Road Safety Fundamentals

UNIT 4: Solving Safety Problems

Concepts, Strategies, and Practices that Reduce Fatalities and Injuries on the Road

U.S. Department of Transportation
Federal Highway Administration

Notice

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16. Abstract

This book provides an introduction to the fundamental concepts of road safety. The book's goal is to equip the reader with a broad base of knowledge about road safety. Thus, the focus is in communicating concepts rather than providing instruction in detailed analysis procedures.

The audience for this book is two-fold. First, this is intended for those whose job addresses some aspect of road safety, particularly in a public agency setting. Second, this book is intended for professors and students in a university setting.

This book seeks to lay the foundation of road safety knowledge regardless of a particular discipline. Professionals with a background in engineering, planning, public health, law enforcement, and other disciplines will benefit from the concepts presented here.

17. Key Words			18. Distribution Statement
road safety, road safety management process, site-level management, system level management, human behavior, safety performance measures, road safety data, multidisciplinary approaches			**No restrictions**
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UNIT 4 Solving Safety Problems

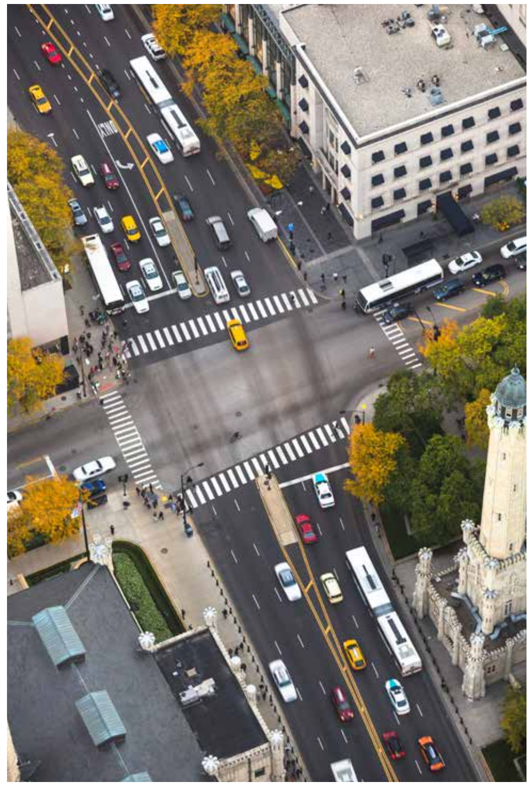
LEARNING OBJECTIVES

After reading the chapters and completing exercises in Unit 4, the reader will be able to:

- **IDENTIFY** three major components of road safety management
- **DEFINE** the process of conducting site-level and system-level safety management
- **USE** safety data to identify safety issues and develop strategies to solving those issues

Road Safety Management

Road safety management refers to the process of identifying safety problems, devising potential strategies to combat those safety problems, and selecting and implementing the strategies. Effective safety management is also proactive and looks for ways to prevent safety problems before they arise. High quality safety data should be used to determine the nature of the road safety problems and how best to solve them. As discussed in Unit 3, the clearest and most readily available indicators of road safety problems are crash data. These data can be used to identify safety problems on a large or a small scale. Other data, such as roadway characteristics, traffic volume, citations, and driver history, can be integrated with crash data to assist in identifying safety trends and high priority locations.



Data quality issues should not prevent a data-driven process

Every transportation agency will acknowledge that it does not have perfect data. All data have issues related to accuracy, coverage, timeliness, and other factors. One agency's crash data may have an incomplete record of low severity crashes. Another agency may have very little data on the traffic volume on low volume rural roads. However, data quality issues should not prevent a transportation agency from using the data to drive its safety management efforts. Even while the agency strives to improve its data, the data on hand should be used in the process of identifying safety problems and devising solutions to those problems.

Data needs for safety analysis

High quality safety analysis demands high quality data. Unfortunately, poor data availability and low quality limit the types of analyses that can be conducted. The data requirements depend on the type of analysis and what safety questions are being asked. Table 4-1 provides examples of various categories of safety analysis and lists the data that would be needed to conduct them.[1]

1 Applying Safety Data and Analysis to Performance-Based Transportation Planning, e-Guidebook, FHWA, http://safety.fhwa.dot.gov/tsp/fhwasa15089/appb.cfm

	SAFETY ANALYSIS QUESTION	DATA NEEDS
BENCHMARKING	How many fatalities and serious injuries are occurring in my area? How does this compare to other areas of my State?	**Total crashes** **Total fatalities and serious injuries** **High-level roadway data** — roadway ownership, functional classification **Agency geographic boundary information**
CRASH TRENDS AND CONTRIBUTING FACTORS	What type of road users are involved in crashes? When are the crashes occurring? What are the major contributing factors to crashes?	**Crash severity** — fatality, injury type, property damage only **Crash incidence data** — time of day, day, month, weather, etc. **Crash type** — road departure, intersection, head-on, angle, etc. **Contributing factors** — age, impairment, seatbelt usage, speed, etc.
SITES FOR SAFETY IMPROVEMENT	What locations (intersections or segments) show the most potential for safety improvements?	**Crash severity** **Crash location** **Roadway and roadside characteristics** — intersection control, number of lanes, presence and type of shoulder, presence and type of median, posted speed, horizontal and vertical alignment, etc. **Traffic volume data** — intersection total entering traffic volume, roadway segment volume per million vehicle miles. **Calibrated safety performance functions**, if predictive methods are used
SAFETY RISK FACTORS	What are the common characteristics of locations with crashes? What are the countermeasures to address these characteristics? How should we prioritize system-wide implementation?	**Crash severity** **Crash location** **Roadway and roadside characteristics** — intersection control, number of lanes, presence and type of shoulder, presence and type of median, posted speed, horizontal and vertical alignment, etc. **Traffic volume data** — intersection total entering traffic volume, roadway segment volume per million vehicle miles.

TABLE 4-1: Safety analysis categories, questions, tools and data needs.

Safety data as performance measures

A transportation agency has many types of data at its disposal for identifying safety problems, but the agency must select which type(s) of data will be the **performance measures** used to identify the road safety emphasis areas. Federal legislation has focused increasingly on fatal crashes and serious injury crashes as performance measures for road safety.

Table 4-2 provides examples of performance measures developed by the National Highway Traffic Safety Administration (NHTSA) and the Governors Highway Safety Association (GHSA) that could be used to identify safety priorities.[2] The sources of the data could be State crash data files, the Fatality Analysis Reporting System (FARS), surveys conducted by the State, or grant applications from law enforcement and other departments. The section on Network Screening in Chapter 11 presents a more detailed discussion of crash-based performance measures and how they can be used to identify sites that are high priority for safety treatment.

DESCRIPTION	SOURCES
Number of traffic fatalities (three-year or five-year moving averages)	FARS
Number of serious injuries in traffic crashes	State crash data files
Fatalities/VMT (including rural, urban, and total fatalities)	FARS, FHWA
Number of unrestrained passenger vehicle occupant fatalities, seat positions	FARS
Number of fatalities in crashes involving a driver or motorcycle operator with a blood alcohol concentration of .08 g/dL or higher	FARS
Number of speeding-related fatalities	FARS
Number of motorcyclist fatalities	FARS
Number of unhelmeted motorcyclist fatalities	FARS
Number of drivers 20 or younger involved in fatal crashes	FARS
Number of pedestrian fatalities	FARS
Observed seat belt use for passenger vehicles, front seat outboard occupants	Survey
Number of seat belt citations issued during grant-funded enforcement activities	Grant activity reporting
Number of impaired-driving arrests made during grant-funded enforcement activities	Grant activity reporting
Number of speed citations issued during grant-funded activities	Grant activity reporting

TABLE 4-2: Safety performance measures and data sources (*Source: NHTSA 2007*)

Performance measure

A numerical metric used to monitor changes in system condition and performance against established visions, goals, and objectives.

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National Highway Traffic Safety Administration (NHTSA). 2007. Performance Measures Discussion. 408 Team Document #005, October 29, 2007. National Highway Traffic Safety Administration.

Components of safety management

The safety management process can be viewed in three general components. These components are carried out by the agency (or agencies) responsible for managing the safety of the road system:

- **Identifying safety problems –** The agency uses crash data and other safety data to identify road safety problems or problem locations.
- **Developing potential safety strategies –** The agency develops potential strategies to address the identified safety problems. These strategies might also be referred to as countermeasures or treatments.
- **Selecting and implementing strategies –** The agency weighs the potential strategies and decides which ones to implement.

Levels of safety management

Although all road safety management follows the same three general components listed above, the specific steps of the safety management process will be different depending on the scope. The process might be intended to address specific site-level issues, such as crash patterns at high priority intersections, curves, or corridors. On a larger scale, the process might be intended to address system-level issues, such as problems that can be addressed by policies, design standards, or broad ranging campaigns of education or enforcement. The following chapters will discuss safety management for these two levels: Chapter 11 presents site-level safety management; Chapter 12 presents system-level safety management.

Site-Level Safety Management

Site-level safety management is the process of identifying and addressing safety issues at high priority **sites**. This contrasts with safety issues that are addressed for an entire transportation system (i.e., all roads in a city, county, or State). System-level safety management is covered in Chapter 12.

Agencies responsible for road safety often conduct some form of site-level safety management. They identify particular sites of concern and determine how best to address the safety problems at these priority sites. The methods of identifying priority sites and the safety strategies used to treat the sites differ according to the type of agency. A department of transportation (DOT) may install a sign or pavement marking; a law enforcement agency might increase enforcement in the area of the site. Regardless of the type of agency, it is important to conduct site-level safety management in a manner that uses good analysis methods driven by safety data.

Chapter 10 presented road safety management in terms of three general components:

- **Identifying safety problems**
- **Developing potential safety strategies**
- **Selecting and implementing strategies**

FIGURE 4-1: Schematic Illustrating the Steps of Site-level Safety Management

When discussing site-level safety management, these three components can be further divided into six distinct steps. This six-step process is common to the engineering discipline and is presented in Part B of the first edition of the Highway Safety Manual[3] (HSM). The process, shown in Figure 4-1, will be the framework for the discussion of site-level safety management in this chapter. The material presented in this chapter is based on the guidance presented in the HSM and material from a series of documents entitled "Reliability of Safety Management Methods" published by FHWA. These FHWA

Site

A narrowly defined location of interest for safety analysis, such as an intersection, road section, interchange, or midblock crossing.

3 Highway Safety Manual, First edition, American Association of State Highway Transportation Officials, 2010.

SAFETY MANAGEMENT COMPONENTS	STEPS OF SITE-LEVEL SAFETY MANAGEMENT
IDENTIFY SAFETY PROBLEMS	**Step 1. Network screening:** Identify locations that could benefit from treatments to reduce crash frequency and severity.
	Step 2. Diagnosis: Identify crash trends and patterns based on reported crashes, assess the crash types and severity levels, and study other elements that characterize the crashes.
DEVELOP POTENTIAL SAFETY SOLUTIONS	**Step 3. Countermeasure selection:** Identify appropriate countermeasures to target crash contributing factors and reduce crash frequency and severity at identified locations.
	Step 4. Economic appraisal: Estimate the economic benefit and cost associated with implementing a particular countermeasure or set of countermeasures.
SELECT AND IMPLEMENT STRATEGIES	**Step 5. Project prioritization:** Develop a prioritized list of safety improvement projects, considering available resources.
	Step 6. Safety effectiveness evaluation: Evaluate how a particular countermeasure (or group of countermeasures) has affected crash frequency and severity where it was installed.

TABLE 4-3: Steps of the Site-level Safety Management Process

documents provide in-depth guidance and examples on the following topics:

- **Network screening** – The network screening guide describes various methods and the latest tools to support network screening.[4]
- **Diagnosis** – The diagnosis information guide describes various methods and the latest tools to support diagnosis.[5]
- **Countermeasure selection** – The countermeasure selection information guide describes various methods and the latest tools to support countermeasure selection.[6]
- **Safety effectiveness evaluation** – The safety effectiveness evaluation guide describes various methods and the latest tools to support safety effectiveness evaluation.[7]
- **Systemic safety programs** – The systemic safety programs guide describes the state-of-the-practice and the latest tools to support systemic safety analysis.[8]

The six steps of the site-level safety management process relate to the three general components of safety management as shown in Table 4-3. Each step is presented in more detail through the following sections in this chapter.

4 Srinivasan, R., F. Gross, B. Lan, G. Bahar (2016), *Reliability of Safety Management Methods: Network Screening*, Report No. FHWA-SA-16-037, Federal Highway Administration, Washington, D.C.

5 Srinivasan, R., G. Bahar, F. Gross (2016), *Reliability of Safety Management Methods: Diagnosis*, Report No. FHWA-SA-16-038, Federal Highway Administration, Washington, D.C.

6 Bahar, G. R. Srinivasan, F. Gross, (2016), *Reliability of Safety Management Methods: Countermeasure Selection*, Report No. FHWA-SA-16-039, Federal Highway Administration, Washington, D.C.

7 Srinivasan, R., F. Gross, G. Bahar (2016), *Reliability of Safety Management Methods: Safety Effectiveness Evaluation*, Report No. FHWA-SA-16-040, Federal Highway Administration, Washington, D.C.

8 See next page.

Step 1. Network screening

Network screening refers to the process of selecting high priority sites that need safety treatment, often through an analysis of crash data. There are many ways in which an agency can use crash data to prioritize sites, ranging from simplistic methods, which are easy to understand and implement but can be inaccurate or ineffective, to more advanced methods, which require statistical expertise and more data but provide a better prioritization of sites.

For many years, the most prevalent methods for ranking specific sites for safety improvements were based on historical crash data alone. Many agencies still use these methods to allocate their road safety funds. Agencies that prioritize sites by historical **crash frequency** identify those sites that have the highest number of crashes in a certain time period (typically three to five years). This serves to assist agencies in addressing the magnitude of the problem, that is, attempting to address the highest number of crashes. By its nature, this method typically identifies sites that have high amounts of traffic (either vehicles, pedestrians, or other road users). However, this method may miss abnormally hazardous sites that do not present a relatively large number of crashes. Another variation of the crash frequency method uses **crash severity**, in which agencies weight the crash frequency by giving greater weight to higher severity crashes. This method counteracts some of the bias in the crash frequency method. For example, a general high crash frequency may prioritize a busy intersection that has many crashes, but a closer examination reveals that most crashes are low speed, low severity rear-end crashes. The crash severity method would lower the priority of this intersection in favor of other sites where more serious crashes occur.

Some agencies prioritize sites by the historical **crash rate**. This method incorporates traffic volume to augment the crash data. The crash frequency at a site is divided by the traffic volume – either the annual average daily traffic (for road segments), total entering volume (for vehicle traffic at intersections), or other volumes, such as pedestrian crossing volume. The typical unit for this method is crashes per 100 million vehicle miles traveled for road segments or crashes per 100 million entering vehicles for intersections. Crash rate in these units is calculated as:

$$\text{Crash rate per 100 million vehicle miles traveled} = \frac{(C \times 100{,}000{,}000)}{(V \times 365 \times N \times L)}$$

C = Number of crashes in the study period

V = Traffic volumes using average annual daily traffic (AADT) volumes

N = Number of years of data

L = Length of the roadway segment in miles

This approach of prioritizing sites by crash rate serves to counteract the bias of crash frequency that overly prioritizes sites with high volume, since higher volume decreases the crash rate. However, it may inefficiently prioritize sites with very low volumes.

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(from previous page) Gross, F., T. Harmon, G. Bahar, K. Peach (2016), *Reliability of Safety Management Methods: Systemic Safety Programs*, Report No. FHWA-SA-16-041, Federal Highway Administration, Washington, D.C.

Crash frequency

The number of observed crashes per year.

Crash severity

The level of injury severity of the crash as an event, typically determined by the highest severity injury of any person involved in the crash.

Crash rate

The number of observed crashes per unit of traffic volume passing through the location.

Agencies might use a combination of these two methods. They may set a minimum crash rate to generate an initial list of priority sites and then prioritize that group by crash frequency or severity. Regardless, these simplistic methods are known to have potential biases. One of the most prevalent biases is that the crash history used to prioritize sites with these methods usually reflects only the short-term trend of crashes. Given that the year-to-year occurrence of crashes at a location is random, it can be the case that a short-term crash history (one to three years) may be relatively high, but in the long run (ten years), the crashes would return to a lower amount, even if no safety improvements were done. This effect creates selection bias or **regression-to-the-mean** (RTM) bias in the safety analysis of this location.

As the years progressed, many transportation safety professionals recognized that while these simplistic methods did identify sites that benefited from safety improvement, they were not the locations where safety funds could be spent the most effectively. The selection of high crash sites was subject to RTM bias. Also, sites with high numbers of crashes were typically complex and required expensive reconstruction in order to reduce crashes appreciably. The question became, "How could road safety funds be spent in a way that provided the biggest bang for the buck?"

As the science of road safety advanced, researchers developed more advanced approaches for prioritizing sites for safety improvements. Dr. Ezra Hauer pushed forward a movement to identify "sites with promise."[9] The main idea was to identify sites that experienced more crashes than would be expected from a site with that particular set of characteristics. In many cases, these abnormally performing sites could be addressed with low cost safety treatments, such as larger signs or pavement markings with greater visibility. This approach uses statistical regression models that predict crashes for a given set of characteristics. These models demonstrate the advantage of bringing together different types of safety data, which in this case could include crash data, roadway characteristics, and traffic volume.

Regression-to-the-mean

The fact that a short term examination of crash history at a location is likely inaccurate (e.g., lower or higher than its true safety performance). When a longer time period of crash history is examined, the crash frequency will "regress" to its "mean" and provide a better picture of the long term average crash frequency.

Comparing road segments by crash frequency and rate

Road Segment A: A three-mile section of road that has had **four** crashes over five years and has a traffic volume of **4,000** vehicles per day.

Road Segment B: A three-mile section of road that has had **10** crashes over five years and has a traffic volume of **12,000** vehicles per day.

If an agency is comparing these segments based on crash frequency, they would prioritize road segment B for having 10 crashes compared to road segment A which had four crashes.

If comparing these segments based on crash rate, the agency would calculate the crash rate of road segment A as (4 crashes x 100,000,000) / (4,000 vehicles per day x 365 x 5 years x 3 miles) = 18.2 crashes per 100 million vehicle miles traveled. Following the same calculation, road segment B has a rate of 15.2 crashes per 100 million vehicle miles traveled. According to crash rate, the agency would prioritize road segment A. The prioritization of these two segments changes when traffic volume is taken into account.

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Hauer, E. (1997), *Observational Before After Studies in Road Safety*, Elsevier Science, New York.

The most basic of these regression methods calculates **predicted crashes**. This method requires information about certain geometric and operational characteristics, such as traffic volume, number of lanes, and type of road.

An SPF is developed or calibrated using data from an entire jurisdiction or State, so it is independent of the crash history of the specific site. This means that the predicted crash value is unaffected by the bias caused by RTM. Using SPFs, transportation agencies can predict crash values for many sites and prioritize the sites according to the highest predicted values. Another use of the predictive method is in systemic safety treatments, presented in Chapter 12 under Risk Based Prioritization.

Predicted crashes

The frequency of crashes per year that would be predicted for a site based on the result of a crash prediction model, called a safety performance function (SPF).

PERFORMANCE MEASURE	ACCOUNTS FOR TRAFFIC VOLUME	ACCOUNTS FOR RTM BIAS	ACCOUNTS FOR CRASH SEVERITY
1. Average crash frequency	*No*	*No*	*Not explicitly**
2. Crash rate	Yes	*No*	*Not explicitly**
3. Equivalent property damage only (EPDO) average crash frequency	*No*	*No*	Yes
4. Relative severity index	*No*	*No*	Yes
5. Critical rate	Yes	*No*	*Not explicitly**
6. Excess predicted average crash frequency using method of moments	*No*	*No*	*Not explicitly**
7. Level of service of safety	Yes	*No*	*Not explicitly**
8. Excess predicted average crash frequency using SPFs	Yes	*No*	*Not explicitly**
9. Probability of specific crash types exceeding threshold proportion	*No*	Not affected by RTM bias**	*Not explicitly**
10. Excess proportion of specific crash types	*No*	Not affected by RTM bias**	*Not explicitly**
11. Expected average crash frequency with empirical Bayes adjustments	Yes	Yes	*Not explicitly**
12. EPDO average crash frequency with EB adjustment	Yes	Yes	Yes
13. Excess expected average crash frequency with EB adjustment	Yes	Yes	*Not explicitly**

* While these measures do not explicitly mention severity, analysts can adapt any of the measures to consider any severity level.

** These two measures will not be affected by RTM only if they are based on data from a long time period.

TABLE 4-4: Performance Measures for Network Screening *(Source: Highway Safety Manual, 1st ed.)*

Where can I get safety performance functions for my State?

SPFs can be obtained in two ways:

1) SPFs can be developed from scratch using crash, roadway, and traffic volume data from roads and intersections in the State. This requires significant data to be collected on hundreds of sites. A statistical expert must use these data to develop SPFs that are tailor made for that State.

2) SPFs can be obtained from national resources, such as the HSM; then calibrated for the particular State of interest. This requires data to be collected on a smaller number of sites than is required for developing a new SPF.

The crashes predicted by the SPF are compared to the crashes observed on the State's roads, and an analyst calculates a calibration factor to adjust the SPF prediction appropriately for the State.

SPF development or calibration is typically handled by the State DOT. FHWA provides guidance on deciding between developing a new SPF or calibrating an existing one.[10] States that decide to develop new SPFs can refer to guidance in a related FHWA publication.[11] NCRHP provides guidance for those who decide to calibrate existing SPFs.[12]

The first edition of the HSM lists several benefits of the predictive method, including:

- RTM bias is addressed as the method concentrates on long-term expected average crash frequency rather than short-term observed crash frequency.
- Reliance on availability of limited crash data for any one site is reduced by incorporating predictive relationships based on data from many similar sites.
- The method accounts for the fundamentally nonlinear relationship between crash frequency and traffic volume.

Agencies can also use the predicted crashes in combination with actual crash history at the site of interest to calculate **expected crashes**. A method called empirical Bayes (EB) brings these two values together to reflect a crash frequency that incorporates the general crash prediction from the SPF with the real world experience of crash history at the site to provide an accurate estimation of how many crashes should be expected at the site (see more detailed discussion of the EB method later in this step). Some agencies may also calculate **excess crashes** as a measure for site prioritization. This is the difference between the expected crashes and the observed crash frequency at the site.

Performance measures in network screening

The key to effective network screening is selecting an appropriate performance measure. Network screening methods should appropriately account for three major factors that can affect the screening outcome:

- **Differences in traffic volumes**
- **Possible bias due to RTM**
- **Crash severity**

Table 4-4 lists the thirteen performance measures discussed in the HSM with an indication of their ability to account for these major factors. While some measures directly account for crash severity (e.g., relative severity index), analysts can adapt any of the measures to account for crash severity.

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Srinivasan, R., D. Carter, and K.Bauer (2013), *Safety Performance Function Decision Guide: SPF Calibration vs SPF Development*, Report No. FHWA-SA-14-004, Federal Highway Administration, Washington, DC.

11

R. Srinivasan and K. Bauer (2013), *Safety Performance Development Guide: Developing Jurisdiction-Specific SPFs*, Report FHWA-SA-14-005, Federal Highway Administration, Washington, DC

12

Bahar, G (2014), *User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors*, HR 20-7(332), National Cooperative Highway Research Program, American Association of State Highway and Transportation Officials, Standing Committee on Traffic Safety, Washington, DC.

Expected crashes, excess crashes

See next page.

Accounting for differences in traffic volumes

As discussed earlier, analysts have traditionally used crash rates to account for differences in traffic volume among sites. Crash rate is the ratio of crash frequency to exposure, which is typically the traffic volume. Crash rates implicitly assume a linear relationship between crash frequency and traffic volume; however, many studies have shown that the relationship between crashes and traffic volume is nonlinear, and the shape of this relationship depends on the type of facility. Nonlinear relationships, such as SPFs, are more appropriate than linear relationships, such as crash rates to account for differences in traffic volume among sites.

SPFs are a more reliable method to account for differences in traffic volume among sites because they reflect the nonlinear relationship between crash frequency and traffic volume. The SPF is an equation that represents a best-fit model that relates annual observed crashes to the site characteristics including annual traffic volume and other site characteristics. Typically, SPFs are estimated for a particular crash type for a type of facility (e.g., run-off-road crashes on rural two

Expected crashes

The frequency of crashes per year that represents the combination of the predicted crashes and the observed crashes that actually occurred at the site.

Excess crashes

The difference between the expected crashes and the observed crash frequency at the site.

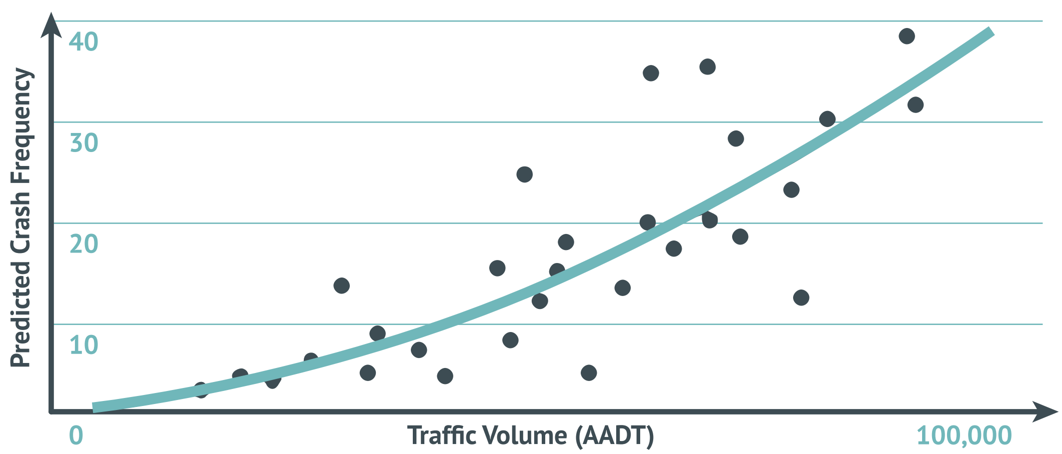

FIGURE 4-2: Example of SPF for multi-vehicle crashes on rural, 4-lane freeways

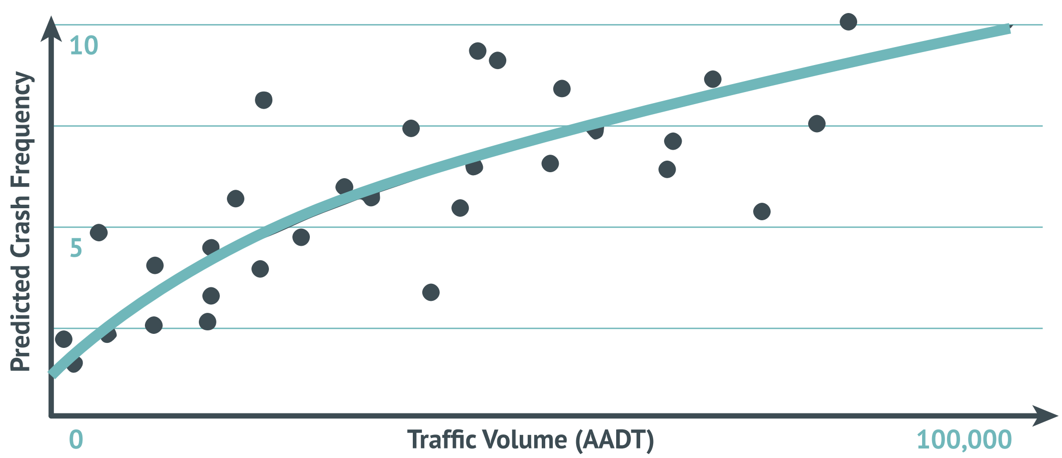

FIGURE 4-3: Example of SPF for single-vehicle crashes on rural, 4-lane freeways

lane roads) using data from an entire jurisdiction or State. Figure 4-2 and Figure 4-3 show example SPFs where the points represent observed crashes at specific traffic volumes for individual sites, and the solid line represents the best-fit model (i.e., the SPF). If the relationship between exposure and crash frequency were linear, then the solid line would be a straight line instead of a curve. These two figures also demonstrate the nature of SPFs – each curve is different. For the rural, four lane freeways used in this example, multi-vehicle crashes rise exponentially with more traffic volume (Figure 4-2) but single-vehicle crashes behave differently; they level off with increasing levels of traffic volume (Figure 4-3).

An SPF produces the average number of crashes that would be predicted for sites with a particular set of characteristics. By comparing a site's observed number of crashes with the predicted number of crashes from an SPF, it may be possible to identify sites that experience more crashes than one would expect from a site with that particular set of characteristics. Sites where the observed number of crashes is larger than the predicted number of crashes from an SPF warrant further review and diagnosis. Two measures in Table 4-4, level of service of safety (LOSS) and the excess predicted average crash frequency using SPFs, use the observed crash frequency and predicted frequency from an SPF to identify sites with promise.

Ideally, SPFs should be estimated using data from the same jurisdiction as the site(s) being studied.[13] However, that may not always be possible due to the availability of data or lack of statistical expertise. In that case, the SPFs developed from another jurisdiction could be calibrated using data from the jurisdiction with the study sites.[15]

SPF Example 1

Some States use Safety Analyst, a software tool from AASHTO, to identify sites that may benefit from a safety treatment.[14] The following is an SPF from Safety Analyst that predicts the total number of crashes on rural multilane divided roads:

$$P = L \times e^{-5.05} \times (AADT)^{0.66}$$

P is the total number of crashes in one year on a segment of length **L**.

This is a relatively simple SPF where the predicted number of crashes per mile is a function of just AADT. For example, if the AADT is 45,000, then the predicted number of crashes for a one mile segment based on the SPF will be the following:

$$P = 1 \times e^{-5.05} \times 45000^{0.66}$$
$$= 7.55 \text{ crashes per year}$$

Avoiding bias due to regression-to-the-mean

As previously discussed, RTM describes the situation when periods with relatively high crash frequencies are followed by periods with relatively low crash frequencies simply due to the random nature of crashes. Figure 4-4 illustrates RTM, comparing the difference between short-term average and long-term average crash history.[16] Due to RTM, the short-term average is not a reliable estimate of the long-term crash propensity of a particular site. If an agency selects sites based

13

R. Srinivasan and K. Bauer (2013), *Safety Performance Development Guide: Developing Jurisdiction-Specific SPFs*, Report FHWA-SA-14-005, Federal Highway Administration, Washington, DC.

14

http://www.safetyanalyst.org/

15

G. Bahar and E. Hauer (2014), *Users Guide to Develop HSM SPF Calibration Factors*, NCHRP Project 20-7(332).

16

Susan Herbel, Lorrie Laing, Colleen McGovern (2010), *Highway Safety Improvement Program (HSIP) Manual*, FHWA-SA-09-029, Federal Highway Administration, Washington, DC.

SPF Example 2

Bauer and Harwood[17] provide a more complex SPF for fatal and injury crashes on rural two lane roads. This model provides a crash prediction that is more tailored to characteristics of the site, such as curve radius and vertical grade of the road:

$$N_{FI} = \exp\,[-8.76+1.00\times\ln(AADT)+0.044\times G+0.19\times\ln(2\times 5730/R)\times I_{HC} +4.52\times(1/R)(1/L_c)\times I_{HC}\,]$$

N_{FI} = fatal-and-injury crashes per mile per year

AADT = annual average daily traffic (vehicles/day)

G = absolute value of percent grade; 0% for level tangents; ≥ 1% otherwise

R = curve radius (ft); missing for tangents

I_{HC} = horizontal curve indicator: 1 for horizontal curves; 0 otherwise

L_C = horizontal curve length (mi); not applicable for tangents

ln = natural logarithm function

on high short-term average crash history, crashes at those sites may be lower in the following years due to RTM, even if the agency does not install countermeasures at those sites.

If RTM is not properly accounted for, sites with a randomly high count of crashes in the short term could be incorrectly identified as having a high potential for improvement, and vice versa. In this case, scarce resources may be inefficiently used on such sites while sites with a truly high potential for cost effective safety improvement remain unidentified.

One approach to address RTM bias is to use the EB method. The EB method is a statistical method that combines the observed crash frequency (obtained from crash reports) with the predicted crash frequency (derived from the appropriate SPF) to calculate the expected crash frequency for a site of interest. This method pulls the crash count towards the mean, accounting for the RTM bias.

The EB method is illustrated in Figure 4-5, which illustrates how the observed crash frequency is combined with the predicted crash frequency based on the SPF.[18] The

17

Bauer, K. and Harwood, D., Safety Effects of Horizontal Curve and Grade Combinations on Two-Lane Highways, Federal Highway Administration, Report No. FHWA-HRT-13-077, January 2014.

18

Susan Herbel, Lorrie Laing, Colleen McGovern (2010), *Highway Safety Improvement Program (HSIP) Manual*, FHWA-SA-09-029, Federal Highway Administration, Washington, DC.

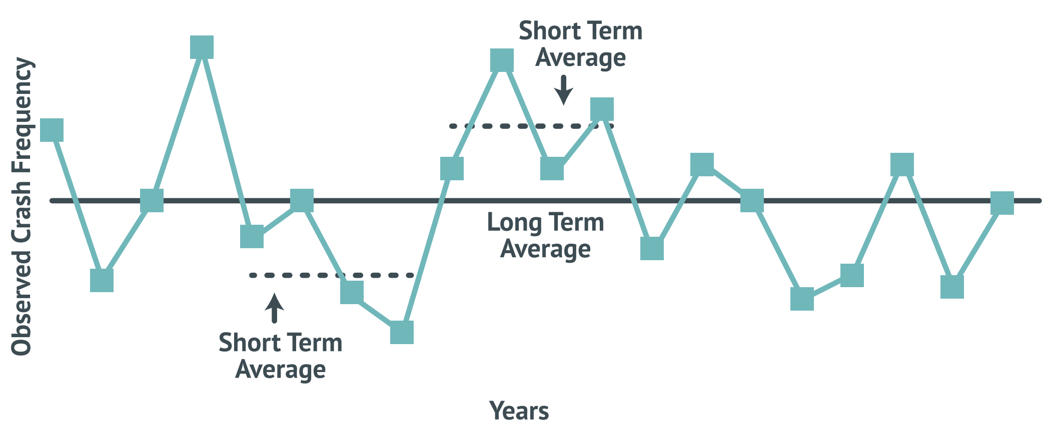

FIGURE 4-4: Chart to illustrate RTM phenomenon *(Source: HSIP Manual, 2010)*

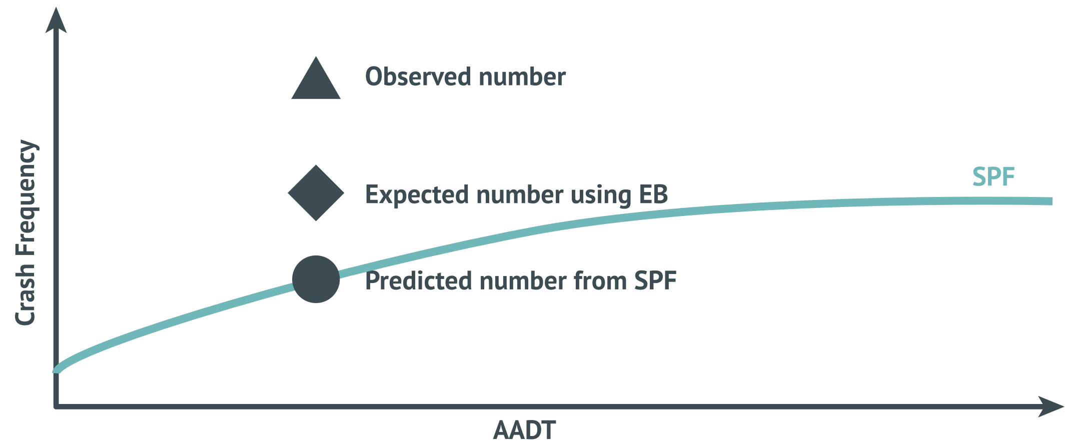

FIGURE 4-5: Schematic to illustrate the empirical Bayes method *(Source: HSIP Manual, 2010)*

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.

Mathematically, the expected number of crashes can be written as a function of the predicted value from the SPF and the observed crashes in the following manner:

Equation 1

$$N_{expected} = w \times N_{predicted} + (1 - w) \times N_{observed}$$

$N_{expected}$ = expected average crash frequency for a certain study period

w = weighted adjustment to be placed on the SPF prediction ($0 < w < 1$)

$N_{predicted}$ = predicted average crash frequency predicted using an SPF for the study period under the given conditions

$N_{observed}$ = observed crash frequency at the site over the study period

The weight w is a function of the predicted crash frequency ($N_{predicted}$) and a statistical parameter called the overdispersion parameter of the SPF. Procedures to estimate the expected average crash frequency are provided in Part B of the HSM. For example, if the observed crash frequency in a particular site was nine crashes per year, the predicted crash frequency from the SPF was 6.4 crashes per year, and the w was 0.3, then $N_{expected}$ will be as follows:

$$N_{expected} = 0.3 \times 6.4 + (1 - 0.3) \times 9$$
$$= 8.22 \text{ crashes per year}$$

We can prioritize sites by calculating the difference between the EB expected crashes at a particular site and the predicted crashes from an SPF. By comparing EB expected crashes at a particular site instead of observed crashes, we account for possible bias due to RTM.

The first eight measures presented in Table 4-4 do not account for possible bias due to RTM. Measure 9 (probability of specific crash types exceeding threshold proportion) and measure 10 (excess proportion of specific crash types) are not affected by RTM unless they are based on short-term crash history. Measure 11 (expected average crash frequency with EB adjustments), measure 12 (EPDO average crash frequency with EB adjustment), and measure 13 (excess expected average crash frequency with EB adjustment) account for possible bias due to RTM using the EB adjustments.

Accounting for crash severity

The severity of crashes at a location can (and should) have a bearing on the priority of the site for safety treatment. Three of the measures in Table 4-4, measure 3 (EPDO average crash frequency), measure 4 (relative severity index), and measure 12 (EPDO average crash frequency with EB adjustment), directly account for crash severity. Measures 3 and 12 use the EPDO method, which converts all crashes to a common unit, namely property damage only (PDO) crashes. Using these measures, the analyst assigns points to each crash based on its crash severity level. A PDO crash typically receives one point and the points increase as the severity of the crash increases.

While other measures do not explicitly mention severity, analysts can adapt any of the measures to consider any severity level. For example, an analyst could use crash frequency and focus on the frequency of fatal and severe injury crashes to priority rank sites. It is important to note that the severity distribution of crashes may be a function of site characteristics including AADT. For example, sections with higher AADT values may be associated with lower speeds and consequently fewer severe crashes.

Step 2. Diagnosis

Diagnosis is the second step in the roadway safety management process, following network screening. Diagnosis is the process of further investigating the sites and issues identified from network screening. The intent of diagnosis is to identify crash patterns and the factors that contribute to crashes at the identified sites. Thorough diagnosis can also identify potential safety issues that have not yet manifested in crashes. Diagnosis often involves a review of the crash history, traffic operations, and general site conditions. While safety professionals could review these data from the office, a field visit provides the opportunity to observe road user behavior and site characteristics that are not available in the data. Sometimes, safety professionals may also conduct a field review at night or at other times that crash history has indicated to be of concern. It is important to diagnose the cause of the problem before developing potential countermeasures, just as a doctor examines symptoms to diagnose an underlying disease before formulating a prescription. Otherwise, resources may be misallocated if a countermeasure that does not target the underlying issues is selected and implemented.

The Haddon Matrix is a framework to identify possible contributing factors (e.g., driver, vehicle, and roadway/environment) which are cross-referenced against possible crash conditions before, during, and after a crash to identify possible reasons for events. This comprehensive understanding of crash contributing factors is important for the diagnosis of safety problems. An example of the Haddon Matrix is presented later under Countermeasure Selection on page 4-20.

The HSM recommends that diagnosis include the following parts:

- **A review of safety data**
- **An assessment of supporting documentation**
- **An assessment of field conditions**

Safety data review

An analyst can conduct a detailed review of the crash data from police reports to identify patterns. This could involve reviewing the crash type, severity, sequence of events, and contributing circumstances. Different visualization tools, such pie charts, bar charts, or tabular summaries, can be used to display various crash statistics. In addition to reviewing descriptive statistics, analysts can use various methods to identify underlying safety issues based on the recognition of crash patterns.

One method would be to identify locations that have a proportion of a specific collision type relative to the total collisions that is higher than some average or threshold proportion value for similar road types. Kononov found that looking at the percentage distribution of collisions by collision type can reveal the "existence of collision patterns susceptible to correction" that may or may not be accompanied by the overrepresentation in expected or expected excess collisions.[19] Heydecker and Wu originally proposed this method.[20] The method is identical for different location types. However, only similar location types should be analyzed together because collision patterns will naturally differ. For example, the collision patterns are different for stop-controlled intersections, signalized intersections, and two-lane roads, so the method would be applied separately to the three types of facilities and separately for urban and rural environments. Another method would be to investigate sites that experience a gradual or sudden increase in mean collision frequency.[21]

Following the detailed review of the crash data, the analyst can create collision diagrams, condition diagrams, and crash maps to summarize the crash information by location. A collision diagram is a tool to identify and display crash patterns. Many resources, including the HSM, provide guidance on developing collision diagrams. Examples of collision diagrams are shown in Figure 4-6 and Figure 4-7. Each crash at the site is displayed according to where it occurred, what type of crash it was, how severe it was, and various other characteristics. An analyst uses symbols to visually represent many of these characteristics.

Condition diagrams include a drawing with information about the site characteristics including information about the roadway (e.g., number of lanes, presence of medians, pedestrian and bicycle facilities, shoulder information), surrounding land uses, and pavement conditions. Condition diagrams can be overlaid on top of collisions diagrams to gain further insight to the crash patterns.

Crash mapping involves the use of geographic information systems (GIS) to integrate information from the roadway network with information from geocoded crash data. If the geocoded crash data are

19

Kononov, J. (2002), Identifying Locations with Potential for Collision Reductions: Use of Direct Diagnostics and Pattern Recognition Methodologies, *Transportation Research Record 1784*, pp. 153-158.

20

Heydecker, B. J., and J. Wu (1991), Using the Information in Road Accident Records Proc., 19th PTRC Summer Annual Meeting, London.

21

Hauer, E. (1996), Detection of Safety Deterioration in a Series of Accident Counts. *Transportation Research Record 1542*, 38-43.

Hauer, E. (1996), Statistical Test of the Difference between Expected Accident Frequencies, *Transportation Research Record 1542*, 24-29.

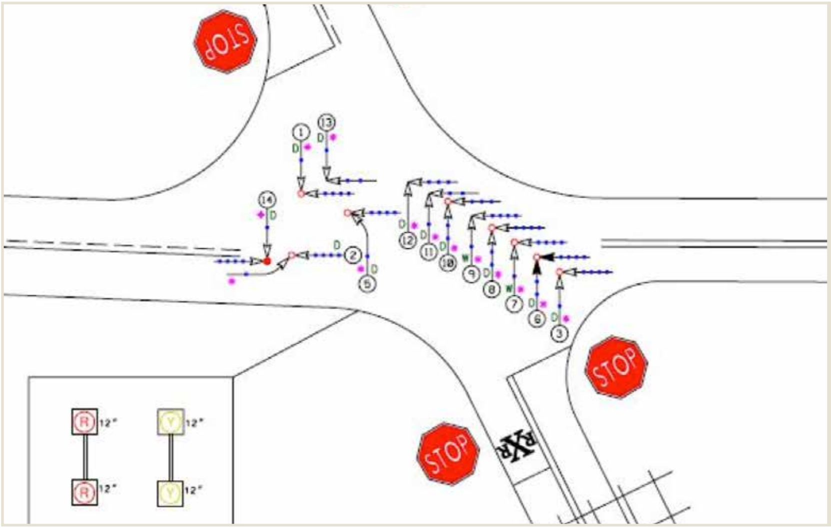

FIGURE 4-6: Example Collision Diagram at an Intersection

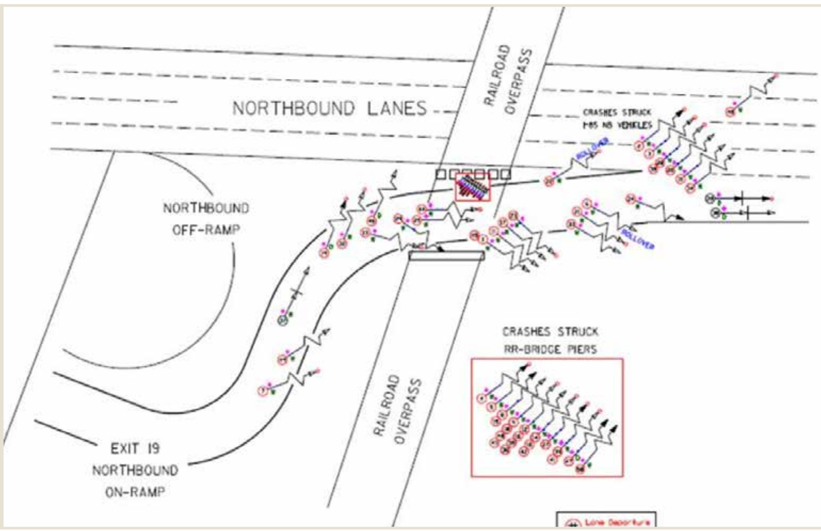

FIGURE 4-7: Example Collision Diagram at a Ramp

accurate, then crash mapping can provide valuable insights into crash locations and crash patterns.

Assess supporting documentation

This step involves a review of documented information about the site along with interviews of local transportation professionals to obtain additional perspectives on the safety data review from the previous step. Examples of supporting documentation include traffic volumes, construction plans and design criteria, photos and maintenance logs, weather patterns, and recent traffic studies in the area.

Assess field conditions

Field observations are useful for supplementing crash data and can help the analyst understand the behavior of drivers, pedestrians, and bicyclists. The first stage of the field investigation should be an on-site examination of a road user's experience. Those conducting the assessment should travel through the site at different times of the day using different modes of transportation (e.g., driving, walking, and bicycling). Assessors should observe the mix of vehicle traffic and other road users. They should also observe traffic movements, conflicts, and

ROAD SAFETY AUDIT	TRADITIONAL SAFETY REVIEW
Independent, multi-disciplinary team	Safety review team within the project team with only safety and/or design experience
Considers all potential road users (pedestrians, bicyclists, motor vehicles, transit users)	Often concentrates only on motor vehicles
Accounts for road user capabilities and limitations	Safety reviews do not normally consider human factor issues
Always generates a formal report	Often does not generate a formal report
Always generates a formal response report	Often does not generate a formal response report

TABLE 4-5: Differences between Road Safety Audit and Traditional Road Safety Review *(Source: FHWA)*

operating speeds. Those conducting the field review could determine whether the road and intersection characteristics are consistent with driver expectation and if roadside recovery zones are clear and traversable.

Road safety audits

One method to assess field conditions is a road safety audit (RSA). This is the formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team. An RSA qualitatively estimates and reports on existing and potential road safety issues and identifies opportunities for safety improvements for all road users. FHWA encourages States, local jurisdictions and tribal governments to integrate RSAs into the project development process for new roads and intersections and to conduct RSAs on existing ones.

The purpose of an RSA is to answer the following questions:

- **What elements of the road may present a safety concern, and to what extent, to which road users, and under what circumstances?**
- **What opportunities exist to eliminate or mitigate identified safety concerns?**

The multidisciplinary audit team consists of people who represent different areas of expertise, such as engineering (e.g., design, traffic, and maintenance), law enforcement, safety educators, public officials, community traffic safety advocates, and others. Any phase of project development (planning, preliminary engineering, design, construction) and any sized project from minor intersection and roadway retrofits to mega-projects are eligible for an RSA.

Most State DOTs have established safety review processes. However, RSAs and a traditional safety reviews are different. Table 4-5 shows the difference between an RSA and a traditional safety review.[22]

22 "Road Safety Audits (RSA)," accessed August 7, 2013, http://safety.fhwa.dot.gov/rsa/

International Road Assessment Programme

The International Road Assessment Programme (iRAP) conducts safety inspections on high-risk roads in more than 70 countries. The iRAP inspectors perform a detailed road survey, focusing on road attributes that are known to be associated with crash risk. These include intersection design, number of lanes, roadside hazards, and provisions for pedestrian crossings. The inspectors use these data to develop a star rating, which reflects the level of safety of the road, and provide detailed feedback to the government agency in the form of an assessment report. iRAP also provides a Road Safety Toolkit, which helps engineers, planners, and policy makers develop safety plans for all road users.[23]

Step 3. Countermeasure selection

After diagnosing the safety issues at the site, analysts select countermeasures to address the contributing factors for observed crashes. The first part of countermeasure selection is to identify countermeasures to target the underlying safety issues. Analysts can use tools like the Haddon Matrix and resources like the NCHRP Report 500 series to identify targeted countermeasures to address or mitigate underlying contributing factors.

Identifying contributing factors

The Haddon Matrix is a tool originally developed for injury prevention, but it is directly applicable to highway safety in both diagnosis and countermeasure selection.[24] The Haddon Matrix is useful to gain a comprehensive understanding of crash contributing factors. Analysts can use the Haddon Matrix to identify human, vehicle, and roadway factors contributing to the frequency and severity of crashes prior to, during, and after the crash event. Then, analysts can identify targeted reactive and proactive countermeasures to address or mitigate the underlying contributing factors for the given site. Chapter 6 of the 1st edition of the HSM provides further discussion of the Haddon Matrix.

The Haddon Matrix is comprised of nine cells to identify human, vehicle, and roadway factors contributing to the target crash type or severity outcome before, during, and after the crash. Pre-crash factors speak to the factors or actions prior to the crash that contributed to the occurrence of the crash. Crash factors speak to those factors or actions that occurred at the moment of the crash. Post-crash factors speak to factors that come into play after the crash that affect the severity of the injuries or speed of response. Examples of human factors include fatigue, inattention, age, and failure to wear a seat belt. Vehicle factors include bald tires, airbag operations, and worn brakes. Examples of roadway factors include pavement friction, weather, grade, and limited sight distance.

Table 4-6 is an example application of the Haddon Matrix from the Highway Safety Improvement Program (HSIP) Manual for crashes in an urban area.[25] The top-left cell identifies driver behaviors or characteristics that may contribute to the likelihood or the severity of a collision, such as poor vision or reaction time, alcohol consumption, speeding, and risk taking. These

23

http://www.irap.net/

http://toolkit.irap.org/

24

Haddon, W., Jr. (1972). A logical framework for categorizing highway safety phenomena and activity. *Journal of Trauma* 12: 193–207.

25

Susan Herbel, Lorrie Laing, Colleen McGovern (2010), *Highway Safety Improvement Program (HSIP) Manual*, FHWA-SA-09-029, Federal Highway Administration, Washington, DC.

26

Highway Safety Improvement Program Manual. Federal Highway Administration, Washington, D.C., 2010, Chapter 3

factors should be considered when selecting countermeasures. For example, based on these human factors, successful countermeasures may be those that improve visibility or reduce speeding. 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.

Countermeasure resources and tools

Diagnosing a roadway safety problem and identifying effective countermeasures is a skill developed through education, training, research, and experience. Many resources are available to help transportation professionals analyze and develop countermeasures. Since the transportation field continuously generates new knowledge and countermeasure approaches, it is important to stay informed of the available resources and tools.[26]

Some of the most useful resources and tools for countermeasure guidance and selection are listed below (alphabetically):

- **Bicycle Safety Guide and Countermeasure Selection System (BIKESAFE, www.pedbikesafe.org/bikesafe)** – This resource provides practitioners with the latest information available for improving the safety and mobility of those who bike. The online tools provide the user with a list of possible engineering, education, or enforcement treatments to improve bicycle safety and/or mobility based on user input about a specific location.
- **Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices** – This document serves as a basic reference to help state

PERIOD	HUMAN	VEHICLE/ EQUIPMENT	PHYSICAL ENVIRONMENT	SOCIO-ECONOMIC
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

TABLE 4-6: Haddon Matrix for crashes in an urban area *(Source: HSIP Manual)*

highway safety offices (SHSOs) select effective, evidence-based countermeasures for traffic safety problem areas related to user behaviors, such as alcohol-impaired and drugged driving, seat belts and child restraints, and aggressive driving and speeding.[27]

- **Crash Modification Factors Clearinghouse (www.cmfclearinghouse.org)** – This website offers transportation professionals a central, online repository of crash modification factors (CMFs) that indicate the safety effect on crashes due to infrastructure improvements. The website also provides additional information and resources related to CMFs. This site is funded by FHWA.
- **FHWA Proven Countermeasures (safety.fhwa.dot.gov/provencountermeasures)** – FHWA regularly compiles a list of countermeasures that have been shown to be effective in reducing crashes but have yet to be widely applied on a national basis.
- **Handbook for Designing Roadways for the Aging Population (safety.fhwa.dot.gov/older_users/handbook)** – This FHWA guide provides practitioners with a practical information source that links aging road user performance to highway design, operational, and traffic engineering features. This handbook supplements existing standards and guidelines in the areas of highway geometry, operations, and traffic control devices.[28]
- **Highway Safety Manual (www.highwaysafetymanual.org)** – This document provides science-based knowledge and tools to conduct safety analyses, allowing for safety to be quantitatively evaluated alongside other transportation performance measures, such as traffic operations, environmental impacts, and construction costs.
- **National Cooperative Highway Research Program (NCHRP) Report 500 Series (safety.transportation.org/guides.aspx)** – This resource is a collection of 23 reports in which relevant information is assembled into single concise volumes, each pertaining to specific types of highway crashes (e.g., run-off-the-road, head-on) or contributing factors (e.g., aggressive driving) related to behaviors, vehicles, and roadways. Countermeasures are categorized as proven, tried, and experimental.
- **Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE, www.pedbikesafe.org/pedsafe)** – This resource provides practitioners with the latest information available for improving the safety and mobility of those who walk. The online tools provide the user with a list of possible engineering, education, or enforcement treatments to improve pedestrian safety and/or mobility based on user input about a specific location.

27

Goodwin, A., Thomas, L., Kirley, B., Hall, W., O'Brien, N., & Hill, K. (2015). *Countermeasures that work: A highway safety countermeasure guide for State highway safety offices*, Eighth edition. (Report No. DOT HS 812 202). Washington, DC: National Highway Traffic Safety Administration. Accessed February 2017 at www.nhtsa.gov/staticfiles/nti/pdf/812202-CountermeasuresThatWork8th.pdf

28

Brewer, M., D. Murillo, A. Pate (2014). *Handbook for Designing Roadways for the Aging Population*, Report No. FHWA-SA-14-015, Federal Highway Administration, Washington, D.C.

29

www.cmfclearinghouse.org

Identifying and selecting countermeasures

After identifying potential countermeasures to target the underlying issues, safety professionals must estimate the safety impact of countermeasures, individually and in combination. It is important to consider positive and negative safety impacts. Subsequent steps of the roadway safety management process (i.e., economic appraisal and project prioritization) include the consideration of other parameters, such as constructability, environmental impacts, and cost.

The agency that will be making the final decision on countermeasure selection should make sure to coordinate with other safety partners to ensure that the countermeasure is appropriate for all parties. For example, a DOT should coordinate with law enforcement and emergency response to make sure that a proposed engineering installation will interfere with enforcement activities or impede emergency responders.

For infrastructure improvements, CMFs associated with different countermeasures provide a mechanism for determining the safety effect of different countermeasures. A CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site.

- If the CMF for a particular treatment is less than 1.0, then that countermeasure is expected to reduce crashes.
- If the CMF for a particular treatment is greater than 1.0, then that countermeasure is expected to increase crashes.
- A CMF of 1.0 implies that a countermeasure will not have any effect on safety.

Guidance on CMF application

FHWA provides an extensive selection of guidance on selecting and applying CMFs through the CMF Clearinghouse (**www.cmfclearinghouse.org**). They present answers to frequently asked questions, such as “How can I apply multiple CMFs?” and “How do I choose between CMFs in my search results that have the same star rating but different CMF values?” The website also houses an archive of annual webinars in which experienced CMF users talk about issues related to applying CMFs in real world situations.

For example, if the expected number of crashes without a countermeasure is 5.6 crashes per year, and the CMF for the particular countermeasure is 0.8, then the expected number of crashes with the countermeasure is:

5.6 crashes per year x 0.8 = 4.48 crashes per year

It is important to recognize that some countermeasures may decrease some types of crashes but increase other types. For example, installing a traffic signal would be expected to decrease severe collisions, such as right angle and left turn crashes, but it would be expected to increase less severe crashes, such as rear ends.

The CMF Clearinghouse and the first edition of the HSM provide CMFs for a variety of countermeasures.[29] Only those CMFs that passed a set of inclusion criteria based on quality and reliability were included in the HSM. The CMFs in the clearinghouse are provided for any published study, regardless of quality, and are continuously updated based on the latest research. The CMFs in the clearinghouse are reviewed and given a star quality rating ranging from one to five stars, based on the quality of the study. Higher stars imply a better quality CMF.

CMFs should be applied to situations that closely match those from which the CMF was developed. Several variables can be used to match a CMF to a given scenario including roadway type, area type, segment or intersection geometry, intersection traffic control, and traffic volume. However, it is critical for practitioners to use engineering judgment when a CMF is not available for the situations encountered as there are some cases for which a CMF that was developed for different conditions might be the best available.

Step 4. Economic appraisal

An economic appraisal of alternative countermeasures should be conducted to ensure that safety funds are being used as efficiently as possible. This appraisal helps transportation agencies achieve their desired safety performance the fastest and at the lowest possible cost. An agency can compare

Calculating benefits due to crash reduction

A city has a stop-controlled intersection with an expected crash frequency of 10 crashes per year, consisting of one A-injury crash, one B-injury crash, two C-injury crashes, and six PDO crashes.

The city is considering installing a roundabout at the intersection. Based on a search of the FHWA CMF Clearinghouse, they decide that they will use a CMF of 0.19 in the calculation of the crash reduction benefit.[30] This CMF applies only to serious and minor injury crashes, so they do not use it to estimate any reduction to fatal or PDO crashes (see note).

They multiply the CMF by the expected crashes before roundabout installation to determine the expected crashes after installation:

	CRASH SEVERITY	FATAL	A-INJURY	B-INJURY	C-INJURY	PDO
I	Expected Crashes per Year before Roundabout	0	1	1	2	6
II	CMF	N/A	0.19	0.19	0.19	N/A
III	Expected Crashes per Year after Roundabout (I x II)	0	0.19	0.19	0.38	6
IV	Crash reduction benefit (I minus III)	**0**	**0.81**	**0.81**	**1.62**	**0**

Thus, the benefit of a roundabout installation is expected to be a reduction of 0.81 A-injury crashes, 0.81 B-injury crashes, and 1.62 C-injury crashes per year.

NOTE: A roundabout would also likely bring a reduction to fatal and PDO crashes (i.e., additional CMFs could be incorporated), but the example has been simplified to a single CMF for illustration purposes.

30

Rodegerdts et al., "NCHRP Report 572: Applying Roundabouts in the United States." Washington, D.C., Transportation Research Board, National Research Council, (2007) the benefits expected from the countermeasure to the estimated costs of the countermeasure.

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 may address the same problem, but at a much lower cost. Although both countermeasures address the same problem, the actual safety benefit may not be the same. 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, while taking into consideration any maintenance costs and long term effectiveness.

Estimating benefits

The primary benefit of a countermeasure is a reduction in crash frequency or severity. To estimate the safety benefits, a safety professional should use CMFs, such as those discussed in the countermeasure selection step. CMFs can be applied to the actual crashes or expected crashes based on the EB method. Expected crashes are preferred because they account for possible bias due to RTM. The estimated change in crashes represents the expected benefit from the countermeasure.

For each proposed countermeasure, the change in crash frequency and/or severity needs to be converted to monetary value, based on the monetary value of the type of crashes reduced. This monetary value is also called the crash cost. Crash costs are based on costs to society, such as lost productivity, medical costs, legal and court costs, emergency service costs, insurance administration costs, congestion costs, property damage, and workplace losses.[31]

The benefit from the countermeasure is the sum of the crash costs for crashes prevented by the countermeasure. Assigning costs to crashes is a topic that is under constant discussion and revision nationwide. States differ widely in the dollar amount that they assign to crashes, though all States apply higher values to more severe crashes. The CMF Clearinghouse provides a synthesis of crash costs that are used by various States.[32]

Additionally, the first edition of the HSM provided a list of crash costs by severity level (Table 4-7). However, since the publication of the first HSM in 2010, the USDOT has issued periodic recommendations that dramatically raised the values. For instance, the monetary value of a

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

TABLE 4-7: Crash Costs by Severity Level in the Highway Safety Manual, 1st ed.

31 Blincoe, L. J., Miller, T. R., Zaloshnja, E., and Lawrence, B. A. The economic and societal impact of motor vehicle crashes, 2010. (Revised), National Highway Traffic Safety Administration, Report No. DOT HS 812 013, Washington, DC, May 2015.

32 http://www.cmfclearinghouse.org/resources_servlifecrashcostguide.cfm

fatal crash was listed as $4 million in the HSM, but recommended as over $9 million in a 2013 policy memo from USDOT.[33]

Although countermeasures are primarily expected to reduce crashes, there might be other benefits, including reduced travel times or lower fuel consumption. For example, a roundabout can decrease total delay at an intersection if applied and configured properly. An AASHTO publication provides guidance on estimating these other non-safety benefits.[34]

Estimating costs

The costs of the proposed countermeasure include the startup cost and the ongoing operational and maintenance costs. These costs can usually be estimated based on costs of materials, labor cost per person-hour, cost of additional right-of-way, and past experience with similar countermeasures. Table 4-8 illustrates the types of startup and ongoing costs that would be incurred for various countermeasures.

Service life

Another important consideration when calculating the benefits and costs of a countermeasure is the length of time that the countermeasure will last. This is referred to as the service life. Countermeasures, such as road edgelines or pavement reflectors, will have a much shorter service life (e.g., three to five years) than countermeasures, such as traffic signal installation or sidewalk construction (e.g., 20 years or more). Many States have a standard list of the service life values used for common countermeasures. The CMF Clearinghouse provides a survey of service life values used by various States for many different countermeasures.[35]

Calculating monetary benefit of crash reduction

The previous example showed that a city calculated a crash savings of 0.81 A-injury crashes, 0.81 B-injury crashes, and 1.62 C-injury crashes per year by installing a roundabout. The city has examined guidance from the HSM, guidance from USDOT, and experiences of other cities and States and determined a standard set of crash costs they will use for all benefit/cost calculations. They apply these costs to determine the monetary benefit of the expected crash reductions:

	CRASH SEVERITY	FATAL	A-INJURY	B-INJURY	C-INJURY	PDO
IV	Crash Reduction Benefit	0	0.81	0.81	1.62	0
V	This City's Standard Crash Cost	$5 mil	$400,000	$100,000	$60,000	$10,000
VI	Monetary benefit of crash reduction (IV x V)	**0**	**$324,000**	**$81,000**	**$97,200**	**0**

Thus, the city expects a total monetary benefit of $324,000+$81,000+$97,200 = **$502,000** per year due to reduction in crashes.

33

Trottenberg, Polly, and Robert Rivkin, "Revised Departmental Guidance 2013: Treatment of the Value of Preventing Fatalities and Injuries," USDOT Office of the Secretary of Transportation, 2013.

34

User and Non-User Benefit Analysis for Highways, American Association of State Highway Transportation Officials, September 2010

35

http://www.cmfclearinghouse.org/resources_servlifecrashcostguide.cfm

COUNTERMEASURE	STARTUP COST	ONGOING COST DURING SERVICE LIFE
Install curve warning sign	**Low –** sign material, minimal labor for installation	**None**
Install roundabout	**High –** Design plan, purchase of additional right-of-way, material, labor, traffic control during construction	**Low –** maintenance of grass and decorative vegetation
Install traffic signal	**High –** Timing plan, material, labor for installation, traffic control during construction	**Moderate –** electricity, bulb replacements, repairs, modifications to timing

TABLE 4-8: Examples of Countermeasure Costs

The service life is used in the calculation of the present value of the benefits and costs of the proposed countermeasure. The calculation of present value includes a discount rate that reflects the time value of money (i.e., present dollars are worth more than future dollars). Present value of countermeasure benefits is calculated as follows:

$$PV = A \times \frac{(1+i)^y - 1}{i \times (1+i)^y}$$

PV = present value of benefits

A = annual benefit (i.e., monetary value of crashes prevented)

i = discount rate

y = service life of countermeasure

Calculating present value in this way assumes a uniform annual benefit. The HSIP Manual demonstrates how to calculate present value if the benefits or costs each year are not the same.[36]

The present value of annual costs (i.e., operational and maintenance costs) can be calculated in the same manner as for benefits. However, for costs, the final present value must also include the startup cost in the year of installation (see examples in Table 4-8).

Calculating the present value of a crash reduction benefit

From the previous example, the city plans to install a roundabout and expects to see a benefit from crash reductions resulting in savings of $502,000 per year. They estimate that the roundabout will have a service life of 20 years and they determine that a discount rate of 5% is appropriate. They calculate the present value of benefits as:

$$PV = \$502{,}000 \times \frac{(1+0.05)^{20} - 1}{0.05 \times (1+0.05)^{20}}$$

$$= \$6{,}256{,}030$$

Methods for economic appraisal

There are several methods for using the values of estimated benefits and costs to evaluate the economic effectiveness of safety improvement projects at a particular site. In particular, these methods

36 Herbel, Susan, Lorrie Laing, Colleen McGovern, Highway Safety Improvement Program (HSIP) Manual, Federal Highway Administration, FHWA-SA-09-029, January 2010

are useful in situations where a safety professional is considering several alternatives and desires to choose the countermeasure with the greatest benefit for the cost.

The HSIP Manual contains guidance on three methods – net present value, benefit/cost ratio, and cost effectiveness index.[37] Net present value (NPV) is generally regarded as the most economically appropriate method, though the other two methods have certain advantages, as discussed below. The following sections provide quoted guidance from the HSIP Manual on economic appraisal.

Net Present Value

The NPV method, also called the net present worth (NPW) method, expresses the difference between the present values of benefits and costs of a safety improvement project. The NPV method has two basic functions: 1) determining which countermeasure(s) is/are most cost efficient based on the highest NPV and 2) determining whether a countermeasure's benefits are greater than its costs (i.e., the project has a NPV greater than zero).

The formula for NPV is:

$$NPV = PVB - PVC$$

PVB = Present value of benefits

PVC = Present value of costs

A countermeasure will result in a net benefit if the NPV is greater than zero. Table 4-9 summarizes the NPV calculations of four alternative countermeasures.

For Alternative A, the NPV can be calculated as follows:

$$NPV = \$1{,}800{,}268 - \$500{,}000 = \$1{,}300{,}268$$

The same calculation is performed for the other three countermeasure alternatives, and rank each countermeasure based on its NPV. As shown, all four alternatives are economically justified with a NPV greater than zero. However, Alternative B has the greatest NPV for this site based on this method.

Benefit/Cost Ratio and Analysis

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

37 Herbel, Susan, Lorrie Laing, Colleen McGovern, Highway Safety Improvement Program (HSIP) Manual, Federal Highway Administration, FHWA-SA-09-029, January 2010.

ALTERNATIVE COUNTERMEASURE	PRESENT VALUE OF BENEFITS (I)	PRESENT VALUE OF COSTS (II)	NET PRESENT VALUE (I-II)	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

TABLE 4-9: Net Present Value *(Source: HSIP Manual, Chapter 4)*

The formula for BCR is:

$$BCR = PVB / PVC$$

PVB = Present value of benefits

PVC = Present value of costs

Table 4-10 shows an example of using BCR to prioritize four alternatives.

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

An incremental benefit/cost analysis provides a basis of comparison of the benefits of a project for the dollars invested. It allows the analyst to compare the economic effectiveness of one project against another; however, it does not consider budget constraints. Optimization methods are best for prioritizing projects based on monetary constraints. An in-depth explanation of incremental benefit/cost analysis and an example is provided in Chapter 4 of the HSIP Manual.

When conducting a benefit/cost analysis, transportation professionals compare all of the benefits associated with a countermeasure (e.g., crash reduction), 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.

Cost-Effectiveness Index

In situations where it is not possible or practical to monetize countermeasure benefits, transportation professionals can use the cost-effectiveness index method in lieu of the NPV or BCR. Cost-effectiveness is simply the amount of money invested divided by the crashes reduced. The result is a number that represents the cost of the avoided crashes of a certain countermeasure. The countermeasure with the lowest value is the most cost-effective and therefore ranked first.

$$\text{Cost-Effectiveness Index} = PVC/CR$$

PVC = Present value of project cost

ALTERNATIVE COUNTERMEASURE	PRESENT VALUE OF BENEFITS (I)	PRESENT VALUE OF COSTS (II)	BENEFIT/ COST RATIO (I/II)	ALTERNATIVE RANK
A	$1,800,268	$500,000	3.6	1
B	$3,255,892	$1,200,000	2.7	2
C	$3,958,768	$2,100,000	1.9	4
D	$2,566,476	$1,270,000	2.0	3

TABLE 4-10: Example of Benefit/Cost Ratio Prioritization *(Source: HSIP Manual, Chapter 4)*

ALTERNATIVE COUNTERMEASURE	PRESENT VALUE OF COSTS	TOTAL CRASH REDUCTION	COST-EFFECTIVE-NESS 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

TABLE 4-11: Cost-Effectiveness Index *(Source: HSIP Manual, Chapter 4)*

CR = Total crash reduction

The Cost-Effectiveness Index is a simple and quick method that provides an indication of a project's value. Transportation professionals can use this formula and compare its results with other safety improvement projects. The Cost-Effectiveness Index method, however, does not account for value differences between reductions in fatal crashes compared to injury crashes, and whether a project is economically justified.[38]

Table 4-11 summarizes the calculations using the cost-effectiveness index method to rank alternative countermeasures, given the present value of the costs and the total crash reduction.

For Alternative A, calculate the cost-effectiveness index as follows:

Cost-effectiveness index = 500,000/43 = 11,628

Calculate the Cost-Effectiveness Index for the remaining alternatives and rank each countermeasure based on its Cost-Effectiveness Index value. With this method, the lowest index is the highest priority and therefore ranked first. Alternative A is ranked first, since it has the lowest cost associated with each crash reduction.

The above example uses the number of crashes to determine the cost-effectiveness index. Transportation professionals can use this same method using EPDO crash numbers, which has the advantage of considering severity.

Step 5. Project prioritization

If a transportation agency is considering installing countermeasures at one or more sites out of a group of potential sites, they will need to prioritize which projects they will implement. Ideally, the agency would implement all projects that bring a safety benefit (e.g., all those with a NPV greater than zero or a BCR greater than one). However, all agencies work within a limited budget and must prioritize where safety funds are spent.

The agency can use steps 1 through 4 of this process to determine which countermeasure(s) would be used at each potential treatment

38 *Highway Safety Improvement Program Manual.* Federal Highway Administration (Washington D.C., 2010), Chapter 4

site and to conduct an economic appraisal of the expected effect of the countermeasure. The next step is to determine project priorities. The HSM discusses how projects can be prioritized by economic effectiveness, incremental benefit/cost analysis, or various optimization methods.

Prioritizing by economic effectiveness

Projects can be prioritized by ranking projects or project alternatives by the economic appraisal values produced in step 4. An agency might select those projects with the highest NPV, the highest BCR, or the highest cost effectiveness index. When using NPV the goal of a safety professional should be to implement all projects that have an NPV greater than zero, since each one brings a safety benefit. However, this is not possible since funds are limited, thus the goal should be to implement the group of projects that have the greatest combined NPV when added together (NPV is an additive property). Maximizing the NPV of a group of projects is different from prioritizing projects with high NPV. In other words, it may be best to implement numerous low cost projects with low NPV than one high cost project with a high NPV – but not higher than the NPV of all the low cost projects added up.

Prioritizing by incremental benefit/cost analysis

This method involves ranking all projects with benefit cost ratio greater than 1.0 in increasing order of their estimated cost. An analyst calculates an incremental BCR as such:

$$\text{Incremental BCR} = \frac{(\text{Benefit of Project A} - \text{Benefit of Project B})}{(\text{Cost of Project A} - \text{Cost of Project B})}$$

If the incremental BCR is greater than 1.0, the project with the higher cost is compared to the next project on this list; however, if the incremental BCR is less than 1.0, the project with the lower cost is compared to the next project on the list. This process is repeated and the project selected in the last pairing is the considered the best economic investment.

Prioritizing by optimization methods

Optimization methods take into account certain constraints when prioritizing projects. Linear programming, integer programming, and dynamic programming (refer to Chapter 8, Appendix A, HSM, 2010) are optimization methods consistent with an incremental benefit/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, rather than manually calculated. Multi-objective resource allocation is another optimization method. It incorporates nonmonetary elements (including decision factors not related to safety) into the prioritization process.

Safety professionals may use software applications to select and rank countermeasures. The SafetyAnalyst tool from AASHTO includes economic appraisal and priority ranking tools.[39] The economic appraisal tool calculates

39 http://www.safetyanalyst.org/

the BCR and other metrics for a set of countermeasures. The priority-ranking tool ranks proposed improvement projects based on the benefit and cost estimates from the economic appraisal tool. The priority-ranking tool can also determine an optimal set of projects to maximize safety benefits.

Step 6. Safety effectiveness evaluation

Once a countermeasure has been implemented at a site, or group of sites, it is important to determine whether it was effective in addressing the safety problem. For a safety professional to evaluate the countermeasure, he or she must determine how the countermeasure affected the frequency, type, and severity of crashes. For example, did the installation of a roundabout reduce the frequency of angle crashes? If so, by how much? Did it cause an increase to any other types of crashes? A countermeasure evaluation can result in a CMF for the countermeasure, which quantifies the effect on crashes (see CMF discussion in Step 4).

Two documents entitled A Guide to Developing Quality Crash Modification Factors[40] (from FHWA) and Recommended Protocols for Developing Crash Modification Factors[41] (from NCHRP) provide guidance on the different methods for conducting evaluations. The following is an overview of study designs and methods for conducting evaluations.

Categories of Study Designs

Study designs fall into two broad categories – experimental and observational. Experimental studies are conducted when sites are selected at random for treatment. There is general consensus that experimental studies are the most rigorous way to establish causality.[42] In contrast, observational studies are conducted when sites are not selected as part of an experiment but selected for other reasons including

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Gross, F., B. Persaud, and C. Lyon (2010), *A Guide for Developing Quality Crash Modification Factors*, Report FHWA-SA-10-032, Federal Highway Administration, Washington, D.C. Available at http://www.cmfclearinghouse.org/resources_develop.cfm. Accessed July 2016.

41

Carter, D., R. Srinivasan, F. Gross, and F. Council (2012), *Recommended Protocols for Developing Crash Modification Factors*, Prepared as part of NCHRP Project 20-07 (Task 314), Washington, D.C. Available at http://www.cmfclearinghouse.org/resources_develop.cfm. Accessed July 2016.

42

Elvik, R. (2011a), Assessing Causality in Multivariate Accident Models, *Accident Analysis and Prevention*, Vol. 43, pp. 253-264.

safety. Truly experimental studies are not common in road safety partly because of potential liability considerations (i.e., a random selection may result in an agency being held liable for failing to treat some sites that have demonstrated high crash history). Observational studies are more common in countermeasure evaluations because most transportation agencies prioritize installation sites based on some kind of past safety performance (see Step 1, Network Screening).

Observational studies of countermeasures can be broadly classified into cross-sectional studies and before-after studies. In cross-sectional studies, an analyst compares a group of sites with a certain feature to a group of sites without that feature. For example, an analyst might compare the safety performance of a group of stop-controlled intersections to that of a group of yield-controlled intersections to determine the effect of the type of traffic control on crashes. Cross-sectional studies can also be thought of as "with/without" studies. In before-after studies, an analyst takes a group of sites and compares the safety performance in the period before a countermeasure is implemented to the period after the countermeasure is implemented. For example, in a before-after study, an analyst could evaluate the effect of converting a stop-controlled intersection to a roundabout by comparing safety data before the roundabout conversion to the safety data afterwards.

CMFs that result from cross-sectional studies are not considered to be as robust as those resulting from a before-after study. In a typical before-after study, an analyst deals with same roadway unit located in a particular place, most likely used by the same road users during the before and after period. Since most of these factors can be assumed to be constant or almost constant in the before and after periods, they are less likely to cause significant biases. On the other hand, "cross-sectional studies compare different roads, used by different road users, located at different places and subject to different weather conditions. Besides, these roads will differ in very many other ways that are not measured."[43] However, there are issues in both types of studies that need to be addressed, and they are briefly discussed below.

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Elvik, R. (2011a), Assessing Causality in Multivariate Accident Models, *Accident Analysis and Prevention*, Vol. 43, pp. 253-264.

Cross sectional studies

Analysts use cross-sectional studies to compare the safety of a group of sites with a feature with the safety of a group of sites without that feature. The resulting CMF can be derived by taking the ratio of the average crash frequency of sites with the feature to the average crash frequency of sites without the feature. For this method to work, the two groups of sites should be similar in their characteristics except for the feature. In practice, this is difficult to accomplish and multiple variable regression models are used. These cross-sectional models are also called SPFs. The coefficients of the variables from these equations are used to estimate the CMF associated with a treatment.

Guidance from FHWA on developing CMFs says that "the basic issue with the cross-sectional design is

Using cross-sectional modeling to calculate a CMF for widening shoulders

A CMF can be obtained from a cross sectional model. Suppose the intent is to estimate the CMF for shoulder width based on the following SPF, which was estimated to predict the number of crashes per mile per year on rural two-lane roads in mountainous roads with paved shoulders (Appendix B of Srinivasan and Carter, 2011[44]):

$$Y = \exp\left[0.8727 + 0.4414 \times \ln\left(\frac{AADT}{10000}\right) + 0.4293 \times \left(\frac{AADT}{10000}\right) - 0.0164 \times SW \right]$$

Where, AADT is the annual average daily traffic and SW is the width of the paved shoulder in feet. If the intent is to estimate the CMF of changing the shoulder width from three to six feet, then the CMF can be estimated as the ratio of the predicted number of crashes when the shoulder width is six feet to the predicted number of crashes when the shoulder width is three feet:

$$CMF = \frac{\exp\left[0.8727 + 0.4414 \times \ln\left(\frac{AADT}{10000}\right) + 0.4293 \times \left(\frac{AADT}{10000}\right) - 0.0164 \times 6 \right]}{\exp\left[0.8727 + 0.4414 \times \ln\left(\frac{AADT}{10000}\right) + 0.4293 \times \left(\frac{AADT}{10000}\right) - 0.0164 \times 3 \right]}$$

This ratio simplifies to:

$$CMF = \exp[-0.0164 \times (6-3)] = 0.952$$

This CMF of 0.952 indicates that changing the shoulder width from three to six feet would be expected to reduce crashes (since the CMF is less than 1.0). Specifically, the expected change in crashes would be a 4.8% reduction (1.0 – 0.952 x 100 = 4.8).

However, it is important to recognize that this CMF of 0.952 is the midpoint in a range of possible values (i.e., the confidence interval). This range can be calculated by using the standard deviation of the CMF. In order to estimate the standard deviation, the standard error of the coefficient of SW is needed, which was reported to be 0.0015 in the original study. The high and low ends of the confidence interval are calculated using -0.0164+0.0015, and then using -0.0165-0.0015, and the difference between the two is divided by two. The equation is given below:

$$StDev(CMF) = \frac{\exp[-0.0164+0.0015 \times (6-3)] - \exp[-0.0164-0.0015 \times (6-3)]}{2} = 0.004$$

The approximate 95% confidence interval for the CMF is (0.952-1.96×0.004, 0.952+1.96×0.004), which translates to a range of 0.944 to 0.960. Since the entire 95% confidence interval is below 1.0, the CMF is statistically significant, thereby indicating that widening the shoulder from three to six feet is very likely to reduce crashes.

that the comparison is between two distinct groups of sites. As such, the observed difference in crash experience can be due to known or unknown factors, other than the feature of interest. Known factors, such as traffic volume or geometric characteristics, can be controlled for in principle by estimating a multiple variable regression model and inferring the CMF for a feature from its coefficient. However, the issue is not completely resolved since it is difficult to properly account for unknown, or known but unmeasured, factors. For these reasons, caution needs to be exercised in making inferences about CMFs derived from cross-sectional designs. Where there are sufficient applications of a specific countermeasure, the before–after design is clearly preferred."[45]

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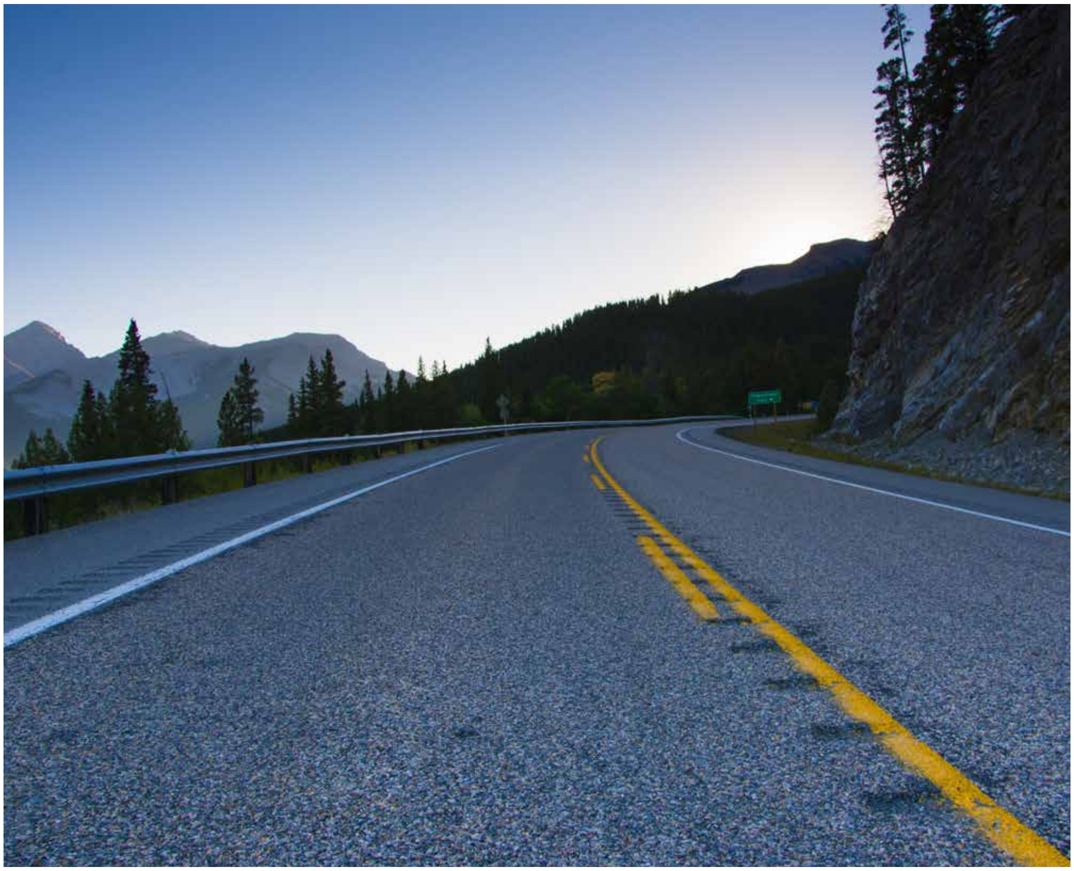
Srinivasan, R. and D. Carter (2011), *Development of Safety Performance Functions for North Carolina*, Report FHWA/NC/2010-09, Submitted to NCDOT, December 2011.

45

Gross, F., B. Persaud, and C. Lyon (2010), *A Guide for Developing Quality Crash Modification Factors*, Report FHWA-SA-10-032, Federal Highway Administration, Washington, D.C. Available at http://www.cmfclearinghouse.org/resources_develop.cfm. Accessed July 2016.



One way to account for some of the limitations of cross-sectional regression models is to use the propensity scores-potential outcome method. This method uses the "individual traits of a site to calculate its propensity score, defined as a measure of the likelihood of that site receiving a specific treatment. Sites with and without the treatment are then matched based on their propensity scores."[46] The matched data are then used to estimate a cross sectional regression model. The propensity score method has been shown to reduce selection bias by accounting for the non-random assignment of treatment sites.[47] Recently, the propensity score method is starting to be used in place of traditional cross-sectional methods to conduct evaluations.[48]

Other types of cross-sectional methods include case control and cohort methods. "Case-control studies select sites based on outcome status (e.g., crash or no crash) and then determine the prior treatment (or risk factor) status within each outcome group."[49] Another critical component of many case-control studies is the matching of cases with controls in order to control for the effect of confounding factors. In cohort studies, sites are assigned to a particular cohort based on current treatment status and followed over time to observe exposure and event frequency. One cohort may include the treatment and the other may be a control group without the treatment. The time to a crash in these groups is used to determine a relative risk, which is the percentage change in the probability of a crash given the treatment.[50]

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Gooch, J.P., Gayah, V.V., and Donnell, E.T. (2016), Quantifying the Safety Effects of Horizontal Curves on Two-Way, Two-Lane Rural Roads, *Accident Analysis and Prevention*, Vol. 92, pp. 71-81.

47

Holmes, W.M., (2013). *Using Propensity Scores in Quasi-Experimental Designs*. SAGE Publications.

48

Wood, J., Porter, R., (2013). Safety impacts of design exceptions on non-freeway segments. *Transport. Res. Rec.: J. Transport.* Res. Board 2358, 29–37.

49

Gross, F., B. Persaud, and C. Lyon (2010), *A Guide for Developing Quality Crash Modification Factors*, Report FHWA-SA-10-032, Federal Highway Administration, Washington, D.C. Available at http://www.cmfclearinghouse.org/resources_develop.cfm. Accessed July 2016.

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See next page.

Before after studies

An analyst can use a before-after study to evaluate a countermeasure by comparing the crashes before the countermeasure was installed to the crashes after installation. This study design is advantageous because the only change that has occurred at the site is the countermeasure installation (assuming the analyst has researched the site histories to discard any sites at which other significant changes occurred).

There are issues for consideration with this study design as well. The analyst must know when the countermeasure was installed and must have data, such as crash and traffic volume, available in the before and after periods. For high-cost, high-profile countermeasures, such as road widening or traffic signal installation, the installation records will be readily available. However, for low-cost countermeasures, such as sign installations, there may be little to no documentation on when they were installed.

The analyst might simply compare the number of crashes per year before the countermeasure to the number of crashes per year after the countermeasure, known as a simple or naïve before-after evaluation. Although a simple before-after evaluation can be done easily using only crash data, it is prone to significant bias. One of the most influential biases for this method is the possible bias due to RTM. As discussed earlier, 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 are vulnerable to the RTM bias. This potential bias 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. A simple before-after evaluation has a high likelihood of showing a much greater benefit from the safety treatment than actually occurred.

As discussed earlier under the network screening section, the EB method is one of the methods that has been found to be effective in dealing with the possible bias due to RTM. The following steps are needed to conduct an EB before-after evaluation:

1. **IDENTIFY** a reference group of sites without the treatment, but similar to the treatment sites in terms of the major factors that affect crash risk including traffic volume and other site characteristics. One way to identify a reference group that is similar to the treatment is to use the propensity score method discussed earlier under cross-sectional studies.
2. Using data from the reference site, **ESTIMATE** SPFs using data from the reference sites relating crashes to independent variables, such as traffic volume and other site characteristics. As discussed in the following steps, SPFs are used in the EB method to predict the average number of crashes based on AADT and site characteristics. By selecting the reference group to be similar to the treatment group in terms of the major risk factors, we can reduce the possible bias due to confounding on these predictions.

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Carter, D., R. Srinivasan, F. Gross, and F. Council (2012), *Recommended Protocols for Developing Crash Modification Factors*, Prepared as part of NCHRP Project 20-07 (Task 314), Washington, D.C. Available at http://www.cmfclearinghouse.org/resources_develop.cfm. Accessed July 2016.

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Srinivasan, R. et al., *Evaluation of Safety Strategies at Signalized Intersections*, NCHRP Report 705, Washington, DC.

Using an EB before-after evaluation to develop a CMF for signal phasing changes

This example is an illustration of an EB before-after evaluation that was conducted as part of NCHRP Project 17-35.[51] The countermeasure was a change from permissive to protected-permissive left turn phasing at signalized intersections in North Carolina. Data from twelve locations were used in this evaluation. A reference group of 49 signalized intersections was identified for the development of SPFs. The analysis looked at total intersection crashes, injury and fatal crashes, rear end crashes, and left turn opposing through (LTOT) crashes. In this example, only the data for LTOT crashes will be used.

The SPF for LTOT crashes based on the data from the reference group was:

$$\text{LTOT crashes/intersection/year} = e^{-0.3696}\,(\text{MajAADT}/10000)^{0.5564}\,e^{0.6585\times(\text{MinAADT}/10000)}$$

Where, MajAADT is the major road AADT and the MinAADT is the minor road AADT. The overdispersion parameter (k) for this SPF was 0.5641.

In the first site of this study, there were 10 observed crashes in the before period (X_b), and the predicted number of crashes from the SPF in the before period was 5.535 (P_b). The formula for obtaining the EB estimate of the expected crashes in the before period (EB_b) is as follows:

$$EB_b = w \times P_b + (1 - w) \times X_b$$

Where, X_b is the observed crashes in the before period, and w is the EB weight that is calculated as follows:

$$w = \frac{1}{(1 + k \times P_b)}$$

Where, k is the overdispersion parameter for the estimated SPF.

In this example:

$$w = \frac{1}{(1 + 0.5641 \times 5.535)} = 0.243$$

The EB estimate of the crashes in the before period (EB_b) = 5.535*0.243 + 10*(1-0.243) = 8.917 crashes.

The predicted number of crashes from the SPF in the after period was 11.391 (P_a).

The formula for the EB expected number of crashes that would have occurred in the after period had there been no countermeasure is given by:

$$\pi = EB_b \times (P_a / P_b)$$

In this example, the EB expected number of crashes in the after period had the countermeasure not been implemented (π) is equal to:

$$8.917 \times (11.391 / 5.535) = 18.350 \text{ crashes}$$

The variance of this expected number of crashes is also estimated in this step:

$$Var(\pi) = \pi \times (P_a / P_b) \times (1 - w)$$

Where, P_a is the SPF predictions in the after period. In this example, the variance of $\pi\pi$ is estimated as follows:

$$Var(\pi) = 18.350 \times (11.391 / 5.535) \times (1 - 0.243) = 28.603$$

This process was repeated for all 12 sites. Based on the data for all the 12 sites that were used in the evaluation, the actual crashes in the after period were 115, the EB expected crashes had the countermeasure not been implemented was 131.933 with a variance of 140.080.

(continued on next page)

The formula for the CMF and its standard deviation (StDev) are as follows:

$$CMF = \frac{\frac{\lambda_{sum}}{\pi_{sum}}}{1 + \frac{Var(\pi_{sum})^2}{\pi^2_{sum}}}$$

$$StDev(CMF) = \sqrt{\frac{CMF^2 \frac{Var(\lambda_{sum})}{\lambda^2_{sum}} + \frac{Var(\pi_{sum})}{\pi^2_{sum}}}{(1 + \frac{Var(\pi_{sum})}{\pi^2_{sum}})^2}}$$

Where, λ_{sum} is the total number of crashes that occurred in the after period, for all the treated sites in the sample, π_{sum} is the total number of expected crashes in the after period had the countermeasure not been implemented, and Var represents the variance. Since crashes are assumed to be Poisson distributed, $Var(\lambda_{sum})$ is usually assumed to be equal to λ_{sum}. So, $(Var(\lambda_{sum}))/(\lambda_{sum}^2)$ will be equal to $1/\lambda_{sum}$.

In this example, the overall CMF was calculated as:

$$CMF = \frac{\frac{115}{131.933}}{1 + \frac{140.080}{131.933^2}} = 0.865$$

This CMF of 0.865 indicates that the countermeasure (changing from permissive to protected-permissive left turn phasing) would decrease crashes, since the CMF is less than 1.0. It would be expected to decrease crashes by 13.5% (1.0 – 0.865 x 100 = 13.5).

Again, it is important to recognize that the CMF is the midpoint of a range of possible values (i.e., the confidence interval). The standard deviation of the CMF can be estimated as follows:

$$StDev(CMF) = \sqrt{\frac{0.865^2 (\frac{1}{115} + \frac{140.080}{131.933^2})}{(1 + \frac{140.080}{131.933^2})^2}}$$

$$= 0.111$$

Based on this standard deviation of the CMF, the approximate 95% confidence interval is (0.865-1.96×0.111, 0.865+1.96×0.111), which translates to a range of 0.647 to 1.083. Since this confidence interval includes values greater than 1.0, the CMF is not statistically different from 1.0 at the 95% confidence level. This indicates that there is less confidence that this countermeasure will reduce crashes compared to a countermeasure whose CMF is significantly different from 1.0.

3. In estimating SPFs, **CALIBRATE** annual SPF multipliers to account for the temporal effects (e.g., variation in weather, demography, and crash reporting) on safety. The annual SPF multiplier is the ratio of the observed crashes to the predicted crashes from the SPF. In using the annual SPF multipliers from the SPFs to account for temporal effects, it is assumed that the trends in the crash counts are similar in the treatment and reference groups.
4. **USE** the SPFs, annual SPF multipliers, and data on traffic volumes for each year in the before period for each treatment site to estimate the number of crashes that would be predicted for the before period in each site.
5. **CALCULATE** the EB estimate of the expected crashes in the before period at each treatment site as the weighted sum of the actual crashes in the before period and predicted crashes from Step 4.
6. For each treatment site, **ESTIMATE** the product of the EB estimate of the expected crashes in the before period and the SPF predictions for the after period divided by these predictions for the before period. This is the EB expected number of crashes that would have occurred had there been no treatment. The variance of this expected number of crashes is also estimated in this step.

The expected number of crashes without the treatment along with the variance of this parameter and the number of reported crashes after the treatment is used to calculate the CMF and the standard deviation of the CMF. This procedure is repeated for each treated site. Once CMFs have been calculated for each individual site in a group of treated sites, the CMFs can be combined to calculate the overall effectiveness of the countermeasure. More details on this procedure are provided in the previously mentioned guidance documents.[52,53]

In some cases, treatments may be installed system-wide for a particular type of facility. For example, a jurisdiction may decide to increase the retroreflectivity of all their stop signs. Since sites are not specifically selected based on their crash history, the bias due to RTM is minimal. However, it is still necessary to account for changes in traffic volume and other trends. To evaluate the safety of such installations, an EB method could still be used, and while a reference group is not necessary, a comparison group is necessary in order to account for trends. SPFs can be estimated using the before-data from the treatment sites and these SPFs can be used to account for changes in traffic volumes. In addition, SPFs could be estimated for a group of comparison sites and the annual factors from these SPFs can be used to account for trends. Further details about such evaluations can be found elsewhere.[54]

52

Gross, F., B. Persaud, and C. Lyon (2010), *A Guide for Developing Quality Crash Modification Factors*, Report FHWA-SA-10-032, Federal Highway Administration, Washington, D.C. Available at http://www.cmfclearinghouse.org/resources_develop.cfm. Accessed July 2016.

53

Carter, D., R. Srinivasan, F. Gross, and F. Council (2012), *Recommended Protocols for Developing Crash Modification Factors*, Prepared as part of NCHRP Project 20-07 (Task 314), Washington, D.C. Available at http://www.cmfclearinghouse.org/resources_develop.cfm. Accessed July 2016.

54

B. Persaud and C. Lyon (2007), Empirical Bayes Before After Studies: Lessons Learned from Two Decades of Experience and Future Directions, *Accident Analysis and Prevention*, 39(3):546-55.

System-Level Safety Management

System-level safety management involves addressing road safety issues that affect the broad transportation system, as opposed to treating specific high priority sites. The size and scope of the transportation system depends on the agency or jurisdiction. For a State DOT, the transportation system would consist of all State-owned roads, signals, bridges, and other features across the entire State, whereas the transportation system for a town would consist of a much smaller area and roadway network. Road safety at a system-level often has to do with policies, whether design policies for the construction and operation of roads and intersections, driver policies for licensing, or vehicle policies that require certain safety technologies. Other system-level efforts would include broad media or enforcement campaigns.

Recall that Chapter 10 presented road safety management in terms of three general components:

- **Identifying safety problems**
- **Developing potential safety strategies**
- **Selecting and implementing strategies**

This chapter will discuss how each of these components can be addressed at a system-level.

System-wide vs. systemic?

System-wide is a general term that refers to treating safety issues across an entire transportation system using policies or campaigns. Systemic is a more specific term that refers to identifying a subset of a transportation system based on risk factors and implementing safety efforts that address the particular characteristics of that subset. See page 4-41 for more discussion on the systemic approach.

Identifying safety problems

To identify safety problems on a system-level, safety professionals analyze safety data that apply to the entire jurisdiction. They examine crash data and link crashes to other safety data to determine the nature and locations of safety problems. Problem identification on a system-level involves identifying crash trends and using risk-based methods to prioritize safety efforts.

Identifying crash type trends

Safety professionals can examine crash types and contributing factors to determine the nature of crashes within their agency's jurisdiction. This type of examination may reveal crash trends, such as those related to alcohol involvement, seat belt use, driver age, or vulnerable road users. For example, crash data might show that crashes involving unbelted occupants have been increasing over the past several years, or it might show that the number of crashes involving unbelted occupants is significantly higher than other nearby agencies, such as adjacent counties or States. This would lead an agency to consider how to increase seat belt use, perhaps through media campaigns, increased enforcement, or educational campaigns in schools. This type of agency-wide analysis of crash data can demonstrate broad scale trends that need to be addressed through broad scale efforts.

It is important that safety professionals are specific when identifying safety problems in crash trends. For example, "crashes involving teen drivers" is not defined well enough, because the causes of crashes for 16 year-olds is markedly different from those of older, more experienced teens. Crashes in which teens are victims of other drivers' errors require different solutions from those where the teen was at fault. Similarly, the cause of crashes depends greatly on the specific time, place and driving environment. A better target crash type would be "crashes occurring between 7-9 a.m. involving 16-year old drivers."

Florida's emphasis on motorcyclist safety

The State of Florida examined its crash data to identify emphasis areas in the development of their SHSP in 2012. One area that continued to be a focus was motorcyclist safety. The data indicated that crashes involving motorcycles had decreased somewhat during the time period analyzed (2006 to 1010) but remained a significant portion of the crashes on Florida roads. Florida's safety professionals recognized that since Florida hosts numerous national motorcycle events, the state's SHSP should have motorcycle safety as an emphasis area.

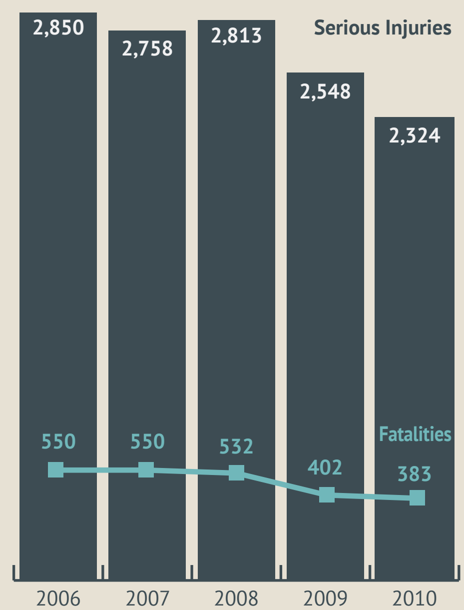

FIGURE 4-8. Florida motorcycle crash trend 2006-2010

Strategic highway safety plan

A statewide-coordinated safety plan that provides a comprehensive framework for reducing highway fatalities and serious injuries on all public roads.

Example of safety problem identification in State Highway Safety Plans

A good example of identifying safety problems from crash type trends can be seen in how States develop **strategic highway safety plans** (SHSPs). The development of a SHSP involves the identification of safety problems on the State and local roads. A State analyzes safety data to determine the priorities, referred to as emphasis areas. The analysis can involve an examination of crash proportions between categories of crashes, crash trends, crash severity (e.g., fatal and serious injury), or more advanced crash modeling techniques. As presented in the call-out boxes, Ohio and Florida conducted analyses of their crash data and identified areas of concern.

Ohio's emphasis on older driver safety

Ohio developed a SHSP in 2014 in which they identified fifteen emphasis areas. One of the emphasis areas was the safety of older drivers (65 and older). The crash data showed that older driver-related crashes accounted for 18% of highway deaths and 16% of serious injuries. They recognized that these numbers would likely increase with an aging population. The crash trends over the time period examined (2003 to 2013) showed a slight upward trend to older driver serious injuries and a slight downward trend to older driver fatalities. This contrasted to other types of crashes that experienced significant declines. These reasons motivated Ohio to make older driver safety an emphasis area in their 2014 SHSP.

Risk based prioritization – the systemic approach

Chapter 11 presented various methods of selecting high priority sites through a process of network screening based on crash data. Many safety professionals recognize that this process of identifying specific locations using past crash data does not adequately address the fact that there may be locations that pose a safety threat but have not yet experienced many (or any) crashes. This recognition led to an increased use of risk-based prioritization, also called the **systemic** approach.[55]

In this approach, a transportation agency identifies priority locations based on the presence of risk factors rather than crashes. In the medical field, doctors pay attention to factors that may elevate a person's risk for disease. A history of smoking, poor eating habits, and a lack of exercise may indicate a higher-than-average risk for heart disease, even if the person has not yet experienced heart problems. Similarly, a section of road with certain characteristics, such as sharp curvature, old pavement, or lack of visibility, may be at risk for run-off-road crashes, even if none have occurred yet. Agencies can be proactive in their approach to safety management by identifying and treating these sites before crashes occur. These treatments are often low cost, such as signs and markings, so many systemic-identified locations can be treated within an agency's limited budget.

An agency using the systemic approach selects the focus crash type(s) and identifies risk factors associated with the focus crashes. Risk factors are site characteristics (e.g., design and operational features) that are common across

Systemic

The process of identifying road or intersection characteristics that increase the risk of crashes and selecting locations for safety treatment based on the presence of these risk factors.

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http://safety.fhwa.dot.gov/systemic/

locations with the focus crash type(s). The agency can identify risk factors by analyzing crash data from their jurisdiction or by reviewing previous research studies. Using the list of risk factors as a guide, the agency identifies a list of sites with those specific characteristics, and then develops targeted treatments to address or mitigate the specific risk factors. The agency can apply crash history and other thresholds to reduce the list of sites based on available resources and program objectives.

The systemic approach has two attractive features. First, an agency can employ the systemic approach even for roads or intersections where crash data are not fully available (e.g., where location accuracy is questionable or underreporting is a problem). For instance, locating crashes accurately and precisely in rural areas or on non-State owned urban roads can be difficult. Second, the systemic approach is useful for treating safety issues where crashes are highly dispersed, such as on rural or low volume roads. Specifically, agencies can use the systemic approach to address existing and potential safety issues across a large portion of the network (e.g., shoulder rumble strips on all rural, two-lane roads with a certain shoulder width and traffic volume level).

Developing potential safety strategies

After safety professionals analyze data and identify safety problems, they must develop potential strategies to address the problems. It is important to engage safety stakeholders and other partners when selecting potential strategies as they may provide unique perspectives. Safety professionals should seek to involve local officials, citizens, and safety partners to produce effective multidisciplinary strategies. For example, addressing a particular safety problem with law enforcement and education can be far more economical than implementing a multimillion-dollar engineering fix. On the other hand, law enforcement tends to be effective only during the time in which it is active, so a more permanent engineering measure may be needed in some cases. It is often the case that a combination of strategies is necessary to effectively address the multitude of contributing factors.

On a system level, agencies must think broadly across the many disciplines represented by those who have a stake in road safety. Potential strategies might address infrastructure policies and practices (e.g., design standards, speed limits, etc.) or they may be directed at specific population focused efforts (e.g., seat belt laws, helmet laws, young driver restrictions, etc.).

Just as the identification of problems was based on safety data, so too must the development and selection of strategies be driven by the data. If an agency identified concerning trends in certain types of crashes, then they should further examine the crash data to determine how best to address the safety problem. For example, Figure 4-9 shows an example of alcohol-related crashes where an agency identified a spike in frequency (or high pole) of crashes occurring near 2:00 AM. Further examination revealed that bars in

Case Study: Systemic Analysis in Thurston County, Washington

The Thurston County Public Works Department in Washington conducted a systemic safety analysis for their road network. Based on a review of severe crashes, Thurston County decided to focus on roadway departure crashes in horizontal curves on arterial and collector roadways when it found that:

1. Most of the severe crashes occurred due to roadway departures, and that
2. 81% of the severe curve /roadway departure crashes occurred on arterial and collector roads. Because this effort coincided with ongoing efforts to identify and upgrade warning signs for horizontal curves on their County road system, Thurston County chose to focus on currently signed horizontal curves.

Thurston County accessed an inventory of their roads and intersections through a database maintained by the Statewide County Road Advisory Board. In addition, Thurston County assembled crash data for the 2006-to-2010 timeframe from the Washington State DOT crash database. They linked the road, intersection, and curve data with crash data and used these data to identify risk factors. Thurston County assembled a list of 19 potential risk factors and then performed a descriptive statistics analysis to identify 9 risk factors for use in screening and prioritizing candidate locations. The identified risk factors were:

- **Roadway class of major rural collector**
- **Presence of an intersection**
- **Traffic volume of 3,000 to 7,500 annual average daily traffic**
- **Edge clearance rating of 3**
- **Paved shoulders equal to or greater than 4 feet in width**
- **Presence of a vertical curve**
- **Consecutive horizontal curves (windy roads)**
- **Speed differential between posted approach speed and curve advisory speed of 0, 5, and 10 miles per hour**
- **Presence of a visual trap (a minor road on the tangent extended)**

Thurston County decided that a risk factor could be worth one point or a one-half point. Those factors present in at least 30% of the severe (fatal and injury) crashes and overrepresented by at least 10% (when comparing the proportion of all locations with the proportion of severe crash locations) were used as a guideline to have a high confidence and assigned one point in the risk assessment process. The risk factors that had a lower confidence in their relative data were assigned one-half point.

Thurston County then tallied the number of risk factors present for each of the curves. The risk factor totals for the ten curves with the highest scores ranged from 4.5 to 6.0. All 270 signed curves were prioritized for potential low cost safety investments. They identified the following low-cost, low-maintenance countermeasures with documented crash reductions to implement at the selected locations:

- **Traffic signs** – enhanced curve delineation with the addition of chevrons and larger advance warning signs
- **Pavement markings** – dotted extension lines at intersections and recessed raised pavement markers
- **Shoulder rumble strips**
- **Roadside improvements** – object removal, guardrail, and slope flattening

Systemic analysis provided Thurston County a proactive, data-driven, and defensible approach to identifying curves for improvement prior to a severe crash occurring, rather than reacting after an incident has occurred.[56]

56 "Thurston County, Washington, Public Works Department Applies Systemic Safety Project Selection Tool" FHWA-SA-13-026, June 2013. http://safety.fhwa.dot.gov/systemic/

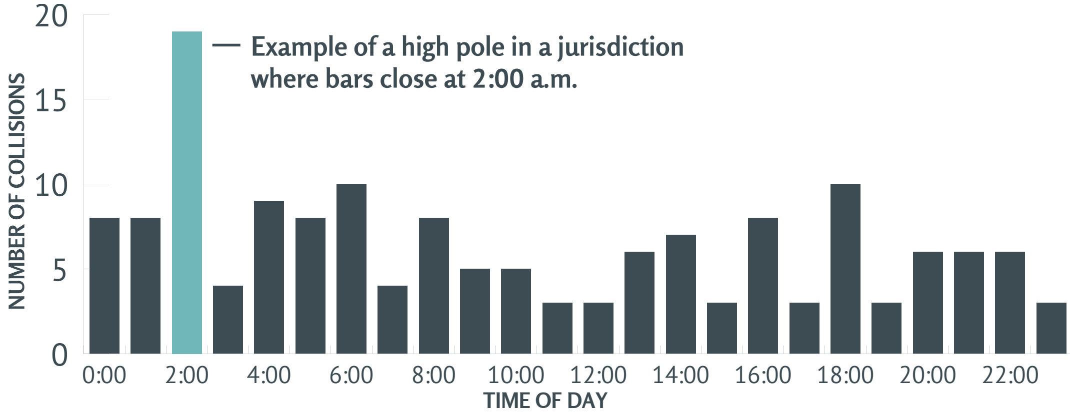

FIGURE 4-9. Example of "high pole" in crash data *(Source: NCHRP Report 501)*

that jurisdiction closed at 2:00 AM. This could lead to potential strategies, such as increased enforcement of impaired driving at that time of night and in the vicinity of bars.

It is also important to use the data to determine the necessary scope of the intervention. If the data show that the problem exists year-round, then the solution needs to match that. For example, a "safe ride program" for drinkers to get home on New Year's Eve is not going to significantly impact the problem of impaired driving overall.

Critical thinking is needed to develop effective solutions to the safety problems at hand. Analysts should look for characteristics of crash trends that could be addressed by practical strategies. An NCHRP report on an integrated safety management process states that safety professionals should use safety data to perform "further analyses of those characteristics that are found to be significantly or practically over-represented on a percentage or rate basis."[57] The report gives a set of guidelines to be considered in analyzing crash data to identify trends and develop potential safety strategies:

Consider How Specific Behaviors Influence the Safety Problem

Safety professionals must identify and target road user behaviors that contribute to the identified safety problem. The target behavior should be specific. For example, "safe driving" is not a specific behavior that can be changed because it involves a number of different behaviors. However, "speeding on Main Street" is a specific behavior that can be targeted. It is also important to consider the factors influencing this behavior. Why are people speeding on Main Street? Which social, cultural, or environmental factors are influencing this behavior? Does it vary by time of day or week, perhaps reflecting the kind of drivers who are speeding?

1. **ASK** the questions, "Is this information sufficient for action item development? If not, what further information is needed to act on this finding?"
2. **CONSIDER** cross tabulations of two variables within the subset of data that pertains to the activities under consideration if one or more of the following types of conditions hold:
   - If the activities are time critical (e.g., all selective

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Bahar, G., M. Masliah, C. Mollett, and B. Persaud, Integrated Safety Management Process, National Cooperative Highway Research Program, Report 501, Transportation Research Board of the National Academies, Washington, D.C., 2003 enforcement strategies), perform a time-of-day by day-of-the-week analysis. As an example, alcohol-related crashes will likely be over-represented in the early morning and on weekend days. A logical approach is to perform a cross tabulation of time-of day by day-of-the-week to determine the best times and days for driving under the influence (DUI) selective enforcement. The goal of the procedure at this point is to determine additional details (who, what, where, when, and how) for those crash types identified by the analyses performed to this point.

- If the over-represented variable is not constant over all crash severities, cross tabulate the variable by severity (e.g., nighttime, rural, and older-driver crashes tend to be more severe).
- If the activities can be targeted to geographic location, age group, gender, race, or any other demographic factor within the crash records, consider these variables for cross tabulation with other over-represented variables.

3. **CONSIDER** creating subsets of the data for additional comparisons where activities are to be targeted to a particular subgroup of the population. For example, insight into a graduated driver's license strategy can be obtained by comparing 16-year-old causal driver crashes against 17- to 20-year-old causal driver crashes. As another example, insight into youth alcohol enforcement activities can be attained by comparing alcohol-related crashes of 16- to 20-year-old causal drivers against alcohol-related crashes of their 21-year-old and older counterparts. Each of these types of comparisons can show differences between the respective subpopulations.
4. **USE** the results of each analysis to determine what further information is needed before the best decision can be made, and repeat the analysis with the additional information.
5. **PERSIST** and maintain a thread of evidence until the information available has been exhausted. If the information generated indicates a significant factor, create further subsets of the data (e.g., youth-pedestrian crashes), and repeat the entire analysis.
6. **REJECT** any strategies and activities at this point that the data clearly show to be counterproductive (i.e., activities that will consume resources that could be better applied elsewhere). Maintain a list of all potential strategies and corresponding activities that will be subjected to further analysis in the optimization procedure.[58]

Many system-level safety strategies focus on behaviors of drivers and other road users. Resources like Countermeasures That Work provide a useful listing of potential safety strategies for system-level safety management.[59] The excerpt from *Countermeasures That Work* in

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Bahar, G., M. Masliah, C. Mollett, and B. Persaud, Integrated Safety Management Process, National Cooperative Highway Research Program, Report 501, Transportation Research Board of the National Academies, Washington, D.C., 2003

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Goodwin, A., Thomas, L., Kirley, B., Hall, W., O'Brien, N., & Hill, K. *Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices*, Eighth edition, National Highway Traffic Safety Administration, Report No. DOT HS 812 202, Washington, DC, 2015.

FIGURE 4-10. Potential Safety Strategies to Address Speeding and Aggressive Driving

1. Laws

COUNTERMEASURE	EFFECTIVENESS	COST	USE	TIME
1.1 Speed limits	★★★★★†	$	High	Short
1.2 Aggressive driving laws	★☆☆☆☆	$	Low	Short

† When enforced and obeyed

2. Enforcement

COUNTERMEASURE	EFFECTIVENESS	COST	USE	TIME
2.1 Automated enforcement	★★★★★	$$$†	Medium	Medium
2.2 High-visibility enforcement	★★☆☆☆	$$$	Low††	Medium
2.3 Other enforcement methods	★★☆☆☆	Varies	Unknown	Varies

† Can be covered by income from citations

†† For aggressive driving, but use of short-term, high-visibility enforcement campaigns for speeding is more widespread

3. Penalties and Adjudication

COUNTERMEASURE	EFFECTIVENESS	COST	USE	TIME
3.1 Penalty types and levels	★★☆☆☆	Varies	High	Low
3.2 Diversion and plea agreements	★☆☆☆☆	Varies	Unknown	Varies

4. Communications and Outreach

COUNTERMEASURE	EFFECTIVENESS	COST	USE	TIME
4.1 Public Information supporting enforcement	★★★☆☆	Varies	Medium	Medium

Effectiveness:

★★★★★	Demonstrated to be effective by several high-quality evaluations with consistent results
★★★★☆	Demonstrated to be effective in certain situations
★★★☆☆	Likely to be effective based on balance of evidence from high-quality evaluations or other sources
★★☆☆☆	Effectiveness still undetermined; different methods of implementing this countermeasure produce different results
★☆☆☆☆	Limited or no high-quality evaluation evidence

Figure 4-10 gives a list of potential strategies for addressing speeding-related crashes, from either laws, enforcement, penalties and adjudication, or communications and outreach. The list also includes an indication of the effectiveness, cost, current usage, and time of each strategy, which are all important considerations when selecting safety strategies to implement.

If the agency identifies safety problems from a systemic analysis, the potential safety strategies should address the types of crashes that were related to the roadway characteristic risk factors. These strategies may often be engineering improvements related to the risk factors. For example, if an examination of crash trends may highlight run-off-road crashes, and a systemic analysis would identify the type(s) of road on which run-off-road crashes are likely to occur. Table 4-12 shows a list of potential safety strategies that could be implemented for engineering treatments for a run-off-road crash problem. In a systemic approach, these engineering treatments would be implemented across some or all roads meeting the risk factors that increase the likelihood of run-off-road crashes.

Example of system-level safety strategies in state highway safety plans

SHSPs provide many good examples of system-level strategies that address safety problems identified through analysis of crash and other safety data. The previous section showed how Ohio and Florida had identified safety priorities on older drivers and motorcyclists, respectively. The SHSPs from these States also demonstrated the types of safety strategies each State intended to pursue to combat the safety problems in these areas.

Florida's strategies for motorcyclist safety

After identifying motorcyclist safety as an emphasis area in their 2012 SHSP, Florida identified a list of strategies to address motorcyclist safety. Example strategies include:

- **Promote personal protective gear and its value in reducing motorcyclist injury levels and increasing rider conspicuity**
- **Promote adequate rider training and preparation to new and experienced motorcycle riders by qualified instructors at State-approved training centers**
- **Incorporate motorcycle-friendly policies and practices into roadway design, traffic control, construction, operation, and maintenance**
- **Develop and implement communications strategies that target high-risk populations and improve public awareness of motorcycle crash problems and programs.**

Selecting and implementing strategies

A transportation agency must determine which of the potential strategies they will implement to address the identified safety problems. Since system-level safety solutions can involve broad changes to policies, design practices, or jurisdiction-wide road user behavior, there are different issues to consider compared to implementing a safety countermeasure at a specific

OBJECTIVES	COUNTERMEASURES	RELATIVE COST TO IMPLEMENT AND OPERATE	EFFECTIVE-NESS
15.1 A: KEEP VEHICLES FROM ENCROACHING ON THE ROADSIDE	15.1A1: Install shoulder rumble strips	Low	Tried
	15.1 A2: Install edgelines "profile marking", edgeline rumble strips or modified shoulder rumble strips on section with narrow or no paved shoulders	Low	Experimental
	15.1 A5: Provide improved highway geometry for horizontal curves	High	Proven
	15.1 A6: Provide enhanced pavement markings	Low	Tried
	15.1 A7: Provide skid-resistance pavement surfaces	Moderate	Proven
15.1 B: MINIMIZE THE LIKELIHOOD OF CRASHING INTO AN OBJECT OR OVERTURNING IF THE VEHICLE TRAVELS OFF THE SHOULDER	15.1 B1: Design safer slopes and ditches to prevent rollovers	Moderate	Proven
	15.1 B2: Remove/relocate objects in hazardous locations	Moderate to High	Proven
15.1 C: REDUCE THE SEVERITY OF THE CRASH	15.1 C1: Improve design of roadside hardware	Moderate to High	Tried
	15.1 C2: Improve design and application of barrier and attenuation systems	Moderate to High	Tried

TABLE 4-12. Potential Safety Strategies for Run-Off-Road Crashes *(Source: NCHRP 500, Volume 6)*

location. Many more people will be affected by the system-level changes. This carries great promise in that safety might be improved across an entire system, but it also carries unique challenges.

Agencies will need to consider the following questions when selecting strategies to implement:

- **Safety effectiveness** – How likely will it address the safety problem?
- **Public acceptance** – How will the strategy be accepted by the public? What kind of marketing will be needed to communicate the intent and benefit of the strategy?
- **Stakeholders and partners** – Which parties will need to be involved in implementing the strategy?
- **Cost efficiency** – What kind of return on the dollar would be expected?
- **Time** – How long will it take to implement the strategy?

Communication is critically important for system-level safety strategies. Both the general public and road users affected by the strategy must understand the benefits. Other public agencies may need to integrate their efforts with the proposed safety strategy. Administrators, lawmakers, and other key decision-making personnel must understand how the strategy will improve road safety for their constituency and bring an overall financial benefit. Unit 5 provides more discussion on communication, marketing, and outreach for agencies who seek to implement system-level safety strategies.

Ohio's strategies for older driver safety

Ohio identified three strategies to address the older driver emphasis area in their 2014 SHSP:

- Coordinate older driver messages developed by multi-agency communication committee.
- Create a comprehensive and coordinated outreach effort that educates older drivers and their caregivers on driving risks and remedies.
- Encourage roadway design and engineering measures that reduce the risks of traffic crashes for older drivers.

Evaluating a system-level strategy (e.g., program or intervention) to determine its effectiveness is a critical but often overlooked step. The transportation agency in charge should evaluate the effect of the safety strategy using good quality data; ideally the same type of data that was used to identify the safety problem initially. If a program or intervention is not effective, the overseeing agency should consider why this might be the case. Can the program be improved, or should other approaches be considered instead? If successful, how can the intervention be institutionalized to ensure long term support (and therefore lasting change)? Finally, it is important to remember that success or failure in one location does not guarantee the same results at a different location.

Example of System-Level Safety Management

The following provides an example of using system-level safety management to address a specific problem. This example demonstrates the three general components of safety management presented in this unit.

1. Identify the safety problem.

County A noticed a large number of crashes involving 16–17 year old drivers occurring weekdays between 11:00am and 1:00pm. Neighboring counties have not experienced this problem. County officials coordinate with school district staff to tackle this issue.

In exploring the problem, the officials discover that County A is the only jurisdiction that has an open campus lunch policy allowing students to leave school during their lunch period. Allowing teens to leave campus during lunch means there are many young, inexperienced drivers on the roads at the same time. They may be carrying additional passengers which research has established leads to an increased risk of a fatal crash.[60,61] The brief lunch period also results in pressure to get back in time for the next class. Combined, these factors lead to a risky driving situation and an increased risk of crashing.

2. Develop potential safety strategies.

In this situation, an informational approach that simply tells teenagers about the problem would likely not make a difference. Teens are not crashing because they lack information about the importance of safe driving or the consequences of unsafe driving. Teens are crashing largely because they lack the driving experience that equips most drivers to intuitively/near instantaneously do the things necessary to avoid crashing. Because of this, changing the environment is more likely to be effective.

The officials recognize that eliminating the policy that allows students to leave campus during lunch would lead to a reduction in crashes during this time. This policy would eliminate exposure to the risky driving situation and reduce the potential for crashes.

3. Select and implement strategies.

The school districts accordingly eliminate the policy allowing students to leave campus during lunch. They recognize that this policy change should be evaluated to determine its safety effect. Crash data would be needed to examine whether the closed school lunch policy has an effect on weekday crashes between 11:00am and 1:00pm. However, it will take many years to accumulate enough data for this evaluation. In this example, there is a proxy measure that can be used in the interim. A before and after observational survey with an appropriate control could quantify the number of students leaving campus during lunch before and after the change. In this case the officials know that the proxy measure (reduced driving from 11:00am to 1:00 pm) is a guaranteed indicator of crash reduction for this specific problem. However, it is not often the case that proxy measures are so closely aligned to the outcome of interest.

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Tefft B.C., Williams A.F., & Grabowski J.G. (2013). Teen driver risk in relation to age and number of passengers, United States, 2007-2010. Traffic Injury Prevention, 14, 283-292.

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Chen, L., Baker, S.P., Braver, E.R., & Li, G. (2000). Carrying Passengers as a Risk Factor for Crashes Fatal to 16- and 17-Year-Old Drivers. Journal of the American Medical Association, 283, 1578-1582.

Unit Summary

Solving road safety problems requires a comprehensive process to identify safety problems, develop potential safety strategies, and select and implement those strategies. To get the most effective results, this process must be based on solid safety data, particularly good quality crash data. The methods of undertaking the safety management process will depend on the scope of the effort.

Safety management of individual sites involves a six-step process of screening the network for high-priority sites, diagnosing the safety issues at those sites, selecting appropriate countermeasures, conducting an economic appraisal for all options, prioritizing the countermeasure projects based on estimated costs and benefits, and evaluating the countermeasure performance afterwards. Safety management at a system-level involves identifying safety problems by examining crash trends or using a systemic approach to identifying high-risk road characteristics. State agencies who are developing system-wide safety strategies must examine the data trends and the road users involved. They must consider factors, such as how system-wide policies and programs will be accepted by the public and who will be the partners to involve in implementing the safety strategy.

EXERCISES

- **PRESENT** an example road safety problem and compare and contrast the ways in which the problem could be addressed at a system-level vs. site-level.

- Your state has a small, rural, mountainous county where a large number of motorcycle crashes are happening. The crash rate per registered motorcycle in this county is nearly 10 times the state average. Upon further investigation you learn that this county is a popular motorcycling tourist destination. People come from all over the country to ride the curvy mountain roads. In fact, the majority of people involved in crashes are not from that area at all. Clusters of crashes occur on certain curves. What are some approaches that could be used to reduce crashes in this county? How could these approaches be evaluated? In particular, **DETAIL** how you would apply the three major components described in this unit:

  - Identify the safety problem
  - Develop potential safety strategies
  - Selecting and implement strategies

  When you work through this process, recall the discussion of human behavior from Unit 2. What are possible behaviors leading to the safety problem? What other factors could be influencing this behavior? How does this affect your identification and selection of potential safety strategies?

- If possible, **OBTAIN** three to five years of crash data for an intersection or section of road in your area. You will likely need to contact the controlling agency – the State DOT, county, or city. Describe how you would apply the steps in Chapter 11 on site-level safety management to this location (the network screening step would not apply since this location is already identified). Consider safety strategies across a range of disciplines (e.g., engineering, law enforcement, public communication and education, etc.).

- This exercise should be conducting using the Excel spreadsheet that accompanies this book. The goal of this exercise is to **USE** selected performance metrics to create a ranked list of sites for further investigation as part of a network screening effort. The Excel spreadsheet includes nearly 1,400 intersections, or sites. Each site has a unique ID number, traffic volume data, and other information about its location and characteristics. Three performance metrics have been calculated for each site. These have been calculated using five years of data (2010-2014) and one year of data (2014), resulting in a total of six performance metrics per site. Your assignment is to rank the sites using these various performance metrics and document the results. Document the twenty highest priority sites based on each method. Use the results to answer the following questions:

  - What were some of the sites that routinely ranked in the top twenty? What were some of their characteristics (volumes, number of lanes, stop/signal control)?
  - Were there any sites that were only occasionally present in the top twenty? What were some characteristics of these sites?

Road Safety Fundamentals is available for free at:
https://rspcb.safety.fhwa.dot.gov/rsf/

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