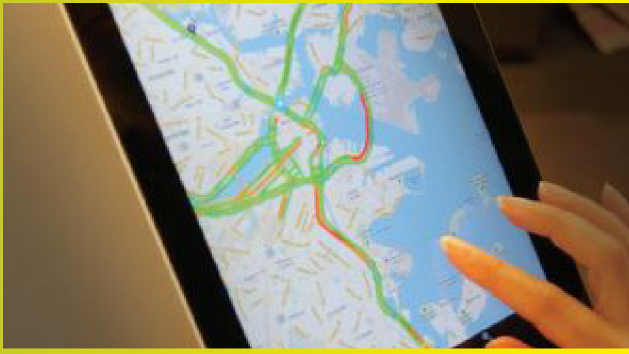
Selecting Projects and Strategies to Maximize Highway Safety Improvement Program Performance



FHWA Safety Program

U.S. Department of Transportation
Federal Highway Administration

ZERO IS OUR GOAL
A SAFE SYSTEM IS HOW WE GET THERE

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Foreword

The safety performance management framework is a strategic approach that relies on data-driven safety analysis methods to inform investment and policy decisions that will result in the greatest possible reduction in fatalities and serious injuries. States set annual safety performance targets to monitor and track progress towards the long-term goal of zero fatalities on our Nation's roads, and select projects and strategies to meet their safety performance goals and targets using various approaches.

The *Selecting Projects and Strategies to Maximize Highway Safety Improvement Program (HSIP) Performance Guide* explains how State departments of transportation, metropolitan planning organizations, and other agencies can use economic analysis methods and safety management approaches to have the greatest potential to reduce fatalities and serious injuries. The Guide discusses how projects affect safety performance, presents current approaches for highway safety management, and provides considerations for new economic methods and strategies that may improve upon current methods. While this Guide focuses on the HSIP and the State agencies that administer HSIP funds, it is applicable to other public agencies and infrastructure programs addressing highway safety. The framework and concepts may also be applicable to non-infrastructure safety programs.

Every phase of the HSIP and project development process has potential impacts on the resulting projects' safety performance. Ensuring that agencies are selecting projects and strategies to maximize HSIP performance will help us reduce fatalities and serious injuries across the country.

The methods and considerations presented in this Guide will be updated as we work to integrate Safe System principles into our existing safety programs and safety project identification and prioritization processes. Zero is our goal. A Safe System is how we get there.

Dana Gigliotti, Director Dana Gigliotti

Office of Safety Programs

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS

A	suspected serious injury crash
A/P	capital recovery factor
AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
BCR	benefit-cost ratio
CC	crash cost
CEI	cost-effectiveness index
CM Score	Countermeasure Score
CMF	crash modification factor
CONSTR	initial construction costs for a project
COTS	commercial-off-the-shelf (as in software products)
CRF	crash reduction factor
DDSA	data-driven safety analysis
DOT	Department of Transportation
EB	Empirical Bayes
FAST Act	Fixing America's Surface Transportation
FHWA	Federal Highway Administration
HSIP	Highway Safety Improvement Program
HSM	Highway Safety Manual
IBCA	incremental benefit-cost analysis
IDOT	Illinois Department of Transportation
INDOT	Indiana Department of Transportation
K	fatal injury crash
KABCO	injury scale used by law enforcement to report crash severity
KYTC	Kentucky Transportation Cabinet
LRSP	local road safety plan
MAP-21 Act	Moving Ahead for Progress in the 21st Century
MnDOT	Minnesota Department of Transportation
MoDOT	Missouri Department of Transportation
MPO	Metropolitan Planning Organization
NCDOT	North Carolina Department of Transportation
NHDOT	New Hampshire Department of Transportation
NPV	net present value
ODOT	Ohio Department of Transportation
O&M	operations and maintenance
PDO	property-damage-only
PE	preliminary engineering
PHB	pedestrian hybrid beacon

PSI	potential for safety improvement
PSIP	Pedestrian Safety Improvement Program
ROW	right-of-way
SaFID	Safest Feasible Intersection Design
SHSP	Strategic Highway Safety Plan
SPF	safety performance function
SSPST	Systemic Safety Project Selection Tool
STIP	Statewide Transportation Improvement Program
UDOT	Utah Department of Transportation
VMT	vehicle-miles traveled
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

The Highway Safety Improvement Program (HSIP) is a State-administered, core Federal-aid Highway Program with the purpose of achieving a significant reduction in traffic fatalities and serious injuries on all public roads. State Departments of Transportation and other highway agencies are responsible for the safety performance of their roadway networks, and they implement HSIP projects to reduce fatalities and serious injuries resulting from traffic crashes. Agencies can measure the performance of the HSIP in terms of various performance measures, including the following five Federally-mandated performance measures:

1. Number of fatalities.
2. Rate of fatalities per 100 million vehicle-miles traveled (VMT).
3. Number of serious injuries.
4. Rate of serious injuries per 100 million VMT.
5. Number of non-motorized fatalities and non-motorized serious injuries.

HSIP managers can maximize the program's expected safety performance by identifying and selecting a set of projects that has the highest overall potential to reduce future fatalities and serious injuries within the available program budget and eligibility criteria. Agencies can use data-driven safety analysis techniques to predict how well infrastructure projects are expected to perform and refine those predictions based on experience and evaluation. However, agencies cannot know a specific project's actual effectiveness until after it is implemented. HSIP performance is based on the predicted performance and range of potential effectiveness of the HSIP (along with external factors). Quantifying the predicted safety performance of potential HSIP projects and selecting and implementing those that maximize the estimated lives saved and injuries prevented improve the probability that a State maximizes its HSIP performance.

This guide presents fundamental analytical methods and a conceptual framework for maximizing the effectiveness of the HSIP by increasing the individual performance of its projects. The best-performing, most-cost-effective, highest-priority HSIP projects deliver the greatest reductions in fatalities and serious injuries at the lowest costs. To address fatal and serious-injury crashes, agencies should focus on the change in fatal and serious-injury crashes, rather than all crashes or all injuries, when selecting projects.

Agencies should prioritize and select HSIP projects using quantitative methods such as the benefit-cost ratio (BCR) when possible. When using the BCR to prioritize projects, agencies can consider estimating the benefits in terms of the dollar value of fatal and serious-injury crashes prevented. This approach focuses on the potential for projects to reduce fatal and serious-injury crashes. While the more reliable data-driven safety analysis methods are preferred for estimating the benefits, there are several alternative methods that analysts can use depending on the availability and quality of data. Estimating the benefits in terms of the dollar value of fatal and serious-injury crashes prevented helps to rank projects that are expected to deliver the greatest reductions in fatalities and serious injuries per dollar spent; however, it is recognized that decision makers may consider other factors not reflected in such predictions when selecting projects (e.g., distribution of projects across district offices, environmental impacts, public inputs, and opportunity to combine safety improvement with other capital improvements such as resurfacing), if appropriate.

Developing high-performing projects starts during planning. A State's Strategic Highway Safety Plan (SHSP) includes high-priority strategies aimed at reducing fatalities and serious injuries and guides the implementation of a State's HSIP. Optimizing the implementation of highly cost-effective countermeasures at sites with high potential for safety improvement maximizes the predicted performance of the HSIP.

FHWA's key findings from this research are as follows.

- Measure the performance of proposed programs or project selection scenarios in terms of expected lives saved and serious injuries prevented to help focus the HSIP on fatal and serious-injury crashes.
- Rank proposed projects by BCR based on the potential for reducing fatal and serious-injury crashes and select the highest ranked projects to offer the maximum predicted safety performance of the HSIP.
- Express the BCR in terms of potential monetary safety benefits and costs. Monetary potential for safety improvement measures a location's estimated contribution to the safety performance of a project independent of countermeasures. The countermeasure score measures a countermeasure's ability to impact the safety performance of a project independent of where it is implemented.
- Develop more planning-level safety performance functions (SPFs) and crash modification factors (CMFs) in terms of fatal and serious-injury crashes, average project costs (or range of costs), and other data that support the BCR_{KA} prioritization method.
- Use a combination of site-specific, systemic, and systematic approaches to develop high-performing projects to fit agency needs.

Agencies can use these findings and the HSIP to potentially help save more lives and prevent more serious injuries. While more complete and higher-quality data can help identify locations and projects with the greatest potential to improve safety, States can implement the concepts and methods of BCR prioritization with almost any level of data. Researchers can assist practitioners by developing new tools that apply these methods, as well as expanding the library of available SPFs and CMFs by severity level, and implemented countermeasure data.

CHAPTER 1. INTRODUCTION

Over 30,000 people have died annually on the nation's roadways since 1946.[(1)] States have been developing and administering Federally-funded highway safety programs since 1966 to implement highway safety engineering countermeasures.[(2,3)] The Highway Safety Improvement Program (HSIP) was then established in 2005 as core Federal-aid highway program with the purpose of achieving a significant reduction in traffic fatalities and serious injuries on all public roads. The HSIP is a State-administered program, and requires a data-driven, strategic approach to improving safety (23 U.S.C. 148(c)(2)(B)). In addition to HSIP funding, States can use other highway funding programs as well as education, enforcement, emergency medical services, legislation, and other initiatives to improve highway safety performance beyond the HSIP.[(3)]

The last three major Federal transportation authorizations[a] increased HSIP funding and expanded requirements for States to plan and implement the HSIP with an emphasis on performance. In response to Moving Ahead for Progress in the 21st Century Act (MAP-21) requirements that were continued in the Fixing America's Surface Transportation (FAST) Act, the Federal Highway Administration (FHWA) established the following five Federally-required performance measures for States to use to carry out the HSIP as well as assess and report on program performance.[(4)]

1. Number of fatalities.
2. Rate of fatalities per 100 million vehicle-miles traveled (VMT).
3. Number of serious injuries.
4. Rate of serious injuries per 100 million VMT.
5. Number of non-motorized fatalities and non-motorized serious injuries.

State Departments of Transportation (DOTs) and metropolitan planning organizations (MPOs) set targets for each performance measure annually and implement projects that have the greatest potential to reduce roadway fatalities and serious injuries (23 CFR Part 924.5(b)). State and local agencies plan, design, and implement infrastructure projects to reduce the number of fatalities and serious injuries; however, there may be opportunities to enhance current HSIP project planning and selection practices to further maximize program performance.

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[a] The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users in 2005, the MAP-21 in 2012, and the FAST Act in 2015.

1.1 OBJECTIVES AND SCOPE

The objective of this guide is to explain how State DOTs, MPOs, and other agencies can use economic analysis methods and safety management approaches to have the greatest potential to reduce fatalities and serious injuries. The guide discusses how projects affect safety performance, presents current approaches for highway safety management, and describes new economic methods and strategies that may improve upon current methods. While this guide focuses on the HSIP and the State agencies that administer HSIP funds, it is applicable to other public agencies and infrastructure programs addressing highway safety. The framework and concepts may also be applicable to non-infrastructure safety programs.

As part of the research efforts to develop this guide, the project team conducted interviews with HSIP managers from eight States and facilitated a focus group meeting with representatives from seven States. The project team followed up with select States after the initial discussions. *Appendix A: Research Materials* includes the questions asked during the interviews and focus group meeting as well as the list of participating States. The outcomes from these discussions supplemented a literature review and developmental research into new methods. This guide presents noteworthy practices from the interviews, focus group meeting, and literature review throughout.

1.2 AUDIENCE

The target audience for this guide is primarily program managers and analysts for the HSIP and similar programs. The guide is also applicable to highway agency executives that oversee, administer, and implement the HSIP and similar programs as well as researchers supporting safety management decision making.

1.3 GUIDE ORGANIZATION

This guide begins by discussing background information about the HSIP and its objectives. The following chapters present approaches and strategies that can help agencies select highway safety improvement projects to increase the number of lives saved and serious injuries prevented.

Chapter 2 discusses the HSIP and project development processes. Additionally, the chapter describes opportunities to improve economic analysis and project prioritization methods that States use to quantify how an HSIP project could cost-effectively improve safety performance. The chapter also discusses other opportunities to improve safety throughout project development.

Chapter 3 presents strategies relating to program management, safety planning, and project implementation that could improve or maintain HSIP performance.

Chapter 4 outlines fundamental benefit-cost analysis and project selection concepts that can help agencies develop programs with the greatest potential to reduce fatalities and serious injuries.

Chapter 5 further explains the concepts and analytical methods agencies could use to maximize the expected safety performance outcomes of the HSIP.

Chapter 6 compares the site-specific, systemic, and systematic approaches to safety management.

Chapter 7 presents two case studies that illustrate how agencies can apply the methods presented in this guide to prioritize projects.

Chapter 8 concludes by summarizing FHWA's findings and suggesting opportunities for improvement in future research and practice.

CHAPTER 2. MAXIMIZING HSIP PERFORMANCE AND MEETING SAFETY PERFORMANCE TARGETS

The States implement infrastructure countermeasures via the HSIP to reduce the frequency and severity of crashes. The HSIP also supports strategic safety planning, safety data and analysis improvements, and workforce development to better steward HSIP funding. The HSIP is a performance-based program, and the HSIP's performance is measured in terms of fatalities and serious injuries. HSIP projects can improve safety performance by directly (e.g., changes to physical infrastructure) or indirectly (e.g., data and analysis improvements) saving lives and preventing serious injuries.

Agencies can use data-driven safety analysis (DDSA) techniques and professional judgment to predict how well infrastructure projects are expected to perform and refine those predictions based on experience and evaluation. However, agencies cannot know a project's actual effectiveness until after it is implemented. Maximizing HSIP performance and meeting or exceeding safety performance targets is based on the predicted performance and range of potential effectiveness of the HSIP (along with external factors). Quantifying the safety performance of potential HSIP projects and selecting and implementing those that maximize the estimated lives saved and injuries prevented can improve the likelihood that the State meets its targets and achieves long term safety goals.

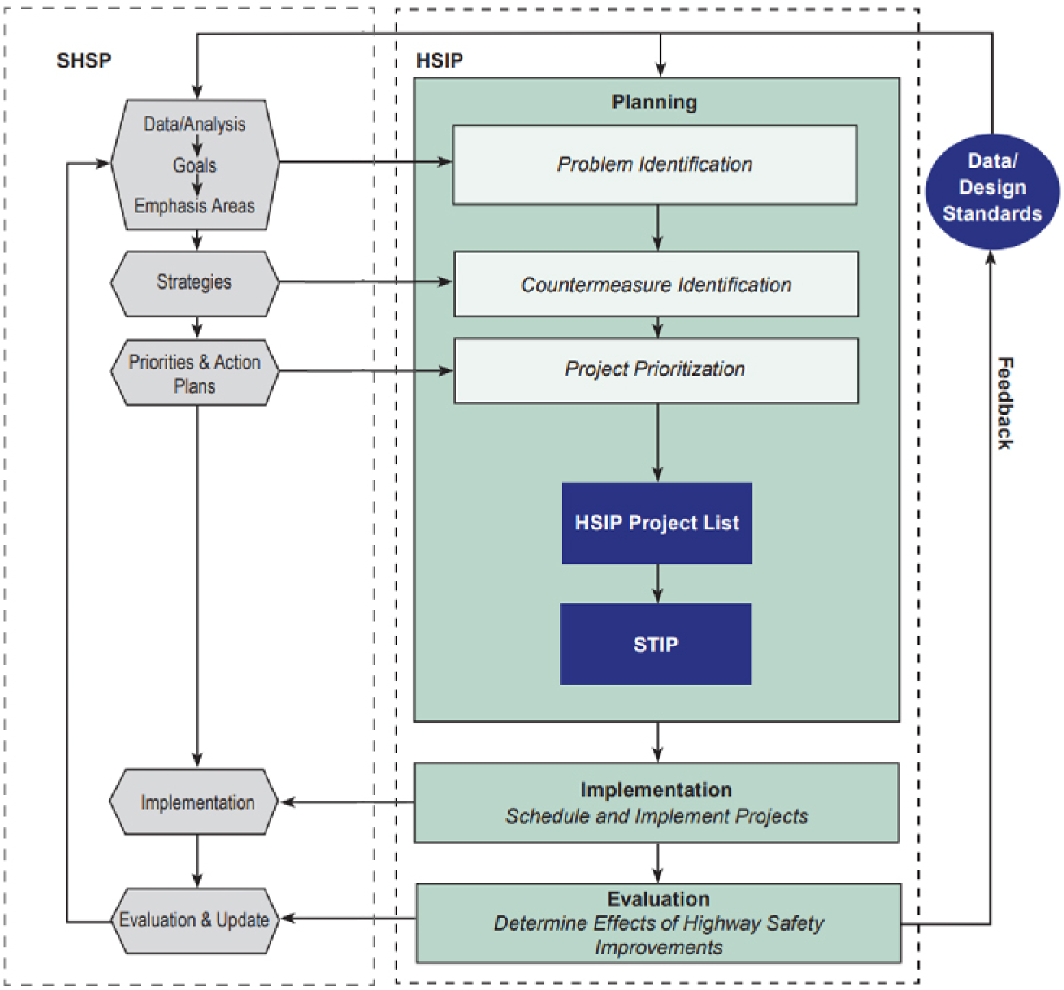
Since meeting or exceeding targets may depend on the magnitude of the targets and other external factors, this guide focuses on opportunities to "maximize HSIP performance" rather than simply meeting targets. HSIP managers can maximize the program's performance by identifying and selecting a set of projects that has the highest overall potential to reduce fatalities and serious injuries within the available program budget and eligibility criteria. Further, since each State's HSIP program consists of a fixed budget for safety improvement projects, this guide also considers "HSIP performance" and "HSIP performance per dollar spent" to be synonymous as well as "performance" and "economic performance."

The remainder of this chapter provides an overview of the HSIP process, how HSIP projects are developed, and opportunities to improve safety performance throughout project development.

2.1 HSIP PROCESS AND PROJECT DEVELOPMENT

The HSIP process, illustrated in figure 1, consists of planning, implementing, and evaluating effective safety countermeasures at locations with potential for safety improvement (PSI). This guide focuses on safety planning, which involves identifying candidate project locations, selecting appropriate countermeasures to address the safety issues at the site, and prioritizing and selecting proposed projects for the Statewide Transportation Improvement Program (STIP).[3]

Safety planning in the HSIP starts with a Strategic Highway Safety Plan (SHSP). The SHSP identifies the statewide goals, objectives, emphasis areas, and related strategies for reducing fatalities and serious injuries on all public roads. Emphasis areas usually represent either types of crashes that commonly result in fatalities and serious injuries or common contributing factors to fatal and serious-injury crashes. Within each emphasis area, stakeholders list strategies or countermeasures that they hope to implement over the next several years. All HSIP projects must be consistent with the State's SHSP (23 U.S.C. 148(c)(1)), so it is important that the SHSP include the types of engineering strategies and countermeasures that have the highest likelihood to improve safety performance. While the SHSP guides investment decisions in the HSIP, it also relies on the results from HSIP evaluations to inform future updates to the plan (i.e., continue using the strategies that work and consider new strategies when one does not perform well).



Source: FHWA

Figure 1. Graphic. HSIP process.[(3)]

The primary factors that influence a project's performance are the countermeasures implemented in the project and the location where the countermeasures are implemented. Agencies identify, propose, and select candidate projects using a wide range of safety management approaches and DDSA methods. Each State has variations in how they develop and implement highway safety improvement projects. The following is a brief overview of the most common safety management approaches in practice.

- **Site-specific approach:** The site-specific approach focuses on identifying locations based on crash experience (e.g., a high number or rate of crashes) and addressing the unique safety issues at each location. In 2010, the FHWA published the most recent *HSIP Manual* and the American Association of State Highway and Transportation Officials (AASHTO) published the *Highway Safety Manual* (HSM).[3,5] Both documents describe the site-specific approach and related methods.

- **Systemic approach:** The systemic approach focuses on addressing crash types that result in fatalities and serious injuries by identifying risk factors for those crashes and implementing countermeasures at locations where the risk factors are present. In 2013, FHWA published the *Systemic Safety Project Selection Tool* (SSPST), which presents a risk-based approach to safety management.[6] Although the systemic approach was not fundamentally new, the analytical methods in the *SSPST* and demonstrated effectiveness in practice spurred a large increase in systemic projects, with about 40 percent of HSIP funds spent on systemic safety projects from 2017-2019.[7]

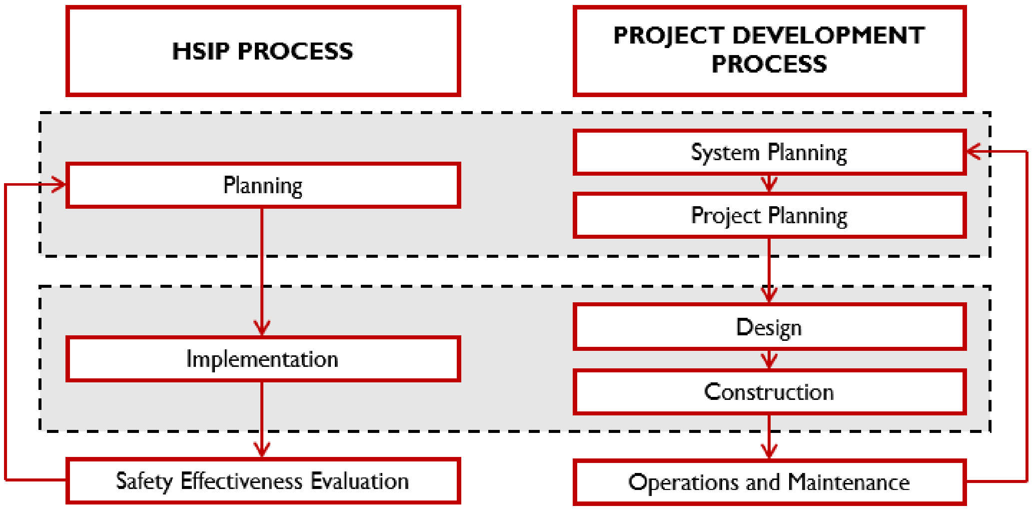
- **Systematic approach:** The systematic approach focuses on treating all eligible locations and is briefly explained in the SSPST. Some States use the systematic approach by incorporating safety countermeasures in design policies (e.g., implementing Safety Edge on all paving projects). Other States identify a proven countermeasure (e.g., curve warning signs, rumble strips, cable median barrier) and install it wherever feasible within a large, standalone project.[6,8]

The *FHWA HSIP Manual*, *HSM*, and many other resources discuss how agencies can apply strategic, data-driven methods to develop higher performing projects. To increase the State's potential to maximize HSIP performance, agencies should prioritize and select HSIP projects based on their potential to cost-effectively improve safety performance. Chapters 3-6 discuss various approaches and methods to maximize performance of the HSIP.

Employing more reliable methods to identify safety improvement opportunities, diagnose crash contributing factors, and select cost-effective countermeasures can help to improve the overall effectiveness and performance of the HSIP.

2.2 OPPORTUNITIES TO IMPROVE SAFETY PERFORMANCE

Once an agency programs projects and allocates resources to implement them, they enter the broader project development process (planning, design, construction, operations, and maintenance), shown in figure 2, which parallels the HSIP process.



Source: FHWA

Figure 2. Graphic. HSIP and project development processes.

Every phase of the HSIP and project development process has potential impacts on the resulting projects' safety performance. Table 1 identifies opportunities throughout the HSIP and project development processes to increase average project benefits and decrease program costs to maximize the cost-effectiveness of the program.

Table 1. Impacts of strategic planning and project development decisions on safety performance.

Development Phase	Potential Safety Performance Impacts from Decision Making
Selecting Emphasis Areas and Strategies	Emphasis area selection guides where funds can and should be spent. Selecting emphasis areas and strategies based on data helps invest funds effectively because HSIP projects must be consistent with the SHSP (23 U.S.C. 148(c)(1)).
Strategic Data and Analysis Improvement	An agency's ability to maximize HSIP performance or quantify their ability to do so is dependent on data and analysis. Data-driven programs and more reliable analysis methods help to select projects to maximize performance.
Program Management	Program management can define specific goals and strategies for funding allocation. Involving various stakeholders in program management and oversight improves program awareness and accountability for program goals.
Network Screening and Project Solicitation	Effective network screening identifies sites with high potential for safety improvement. Further investigation omits sites where projects are not feasible. Complete network screening (i.e., screening all public roads) and more reliable methods can maximize the opportunities to cost-effectively improve safety.
Diagnosis and Countermeasure Selection	Diagnosis helps to understand the underlying safety problems. Identifying targeted countermeasures helps to mitigate the contributing factors to severe crashes or reduce the severity of crashes that do occur. Further, kinetic energy transferred to people during crash events is the primary cause of fatal and serious injuries. Agencies can implement safe system principles to reduce conflict points (i.e., minimize the potential for crashes) and manage the transfer of kinetic energy (i.e., minimize the severity of crashes that do occur).
Economic Analysis and Eligibility Criteria	Effective economic analysis can help control project costs and identify projects that yield a positive return on investment. Conducting economic analysis consistently, reliably, and fairly across all projects can improve the average performance of projects selected based on those methods. Establishing higher eligibility thresholds for projects can increase the potential that projects cost-effectively address safety problems and contribute to an agency's safety performance goals.
Project Prioritization and Selection	Effective project prioritization and selection methods help assure the most cost-effective projects are funded and the overall program provides the greatest possible contribution to safety performance. Project applications and submittal deadlines can help program managers compare and prioritize projects fairly to select the best combination of projects for the program.
Effectiveness Evaluation	Estimating the safety effectiveness of programs, countermeasures, and projects improves an agency's ability to plan safety improvements in the future. Analyzing the program provides important feedback on contributions toward safety performance outcomes and targets. Evaluating implemented projects helps to assess if the predicted crash reduction is realized and if associated CMFs are reasonable.
Improving Future Policies and Practices	Program managers should continue to seek improvement to policies and practices that incorporate more safety features, cut costs, enhance data, improve analysis, add efficiency in project delivery, and ultimately improve safety by reducing fatalities and serious injuries. Evaluation results can feed future policy changes.

2.3 CHAPTER SUMMARY

Each State establishes policies, procedures, and practices to guide the implementation of their HSIP. The HSIP managers increase the potential to maximize HSIP performance when they maximize the *expected* safety performance (and therefore the economic performance) of the HSIP. One opportunity to impact expected performance is during the system and project planning stages when selecting sites, countermeasures, and projects to fund with the HSIP. There are other opportunities to influence expected performance throughout project development, including the use of Safe System principles in project design. Finally, there is an opportunity to evaluate the effectiveness of past projects and programs to improve future policies and practices.

CHAPTER 3. HSIP IMPLEMENTATION STRATEGIES

This chapter discusses demonstrated program management (section 3.1), safety planning (section 3.2), and project implementation (section 3.3) strategies that can help improve or maintain HSIP implementation capabilities and performance over time. It is difficult to quantify the benefits of these strategies; however, research and successful State practices indicate these strategies can be effective.

3.1 PROGRAM MANAGEMENT STRATEGIES

The following strategies represent select noteworthy practices in HSIP management that can have an impact on safety performance. Each subsection describes one strategy.

- Establishing an HSIP stakeholder committee.
- Developing a State HSIP Manual or Implementation Plan.
- Prioritizing and selecting HSIP projects based on predicted future safety performance.
- Creating funding goals to prioritize projects.
- Programming HSIP projects as placeholders in the STIP.
- Supporting local agencies through funding exchange and technical assistance.

3.1.1 Establishing an HSIP Stakeholder Committee

Establishing a committee or task force can help guide and monitor the implementation of the HSIP as well as provide formal management and governance over project decisions and policy changes. Such a committee bridges across business units and may include external agencies, building a collaborative approach to set program priorities and increase participation. It can also help to inform agency executives and other stakeholders about the program and reduce the impacts of staff turnover.

This approach increases an agency's ability to maximize HSIP performance by more actively managing the program, assuring the program serves its purpose, and encouraging consistency in program administration and policy.

The New Hampshire DOT's (NHDOT) HSIP Committee is chaired by the Assistant Director of Project Development and includes representation from the Bureaus of Highway Design, Highway Maintenance, Planning and Community Assistance, and Traffic. The Committee also includes the FHWA Division Office Safety Engineer and representation from regional planning agencies and municipalities. The regional and municipal representatives serve three-year terms, and the rotation of these committee members seeks to achieve geographic diversity. The NHDOT HSIP Committee has helped HSIP stakeholders learn and share about the program, garners statewide input into decision making, and it provides transparency to the project selection and programming processes.

3.1.2 Developing a State HSIP Manual or Implementation Plan

Many States develop their own HSIP Manual or HSIP Implementation Plan to document their policies, strategies, procedures, and practices. Documenting the HSIP process helps promote consistency between decision makers and analysts across the State. An HSIP Manual can provide the tools that local agencies need to get involved in the program. HSIP Manuals also help agencies maintain the capability to implement a high-performing program after staff promotions or succession. The *FHWA HSIP Planning website* references the *FHWA HSIP Manual* as well as several example State HSIP Manuals. The following are potential contents for a State HSIP Manual.[3,9]

- Program administration information, contacts, and high-level policies.
- Background and references to legislation governing the program.
- General program strategy and objectives.
- Project eligibility needs and funding process.
- Project development process.
- Data and analysis tools and procedures.

FHWA also issued *HSIP Implementation Plan Guidance* that includes the following outline for the information an agency should include in their HSIP Implementation Plan.(10)

- Available funding for the plan period.
- Funding allocation goals (e.g., by SHSP emphasis areas, by ownership, by safety management approach).
- Description of HSIP programs, strategies, and activities including their purpose, cost, methodology and implementation, and expected benefits.
- Implemented project list linking each project to the relevant program, strategy, or activity in the plan.
- Summary of actions.

> *In 2020, the Alaska DOT and Public Facilities developed the 19th edition of the HSIP Handbook. The new HSIP Handbook outlines the methodology for identification, prioritization, and evaluation of HSIP projects. The handbook assists practitioners preparing new project proposals and the HSIP Annual Report.(11)*

3.1.3 Prioritizing and Selecting HSIP Projects Based on Safety Performance

Safety practitioners use DDSA methods and professional judgment to select projects to improve safety performance. If other offices or groups, internal or external to the DOT, alter the projects programmed with HSIP funds or select projects without consideration of expected safety performance, it may degrade the performance of the program and lower the likelihood the State meets its targets. For this reason, to the extent possible, HSIP project prioritization and programming decisions should rest with the division, office, or bureau responsible for highway safety within the State DOT.

3.1.4 Creating Funding Goals to Prioritize Projects

States can set aside funding for subprograms (a.k.a., funding goals) to achieve a certain level of equity, address Safe System principles, and focus on emphasis areas or program needs not addressed by the projects selected from the overall competitive ranking by BCR, as discussed later in chapters 4 and 5.(12) For example, an agency might allocate a set amount of funding to each District based on the percentage of fatalities and serious in each District. Other agencies may apply set-aside funding to address emphasis areas such as non-motorized safety. Establishing subprograms may reduce the overall cost-effectiveness of the program; however, this may be necessary to implement the program, account for data limitations, promote equity, or to improve the type and diversity of projects selected from a safety management approach. Chapter 6 discusses how each approach can focus on certain types of projects.

Agencies can establish subprograms using a quantitative approach that reflects the relative importance of the subprogram. For example, an agency could allocate funding to various subprograms based on the distribution of fatalities and serious injuries (or other factors) associated with each subprogram. Program managers and key stakeholders can decide on a strategy to distribute funds and select projects within each subprogram—preferably competitively based on BCR or through other data-driven methods.

The following are potential advantages of establishing funding goals.

- Funding goals provide a way for an agency to select competitive projects that address an SHSP emphasis area that would not be addressed otherwise.
- Funding goals can help achieve an equitable distribution of HSIP funds between State and local systems, urban and rural areas, various facility types, or geographic regions.
- Agencies can set aside funding for pilot projects that implement new countermeasures, countermeasures with no CMFs, and data improvements.

The Kentucky Transportation Cabinet (KYTC) developed an investment plan that outlines how they would distribute HSIP funds under the FAST Act.[13] Their Investment Plan ties the HSIP to their SHSP with sections for roadway departure, intersections, commercial vehicles, non-motorized, and "other." KYTC distributes funding to roadway departure, intersections, and other types according to the distribution of fatalities between each crash type after taking out fixed amounts for commercial vehicle and non-motorized safety projects. About two-thirds of fatalities are related to roadway departure, so they spend two-thirds of the funds on roadway departure improvements. Intersections and other types account for about 15 percent respectively, and each gets 15 percent of funds. Each District gets enough funding to implement at least some improvements, and additional funding is distributed to Districts within each subprogram by the number of related fatalities in each District.

3.1.5 Programming HSIP Projects in the STIP

States can consider programming HSIP projects in the STIP without clearly defining each project's scope. Programming with grouped projects also gives more flexibility in program management to adapt and address future needs or issues as they arise (23 CFR 450.326(h); 23 CFR 450.218(j)).

> *KYTC plans placeholder HSIP projects in their STIP that represent each year's approximate annual HSIP apportionment.[14] This occurs before defining the scope of any of KYTC's HSIP projects. KYTC assumes that if the site showed a high value for excess expected crashes (i.e., PSI) during screening with State-specific SPFs, there is likely a cost-effective solution available. By setting budgets with an undefined scope, they can accept proposals rather than bids for a project and do planning and design under the same contract. KYTC plans approximately twice as many countermeasures and improvements than could fit in the budget, which allows them to select the most effective countermeasures and quickly deliver projects using the same contractor team in a total of 9 to 15 months. Timeliness is a major factor in how KYTC implements their HSIP projects.*

3.1.6 Supporting Local Agencies through Funding Exchange and Technical Assistance

Some local agencies do not have the resources or expertise to administer Federal-aid projects though they are eligible to receive Federal-aid funding, including HSIP. Several States offer a safety funding exchange or swap program in which the State DOT exchanges Federal safety funds for State safety funds to local agencies planning Federal-aid projects.[15] By using State safety funds instead of Federal safety funds, local agencies can streamline the project delivery process and implement projects without the administrative responsibilities, costs, and timelines associated with Federal-aid requirements.[4] Each State with a funding exchange program has their own variant based on State and local laws. Such an exchange program may need a change in State code related to funding administration and eligibility, and the program is contingent on the State having funding available to exchange.

> *In 2018, the Iowa DOT modified the funding source of their County-focused safety program, HSIP-Secondary. Instead of relying on Federal HSIP, the program now awards $2 million per year in State funds through the HSIP-SWAP for safety projects on county roads. The program promotes systemic safety and focuses on reducing crashes related to lane departures and intersections.[16]*

Local safety programs should be paired with technical assistance from the State to help local agencies develop safety plans and identify and prioritize safety issues and projects.

> *Washington Department of Transportation (WSDOT) provides support for counties to develop Local Road Safety Plans (LRSPs). While counties are required to complete an LRSP to apply for HSIP funding, WSDOT eases the process and prepares summary data to help counites prioritize the crash types.[17] Additionally, WSDOT has hosted workshops throughout the State providing training for how to use the SSPST.[18]*

States can help local agencies access crash, roadway, and traffic volume data, conduct and interpret safety analysis, apply for HSIP projects, and evaluate implemented projects. As States employ and need more reliable DDSA methods to support decision making, some local agencies cannot keep up or develop competitive project applications on their own. Several States offer technical assistance opportunities to local agencies, either from the State DOT directly or through consultant and university contracts. The scale and scope of technical assistance needs may vary based on agency size, staffing, and expertise.

Local roads account for over 85 percent of Illinois's public road network. Illinois DOT (IDOT) places a high priority on local safety projects. The IDOT Bureau of Safety Engineering offers safety data, a benefit-cost tool and other software, HSM training, and direct technical assistance (through IDOT and contractors) to local agencies seeking HSIP funding. IDOT noticed that local agencies using these data, tools, and technical assistance opportunities have submitted applications for more effective, proactive HSIP projects over time. This allows the State to better address local safety needs.[(19)]

Other States have developed resources such as guides, forms, spreadsheets, and plans to help local agencies. State-specific CMF lists, expected countermeasure service life, and average project costs are particularly useful to support local safety analysis efforts.

3.2 SAFETY PLANNING STRATEGIES

The following strategies represent select noteworthy practices in safety planning that can have an impact on safety performance. Each subsection describes one strategy.

- Developing LRSPs.
- Employing database and software tools.
- Developing State-specific CMF lists.
- Implementing a standard project application process.

Minnesota DOT (MnDOT) has created a traffic safety webpage under the State Aid for Local Transportation program. This webpage serves as a one-stop shop for local HSIP efforts, including general information and application forms, county road safety plans, and examples of road safety audits and before-after studies. The website also provides crash data information such as crash rates by county and access to the Minnesota Crash Mapping Analysis Tool.[(20)]

3.2.1 Developing Local Road Safety Plans

LRSPs complement the State SHSP by taking a systemic approach to local road safety. An analysis of local crash, traffic, and roadway information highlights specific regional safety concerns, emphasis areas, strategies, and risk factors. LRSPs usually include detailed information about the strategies, projects, and even locations for potential safety improvements. State and local agency work plans can incorporate projects directly from LRSPs.

WSDOT spends approximately 70 percent of their HSIP funding on local road safety improvements. To be eligible, counties and cities must develop an LRSP based on fatal and serious-injury crashes using the systemic approach.[17] Currently, 36 of 39 counties have an LRSP, and their success led to WSDOT expanding the program to cities.

MnDOT recognized that there was an opportunity to engage and assist local agencies with improving safety beyond the strategies included in the statewide SHSP. MnDOT helps all 8 MnDOT districts, 87 counties, and several cities develop and implement a local roadway safety plan that tailors the SHSP to their jurisdiction. Each plan lists specific projects and countermeasures that the agency intends to implement based on data analysis and safety planning in each district and county. To assure counties can implement the plans, MnDOT provides locals a percentage of HSIP funding based on the split of fatalities and serious injuries between State and local roads in each district.[21]

3.2.2 Employing Database and Software Tools

Agencies can employ database and software tools to manage the safety of their road networks more efficiently and effectively. Databases and software, along with the training and skills to use them, are necessary to efficiently implement the most reliable safety performance management approaches across all public roads. The FHWA *Roadway Safety Data and Analysis Toolbox* contains tools and resources that can help agencies maximize HSIP performance.

3.2.3 Developing State-Specific CMF Lists

State-selected lists of approved CMFs can increase the reliability of analysis by assuring CMFs are applicable to the State. State-selected CMF lists also promote consistency and fairness in analysis, preventing situations where similar projects would have different effectiveness and priority solely due to the use of different CMFs. A committee of experts in the State typically develop CMF lists and regularly review them (e.g., continually, annually, or biannually) to identify new CMFs from research and remove or replace old ones as appropriate. The CMFs are often categorized by crash severity, and sometimes even by crash type. CMF lists can include a short list of commonly used countermeasures or a longer, comprehensive listing of potential countermeasures. The *CMF Clearinghouse* lists several example State-selected CMF lists.[22]

WSDOT developed a standardized CMF Short List that provides the most common CMFs analysts need. The list reduces the amount of time analysts spend identifying and selecting an appropriate CMF but does not replace the CMF Clearinghouse. WSDOT's considerations for CMFs are the quality of research, countermeasure context, and the target crash types and severities. WSDOT documents every CMF chosen for the Short List on a CMF Review Form in detail along with the reasons for choosing that CMF. The WSDOT CMF Short List and the CMF Review Form for each CMF are available to staff on the WSDOT Intranet.

3.2.4 Implementing a Standard Project Application Process

States can have District Offices and local stakeholders submit projects for consideration in the HSIP using a regular project application process or standard submission forms. Project application forms (e.g., paper, fillable electronic files, website) that include information about the project (e.g., its purpose, scope, and BCR) help HSIP managers consistently and fairly compare projects developed by different stakeholders as well as assure projects are data-driven and meet program eligibility requirements.(4) Establishing a project submission deadline or prioritization schedule allows agencies to rank and compare competing projects.

3.3 PROJECT IMPLEMENTATION STRATEGIES

The following strategies represent select noteworthy practices in HSIP project implementation that can have an impact on safety performance. Each subsection describes one strategy.

- Employing Safe System principles.
- Encouraging project bundling.
- Exploring design-build contracting for HSIP projects.

3.3.1 Employing Safe System Principles

Australia and several European countries have been implementing the "Safe System" approach to road safety, and some agencies in the United States are beginning to implement this approach as well. According to FHWA's Zero Deaths and Safe System website, the Safe System approach generally assumes that it is impossible to avoid all crashes, and therefore, agencies should design their roads to reduce the kinetic energy transferred to road users in a collision.(23) The approach is based on the ethical position that fatalities and serious injuries from using the road network are unacceptable, and that road owners are responsible for making sure road users arrive at their destinations safely. Agencies can achieve these outcomes by adopting policies and implementing designs to reduce conflicts, reduce speeds, reduce impact angles, and separate traffic with large differences in mass and velocity. Applying these concepts and principles throughout the HSIP has the potential to improve the program's performance outcomes.(24)

Most of the available DDSA methods do not directly quantify the impacts of conflicts, speed, or traffic separation—they are implied in SPFs and CMFs (e.g., for roundabouts) and can also be accounted for during site diagnosis.(25) To apply Safe System principles, agencies can first design to achieve a desired level of safety. The design for safety then defines or limits the level of mobility (i.e., in the form of a hierarchy of safety over mobility, rather than a tradeoff). Analysts can assess risks related to road-user exposure to conflicts, crash likelihood from the exposure, and the likelihood of severity outcomes. Adopting principles associated with the Safe System approach to road safety can help complement and advance the approaches and methods presented in this guide.[25]

> *North Carolina's SHSP, published in 2020, includes a provision to implement their Safest Feasible Intersection Design (SaFID) policy.[26] SaFID involves choosing the lowest-CMF intersection design alternative that applies to the average annual daily traffic (AADT) and number of lanes on each approach. North Carolina DOT (NCDOT) developed a table that lists the various alternatives and associated CMFs for designs applicable to each bin of approach AADTs and number of lanes to assist with implementing this policy. The SaFID policy integrates intersection control evaluation techniques with the Safe System approach. NCDOT would then need to present justification to deviate from the safest feasible alternative (e.g., to choose a more cost-effective design, to account for mobility needs).*

3.3.2 Encouraging Project Bundling

Due to the level of effort needed to manage Federal-aid highway projects, it can be more cost-effective to select projects with higher project costs or bundle smaller projects to gain efficiencies during project delivery and assure most of the budget is spent on implementing countermeasures. This applies to both State and local agency projects. Agencies can encourage capitalizing on economies of scale by bundling lower-cost countermeasures or projects into larger contracts. Project bundling often allows agencies to address a greater number of locations at a lower unit cost than could be achieved through multiple smaller projects. FHWA's Every Day Counts—Round 5 includes a Project Bundling initiative. Refer to the Every Day Counts website for more information.

> *The Indiana DOT (INDOT) has several strategies for improving the efficiency of project implementation. For example, when individual projects come in with low costs (e.g., under $25,000) or a high overhead, program managers encourage increasing the scale of the design and construction scope to achieve economies of scale, principally by pooling the same countermeasure across multiple State districts into a statewide contract or bundling nearby projects of different work types.[b]*

3.3.3 Exploring Design-Build Contracting for HSIP Projects

Typical design-build projects issue a scope of work and then score contractor teams' proposals based on the value of their bids and qualifications to design and deliver the scope. Design-build

[b] INDOT shared this information with the project team during a focus group interview noted in appendix A.

and other alternative contracting methods are potentially applicable to projects developed with the site-specific, systemic, systematic, and other approaches. Design-build projects can accelerate delivery, reduce costs, and reduce internal staff needs for planning and design. Agencies can also consider letting design-build projects with a fixed budget and allow contractors to propose a scope that offers the highest opportunity to improve safety performance from various options using the team's bid prices. Agencies can score contractors based on qualifications as well as the safety and economic performance of the contractor teams' proposed countermeasures and designs.

The Missouri DOT (MoDOT) implemented a safety-performance-based design-build project in the St. Louis District, implementing over 20 different countermeasures at 31 locations in two counties at a cost of over $24 million. The countermeasures included high-friction surface treatments, reflective pavement markers, rumble strips, intersection conflict warning systems, and flashing beacons on stop signs. MoDOT estimates that the project is expected to prevent over 70 fatalities and serious injuries over 10 years.[27]

3.4 CHAPTER SUMMARY

This chapter presents strategies agencies can employ in program management, safety planning, and project implementation to improve decision making and the overall performance of the HSIP. These strategies include opportunities to improve program policies and procedures, encourage and support local agency involvement, and select and implement projects based on safety performance.

CHAPTER 4. BENEFIT-COST ANALYSIS AND PROJECT SELECTION

While there are differences in how analysts identify opportunities for safety improvement and select countermeasures, the economic appraisal and prioritization methods are generally the same for all infrastructure projects in the HSIP. The HSIP managers and analysts use a combination of policies, strategies, analytical methods, and research to select HSIP projects that maximize the lives saved and serious injuries prevented by their infrastructure programs. Benefit-cost analysis allows analysts to quantify and compare the benefits and costs among highway safety improvement projects. The results of benefit-cost analysis help program managers select a combination of cost-effective projects that improve the HSIP's potential to save lives and prevent serious injuries.

This chapter includes:

- Section 4.1, which describes fundamental DDSA concepts for estimating highway safety performance.
- Section 4.2, which compares economic measures used in highway safety benefit-cost analysis.
- Section 4.3, which demonstrates project prioritization and selection approaches for safety performance.
- Section 4.4, which applies a cost-justification analysis for projects with unquantifiable benefits.
- Section 4.5, which summarizes the chapter.

4.1 QUANTIFYING HIGHWAY SAFETY PERFORMANCE

Analysts can estimate the safety performance of an existing or proposed roadway using average historical crash frequencies to calculate observed crash frequency, SPFs to determine predicted crash frequency, or a weighted average of both called expected crash frequency. SPFs are best-fit regression models that predict average crash frequencies based on sites with similar characteristics and traffic volume. Planning-level SPFs typically rely on few data elements (e.g., traffic volume and segment length) so agencies can more readily apply them to all roads. Design-level SPFs typically incorporate more variables (e.g., roadway and operational characteristics) to be more precise and reflect the safety performance under specific design scenarios. CMFs are multipliers agencies can use in conjunction with observed, predicted, and expected crashes to estimate the change in crashes due to a countermeasure. Lower CMFs represent a higher average crash reduction. Although SPFs and CMFs are in terms of crashes, reducing and preventing fatal and serious-injury crashes can reduce the number of fatalities and serious injuries.[3]

SPFs and CMFs represent the predicted crash frequency and expected change in crash frequency, respectively, and can apply to specific crash types and severities. Crash severity is commonly represented in terms of the KABCO scale: K = fatal injury, A = suspected serious injury, B = suspected minor injury, C = possible injury, and O = no apparent injury. After a crash, law enforcement officials report the KABCO injury severity based on their assessment of injuries and the injured persons' complaints.[3] The remainder of the guide uses the K and A notation for brevity at times to represent fatal and serious-injury crashes.

4.1.1 Estimating the Benefits of Highway Safety Projects

The benefits of an HSIP project come from preventing future crashes that would have occurred over its service life had the project not been implemented or by reducing the average severity of such crashes. Although it may be desirable to consider a project's benefits and disbenefits beyond safety, it is currently infeasible to do so consistently and fairly, and it does not represent current practice in the field. Focusing solely on projects' safety performance allows HSIP managers to maximize the safety benefits of the HSIP.

By estimating the long-term average crash frequency at the site without the project (i.e., in terms of observed, predicted, or expected crash frequency), analysts can estimate the safety performance benefits of the projects by multiplying the no-build crash frequency estimate by a CMF representing the countermeasure's effectiveness. Another option is to compare the crash frequency estimates for two alternative conditions. The difference in average crash frequency between existing and proposed conditions represents the safety benefits of the project. Analysts can use average crash costs to monetize a project's safety benefits and compare the benefits to project costs. The *Crash Costs for Highway Safety Analysis* guide contains national crash costs and procedures to update and adjust them to individual States. Chapter 5 of this guide discusses these concepts further in the context of project selection methods to maximize HSIP performance.

4.1.2 Assessing the Range of Estimated Countermeasure Effectiveness

CMFs represent the mean estimated effectiveness of countermeasures under average conditions, as shown in figure 3. Analysts almost universally apply CMFs as the mean point estimate of the CMF; however, the crash reduction indicated by the CMF is not guaranteed—there is random variation associated with the estimate. Many CMFs also have an associated standard error, listed in the *CMF Clearinghouse*, indicating the variance in the sample of data used to develop the CMF. Analysts could use the CMF and associated standard error to determine confidence intervals for the estimated change in crash frequency. Analysts should confirm that the CMF fits the scenario at hand (e.g., rural versus urban application).

$$\text{Esimated Crashes WITH Treatment} = \text{CMF} \times \text{Estimated Crashes WITHOUT Treatment}$$

Figure 3. Equation. Application of CMF to estimate crashes with treatment.

Using more conservative CMF values, such as the lower bound of the confidence interval as shown in figure 4, to estimate performance outcomes increases the likelihood that those outcomes are met. It also favors countermeasures with low CMFs and small standard errors, which is a desirable scenario. The Multiple of Standard Error is approximately equal to 1 for a 68-percent confidence interval, 2 for 95-percent, and 3 for 99.7 percent.

$$\text{Confidence Interval} = \text{CMF} \pm (\text{Standard Error} \times \text{Multiple of Standard Error})$$

Figure 4. Equation. Calculating a CMF confidence interval.

When a project's range of predicted effectiveness includes CMF values at or above 1.0, project managers can consider what success factors would be necessary for the project to meet expectations. For example, the 95-percent confidence interval for a CMF of 0.90 with a standard error of 0.10 is approximately 0.70 to 1.10, which indicates there is a 95-percent chance the true value of the CMF falls within this range. As such, there is a chance that crashes could increase (i.e., true value is greater than 1.0) as a result of the countermeasure.

4.2 QUANTIFYING SAFETY PERFORMANCE IN ECONOMIC TERMS

Agencies can use many measures, indices, and factors to prioritize proposed projects. Table 2 lists the safety-related economic prioritization criteria commonly discussed in the literature and indicates whether the methods consider benefits, costs, and monetary values.[3,5]

Table 2. Comparison of safety-related economic prioritization criteria.

Economic Measure	Considers Benefits	Considers Costs	Considers Monetary Benefits and Costs
Number of crashes reduced	Yes	No	No
Project costs	No	Yes	No
Cost-effectiveness index (CEI)	Yes	Yes	No
BCR	Yes	Yes	Yes
Net present value (NPV)	Yes	Yes	Yes
Payback period	Yes	Yes	Yes
Incremental benefit-cost analysis (IBCA)	Yes	Yes	Yes

The bottom four measures in table 2 directly compare monetary benefits and costs, which is necessary to prioritize projects economically in a fiscally-constrained program. As described in the *HSM*, the IBCA method yields the same priority ranking as NPV.[5] The payback period does not consider the full extent of benefits—only up to the value of costs.

4.2.1 Measuring the Cost Effectiveness of Performance Impacts

FHWA's *Highway Safety Benefit-Cost Analysis Guide* states that BCR and NPV are often the most appropriate economic measures to assess alternatives. The BCR is a unitless ratio of total safety benefits to project costs and it indicates the value of crash reduction per dollar spent. Further, analysts can use the BCR to compare safety projects on economic merit. Figure 5 shows the basic equation for BCR.[28] Chapter 5 of this guide discusses why the BCR in terms of the change in fatal and serious-injury crashes per dollar invested is the preferred measure to rank HSIP projects in order of estimated performance and cost effectiveness.

$$\text{BCR} = \frac{\text{Total Safety Benefits}}{\text{Project Costs}}$$

Figure 5. Equation. Benefit-cost ratio calculation.

4.2.2 Measuring the Magnitude of Safety Performance Impacts

With respect to the overarching goal of the HSIP, the magnitude of safety performance impacts from infrastructure projects is represented in terms of the change in fatal and serious-injury crashes. Analysts can apply average injury-to-crash ratios (e.g., 1.1 fatalities and 0.3 suspected serious injuries per fatal crash) to translate crashes into fatalities and injuries when predicting how a project or program affects the standard performance measures listed in chapter 1. These measures represent the overall outcomes of the program given its fixed inputs. The BCR provides an objective measure of the cost-effectiveness of the program. If the program budget is generally consistent over time, it is not necessary to compute the BCR or monetize the safety benefits since the denominator remains the same (or at least similar). Instead, there is an opportunity to simply compare the outcomes of the program. Analysts can add the crashes reduced across projects to determine the total effect of multiple projects, subprograms, or the whole HSIP on safety performance.

The NPV (a.k.a., net benefits, net return) is the difference between a project's total safety benefits and costs, which indicates the monetary safety benefits that each project is expected to generate beyond its costs to taxpayers. Figure 6 shows the basic equation for NPV. The NPV does not have much practical meaning in highway safety because projects do not have to pay back costs to taxpayers before realizing the investment's desired benefits (i.e., unlike benefit-cost analysis for buying a business or other private investment). For this reason, it is meaningful to include the total safety benefits of the program or a project—not the net benefits.

$$\text{NPV} = \text{Net Safety Benefits} = \text{Total Safety Benefits} - \text{Project Costs}$$

Figure 6. Equation. Net present value calculation.

4.3 PRIORITIZING AND SELECTING PROJECTS

While there are distinct differences in how agencies employ the site-specific, systemic, and systematic approaches to identify and address safety issues, all these approaches deliver projects with the purpose of cost-effectively saving lives and preventing serious injuries. The economic analysis and prioritization methods to estimate the cost effectiveness of each project are generally the same for all infrastructure projects in the HSIP regardless of the approach to identify and develop the projects. Benefit-cost analysis is an important component of the HSIP process because it allows analysts to quantify and compare the benefits and costs of all HSIP projects in consistent terms. The results of benefit-cost analysis help program managers select a combination of cost-effective projects that yield the greatest opportunity to maximize HSIP performance. Section 4.3.2 discusses how qualitative factors, such as scheduling and public involvement, can also play a role in project selection.

Project selection practices in the HSIP are largely driven by whether projects are analyzed with benefit-cost analysis or not. States are not required to use benefit-cost analysis; however, they are required to consider the potential reduction in fatalities and serious injuries, the cost effectiveness of their projects, and the priorities in their SHSP (23 CFR Part 924(a)(6)). Thus, most States conduct benefit-cost analysis for at least some projects, and many prioritize projects primarily using benefit-cost analysis. Many of those States use BCR to rank projects, and a few use NPV. The *Highway Safety Benefit-Cost Analysis Guide* includes methods to prioritize projects by BCR, indicating that ranking by NPV can result in less-efficient projects and reduce the overall effectiveness of the program.(28) Regardless of the approach and methods, applying safety management approaches and DDSA methods reliably and consistently across all projects is important.

Applying total safety benefits or NPV as a cost-effectiveness measure involves also knowing the costs needed to achieve those benefits. On the other hand, BCR is a direct measure of cost-effectiveness on its own. Table 3 illustrates this comparison with two hypothetical projects. Each project is estimated to result in an NPV of $100,000. To achieve the same NPV, Project 1 needs an investment of $200,000 and Project 2 needs an investment of $1,000,000. These projects are equal based on NPV. Based on BCR, Project 1 is a much better investment since it yields the same net outcome at five times lower costs, allowing program managers to use the other $800,000 more cost-effectively elsewhere. In summary, BCR is a better measure of cost-effectiveness as well as the expected performance of each project because the program is fiscally constrained.

Table 3. Example projects to compare NPV and BCR.

Project	Total Safety Benefits	Project Costs	NPV	BCR
Project 1	$300,000	$200,000	**$100,000**	1.5
Project 2	$1,100,000	$1,000,000	**$100,000**	1.1

4.3.1 Hypothetical Project Prioritization and Selection Example

Optimizing the implementation of highly cost-effective countermeasures at sites with high PSI maximizes the estimated performance of the HSIP. Table 4 shows the total safety benefits, project costs, NPV, and BCR for 10 hypothetical projects. All projects have a BCR greater than or equal to 1.5. Analysts can rank the projects by BCR to determine their priority in terms of cost-effectiveness. A simple approach would then be to select projects down the list until the available budget is spent based on implementation costs. While analysts should consider total maintenance costs over the service life of the project (whether these come from HSIP dollars or other funding sources) in computing the BCR, funding is constrained by implementation costs. This exercise could be completed with any set of projects to demonstrate their relative effectiveness and priority.

Table 4. Present value economic data for 10 hypothetical safety projects.

Project	Total Safety Benefits	Implementation Costs	Total Maintenance Costs over Service Life	BCR
Project 1	$900,000	$300,000	$60,000	2.5
Project 2	$500,000	$250,000	$40,000	1.7
Project 3	$700,000	$200,000	$5,000	3.4
Project 4	$1,000,000	$400,000	$100,000	2.0
Project 5	$150,000	$75,000	$25,000	1.5
Project 6	$600,000	$100,000	$50,000	4.0
Project 7	$400,000	$100,000	$10,000	3.6
Project 8	$250,000	$100,000	$15,000	2.2
Project 9	$250,000	$50,000	$10,000	4.2
Project 10	$150,000	$50,000	$0	3.0

Note: Budgetary calculations may change depending on which budget the maintenance costs come from, especially if local agencies use their funds to maintain the treatment.

For this example, suppose $800,000 is available within the HSIP budget and an agency wants to determine which of the 10 projects in table 4 represent the best investments in improving systemwide safety performance. Table 5 lists the project priority ranking by BCR (based on total projects costs). The agency selects projects from the top of the list based on implementation costs until the $800,000 budget is filled. Rows are shaded gray for projects that do not fit within the budget. The economic measures for the programmed projects in table 5 are listed in table 6.

Table 5. BCR ranking and selection of hypothetical projects within an $800,000 budget.

Project	Total Safety Benefits	Implementation Costs	Total Maintenance Costs over Service Life	BCR
Project 9	$250,000	$50,000	$10,000	4.2
Project 6	$600,000	$100,000	$50,000	4.0
Project 7	$400,000	$100,000	$10,000	3.6
Project 3	$700,000	$200,000	$5,000	3.4
Project 10	$150,000	$50,000	$0	3.0
Project 1	$900,000	$300,000	$60,000	2.5
Project 8*	*$250,000*	*$100,000*	*$15,000*	*2.2*
Project 4*	*$1,000,000*	*$400,000*	*$100,000*	*2.0*
Project 2*	*$500,000*	*$250,000*	*$40,000*	*1.7*
Project 5*	*$150,000*	*$75,000*	*$25,000*	*1.5*

* Note: These projects do not fit within the budget.

Table 6. Estimated outcomes of example projects ranked by BCR.

Economic Measure	Outcomes from BCR Ranking
Total Safety Benefits	$3,000,000
Total Costs	**$935,000**
BCR	3.2

4.3.2 Adjusting Priority and Selecting Projects

Analysts can conduct benefit-cost analysis as projects are planned and proposed and use approaches such as those shown in section 4.3.1 to select projects based on safety performance. Chapter 5 of this guide describes a refined BCR ranking approach focusing only on fatalities and serious injuries. However, limitations to DDSA approaches may necessitate adjustments in the prioritization process. Agencies can review BCR data and associated calculations as well as the relative ranking to consider whether it is necessary to adjust the priority of any projects. Agencies using the BCR ranking method would then select sites in priority order after any necessary adjustments.

The following are some factors that may warrant adjustments to the BCR priority ranking.

- Projects may have higher priority when other planned concurrent construction projects at the location could contribute to less overall impacts to road users or a cost savings for the HSIP.
- Projects with lower maintenance needs over their service life may be higher priority than others.
- Projects addressing higher-priority emphasis areas or promoting equity may be given higher priority during selection.
- It may not be practical to use all HSIP funds in one District or region. Some agencies may need to balance work across staff in all regions.
- Projects needing right-of-way (ROW) acquisition may have lower priority than similar projects with no ROW needs due to schedule impacts and risk.
- Projects with positive environmental impacts may have higher priority than similar projects with no or negative environmental impacts.
- Projects that can be implemented sooner and easier may have higher priority.
- Not having experience with implementing a countermeasure may warrant a higher or lower priority depending on others' experiences, theoretical basis, and professional judgment.
- Projects with favorable public feedback, support by local elected officials, or that address high-priority needs (e.g., school safety) could be given higher priority over projects with similar levels of safety benefit.

4.4 APPLYING COST-JUSTIFICATION ANALYSIS FOR PROJECTS WITH UNQUANTIFIABLE BENEFITS

To prioritize by BCR, there is a need to first estimate the quantifiable benefits of the projects. However, agencies can implement projects that have unquantifiable benefits. For example, it is difficult to quantify the benefits of pilot projects, workforce development, and safety data and analysis tool improvements, but those types of projects are necessary to improve decision making and maintain a successful program. Without quantifiable benefits, the methods in previous sections of this chapter (e.g., SPFs and CMFs) do not directly apply to selecting these types of projects. Instead, analysts can apply cost-justification analysis to any project with defined costs and unquantifiable, but reasonably expected, safety benefits.

Cost-justification analysis helps agencies consider the likelihood that a project without a quantifiable benefit exceeds some level of cost-effectiveness (i.e., BCR > 1.0). While not the ideal approach (since seeking the highest BCR is generally better than meeting a minimum threshold), it can provide a framework for an agency to think through their investment decisions for these types of projects and use judgment to determine if the projects are worth the cost.

Cost-justification analysis is simplest when comparing the present value of project costs (i.e., not annualized as the rest of this guide suggests) to the total safety benefits over the life of the project. For example, if a proposed project's estimated present value costs are $300,000 and a serious-injury crash cost is presently valued at $300,000, then the project would need to prevent at least one serious-injury crash (or the equivalent value of multiple minor crashes) over its service life to meet a BCR of 1.0.

A more quantitative (but still subjective) approach, shown in figure 7, is also applicable to projects with unquantifiable benefits that are expected to indirectly increase the average BCR of future projects. Project stakeholders could estimate the magnitude of that increase over time (i.e., ΔBCR) as well as the total budget of affected projects to calculate the total expected impacts of the project. Agencies would need to determine if the average improvement over many projects would offset the costs at a reasonable ΔBCR value.

$$\text{Value of Crash Reduction} = (\Delta BCR) \times (\text{Budget of Affected Projects})$$

Figure 7. Equation. Estimating reduction in fatal and serious-injury crashes from DDSA and safety workforce development projects.

Where: Value of Crash Reduction = estimated dollar value of crashes reduced by a project with unquantifiable benefits over its service life.

ΔBCR = average percent increase in cost-effectiveness, expressed as a decimal, of affected projects with quantifiable benefits in the future after the project with unquantifiable benefits is implemented due to improved decision making.

Budget of Affected Projects = amount of funding for which decision making is expected to improve over the service life of the project.

For example, a project that provides an estimated 2-percent average improvement in BCR across $30 million in projects (e.g., by improving safety data and analysis tools or supporting workforce development) could not cost more than $600,000. Program managers can use this information to determine if the proposed project with unquantifiable benefits would be likely to produce such returns over its life by selecting better projects with less resources.

> *KYTC assesses DDSA-related projects against the whole budget. If a one-time, $100,000 DDSA project improves decision making for several years across their $41 million annual apportionment, they would consider using funds to advance DDSA capabilities. In contrast, with some advanced DDSA capabilities already, a $20 million DDSA project may not return enough benefits beyond what investing $20 million in more countermeasures would provide within the $41 million overall budget.*

4.5 CHAPTER SUMMARY

Analysts can use many economic measures in highway safety benefit-cost analysis; however, BCR is the preferred measure of cost-effectiveness. The estimated number of crashes prevented is the preferred measure of the magnitude of total performance impacts. Agencies should generally prioritize projects based on quantitative methods such as the BCR when possible, and select projects from the top of that list, considering case-by-case adjustments as appropriate.

Because the HSIP is focused on fatalities and serious injuries, the ideal prioritization method would focus only on the crashes that involve those injuries (i.e., fatal and serious-injury crashes). Chapter 5 describes economic methods to rank projects by their BCR pertaining to fatal and serious-injury crashes, which helps agencies select the best-performing projects with respect to the overarching goals of the HSIP.

CHAPTER 5. METHODS TO MAXIMIZE HSIP PERFORMANCE

The performance of the HSIP is dependent on the performance of its projects. Maximizing the safety performance of HSIP projects means maximizing the number of lives they save and serious injuries they prevent. As explained in chapter 4, agencies can support investment decisions by predicting the outcomes of competing projects or alternatives and using those predictions to prioritize projects through benefit-cost analysis. **The best-performing, most-cost-effective, highest-priority HSIP projects deliver the greatest expected reductions in fatalities and serious injuries at the lowest costs.**

DDSA and benefit-cost analysis methods allow analysts to estimate the number of fatalities and serious injuries that a project would reduce and develop a BCR based on that value by dividing by the project's costs. Having a higher than expected fatal and serious-injury crash frequency, a lower CMF, or lower costs per percent of crashes reduced does not mean that a project will be cost-effective—all three factors are equally important in maximizing a project's safety performance.

This chapter is divided into four sections where:

- Section 5.1 translates the concepts into mathematical terms showing how to measure and increase the performance of the HSIP.
- Section 5.2 explains how to calculate inputs to the BCR equation, recognizing that SPFs and CMFs are not always available specifically for K and A crashes.
- Section 5.3 reworks the BCR equation in a way that makes it easier to apply in rules of thumb by not relying on direct comparisons of benefits and costs.
- Section 5.4 describes strategies based on available data and judgement that prevent K and A crashes most cost effectively.

5.1 MEASURING AND INCREASING HSIP PERFORMANCE

As discussed throughout this guide, the BCR is the best measure of economic performance for projects, countermeasures, and the overall program. Because the HSIP is constrained by a budget, the projects that improve safety performance most cost-effectively should maximize HSIP performance. BCR allows agencies to rank projects by their performance and select the best-performing combination of projects.

To improve systemwide safety performance in terms of lives saved and serious injuries prevented, there is a need to focus the BCR on fatal and serious-injury crashes only (i.e., BCR_{KA}). Most States do not currently limit their benefit-cost analysis to only fatal and serious-injury crashes because those crashes are relatively rare and random at individual locations. SPFs and CMFs for those crash types alone are not prevalent, and the method has not been well-documented and explained elsewhere in prominent literature. (See references 3, 4, 5, 6, 28, and 30). Focusing on fatal and serious-injury crashes in benefit-cost analysis, and ignoring crashes resulting in minor injuries or no injury, is important to FHWA's goal of maximizing serious injury reduction, not only the monetary impacts of crashes of all severities.

Figure 8 shows a project's BCR_{KA}, which can be interpreted as the dollar value of prevented fatal and serious-injury crashes per dollar spent to implement and maintain the project over its service life. Projects with a higher BCR_{KA} have greater opportunities to improve HSIP performance, and thus provide a greater potential for the State to meet its safety performance targets. A BCR_{KA} value of 1.0 indicates that the value of the safety benefits based on KA crashes are equal to the project costs; a value less than 1.0 indicates the safety benefits are less than the project costs; and a value greater than 1.0 indicates the safety benefits exceed project costs.

$$BCR_{KA} = \frac{\text{Value of Fatal and Serious Injury Crashes Prevented by the Project}}{\text{Project Costs}} = \frac{\sum \text{Benefits}_{KA}}{\sum \text{Costs}}$$

Figure 8. Equation. HSIP project cost-effectiveness measured by BCR_{KA}.

Agencies can use BCR_{KA} to evaluate projects as well as the entire HSIP. Figure 9 shows the BCR_{KA} of the whole HSIP (i.e., $BCR_{KA,HSIP}$), which is equal to the average BCR_{KA} value of all implemented projects. Since the program budget is generally fixed, figure 9 implies that maximizing the average BCR_{KA} of selected projects maximizes the program's expected performance. The figure 9 equation is applicable to the entire program as well as any subprograms (a.k.a., funding goals), strategies, or activities. Agencies can review proposed projects and optimize the expected safety benefits of their program by identifying the program of projects that maximize the equation in figure 9.

$$BCR_{KA,HSIP} = \frac{\text{Value of Fatal and Serious Injury Crashes Prevented by the HSIP}}{\text{Total HSIP Budget}} = \frac{\sum \text{Project Benefits}_{KA}}{\sum \text{Project Costs}}$$

Figure 9. Equation. Overall HSIP cost-effectiveness measured by BCR_{KA}.

Rearranging and simplifying figure 9 yields figure 10, which shows lives saved and serious injuries prevented by the HSIP (i.e., ability to maximize HSIP performance) is proportionate to the average BCR_{KA} of implemented HSIP projects and the amount of funding spent on HSIP projects.[c] As stated previously, this equation shows that with a fixed amount of HSIP funding, an increase in program BCR is correlated with an increase in expected lives saved and serious injuries prevented by the HSIP.

$$\text{Lives Saved and Serious Injuries Prevented by the HSIP} \propto \left(BCR_{KA,HSIP} \times \text{Funding Spent on the HSIP}\right)$$

Figure 10. Equation. HSIP performance is dependent on average HSIP project cost-effectiveness and the total funding spent on HSIP projects.

Figure 10 implies that determining whether a project's overall BCR is greater than 1.0 (or whether its overall NPV is greater than $0) is unnecessary. As discussed throughout this guide, agencies striving for higher BCR_{KA} program values, rather than meeting a minimum BCR threshold at the project level, can maximize HSIP performance. Figure 10 is applicable to the HSIP, related subprograms, and other safety projects beyond the HSIP. Since simply adding funding does not make the HSIP more efficient, figure 10 also confirms that $BCR_{KA,HSIP}$ is a direct measurement of how effectively the HSIP uses its funding to improve safety performance.

5.2 MAXIMIZING THE PERFORMANCE OF HSIP PROJECTS

By better understanding how BCR_{KA} is calculated, analysts can optimize its inputs and therefore increase project benefits and HSIP performance.

[c] The mathematical symbol in figure 10 ($\propto$) means "is proportionate to."

Analysts can estimate a project's economic benefits in terms of the dollar value of prevented fatal and serious-injury crashes (i.e., $Benefits_{KA}$) using the following three-step process, where each step is further explained in sections 5.2.1 through 5.2.3.

1. Estimate the number of fatal and serious-injury crashes that would be expected to occur over the proposed project's service life if it were not implemented ($N_{exp,KA}$). Analysts can substitute observed or predicted fatal and serious-injury crash frequency instead of the expected fatal and serious-injury crash frequency but with lower reliability.

2. Apply an estimate of the combined effectiveness of all countermeasures and strategies in reducing fatal and serious-injury crashes (i.e., the project's effective CMF_{KA}).

3. Monetize those benefits by applying average comprehensive fatal and serious-injury crash costs (i.e., CC_{KA}).

Figure 11 shows the equation that applies this method to calculate the monetary value of fatal and serious-injury crashes reduced by a project (i.e., $Benefits_{KA}$). BCR_{KA} ignores any changes in B, C, and O crash frequency from the project.

$$Benefits_{KA} = N_{exp,KA} \times (1 - CMF_{KA}) \times CC_{KA}$$

Figure 11. Equation. General equation to determine the monetary value of a project's safety benefits in terms of reduced fatal and serious-injury crashes.

Where: $N_{exp,KA}$ = expected fatal and serious-injury crash frequency in the future without the proposed project (in terms of crashes per mile per year for segments and ramps, or crashes per year at intersections).

CMF_{KA} = effective CMF in terms of fatal and serious-injury crashes for the proposed countermeasures. The difference between 1.0 and the CMF value is equal to the proportion of crashes reduced by the project.

CC_{KA} = weighted average comprehensive fatal and serious-injury crash cost.

Figure 12 provides the general equation to estimate an HSIP project's BCR_{KA} (i.e., its cost-effectiveness and priority) based on figure 11. Project costs typically include preliminary engineering (PE), ROW, construction, and operations and maintenance (O&M) costs incurred over the project's service life (see section 5.2.4 for further details on project costs). The selected project sites and the countermeasures, which are largely dependent on the agency's safety management approach to develop the project, determine the inputs to figure 12. Chapter 6 further discusses safety management approaches.

$$BCR_{KA} = \frac{N_{exp,KA} \times (1 - CMF_{KA}) \times CC_{KA}}{\text{Project Costs}}$$

Figure 12. Equation. General equation for BCR_{KA}, which indicates a project's relative cost effectiveness, priority, and performance.

Figure 13 replaces figure 12 when using design-level DDSA methods such as in the Interactive Highway Safety Design Model, rather than $N_{exp,KA}$ with standalone CMFs.

$$BCR_{KA} = \frac{\left(N_{exp,KA,existing} - N_{exp,KA,proposed}\right) \times CC_{KA}}{\text{Project Costs}}$$

Figure 13. Equation. Determining BCR_{KA} with project-level predictive methods.

Rather than using weighted average inputs as in the previous equations, analysts with enough data may prefer calculating BCR_{KA} with disaggregate crash severity inputs, as shown in figure 14.

$$BCR_{KA} = \frac{\sum_{sev=\{K,A\}}[N_{sev} \times (1 - CMF_{sev}) \times \text{Crash Cost}_{sev}]}{\text{Project Costs}}$$

Figure 14. Equation. Disaggregate equation for BCR_{KA} and HSIP project priority.

Agencies can increase the expected performance of their HSIP projects by selecting sites with higher (and more severe) expected no-build crash frequencies (i.e., $N_{exp,KA}$) and implementing countermeasures that have a lower CMF_{KA} and lower implementation and maintenance costs. Agencies can also improve performance outcomes by installing HSIP countermeasures simultaneously with other projects to reduce costs. For example, if an agency proposes a turn lane with a high-safety BCR_{KA} at a location that was also slated for resurfacing, implementing them both at the same time could reduce costs and user impacts when compared to implementing them separately.

5.2.1 Calculating Expected Fatal and Serious-Injury Crash Frequency

Many agencies estimate expected no-build crash frequencies during network screening. Analysts can calculate a site's expected fatal and serious-injury crash frequency (i.e., $N_{exp,KA}$) with the Empirical Bayes (EB) method, which determines a weighted average of observed fatal and serious-injury crash frequency ($N_{obs,KA}$) and predicted fatal and serious-injury crash frequency ($N_{pred,KA}$). $N_{obs,KA}$ is an estimate of a site's future crash frequency based on the average of historical fatal and serious-injury crash frequency over a period. $N_{pred,KA}$ is an estimate of future fatal and serious-injury crash frequency based on an SPF, which is based on the safety performance of many other similar sites, ignoring historical crash frequency. Planning-level

SPFs—based on facility type, AADT, and length—are appropriate for this purpose to minimize the amount of data needed to apply the models to all public roads.

> *The KYTC partners with University of Kentucky to develop State-specific, planning-level SPFs for predicting fatal and serious-injury crashes as well as lower severities. Their State-specific SPFs are the basis for their network screening analysis and ranking.*

If analysts do not have the data or tools to calculate $N_{exp,KA}$, they can consider adjusting expected fatal and all injury crash frequency (i.e., $N_{exp,KABC}$) by the average ratio of KA-to-KABC crashes to estimate $N_{exp,KA}$ with lower reliability. For example, this may be necessary when SPFs for KABC are the highest-severity SPFs available for the facility type of interest. Changes in property-damage-only crash frequency (i.e., O in KABCO) are generally not reflective of changes in fatal and serious-injury crashes. Omitting O crashes and minor injuries from benefit-cost analysis is expected to increase the likelihood that high-BCR projects target fatalities and serious injuries. Figure 15 shows the approximation to translate $N_{exp,KABC}$ to $N_{exp,KA}$ by an average proportion.

$$N_{exp,KA} \approx N_{exp,KABC} \frac{N_{KA}}{N_{KABC}}$$

Figure 15. Equation. Expected fatal and serious-injury crash frequency as a proportion of expected fatal and all injury crash frequency.

Where: $N_{exp,KA}$ = expected fatal and serious-injury crash frequency.

$N_{exp,KABC}$ = expected fatal and all injury crash frequency.

N_{KA} / N_{KABC} = ratio of number of fatal and serious-injury crashes to the number of fatal and all injury crashes in a State or region over the same period.

When it is not feasible to use $N_{exp,KA}$, analysts can consider substituting $N_{obs,KA}$ or $N_{pred,KA}$ with the potential for lower reliability. Analysts may need to use $N_{obs,KA}$ when SPFs and input data are not available or not reliable enough to use as a basis for decision making, as determined by professional judgment. Similarly, analysts may find it necessary to use $N_{pred,KA}$ when site-specific crash data are either unavailable or unreliable to use for decision making. Ultimately, using $N_{pred,KA}$ is a more proactive approach (i.e., independent of experience) and using $N_{obs,KA}$ is more reactive (i.e., solely based on experience). Readers may refer to FHWA's *Scale and Scope of Safety Assessment Methods in the Project Development Process* for more information on how to select and apply an appropriate method to estimate the safety performance of proposed projects.

5.2.2 Calculating Effective Fatal and Serious-Injury CMF

Analysts select CMFs during countermeasure selection and economic analysis. A project's effective CMF for the change in fatal and serious-injury crashes (i.e., CMF_{KA}) is the combined value of CMF_{KA} for the various countermeasures and strategies implemented in the project. Analysts can consider using CMF_{K}, CMF_{KABC}, or other values if CMF_{KA} is not available for the countermeasure of interest. This assumes the CMF is the same for all crash severity levels included in the original CMF. For example, if the original CMF is 0.8 and applies to total crashes, then the analyst could assume the CMF is 0.8 for K, A, B, C, and O crashes. If two CMFs are available, one for KABC crashes (i.e., all injury crashes combined) and one for PDO crashes, the analyst could assume the CMF for KABC crashes is representative of K, A, B, and C crashes individually and the CMF for PDO crashes represents O crashes individually. It is important to recognize the limitations of this assumption, which may result in lower reliability and may lead to over- or under-estimating changes in fatal and serious-injury crashes. As such, analysts should exercise caution when applying CMFs for other severities (e.g., CMF_{KABCO}) to estimate a change in fatal and serious-injury crashes. The following FHWA 'how-to' videos describe methods to select and combine CMFs.

- Application of CMFs.
- Selecting a Method to Analyze Multiple CMFs.
- Applying a Method to Analyze Multiple CMFs.

FHWA's *CMF Clearinghouse* is the most comprehensive source of CMFs. As of January 2021, the CMF Clearinghouse had only 174 CMF_{KA} values out of all 7,595 star-rated CMFs listed in the database (i.e., two percent), and many of those CMF_{KA} values are for the same countermeasures. Of the 174 CMF_{KA} values in the CMF Clearinghouse, 100 are in terms of all crash types, 36 for non-motorized crashes, and the remainder are mixed between single-vehicle and multiple-vehicle types.[22] Additionally, 87 CMF_{KA} values have a star rating of 3, 18 have a star rating of 4, and zero have a star rating of 5. These numbers demonstrate that countermeasure effectiveness in terms of improving HSIP performance (i.e., reducing fatal and serious-injury crashes) is not well known, and past research has not focused on measuring—or has not been able to measure—the necessary effects (i.e., CMF_{KA}). There is an opportunity to research CMF_{K}, CMF_{A}, and CMF_{KA} data to better understand how countermeasures affect HSIP performance.

Table 7 summarizes the CMF Clearinghouse entries for higher-severity CMFs as of January 2021. Table 7 demonstrates the opportunity to develop new CMF_{KA} data in the future as well as the need to use CMF_{KABC} or other values in the near term as an approximation of CMF_{KA}.[22]

Arizona, Virginia, and Utah are among the States that use CMF_{KABC} as an approximation of CMF_{KA}.[29]

Table 7. Summary of CMF Clearinghouse entries by severity as of January 2021.[22]

Star Rating	CMF_{KA} Values	CMF_{K} Values	CMF_{A} Values	CMF_{KABC} Values	CMF_{KAB} Values	CMF_{ABC} Values	CMF_{AB} Values
5	1	1	0	72	1	17	0
4	28	68	2	391	31	111	0
3	58	56	8	620	12	198	2
2	49	54	12	258	2	74	0
1	20	26	3	108	0	34	0
Unrated	18	3	0	18	0	5	0
Total	174	208	25	1467	46	439	2

Analysts can also estimate a project's CMF_{KA} using the ratio of expected fatal and serious-injury crash frequency under proposed and existing conditions, as shown in figure 16.

$$CMF_{KA} = \frac{N_{exp,KA,proposed}}{N_{exp,KA,existing}}$$

Figure 16. Equation. Estimating a project's CMF_{KA} using expected fatal and serious-injury crash frequency under proposed and existing conditions.

Where: $N_{exp,KA,proposed}$ = a project's expected fatal and serious-injury crash frequency under proposed conditions.

$N_{exp,KA,existing}$ = expected fatal and serious-injury crash frequency for existing conditions (i.e., no-build).

5.2.3 Calculating Weighted Comprehensive Fatal and Serious-Injury Crash Costs

Most States establish standard comprehensive crash costs for use in HSIP analysis. FHWA's *Crash Costs for Highway Safety Analysis* guide presents national crash costs and the associated methods to adjust them by year and State. That guide also presents a method to weight crash costs. The average comprehensive fatal and serious-injury crash cost (CC_{KA}) is the weighted average of the comprehensive fatal crash cost (CC_{K}) and comprehensive suspected serious-injury crash cost (CC_{A}) by severity proportions.

The costs are weighted by the average severity distribution for the facility type (or an entire State or region) as shown in figure 17.[30]

$$CC_{KA} = CC_K \frac{N_K}{N_{KA}} + CC_A \frac{N_A}{N_{KA}}$$

Figure 17. Equation. Weighted average comprehensive fatal and suspected serious-injury crash cost.

Where: N_K / N_{KA} = ratio of number of fatal crashes to the number of fatal and serious-injury crashes across a State, region, or facility type over the same period.

N_A / N_{KA} = ratio of number of serious-injury crashes to the number of fatal and serious-injury crashes in a State, region, or facility type over the same period.

The FHWA *Crash Costs for Highway Safety Analysis* guide indicates that using weighted average crash costs is not an ideal practice, but is appropriate when disaggregate crash frequency estimates (e.g., separate SPFs for K and A) are not available.

5.2.4 Calculating Project Costs

Analysts estimate project costs during countermeasure selection and economic analysis. It is simplest to express project costs in annualized values since projects have different service lives. Analysts can also compare benefits and costs in present value or other equivalent terms if they account for differences in service lives. A common practice for comparing countermeasures with different service lives in terms of present value is to analyze multiple subsequent installations within the least common multiple of their service lives. For example, the common analysis period is 2,100 years when analyzing countermeasures with service lives of 3, 5, 7, 10, 20, and 50 years. Using service lives that have a lower common multiple reduces the analysis period. For example, an analysis period of 50 years would be appropriate for analyzing countermeasures with service lives of 5, 10, 25, and 50 years.

Agencies typically incur implementation costs involving PE, ROW acquisition, and construction (CONSTR) as well as the annual increase to O&M costs resulting from the project over its service life. Most projects do not incur maintenance costs in the first year or two. Estimating annual maintenance costs throughout the service life is conservative and offers a simpler calculation. Analysts can calculate equivalent annuities for non-uniform operations and maintenance costs if judgment indicates it is necessary. Figure 18 shows how to calculate annualized project costs in these terms. Service lives for many countermeasures are listed in FHWA's Countermeasure Service Life Guide.[31]

$$\text{Annualized Project Costs} = (A/P, i, n)(\text{PE} + \text{ROW} + \text{CONSTR}) + \text{O\&M}$$

Figure 18. Equation. Annualized project costs.

Where: *A*/*P* = capital recovery factor as shown in figure 19.

i = interest rate.

n = estimated project service life before needing major reconstruction or until full deterioration of safety benefits.

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

Figure 19. Equation. Capital recovery factor for equivalent annual costs.

5.2.5 Sample BCR_{KA} Calculations with Benefits and Costs

Table 8 presents BCR_{KA} for three hypothetical projects to demonstrate the calculations. For Project 1, the total annual safety benefits (i. e., $143,500) are equal to the product of $N_{exp,KA}$ (i.e., 0.25 average expected fatal and serious-injury crashes per mile per year), 1 – CMF_{KA} (i.e., 0.20), and CC_{KA} (i.e., $2,870,000). The annualized project costs (i.e., $29,214) are equal to the product of the present value implementation costs (i.e., $500,000) and the capital recovery factor (i.e., 0.05743) plus the annual operations and maintenance costs (i.e., $500). The BCR_{KA} (i.e., 4.9) is equal to the total annual safety benefits (i.e., $143,500) divided by annualized project costs (i.e., $29,214).

An agency can use economic analysis results as summarized in table 8 to prioritize projects. An agency looking to maximize cost-effectiveness would select Project 1, as this project provides the best return on investment. Meanwhile, agencies looking to maximize the reduction in KA crashes, regardless of project cost, would select Project 3, which is expected to prevent 0.12 KA crashes (compared to 0.05 in Project 1 and 0.005 in Project 2).

Table 8. BCR_{KA} calculations for three hypothetical projects using benefits and costs.

Value	Project 1	Project 2	Project 3
$N_{exp,KA}$	0.25	0.10	0.40
CMF_{KA}	0.80	0.95	0.70
Expected KA crash reduction	0.05	0.005	0.12
CC_{KA}	$2,870,000	$2,870,000	$2,870,000
Implementation costs (present value)	$500,000	$150,000	$3,000,000
Operations and maintenance costs (annual)	$500	$1,000	$2,500
Service life (years)	25	10	50
Interest rate	3 percent	3 percent	3 percent
Capital recovery factor (A/P, i, n)	0.05743	0.11723	0.03887
Total safety benefits (annual)	$143,500	$15,000	$360,000
Project costs (annualized)	$29,214	$18,585	$119,096
BCR_{KA}	4.9	0.8	3.0

5.3 IMPROVING THE INTERPRETATION OF SAFETY PERFORMANCE

As explained in section 4.2, agencies can appraise the benefits and costs of projects as shown in figure 5 and figure 8. The challenge with calculating BCR this way is that countermeasure-dependent inputs are associated with the numerator (i.e., benefits) and denominator (i.e., costs) of the equation. This makes it difficult to compare the monetary benefits of countermeasures independent of their location. Alternatively, comparing countermeasures by their CMF or total safety benefits does not account for their cost effectiveness—a lower CMF does not necessarily increase the BCR because it may come at disproportionately higher costs, and vice versa.

It would be easier to understand how to maximize a site or countermeasure's anticipated contributions to the performance of a project by consolidating the site-dependent and countermeasure-dependent inputs to single factors (i.e., rather than benefits and costs). Rearranging figure 12 yields figure 20, which separates site-dependent and countermeasure-dependent factors in each set of brackets, respectively. Crash costs (i.e., CC_{KA}) are applied to the site-specific crash frequency and are grouped accordingly. Additionally, although project costs are somewhat site-dependent (e.g., land use, real estate value) they are mostly driven by what countermeasures are proposed in the project.

$$BCR_{KA} = \left[N_{exp,KA} \times CC_{KA}\right] \times \left[\frac{1 - CMF_{KA}}{\text{Project Costs}}\right]$$

Figure 20. Equation. Rearranged equation for BCR_{KA} showing site- and countermeasure-dependent inputs.

The site-dependent component of figure 20 (i.e., the product of $N_{exp,KA}$ and CC_{KA}) represents the monetary value of expected future crashes if a project were not implemented. This measure could also be considered the maximum amount of monetary benefit available at a location in terms of fatal and serious-injury crashes ($PSI_{\$,KA}$), as shown in figure 21.

$$PSI_{\$,KA} = N_{exp,KA} \times CC_{KA}$$

Figure 21. Equation. Maximum monetary potential for safety improvement.

The countermeasure-dependent component of figure 20 (i.e., ($1 - CMF_{KA}$) / Project Costs) represents the proportion of fatal and serious-injury crashes reduced per dollar. However, in practice this ratio is difficult to interpret or apply. The difference of ($1 - CMF_{KA}$) is a proportion, not a percent. It would be easier for practitioners to interpret this measure in practice with a CRF, which is in terms of percent crash reduction. Substituting $PSI_{\$,KA}$ and CRF_{KA} into figure 20 yields figure 22.

$$BCR_{KA} = PSI_{\$,KA} \times \frac{CRF_{KA}}{\text{Project Costs} \times 100}$$

Figure 22. Equation. BCR_{KA} equation based on $PSI_{\$,KA}$, CRF_{KA}, and project costs.

However, the combined ratio of CRF_{KA} to project costs shown in figure 22 can also be difficult to interpret when the percent crash reduction per dollar is very small. Conceptually, practitioners may want to compare how much it costs to reduce a comparable amount of crashes with different countermeasures, not how many crashes each countermeasure can reduce at a comparable cost. Rather than scaling up this ratio (e.g., CRF_{KA} per $100,000), inverting the ratio indicates the average cost to reduce one percent of fatal and serious-injury crashes, which could be referred to as a Countermeasure Score (CM $Score_{KA}$).

The CM $Score_{KA}$ measure is shown in figure 23. In general, lower CM Scores are desirable. The project costs in CM Scores need to be in terms of annualized value per unit installation (e.g., mile, intersection) to compare projects with different service lives and extents. CM Scores have the same geometric, operational, and spatiotemporal applicability ranges as the associated CMFs and costs. Agencies could also consider developing CM Scores for different severity levels.

$$\text{CM Score}_{KA} = \frac{\text{Project Costs}}{\text{CRF}_{KA}} = \frac{\text{Project Costs}}{(1 - \text{CMF}_{KA}) \times 100} = \frac{\text{Project Costs}}{\left(1 - \frac{N_{exp,KA,proposed}}{N_{exp,KA,existing}}\right) \times 100}$$

Figure 23. Equation. Various ways to calculate CM Score$_{KA}$.

Substituting CM Score$_{KA}$ from figure 23 into figure 22 yields figure 24. PSI$_{\$,KA}$ measures the dollar value of potential benefits at a location and a countermeasure's CM Score$_{KA}$ represents how much it costs to generate one percent of those potential benefits. Thinking about HSIP projects in these terms can make it to easier for decision makers and analysts to understand how to improve the HSIP's performance. In summary, the objective of safety management is to find locations with a relatively high dollar value of expected fatal and serious-injury crash frequency (i.e., high PSI$_{\$,KA}$) and implement countermeasures with a relatively low implementation and maintenance costs per percent fatal and serious-injury crash reduction over the service life (i.e., low CM Score$_{KA}$) at those locations.

$$\text{BCR}_{KA} = \frac{\text{PSI}_{\$,KA}}{\text{CM Score}_{KA} \times 100}$$

Figure 24. Equation. Simplified BCR$_{KA}$ equation based on PSI and countermeasure cost-effectiveness.

Where: PSI$_{\$,KA}$ = equivalent dollar value of the average number of fatal and serious-injury crashes anticipated to occur annually per mile per year if an HSIP project were not implemented at a location.

CM Score$_{KA}$ = costs incurred to implement and maintain a project over its service life per percent reduction in fatal and serious-injury crashes.

While BCR$_{KA}$ is appropriate to prioritize projects and alternatives among different locations, analysts can use CM Scores to select among countermeasures at a given location. Considering the no-build expected fatal and serious-injury crash frequency ($N_{exp,KA}$)—and therefore PSI$_{\$,KA}$—is fixed for projects in the design phase, designers would minimize the CM Score$_{KA}$ of their proposed design to maximize a project's expected performance, rather than maximizing the BCR$_{KA}$. To accurately compare CM Scores, the values should be expressed in terms of the underlying unit costs (e.g., per mile, per site, per project).

5.3.1 Developing Average CM Scores

In the future, it may be desirable to compare CM Scores across multiple locations and projects in addition to or in place of CMFs, CEI, total safety benefits, NPV, or BCR. Of those five other measures, only the CMF is location-independent (i.e., assuming costs are primarily driven by the proposed countermeasures) and it does not account for costs. The countermeasures with the lowest CM $Score_{KA}$ generally have the greatest opportunity to cost-effectively reduce fatalities and serious injuries based on predictive analysis.

- The CM Score improves upon the CMF because the percent reduction is not enough to compare countermeasure cost-effectiveness—implementation and maintenance costs are also needed. The CM Score incorporates both components in one measure.
- The CM Score improves upon the CEI, total benefits, NPV, and BCR because the CM Score is independent of project location. As shown in figure 24, the CM $Score_{KA}$ is directly related to BCR_{KA}. Therefore, the CM $Score_{KA}$ is another measure of HSIP performance.

Agencies could develop and maintain average CM Scores (i.e., like a State CMF list as explained in section 3.2.4) to compare countermeasures based on performance and to develop rules of thumb about implementation. Each State or region could develop CM Scores using locally-developed CMFs from safety effectiveness evaluations as well as average bid or construction prices for a countermeasure across many projects. Agencies can consider listing the most cost-effective countermeasures (i.e., lowest CM Score) in the SHSP for each emphasis area or related to various facility types. This strategy helps reinforce the implementation of those high-performing countermeasures.

CM Scores could also be developed nationally (e.g., using the highest quality CMFs and average costs, using averages of States' CM Scores). Average CM Scores may be transferrable between States or area types using an index representing relative construction costs, and this approach would be helpful for States lacking their own data. However, calibrating CMFs and transferring costs separately may be more appropriate.

The CMFs, costs, and service lives used in determining CM Scores have a large effect on the relative comparison between countermeasures. CM Scores would ideally use costs from projects that cover the same range of AADTs and facility types that the CMF is applicable to. Each countermeasure could have multiple CM Scores applicable to different site characteristics or regions. Development of such accurate and precise CM Scores would need a complete and regular evaluation program as well as an integrated and accessible implemented countermeasure data set. Updating project costs to the current year (or a consistent period) is important when comparing CM Scores based on historical cost data.

Additionally, agencies could explore developing ranges of CM Scores for each countermeasure using low, medium, and high costs and a range of applicable CMFs to improve decision making. Table 9 displays data and example CM $Score_{KA}$ calculations for common countermeasures. CMF inputs in table 9 are from the CMF Clearinghouse. The implementation and maintenance costs in table 9 come from the Utah and North Carolina CMF lists, also available on the CMF Clearinghouse.

Table 9. Example Countermeasure Score calculations with CMF Clearinghouse IDs and hypothetical costs.[22]

Countermeasure	CMF ID	CRF_{KA}	Implementation Costs (Initial)	O&M Costs (Annual)	Cost Units	Service Life (yr)****	Interest Rate	A/P	CM $Score_{KA}$
Install chevron signs	2438	16**	$9,000	$0	Curve	15	0.03	0.0838	$47
Install centerline and shoulder rumble strips	2420	18	$60,000	$0	Mile	10	0.03	0.1172	$391
Install cable median barrier	3173	44	$300,000	$1,500	Mile	25	0.03	0.0574	$426
Convert higher speed intersection to roundabout	4697	68***	$800,000	$2,500	Intersection	25	0.03	0.0574	$712
Install raised median	3035	44	$500,000	$0	Mile	20	0.03	0.0672	$764
Provide intersection illumination	436	42***	$400,000	$1,000	Intersection	15	0.03	0.0838	$822
Convert minor STOP to modern roundabout	7868	71**	$1,000,000	$2,500	Intersection	20	0.03	0.0672	$982
Install high friction surface treatment	7901	52***	$650,000	$0	Mile	10	0.03	0.1172	$1,465
Install pedestrian hybrid beacon	2917	15**	$250,000	$600	Crossing	10	0.03	0.1172	$1,994
Install w-beam guardrail	8393	16	$450,000	$1,500	Mile	15	0.03	0.0838	$2,450

*Note: * = CRF_{KAB}; ** = CRF_{KABC}; *** = CRF_{KABCO}; and **** = values based on FHWA's Countermeasure Service Life Guide.*[31]

5.3.2 Sample BCR_{KA} Calculations with PSI and Countermeasure Scores

Table 10 presents example BCR_{KA} calculations for the same three hypothetical projects from table 8. For Project 1, the $PSI_{\$,KA}$ (i.e., $717,500) is equal to the product of $N_{exp,KA}$ (i.e., 0.25 average expected fatal and serious-injury crashes per year) and CC_{KA} (i.e., $2,870,000). The CM $Score_{KA}$ (i.e., $1,461) is equal to the annualized project costs (i.e., $29,214) divided by the CRF_{KA} (i.e., 20). Annualized project costs (i.e., $29,214) are equal to the product of the present value implementation costs (i.e., $500,000) and the capital recovery factor (i.e., 0.05743) plus the annual operations and maintenance costs (i.e., $500). The BCR_{KA} (i.e., 4.9) is equal to the $PSI_{\$,KA}$ (i.e., $717,500) divided by 100 times the CM $Score_{KA}$ (i.e., $1,461 x 100 = $146,100).

Given the $PSI_{\$,KA}$, CM $Score_{KA}$, and BCR_{KA} of the three projects in table 10, Project 1 offers the greatest potential to improve systemwide safety performance because it has the highest BCR_{KA} and lowest CM $Score_{KA}$.

Table 10. BCR_{KA} calculations for three hypothetical projects using $PSI_{\$,KA}$ and CM $Score_{KA}$.

Value	Project 1	Project 2	Project 3
$N_{exp,KA}$ (expected KA crash frequency)	0.25	0.10	0.40
CMF_{KA}	0.80	0.95	0.70
$(1\text{-}CMF_{KA})$	0.20	0.05	0.30
CRF_{KA} (percent KA reduction)	20	5	30
Expected KA crash reduction	0.05	0.005	0.12
CC_{KA} (weighted average comprehensive)	$2,870,000	$2,870,000	$2,870,000
Implementation costs (present value)	$500,000	$150,000	$3,000,000
Operations and maintenance costs (annual)	$500	$1,000	$2,500
Service life (years)	25	10	50
Interest rate	3 percent	3 percent	3 percent
Capital recovery factor (*A/P*, *i*, *n*)	0.05743	0.11723	0.03887
$PSI_{\$,KA}$ (annual)	$717,500	$287,000	$1,148,000
CM $Score_{KA}$ (annualized)	$1,461	$3,717	$3,970
BCR_{KA}	4.9	0.8	3.0

5.4 SELECTING PROJECTS TO MAXIMIZE HSIP PERFORMANCE

Selecting projects and strategies to maximize HSIP performance means applying available funding to projects and strategies that prevent fatal and serious-injury crashes most cost effectively based on available data and professional judgment. Agencies can determine whether to prioritize all or a portion of their funding by BCR and whether to establish multiple funding goals (e.g., subprograms or set-asides) to program projects within. Agencies prioritizing a portion of their funds by BCR can create separate funding goals for projects selected by BCR and those selected using other means. Higher-quality safety data and more-reliable DDSA methods support more-objective decision making.

5.4.1 Selecting Projects for Maximum Predicted Performance

Agencies can consider using the following three-step process to select projects for maximum predicted performance.

1. Calculate BCR_{KA} or BCR of a lower severity level (e.g., BCR_{KABC}) for each project. Agencies should use a consistent ranking measure to promote fair prioritization if possible (i.e., rank all projects by either BCR_{KA} or BCR_{KABC}, not a mix of both).

2. Prioritize (i.e., sort) all feasible projects with quantifiable benefits that are in consideration for funding (as in table 5) by BCR.

3. Select projects in BCR order until either:

    a. The sum of all proposed projects' implementation costs (i.e., PE, ROW, and CONSTR) plus reasonable contingencies exceeds the available HSIP funding for the target program year.

    b. The sum of all proposed projects' annual maintenance costs exceeds an agency-defined limit of allowable maintenance cost increases annually, if such a threshold is set. After hitting this threshold, the agency could fill the rest of the program with projects needing no more maintenance beyond existing conditions.

5.4.2 Selecting Projects Using Multiple Factors

Agencies can consider the following two methods to rank and select projects considering multiple factors.

- Develop a weighted average index that accounts for BCR and other factors, such as those listed in section 4.3.2, by applying a standard weighting or scoring scheme for each factor of interest and summing the results as an index.

- Apply the method from section 5.4.1 and determine if any changes to the proposed program of projects are necessary based on other factors, such as those listed in section 4.3.2, using consensus agreement and professional judgment.

INDOT conducts a two-step process to generate its annual capital program of traffic safety projects. Initially, statewide screening to identify highest-need sites is carried out by means of an application capturing core traffic safety performance metrics. Highest value candidates are then further assessed individually to confirm the best treatment, then each is explicitly scored based on formal business rules, such that the highest scoring in order are funded until the program budget is exhausted. (Overrides are rare but in select cases enable an otherwise lower-scoring candidate project to be evaluated in priority, to be potentially funded where scoring criteria fail to truly capture merit; and there are special set-asides for a number of recurring systemic countermeasures.) Project score, thus priority for funding, is a function of 7 scoring factors and 2 supplemental scoring factors, with associated weightings, based on a base 100-point scale:

- *Crash severity (40 points).*
- *Crash frequency (10 points).*
- *Benefit-cost ratio (35 points).*
- *Mobility improvement (3 points).*
- *Public & other interests (5 points).*
- *Route continuity & corridor completion (2 points).*
- *Multimodal components (5 points).*
- *Supplemental a: external funding contributions of offsets (25 points).*
- *Supplemental b: coordination with other disciplines (5 points).*

5.5 CHAPTER SUMMARY

This chapter presents analytical approaches to estimate and improve upon overall HSIP performance as well as the performance of HSIP projects. In general, agencies can save more lives and prevent more serious injuries by increasing the average BCR_{KA} of implemented projects or increasing the funding spent on performance-based safety improvements. BCR_{KA} is a direct measure of program and project cost-effectiveness, priority, and performance.

Analysts can calculate BCR using annualized total safety benefits and project costs or with $PSI_{\$}$ and CM Score measures. Agencies can improve average project BCR_{KA} by selecting sites with higher expected fatal and serious-injury crash frequencies and implementing countermeasures that have a lower annualized project cost per percent reduction in fatal and serious-injury crashes. Site and countermeasure selection are largely dependent on the safety management approach an agency uses to develop HSIP projects.

Agencies should prioritize projects based on quantitative methods such as the BCR and other factors when possible, regardless of the approach used to identify the project. There are many ways to select projects. Applying a transparent, consistent, performance-based process to select projects, and improving upon and refining that process over time, can help agencies maximize HSIP performance. Transparency helps stakeholders develop competitive projects and can promote participation from local agencies. Consistency promotes fairness and helps evaluate the effectiveness of the project selection process.

The fundamental components necessary to implement a BCR prioritization approach, at least for a portion of projects, are currently available to agencies: crash frequency estimates or SPFs, crash costs, CMFs, project costs, and relevant analysis methods. Applying the general approach to prioritize projects by BCR is essential to improving the HSIP's performance. One challenge to implement the approach in practice for fatal and serious-injury crashes is the need for reliable CMF_{KA} data, which are lacking for many facility types and countermeasures. While DDSA tools are expected to continue to improve over time, agencies can use variations of the approach (e.g., applying BCR_{KABC}) as an approximation in the interim.

Chapter 6 discusses how agencies can apply BCR_{KA} concepts in safety management to develop high-priority, cost-effective, well-performing projects during site and countermeasure selection. Applying BCR_{KA} concepts allows agencies to be more strategic and performance-oriented throughout safety planning.

CHAPTER 6. PLANNING HIGH-PERFORMING SAFETY PROJECTS

As discussed in chapter 5, tools are available to estimate a project's expected performance in terms of BCR and the calculation is relatively straightforward. Planning and developing high-performing projects that include highly cost-effective countermeasures at sites with high PSI is not as simple. For many years, practitioners have been using the site-specific, systemic, and systematic approaches to strategically identify high-priority safety issues and implement targeted countermeasures. Each approach represents a different philosophy and framework for improving highway safety.

In general, decision makers should select the best projects for their HSIP regardless of the approach used to identify those projects. Research has not yet demonstrated the relative performance of each safety management approach in practice—only the relative difference in countermeasure effectiveness. Safety benefits come from the countermeasures, how cost-effective they are, and where they are implemented—not the approach used to plan and implement them. Further, agencies may need to use more than one approach to find the most cost-effective projects from such a wide range of potential options. If DDSA indicates one countermeasure is substantially more cost-effective than others, then maximizing the implementation of that countermeasure in a systematic approach could be a good option to consider. If a group of relatively high PSI sites have a similar focus crash type suitable for the systemic approach, then that could produce a good project. When some sites have extraordinarily high PSI or cost-effective countermeasures that are not applicable to the other approaches, the site-specific approach may be effective.

This chapter refines current safety management approaches to gear them toward developing projects with optimal inputs to the BCR_{KA} equations in figure 12 and figure 24. Sections 6.1, 6.2, and 6.3 outline procedures to implement the site-specific, systemic, and systematic approaches in practice. Table 11 includes an overview of the strengths, limitations, and variations of the approaches.

Table 11. Comparison of safety management approaches.

Approach	Main Strengths	Main Limitations	Main Variations
Site-specific	Address sites with higher than expected crash frequency; high potential crash reductions per location	Usually limited to one site	All crash types; Crash type-based screening; Corridor projects
Systemic	Address sites with severe crash risk in a focus crash type; does not need site-specific crash data	Usually addresses one crash type with one countermeasure; data to choose risk factors may be limited	SSPST; AASHTOWare Safety; usRAP; other COTS* software
Systematic	Efficiently deploy highly cost-effective countermeasures; independent of crash data	Does not consider site-specific potential for safety improvement	Standalone; Policy-based

*Note: * COTS: commercial-off-the-shelf.*

6.1 APPLYING THE SITE-SPECIFIC APPROACH

Agencies applying the site-specific approach to safety management identify high-crash locations and select the most effective and appropriate countermeasures for those sites. Site selection involves identifying the locations across the road network with the highest PSI based on the selected measure of performance (e.g., $N_{exp,KA}$). Agencies select countermeasures that address crash patterns or hazards constituting a large portion of each site's $N_{exp,KA}$. Site-specific projects usually aim to implement highly-effective countermeasures that can reduce as many crashes as possible at these locations over the long term.

6.1.1 Implementing BCR_{KA} in the Site-Specific Approach

The following steps outline the use of BCR_{KA} in the site-specific approach to maximize or control for each of the factors in figure 12:

1. Conduct network screening to identify locations with high expected fatal and serious-injury crash frequency (i.e., $N_{exp,KA}$). When it is not feasible to perform network screening with $N_{exp,KA}$, agencies can use $N_{exp,KABC}$ or $N_{exp,KABCO}$ in screening with the assumption that those measures are expected to identify sites that also have potential for improvement in fatalities and serious injuries. Agencies should consider using the EB method to determine $N_{exp,KA}$ in terms of expected average fatal and serious-injury crash frequency. When it is not feasible to use the EB method, the observed fatal and serious-injury crash frequency may be a reliable surrogate in screening. The *Reliability of Safety Management Methods: Network Screening* guide demonstrated empirically that observed fatal and injury crash frequency (i.e., $N_{obs,KABC}$) is nearly as effective as $N_{exp,KABC}$ in screening the network for locations that lead to cost-effective projects.[32]

2. Set a reasonable threshold of sites to review from the network screening results based on staff and funding availability. While agencies can review locations and develop projects beyond the available HSIP budget, it is not necessary to investigate every site across the network every year and it is not an effective use of resources to develop projects that are not cost-effective. However, it is unlikely that every high-ranking site from screening is a feasible location for HSIP projects (i.e., due to eligibility and budget limitations). As such, agencies could review and develop projects at more locations than are likely to receive funding. Agencies should consider developing a backlog of unfunded safety needs that are regularly prioritized against new projects and can enter the program as needed when planned projects experience issues with schedule or budget.

3. Diagnose safety concerns at each location chosen for further investigation from network screening. Specifically, analysts consider the crash types and contributing factors that indicate the potential for future fatal and serious-injury crashes. Diagnostic analysis may

involve crash summaries, a collision diagram, investigating individual crashes, and road safety audits or field reviews.

4. Select feasible, appropriate countermeasure alternatives that target prominent safety concerns or contributing factors related to fatal and serious-injury crashes. This is an opportunity to employ the Safe System approach, which favors countermeasures that remove the risk, reduce the risk, change road user behavior, protect the road user, or knowingly retain the risk if necessary, in that order.[33] Agencies should consider using the CMF_{KA} and average life-cycle project costs in countermeasure selection (i.e., selecting targeted countermeasures that also provide a relatively high benefit in fatal and serious-injury crashes). When a countermeasure's effects on fatal and serious-injury crashes are unknown, analysts can use CMF_{KABC} or CMF_{KABCO} as an approximation of CMF_{KA}, recognizing that this assumption may lead to over- or underestimating changes in specific severity levels.

5. Apply crash costs (e.g., CC_{KA}) in benefit cost analysis to determine each project's BCR. Agencies can apply average crash costs by severity (CC_K and CC_A) to the expected change in fatal and serious-injury crashes, respectively. When this information is not available by severity, analysts can estimate benefits using more aggregate severity levels (KA, KABC, or KABCO).

6. Rank alternatives by BCR and select economically valid alternatives that address the needs of stakeholder agencies and the public at the project location. To maximize lives saved, agencies can analyze and prioritize projects by BCR_{KA}. When it is not possible or practical to estimate BCR_{KA}, analysts can estimate the BCR using more aggregate severity levels (BCR_{KABC} or BCR_{KABCO}).

6.1.2 Strengths and Limitations of the Site-Specific Approach in Practice

The site-specific approach has the following strengths in practice.

- It addresses locations with history of frequent severe crashes, poor safety performance, or negative public perception (e.g., frequent near misses or high-profile fatalities).

- It concentrates the implementation of countermeasures where many crashes are likely to occur and where many road users are likely to benefit from them, especially when paired with the EB method. The EB method can help to account for regression-to-the-mean, which is particularly relevant when focusing on KA crashes.

- The approach relies on integrated high-level crash and roadway data across the network, and in some cases crash data is enough to identify candidate project locations. Detailed crash and roadway data are only necessary on a site-by-site basis because the only inputs for planning-level SPFs used in network screening are high-level crash and roadway data.

- The process is straightforward and easy to learn, implement, and communicate to others.
- Most agencies already have well-defined procedures to implement the approach.
- Many existing resources document the site-specific approach and related methods.

The site-specific approach has the following limitations in practice.

- Program managers and analysts review sites iteratively, which is not an efficient way to identify the most effective projects across all public roads.
- Achieving a high-crash reduction can be more important for project stakeholders than cost-effectiveness due to extraordinarily high-crash frequencies at each location (i.e., if agencies prefer ranking NPV over BCR for mutually-exclusive alternatives).
- The approach tends to concentrate fewer projects at high-volume, urban locations. Agencies could establish supplemental policies or procedures to promote more equitable funding distribution across all high PSI sites.
- Investing a large amount of funds at each site can cause significant impacts to the HSIP's expected performance when even one project does not achieve its intended outcome.
- Using observed crashes, particularly observed K and A crashes, in the site-specific approach is prone to issues related to regression-to-the-mean. As discussed in the previous list of strengths, using the EB method can help to account for regression-to-the-mean.

6.2 APPLYING THE SYSTEMIC APPROACH

Rather than concentrating projects at high-crash frequency locations, agencies apply the systemic approach to widely implement countermeasures that can address fatal and serious-injury crash types with a high average BCR across a corridor, region, or the whole network. Agencies typically use crash trees, summaries, statistics, and other tools to select focus crash types as well as facility types where those crash types are common or overrepresented. Analysts then identify risk factors by reviewing data to identify geometric, operational, and contextual characteristics that are overrepresented at the locations where those severe crash types occur. Some systemic projects begin with a focus crash type and a highly-cost-effective countermeasure that an agency wants to use to address those crashes. Agencies following this approach use the same process but can tailor their risk factors to characteristics that indicate the site's need and suitability for the countermeasure. The SSPST contains more information about selecting focus crash types, facility types, and risk factors.[6]

> *IDOT's Systemic Safety Improvements: Analysis, Guidelines and Procedures document demonstrates benefit-cost analysis for systemic projects using their benefit-cost tool. The tool uses crash frequency, countermeasure costs and quantities, target crash types, CMFs, and service life to calculate a BCR and the total estimated number of lives saved by the systemic project.*[34]

6.2.1 Implementing BCR_{KA} in the Systemic Approach

The following steps outline the use of BCR_{KA} in the systemic approach as laid out in the *SSPST* to maximize or control for each of the factors in figure 12:

1. Select a focus crash type from the SHSP or identify focus crash types from crash type distributions for observed fatal and serious-injury crashes across a corridor, region, or the whole network.

2. Determine a focus facility type where many sites have a relatively high expected fatal and serious-injury crash frequency for the focus crash type (i.e., high $N_{exp,KA,type}$) or where the focus crash type is proportionally overrepresented (i.e., high ratio of $N_{obs,KA,type}$ to $N_{obs,KA}$).

3. Select risk factors that indicate a greater potential for severe focus crashes to occur. Agencies may determine risk factors from existing resources (e.g., *SSPST*, *CMF Clearinghouse*) or existing safety databases, or they may collect new data to use as risk factors. There is typically limited information on risk factors across the network that can be readily used for analysis. Agencies should consider basing risk factor selection on statistical correlations and the predictive power of potential risk factors.

4. Screen and prioritize sites based on high $N_{exp,KA,type}$ or the presence of risk factors. Figure 12 and figure 14 demonstrate that projects are expected to be more effective when a site's $N_{exp,KA}$ is higher as well as when $N_{exp,KA,type}$ represents a higher proportion of a site's $N_{exp,KA}$.

5. Select feasible, appropriate countermeasure alternatives that target the focus crash type. Agencies should consider the CMF_{KA} and average project costs in countermeasure selection. When a countermeasure's effects on fatal and serious-injury crashes are unknown, analysts can use CMF_{KABC} or CMF_{KABCO} to approximate CMF_{KA}, recognizing that this assumption may lead to over- or underestimating changes in specific severity levels.

6. Apply crash costs (e.g., CC_{KA}) to determine the project's BCR, considering the benefits and disbenefits to all fatal and serious-injury crashes (i.e., not solely the focus crash type). Agencies should consider applying average crash costs by severity (CC_K and CC_A) to the expected change in fatal and serious-injury crashes, respectively. When this information is not available by severity, analysts can estimate benefits using more aggregate severity levels (KA, KABC, or KABCO).

7. Rank alternatives by BCR and select alternatives from the list that address the needs of stakeholder agencies and the public at the project location. Agencies should consider using BCR_{KA}. When it is not possible or practical to estimate BCR_{KA}, analysts can estimate the BCR using more aggregate severity levels (BCR_{KABC} or BCR_{KABCO}).

The following steps outline an alternative implementation of the systemic approach based on the BCR_{KA} equation in figure 24. Analysts can consider this version of the systemic approach to overcome concerns about the quality of data used to identify risk factors or high-PSI locations.

1. Select a focus crash type, as discussed in Step 1 in the previous systemic process.

2. Select one or more facility types where the focus crash type is highly prevalent or where previous research (e.g., NCHRP Report 500 guides and FHWA's *Contributing Factors for Focus Crash and Facility Types: Quick Reference Guide*) has indicated a risk for the focus crash type.[35,36]

3. Select one or more countermeasures with a low CM $Score_{KA}$ that are likely to address the focus crash type and are appropriate for the focus facility types.

4. Select sites based on high $PSI_{\$,KA,type}$ where the countermeasure is applicable and feasible. In lieu of reliable site-specific data, analysts could assess and compare whole corridors or functional classifications of sites based on their anticipated fatal and serious-injury crash frequency.

5. Rank alternative projects or locations by BCR_{KA} and select alternatives that address the needs of stakeholder agencies and the public.

6.2.2 Strengths and Limitations of the Systemic Approach in Practice

The systemic approach has the following strengths in practice:

- Can implement countermeasures at far more sites than could reasonably be addressed with the site-specific approach.
- Often focuses on implementing proven, highly cost-effective, low unit-cost countermeasures that generate favorable BCRs at many levels of N_{exp}. Previous research has suggested that systemic projects are empirically almost three times more cost-effective on average than site-specific projects.[8]
- Investing small amounts of funding at each location prevents significant impacts to the HSIP's performance when any one implementation does not achieve its intended outcomes (i.e., the overall project would still likely be highly cost-effective).

The systemic approach has the following limitations in practice.

- Some States do not estimate the BCR for systemic projects. Based on interviews with several States, one reason for not conducting benefit-cost analysis for systemic projects is the level of effort to do so for projects that span many miles or intersections. Another reason is the difficulty in integrating the roadway, crash, and traffic data needed to support benefit-cost analysis.
- Some countermeasures are not applicable to the systemic approach because of the nature of the countermeasure or limited budgets.

6.3 APPLYING THE SYSTEMATIC APPROACH

The systematic approach to safety management involves implementing proven, cost-effective countermeasures or upgrades to existing safety features at most or all feasible locations across a facility type (e.g., freeways, signals), region, or the whole network. Agencies either implement the systematic approach through standalone projects or by integrating countermeasures into the agency's design standards. The preferred approach is to integrate the most cost-effective countermeasures into design standards, so the costs are distributed amongst all projects and not incurred solely by the HSIP.

However, agencies may want to consider implementing standalone systematic HSIP projects for highly cost-effective countermeasures in the following situations:

1. If DDSA or performance-based analysis demonstrates a countermeasure is extremely cost-effective and can be feasibly implemented at most sites of the applicable facility types (e.g., rumble strips, retroreflective backplates).
2. If the agency does not have resources or tools to reasonably identify candidate project locations, which is a necessity in the site-specific and systemic approaches.
3. If the quality of site-specific crash data is relatively poor or generally unknown.

KYTC lists cost-effective countermeasures like rumble strips in their SHSP. Once the countermeasure has been deployed on most high-priority locations using HSIP funding, it gets incorporated into KYTC's design standards and is no longer implemented on State-owned facilities using HSIP funds.

6.3.1 Implementing BCR_{KA} in the Systematic Approach

Systematic projects do not consider site-specific safety performance during countermeasure implementation. This means that the only factor impacting the performance of this approach (i.e., beyond network safety performance) is the project cost per percent reduction in fatalities and serious injuries over the proposed project's service life, which is determined by CMF_{KA} and project costs.

1. Select a focus crash type from the SHSP or identify focus crash types from crash type distributions for observed fatal and serious-injury crashes across a corridor, region, or the whole network.
2. Select feasible, appropriate countermeasure alternatives that target a focus crash type. Agencies should consider using CMF_{KA} and estimates of project costs in countermeasure selection. Because systematic projects are generally implemented at all feasible locations, agencies may want to emphasize lower-unit-cost countermeasures. When a countermeasure's effects on fatal and serious-injury crashes are unknown, analysts can use CMF_{KABC} or CMF_{KABCO} to approximate CMF_{KA}, recognizing that this assumption may lead to over- or underestimating changes in specific severity levels.
3. Identify candidate locations and determine the scale and cost of the project.
4. Apply crash costs (e.g., CC_{KA}) to determine the project's BCR, considering the benefits and disbenefits to all fatal and serious-injury crashes (i.e., not only the focus crash type). Agencies should consider applying average crash costs by severity (CC_K and CC_A) to the expected change in fatal and serious-injury crashes, respectively. When this information

is not available by severity, analysts can estimate benefits using more aggregate severity levels (KA, KABC, or KABCO).

5. Rank alternatives by BCR and select alternatives from the list that address the needs of stakeholder agencies and the public at the project location. Agencies should consider using BCR_{KA} to rank and select proposed projects. When it is not possible or practical to estimate BCR_{KA}, analysts can estimate the BCR using more aggregate severity levels (BCR_{KABC} or BCR_{KABCO}).

The use of BCR_{KA} in the systematic approach simply involves selecting countermeasures with the lowest CM $Score_{KA}$ that can be widely implemented to nearly all applicable sites. Integrating these countermeasures into agency standards is the preferred approach but standalone projects can be highly cost-effective as well.

6.3.2 Strengths and Limitations of the Systematic Approach in Practice

The systematic approach has the following strengths in practice:

- It is simple and needs the least analysis of the major safety management approaches, because it needs no site-specific crash data.
- Accurate risk assessment is not a component, and therefore it is especially applicable to widely addressing low volume roads where relative differences in risk between sites are negligible.

The systematic approach has the following limitations in practice.

- While the decision to implement a countermeasure systematically may be based on average cost-effectiveness, the approach does not consider the relative cost-effectiveness of implementation at different locations (i.e., like site-specific or systemic) and therefore may include locations that are not the most cost-effective.
- Some countermeasures are not reasonable or feasible to implement widely across the network.

6.5 CHAPTER SUMMARY

This chapter presents three safety prioritization approaches that can help agencies plan high-performing highway safety infrastructure projects. Agencies can implement the site-specific, systemic, and systematic approaches to strategically identify sites, select countermeasures, and develop projects that quantitatively improve safety with available resources, data, and analytical tools. Each approach has strengths and limitations related to ease, efficiency, and scalability of implementation; data needs; accuracy of the results; and the resulting projects' cost-effectiveness.

Agencies can tailor each safety management approach to their needs and resource constraints using different analytical methods with varying levels of reliability. Agencies with relatively high data and analysis capabilities can implement each approach using more reliable DDSA methods. Agencies with relatively low data or analysis capabilities can still implement each approach (as discussed further in the *FHWA HSIP Manual*, *SSPST*, and other resources).

CHAPTER 7. CASE STUDIES

This chapter presents case studies that illustrate how agencies can apply two quantitative methods discussed in chapters 4 and 5, the BCR_{KA} and the CM Score, to prioritize projects. Two States, Ohio and Utah, supplied safety data and permitted the project team to compare their methods for prioritizing HSIP projects to the BCR_{KA} method. Additionally, the project team used State-supplied information to compute CM Scores for several countermeasures.

7.1 CASE STUDY 1: USING BCR_{KA} TO SELECT HSIP PROJECTS

Ohio and Utah both calculate BCRs using expected benefits from crashes of all severities when evaluating HSIP applications. The project team calculated the BCR_{KA} for each State-supplied HSIP application and ranked the applications according to the newly-calculated BCR_{KA} to determine differences in ranking results.

7.1 1 Abbreviated Methodology

Typically, when agencies calculate BCR_{KA} to evaluate HSIP applications, they apply crash costs by severity to the expected change in fatal and serious-injury crashes, convert these safety benefits to present value, and divide by present-value costs of the project. However, the Ohio and Utah case studies began with HSIP data that included a BCR that considers all crash severities. As such, the project team used an abbreviated method to calculate the BCR_{KA}, as follows. The project team:

1. Determined the fraction of the safety benefit derived from reductions in fatal and serious-injury crashes (as opposed to reductions in all crash severities) for each HSIP application. This fraction is labeled the **K&A fraction**.
2. Multiplied the existing BCR by the K&A fraction to calculate the BCR_{KA} for each HSIP application.

The reason for using this abbreviated approach is to capture the assumptions contained in the State-specific methods. The State-specific methods and resulting BCRs consider elements such as project service life, forecast project costs by year, and forecast traffic growth. The project team used the existing BCRs as a starting point for the calculation and retained the assumptions inherent in these values when computing the BCR_{KA}.

The project team calculated the BCR_{KA} for all HSIP applications and ranked each State's applications according to the BCR_{KA}. Using a consistent HSIP budget, the project team compared results from each State's existing HSIP project selection methodology with the results from the BCR_{KA} method. Specifically, the project team compared each method with respect to the overall performance (i.e., estimated reduction in fatal and serious-injury crashes and reduction per dollar spent) within the given HSIP budget.

7.1.2 Ohio

The Ohio DOT (ODOT) provided crash costs by severity for HSIP project applications considered for funding in 2020. ODOT also provided HSIP project applications and summary data for each application, which included the expected annual number of crashes for each severity level for both existing and proposed conditions. The project team identified 108 applications suitable for analysis in this case study. Of the 108 HSIP applications investigated, ODOT approved 47 applications (44 percent) for HSIP funding. Following are characteristics of these 47 applications:

- Collectively, the approved projects are expected to reduce 12.3 fatal and serious-injury crashes per year, a K&A benefit of about $4.5 million annually.
- The projects are expected to gain about 40 percent of their crash benefit from reductions in fatal and serious-injury crashes.
- Collectively, the projects have an expected total initial cost of about $176.2 million.

The project team calculated a **crash-prevention ratio** as the number of annual fatal and serious-injury crashes prevented per year divided by the initial program cost. For ODOT's existing project selection method, this ratio is 6.98 fatal and serious-injury crashes prevented per year per $100 million in initial cost.

If ODOT had selected projects starting from the highest BCR_{KA} and worked down until the same budget was expended, the agency could have selected 52 projects for funding with a total initial cost of $176.3 million—nearly identical to the cost of the projects actually funded. These 52 projects with the highest BCR_{KA} would have the following characteristics:

- ODOT would have funded 27 of the projects (52 percent).
- Collectively, the projects would be expected to reduce 14.4 fatal and serious-injury crashes per year, 2.1 more annual crashes than ODOT's existing selection method.
- The projects' crash-prevention ratio would be 8.17 fatal and serious-injury crashes prevented per year per $100 million in initial program cost. Projects from the BCR_{KA} methods are expected to prevent about 17-percent more fatal and serious-injury crashes per program dollar than projects from ODOT's existing method.

Table 12 summarizes the differences between ODOT's actual program and a potential program using the BCR_{KA}.

Table 12. Comparison of actual and potential ODOT HSIP Program.

Value	Actual Program	Potential Program if Maximized by BCR_{KA}
Total HSIP applications	108	108
Applications funded	47	52
Cost of funded projects	$176.2 million	$176.3 million
Expected annual reduction in fatal and serious-injury crashes	12.3	14.4
Expected fatal and serious-injury crashes prevented per year per $100 million in program cost	6.98	8.17

7.1.3 Utah

Like ODOT, Utah DOT (UDOT) provided crash costs by severity and summary data for recent HSIP project applications. The project team identified 74 project applications dated 2019 through 2021 for analysis. Of the 74 HSIP applications investigated, UDOT approved 56 for HSIP funding. These 56 funded projects have the following characteristics:

- Collectively, the projects are expected to reduce 14.9 fatal and serious-injury crashes per year, a K&A benefit of about $42.8 million annually.
- The projects are expected to generate 78 percent of their crash benefit from reductions in fatal and serious-injury crashes.
- Collectively, the projects have a total initial program cost of $115.0 million.
- The project team calculated the crash-prevention ratio of 12.96 fatal and serious-injury crashes prevented per year per $100 million in HSIP program funding.

If UDOT had selected projects according to their BCR_{KA}, 48 projects could have been funded for a program cost of $114.6 million. These 48 projects with the highest BCR_{KA} have the following characteristics:

- Forty projects (83 percent) are among those funded by UDOT.
- The projects are expected to reduce 16.5 fatal and serious-injury crashes per year, 1.6 more annual crashes than UDOT's selection method.

- The crash-prevention ratio would be 14.40 fatal and serious-injury crashes prevented per year per $100 million in program cost. The projects from the BCR_{KA} method are expected to prevent about 11-percent more fatal and serious-injury crashes per program dollar than projects from UDOT's existing method.

Table 13 summarizes the differences between UDOT's actual and a potential program using the BCR_{KA}.

Table 13. Comparison of actual and potential UDOT HSIP Program.

Value	Actual Program	Potential Program if Maximized by BCR_{KA}
Total HSIP applications	74	74
Applications funded	56	48
Cost of funded projects	$115.0 million	$114.6 million
Expected annual reduction in fatal and serious-injury crashes	14.9	16.5
Expected fatal and serious-injury crashes prevented per year per $100 million in program cost	12.96	14.40

7.1.4 Observations and Conclusions

ODOT used crash costs that were much lower than UDOT's—about 7.7 times lower for weighted fatal and serious-injury crashes. This difference in cost led to several observations:

- UDOT's BCRs tend to be higher than ODOT's BCRs. When considering all applications, those both funded and unfunded, UDOT's HSIP applications have a median BCR of about 5.3, and ODOT's have a median BCR of about 0.80.
- Higher costs of fatal and serious-injury crashes provide greater weight to severe crashes when calculating the BCR using all severities. The higher the cost for fatal and serious-injury crashes, the closer the BCR calculated using all severities will be to the BCR_{KA}.
- ODOT indicated that its assumed crash-cost values are based on human capital costs. An alternative, comprehensive societal crash costs, if used, would increase the weighted cost of fatal and serious-injury crashes to about $1.118 million, according to ODOT. Since projects can be justified with the lower human capital cost, ODOT considered this method to be a conservative estimate of future safety benefits. If using the BCR_{KA}, ODOT indicated that it would consider using comprehensive societal costs to justify project investments.

Other case-study observations and conclusions include the following:

- In these case studies, the BCR_{KA} method resulted in selecting projects expected to prevent more fatal and serious-injury crashes than the current project selection methods used by the two States. The BCR_{KA} method is expected to prevent 17-percent more severe crashes in Ohio and 11-percent more in Utah.
- The BCR_{KA} is virtually always equal to or lower than the all-severity BCR. In Ohio, the median BCR_{KA} was 0.34, compared with a median BCR of 0.80. In Utah, the median BCR_{KA} was 4.1, compared with a median BCR of 5.3. If States use a minimum threshold BCR to consider an application for HSIP funding, the use of the BCR_{KA} is likely to cause fewer projects to meet the threshold than a BCR that considers all crash severities.
- ODOT ranks HSIP applications using a scoring system that assigns points based on several factors; the BCR accounts for 30 percent of the total scoring. However, ODOT uses a subjective process to allocate funding rather than strictly according to the results of the scoring.
- UDOT prioritizes applications according to the BCR, but funding decisions also consider other factors, such as project readiness. If Utah had selected projects solely according to the original State-calculated BCR, the funded projects would have had a crash-

prevention ratio of 14.29 fatal and serious-injury crashes prevented per year per $100 million in program cost. The BCR_{KA} method—with a ratio of 14.40—would have improved on this by 0.8 percent.

- States often consider factors (as described in section 5.4) other than the BCR in allocating HSIP funding. However, States should recognize that the more they deviate from strictly funding applications with the highest BCR_{KA}, the less effective the HSIP program becomes at preventing fatal and serious-injury crashes.

7.2 CASE STUDY 2: COUNTERMEASURE SCORE

Ohio and Utah provided information about the costs, typical crash reduction factors, service life, and other information related to a series of countermeasures. The project team used this information to compute CM Scores for several countermeasures to assess the reasonableness of the method.

7.2.1 Ohio

ODOT provided average implementation cost and service life for several systemic countermeasures from the Ohio Pedestrian Safety Improvement Program (PSIP). The project team used the method discussed in chapter 5 to compute CM Scores for the countermeasures, as shown in table 14. Lower CM Scores indicate countermeasures that more efficiently reduce fatal and serious-injury crashes.

The project team sourced CRFs for the countermeasures from the CMF Clearinghouse where available. Most CRFs for PSIP countermeasures have only a 2- or 3-star quality rating; none have 5-star ratings. All but one CRF applied to crashes of all severities. It was assumed that the remaining CRFs are uniformly applicable to all vehicle/pedestrian crash severity levels.

ODOT provided CRFs for some countermeasures that other agencies had developed. The project team used ODOT-provided CRFs when no other CRF was available or when the CRF from the CMF Clearinghouse had only 1 or 2 stars or was not applicable to a specific treatment. Table 14 indicates the source of the CRF used for each countermeasure.

ODOT provided annual operation and maintenance cost for a pedestrian-hybrid beacon (PHB). The project team estimated the operation and maintenance cost for streetlighting, which includes power and periodic lamp replacement. ODOT provided no operation and maintenance cost for the remaining countermeasures, assuming these costs will be borne by localities rather than the State itself.

7.2.2 Utah

UDOT provided service life, CRF, and cost ranges for five intersection improvement treatments that allowed the project team to compute CM Scores, as shown in table 15. The costs in the table are the midpoint of a broad range of costs, reflecting UDOT's belief that costs are highly site-specific. The costs appear to be high for some countermeasures, such as lighting, which, according to UDOT, reflects the potential need to relocate conflicting overhead utility lines. Other agencies may find costs for lighting to be lower than those assumed by UDOT. Operation and maintenance cost for a PHB was estimated from ODOT-provided information, and the project team estimated annual cost for intersection lighting based on four luminaires per intersection.

Table 14. Countermeasure score calculations for PSIP countermeasures using ODOT data.

Countermeasure	CRF_{KA}*	Implementation Costs (Initial)	O&M Costs (Annual)	Cost Units	Service Life (yr)**	A/P***	CM $Score_{KA}$	CRF source
Street lighting	52.5	$3,000	$25	Luminaire	30	0.0510	$3	Wanvik 2009 (2 stars), nighttime, injury, rural****
Pedestrian countdown signals	70	$4,000	NA	Crosswalk	10	0.1172	$7	Van Houten 2012 (3 stars)
Ground-mounted signs	10	$1,000	NA	Crosswalk	15	0.0838	$8	ODOT
Advance yield markings and signs	25	$1,500	NA	Crosswalk	4	0.2690	$16	Zegeer 2017 (3 stars)
RRFBs	47.4	$15,000	NA	Crosswalk	10	0.1172	$37	Zegeer 2017 (3 stars)
High-visibility crosswalk markings	20	$3,000	NA	Crosswalk	4	0.2690	$40	ODOT
Raised crosswalks	30	$20,000	NA	Crosswalk	20	0.0672	$45	ODOT
Curb extensions	30	$20,000	NA	2 extensions	20	0.0672	$45	ODOT
Refuge islands	56	$40,000	NA	Crosswalk	20	0.0672	$48	FHWA Proven Safety Countermeasures
Overhead signs	10	$20,000	NA	Crosswalk	30	0.0510	$102	ODOT
Pedestrian hybrid beacons	56.8	$75,000	$500	Crosswalk	10	0.1172	$164	Zegeer 2017 (4 stars)
In-pavement flashers	10	$20,000	NA	Crosswalk	2	0.5226	$1,045	ODOT

** = Vehicle-pedestrian crashes only; ** Source: ODOT; *** = Assumes interest rate of 3 percent per year; and **** = CRF was determined by multiplying Wanvik CRF of 70 by 75-percent fraction of pedestrian crashes that occur at nighttime.*

Table 15. Countermeasure score calculations for intersection countermeasures using UDOT data.

Countermeasure	CRF_{KA}*	Implementation Costs (Initial)	O&M Costs (Annual)	Cost Units	Service Life (yr)**	A/P***	CM $Score_{KA}$	CRF source**
Install left-turn lanes on major approach	27	$140,000	NA	2 approaches	20	0.0672	$348	Highway Safety Manual, Table 14-11
Convert from STOP control to signal control	44	$250,000	$600	Intersection	20	0.0672	$395	CMF Clearinghouse
Convert from minor-street STOP control to roundabout**	88	$800,000	NA	Intersection	30	0.0510	$464	CMF Clearinghouse
Convert from signal control to roundabout	66	$750,000	NA	Intersection	30	0.0510	$580	CMF Clearinghouse
Install intersection lighting	38	$400,000****	$100	4 luminaires	15	0.0838	$885	Highway Safety Manual

** = Multiple crash types; ** Source: UDOT; *** = Assumes interest rate of 3 percent per year; **** = For high-speed (40 to 65 mph) major roadways; and **** = agencies may find lighting costs to be lower than those assumed by UDOT.*

7.2.3 Observations and Conclusions

In Ohio, the high CM Score for PHBs is due to their high initial cost. It seems likely that the service life of a PHB is longer than ODOT's assumed service life (perhaps 20 years instead of 10 years); a large variation in an average cost or service life can result in a large variation in CM Score.

In Utah, the lowest (most favorable) CM Score is for adding left-turn lanes on major street approaches. Despite having the lowest CRF (smallest expected crash reduction) of the treatments evaluated, the low CM Score reflects the modest initial cost compared with other countermeasures evaluated. The conversion to a roundabout had a higher CM Score due to higher estimated costs, despite a roundabout's higher CRF for severe crashes. The highest CM Score was for lighting, which is likely due to the relatively high cost and a relatively low CRF. As noted earlier, agencies may find actual lighting costs to be lower than those UDOT assumed.

A challenge with the CM Score method may be the lack of CRFs specifically for severe crashes. CRF_{KA} values are difficult to obtain for many treatments due to the relative randomness and infrequency of severe crashes. Some CRFs were developed for injury crashes (for all injury severity levels), but most CRFs are for crashes of all severities, including those where no injury was reported. Calculating CM $Score_{KA}$ often needs an assumption that the selected countermeasure reduces fatal and serious-injury crashes at the same rate as all crashes. It is important to recognize the limitations of this assumption, which may lead to over- or underestimating changes in specific severity levels.

An additional concern about the CM Score is that it does not explicitly refer to the types of crashes considered. For instance, table 14 shows that high-visibility crosswalk markings have a CM Score of $40, which means the markings can typically reduce 1 percent of severe crashes for a cost of $40. However, the type of crashes susceptible to correction by crosswalk markings is typically pedestrian crashes and not, for instance, roadway departure crashes. It may not be appropriate to compare the CM Score for countermeasures targeting pedestrian crashes with countermeasures targeting other types of crashes, such as horizontal curve signing.

CHAPTER 8. SUMMARY

This guide presents various approaches and methods agencies can use to maximize HSIP performance. Agencies can use DDSA techniques to predict how well infrastructure projects are expected to perform. By selecting and implementing those projects that maximize the estimated lives saved and injuries prevented, agencies can improve the safety performance of the HSIP and the likelihood to meet safety performance targets and long-term safety goals.

Section 8.1 summarizes the salient points of the guide. Section 8.2 poses opportunities for future research to develop and expand upon the methods discussed in this guide.

8.1 SAFETY MANAGEMENT AND PROJECT SELECTION

As described in chapters 2 and 3, many different decisions through project planning and development can impact program performance. This guide focuses on safety planning, in which agencies propose projects that may implement various countermeasures across the roadway network. BCR_{KA}, which measures the monetary safety benefits in terms of fatal and serious-injury crashes reduced per dollar spent to implement and maintain a project over its service life, is the best economic measure of a project's priority, cost-effectiveness, and effect on safety performance with respect to the overall goals of the HSIP (i.e., to reduce fatalities and serious injuries on all public roads). The BCR_{KA} accounts for the fact that the program is fiscally constrained, even if individual projects are not, and focuses on the program's intended benefits—lives saved and serious injuries prevented. Projects with higher BCR_{KA} are expected to be more cost effective at saving lives and preventing serious injuries than projects with lower BCR_{KA}. BCR_{KA} is dependent on four main inputs:

- The average annual number of fatal and serious-injury crashes that would be expected to occur over the project's service life if it were not implemented (i.e., $N_{exp,KA}$).
- The combined effectiveness of the project's countermeasures and strategies in reducing fatal and serious-injury crashes (i.e., the project's effective CMF_{KA}).
- Average comprehensive fatal and serious-injury crash costs (i.e., CC_{KA}).
- Annualized implementation and maintenance costs incurred over the project's service life (i.e., project costs).

Analysts can calculate BCR_{KA} using the ratio of $Benefits_{KA}$ to project costs (as in figure 12) or the ratio of $PSI_{\$,KA}$ to CM $Score_{KA}$ (as in figure 24). The $PSI_{\$,KA}$ and CM $Score_{KA}$ represent site-dependent and countermeasure-dependent factors, respectively, that contribute to a project's performance. Projects with higher $Benefits_{KA}$ and $PSI_{\$,KA}$ values and lower project costs and CM

$Score_{KA}$ values generally provide the greatest opportunity to reduce fatalities and serious injuries and thereby maximize HSIP performance. Agencies can improve the reliability of decision making based on BCR prioritization by using higher-quality safety data, more reliable predictive methods, and benefit-cost analysis.

FHWA suggests that agencies can plan more HSIP projects than they can implement, rank those by BCR_{KA}, and select feasible projects from the top of that list until the cumulative implementation costs exceed the program's available budget. Agencies may also consider other factors as discussed in sections 4.3.2 and 5.4.2. When it is not feasible to calculate BCR_{KA} for all proposed projects, approximating BCR_{KA} with BCR_{KAB} or BCR_{KABC} may be necessary.

There are at least three safety management approaches—site-specific, systemic, and systematic—that allow agencies to strategically identify candidate project locations, select appropriate countermeasures, and develop high-performing projects. This guide refines these safety management approaches to help agencies develop high-BCR_{KA} projects in practice. Agencies can also explore other approaches that may better fit their needs. Generally, agencies should select the best projects regardless of the safety management approach. While many agencies try to implement strategies to address several emphasis areas each year, it may be effective to focus on fewer emphasis areas and widely implement a few countermeasures that have an especially high BCR_{KA} until the candidate locations are exhausted.

When benefit-cost analysis is not applicable, agencies can prioritize by available data as well as frameworks such as the Safe System approach. Agencies can also consider how to best handle projects for which it is difficult to quantify benefits (e.g., data improvements, software upgrades, workforce development). This can be done by prioritizing subjectively in a separate funding goal using alternative economic measures described in section 5.4.

8.2 KNOWLEDGE GAPS AND FUTURE RESEARCH NEEDS

The main limitation in implementing a BCR_{KA} prioritization framework is gaps in applicable DDSA tools. Calculating BCR_{KA} using the most reliable methods needs SPFs and CMFs applicable to fatal and serious-injury crashes; however, there are few CMFs currently available for fatal and serious-injury crashes. Developing more CMF_{KA} estimates would support the implementation of engineering countermeasures to reduce fatalities and serious injuries. While CMF development to prioritize all projects by fatal and serious-injury crashes carries high costs and would take time to fully develop, analysts can approximate BCR_{KA} with a lower level of reliability using observed or predicted crashes and a CMF applicable to all injury crashes. Agencies can consider the benefits and costs of additional research to determine if it is worth the costs or if there are other methods that would work nearly as well or better at a lower cost. Agencies may determine that calculating BCR for all projects in consistent terms (i.e., all

BCR_{KA} or BCR_{KABC}) may be more important than estimating BCR_{KA} for a portion of projects and not having the DDSA tools necessary to compute BCR_{KA} for others.

Generally, agencies could benefit from higher-quality (e.g., complete, accurate, accessible) safety data regarding their implemented projects and countermeasures (e.g., locations, implementation dates, costs, service life, effectiveness). As discussed throughout this guide, relatively high-quality safety data is helpful in improving an agency's safety performance.

Another gap in knowledge is how to compare expected, observed, and predicted crash frequencies, BCRs for different severities, and BCRs related to specific crash types. If methods were available to better compare and relate these values, agencies would be able to use more of the available DDSA tools and prioritize projects fairly with fewer funding goals. Additionally, some sites are not conducive to predictive modeling (e.g., when the facility types comprise only a few unique sites). That does not mean projects would be any less effective, but analysts may not know how effective they are because it is difficult to quantify with such a limited sample.

This guide focuses on implementing engineering countermeasures to improve safety. However, there are numerous other ways that States can improve safety performance. There is little data available about the relative cost-effectiveness of safety improvements and strategies implemented through other disciplines (e.g., education, enforcement, vehicle design, and technology). With a goal of reaching zero fatalities and serious injuries at some point in the future, it may be important to consider which disciplines, strategies, and methods offer the greatest cost-effectiveness toward that goal (i.e., getting there the fastest and using the least resources).

8.3 SUMMARY

FHWA's key findings of this research are as follows.

- Measure the performance of proposed programs or project selection scenarios in terms of lives saved and serious-injuries prevented to help focus the HSIP on fatal and serious-injury crashes.
- Rank proposed projects by BCR_{KA} and select the highest-ranked projects offers based on the maximum predicted performance of the HSIP. Agencies can consider other factors not reflected in DDSA results (e.g., geographic distribution of projects, environmental impacts) when selecting projects.
- Express the BCR in terms of potential monetary safety benefits and costs or $PSI_{\$}$ and CM Score. The $PSI_{\$}$ measures a location's estimated contribution to the safety performance of a project independent of countermeasures. The CM Score measures a

countermeasure's ability to impact the safety performance of a project independent of where it is implemented.

- Develop more planning-level SPFs and CMFs in terms of fatal and serious-injury crashes, average project costs (or range of costs), and other data to support the BCR_{KA} prioritization method.
- Use a combination of site-specific, systemic, and systematic approaches to develop high-performing projects to fit their needs.

APPENDIX A: RESEARCH MATERIALS

The authors interviewed the following agencies to inform the development of this guide. Section A.1 lists the interview question prompts.

- Indiana DOT.
- Kentucky Transportation Cabinet.
- Montana DOT.
- Nevada DOT.
- New Hampshire DOT.
- North Carolina DOT.
- Virginia DOT.
- Wisconsin DOT.

The authors held a focus group meeting with the following agencies get provide feedback on the issues addressed in this guide. Section A.2 lists the focus group agenda and discussion questions.

- Arizona DOT.
- Georgia DOT.
- Massachusetts DOT.
- Missouri DOT.
- New Mexico DOT (on behalf of the FHWA New Mexico Division Office staff).
- Oregon DOT.
- Washington State DOT.

A.1 INTERVIEW QUESTION PROMPT

Thank you for meeting with us today. We appreciate the opportunity to speak with you about how you select and program projects at your agency. We expect this meeting to last about 60 minutes. The purpose of this meeting is to learn about your practices, policies, and procedures around identifying, selecting, and programming safety improvement projects. Our goal is to better understand how States could choose projects to maximize HSIP performance.

1. How does your State select SHSP emphasis areas and related strategies to most effectively maximize your State's HSIP performance?
2. How do the strategies documented in your State's SHSP influence the development of engineering safety improvement projects?
3. What performance measures do you track and set targets for, beyond the five required for the HSIP?
4. What approaches does your agency use to screen your network for locations with potential safety improvement or otherwise solicit safety improvement projects?
5. What is the importance of data quality and analysis improvements in your ability to maximize HSIP performance?
6. How does your State assure projects are economically justified and meet program eligibility requirements?
7. How are projects outside of the HSIP (e.g., other safety programs or where safety is not the primary purpose and need) considered when assessing your State's ability to maximize HSIP performance?
8. How does your State prioritize safety improvement projects and program projects within your available budgets?
    a. Site-specific, systemic, systematic, nominal safety, and data improvements?
    b. Non-monetary considerations?
    c. Data-limited projects?
    d. Equity across districts/regions, urban/rural, road type, etc.?
    e. Across multiple program years?
9. Does your State establish funding areas within the program budget (e.g., 50% of funds for one area or project type, 25% for another, etc.)? If so, how are the areas chosen and how are the funding amounts selected?
10. How does your State evaluate the effectiveness of your safety improvement programs? How do your evaluations affect future planning or changes to program policy and procedures?

11. What other approaches does your State use to help improve the potential for safety improvement projects to maximize HSIP performance?
12. What are the biggest challenges or barriers impacting your ability to maximize HSIP performance and meet safety performance targets most effectively?

A.2 FOCUS GROUP AGENDA AND DISCUSSION QUESTIONS

FHWA is developing a guide for State DOTs and their partners relating to selecting safety improvement projects and strategies to meet safety performance targets. The purpose of the guide is to present various organizational, management, and analysis approaches to more effectively and reliably meet safety performance targets. This focus group meeting will help refine the guide's content and identify new approaches that may be used in the future.

Focus Group Agenda (90 minutes)

10 minutes **Welcome**

- Introductions and expectations for the meeting
- Overview of research process and objectives

50 minutes **Open Discussion**

Setting Safety Performance Targets (20 minutes)

1. How important is it for States to quantify their ability to meet their targets, rather than simply focusing on implementing the best projects?
2. How could States account for budgetary constraints when setting targets?
3. How much involvement do MPOs and local agencies have in target setting?
4. How important is it to factor in the economy and other aspects when setting targets and analyzing program effectiveness? What are the barriers to doing so?

Practical Implementation (20 minutes)

5. What program management and project delivery considerations hinder your ability to deliver the most cost-effective projects?

6. How do you address behavioral safety in your safety engineering programs?

7. How do you select effective bicycle and pedestrian safety improvements?

8. Apart from B/C and budget, what can impact a project's priority or timeline?

New Methods (10 minutes)

9. If you are not totally happy with your current procedure or approach to selecting safety improvement projects and strategies, what would you change?

10. What new project selection approaches could be beneficial in the future?

20 minutes **Feedback on Objectives and Draft Outline**

11. What information or direction would you look for in this guide, and how could the guide most help your State?

12. After reviewing the draft outline, what topics or approaches would you like to see (or not see) in the guide? Is anything missing?

10 minutes **Wrap up**

- Closing thoughts/miscellaneous feedback
- Questions, next steps, and adjourn

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