
PDO (O)	$7,400

Source: Highway Safety Manual, First Edition, Draft 3.1, April 2009.

Since the service life of countermeasures varies, the annual monetary safety benefit should be converted to a present value so projects can be compared over a given time period. States typically have a list of the service lives of countermeasures to use for estimating project costs. Two methods are presented here for converting benefits to a present value. The first method is used when the annual benefits are uniform throughout the service life of the project, and the second is used when the annual benefits vary throughout the service life of the project.

Method 1: Uniform Annual Benefits

$$PVB_v = TotalAnnualMonetaryBenefits \times (P/A, i, n)$$

Where:

PVB_v = present value of the safety benefits for a specific site, v.

$(P/A,i,n)$ = is a factor that converts a series of uniform annual amounts to its present value.

$$(P/A,i,n) = \frac{(1+i)^n - 1}{i(1+i)^n}$$

i = minimum attractive rate of return or discount rate (i.e., if the discount rate is 4 percent, i = 0.04).

n = year in the service life of the countermeasure(s).

For example, if the expected lifespan of a project is five years, the discount rate is four percent, and the annual monetary benefit is \$1,667,500, the present value of the safety benefits is calculated as follows:

$$(P/A,i,n) = \frac{(1+0.04)^5 - 1}{0.04(1+0.04)^5} = 4.452$$

$$PVB_v = \$1,667,500 \times 4.452 = \$7,423,414$$

Method 2: Nonuniform Annual Benefits

The safety effectiveness of some countermeasures is not consistent throughout the project, such as retroreflectivity of lane markings which change over time. When the benefit of the countermeasure varies over the service life of the project, nonuniform annual monetary values should be calculated for each year of service, which are then combined to determine a single present value. Start by calculating the present worth values for each year of service:

$$PVB_v = TotalAnnualMonetaryBenefits \times (P/F,i,n)$$

Where:

$(P/F,i,n)$ = is a factor that converts a single future value to its present value.

$$(P/F,i,n) = (1+i)^{-n}$$

i = discount rate.

n = year in the service life of the countermeasure(s).

The individual present worth values are then added together to develop a single present worth value for the safety benefits of the countermeasure.

For example, the annual monetary benefits associated with a safety improvement for each of the five years of a project's service life are provided in the following table. This discount rate is four percent.

Year in Service Life	Annual Monetary Value of Benefits	(P/F,i,n)	Present Value of Benefits
1	$923,237	0.962	$887,728
2	$929,655	0.925	$859,518
3	$935,235	0.889	$831,421
4	$912,879	0.855	$780,333
5	$931,880	0.822	$765,937
Total			**$4,124,937**

The first step is to calculate the factor that converts the future value to a present value for each year. For the first year:

$$(P/F,i,n) = (1+0.04)^{-1} = 0.962$$

The factor is calculated for each of the years as shown in the above table, and then the annual monetary benefits are multiplied by this factor to obtain the present value of the benefits. For the first year:

$$PVB_v = \$923,237 \times 0.962 = \$887,728$$

The present value of the benefits is then summed for each year to obtain the total present value of benefits, which is $4,124,937 for the service life of this project.

Project Cost Estimation

The project cost estimation procedure for evaluating safety countermeasures follows the same process as cost estimates for other construction or program implementation projects. Project costs are unique to each site and proposed countermeasure and may include costs associated with: right-of-way acquisition, material costs, grading and earthwork, utility relocation, environmental impacts, maintenance, and cost related to planning and engineering design work prior to construction.

According to AASHTO, all of the costs incurred over the service life of a project should be incorporated in the present value cost calculation, including all future maintenance, construction, or operating costs expected to occur during a project's lifespan. Chapter 6 of the AASHTO Redbook[6] provides additional guidance on categories of costs and their treatment in a benefit/cost analysis for:

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[6] The AASHTO Redbook addresses benefit/cost analysis for highway improvement projects. It provides decision-makers with a clear description of the approach and understanding of the results of project benefit/cost analyses along with sufficient detail for practitioners to perform these technical analyses. Specifically, it concentrates on highway-user benefits and costs and on project-level analyses.

- Construction and other development costs;

- Adjusting development and operating cost estimates for inflation;

- Cost of right-of-way;

- Measuring the current and future value of developed or undeveloped land;

- Placing a value on already owned right-of-way;

- Maintenance and operating costs; and

- Creating cost estimates.

To conduct a benefit/cost analysis, the project costs need to be expressed as present values. Typically construction and/or implementation costs already are expressed as present values; however, any future costs will need to be converted to present values using the methods presented in the benefits section.

Once the project benefits and costs have been estimated, they can be used to prioritize alternative countermeasures at a particular site or several projects across various sites. The next two sections focus on these prioritization methods.

4.3   COUNTERMEASURE EVALUATION METHODS

Economic evaluations should be conducted on alternative countermeasures to verify a project is economically justified, meaning the benefits are greater than the costs. The net present value method and a benefit/cost ratio are two methods for evaluating the economic effectiveness and feasibility of safety improvement projects at a particular site. The cost-effectiveness index can be used when it is not possible to express the benefits in monetary terms.

Net Present Value

The net present value (NPV) method, or net present worth (NPW) method, expresses the difference between the discounted costs and discounted benefits of a safety improvement project. The costs and benefits are "discounted" meaning they have been converted to a present value using a discount rate.

The NPV method has two basic functions. It can be used to determine which countermeasure(s) provides the most cost-efficient means based on the countermeasure(s) with the highest NPV. It also can determine if a project is economically justified meaning a project has a NPV greater than zero (or the benefits are greater than the costs).

The NPV is calculated based on the present value calculations of the project benefits and costs previously discussed.

NPV = PVB – PVC

Where:

PVB = Present value of benefits; and

PVC = Present value of costs.

A project is economically justified if the NPV is greater than zero. This method identifies the most desirable countermeasure(s) for a specific site, and it also can be used to evaluate multiple projects across multiple sites.

Benefit/Cost Ratio

The benefit/cost ratio (BCR) is the ratio of the present value of the benefits of a project to the present value of costs of the project.

BCR = PVB/PVC

Where:

PVB = Present value of benefits; and

PVC = Present value of costs.

A project with a BCR greater than 1.0 is considered economically justified. However, the BCR is not applicable for comparing various countermeasures or multiple projects at various sites; this requires an incremental benefit/cost analysis.

Cost-Effectiveness

In situations where it is not possible or practical to monetize countermeasure benefits, a "cost-effectiveness" metric can be used in lieu of the net present value or benefit/cost ratio. Cost-effectiveness is simply the amount of money invested divided by the benefit in crash reduction. It is expressed as the cost for crash avoided with a certain countermeasure. In this case, the countermeasure with the lowest value is ranked first.

A cost-effectiveness Index can be calculated as follows:

Cost-Effective Index = PVC/AR

Where:

PVC = Present value of project cost; and

AR = Total crash reduction.

The present value of the project cost is calculated in the same manner as in benefit/cost analysis. This is a simple and quick method which provides a general sense of a project's value and can be used to compare other safety improvement projects. However, this method does not account for value differences between reductions in fatal crashes as opposed to injury crashes, and whether a project is economically justified.

4.4 PRIORITIZATION METHODS

Once alternative countermeasures or projects have been determined to be economically justified, the next step is to prioritize them for implementation. Alternative countermeasures identified at one or several sites can be prioritized using ranking, incremental benefit/cost analysis, or optimization methods. Ranking is the simplest of the methods presented and is best for making decisions on a limited number of sites. While an incremental benefit/cost analysis allows the analyst to compare the economic effectiveness of one project against another, it does not consider budget constraints. Optimization methods are best for prioritizing projects based on monetary constraints.

Ranking

Ranking is the simplest method for prioritizing countermeasures at a site or prioritizing projects across multiple sites. Some economic effectiveness measures that can be used for ranking include:

- Project costs;

- Monetary value of project benefits;

- Total number of crashes reduced;

- Number of fatal and injury crashes reduced;

- Net present value; and

- Cost-effectiveness index.

Individually, these ranking measures will not help safety practitioners obtain the best return on investment. For example, ranking the countermeasures based solely on the number of fatal and injury crashes reduced does not account for the cost of each countermeasure. Additionally, the countermeasure with the least cost may not have as significant reduction in fatal and injury crashes compared to a slightly higher-cost project. It is best to account for multiple measures when ranking countermeasures such as using the net present value or cost-effectiveness methods.

Net Present Value

The following is an example using the net present value to rank four alternative countermeasures to improve safety at a site. The present value of the benefits and costs of each alternative are provided in the following table.

Alternative Countermeasure	Present Value of Benefits	Present Value of Costs	Net Present Value	Alternative Rank
A	$1,800,268	$500,000	$1,300,268	3
B	$3,255,892	$1,200,000	$2,055,892	1
C	$3,958,768	$2,100,000	$1,858,768	2
D	$2,566,476	$1,270,000	$1,296,476	4

For Alternative A, the net present value is calculated:

NPV = $1,800,268-$500,000 = $1,300,268

This same step is repeated for the other three countermeasure alternatives, which are then ranked based on their net present value. As shown, all four alternatives are economically justified with a net present value greater than zero. However, Alternative B has the greatest net present value for this site based on this method.

Cost-Effectiveness Index

The following is an example of using the cost-effective index to rank alternative countermeasures, given the present value of the costs and the total crash reduction.

Alternative Countermeasure	Present Value of Costs	Total Accident Reduction	Cost-Effective Index	Alternative Rank
A	$500,000	43	11,628	1
B	$1,200,000	63	19,048	3
C	$2,100,000	70	30,000	4
D	$1,270,000	73	17,397	2

For Alternative A, the cost-effective index is calculated:

Cost-Effective Index = 500,000/43 = 11,628

With this method, the lowest index is ranked first. The cost-effective index is calculated for the remaining alternatives as shown in the table, and Alternative A is ranked first, since it has the lowest cost associated with each crash reduction.

The above example simply used the number of crashes. This method also could be used with Equivalent Property Damage Only (EPDO) crash numbers and has the advantage of taking severity into account.

Incremental Benefit/Cost Analysis

The benefit/cost ratios of the individual safety improvement projects are the starting point for an incremental benefit/cost analysis. The process for conducting an incremental benefit/cost analysis is as follows:

1. Rank the individual projects with a BCR greater than 1.0 in increasing order based on cost, with the smallest cost listed first.

2. Starting from the top of the list, calculate the difference between the first and second project's benefits, and then calculate the difference between the first and second project's costs. Calculate an incremental benefit/cost ratio by dividing the difference in benefits of the two projects by the difference in costs of the two projects.

3. If the incremental BCR is greater than 1.0, the project with the higher cost is ranked higher and compared with the next project on the list, meaning the magnitude of the benefits of the higher-cost project outweighs the higher cost. However, if the incremental BCR is less than 1.0, the project with the lower cost is ranked higher and compared with the next project on the list.

4. Repeat this process for the entire list. The best economic investment is the project selected in the last pairing.

5. To produce a ranking of projects, repeat the entire process for the remaining unranked projects to determine the project with the next best economic investment until all of the projects are ranked.

In instances where two projects have the same cost, the project with the greater benefit should be selected.

Example

The following is an example application using the incremental benefit/cost analysis, using the same four alternative countermeasures.

Alternative Countermeasure	Present Value of Benefits	Present Value of Costs	Benefit/Cost Ratio
A	$1,800,268	$500,000	3.60
B	$3,255,892	$1,200,000	2.71
D	$2,566,476	$1,270,000	2.02
C	$3,958,768	$2,100,000	1.89

1. The first step is to rank the alternatives by the present value of the costs, from lowest to highest, which already has been done in the table.

2. The incremental difference is calculated for the benefits and the costs for Alternatives A and B.

   Incremental Benefits = $3,225,892-$1,800,268 = $1,455,625

   Incremental Costs = $1,200,000-$500,000 = $700,000

   Incremental B/C = $1,455,625/$700,000 = 2.08

3. Since the incremental benefit/cost ratio is greater than 1.0, Alternative B should be compared to Alternative D.

4. The incremental benefit/cost ratio is calculated for Alternatives B and D:

   Since the incremental benefits are negative, Alternative B should be compared to Alternative C.

   Incremental B/C = $702,845/$900,000 = 0.78

   Since the incremental BCR is less than one, Alternative B is then ranked first.

5. This same process is continued until all of the alternatives have been ranked. The ranking results are shown in the following table.

Alternative Countermeasure	Benefit/Cost Ratio	Alternative Rank
A	3.60	3
B	2.71	1
C	1.89	2
D	2.02	4

Notice although Alternative A had the highest individual project benefit/cost ratio, it was ranked third. In addition, it is also important to notice the alternative rankings are the same using the net present value method or the incremental benefit/cost analysis.

An incremental benefit/cost analysis provides a basis of comparison of the bene-
fits of a project for the dollars invested. However to take monetary constraints into
consideration, optimization methods must be used.

Optimization Methods

Optimization methods take into account certain constraints when prioritizing
projects. Linear programming, integer programming, and dynamic program-
ming are optimization methods consistent with an incremental benefits/cost
analysis, but they also account for budget constraints in the development of the
project list. (These optimization methods are more likely to be incorporated into
a software package than directly applied and will not be addressed further in
this manual.) Multi-objective resource allocation is another optimization method
which incorporates nonmonetary elements, including decision factors not related
to safety, into the prioritization process.

Software programs are available to assist in the selection and ranking of coun-
termeasures. *SafetyAnalyst* includes economic appraisal and priority ranking tools.
The economic appraisal tool calculates the benefit/cost ratio and other metrics for
a set of countermeasures. The priority ranking tool provides a priority ranking of
sites and proposed improvement projects based on the benefit and cost estimates
determined by the economic appraisal tool. The priority-ranking tool also has the
ability to determine an optimal set of projects to maximize safety benefits.

The prioritization methods presented in this unit are consistent with those in the
HSM. The HSM provides additional resources and examples of many of these
methods.

So far this unit has focused on prioritizing hot spot improvements. The next sec-
tion will address systemic improvements and balancing between the two types.

4.5 APPROACHES ADDRESSING CURRENT AND FUTURE SAFETY PROBLEMS

As discussed in Unit 2, transportation safety practitioners are focusing more on
systemic improvements using countermeasures proven to be successful rather
than on a particular location with an identified problem or "hot spot." For
example, some states have identified systemic problems (e.g., high occurrence of
run-off-road, median crossover crashes, etc.) through crash data analysis, and are
implementing cable median barrier and rumble strips on roads even if no safety
problem has been identified at a particular location. These are proven effective
countermeasures and it is more efficient to add these road improvements while
addressing infrastructure functions, such as resurfacing, routine maintenance,
and construction on a systemic basis. These actions may prevent or minimize the
severity of future crashes even though a road segment or intersection may not
have yet had a safety problem resulting in crashes.

Embedding these improvements into state or local policy leaves a lasting legacy for safety. A historical example is pavement marking, which at one point was not a standard installation on highway projects. Today, a highway agency would not consider opening a new section of highway without striping. In at least one state, rumble strips have been given this same status. On any overlay project on a major highway, rumble strips are a required addition, regardless of the road's crash history. The addition of rumble strips has simply replaced traditional striping as the state standard for pavement marking on its highways. The safety treatment has been institutionalized, and the benefit of this policy change will outlast any specific safety project or program.

Since systemic improvements are intended to be implemented on several miles of roadway or at several locations, they do not necessarily have to be prioritized by location per se; however, it may be necessary to determine a point of departure for implementing these improvements. An agency might consider incorporating improvements into maintenance/design practices (e.g., all rural roads projects include the safety edge or shoulder rumble strips/stripes during paving projects), or at high risk locations that have:

- A high exposure – high ADT, lots of curves;
- A high-crash frequency;
- A high-crash rate; or
- A high-crash density.

When developing their HSIP, an additional issue that states will need to address is how to balance systemic improvements versus hot spot improvements.

Striking a Balance

No prescriptive method exists for determining the proportion of HSIP projects that should be systemic improvements versus hot spot improvements. While the majority of fatal crashes tend to occur in rural areas, urban areas comprise a much greater proportion of injury and property damage only (PDO) crashes. Due to the inherent differences in the two area types, the focus of the improvements will vary. Although improvements in rural areas typically focus more on systemic improvements, and urban areas typically focus more on hot spot locations, both types of improvements can be used in either area type. However, since rural areas are associated with a lower crash density (i.e., crashes spread over many miles of roads), systemic improvements are more likely to address sites with potential for safety improvement that might not be identified through a crash analysis. The appropriate balance between systemic and hot spot improvements should be determined by each state. For example, some states set aside a portion of their HSIP funds to implement systemic improvements.

4.6 SUMMARY

States may select a combination of project prioritization strategies and typically consult with other agencies (e.g., DOT district or regional offices, FHWA Division Safety staff) during this process. A balance is needed in the HSIP among hot spot, segment/corridor, and systemic improvements to ensure the best mix of safety solutions is identified and implemented to reduce fatalities and serious injuries.

Once the prioritized projects are included in the HSIP, the next step is implementation. Implementation is addressed in the next unit.

5.0 Implementation

The previous three units focused on the planning component of the HSIP – identifying the problems, selecting appropriate countermeasures, and prioritizing projects. Now it is time to implement the projects and put the planning efforts into action.

The first step towards implementing prioritized projects is to identify funding sources. Once funding is identified, projects are included in the transportation improvement program and move forward into design and construction.

Unit 5 begins with a discussion on several funding topics, including: HSIP funding requirements, other safety funding sources, allocation issues, and a discussion on state solutions to funding challenges. This unit also includes a discussion on programming projects into the transportation improvement program and concludes with a discussion on the development of evaluation plans.

5.1 HSIP FUNDING REQUIREMENTS

Under 23 U.S.C. 148(a)(3), a variety of highway safety improvement projects are eligible for HSIP funding on all public roadways. States should identify projects or activities that are most likely to reduce the number of and potential for fatalities and serious injuries. In most cases, the Federal share is 90 percent except for certain safety improvements listed in 23 U.S.C. 120(c) which are funded at 100 percent.

A highway safety improvement project is defined as a project consistent with the SHSP that corrects or improves a hazardous road location or feature or addresses a highway safety problem. Projects include, but are not limited to, the following:

- An intersection safety improvement;

- Pavement and shoulder widening (including addition of a passing lane to remedy an unsafe condition);

- Installation of rumble strips or other warning devices, if the rumble strips or other warning devices do not adversely affect the safety or mobility of bicyclists, pedestrians, and persons with disabilities;

- Installation of a skid-resistant surface at an intersection or other location with a high frequency of crashes;

- An improvement for pedestrian or bicyclist safety or for the safety of persons with disabilities;

- Construction of any project for the elimination of hazards at a railway-highway crossing that is eligible for funding under 23 U.S.C. 130, including the separation or protection of grades at railway-highway crossings;

- Construction of a railway-highway crossing safety feature, including installation of highway-rail grade crossing protective devices;

- The conduct of an effective traffic enforcement activity at a railway-highway crossing;

- Construction of a traffic calming feature;

- Elimination of a roadside obstacle or roadside hazard;

- Improvement of highway signage and pavement markings;

- Installation of a priority control system for emergency vehicles at signalized intersections;

- Installation of a traffic control or other warning device at a location with high-crash potential;

- Transportation safety planning;

- Improvement in the collection and analysis of safety data;

- Planning integrated interoperable emergency communications equipment, operational activities, or traffic enforcement activities (including law enforcement assistance) relating to work zone safety;

- Installation of guardrails, barriers (including barriers between construction work zones and traffic lanes for the safety of road users and workers), and crash attenuators;

- The addition or retrofitting of structures or other measures to eliminate or reduce crashes involving vehicles and wildlife;

- Installation and maintenance of signs (including fluorescent yellow-green signs) at pedestrian-bicycle crossings and in school zones;

- Construction and operational improvements on high-risk rural roads; and

- Conducting road safety audits.

Many Federal funding sources are eligible for HSIP projects and programs. The next section details these sources and additional behavior-related Federal funds which may be available to benefit HSIP programs and projects, especially through SHSP partnerships and initiatives.

5.2 FEDERAL SAFETY FUNDING SOURCES

Funding for safety projects comes from a variety of Federal, state, and local sources. This section identifies Federal funding resources to help leverage your HSIP projects and programs.

SAFETEA-LU established new programs and set-asides, including the following funding sources:

- **High-Risk Rural Roads Program (HRRRP) –** The HRRRP is a set-aside of the HSIP and supports road safety program efforts through construction and operational improvements on high-risk rural roads. The HSIP, including the HRRRP element, must consider all public roads.

- **23 U.S.C. 130: Railway-Highway Grade Crossing Program (RHGCP) –** SAFETEA-LU continued the RHGCP as a set-aside program of the HSIP. It is focused on reducing the occurrence of crashes at railway-highway crossings. States can use the apportioned funds for related data compilation and analysis which will allow informed decisions to prioritize railway-highway crossing improvements (e.g., crash data, traffic volume and mix, road inventory, etc.). States can use not more than 2 percent of funds apportioned to a state for the data compilation and analysis. At least half of the funds are to be used for the installation of protective devices at railway-highway crossings, with special emphasis given to the legislative requirement that all public crossing be provided with standard signing.

- **Safe Routes to School (SRTS) –** The program is designed to make walking and bicycling to school safe and more appealing; and to facilitate the planning, development, and implementation of projects which improve safety and reduce traffic, fuel consumption, and air pollution in the vicinity of schools. Each state is apportioned funds based on its relative share of total enrollment in primary and middle schools (kindergarten through eighth grade), but no state receives less than $1 million annually.

Other Federal-aid funds are eligible to support and leverage the HSIP. States are encouraged to fund improvements to safety features routinely provided as part of a broader Federal-aid project from the same source as the broader project, as per 23 CFR 924. States should address the full scope of their safety needs and opportunities on all roadway categories by using other funding sources such as the following:

- **Interstate Maintenance (IM) –** Provides funding for resurfacing, restoration, rehabilitation, and reconstruction; reconstruction or new construction of bridges, interchanges, and over crossings along existing Interstate routes, including the acquisition of right-of-way where necessary; capital costs for operational, safety, traffic management, or intelligent transportation systems (ITS) improvements (operating costs are not eligible for IM funds); and preventive maintenance.

- **Surface Transportation Program (STP) –** Provides funding for a variety of transportation purposes. With some exceptions, these funds can be used on all public roads except those functionally classified as local or rural minor collectors. Highway safety improvement projects, including projects to improve signing and pavement markings, may be funded on any public road.

- **National Highway System (NHS**) **–** Provides funding for resurfacing, restoring, rehabilitating, and reconstructing highways on the NHS.

- **Congestion Mitigation and Air Quality Improvement Program (CMAQ) –** Provides funding for projects and programs in air quality nonattainment and maintenance areas for ozone, carbon monoxide (CO), and particulate matter (PM_{10}, $PM_{2.5}$) which reduce transportation-related emissions.

- **State Planning and Research (SPR) –** The state DOTs must provide data that supports the FHWA's responsibilities to the Congress and to the public, including information required for preparing proposed legislation and reports to the Congress; and evaluating the extent, performance, condition, and use of the Nation's transportation systems. States have used SPR funds for data improvements.

- **Equity Bonus –** Ensures each state receives a specific share of the aggregate funding for major highway programs, with every state guaranteed at least a specified percentage of that state's share of contributions to the Highway Account of the Highway Trust Fund. The Federal share for the funds programmatically distributed to other programs has the same Federal share as those programs.

In addition to the major highway program funding sources, other Federal safety resources may assist with HSIP implementation. These grant programs are administered by NHTSA and FMCSA and can be used to assist with law enforcement efforts and improve traffic record data collection and data systems. They include:

- **23 U.S.C. 154 and 164 Transfer Funds –** States in which Federal-aid highway funds are transferred based on noncompliance with 23 U.S.C. 154 Open Container Requirements or 23 U.S.C. 164 Minimum Penalties for Repeat Offenders for Driving While Intoxicated or Under the Influence can use the transfer funds on approved projects for alcohol-impaired driving countermeasures or direct the funds to state/local law enforcement to increase impaired driving enforcement. States also may elect to use the funds for hazard elimination activities eligible under 23 U.S.C. 152.

- **23 U.S.C. 402: State and Community Highway Safety Grants –** Supports a full range of highway safety behavioral programs, including alcohol countermeasures, occupant protection, police traffic services (e.g., enforcement), emergency medical services, traffic records, motorcycle safety pedestrian and bicycle safety, nonconstruction aspects of road safety, and speed enforcement and management programs. A minimum of 40 percent of a state's Section 402 funds must be expended by local governments, or be used for the benefit of local governments. To receive Federal highway safety grant funds, State Highway Safety Offices must submit an annual Highway Safety Plan (HSP) to the NHTSA.

- **23 U.S.C. 405: Occupant Protection Incentive Grants –** Provides incentive grants to encourage states to adopt and implement effective programs to reduce highway deaths and injuries resulting from individuals riding unrestrained or improperly restrained in motor vehicles.

- **23 U.S.C. 406: Safety Belt Performance Grants –** Encourages states to enact and enforce primary safety belt laws. A state may use these grant funds for any behavioral or infrastructure safety purpose under Title 23, for any project which corrects or improves a hazardous road location or feature, or proactively addresses highway safety problems. However, at least $1 million of each state's allocation must be obligated to behavioral highway safety activities.

- **23 U.S.C. 408: State Traffic Safety Information System Improvement Grants –** Encourages states to adopt and implement effective programs to improve the timeliness, accuracy, completeness, uniformity, integration, and accessibility of state data needed to identify priorities for national, state, and local highway and traffic safety programs; to evaluate the effectiveness of efforts to make such improvements; to link the state's data systems, including traffic records, with other data systems within the state; and to improve the compatibility of the state's data system with national data systems and data systems of other states.

- **23 U.S.C. 410: Alcohol-Impaired Driving Countermeasures Incentive Grants –** Provides an incentive to states to implement effective programs to reduce traffic safety problems resulting from impaired driving.

- **SAFETEA-LU Section 2010: Motorcyclist Safety Grants –** Provides grants to states which adopt and implement effective programs to reduce the number of crashes involving motorcyclists. Funds can be used only for motorcycle training and motorist awareness programs.

- **CFR Title 49 Part 350 Commercial Motor Carrier Safety Assistance Program (MCSAP) –** Provides financial assistance to states to reduce the number and severity of crashes and hazardous materials incidents involving commercial motor vehicles (CMV). The goal of MCSAP is to reduce CMV-involved crashes, fatalities, and injuries through consistent, uniform, and effective CMV safety programs.

Many sources of funding are available to resourceful transportation safety professionals. Sometimes understanding the regulations associated with the funding can be challenging. The following section addresses the most common funding allocation issues and provides examples of what states have done to meet those challenges.

5.3 FUNDING ALLOCATION ISSUES

The impact of HSIP funding allocations on state programs is not always as clear-cut as it may appear from reading the legislation. While the issues are complicated and can provide challenges, they can often be overcome through collaboration and innovative solutions.

As an example, a flexible funding provision in SAFETEA-LU allows states to use a portion HSIP funds for noninfrastructure projects if the state has adopted a strategic highway safety plan and certified all safety infrastructure and railway-highway crossing needs have been met. The HSIP flexible funding provision allows states to transfer up to 10 percent of the HSIP funds to noninfrastructure projects identified in the SHSP, including projects to promote public awareness and educate the public concerning highway safety matters and projects to enforce highway safety laws.

A study focusing on HSIP implementation following SAFETEA-LU found many states could not meet the certification requirement because of ongoing infrastructure needs and concerns about potential legal liability a state could incur by certifying all its infrastructure safety needs have been met; however, states working closely with their FHWA Division Offices have been able to certify the needs have been met and successfully flexed some of their HSIP funds.

State Allocation Issues

A primary allocation issue involves "best use of funds" versus "eligibility." To qualify as an eligible highway safety improvement project under Section 148, a project must be described in the state strategic highway safety plan and correct or improve a hazardous road location or feature, or address a highway safety problem.

Safety engineers and their managers should employ a proactive approach in allocating HSIP funding for projects. The following tactics will help move projects forward, while optimizing the use of safety funds:

- Use a data-driven process to identify projects for which HSIP funds are allocated.

- Collaborate with stakeholders, decision-makers, and within the agency to help generate internal and external support.

- Provide clear and continuous communication to educate decision-makers and the public about the importance of safety and the successes achieved.

Making use of these practices also will help avoid potential allocation issues such as the following:

- HSIP funds are not spent on safety or not spent at all due to management decision-making processes.

- Management believes all infrastructure projects improve safety, resulting in safety funds being used for purposes other than addressing the specific safety problems identified through data analysis. Examples include using the safety funds to pay for safety elements (e.g., guardrail, lighting, etc.) on projects not identified as part of the HSIP.

- HSIP funds are used to make up the difference between obligation authority and obligation limitation.

State Solutions

Some agency decision-makers have considerable discretion on proportional allocation and eligibility. When a single activity accomplishes multiple purposes (e.g., pavement preservation and improved safety), these agencies attribute the cost associated with each improvement to the appropriate program. Lack of flexibility encourages delivery of only single-purpose projects. The ability to distribute the cost of a single project to multiple funding programs is an important asset when allocations are not restricted legislatively by eligible expenditures and amounts.

Safety engineers who are successful in making the case to "put the money on the road" use the following strategies to expedite the implementation of safety projects:

- Program safety projects by line items in the STIP, also referred to as "lump sum programming," which allows for flexibility in moving projects forward.

- Bundle multiple projects to save on time and resources when letting projects for bid.

- Mainstream safety elements (e.g., guardrail, rumble strips, edgeline on horizontal curves, etc.) into the overall construction program; hence, the projects are separated from the HSIP, which frees up resources.

- Expedite a safety project by qualifying for a categorical exclusion (CE), which eliminates the need for an environmental assessment or environmental impact statement under the National Environmental Policy Act (NEPA). Projects may be eligible for a CE if they do not pose a significant impact on the human environment. Examples of such projects are included in 23 CFR 771.

- Streamline contract negotiations by utilizing indefinite delivery/indefinite quantity (IDIQ) or task order contracts. These contracts are awarded to a selected company or companies for a base period of time and provide minimum and maximum limits for services in dollar values.

- Use force account construction for small projects. If agencies can document a finding of cost-effectiveness, they can use their own workers for the project and forego the procurement process.

- Integrate safety improvements into resurfacing and restoration projects, which may be an effective and efficient method for simultaneously pursuing infrastructure and safety goals.

Once funding sources have been identified, the next step in implementing prioritized safety projects is to include them in the statewide transportation improvement program.

5.4 PROGRAMMING PROJECTS

The statewide transportation improvement program (STIP) is the financial programming document for the state. It represents a commitment of the projects and programs that will be implemented throughout the state using Federal-aid transportation and transit funding.

For most categories of transportation projects, FHWA/FTA funds cannot be used unless the project is included in a fiscally constrained STIP. Safety projects funded under 23 U.S.C. 104(b)(5) must be included in the STIP.

- The STIP must identify reasonably available or committed revenue to match the estimated costs of the strategies included in the STIP.

- The STIP identifies implementation timing for specific projects and must cover a period of at least four years.

- The STIP must be fiscally constrained; however, a financial plan is optional.

- The FHWA/FTA must approve the STIP before STIP projects can proceed to implementation.

In urbanized areas with populations over 50,000, MPOs develop a transportation improvement program (TIP) which is the programming document for the metropolitan planning area. The TIP identifies the projects and funding to be implemented to reach the vision for the metropolitan area's transportation system and services. The TIP represents a commitment of the projects and programs that will be implemented in the metropolitan planning area using local, state, and Federal-aid funds. TIPs are incorporated directly, without change, into the STIP.

Amendments to the STIP are common given the frequent changes in engineering practices, environmental issues, contracting issues, project readiness, and other factors that can require adjustments to project schedules and budgets.

Improvements listed in the STIP may be by location or improvement type. For example, several low-cost safety enhancements could be grouped together and listed as various safety improvements with an estimated cost and funding source identified.

Once projects have been programmed, they can move forward into design and construction. However, since the HSIP is a data driven process, it is important to first develop an evaluation plan.

5.5 EVALUATION PLAN DEVELOPMENT

Well-designed evaluations reduce agency reliance on professional judgment by providing quantitative information on the impacts of highway safety improvements. Evaluation plans should always be considered prior to implementing any project or program.

The level of detail will depend upon the scope and complexity of the project or program. Following are typical steps in developing the evaluation plan:

- Write a statement defining the purpose(s) of the evaluation;
- Define the target population (e.g., facility, crash types, etc.);
- Clearly state goals, objectives, and performance measures;
- Define data needs based upon performance measures;
- Determine budget, staff, materials and other resource needs;
- Determine what method(s) will be used for collecting the information;
- Identify an evaluation timeline and milestones; and
- Identify the type of evaluation(s) and analyses to be used (e.g., design and combination of quantitative and qualitative analyses).

Rather than being considered an integral part of the HSIP process, evaluations are often an after thought. As a result, the opportunity to collect critical baseline data may be lost thereby compromising the effectiveness of the evaluation. Agencies should consider establishing evaluation guidelines to reinforce their commitment to evaluation, provide consistency, and improve the quality of evaluations.

5.6 SUMMARY

Understanding HSIP funding requirements and sources, as well as potential allocation issues and solutions will assist in a smooth transition into the HSIP implementation process. While incorporating safety into programs and projects may be challenging, states are proving it is possible to implement countermeasures that demonstrate safety benefits even with limited resources. Development of an evaluation plan, prior to implementing the project, will help agencies identify the appropriate data to collect and use in the next phase of the HSIP process – evaluation. The evaluation component of the HSIP process is critical as it documents the effectiveness of projects and programs and provides feedback to improve future project and program planning and implementation.

6.0 Evaluation

The ultimate measure of success for the HSIP is a reduction in motor vehicle related crashes and the resulting fatalities and serious injuries. SAFETEA-LU established the HSIP as a core program and nearly doubled the funds for infrastructure safety. With the increased funding also came a required focus on results, which further heightens the importance of the state's procedures for evaluating individual projects and programs, as well as the overall HSIP program.

The goal of evaluation in the HSIP process is for agencies to estimate the effectiveness of highway safety improvements. The evaluation process reveals if the overall program has been successful in reaching performance goals established in the planning process, including its effectiveness in reducing the number of crashes, fatalities, and serious injuries or the potential for crashes. Evaluation results should flow back into the various HSIP components to improve future planning and implementation, ensure resources are used effectively, and increase the effectiveness of future safety improvements.

Unit 6 discusses project and program evaluations. It addresses CMFs, evaluation studies, program evaluation methods, and using evaluation feedback to impact future safety planning and decision-making. The unit does not detail statistical and economic assessment methodologies to determine the effectiveness of HSIP projects or programs in achieving their goals; these methodologies are addressed in the HSM.

6.1 PROJECT EVALUATION

Evaluation is critical to determine if a specific project or group of projects is achieving the desired results and to ensure the investments have been worthwhile. The evaluation will provide a quantitative estimate of the effects on safety of a specific countermeasure, project, or group of projects. The evaluation results can provide valuable information for future planning. For example, the evaluation of a particular countermeasure can be used to determine if it should be used at more sites.

The evaluation may include determining the effectiveness of:

- A single project at a specific location or site;
- A group of similar projects; or
- A group of projects to quantify a CMF for a particular countermeasure.

The evaluation must be stated in terms related to the desired results. If the goal is to reduce the hazard to pedestrians at an intersection, at least one of the performance measures must gauge the affect on pedestrian-related crashes.

Agencies should identify actionable and measurable performance goals (e.g., reduce the number of fatalities and serious injuries) for the evaluation.

A basic task of project evaluation is to measure conditions, including the performance measures, both before and after a change is made. The effectiveness of the change is determined by comparing change in the value of the performance measure (e.g., frequency or rate of crashes) with the *change which would have been expected if the site had not been treated.* This approach is appropriate whether one is evaluating the application of strategies at a site or subjects (e.g., drivers). The challenge is estimating the change in the performance measure without a treatment. It is especially difficult because all other things do not remain equal as noted earlier. Since crash rates can vary significantly from year to year, crash estimates are susceptible to regression to the mean (RTM).

Developing Crash Modification Factors

In addition to project specific evaluations (single or multiple sites), agencies can use the results of evaluation studies to develop state-specific CMFs. By developing their own CMFs, states will have a more accurate indication of the countermeasure effects. Using a CMF developed by another agency does not necessarily account for actual driver, roadway, traffic, climate, or other characteristics in a state and may over or underestimate the effectiveness of a countermeasure. In addition, the methodology used by another agency to develop a CMF may be uncertain. Developing state-specific CMFs not only allows a state to evaluate the effectiveness of their efforts, it also verifies their efforts are working to improve safety.

As previously discussed in Unit 3, a CMF is the ratio of the expected number of crashes with a countermeasure to the expected number of crashes without a countermeasure.

$$CMF = \frac{Expected\ crash\ frequency\ with\ treatment\ 't'}{Expected\ crash\ frequency\ with\ conditions\ 'a'} = \frac{E_t}{E_a}$$

Where:

    CMF = CMF for treatment "t" implemented under conditions "a";

    E_t = the expected crash frequency with the implemented treatment; and

    E_a = the expected crash frequency under identical conditions but with no treatment.

When developing CMFs, it is not recommended to use data from only one site because it may overestimate the effectiveness of a change. It is best to use data from a minimum of 10 to 20 sites, as it is less biased and will produce a more reliable result.

Some states already develop their own CMFs based on past HSIP projects. Other states refine CMFs (or crash reduction factors) to account for local road conditions, crash severity, injury severity, collision manner, and weather condition. Lastly,

other agencies use before/after EB analysis to revise CMFs, and use these factors to analyze and prioritize new programs and projects.

This section demonstrates the various evaluation methods that can be used to determine the effectiveness of a single project at a specific site or a group of similar projects, and also provides information related to calculating CMFs.

Evaluation Methods

The three basic types of evaluations used to measure a safety improvement are:

1. Observational before/after studies;

2. Observational cross-sectional studies; and

3. Experimental before/after studies.

Observational studies are more common in road safety evaluation because they consider safety improvements implemented to improve the road system, not improvements implemented solely to evaluate their effectiveness. Conversely, experimental studies evaluate safety improvements implemented for the purpose of measuring their effectiveness.

The remainder of the project evaluation section will outline these three evaluation methods.

Observational Before/After Studies

Observational before/after studies are the most common approach used in safety effectiveness evaluation. An observational before/after study requires crash data and volume data from both before and after a safety improvement. These studies can be conducted for any site where improvements have been made; however, if a site was selected for an improvement because of an unusually high-crash frequency, evaluating this site may introduce the RTM bias.

Simple Before/After Evaluation

An observational before/after study conducted without consideration to non-treatment sites is referred to as a simple before/after evaluation. Figure 6.1 demonstrates a simple before/after evaluation.

In this figure and the series of figures that follows, the y-axis represents the value of the performance measure (e.g., number of crashes, number of fatalities, etc.), and the x-axis represents the time increment of the performance measure data (e.g., monthly, annually, etc.). The period between before and after measurements is shown by the vertical line, which can range from instantaneous (e.g., where the change may be a law coming into effect), to more than a year (e.g., where a period is required for construction and adjustment of traffic).

In a simple before/after evaluation, the average value of the performance measure for all treatment sites remains unchanged in the after period, as shown by the dashed line. The assumption is the expected value would remain the same as in the before period. This simplifying assumption weakens the ability to conclusively say the difference measured in the after period was due solely to the applied treatment. This approach is not recommended, and has sometimes been referred to as a naïve method.

Figure 6.1   Simple Before/After Evaluation

Performance Measure

Observed Value Before Period without Treatment

*B*without

Estimated Value After Period without Treatment

*A*without

$$CMF = \frac{A_{with}}{A_{without}}$$

*A*with

Observed Value After Period with Treatment

Time

Before Period without Treatment   **After Period with Treatment**
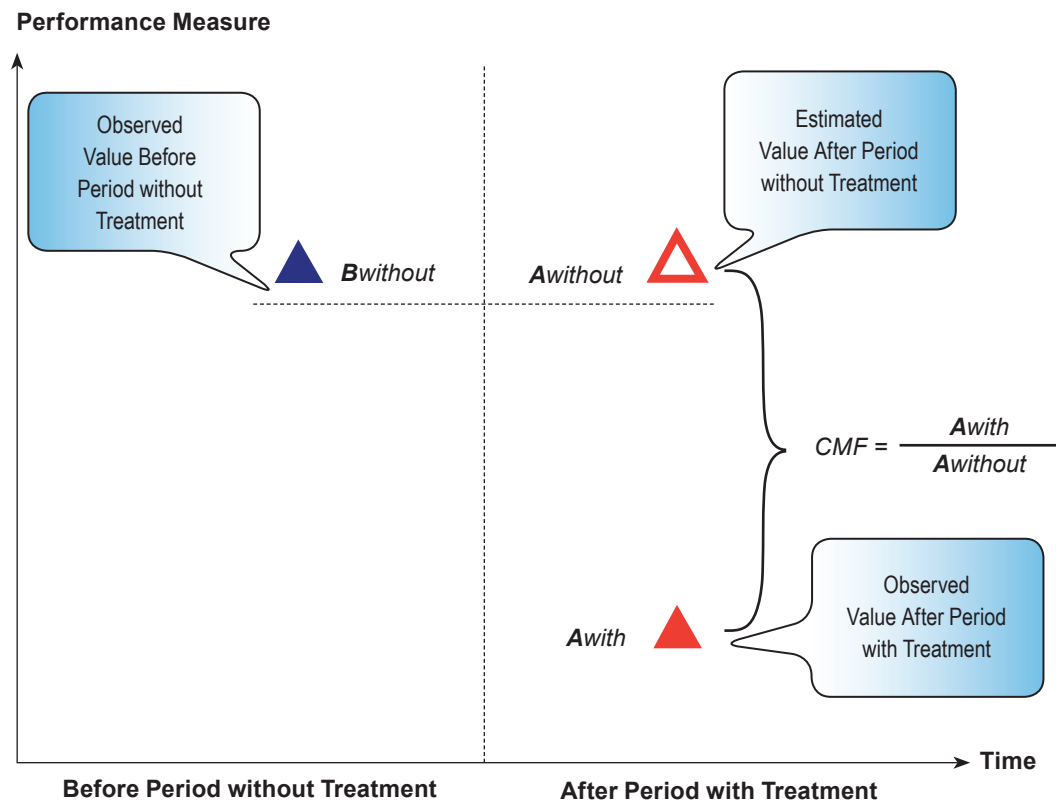
As shown in Figure 6.1, a CMF can be developed using a simple before after study by taking the ratio of the observed value of the performance measure in the after period with the treatment to the estimated value of the performance measure in the after period without the treatment. However, this is not a preferred method for developing CMFs.

Observational before/after evaluations can incorporate nontreatment sites by using the EB method or by using a comparison group. These methods are preferred over a simple before/after evaluation.

Observational Before/After Evaluation Using Empirical Bayes Method

Incorporating the Empirical Bayes (EB) method into a before/after study compensates for the RTM bias. The EB method can be used to calculate a site's expected crash frequency "E." The EB analysis requires AADT and crash data

for the treatment site for both before and after the treatment was implemented. The SPF, discussed in Unit 2, is incorporated into the EB analysis to determine the average crash frequency at similar sites. The sites expected crash frequency can be calculated is as follows:

$$E = \textbf{Weight} \times \mu + (1 - \textbf{Weight}) \times \textbf{Count of crashes on this entity}$$

Where: $Weight = \dfrac{1}{1 + (\mu \times Y)/\varphi}$

μ = SP = The average number of crashes/(mile-year) on similar entities (determined from SPF);

Y = Number of years in evaluation period; and

φ = Overdispersion parameter estimated per unit length for segments (calculated in the development of the SPF).

The EB method pulls the crash count towards the mean, accounting for RTM bias. Figure 6.2 illustrates how the observed crash frequency and the predicted crash frequency are combined to calculate a corrected value, which is the expected crash frequency using EB. The expected crash frequency will lie somewhere between the observed crash frequency and the predicted crash frequency from the SPF.

The reliability of the data affects the "weight." The more reliable the data is, the more weight will go to the data; conversely, the less reliable the data is, the more the weight will go to the average.

The standard deviation of the estimated expected crash frequency can be calculated as follows:

$$\sigma = \sqrt{(1 - Weight) \times E}$$

Figure 6.2   Empirical Bayes Method
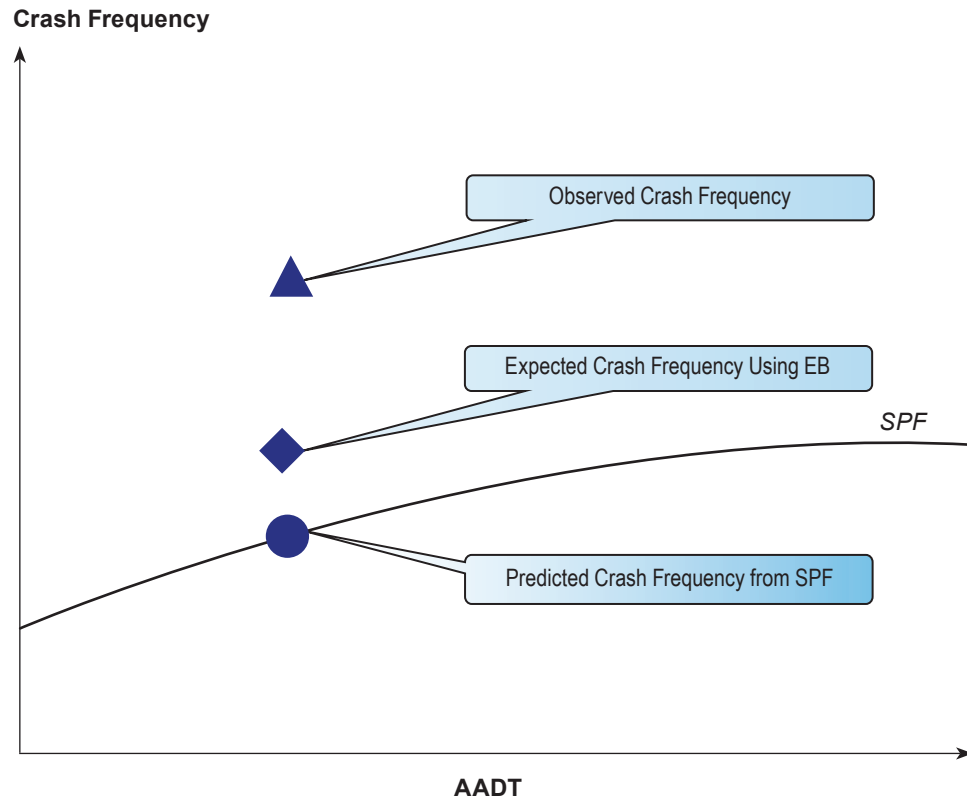
Crash Frequency

The following is an example application of the EB method to estimate the expected crash frequency (Hauer, 2001):

Given a 1.1-mile road segment with annual crash counts of 12, 7, and 8 over a three-year time period and an ADT of 4,000 vehicles per day (for all three years). The safety performance function for similar roads is $0.0224 \times ADT^{0.564}$ crashes per mile-year with an overdispersion parameter $\varphi = 3.25$ per mile. The expected safety of the road is estimated as follows:

1. Calculate the predicted crash frequency for entities of this kind using the SPF:

   μ = 0.0224x4000$^{0.564}$ crashes/(mile-year) = 2.41 crashes/(mile-year).

   On the 1.1-mile segment in three years we can expect:

   2.41 crashes/(mile-year) x (3 years) x (1.1 mile) = 7.95 crashes.

2. Calculate the Weight:

   A "weight" is needed for joining crash counts to average count from Step 1.

   $$Weight = \frac{1}{1+(\mu \times Y)/\varphi} = \frac{1}{1+(2.41+3)/3.25} = 0.375$$

3. Estimate the expected crash frequency:

   $$\text{E} = Weight \times \mu + (1 - Weight) \times Count\ of\ accidents\ on\ this\ entity$$

   E = 0.375 x 2.41 + (1-0.375) x (12 + 7 + 8) = 17.78 crashes in three years.

With a standard deviation:

$$\sigma = \sqrt{(1-Weight) \times E} = \sqrt{(1-0.375) \times 17.78} = 3.35\ \text{crashes in three years}$$

The expected number of crashes is 17.78 ± 3.35 crashes in three years or 5.39 ± 1.01 crashes/(mile-year).

Figure 6.3 illustrates an observational before/after evaluation using the EB method. In the before period, the SPF is used to calculate the predicted value without the treatment, and then the observed value and the predicted value from the SPF are used to calculate an expected value. In the after period, the predicted value with the treatment is calculated using the SPF. The expected value in the after period without the treatment is then calculated by taking the ratio of the predicted values from the SPFs of the after "with" treatment to the before "without" treatment, and then multiplying this ratio by the expected value in the before period without the treatment. The expected value for the after period without the treatment can then be used to calculate a CMF by dividing the observed value in the after period with the treatment by this value.

Figure 6.3   Before/After Evaluation Using the EB Method

Performance Measure

Before Period without Treatment   **After Period with Treatment**
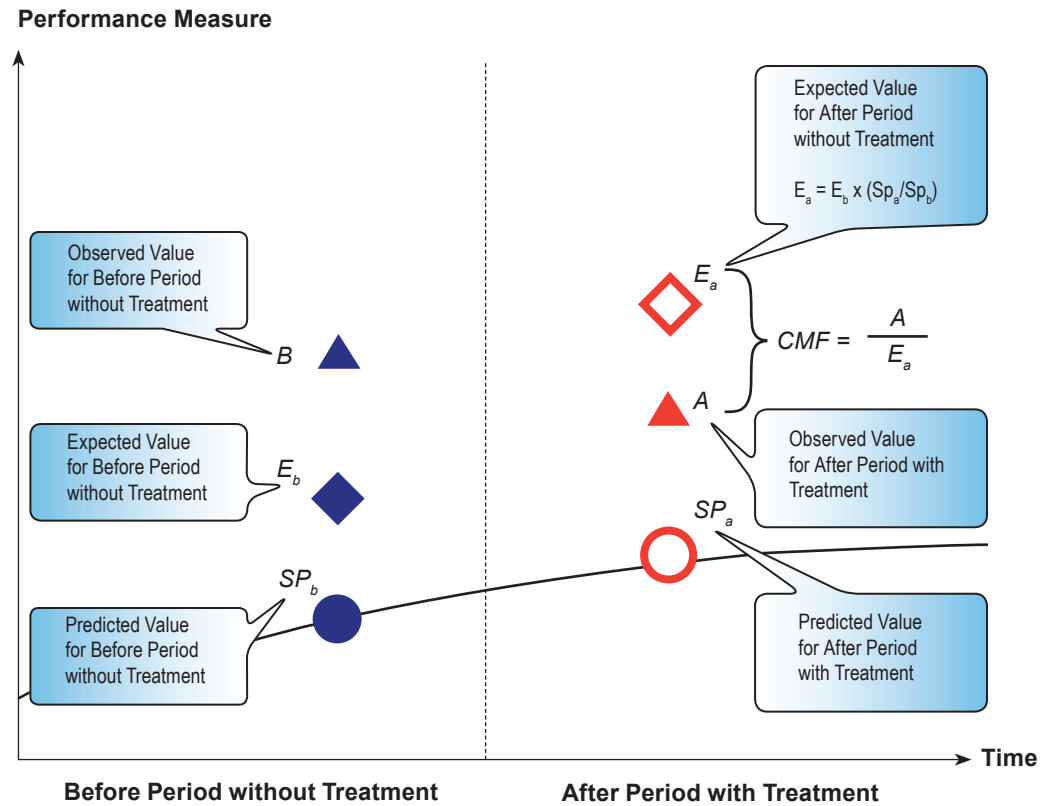
The EB method can be used by agencies to evaluate countermeasures and to calculate CMFs for specific sites as demonstrated in the following example.

Using the same 1.1-mile road segment from the previous example, a countermeasure was implemented to improve safety on the roadway. For the three years following the implementation of the countermeasure, the observed crash experience was 4, 7, and 5 crashes per year with an ADT of 4,200 for each year. The CMF for this project is calculated as follows:

1. In the previous example, we already calculated the predicted crash frequency using the SPF and the expected crash frequency using EB, so the first step is to calculate the predicted crash frequency in the after period using the SPF (for simplicity purposes, the same SPF is used without adjustments):

    $\mu = 0.0224 \times 4200^{0.564}$ crashes/(mile-year) = 2.47 crashes/(mile-year).

    On the 1.1-mile segment we can expect:

    2.47 crashes/(mile-year) x (3 years) x (1.1 mile) = 8.17 crashes.

4. Next we calculate the expected crash frequency in the after period:

$$\mathbf{E_a} = \mathbf{E_b} \times \left(\frac{\mu_a}{\mu_b} \right) = \mathbf{E_b} \times \left(\frac{\mathbf{SP}_a}{\mathbf{SP}_b} - \right) = 17.78 \times \left(\frac{8.17}{7.95} \right) = 17.65$$

5. Finally we calculate the CMF:

$$\mathbf{CMF} = \frac{\mathbf{A}}{\mathbf{E_a}} = \frac{(4+7+5)}{17.65} = 0.91$$

Observational Before/After Evaluation Using a Comparison Group

Observational before/after studies can incorporate nontreatment sites into the evaluation by using a comparison group (or control sites). A comparison group typically consists of nontreated sites comparable in traffic volume, geometrics, and other site characteristics to the treated sites which do not have the improvement being evaluated. Crash and traffic volume data must be collected for the same time period for both the treated sites and the comparison group.

A valid comparison group is essential for conducting an observational before/after study using a comparison group. There should be consistency in the rate of change in crashes from year to year between the treatment sites and the comparison group, which is generally determined using a statistical test (refer to the HSM for detailed information on statistical tests).

The comparison group is used to estimate what would have happened if no treatment had been implemented. Figure 6.4 demonstrates the use of a comparison group.

Figure 6.4   Before/After Evaluation Using a Comparison Group
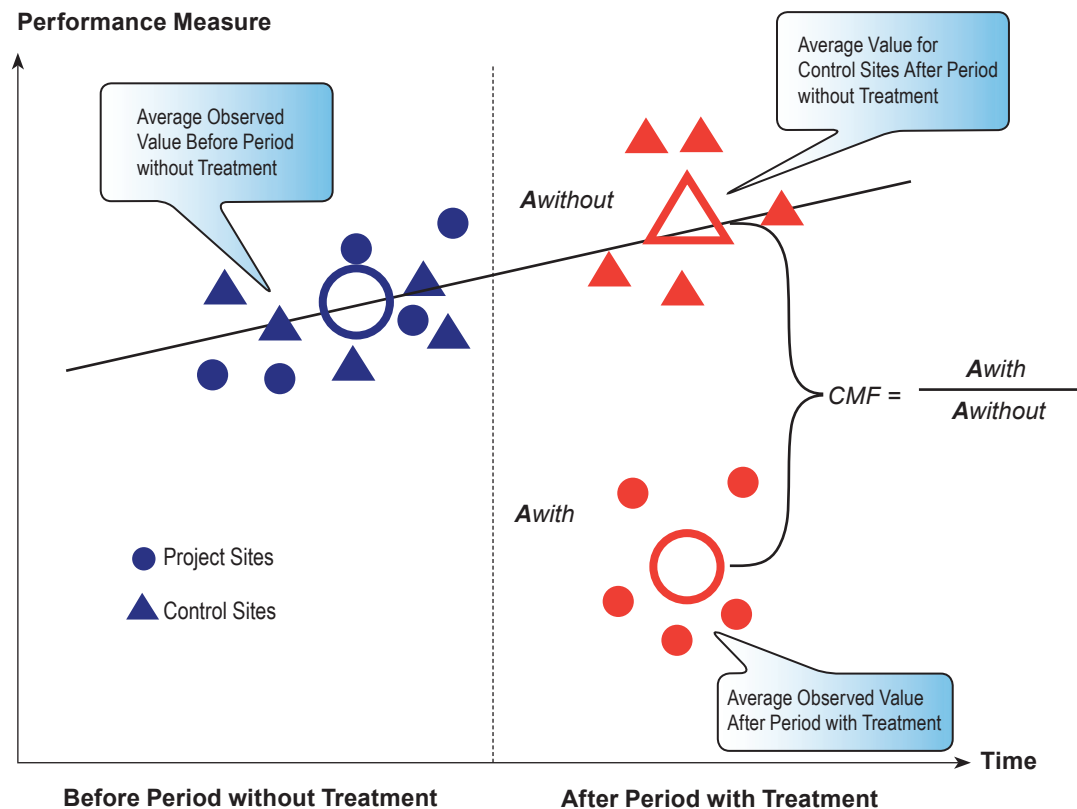
Similar to the previous figures, the period between before and after measurements is shown by the vertical line. With a comparison group, similar measurements are taken for both the comparison group and the sites being treated in both the before and after periods.

The values for the performance measure at the control sites are used to predict what would have happened if no change had occurred at a treatment sites. Figure 6.4 demonstrates how a change at the comparison sites could be estimated by using averages for the before and after period. It also shows individual site values may be used to perform a regression or trend analysis. Several statistical techniques are available to do this, some more "sophisticated" than others (the statistical techniques are described in the HSM). The choice of which technique to use is dependent upon the resources and time available to complete the evaluation, as well as the nature and significance of the treatment.

Figure 6.4 illustrates how a comparison group evaluation can be used to develop a CMF. The CMF is developed by dividing the average observed value of the performance measure for the project sites in the after period by the average observed value for the control sites in the after period.

In some cases, adequate comparison sites will not exist. An example would be what occurs as a result of a change in a state or Federal law intended to impact driving behavior (e.g., the national maximum speed limit, or lowering of the blood alcohol concentration (BAC) limit which defines DUI). In such cases, all sites or subjects which can be considered similar come under the category of "treated." While not covered in this Manual, statistical procedures are available for conducting trend analyses which may be applied to this situation.

Observational Cross-Sectional Studies

In some cases, evaluations have been performed only after the fact, and data were not available for the performance measure during the before period. This might be necessary when:

- Treatment installation dates are not available;

- No crash and traffic volume data are available for the period prior to treatment; or

- The evaluation needs to explicitly account for effects of roadway geometrics or other related features by creating a CMF function, rather than a single value for a CMF.

In these cases, a cross-sectional study is often used. As demonstrated in Figure 6.5, the studies only measure the "after" period. Control sites or subjects are chosen to compare with the treated site(s). The assumption is the average value of the performance measure for all similar sites would be the same, so any difference among the averages would be due to the application of the strategy(ies) at the sites, or to the subjects. This approach is commonly referred to as a "with and without study."
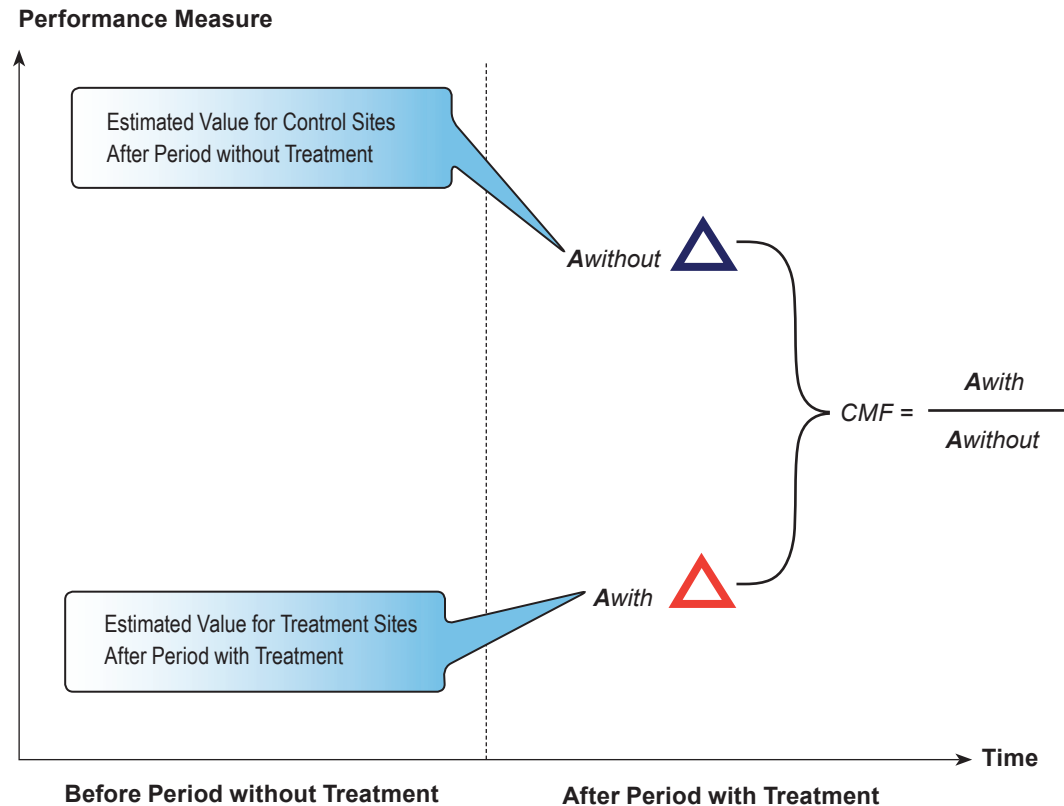
Figure 6.5   Cross-Sectional Evaluation

Figure 6.5 illustrates how a CMF is developed using an observational cross-sectional study. The CMF is the ratio of the estimated value of the performance measure for the treatment sites to the estimated value of the performance measure for the control sites.

Limitations exist when using a cross-sectional study. This approach limits the ability to be confident in the conclusions since trends over time are not taken into account. This method does not account for RTM, which threatens the validity of the results, especially if the treated sites were selected because they were identified as high-hazard locations. In addition, it is usually quite difficult to find control sites or subjects about which, or whom, it can be said there is true similarity, for the purposes of the evaluation.

Even in a well-designed evaluation, care should be taken to differentiate between the documented change and assumptions regarding the causes of the change. The stronger the evaluation, the more confident the evaluator can be that the strategies employed to improve safety brought about the change. However, limits to the confidence one can have exist, both of the type which can be measured statistically and due to the inability to account for the myriad of factors which may be present.

Experimental Before/After Studies

Experimental studies are those in which comparable sites with respect to traffic volumes and geometric features are randomly assigned to a treatment group or nontreatment group. In these studies, crash and traffic volume data is obtained for time periods before and after the treatment for the sites in the treatment group. Optionally, data also may be collected from sites in the nontreatment group during the same time period. One example of an experimental study is evaluation of the safety effectiveness of a new signing treatment.

The RTM bias is reduced in an experimental study compared to an observational study because of the random assignment of sites to the treatment or nontreatment groups. However, experimental studies are rarely used in highway safety due to the reluctance to randomly assign locations for improvements. This reluctance is largely due to budget and potential liability issues; however, a negative connotation may also be associated with denying improvements to certain populations or locations.

Data Needs for the Evaluation Methods

The necessary data will vary based on the evaluation method chosen. Table 6.1 summarizes the minimum data requirements for each study type.

Table 6.1   Safety Evaluation Method Data Requirements

Data Needs and Inputs	Safety Evaluation Method			
	EB Before/After	Before/After with Comparison Group	Cross-Sectional Study	Experimental Before/After
10 to 20 treatment sites	●	●	●	●
10 to 20 comparable nontreatment sites		●	●	
3 to 5 years of crash and volume data from before treatment	●	●		●
3 to 5 years of crash and volume data from after treatment	●	●	●	●
SPF for treatment site types	●	●		
SPF for nontreatment site types		●		

Source: Highway Safety Manual, First Edition, Draft 3.1, April 2009.

Although a step-by-step process has not been provided for each of these methods, the HSM provides details on how to conduct each of these evaluations, and includes examples. Additional references on the techniques to use for highway safety evaluation and the EB method are included in the Resources section at the end of this document.

Agencies can use the safety effectiveness evaluations presented in this section to evaluate an individual project, group of projects, or a particular countermeasure. Cumulatively, the results of these evaluations feed into the assessment of the overall program.

6.2 PROGRAM EVALUATION

Agencies conduct program-level evaluations to assess the HSIP's contribution in reaching established performance goals. Section 1.7 addressed setting performance goals and more specific performance measures to determine the effectiveness of countermeasures and how changes in the system will affect performance. Now that the program has been implemented, it is time to analyze the data to determine the overall effectiveness of the HSIP and individual HSIP subprograms.

Assessing Overall HSIP Success

Agencies can utilize several different methods for assessing the overall success of their HSIP. States should perform evaluations that are most meaningful to them. Several common methods for measuring overall program success include, but are not limited to, process output and outcome performance measures, general statistics, trend analysis, benefit/cost analysis and safety culture. Each of these methods are described in more detail below.

Process Output and Outcome Performance Measures

One basic program evaluation method uses a compilation of output and outcome performance measures as a means to measure HSIP progress.

- Process performance measures identify the progress in utilizing resources, such as the total number of projects, total funding, and related output measures (e.g., the number of traffic signals installed or the number of intersections with improved pavement markings, etc.).

- Outcome performance measures are focused on the results of the program. General statistics (e.g., the number of crashes and crash rates), trend analysis, and benefit/cost analysis measure outcomes of performance.

General Statistics

Agencies typically calculate crashes and crash rates (crashes per million vehicle-miles traveled) which are summarized by fatal crashes, injury crashes, property damage only crashes and total crashes. As an example, Figure 6.6 summarizes the annual fatal crashes by facility type. This summary is useful for determining if the program has been successful in reducing fatalities on particular roadway types.

Figure 6.6   General Statistics

Number of Fatal Crashes   **Fatal Crashes by Facility Type and Year**

	Rural	Rural	Rural	Rural	Rural	Rural	Urban	Urban	Urban	Urban	Urban	Urban
	Interstate	Other	Minor Arterial	Major Collector	Minor Collector	Local Road	Interstate	Frwy/ Xprwy	Other	Minor Arterial	Collector	Local Road
■ 2004	26	27	34	114	27	126	34	11	46	75	41	77
□ 2005	24	25	39	111	37	112	26	7	71	68	45	53
□ 2006	22	37	35	106	41	127	37	11	60	70	35	66
□ 2007	18	24	41	114	27	181	44	10	58	80	40	65
□ 2008	26	33	32	96	18	186	52	9	49	44	15	74

Trend Analysis

Another method for measuring overall program success is to identify the crash trends for each of the agency's focus areas. In this case, the established performance goal(s) are compared to the actual number of crashes for the past five-year period (although longer is preferred to better identify the trend). As an example, if one of the goals is to reduce the fatality rate by 50 percent by 2010, the trend rate can be determined by plotting the annual fatality rates as shown in Figure 6.7. The slope of the trend line identifies the average annual change in fatality rates.

Figure 6.7   Trend Analysis

Fatality Rate/100 Million VMT

Annual Fatality Rates
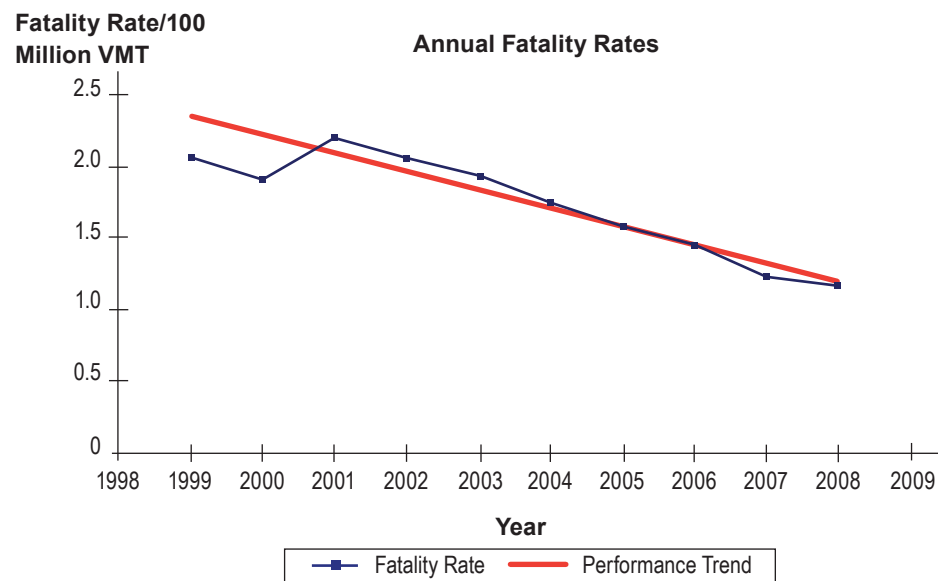
Trend lines help identify if the actual number of crashes each year is better or worse than would be expected if the trend stayed the same from year to year. In Figure 6.7, the end year data point is below the trend line, meaning the trend in fatality rates is better than would be expected had all other things been equal. Studying crash trends provides an indication of overall safety performance. However, since it is possible various programs or actions were causing this decline, additional evaluation of individual programs within the HSIP are beneficial for identifying which aspects of the program had the most impact on reducing fatalities.

Benefit/Cost Analysis

Conducting a benefit/cost analysis of all HSIP-related projects provides another indicator of overall HSIP success. To conduct a benefit/cost analysis for the overall HSIP program, add the present value of the benefits for all HSIP projects together to get an overall benefit and add the present value of all of the project costs to get an overall cost. The benefit/cost ratio is calculated by dividing the present value of the overall program benefits by the present value of the overall program costs (Section 4.2 of this manual discusses benefit/cost analysis in detail). If the benefit/cost ratio is greater than one, the benefits of the program have outweighed the costs, and it provides some indication the program has shown success in improving safety. Typically, program benefit/cost analysis is conducted using three years data for both before and after implementation of improvements.

Safety Culture

Qualitative measures also may demonstrate the effectiveness and success of the HSIP. For example, successful implementation of HSIP-related programs, strategies, and/or treatments may lead to policy or design standard changes. These policy and design standard changes result in safety treatments being applied across all projects and not just safety-specific projects. This reflects not only a policy-level change, but a shift in the safety culture of the agency.

Evaluating Specific Program Effectiveness

States are expected to focus their HSIP resources on their areas of greatest need and those with the potential for the highest rate of return on the investment of HSIP funds. As the HSIP has evolved, one noteworthy change has been the shift in focus towards evaluation of individual HSIP programs. While it is beneficial to determine the overall effectiveness of a state's HSIP in terms of achieving statewide performance goals; it is just as important to determine the success of specific HSIP-funded programs.

A highway safety program is a group of projects, not necessarily similar in type or location, implemented to achieve a common highway safety goal. Examples of highway safety programs include an established program administered by a Federal agency (e.g., Highway-Rail Grade Crossing Program), a systemic program to address a specific crash type (e.g., lane departures, "drift-off-the-roadway" crashes), and a speed management program combining engineering, enforcement, emergency response, and public education strategies designed to address a Strategic Highway Safety Plan (SHSP) emphasis area of speed-related crashes on selected rural road corridors.

Identifying programs that have the least amount of impact on the performance goals can result in subtle changes, such as new or additional treatments to move the program toward its intended purpose. Alternatively, implementation of successful programs and treatments implemented as part of the HSIP should continue.

Measures of program effectiveness include observed changes in the number, rate, and severity of traffic crashes resulting from the implementation of the program. Program effectiveness is also examined with respect to the benefits derived from the program given the cost of implementing the program.

The following examples of program evaluations provide an overview of how an agency might conduct an evaluation of each type of highway safety programs. Other examples of program evaluation criteria might better demonstrate the success of HSIP-related program.

SHSP Emphasis Areas

Similar to determining overall HSIP effectiveness, overall SHSP success can be seen in the crash trends for each of the emphasis area performance measures (i.e., fatalities and serious injuries, all crashes). Figure 6.8 illustrates a summary of statewide fatalities by SHSP emphasis area.

**Figure 6.8   SHSP Emphasis Area**

Statewide Fatalities by SHSP Emphasis Area
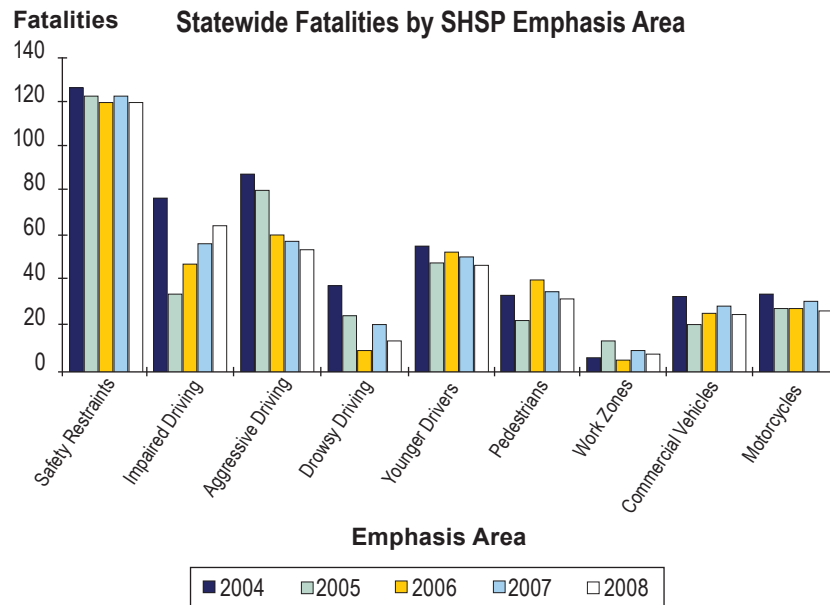
HSIP Subprograms

The evaluation process also must assess if the HSIP contributed to reaching the specific performance goals aligned with the state's SHSP. Programs administered under the HSIP often target subsets of the SHSP emphasis areas or specific strategies (e.g., cable median barrier program or speed management program). States should evaluate the overall effectiveness of these programs.

As an example, if a state has been implementing a median guard cable program for the past several years, trends in cross median crashes should be evaluated. An effective approach is to compare the cross median fatalities to the miles of guard cable installed, as shown in Figure 6.9. This figure demonstrates a decrease in cross-median fatalities as the miles of median guard cable installation increased.

Figure 6.9   HSIP Subprogram
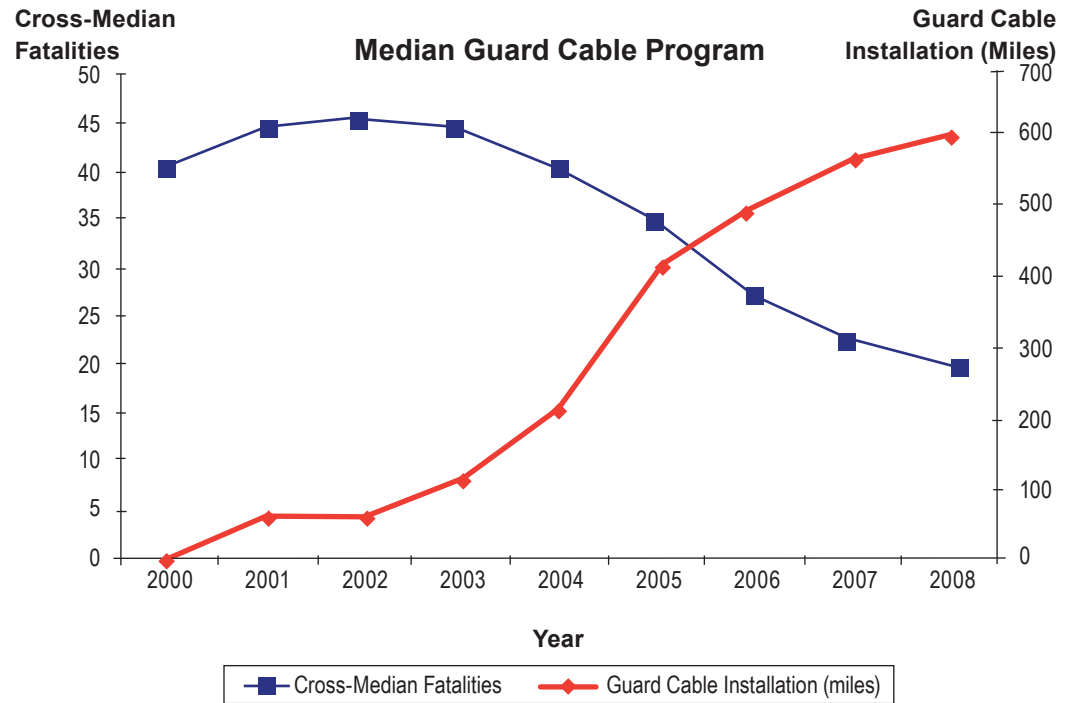
Source: Chandler (2007).

Systemic Treatments

With the increasing move toward systemic application of countermeasures, program evaluations are effective in determining what may be the best and most efficient use of resources to impact statewide fatalities and injuries. For example, if a state agency implemented a "Chevron Warning Sign Program" using HSIP funds to target horizontal curve crashes on a systemic basis, the agency could evaluate the effectiveness of the program based on the reduction in the targeted crash type as shown in Figure 6.10. The agency would report on the effectiveness of the HSIP-funded "Chevron Warning Sign Program" based on the reduction in horizontal curve crashes, and encourage other "off-system" partners to consider this treatment for similar crashes in their jurisdiction.

Figure 6.10   Systemic Treatment

**Number of
Off-Roadway
Fatal Crashes**

Off-Roadway Fatal Crashes
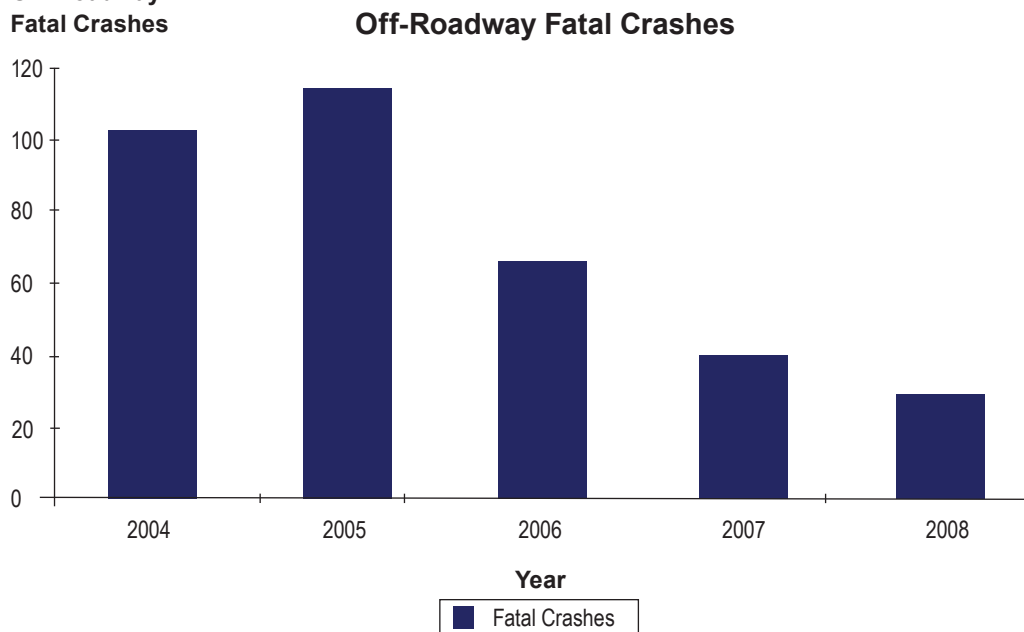
Program Evaluation Challenges

The most common program evaluation challenges are related to data issues and available resources for conducting evaluations. Numerous reports indicate states are making progress in resolving data issues. Resolving resource issues associated with performing evaluations can include training, hiring additional staff, obtaining outside assistance, or identifying additional funding to support the oversight and conduct of the state's evaluation efforts. Resolving data and resource issues will improve future HSIP planning and decision-making.

To identify some of these challenges, it is beneficial to periodically take a step back and conduct an assessment of the HSIP. An assessment allows states to review their HSIP, or elements of the program, to identify noteworthy practices and/or opportunities for improvement. The FHWA Office of Safety provides an HSIP Assessment Toolbox containing tools and resources to aid state DOTs in evaluating their HSIP program and processes. The toolbox provides information on several options available to conduct program assessments. The state can choose a self assessment, program review or peer exchange. States interested in obtaining more information about the HSIP Assessment Toolbox should contact their FHWA Division Office.

It is important to conduct evaluations to determine the overall effectiveness of the HSIP and of individual HSIP programs. However, evaluations can only provide benefit if they are used. The next section discusses the importance of using evaluation results to impact future actions.

6.3 FEEDBACK TO FUTURE PLANNING

Evaluation is a critical element in efforts to improve highway safety. Program and project evaluations help agencies determine which countermeasures are most effective in saving lives and reducing injuries. Agencies also may identify which countermeasures are not as effective as originally expected and decide not to use them in the future. The results of all evaluations should be captured in a knowledge base to improve future estimates of effectiveness and for consideration in future decision-making and planning.

As mentioned previously, states are conducting more rigorous statistical evaluations and refining CMFs based on crash data from past HSIP projects, using before/after EB analysis to revise CMFs, and using these findings to analyze and prioritize new programs and projects. At least one state has implemented a program which moves data from completed projects into a historical file that recalculates the CMFs.

Documentation is critical for the evaluation process. States should document key findings and issues occurring throughout the implementation process. Identifying potential issues and solutions before they occur can ease the implementation of similar programs and projects in the future.

To aid future planning, a state's project analysis should:

- Summarize assessment data reported during the course of the project;

- Analyze both output and outcome performance measures (qualitative and quantitative);

- Evaluate the degree to which goals and objectives were achieved (using performance measures);

- Estimate costs (especially in relation to pre-implementation estimates);

- Document anecdotal material which may provide insight for improving future projects and implementation efforts; and

- Conduct and document debriefing session(s) with persons involved in the project, including anecdotal evidence of effectiveness, and recommended revisions.

Results of a well designed analysis can be fed back into making better estimates of effectiveness for use in planning future strategies.

Project results should be reported back to those who authorized them, and any stakeholders, as well as others in management involved in determining future projects. Decisions must be made on how to continue or expand the effort, if at all. If a program is to be continued or expanded, as in the case of a pilot study, the results of its assessment may suggest modifications. In some cases, a decision may be needed to remove what has been placed in the highway environment as part of the program, due to a negative impact. Even a "permanent" installation (e.g., rumble strips) requires a decision regarding investment for future maintenance, if its effectiveness is to continue.

Evaluation results also can provide justification for changing design standards and department policies. For example, countermeasures proven to be effective at improving safety based on the evaluation could be incorporated into new roadway design standards and included on all resurfacing projects.

One successful program evaluation strategy states employ is to monitoring performance in achieving fatality-reduction goals for specific SHSP emphasis areas and reporting those results periodically to state transportation leaders. By doing so, the evaluation process can lead to outcomes, such as further studies; the implementation of projects; refinement of planning, design, operational or maintenance standards; new practices and policies; and new regulations.

6.4 SUMMARY

The HSIP development process is continuously evolving. States work to improve data deficiencies through their Traffic Records Coordinating Committee (TRCC), which in turn results in more accurate analysis for future programs. States make use of countermeasures proven effective based on project and program evaluations, and incorporate lessons learned into future HSIP and SHSP planning efforts. In combination, all these collaborative efforts result in moving the nation toward our goal of fewer motor vehicle-related fatal and serious injury crashes.

Appendices

A. Multidisciplinary Case Study

Multidisciplinary approaches can be used to improve safety along designated corridors which many states are implementing. In one state, the program began in 1992. Since that time, 32 projects have been launched and 7 completed. Corridor selection criteria include: statistical evidence (established by the state DOT) that a section or set of roadways is experiencing a significant crash problem, local-level support, and low-cost, near-term solutions.

The goal of the corridor safety program is to reduce fatal and disabling collisions on roadways through partnerships with community groups, businesses, engineering, enforcement, education, and emergency services organizations. The safety corridor programs are implemented at the community level.

The state's most noteworthy corridor program encompassed seven miles of roadway located within one city's boundaries. The program's steering committee was comprised of local government agencies, law enforcement officials, emergency response personnel, school districts, and other interested parties.

Law Enforcement
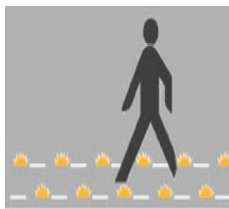
Project funding provided increased traffic patrols focused on crosswalk safety, driving under the influence (DUI) of alcohol or drugs, and red light running. The police department reported 4,147 contacts, 2,539 citations, 149 suspended or miscellaneous criminal violations; 44 DUI arrests, 35 warrant arrests, and 1,667 verbal warnings. (Note: warnings plus infractions is slightly higher than total contacts because some drivers were cited for multiple violations).

Traffic Engineering

The engineering team completed several low-cost, near-term improvements to the corridor, including installation of signs to mark the corridor, improved timing, and upgrades to traffic signals and crosswalks, installation of pedestrian warning lights, and bus stop upgrades.

Public Education

During the project, steering committee members educated the public by hosting a traffic safety fair, making pedestrian safety presentations to area elementary and middle school students, utilizing transit advertising, and distributing pedestrian safety information brochures in English, Spanish, and Russian to residents and businesses.

Results

Results of the two-year effort showed a 19 percent drop in fatal/disabling and injury collisions and a 14 percent decrease in total collisions. Rear end collisions, which were the leading type of collision in the corridor, decreased 10 percent, while drivers failing to yield decreased 44 percent.

The 14 percent reduction in total collisions on this corridor is nearly three times higher than we find on a typical safety corridor project.
DOT Program Manager

B. Resources

Constant evaluation of policies, procedures, engineering judgment, and conventional wisdom lead to new methods for improving road safety. Transportation safety professionals stay knowledgeable in road safety through research, continuing education, and peer networking. The resources below provide additional tools and references for the concepts presented in the unit under which they are listed.

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C. The Haddon Matrix

The Haddon Matrix is commonly used to approach safety analysis at a site in a systematic fashion. Developed in 1980 by William Haddon, the Matrix is a two-dimensional model which applies basic principles of public health to motor vehicle-related injuries. The first dimension is the phase of injury divided into pre-crash, crash, and post-crash. The second dimension is the four factors of injury: human, vehicle/equipment, physical environment, and socioeconomic.

The Haddon Matrix is completed through the evaluation of sites and/or crash details associated with a site or sites. When completed, it provides insight into the range of possible safety issues and concerns as well as possible solutions. This model is an extremely effective tool for not only identifying where and when to implement traffic safety countermeasures, but also planning crash-related data collection, and identifying organizations and agencies for collaboration efforts.

The value of the Haddon Matrix is each cell represents a different area in which interventions can be identified and implemented for transportation system safety improvement. The Haddon Matrix is completed upon examination of crashes for a set of locations or single location under study, and is used to inform the road safety analyst.

For example, the Haddon Matrix below might be constructed from a set of crashes in an urban area. The top-left cell (pre-crash human) identifies potential modifications to driver behavior that may reduce the likelihood or the severity of a collision. As shown in the example table, it is poor vision or reaction time, alcohol consumption, speeding, and risk taking. The matrix in its entirety provides a range of potential issues that can be addressed through a variety of countermeasures, including education, enforcement, engineering, and emergency response solutions (the 4Es of Safety).

Table C.1   Haddon Matrix

	Human	Vehicle/ Equipment	Physical Environment	Socioeconomic
Pre-Crash	Poor vision or reaction time, alcohol, speeding, risk taking	Failed brakes, missing lights, lack of warning systems	Narrow shoulders, ill-timed signals	Cultural norms permitting speeding, red light running, DUI
Crash	Failure to use occupant restraints	Malfunctioning safety belts, poorly engineered air bags	Poorly designed guardrails	Lack of vehicle design regulations
Post-Crash	High susceptibility, alcohol	Poorly designed fuel tanks	Poor emergency communication systems	Lack of support for EMS and trauma systems

D. Glossary

3R is a common term which refers to resurfacing, restoration, and rehabilitation projects.

4Es of Safety refers to the four major categories for addressing road safety; Engineering, Enforcement, Education, and Emergency Medical Services, which have typically been used either as measures to correct existing road safety issues or as crash prevention strategies.

Analysis period refers to a defined period of time for analysis. Crash experience can vary at a location from year to year; therefore, it is important to use more than one year of data for the analysis; generally a minimum of three years is used.

Benefit/cost analysis is a quantitative measure commonly used in prioritizing projects and countermeasures which compares all of the benefits associated with a countermeasure (e.g., crash reduction, etc.), expressed in monetary terms, to the cost of implementing the countermeasure.

Crash Modification Factors (CMF) is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site.

Coefficient of variation is a normalized measure of dispersion of a probability distribution. It is the ratio of the standard deviation to the mean value.

Cost-effectiveness is the amount of money invested divided by the benefit in crash reduction.

Crash Reduction Factors (CRF) is the percentage crash reduction that might be expected after implementing a given countermeasure

Data accessibility is a measure of how easy is it to retrieve and manipulate data in a system, in particular by those entities that are not the data system owner.

Data accuracy is a measure of how reliable the data are, and if the data correctly represent an occurrence.

Data completeness is a measure of missing information, including missing variables on the individual crash forms or underreporting of crashes.

Data integration is a measure of how well various systems are connected or linked.

Data timeliness is a measure of how quickly an event is available within a data system.

Data uniformity is a measure of how consistent information is coded in the data system, and/or how well it meets accepted data standards.

General Estimates System (GES) is a database of a national representative sample of police reported motor vehicle crashes of all types. GES is directed by the National Center for Statistics and Analysis, which is a component of Research and Development in NHTSA.

Highway Performance Monitoring System (HPMS) is a national-level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the Nation's highways.

Interactive Highway Safety Design Model (IHSDM) is a software analysis package that assists engineers with evaluating safety for two-lane rural highway design alternatives.

"KABCO" Injury Scale is frequently used by law enforcement for classifying injuries and also can be used for establishing crash costs. (K – Fatal; A – Incapacitating injury; B – Nonincapacitating injury; C – Possible injury; and O – No injury.)

Overdispersion is a systematic variation in the number of accidents, whenever the variance exceeds the mean. The amount of overdispersion of a data set is described in terms of the overdispersion parameter.

Net Present Value (NPV) is a method which expresses the difference between the discounted costs and discounted benefits of a safety improvement project. The costs and benefits are "discounted" meaning they have been converted to a present value using a discount rate. NPV also is referred to as net present worth (NPW).

Nominal safety refers to whether or not a design or design element meets minimum design criteria based on national or state standards and guidance documents such as the AASHTO Green Book and the MUTCD. Nominal safety does not characterize the actual or expected safety of a roadway.

Quantitative analysis typically involves the identification and comparison of cost, effectiveness, and resilience (how long it is effective) for each countermeasure or program based on the latest research.

Regression to the Mean (RTM) describes a situation in which crash rates are artificially high during the before period and would have been reduced even without an improvement to the site. Variations at a site are usually due to the normal randomness of crash occurrence. Because of random variation, the extreme cases chosen in one period are very likely to experience lower crash frequencies in the next period – the highest get lower and the lowest get higher.

SafetyAnalyst is a set of software tools which utilizes SPFs for evaluating roadway locations and contains over 100 SPFs for various roadway segment types. *SafetyAnalyst* includes modules for identifying locations for potential safety improvement, diagnosis and countermeasure selection, economic appraisal and priority ranking, and evaluation of implemented improvements.

Safety Performance Functions (SPF) are the change in the expected number of crashes as average daily traffic (ADT) or some other exposure measure increases, while all other factors affecting crash occurrence are held constant.

Statewide Transportation Improvement Program (STIP) is the financial programming document for the state representing a commitment of the projects and programs that will be implemented throughout the state using Federal-aid transportation and transit funding.

Substantive safety refers to the actual or expected safety on a roadway.

Transportation Improvement Program (TIP) is the programming document for metropolitan planning areas (urbanized areas with populations over 50,000) that identifies the projects and funding to be implemented to reach the vision for the metropolitan areas' transportation system and services.

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