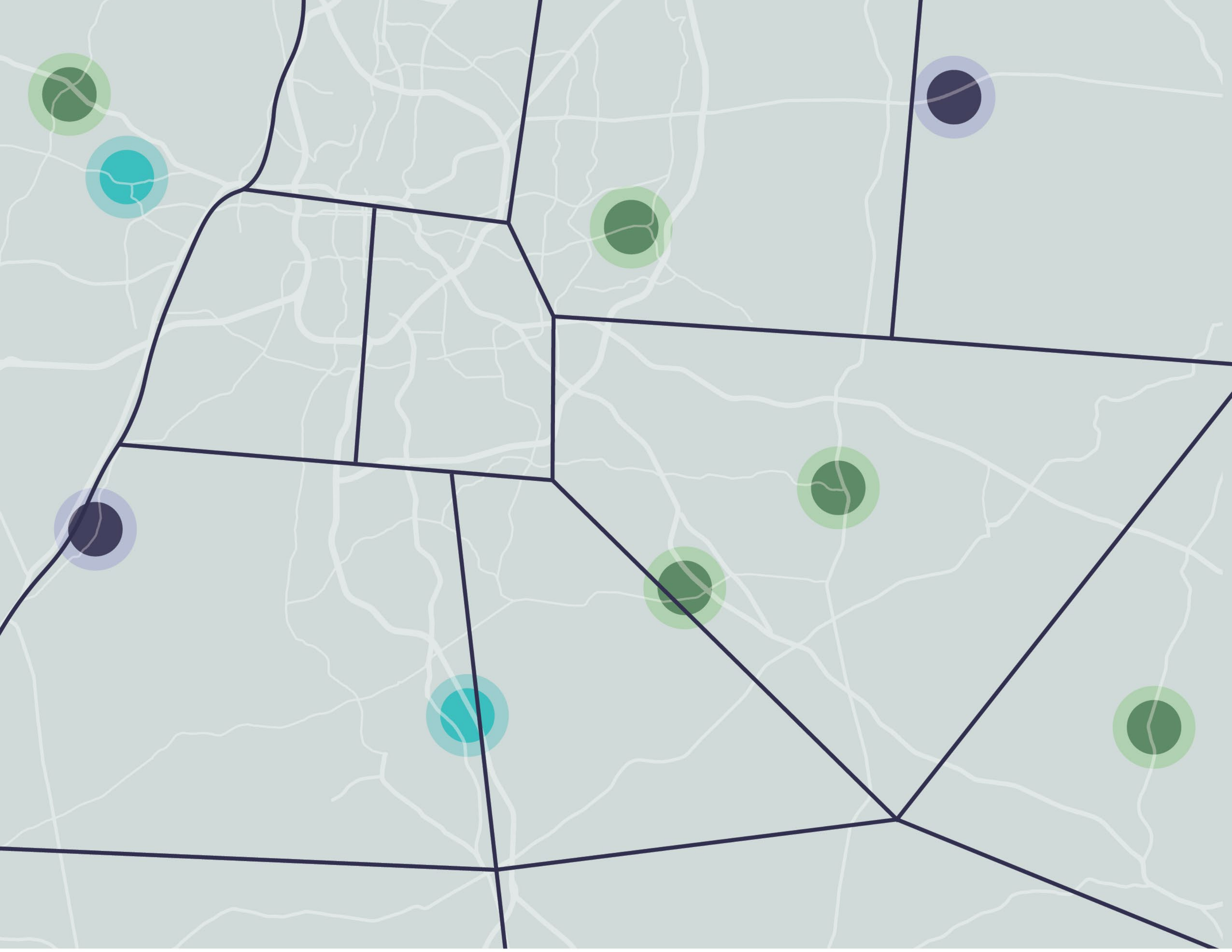

Systemic Safety User Guide

U.S. Department of Transportation
Federal Highway Administration

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

FOREWORD

The 2024 *Systemic Safety User Guide* is a substantial update to the Federal Highway Administration's *Systemic Safety Project Selection Tool*, published in July 2013. Since the introduction of the systemic approach to safety, transportation agencies, at all levels of government, have made tremendous strides incorporating this analysis as part of their comprehensive safety management strategies. A systemic approach continues to be a fundamental component of how agencies determine proactive, equitable, and cost-effective approaches to improve safety throughout their transportation system.

The updated Guide highlights an ever-expanding range of flexibility and creativity that agencies have taken in applying the systemic approach to address the safety of all transportation users – even without what may be considered an ideal dataset. The Guide now includes how systemic analysis can support a Safe System Approach by using risk-based assessments at scale. The Guide devotes one chapter to each of the six steps of the systemic approach, with one additional chapter that brings the process together in an overarching systemwide risk assessment example. The Guide also includes a wide variety of transportation agency practices that demonstrate various ways to accomplish each step. Each chapter includes a range of analysis methods and tips for completing the task at hand, as well as frequently asked questions. In addition, the Guide includes case studies that highlight notable systemic safety efforts from rural and urban agencies, both small and large.

Using the systemic approach to perform data-driven safety analysis supports the Safe System Approach principle: Safety is Proactive, a fundamental component of the Department of Transportation's National Roadway Safety Strategy. The systemic approach can be used to develop Comprehensive Safety Action Plans, Strategic Highway Safety Plans, and other safety action plans. This approach can identify opportunities to install Proven Safety Countermeasures to effectively reduce fatalities and serious injuries at scale. For additional information, please visit the Systemic Approach to Safety website.

Robert Ritter

Associate Administrator

Office of Safety

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16. Abstract

The *Systemic Safety User Guide* is an update to the Federal Highway Administration's *Systemic Safety Project Selection Tool*. The Guide presents a process for incorporating systemic planning into the safety management process. The chapters describe how agencies can identify focus crash types, facility types, and risk factors; screen and prioritize candidate locations using risk; identify and select countermeasures for systemic deployment; prioritize and deliver systemic projects; and evaluate systemic projects. The Guide includes several examples and case studies to show real world applications of the systemic approach in practice. The guide is intended for use by transportation safety practitioners at the Federal, State, Tribal, regional, and local level to plan, implement, and evaluate proactive safety programs.

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SI* (MODERN METRIC) CONVERSION FACTORS

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)

Contents

List of Figures

List of Tables

Acronyms

ADT – average daily traffic

AADT – annual average daily traffic

ADA – Americans with Disabilities Act

APS – Accessible Pedestrian Signal

ARC – Atlanta Regional Commission

BCR – benefit-cost ratio

CFR- Code of Federal Regulations

CM Score – Countermeasure Score

CMF – crash modification factor

CRAB – County Road Administration Board

CRF – crash reduction factor

CRSP – County Road Safety Plan

CSAH – County State-Aid Highway

DOT – Department of Transportation

EB – Empirical Bayes

EJ – Environmental Justice

EPA- Environmental Protection Agency

EPDO – Equivalent Property Damage Only

FARS – Fatality Analysis Reporting System

FDE – Fundamental Data Element

FDOT – Florida Department of Transportation

FHWA – Federal Highway Administration

FI – fatal injury

FIRST – Fatality and Injury Reporting System Tool

FLH – Federal Lands Highway

FYA – flashing yellow arrow

GDOT – Georgia Department of Transportation

GIS – geographic information system

GRPC – Gulf Regional Planning Commission

HIN – High Injury Network

HOI – Health Opportunity Index

HSIP – Highway Safety Improvement Program

HSM – Highway Safety Manual

ID/IQ – Indefinite Delivery/Indefinite Quantity

KA – fatal or suspected serious injury crash

KYTC – Kentucky Transportation Cabinet

LED – light-emitting diode

LPI – Leading Pedestrian Interval

LiDAR – Light Detection and Ranging

LRSP – Local Road Safety Plan

LTAP – Local Technical Assistance Program

MaineDOT – Maine Department of Transportation

MassDOT – Massachusetts Department of Transportation

MEV – million entering vehicles

MIRE – Model Inventory of Roadway Elements

MMUCC – Model Minimum Uniform Crash Criteria

MnDOT – Minnesota Department of Transportation

MoDOT – Missouri Department of Transportation

MORPC – Mid-Ohio Regional Planning Commission

MPH – miles per hour

MPO – Metropolitan Planning Organization

MVMT – million vehicle miles traveled

NBI – National Bridge and Tunnel Inventory and Inspection Standards

NCHRP – National Cooperative Highway Research Program

NEPA – National Environmental Protection Act

NHDOT – New Hampshire Department of Transportation

NHTSA – National Highway Traffic Safety Administration

NRSS – National Roadway Safety Strategy

NYSDOT – New York State Department of Transportation

ODOT – Ohio Department of Transportation

OUI – Operating Under the Influence

PDO – property damage only

PennDOT – Pennsylvania Department of Transportation

PHB – pedestrian hybrid beacon

PS&E – Plans, Specifications, & Estimates

PSAP – Pedestrian Safety Action Plan

PSI – Potential for Safety Improvement

PSIP – Pedestrian Safety Improvement Program

RCHP – Railway-Highway Crossing Program

RRFB – rectangular rapid flashing beacons

RSA – Road Safety Audit

SCDOT – South Carolina Department of Transportation

SDOT – Seattle Department of Transportation

SFMTA – San Francisco Municipal Transportation Agency

SHSP – Strategic Highway Safety Plan

SJNF – San Juan National Forest

SPF – safety performance function

SSC – speed safety camera

STA – State Transportation Agency

SSI – Safe System Approach for Intersections

STEP – Safe Transportation for Every Pedestrian

TDOT – Tennessee Department of Transportation

TTP – Tribal Transportation Program

TxDOT – Texas Department of Transportation

USDOT – United States Department of Transportation

usRAP – United States Road Assessment Program

USTH – United States Trunk Highway

VDOT – Virginia Department of Transportation

VMT – vehicle miles traveled

WAPDD – Western Arkansas Planning and Development District

WSDOT – Washington State Department of Transportation

Introduction

A total of 197,941 people lost their lives in crashes on public roads in the United States between 2018 and 2022, an average of 39,588 fatalities per year (NHTSA, 2024a). This senseless loss of life and suffering is unacceptable—the only acceptable number of deaths and serious injuries on our Nation's roadways is ZERO.

In 2022, the United States Department of Transportation (USDOT) published the National Roadway Safety Strategy (NRSS) (USDOT, 2022). The NRSS provides a strategic, comprehensive approach to significantly reduce deaths and serious injuries on public roads and work towards a long-term goal of eliminating all roadway deaths and serious injuries. To achieve this goal, the NRSS adopts the Safe System Approach, shown in figure 1. The NRSS identifies actions to address the five core elements of the Safe System Approach:

1. Safer People.
2. Safer Roads.
3. Safer Vehicles.
4. Safer Speeds.
5. Post-Crash Care.

The following principles of the Safe System Approach guide the actions presented in the NRSS:

1. Death/Serious Injury is Unacceptable.
2. Humans Make Mistakes.
3. Humans are Vulnerable.
4. Responsibility is Shared.
5. Safety is Proactive.
6. Redundancy is Crucial.

Figure 1. Graphic. The Safe System Approach (Source: FHWA, 2020a).

To implement the NRSS, transportation agencies can employ a comprehensive approach to safety management, guided by the Safe System principles. A comprehensive approach is both reactive and proactive. The reactive component typically focuses on site-specific (also known as spot or hot spot) locations based on historical crashes or estimated future crashes through statistical modeling. The proactive component typically addresses locations based on the presence of risk factors and the potential for future crashes.

The *Systemic Safety User Guide* supports the Safe System principle that Safety is Proactive and provides a framework for the proactive component of a comprehensive approach to safety management.

Introduction to Safety Management

The road safety management process is generally a six-step cycle, consisting of the following (AASHTO, 2010):

1. **Network screening** – scanning the transportation system to identify sites with the potential or need for safety improvement.
2. **Diagnosis** – reviewing the conditions and crash data at a site or across a system to identify specific safety issues and contributing factors.
3. **Countermeasure selection** – identifying possible countermeasures to treat or mitigate the previously-identified safety issues and contributing factors at the site.
4. **Economic appraisal** – reviewing the potential economic benefits of the proposed countermeasures at a site.

5. **Project prioritization** – comparing estimates of economic, safety, and other data to develop a portfolio of projects that maximizes the benefits of available funding.
6. **Safety effectiveness evaluation** – evaluating the safety and economic performance of safety projects, countermeasures, and programs, at specific locations and across the system, to quantify benefits and inform future investments.

Safety management is cyclical, with one step feeding into the next, including evaluation of results feeding back into future cycles (see figure 2).

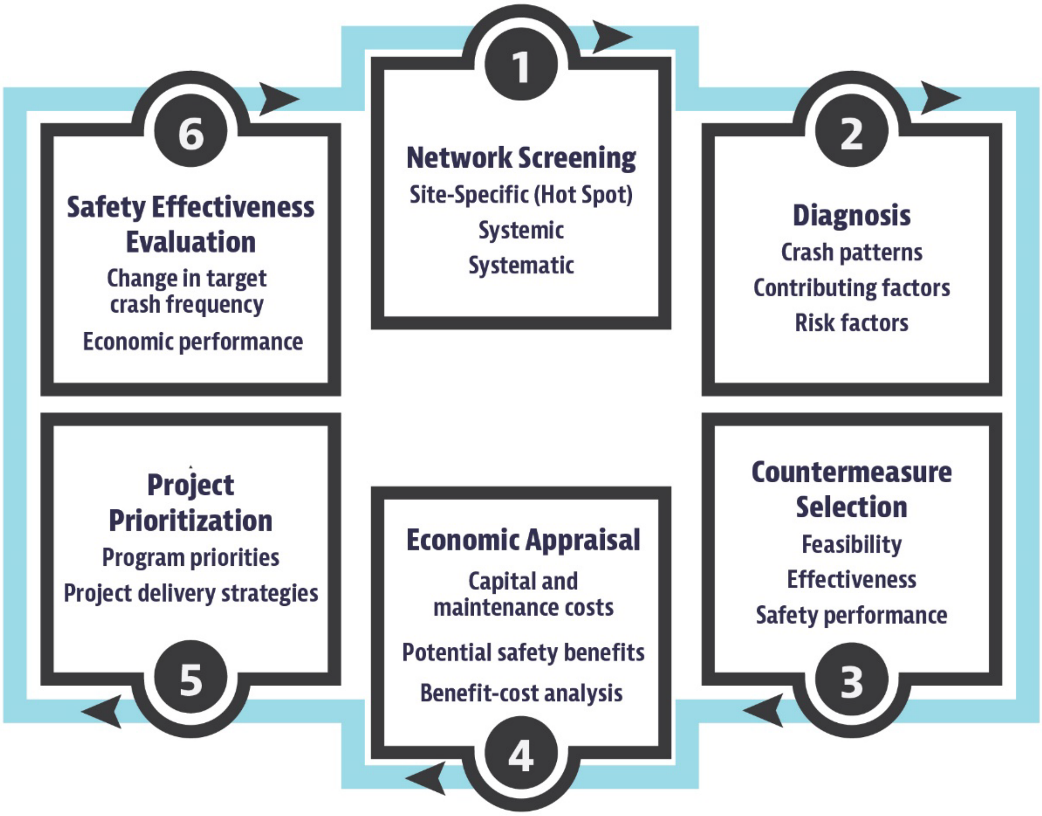


Figure 2. Graphic. The safety management cycle (Source: FHWA).

An effective safety management program includes a combination of both reactive and proactive safety projects focused on reducing the frequency of crashes which result in severe injuries, including fatalities. The reactive component—**site-specific**—is built from traditional network screening approaches as characterized in Part B of the Highway Safety Manual (HSM), where sites are identified for potential improvement based on historical crash data and estimated safety performance based on similar sites (AASHTO, 2010).

Developing a Site-Specific Project

A city might review statewide crash-based network screening results and find one of their stop-controlled intersections ranked in the top five percent in the State for crashes in terms of severity-weighted crash frequency. Severity-weighting is a measure that prioritizes locations with more severe crashes over locations with less severe crashes. After reviewing the crash data and performing a Road Safety Audit (RSA), the city could determine a roundabout was the preferred countermeasure. An economic appraisal might show a favorable benefit-cost ratio, and the city might then prioritize and develop the project. The city could then work with the State agency to obtain funding from the Highway Safety Improvement Program (HSIP) for a site-specific improvement at that intersection to support construction of the roundabout.

Agencies can be proactive using two approaches – **systematic** and **systemic**. **A systematic approach to safety involves the installation of a safety countermeasure at all sites system-wide that meet specific criteria**. This is also sometimes described as a policy-based approach, in which all sites that meet criteria will eventually receive a certain treatment. It is also exclusionary in some ways, working from the assumption that a countermeasure should be installed everywhere except for those sites that do not meet certain criteria. Systematic improvements are typically low-cost, proven safety countermeasures that are often delivered in a cost-effective manner, either in large, bundled projects or implemented into highway design or maintenance projects and programs. Examples include implementing rumble strips and SafetyEdge^{SM} as part of a pavement rehabilitation program.

Developing a Systematic Safety Project

The New Hampshire DOT (NHDOT) uses a systematic approach for installing rumble strips on their undivided highways. Table 1 summarizes the criteria used by NHDOT to determine where to install center line and shoulder rumble strips (NHDOT, 2019). This systematic approach results in consistent implementation of a proven safety countermeasure along NHDOT's system.

Table 1. Summary of NHDOT's rumble strip criteria for undivided highways.

Center Line Rumble Strip Criteria	Shoulder Rumble Strip Criteria
Posted speed limit of 40 miles per hour (mph) or greater	Posted speed limit of 40 mph or greater
Pavement width of 28 ft or greater	Paved shoulder width at least 6-ft wide (or 8 ft if guardrail or curb is present)
Pavement surface in good condition	Pavement surface in good condition

A systemic approach involves the installation of low- to moderate-cost countermeasures at locations with the highest risk of severe crashes. Risk can be a vague concept, but often serves as a measure of the likelihood of a future severe crash at a site. This can be true even if a site has had no severe crashes in its recent history. As described throughout this Guide, agencies can identify and quantify risk using various methods. The systemic approach includes targeted improvements for a focus crash type on focus facility types which are prioritized based on the level of risk.

Developing a Systemic Safety Project

As an alternative to NHDOT's systematic approach described above, a transportation agency might use the systemic approach to implement rumble strips on undivided roads on its system. After identifying roadway departure (also known as lane departure) crashes as a focus crash type and rural two-lane undivided roads as the focus facility type, the agency could identify factors associated with an increased risk of severe roadway departure crashes on rural, two-lane undivided roads, such as a curve radius less than 800 ft and a roadside with narrow clear zone. The agency could then use these risk factors to prioritize locations for center line and edgeline rumble strips.

Another option is to employ a combined approach, using the systematic criteria to identify all eligible locations and then applying the systemic risk factors to prioritize locations for treatment.

Terminology

Systemic safety is typically centered around the term "risk", or the potential for a severe crash. This Guide primarily uses the term "risk" and "risk factors", though other terms users may employ include "contributing factors", "features", "characteristics", and "indicators", all of which serve as terms for features which are correlated with increased target crash likelihood (National Academies of Sciences, Engineering, and Medicine, 2020a). These terms generally serve as synonyms for a "risk factor" – a feature whose presence is correlated with an increased likelihood of a severe crash. Agencies can use any terms they see fit when documenting systemic safety programs. NCHRP Legal Research Digest 83 is a valuable resource for agencies looking to select the appropriate terminology for their application (National Academies of Sciences, Engineering, and Medicine, 2020b)

Agencies should consider projects of all three approaches—site-specific, systematic, and systemic—to optimize their safety program. Table 2 summarizes the goals, benefits, and drawbacks of each approach. Each approach targets specific problems and issues. The systemic approach can provide an economically efficient balance between risk-based prioritization and addressing as many miles and intersections on the system as possible. Throughout the Guide, the term "projects" includes dedicated safety projects as well as safety improvements implemented as one component of a traditional construction or maintenance project (e.g., resurfacing), or as part of routine maintenance efforts.

Table 2. Goals, benefits, and potential drawbacks of safety management approaches.

	Site-Specific	Systematic	Systemic
Goals	Address a severe crash issue at a specific location.	Implement safety improvements at all sites that meet specific criteria.	Reduce severe crash probability across the system based on risk.
Benefits	Addressing a specific safety issue through improvements tailored to the location.	Proactively addressing safety through widespread implementation of safety improvements.	Proactively reducing severe crash likelihood through safety improvements at higher-risk locations.
Drawbacks	Tends to be higher cost, allowing for fewer improvements elsewhere. May miss locations with the highest overall risk. Subject to regression-to-the-mean bias depending on the network screening methodology.	May not be the most efficient distribution of safety improvements because there is no prioritization process. May need to wait for capital projects to implement safety improvements.	There may be concern around installing safety features at locations with no severe crash history.

There are slight variations for each step in the safety management process depending on the approach. Table 3 summarizes those variations, highlighting notable differences between the three approaches.

Table 3. Variations in safety management approaches.

Safety Management Step	Site-Specific Projects	Systematic Projects	Systemic Projects
Network Screening	High-crash locations, high excess-crash locations.	Locations that meet criteria.	High-risk locations.
Diagnosis	Review site and crash data.	Limited diagnosis is performed, typically based on site criteria.	Review risk factors present, site data, and crash data.
Countermeasure Selection	Low-, medium-, and high-cost countermeasures considered, tailored to the site.	Primarily low-cost countermeasures considered, based on policy.	Primarily low- and medium-cost countermeasures considered, based on risk.
Economic Appraisal	Calculate benefit-cost ratio (BCR) for each project, typically at site level.	An economic appraisal is typically not performed as the treatment is implemented based on policy.	Calculate an aggregated BCR for a bundle of improvements at prioritized locations.
Project Prioritization	Consider BCR, program goals, and other factors.	Typically included as part of a larger capital project that is prioritized for other reasons.	Should consider BCR, program goals, and other factors.
Evaluation	Review crash reduction and BCR.	Review crash reduction, BCR, and number of sites meeting criteria addressed.	Review focus crash reduction, BCR, and number of high-risk sites addressed.

Why Systemic Safety?

Severe crashes often occur at seemingly random locations and tend not to cluster over time, especially for pedestrians and bicyclists and for motorists in rural and low to moderate traffic volume contexts. However, **the factors associated with severe crashes are strikingly consistent**. Consider the potential events involved in a severe roadway departure crash—a distracted driver may leave the road at any point, but a crash is more likely to occur if the driver leaves the road on a horizontal curve or a location where there are narrow shoulders and no rumble strips to alert the driver. The crash is more likely to result in severe injury at a location where there are risk factors such as steep roadside embankments and fixed objects (e.g., trees) compared to a flat and clear roadside. As a result, it may not be prudent to implement a project seeking to remedy the risk factors at one specific location (e.g., a site-specific project only addressing the one curve and tree) because it is unlikely a driver will depart the road at the exact same location in the future. Rather, this is a case where one should proactively address sites with similar risk factors, such as horizontal curves with trees near the roadway edge, which are higher risk for a crash involving a severe outcome. As an example, figure 3 shows the locations of fatal rural roadway departure crashes in Virginia between 2017 and 2021. While some corridors have more crashes than others, geographic clustering is rare.

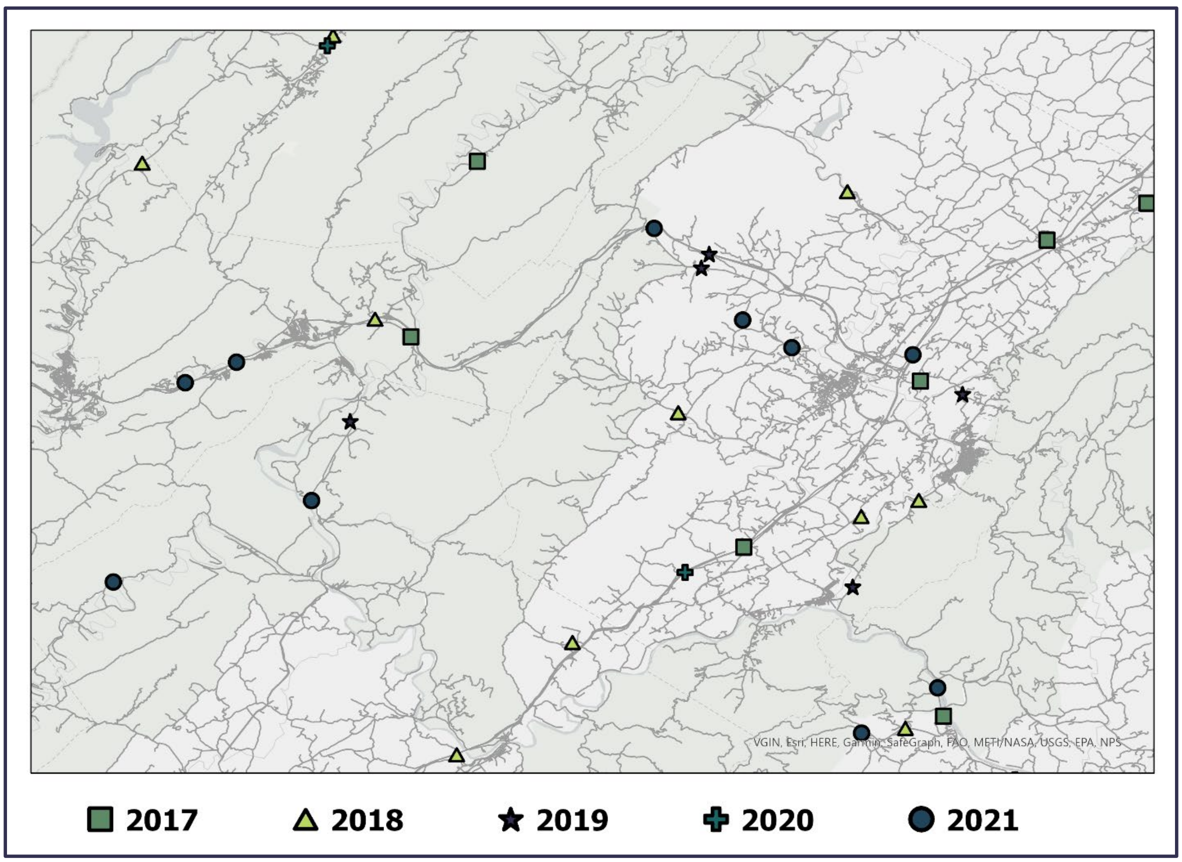


Figure 3. Graphic. Fatal rural roadway departure crashes in Virginia (Source: FHWA).

For less common high-severity crash types, including pedestrian and bicyclist crashes, the systemic approach is particularly well suited to overcome data limitations and address safety issues related to those crashes. Common data limitations for pedestrians and bicyclists include proportionally fewer crashes and limited exposure data to help predict crashes. Instead, the systemic approach can incorporate other characteristics, such as vehicular volume, traffic speed, and the presence (or absence) of infrastructure, to proactively assess risk in the absence of high numbers of crashes.

The systemic approach also helps to avoid issues related to "regression to the mean". Regression to the mean refers to the seemingly random fluctuation in crash locations over time and explains how a segment with several crashes one year may, without any intervention, experience below average crashes in subsequent years or vice versa. For instance, the average number of bicycle and pedestrian crashes at any intersection or midblock location is usually zero, but this may vary over time. Despite this variability in observed crashes year to year, the risk of a crash occurring is still present, and this risk is higher at some locations based on the site-specific characteristics. While historical crash data may not identify these locations as high priority, the systemic approach can help to identify sites with high risk.

Systemic Safety and Personal Health

The systemic safety approach can be thought of in terms of a medical analogy. Heart attacks and strokes can be fatal, so doctors are proactive and try to intervene before they happen. Doctors screen patients for known risk factors of cardiac issues—including high blood pressure, obesity, high cholesterol, personal health habits, and family health history—and try to address the underlying factors to reduce the risk of the heart attack or stroke. In the same way, safety professionals should try to identify the risks of a severe crash and implement countermeasures to prevent them before they occur. If a roadway departure crash is a heart attack, the high blood pressure may be narrow shoulders, obesity may be a roadside with fixed objects within the clear zone, and high cholesterol may be poor or absent delineation. Figure 4 illustrates these similarities.

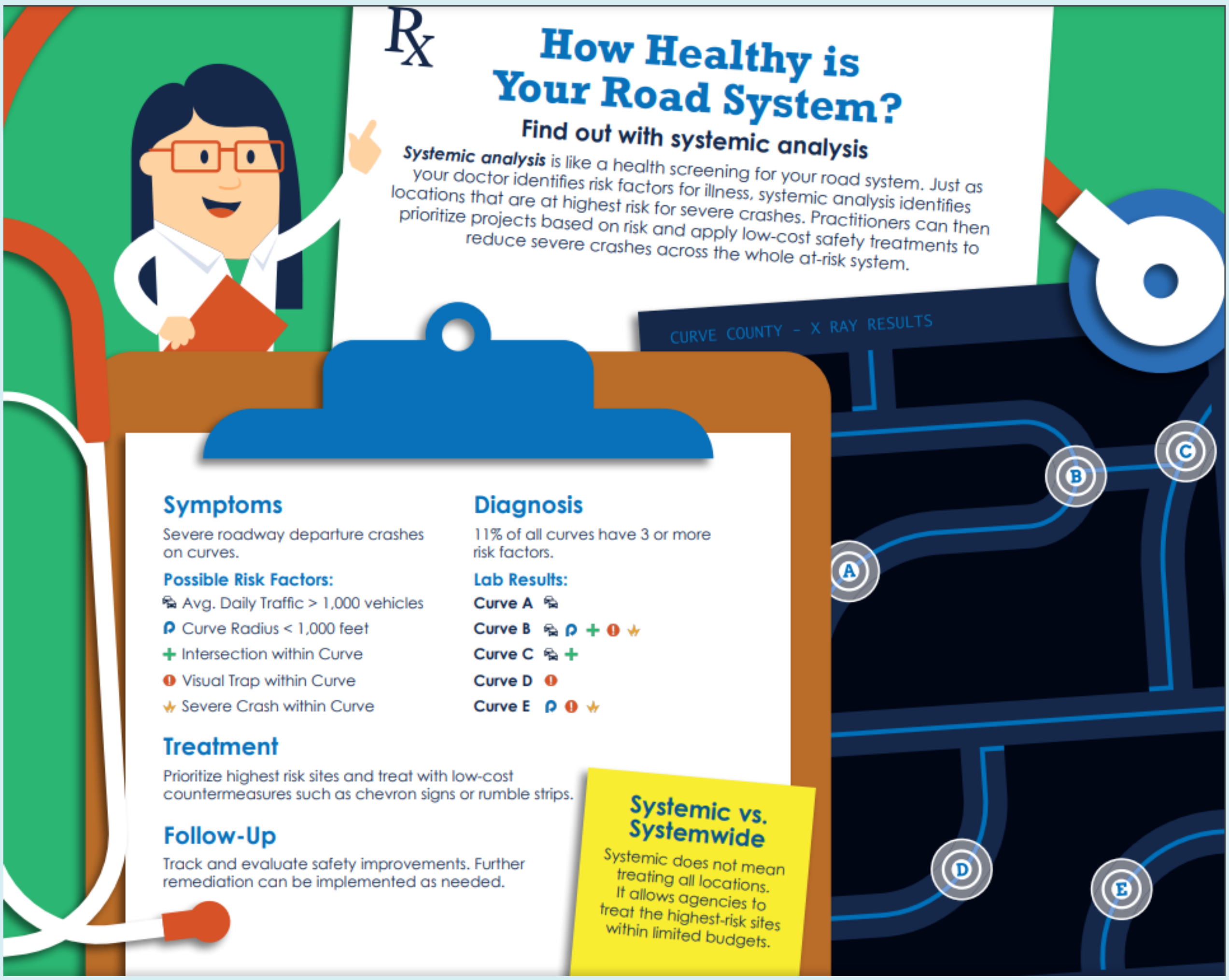


Figure 4. Graphic. Similarities between systemic safety approach and medical health screenings (Source: FHWA, 2021a).

By focusing on the most severe outcomes—fatal and serious injury crashes—the systemic approach helps align transportation agencies' processes with the goals and requirements of many funding programs, such as the Federal HSIP, and the Safe System Approach.

Systemic Safety in Law

Under section 924.9(a)(4)(i) of Title 23 of the Code of Federal Regulations (CFR), State DOTs must incorporate a process for analyzing safety data which will help "develop a program of highway safety improvement projects, in accordance with 23 U.S.C. 148(c)(2), to reduce fatalities and serious injuries on all public roads through the implementation of a comprehensive program of ***SYSTEMIC*** and spot safety [(i.e., site-specific)] safety improvement projects."

Potential opportunities for agencies to apply the systemic approach include:

- Local Road Safety Plans (LRSPs).
- Vulnerable Road User Safety Assessments.
- Safety Action Plans.
- Risk-Based Network Screening.
- Prioritization of Maintenance Activities.

The systemic approach can be an important part of any transportation agency's safety management practices. But what if an agency encounters resistance? To address skeptics and mitigate resistance, it is important to communicate the benefits of systemic safety to decision-makers, stakeholders, elected officials, and the public. This Guide provides examples of the methods and evidence of their effectiveness that can be used to provide support for the systemic safety approach.

Addressing systemic safety issues and adopting the Safe System Approach may require a shift in traffic safety culture, elevating safety as a priority in transportation decisions (FHWA, 2024a; National Academies of Sciences, Engineering, and Medicine, 2024; Girasek, 2012; Ward, 2019). A shift in safety culture should acknowledge that safety issues and risk across the transportation system are unevenly distributed and can lead to inequitable traffic safety outcomes, impacting certain populations and users disproportionally in terms of crash fatalities and serious injuries (FHWA, 2023a). Stakeholders need to accept that any fatality or serious injury on the system is ultimately a failure of the stakeholders to deliver a Safe System, not necessarily the fault of the users (Job et al., 2022). As a result, transportation stakeholders will need to create a traffic safety culture that promotes the use of all available tools to help achieve a Safe System, including infrastructure improvements, public health campaigns, education, enforcement, zoning, and land use, to name a few. A proactive, Safe System-oriented traffic safety culture will inherently advance the systemic approach to safety.

Organization of the Guide

The *Systemic Safety User Guide* (the Guide) is an update of the *Systemic Safety Project Selection Tool* (Preston et al., 2013) and builds upon current practices. The structure of this guide is as follows:

- **Introduction –** includes an introduction to safety management, motivation to apply the systemic approach to safety, and a description of the structure of the Guide.
- **Chapter 1 – Identify Focus Crash Types, Facility Types, and Risk Factors** describes how an agency can select the focus crash types, facility types, and risk factors for the systemic safety analysis.
- **Chapter 2 – Screen and Prioritize Candidate Locations** describes the methods for agencies to develop a prioritized list of candidate sites for improvement.
- **Chapter 3 – Identify and Select Countermeasures** describes how agencies can develop a menu of countermeasures and select them for each site.
- **Chapter 4 – Prioritize Systemic Projects** describes how agencies can prioritize systemic projects for the HSIP or other transportation programs.
- **Chapter 5 – Deliver Systemic Projects** describes the various methods for preparing, implementing, and tracking systemic safety improvement projects.
- **Chapter 6 – Evaluate Systemic Safety Results** describes the methods agencies can use to evaluate systemic safety projects, countermeasures, programs, and overall performance.
- **Bringing it All Together** describes an example application of the systemic approach to safety.
- **Case Studies** includes select case studies to highlight notable systemic safety efforts.

Figure 5 summarizes the steps in the Guide. The circular aspect reinforces that the analysis is a cyclical process, where the results of each step feed into the next. This includes evaluating results to inform the next cycle of analysis. The systemic safety process can also be an iterative process, so agencies may return to a previous step in the process based on the results of a subsequent step.

All steps and methods described in this Guide are scalable based on an agency's desired level of effort, data, and resources. Agencies are encouraged to tailor and modify the process to meet their needs. Helpful hints and considerations are provided throughout the document to reinforce this point and provide additional clarity. Additionally, each chapter includes responses to frequently asked questions. Throughout the Guide, the information in the blue boxes contains notable systemic safety efforts, tips and other case studies by agencies for consideration.

The Guide is aimed toward use by public agencies at all levels—Federal, State, Tribal, local, and regional—interested in using the systemic safety approach. The target audience includes analysts, engineers, public works personnel, planners, technicians, specialists, program managers, and anyone else with a safety-related role. The Guide provides links to specific resources if readers desire additional technical detail.

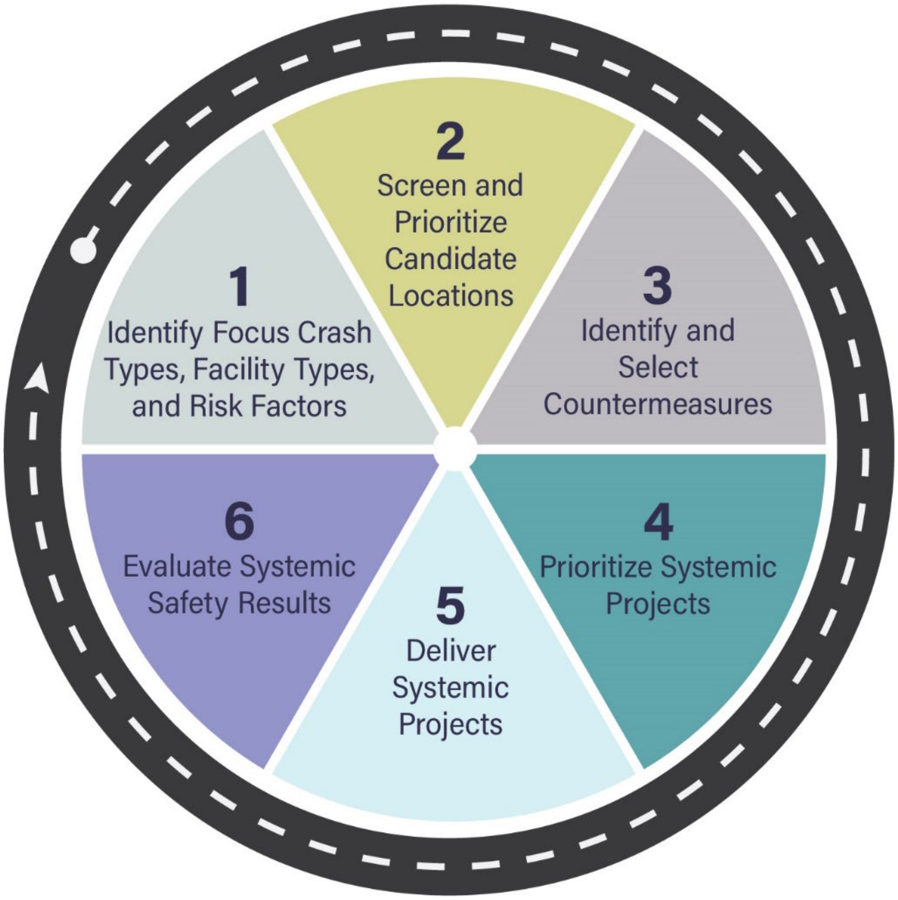


Figure 5. Graphic. The steps of the *Systemic Safety User Guide* (Source: FHWA).

Chapter 1 – Identify Focus Crash Types, Facility Types, and Risk Factors

The first step of the systemic safety process is to identify focus crash types, focus facility types, and risk factors. This chapter describes how agencies can complete that process using several methodologies. Agencies are encouraged to select the methods that work best for their needs, resources, and available data. Agencies can also mix-and-match different methodologies. Figure 6 shows the tasks incorporated in this first step of the systemic safety process.

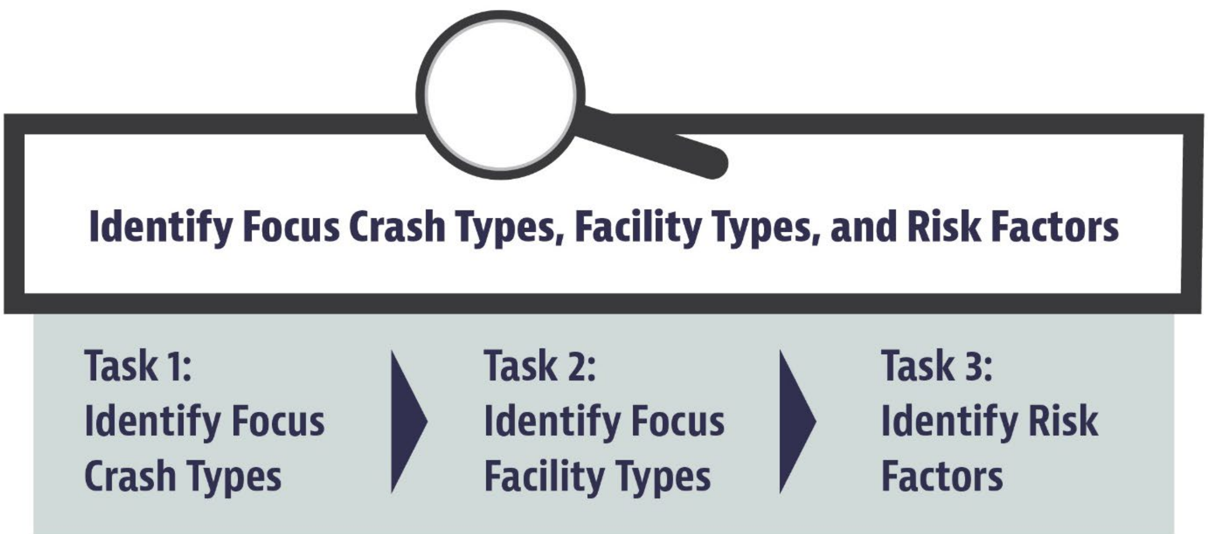


Figure 6. Graphic. Tasks to identify focus crash types, focus facility types, and risk factors (Source: FHWA).

Data

Data needs vary significantly based on the desired level of effort. Preferably, agencies should have crash data to identify crash type (or pre-crash movements or actions), mode of travel, severity, and location. Ideally, these crashes are geolocated and integrated with roadway and traffic data, so an analyst can connect the existing roadway and traffic conditions to each crash.

The **ideal dataset** for this step includes the following data integrated at the crash- and site-level:

- Crash data, including pre-crash movements or actions to develop crash types.
- Facility data (roadway segments and intersections).
- Traffic volume data (vehicles and non-motorized users).
- Additional relevant data, including socioeconomic data and equity indicators, land use data, and asset management inventories (e.g., horizontal curve inventories, sign inventories).

Lack of data should not be viewed as an impediment to making proactive systemic safety improvements. For agencies with **limited or no crash data**, the Fatality Analysis Reporting System (FARS) and Fatality and Injury Reporting System Tool (FIRST) tools from the National Highway Traffic Safety Administration (NHTSA) provide fatal and injury crash data for all public roads in the United States. Agencies can use these crash data, specifically the FARS fatal crash data, to identify the crash types which kill the highest number of travelers on their roads, and factors commonly contributing to those crashes. If only fatal crash data are used, or the sample is otherwise small or underreported (such as for pedestrian and bicycle crashes), additional efforts such as community outreach should be made to supplement the safety analysis with an understanding of community perceptions of safety issues, particularly for people walking and bicycling. As shown later, these data can be collected and organized in a standard manner to feed a consistent systemic program. Emergency services data, including police responses and ambulance trips, may also provide insight into inherent risk along the system. Finally, agencies may work with local health groups to review anonymized hospitalization data related to crash events.

When risk factor data are not available, agencies can incorporate qualitative data, anecdotal information, and data or results from neighboring geographic areas with similar systems or safety issues to identify risk factors. Care should be taken to ensure that these supplemental data represent the spectrum of the community in terms of race, ethnicity, age, and gender, given documented disparities in traffic safety outcomes along these demographic lines (Bellis et al., 2021; Sanders & Schneider, 2022).

For pedestrian and bicyclist crashes, the systemic approach follows the same general process as for other crash types, but there are some additional considerations in the data and analysis procedures used. These are described throughout this chapter for Task 1 (Identify Focus Crash

Types) and in the following sections for Task 2 (Identify Focus Facility Types) and Task 3 (Identify Risk Factors).

It is also important to consider the role of systemic safety in reducing speeds and speeding-related crashes. Speed is directly proportional to the kinetic energy of a vehicle, and the sudden transfer of kinetic energy is a primary determinant in the resulting severity of a crash (Kumfer et al., 2023). This is why the Safe System Approach focuses on minimizing impact energy on the body to tolerable levels (FHWA, 2020a).

When discussing speed, an important factor to consider is operating speed. Operating speeds can be difficult to obtain on a system level for systemic analysis, though recent advances in probe data may alleviate this issue. Speed is also discussed in terms of the posted speed limit, which is typically a statutory value, but may be adjusted based on field studies or tools such as USLIMITS2 (FHWA, 2020b). In addition to operating speed, other speed values, such as design speed (speed used to design the roadway) and inferred speed (speed inferred based on the built environment, roadway design, and operational features) (Donnell et al., 2009) can be considered for systemic safety analysis.

Agencies should take special care to collect and analyze safety data equitably. To learn more about strategies and tools to assist with equitable data collection and analysis, review the resources available at https://highways.dot.gov/safety/zero-deaths/collect-and-analyze-safety-data-equitably.

Data Resources

Enhanced data capabilities allow for enhanced analysis. Agencies interested in enhancing data capabilities should review FHWA's Model Inventory of Roadway Elements (MIRE) and NHTSA's Model Minimum Uniform Crash Criteria (MMUCC), which provide model datasets for roadway elements and crash data. States are required to have access to a complete collection of the MIRE Fundamental Data Elements (FDEs) on all public roads by September 30, 2026 (23 CFR 924.11(b)). Practitioners may consider using available MIRE data to inform their safety management efforts. Non-state agencies can coordinate with their State DOT MIRE data stewards to request relevant data.

Task 1 - Identify Focus Crash Types

Systemic safety analysis begins with the selection of the focus crash type(s). The rest of the process concentrates on reducing the frequency and severity of the focus crash type(s). Focus crash types are typically those that represent the highest frequency of severe crashes or highest potential of a severe crash on the system. Commonly, agencies use crash severity as well as manner of collision or first harmful event to define the focus crash type. Agencies may also use the emphasis areas in their State's Strategic Highway Safety Plan (SHSP), LRSP, or Safety Action Plan to determine a focus crash type. The National Cooperative Highway Research Program (NCHRP) Research Report 955 *Guide for Quantitative Approaches to Systemic Safety Analysis* lists several crash data elements agencies can consider when identifying focus crash types (National Academies of Sciences, Engineering, and Medicine, 2020a):

- Crash severity.
- Manner of collision.
- First harmful event.
- Speed-related.
- Alcohol involvement.
- Drug involvement.
- Light conditions.
- Sequence of events.

Approaches to Focus Crashes

Focus crash types can be a combination of many crash attributes. Examples include:

- Fatal crashes involving excessive speed.
- Fatal and serious injury right-angle crashes.
- All crashes involving an alcohol-impaired driver at night.
- All fatal and injury crashes in which a motorist struck a tree.
- All fatal and injury crashes involving a pedestrian crossing at an unsignalized intersection and a motorist going straight.

Agencies have employed three common approaches to selecting a focus crash type:

- Most frequent severe crashes or crashes contributing to the highest number of fatalities and serious injuries.
- Crashes with the highest probability of being severe.
- Alignment with plans/programs (e.g., SHSP, LRSP).

Figure 7 ties several focus crashes to the elements of the Safe System Approach. This reinforces how systemic safety supports a Safe System. The fifth element, Post-Crash Care, is cross-cutting because quick and effective post-crash care can reduce the severity of injuries from all crashes.

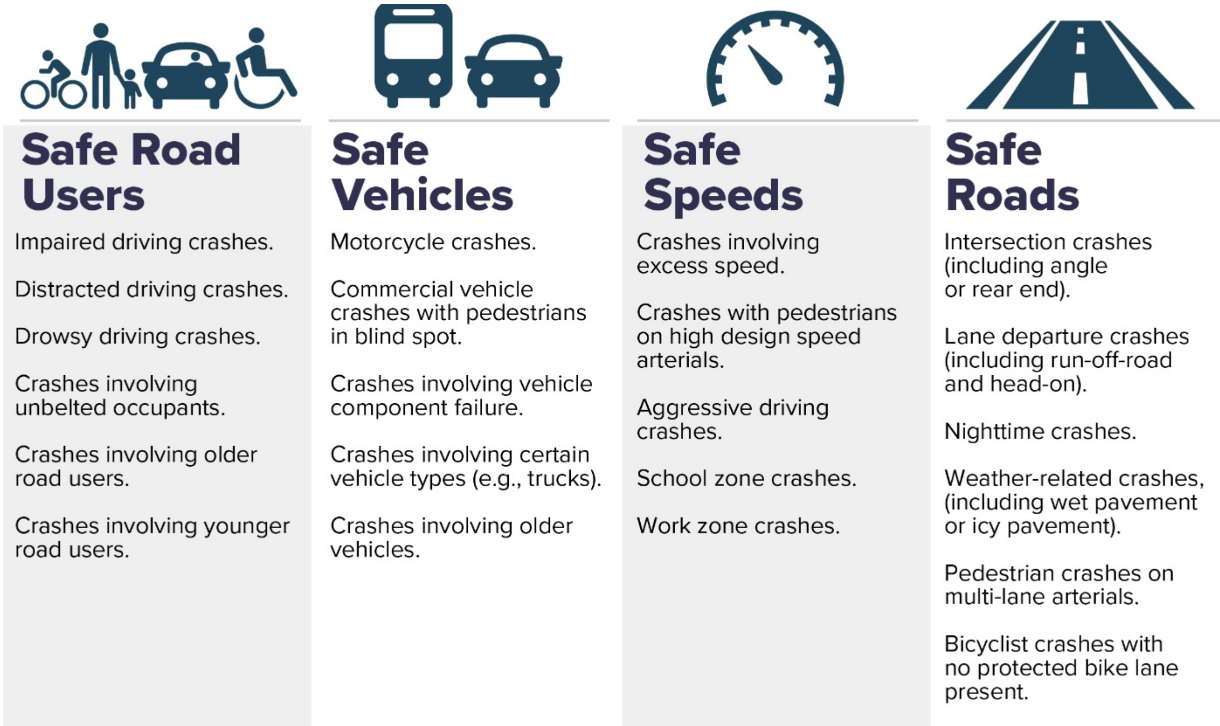


Figure 7. Graphic. Connecting systemic safety focus crashes to the Safe System Approach elements (Source: FHWA).

Considerations for Identifying Focus Crash Types for Pedestrians and Bicyclists

Pedestrian and bicyclist crashes are commonly grouped together as a single type (e.g., all pedestrian crashes, or all bicyclist crashes), but these broad categories can obscure important differences in patterns of interactions with motorists. Analysts can identify specific subtypes of pedestrian and bicycle crashes, similar to how motor vehicle crashes are categorized, to clarify safety issues within a system. In the absence of a pre-defined crash type field in crash data, combinations of other fields (e.g., location type, motorist pre-crash action, pedestrian or bicyclist pre-crash action, and lighting) can be used to define crash subtypes (FHWA, 2022a; Schneider and Stefanich, 2016; National Academies of Sciences, Engineering, and Medicine, 2018).

NCHRP Research Report 893 *Systemic Pedestrian Safety Analysis*, which focuses on systemic safety analysis for pedestrians, recommends detailed focus crash types when the data are available to support such an approach For example, rather than focusing on just pedestrian crashes at intersections, the focus can be pedestrians struck by left-turning motorists. While detailed, this approach is more direct and effective at identifying and targeting countermeasures (National Academies of Sciences, Engineering, and Medicine, 2018)..

The City of San Diego (2019), for example, used these detailed focus crashes for their systemic analysis, identifying the following crash types:

1. Motorists proceeding straight and running a red light, resulting in a broadside angle crash.
2. Pedestrians crossing outside the intersection near traffic signals.
3. Pedestrians crossing against the signal.

The following sections describe three approaches to selecting a focus crash type. Generally, agencies use one of the three options but can select any combination to suit their needs.

Option 1 – Severe Crash or Injury Frequency

The first approach is to select the crashes which account for the highest frequency of severe crashes or severe injuries on the system. If the goal of systemic safety is to realize a proactive reduction in severe crashes and injuries, focusing on the crashes that account for the highest frequency of severe outcomes clearly helps to accomplish that goal. This approach is straightforward from an analytical perspective, where agencies summarize the data by the field of interest, typically manner of collision or first harmful event, and then identify the attribute with the highest frequency of severe crashes or severe injuries. Common crashes that fall into this category include roadway departure crashes, intersection right-angle crashes, and crashes involving persons who are walking or biking[1].

Focus Crashes in Maine

To guide systemic analysis, the Maine Department of Transportation (MaineDOT) created pie charts (figure 8) showing the distribution of total crashes and fatal crashes by crash type. MaineDOT selected "Went-Off-Road" as a focus crash type because these crashes accounted for the highest proportion of fatal crashes (Hanscom, 2018).

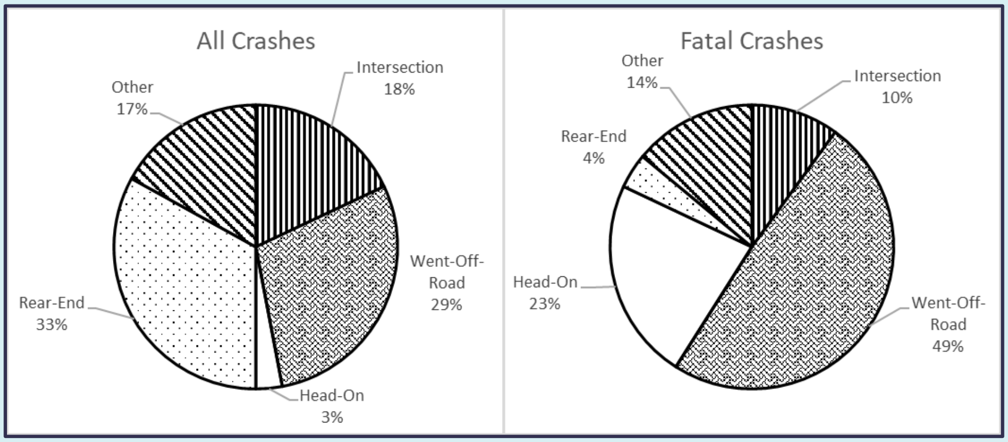


Figure 8. Graphic. Comparison of all crashes and fatal crashes by MaineDOT (Source: Hanscom, 2018).

[1] As stated above, when there are high numbers of pedestrian and bicyclist crashes, efforts should be made to create and examine more detailed crash types.

Option 2 – Severe Crash Overrepresentation

Many factors contribute to the severity of a crash, including the vehicle speed(s), impact angle, and vulnerability of users. As such, some crashes are inherently more likely to produce a severe outcome than others. Though these crashes may be infrequent, agencies can focus on them in the systemic approach.

To identify such crashes, agencies typically use overrepresentation analysis, comparing all severe crashes on the system to all crashes, or less severe and property damage only (PDO) crashes, on the system. This allows agencies to compare the proportion of severe crashes with certain attributes to the proportion of remaining crashes with that same attribute. Overrepresented crashes are those where the proportion of severe crashes with a certain attribute is notably higher. Agencies can select the overrepresented categories as the focus crash type and perform overrepresentation analysis using data for their own roads by comparing to neighboring peer agencies. If an agency's data shows overrepresentation for a severe crash type compared to the proportion of severe crashes of the same type for neighboring or peer agencies, consider selecting this as a focus crash type. Common crash types that fall into this category include pedestrian crashes, bicycle crashes, and head-on crashes. Again, agencies should investigate more specific crash types when the sample allows.

Focus Crashes in Maine

While reviewing the crash data in figure 8, MaineDOT identified that while head-on crashes only account for 3 percent of all crashes, they account for 23 percent of fatal crashes (Hanscom, 2018). Due to this overrepresentation, MaineDOT selected head-on crashes as a focus crash type.

Option 3 – Other Sources

Agencies can use other work to guide the selection of focus crash types. State agencies may refer to the emphasis areas in the State SHSP to guide the selection of focus crash types. As an example, the Massachusetts DOT (MassDOT) took such an approach when embarking on their first systemic safety analysis (MassDOT, 2021a). Local agencies can also refer to the State SHSP or refer to an LRSP. LRSPs typically reflect the State SHSP emphasis areas, but are informed by local data analysis, which may prioritize certain emphasis areas or identify new emphasis areas. While this option does not need agencies to perform their own data analysis, it is often guided by data analysis performed in other projects.

Buchanan County Focus Crashes

Buchanan County, Iowa developed an LRSP to identify and address safety issues on county roadways (Buchanan County, 2016). The County used systemic safety analysis to inform the LRSP. To select emphasis areas (i.e., focus crash types), the County summarized fatal and serious injury (KA) crashes based on the categories in the 2013 Iowa SHSP (the relevant SHSP at the time of LRSP development). Table 4 shows a recreation of the data summary and which crash types the County selected as key emphasis areas.

Table 4. Summary of severe Buchanan County crashes for focus crash identification (Buchanan County, 2016).[2]

Category	State Emphasis Area	KA Crashes, State	Percentage of KA Crashes, State	Rank, State	KA Crashes, County	Percentage of KA Crashes, County	Rank, County	County Emphasis Area
Drivers	Younger Drivers	3,862	37%	5	16	32%	6	Yes
Drivers	Older Drivers	1,723	16%	9	9	18%	9	Yes
Drivers	Speed Related	5,126	48%	3	23	46%	3	Yes
Drivers	Impaired Driving	1,902	18%	8	10	20%	7	Yes
Drivers	Distracted Driving	477	5%	14	1	2%	15	Yes
Drivers	Unprotected Persons	3,971	38%	4	10	20%	7	Yes
Highway	Train	47	0.4%	17	0	0%	17	No
Highway	Lane Departures	5,609	53%	1	26	52%	2	Yes
Highway	Roadside Collision	3,485	33%	6	22	44%	4	Yes
Highway	Intersections	3,210	30%	7	19	38%	5	Yes
Highway	Work Zone	159	2%	16	0	0%	17	No
Highway	Local Roads	5,521	52%	2	28	56%	1	Yes
Highway	Winter Road Conditions	1,224	12%	11	3	6%	12	No
Special Users	Pedestrian	561	5%	13	3	6%	12	No
Special Users	Bicyclist	227	2%	15	1	2%	15	No
Vehicles	Motorcycle	1,491	14%	10	7	14%	10	No
Vehicles	Heavy Truck	1,209	11%	12	6	12%	11	No
Vehicles	Other Special Vehicle	193	2%	17	2	4%	14	No

[2] The percentage of crashes does not sum to 100 percent within categories due to the potential for crashes to be attributed to more than one emphasis area. The State crash data were taken from the 2013 Iowa SHSP, and County crash data represent crashes from 2009 through 2013.

FHWA Crash Data Summary Template

Agencies can use FHWA's Crash Data Summary Template to analyze crash data and compare a subject group of crashes—such as those meeting a certain severity within a geographic area or on a specific jurisdiction road—to larger comparison groups (FHWA, 2020c). The tool identifies overrepresented attributes in the subject data compared to comparison group data. Attributes are flagged as overrepresented if the subject data proportion is five-percent higher or two-times higher than the comparison group data.

Figure 9 is a screenshot of the template populated with crash data from the Frontier Metropolitan Planning Organization (MPO) in Arkansas. The Frontier MPO compared KA crashes within the MPO to those in the larger geographic area encompassed by the Western Arkansas Planning and Development District (WAPDD). Reviewing Manner of Collision results, Frontier MPO could use Option 1 to select single vehicle crashes as a focus crash type, as these account for the highest proportion of KA crashes. Using Option 2, the MPO could select angle and front to rear (i.e., rear end) crashes because they are overrepresented in the MPO compared to the distribution of crashes in the WAPDD. The template is downloadable from FHWA as a Microsoft Excel file and requires the user to input their crash data.

Accessibility: OFF

Crash Data Summary Template

Year 1 - Year 5 Subject Data	KA Crashes							KA Crashes						
	WAPDD							Frontier						
	Year 1 - Year 5	%	2016	2017	2018	2019	2020	Year 1 - Year	%	2016	2017	2018	2019	2020
Manner of Crash														
Single vehicle crash	599	56.4%	133	146	121	83	116	237	45.1%	48	53	53	38	45
Front to rear	118	11.1%	26	32	18	23	19	87	16.6%	19	29	10	13	16
Front to front	84	7.9%	13	21	17	19	14	38	7.2%	8	8	10	9	3
Angle	194	18.3%	43	46	41	32	32	130	24.8%	24	31	34	19	22
Sideswipe, same direction	23	2.2%	9	7	1	3	3	15	2.9%	6	4	1	2	2
Sideswipe, opposite direction	24	2.3%	8	3	9	0	4	9	1.7%	3	1	3	0	2
Rear to sid	2	0.2%	2	0	0	0	0	1	0.2%	1	0	0	0	0
Rear to rear	1	0.1%	0	0	0	0	1	1	0.2%	0	0	0	0	1
Other	17	1.6%	3	2	1	6	5	7	1.3%	2	1	0	2	2
Unknown	0	0.0%	0	0	0	0	0	0	0.0%	0	0	0	0	0

Figure 9. Graphic. Sample screenshot of the FHWA Crash Data Summary Template (Source: FHWA, 2020c).

Helpful Hints and Considerations

How many crash types should I select?

There are various factors to consider when determining the number of focus crash types. What do the data say? Is there a crash type that clearly produces **more** severe crashes than the rest? Or are there many? What resources (people, data, technology, funding) are available for the analysis? Agencies should consider these factors and the scope of the analysis when deciding how many and which focus crash types to select.

Can crashes be assigned to multiple categories?

Yes, with the most obvious example being a crash that falls within multiple emphasis areas. For instance, a roadway departure crash may also involve excessive speed and an impaired driver. Thus, this crash would be included in all three categories. If crashes are double-counted, agencies should document the process.

Can a local jurisdiction select a focus crash type separate from statewide focus areas?

Yes! Any agency performing a systemic safety analysis should concern themselves with crashes that are a priority within their jurisdiction. In some cases, focus crash types may mirror the statewide focus areas, but in other cases, the crash trends in a local agency's jurisdiction could be different than a statewide analysis. If there is Federal or State funding available for local projects related to statewide focus areas, then local agencies may consider modifying their approach to select from statewide focus areas in their analysis.

Should focus crashes be limited to infrastructure-related crash types?

No. Agencies can identify any crash type as a focus crash type, including those related to driver behaviors. This also opens the opportunity for interaction between various stakeholders, including education, public health, engineering, law enforcement, and emergency services.

Can I incorporate speed concepts within systemic safety?

Yes! Several agencies have shown how speed can be addressed or used to inform systemic safety. For example, MassDOT used crashes where drivers "Exceed[ed the] Speed Limit" as a focus crash type and found change in posted speed limit as a risk factor (MassDOT, 2021b); the Mid-Ohio Regional Planning Commission (MORPC) used posted speed limits to define focus facility types (MORPC, 2019); the New York State DOT (NYSDOT) used speed to inform a side-friction risk factor for horizontal curves (NYSDOT, 2024); and the Atlanta Regional Commission (ARC) identified risk factors for certain operational speeds (ARC, 2022).

Table 5 summarizes several considerations for analysts when selecting focus crash types for roadway departure crashes, intersection crashes, pedestrian crashes, bicycle crashes, and speeding crashes.

Table 5. Focus crash type considerations for select emphasis areas.

Roadway Departure Crashes	Intersection Crashes	Pedestrian and Bicycle Crashes	Speed-Related Crashes
When evaluating roadway departure crashes, agencies should consider focusing beyond just whether the crash involved a roadway departure or not. Potential focus crashes include: • Head-on crashes. • Run-off-road crashes. • Overturn or rollover crashes. • Fixed-object crashes. • Pedestrians and bicyclists struck on shoulders.	Intersection design involves conflicting movements between vehicle streams, often at differing angles and speeds. Focus intersection crashes can include: • Right-angle crashes. • Left-turn crashes. • Rear-end crashes. • Pedestrian crashes. • Red-light-running crashes.	To improve countermeasure selection when considering vehicle-pedestrian or vehicle-bicycle crashes, it is helpful to further divide these crashes when the sample size allows. Potential focus crashes include: • Pedestrian crossing mid-block. • Pedestrian in intersection crosswalk struck by left-turning motorist. • Bicyclist struck by right-turning motorist at intersection.	Examining speed-related data along with crash and roadway data can help clarify the degree to which statutory/regulatory and operating speed, in addition to illegal speeding behavior, is more likely to occur and/or be related to crash patterns. Potential focus crashes include: • Pedestrian-motor vehicle crashes along higher-speed roadways at night. • Crashes where vehicle speed is 10-mph greater than the posted speed limit. • Crashes in which the motorist is reported to have been travelling at excessive speed.

Task 2 – Identify Focus Facility Types

Once an agency has identified focus crash types, it is important to identify where those crashes are occurring. The most common practice for answering this question is to use a crash tree—a diagram which shows the distribution of crashes or injuries by selected roadway elements. The goal of using the crash tree is to identify the focus facility type. The focus facility type will be whittled down from the whole system. Consider starting generally, looking at area type (rural or urban), then facility type (segment or intersection), followed by more detailed characteristics, such as number of lanes, functional class, geometry, and traffic control. As with Task 1, agencies can choose from several options to select a focus facility type, including:

1. Sites with the highest focus crash frequency or proportion of focus crashes.
2. Sites with more focus crashes than expected.
3. Sites selected from another source (e.g., SHSP, LRSP).

Note that crash trees are built using crash data as the basis. It is useful to integrate roadway and intersection data with the crash data to further refine crash trees.

Crash Trees

Typically, a crash tree shows the distribution of crashes by area type (urban versus rural), ownership (State versus local), geographic area (district or region), and facility type (segment versus intersection). The tree could also refine the facility type. For segments, the crash tree may include whether the segment is divided or not, number of lanes, and access control. For intersections, the crash tree may include the number of legs and traffic control.

Agencies can further refine the crash tree using factors such as:

- Posted speed limit.
- Horizontal geometry (tangent or curve).
- Presence of lighting.
- Traffic volume.

Example focus facility types include:

- Rural horizontal curves on two-lane roads.
- Suburban four-lane undivided arterial segments with annual average daily traffic (AADT) >15,000 vehicles/day.
- Rural high-speed, stop-controlled, three-leg intersections.
- Urban four-leg signalized intersections.

Considerations for Identifying Focus Facility Types for Pedestrians and Bicyclists

In the absence of pedestrian and bicyclist volume data, it is possible to normalize by roadway mileage or number of intersections to identify the greatest concentration of crashes on the system. This technique can also be used with analyzing specific risk factors in subsequent analysis steps. One can also look at relative severity of crashes across different location types to help choose focus areas. Mode-specific High-Injury Networks (HIN) can help highlight focus facility types and subcategories.

Note that for pedestrian and bicycle crashes, facility type and risk factors are often highly correlated. For example, “arterials” usually imply a package of higher-risk elements for vulnerable road users (e.g., wide crossing distances, long distances between signalized crossings, high motor vehicle volumes, higher speeds, etc.). Identifying focus facility types can help identify broad categories of facilities, while subsequent steps can drill down into specific risk factors associated with the facilities (Schneider et al., 2021).

Additionally, research has found that risk factors for severe pedestrian crashes are disproportionately located in lower-income areas and communities of color (Sanders & Schneider, 2022). One example of this impact is "arrested mobility." Arrested mobility refers to limited access to safe mobility for Black and Brown communities as a result of inequitable distribution of safe road infrastructure and planning and disproportionate enforcement (Brown, 2021; Brown et al., 2023). Systemic efforts to address these risk factors will also help address community inequity.

Option 1 – Focus Crash Frequency

The first and most common option for selecting a focus facility type is to identify the facility type with the highest number of focus crashes or severe focus crash injuries as identified in Task 1 – Identify Focus Crash Types. As described earlier, this is best completed using a crash tree.

Crash Trees for Pedestrian Crashes in Ohio

The MORPC selected overall pedestrian crashes as a focus crash type for their systemic safety pilot project (MORPC, 2019). The MPO then used crash trees to identify focus facility types, as shown in figure 10. MORPC selected two focus facility types for pedestrian crashes—local intersections on straight roads with a posted speed limit less than or equal to 30 mph, and local intersections on straight roads with a posted speed limit from 31 to 35 mph. These were selected by the crash tree branches which accounted for the highest proportion of crashes within the set of features.

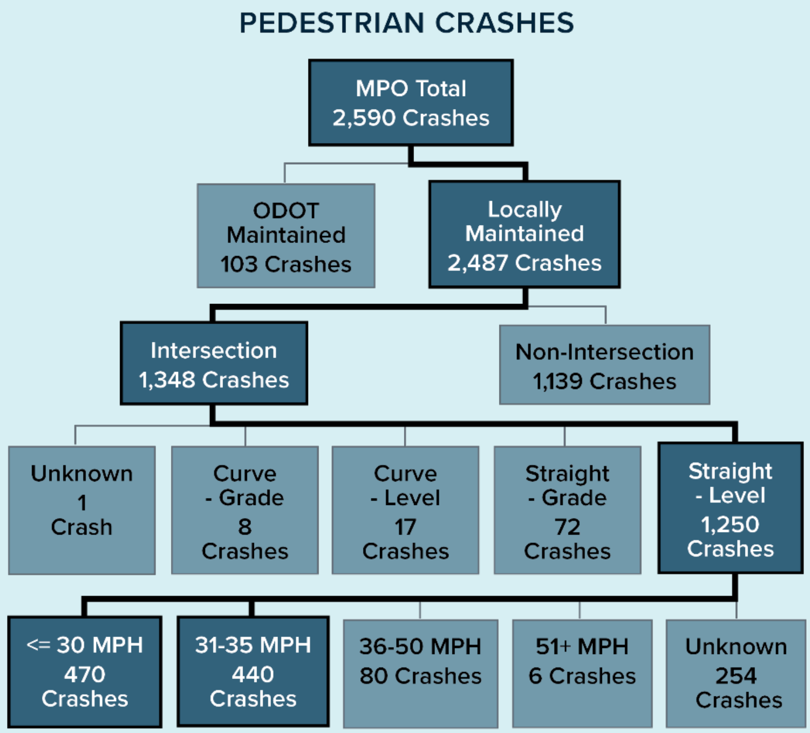


Figure 10. Graphic. Pedestrian crash tree for the MORPC (Source: MORPC, 2019).

Option 2 – Excess Focus Crashes

Another method for selecting a focus facility type using a crash tree is to include metrics normalizing for exposure on the focus facilities, such as roadway mileage, number of intersections, vehicle miles traveled (VMT) or entering vehicles. Agencies can compare the proportion of focus crash types on the facility to the proportion of exposure on the facility, selecting those with a higher proportion of crashes than proportion of exposure. Alternatively, agencies can compare the proportion of focus crash types with certain attributes to the proportion of total crashes on those facilities. Facilities with a higher proportion of focus crash types compared to total crashes can be selected as focus facilities. Agencies can use a statistical test, such as a chi-squared test or comparison of sample mean and errors, to confirm the overrepresentation for a level of statistical confidence.

Tabular Crash Trees in Atlanta

The ARC incorporated lane-miles as a measure of exposure to inform the focus facility types for the Regional Safety Strategy (ARC, 2022). While the preference was to use VMT, the Region does not have complete traffic volume data for the entire system, so lane-miles served as a useful proxy. Table 6 is an excerpt from one of ARC's crash tree equivalents developed for KA pedestrian crashes. The ARC selected urban, State, and principal arterial-other segments with four lanes and six lanes as focus facilities due to the overrepresentation of KA pedestrian crashes compared to lane-miles on these facilities.

Table 6. Excerpt of a crash tree equivalent from ARC for KA pedestrian crashes (ARC, 2022).

Area Type	Owner	Functional Class	Number of Lanes	Proportion of Lane Miles	Proportion of KA Crashes	Excess KA Crash Proportion
Urban	State	Principal Arterial – Other	1	<0.05%	0%	0%
Urban	State	Principal Arterial – Other	2	0.5%	1.1%	0.6%
Urban	State	Principal Arterial – Other	3	0.1%	0.1%	0%
Urban	State	Principal Arterial – Other	4	2.7%	13.5%	10.8%
Urban	State	Principal Arterial – Other	5	0.1%	1.1%	1.0%
Urban	State	Principal Arterial – Other	≥6	0.6%	6.6%	6.0%

Machine Learning Crash Trees in Virginia

While most agencies simply use summary statistics to build crash trees, the Virginia Department of Transportation (VDOT) took an enhanced approach, using a machine learning technique to construct crash trees and select focus facility types (Cho et al., 2020). VDOT developed the tree using Potential for Safety Improvement (PSI) for roadway departure crashes (i.e., excess expected roadway departure crashes based on Empirical Bayes [EB] network screening). Rather than users selecting facility types, the machine learning process identified the roadway features most correlated with PSI, producing the list of site elements to define the focus facility type. Part of the machine learning process includes identifying correlations based on overrepresentation of PSI compared to roadway mileage or sites with the same characteristic. More information is available from VDOT at https://www.virginiadot.org/vtrc/main/online_reports/pdf/21-r10.pdf.

Some local agencies use a modified version of the excess approach by focusing their effort on the HIN, which consists of the portions of the system that account for a disproportionate number of focus crashes. HINs are often identified as part of an overall Vision Zero initiative, which typically includes widespread implementation of low-cost safety countermeasures. Agencies can use the HIN to identify crash profiles—combinations of roadway characteristics more likely to be associated with crashes or severe crashes—and subsequently use the profiles in future network screening efforts. Additionally, HINs often run through or disproportionately surround communities of concern, increasing the opportunity for an agency to implement equitable transportation solutions.

Identifying a HIN

The Vision Zero Network maintains a webpage highlighting the use of HINs around the United States: https://visionzeronetwork.org/tag/high-injury-network/.

HINs are typically constructed using integrated crash, roadway, and other data in the geographic information system (GIS). ArcGIS has solutions which can support the calculations needed to identify an HIN: https://doc.arcgis.com/en/arcgis-solutions/latest/reference/use-traffic-crash-analysis.htm.

City of Eugene HIN

The City of Eugene, Oregon identified that 9 percent of streets in the city accounted for 70 percent of fatal and life-changing injuries[3] (City of Eugene, 2022). The agency designated the HIN shown in figure 11 as the focus facility type.

Figure 11. Graphic. HIN for the City of Eugene, Oregon (Source: City of Eugene, 2022).

[3] This terminology is specific to the City of Eugene's Vision Zero plan.

Option 3 – Other Sources

Agencies can use other work to select focus facility types. Local agencies focusing on a similar analysis as a State agency or neighboring local agency may select the focus facility type used by that other agency. Agencies can also use documented research to guide the selection. For example, the San Juan National Forest (SJNF) used the systemic approach to address roadway departure crashes on public roads in the National Forest. After selecting roadway departure crashes as a focus crash type, the SJNF and FHWA's Office of Federal Lands Highway (FLH) lacked comprehensive roadway data for further crash tree analysis. However, SJNF had curve radius information available (obtained using a GIS tool) and decided to focus on horizontal curves based on the proven correlation between horizontal curves and crash frequency (AASHTO, 2010). Reviewing research on low-volume roads (Al-Kaisy and Huda, 2020), the SJNF prioritized horizontal curves at least 50 ft in length, a radius of less than 300 ft, and a vertical grade steeper than 4 percent as their focus facility type.

FHWA Crash Tree Diagram Tool

FHWA's *Crash Tree Diagram Tool* is a Microsoft Excel macro which allows users to create crash trees using their own data or pre-loaded FARS data (FHWA, 2020c). After selecting the data source, users select which fields appear at which levels. The trees are created in an Excel worksheet and can be exported in various formats. Figure 12 is a sample crash tree built using the tool. The patterned cells show the characteristics accounting for the highest proportion of crashes.

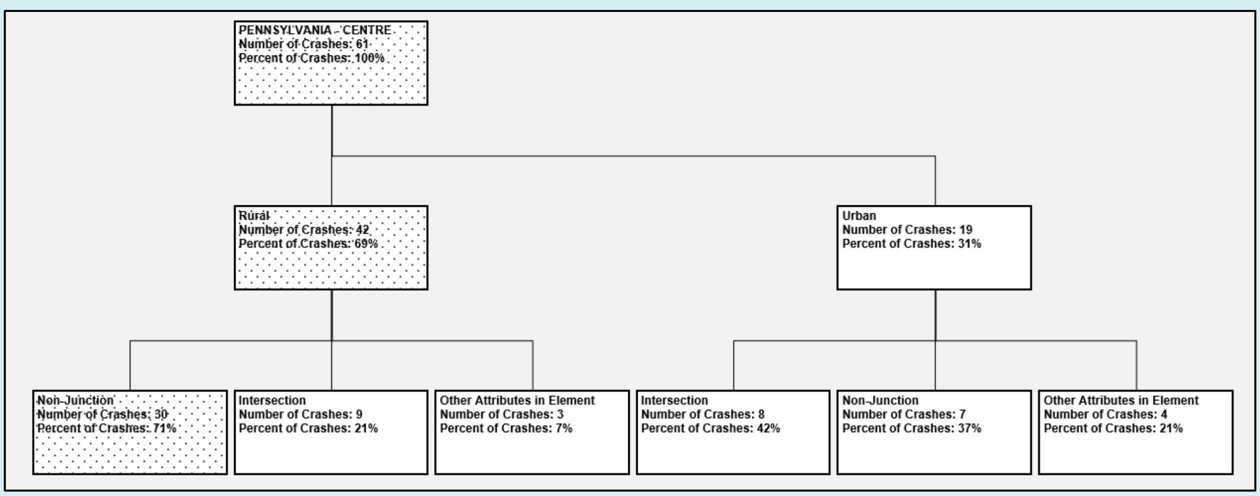


Figure 12. Graphic. Sample crash tree built using FHWA's *Crash Tree Diagram Tool* (Source: FHWA).

Selecting the Appropriate Level of Focus Facility

When considering what system elements should comprise the focus facility type, agencies should consider what countermeasures may be used to address focus crashes. For instance, engineering countermeasures are applied at the site level. For educational and enforcement campaigns, agencies may need to prioritize larger geographic areas, such as towns, block groups, or other areas as the focus facility type. MassDOT incorporated this approach to address behavioral crashes such as impaired driving, distracted driving, and unbelted occupants (MassDOT, 2021a). MassDOT then identified risk factors at the town-level and prioritized towns for education grants.

Helpful Hints and Considerations

How many levels should my crash tree include?

The number of levels is up to the analyst and depends on the starting point of the tree. Analysts can filter the data before starting the tree to focus on segments or intersections, which would reduce the size of the tree. Ultimately, the number of levels in the tree should be the appropriate number to comfortably select a focus facility type. Keep in mind that crash trees grow exponentially, so analysts should limit the size to keep it usable.

Does the crash tree include all severe crashes or just severe crashes for the focus crash type?

The purpose of a crash tree is to identify the focus facility type for the focus crash type. As such, the primary approach should be to use severe crashes for just the focus crash type. If the sample size is too small, consider adding less severe focus crashes to the crash tree.

How many facility types should I select?

In general, selecting fewer facility types will allow for a more streamlined selection of risk factors and identification of sites for improvement. Additionally, this will ease identification of countermeasures and implementation of systemic safety improvements.

What if my crash data are missing facility type data?

Agencies can use GIS software packages to integrate geolocated crash data with roadway and intersection data. Analysts can use that integration to transfer data necessary for identifying focus facilities to the appropriate crashes. These data are becoming increasingly available due to MIRE FDE requirements (*see* 23 CFR 924.11(b)).

Can I combine Tasks 1 and 2?

Yes! For instance, you can use a crash tree starting with all severe crashes, identifying the focus crash types in the first or second level, then identify the focus facility type in the following levels. Alternatively, analysts can identify the facilities that account for the highest proportion of severe crashes, then see which crash types are most common on those facilities. Both are methods of combining Tasks 1 and 2 into one step.

Table 7 describes focus facility type considerations for several common emphasis areas, including roadway departure crashes, intersection crashes, pedestrian and bicycle crashes, and speeding crashes.

Table 7. Focus facility type considerations for select emphasis areas.

Roadway Departure Crashes	Intersection Crashes	Pedestrian and Bicycle Crashes	Speed-Related Crashes
Roadway departure crashes can occur anywhere. Use crash trees to determine what facilities they are occurring on most frequently throughout the system. Example roadway departure focus facility types include: • Two-lane rural roads with a posted speed limit of 55 mph. • Curve radius sharper than 600 ft. • Urban collector streets with less than 10,000 vehicles/day.	A roadway system may have an extensive number of intersections, so agencies should be specific when selecting focus intersection facilities. Example intersection focus facilities include: • Urban four-leg signalized intersections. • Rural three-leg, stop-controlled intersections. • Signalized intersections on high-speed suburban arterials. • Uncontrolled intersections on high-speed urban and suburban arterials.	Consider intersections, segments, and mid-block crossings when selecting focus facilities. Potential focus facilities include: • Urban high-speed arterials. • Suburban signalized intersections. • Rural town mid-block crossings. • Other facilities as identified in a mode-specific HIN.	While there is potential for speeding on any road, some roadway designs are more likely to permit or encourage speeding than others. Agencies should consider statutory/regulatory speed limit, or ideally motorist operating speed data, in their crash trees. Potential focus facilities include: • Rural two-lane highways with a posted speed limit of 55 mph. • Urban collectors where the 85th percentile is 10-mph higher than the posted speed limit.

Task 3 – Identify Risk Factors

Task 3 identifies the factors most associated with an increased risk of a severe focus crash type on a focus facility type. The term "risk" has a wide range of definitions, but for the purpose of this Guide, it serves as a qualitative or quantitative measure of the likelihood of a severe crash relative to typical conditions. As stated previously, agencies are free to use "contributing factors," "characteristics," "features," or other terms in place of "risk factors." In a systemic safety program, risk factors are used to prioritize system elements for safety improvements.

Agencies can use a wide range of data to identify risk factors. Categorically, risk factor data can include:

- **Infrastructure characteristics**, such as geometric alignment, cross-section data, number of driveways, and intersection design.
- **Operational data**, including traffic volume and demand, non-motorist volume, and posted and operational speed data.
- **Asset management data**, including the presence, location, and condition of signage, pavement markings, barrier, and other assets.
- **Community and contextual data**, such as adjacent land use, trip generators including transit stops and schools, and sales establishments like vendors with liquor licenses.
- **Socioeconomic data**, including American Community Survey data, Census data, and equity indicators, such as areas of persistent poverty and historically disadvantaged communities.
- **Crash and safety data**, including crash frequency, crash density, excess crashes, or even surrogate safety data.

Generally, risk factors either have a direct or indirect (i.e., surrogate) relationship with the target crashes. An example of a direct relationship is shoulder width and roadway departure crashes—it is commonly accepted that roadways with narrow shoulders are at a higher risk of a roadway departure crash than those with wider shoulders. Indirect relationships, on the other hand, are often surrogate measures of some inherent risk which cannot be captured with available data. For instance, pedestrian crash risk is typically considered relatively higher at intersections with high pedestrian volume. While pedestrian volume data are often difficult to obtain, the presence of pedestrian trip generators, such as transit stops and schools, are often more readily available. Without pedestrian volume available, analysts may find correlation between severe pedestrian crashes and the presence of these trip generators, despite the fact that they do not necessarily create a safety issue. For instance, the risk of a severe pedestrian crash may increase near bus stops. It is not the transit itself that increases risk, but it is the attraction of more pedestrians and potential lack of facilities such as sidewalks and high-visibility crossings to accommodate pedestrians. As such, the presence of bus stops would be a surrogate risk factor.

Note that the absence of a safety countermeasure at a site or along a facility, such as a safety edge treatment, pavement markings, rumble strips, or signage can also be considered a risk factor.

Innovative and creative techniques can be used to obtain risk factors when certain data are not available. For example, when formal horizontal and vertical geometry is not available, a GIS curve finder type algorithm and Light Detection and Ranging (LiDAR) data could be used to derive horizontal curve data and vertical grade. If pedestrian and bicycle demand is not readily available, demand models or surrogates can be useful substitutes – the Minnesota Department of Transportation (MnDOT) SPACE Score (MnDOT, 2022) is an example application that also incorporates equity data (FHWA, 2023a).

Risk factors can be applied at varying levels. While risk factor analysis is typically done at the site level, risk factors can be estimated at spatial levels and transferred to the focus facility system elements. For instance, socioeconomic data or risk factors at the census block level can be applied to all sites within that block group. Spatial data management and analysis tools, including GIS, are useful for this integration.

Data needs for pedestrian and bicyclist risk factor analysis have some overlap with motor vehicle safety analysis, but many important data types are not widely available. Table 8 describes the type and availability of several key data and how they provide value for pedestrian or bicyclist safety analysis. The table notes which data elements are considered *primary* (i.e., provide direct measures of risk) and *surrogate* (i.e., provide indirect measures of risk), and which measures are critical (i.e., necessary for analysis) versus ideal (provide important information and context, but not widely available). Note that certain critical measures may act as surrogates for other critical measures; these are noted in the table where applicable. Many of the features considered critical are readily available to planners and engineers because they are also required as MIRE FDEs or for Highway Performance Monitoring System (HPMS) reporting. Additionally, critical elements already have a documented correlation with the risk of a severe crash for pedestrians and bicyclists (National Academies of Sciences, Engineering, and Medicine, 2018). These variables are critical for both original systemic analysis and applications of established findings or published safety performance functions. If an agency is missing a critical element, they may use one of the suggested surrogate elements, though they should work with their data partners to obtain missing critical elements, in the form of direct measurement, for future analysis.

Table 8. Data considerations for pedestrian and bicyclist risk factors.

Category	Purpose	Data Examples	Availability
Pedestrian or Bicyclist Exposure Data	**Primary for Pedestrian or Bicyclist Demand** Important for characterizing relative risk and prioritizing high need locations. Additionally, exposure may inform pedestrian, bicyclist, and driver behavior, i.e., the "safety in numbers" effect (Hamilton et al., 2021).	**Ideal:** Pedestrian or bicyclist volume data, exposure models (Turner et al., 2018).	Accurate counts or volume data are rarely available for non-motorists, but exposure can be estimated based on surrogates like vendor data or other known related factors (land use, demographics, etc.). Vendor data are often presented as relative indices, and in many cases may be heavily biased by their underlying source data (National Academies of Sciences, Engineering, and Medicine, 2018; Turner et al., 2018).
Pedestrian Crossing Facilities at Intersections	**Primary for Conflict Exposure and Surrogate for Pedestrian Demand** Important for understanding where existing countermeasures are located and where gaps may be, as well as pedestrian crossing distance. These data also provide insight into potential pedestrian demand and protection from risk. Ideal to have type.	**Ideal**: Crosswalk markings, curb extensions, median crossing islands.	Varies by agency and data type; presence is more common than detailed attributes like width or buffer. Install date is ideal if newer. Americans with Disabilities Act (ADA) inventory data may have additional attributes (curb ramps, width, buffer, materials, etc.).

Category	Purpose	Data Examples	Availability
Midblock Crossing Facilities	**Primary for Conflict Exposure and Surrogate for Pedestrian Demand** Important for understanding where existing countermeasures are located and where gaps may be. May indicate elevated crossing demand and/or enhanced protection compared to elsewhere on the system.	**Ideal**: Crosswalk markings, signage, enhanced crossing signals – Rectangular rapid-flashing beacons (RRFB), high-intensity activated crosswalk beacon.	Varies by agency and data type. Data related to ADA are generally more commonly available (e.g., Accessible Pedestrian Signals (APS)) than specific pedestrian or bicycle treatments or timing (e.g., bicycle signal, leading pedestrian interval (LPI)). Data may be in less usable formats (e.g., not geocoded or systematically collected).
Traffic Control	**Primary for Conflict Exposure and Surrogate for Motorist and Pedestrian Demand** Traffic control device type is important for understanding operations and conflict risk. Other important elements are APS, conflicting concurrent phases, and LPI.	**Critical**: Presence of traffic control devices, such as traffic signal, stop control, etc. **Ideal**: Pedestrian signal presence, pedestrian signal type, bicycle signal presence, bicycle signal type, countdown timers, pushbutton presence.	Usually available. Level of detail may vary by agency; ideally includes type, operation, and install date (if newer).
Roadway Cross Section	**Primary for Context and Conflict Exposure** Important for characterizing pedestrian crossing distance to motorists and understanding the prevalence of established risk factors.	**Critical:** Number of through lanes. (AADT may act as surrogate if unavailable.) **Ideal:** Width, median refuge presence, number of turn lanes, wide paved shoulder presence.	Typically available from roadway inventory data.
Motor Vehicle Volumes	**Primary for Conflict Exposure** Motor vehicle volume is a well-documented risk factor.	**Critical:** AADT (Number of lanes may act as surrogate if unavailable.) **Ideal**: Heavy vehicle AADT.	Typically available through traffic data counts.

Category	Purpose	Data Examples	Availability
Socioeconomic, Demographic, and Equity-Related Data	**Primary for Pedestrian or Bicyclist Demand** Important for understanding equity-related disparities in safety and for prioritizing investment for greatest impact.	**Ideal:** Historically-disadvantaged communities, population characteristics (such as race, ethnicity, income, education, disability, vehicle ownership), local equity indices or measures.	Usually widely available from local agencies (e.g., parcel data). National data used for Justice40, the US Census, and the American Community Survey can also be helpful.
Speed	**Primary for Conflict Severity** Important for understanding the potential severity of a collision between a motorist and a pedestrian or a bicyclist.	**Critical:** Posted speed limit. (Functional classification or number of lanes + land use may act as surrogate if unavailable.) **Ideal:** Operating speed, inferred speed, design speed.	Posted speed limit is typically available through road inventory data. Design speed data and inferred data may be obtained through design plans and speed modeling. Operating speed can be obtained through field data and/or probe data.
Bicycle Facilities	**Surrogate for Bicycle Demand** Important for understanding bicyclist exposure to motorist traffic. Facility presence and directionality are the most important variables; facility type and separation from traffic are helpful.	**Ideal:** One-way bike lane with painted buffer, bi-directional separated cycle track with concrete barrier, shared lane marked with sharrow.	Often available for collectors and arterials. Commonly collected and analyzed for crash and risk factor analysis. Install date is ideal if newer.
Sidewalk and Side Path Facilities	**Surrogate for Pedestrian Demand** Important for understanding pedestrian exposure to motorist traffic. Facility presence and some accessibility features (such as curb ramps) are the most important; width, buffer, and other characteristics are helpful.	**Ideal**: Sidewalk presence, sidewalk width, accessible curb ramps, buffer presence.	Usually available for functional classes with Highway Performance Monitoring System (HPMS) reporting requirements. Commonly collected and analyzed for crash and risk factor analysis.

Category	Purpose	Data Examples	Availability
Land Use and Built Environment Features	**Surrogate for Pedestrian or Bicycle Demand** Important both as a proxy for pedestrian volumes and as a supplement to exposure data to help identify sensitive land uses that may require more frequent and more careful treatment.	**Ideal**: Residential and commercial land uses, schools/youth facilities, universities, senior housing, libraries, parks, alcohol sales establishments, grocery stores, convenience stores, restaurants, and other common pedestrian generators.	Usually available from several sources, including regional and State planning agencies.
Transit Data	**Surrogate for Pedestrian or Bicycle Demand** Important both as a proxy for pedestrian volumes and as a supplement to exposure data to identify areas with high pedestrian crossing needs.	**Ideal**: Stops/stations, transit mode (e.g., rail or bus), boardings and alightings, vehicle frequency, and trip frequency.	Varies by agency; data may be in a less usable format for some agencies (e.g., not geocoded or systematically collected). General Transit Feed Specification data is available for many cities.

Considerations for Identifying Risk Factors for Pedestrians and Bicyclists

The same methodologies apply to risk factor identification for pedestrian and bicyclist crashes (overrepresentation, statistical modeling, established findings, local knowledge). Statistical modeling is highly recommended for identifying pedestrian and bicyclist risk factors (National Academies of Sciences, Engineering, and Medicine, 2018); however, this method has the greatest data needs and requires modeling expertise. An alternative approach is to apply existing statistical models. This can overcome the need for modeling expertise to develop models but would still require a comprehensive dataset to apply the models. In the absence of both expertise and comprehensive data, agencies can use select risk factors from established findings to screen the system based on available data. NCHRP Research Report 893 *Systemic Pedestrian Safety Analysis* includes an inventory of common risk factors and their expected relationship with crashes (National Academies of Sciences, Engineering, and Medicine, 2018). Crash modification factors (CMFs) from FHWA's CMF Clearinghouse can be used as well.

Pedestrian and bicyclist exposure data are useful for identifying high-risk locations. In the absence of pedestrian and bicyclist exposure data, surrogates such as pedestrian generators, land use, socioeconomic status, and demographic information can help to identify higher-risk locations.

There are four general approaches to identifying risk factors:

- Overrepresentation.
- Statistical modeling.
- Established findings.
- Local knowledge.

Agencies can select one or more of these methodologies when performing systemic safety analysis. The following sections describe each methodology and include an example application of each.

Option 1 – Overrepresentation

One method for identifying risk factors is overrepresentation. Agencies compare the proportion of focus crashes on focus facilities with given attributes to the proportion of an exposure measure, such as mileage, number of sites, or VMT. Agencies can also compare against a larger comparison group of crashes to identify risk factors.

Roadway Departure Risk Factors in New York

The NYSDOT used overrepresentation analysis to identify risk factors in their Roadway Departure Safety Action Plan (NYSDOT, 2024. NYSDOT selected two focus crash types—head-on crashes and other roadway departure crashes. They then selected several focus facility types for each focus crash type. Finally, NYSDOT used overrepresentation to select risk factors—comparing the proportion of severe (KA) focus crashes to the proportion of VMT for specific system elements of interest. Figure 13 is an example risk factor plot NYSDOT used to identify shoulder width risk factors for non-intersection roadway departure crashes on State-maintained rural major collectors. Based on the comparison of KA crashes to VMT, NYSDOT selected 1- to 4-ft shoulders as a risk factor.

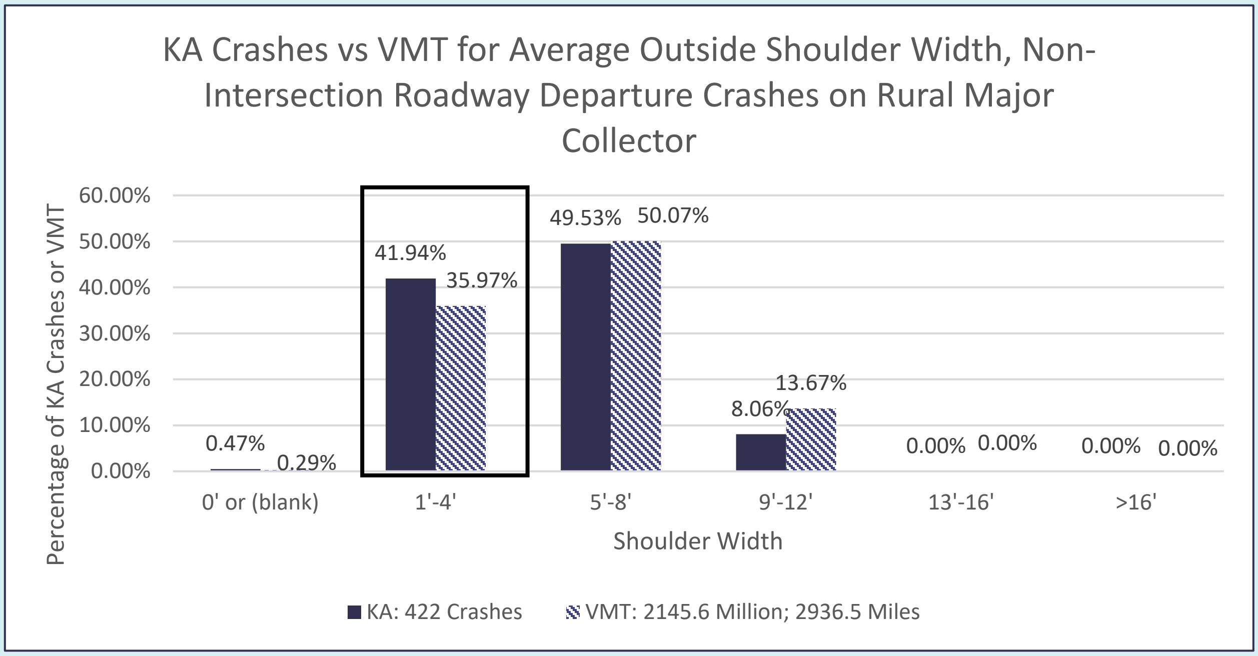


Figure 13. Graphic. Sample overrepresentation plot from the identifying risk factors for shoulder width (Source: NYSDOT, 2024).

Risk Factors in Indiana

Boone County, Indiana also used overrepresentation for risk factor analysis, in this case for an LRSP (Boone County, 2020). The County created plots comparing the proportion of crashes with certain features to the proportion of roadway segments with the same feature. Figure 14 is an example of a risk factor plot from this LRSP. Based on the comparison of crash data and segment data, Boone County selected AADT greater than 1,000 vehicles per day as a risk factor because 59 percent of crashes occurred on 18 percent of the roadway segments with AADT greater than 1,000 vehicles/day.

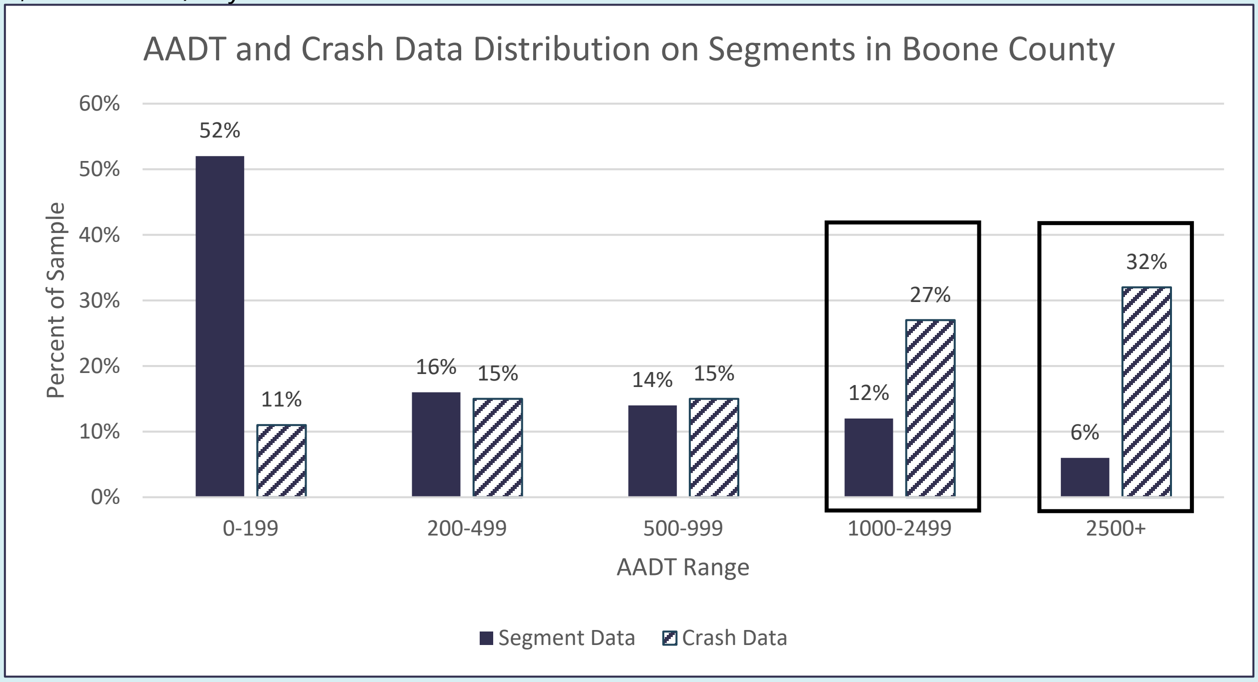


Figure 14. Graphic. Risk factor plot for AADT from Boone County, Indiana (Source: Boone County, 2020).

For consistency, agencies should consider a fixed percentage difference (e.g., 5 percent) or statistical test (e.g., chi-squared test) to confirm that an overrepresented attribute should be a risk factor. For instance, the Georgia Department of Transportation (GDOT) considers an attribute overrepresented if the proportion of subject crashes is either five-percentage-points higher or two-times higher than the comparison group. MassDOT, on the other hand, considers an attribute overrepresented if a two-sample t-test suggests the proportion of subject crashes is higher than the comparison sample at a pre-defined level of statistical significance.

Option 2 – Statistical Modeling

Statistical modeling is one of the more rigorous methods agencies can use to identify risk factors. In this option, agencies use their own data to develop crash frequency or crash probability regression models for focus crashes on focus facility types. The regression model uncovers features that are statistically correlated with increased frequency or probability of the focus crash, depending on the model type. Each variable in the final model can be considered a risk factor.[4] Agencies can use the model results directly to prioritize sites based on modeled risk. Another option is to use the model results to identify risk factors and then assign a binary, weighted, or otherwise custom scoring for each risk factor based on input from stakeholders or similar systemic programs.

The Seattle Department of Transportation (SDOT) estimated safety performance functions (SPFs) to model the risk of specific types of pedestrian and bicycle crashes at intersections for a systemic safety program (SDOT, 2016). First, SDOT generated pedestrian and bicycle demand estimates (i.e., traffic volumes) for each intersection from exposure models built on observed count data. These models included several forms of data, including socioeconomic data. SDOT then developed several SPFs, including one for total pedestrian crashes at intersections and one for pedestrians crossing at intersections struck by a motorist going straight. SDOT used cross-tabulations and the data reduction technique “Conditional Random Forest” to identify important relationships between the variables and facilitate the SPF model development. Table 9 summarizes the SPF results, which were estimated using negative binomial regression. Ultimately, SDOT used these models to apply the EB approach and assess potential for safety improvement across their system—a hybrid application of crash-based and risk-based network screening.

[4] For segments, length should be included in the model, but excluded as a final risk factor.

Table 9. Summary of the negative binomial regression SPFs for the City of Seattle (SDOT, 2016).

Risk Factors	Total Pedestrian Crashes		Pedestrian Crossing Crashes	
	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-10.8298	1.0123	-11.6231	1.5733
Number of commercial properties within 0.10 mi of intersection	0.0248	0.0036	0.0313	0.0055
Number of buses and trains stopping within 150 ft of an intersection on a typical weekday	0.0016	0.0003	0.0022	0.0004
All building volume (height * area) within 0.10 mi of intersection	$3.24 * 10^{-8}$	<0.0001	$3.21 * 10^{-8}$	<0.0001
Natural log of estimated average annual daily pedestrian volume at an intersection	0.7199	0.1378	0.6440	0.2102
Estimated average annual daily pedestrian volume at an intersection	-0.0917	0.0189	-0.0741	0.0294
Commercial only building volume within 0.10 mi of an intersection	$-3.28 * 10^{-8}$	<0.0001	$-4.00 * 10^{-8}$	<0.0001
Proportion of legs at the intersection that are local streets	-1.0584	0.1595	-0.7632	0.2600
Mean income within 164 ft of an intersection.	$-5.72 * 10^{-6}$	<0.0001	$-6.40 * 10^{-6}$	<0.0001
Average slope of terrain within 0.50 mi surrounding an intersection.	-0.0976	0.0472	N/A	N/A
Total population within 0.10 mi of an intersection.	0.0002	0.0001	N/A	N/A
Intersection controlled by a signal = Yes (Baseline is No)	1.0818	0.0792	0.2849	0.1290

Risk Factors	Total Pedestrian Crashes		Pedestrian Crossing Crashes	
	Coefficient	Standard Error	Coefficient	Standard Error
Number of legs present at the intersection = 4 (Baseline is 3)	0.6052	0.0873	0.8687	0.1128
Number of legs present at the intersection ≥ 5 (Baseline is 3)	0.6719	0.1449	0.6630	0.2296
Total number of motor vehicle travel lanes for all legs at an intersection = 7-8 (Baseline is 3-6)	0.4440	0.1231	N/A	N/A
Total number of motor vehicle travel lanes for all legs at an intersection = 9-26 (Baseline is 3-6)	0.4770	0.1681	N/A	N/A
Total number of motor vehicle lanes on the largest approach leg = 3-4 (Baseline is 1-2)	-0.0624	0.1114	0.0691	0.1249
Total number of motor vehicle lanes on the largest approach leg = 5-12 (Baseline is 1-2)	0.4053	0.1312	0.3907	0.1562
The highest arterial class entering an intersection is Major (Baseline is Local)	1.2129	0.1578	1.9278	0.2563
The highest arterial class entering an intersection is Minor (Baseline is Local)	1.1736	0.1504	1.8381	0.2423
The highest arterial class entering an intersection is Collector (Baseline is Local)	0.6537	0.1661	1.4117	0.2610
Presence of parking on any intersection leg is yes (Baseline is No)	0.2230	0.0749	N/A	N/A
Scale (Overdispersion Parameter)	0.7994	0.0676	1.3819	0.2126

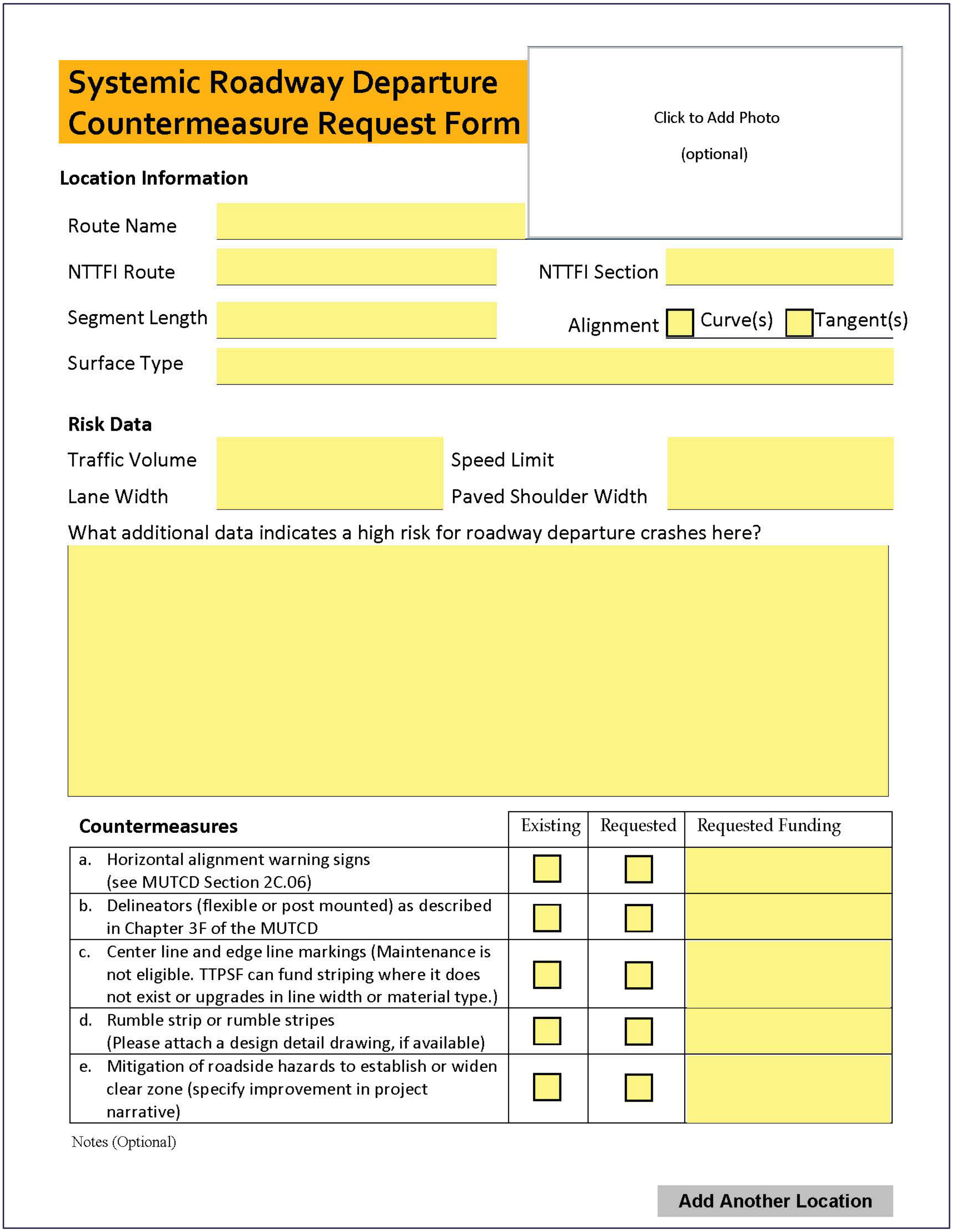
The findings from SDOT show the wide range of features which can be considered risk factors for pedestrian crashes at intersections, including pedestrian demand; adjacent land use and development; roadway features including cross-section, functional class, and parking; socioeconomic data, including income and population; and transit data. Agencies should consult previous studies and literature, as well as think outside the box about factors related to their local context, when identifying risk factors for a systemic analysis.

Option 3 – Established Findings

If agencies do not have the resources or capabilities to perform their own analysis, they may elect to use established findings for their risk factors. Several resources are available for agencies to borrow risk factors. The HSM includes crash prediction models for many common facility types—agencies can use the adjustment factors from these models as risk factors. Related to the HSM, the FHWA CMF Clearinghouse documents several relationships between roadway and traffic features with crash frequency and severity – agencies can use these CMFs to guide risk factor selection. Another national resource is the United States Road Assessment Program (usRAP), which includes an extensive collection of risk factors to assess the safety of roadway facilities for various focus crash types. Academic research is also a resource for identifying risk factors that are targeted to an agency or area type – NCHRP Research Reports 893 and 955 are examples of such resources (National Academies of Sciences, Engineering, and Medicine, 2018; National Academies of Sciences, Engineering, and Medicine, 2020a). Finally, agencies can also borrow risk factors identified by neighboring or peer agencies with similar roadway systems.

Applying Existing Knowledge for Risk Factors on Tribal Lands

The Tribal Transportation Program (TTP) identified roadway departure crashes as a focus crash for Tribal Nations in the United States (Tribal Transportation Safety Management System Steering Committee, 2017), accounting for 63 percent of fatalities on Tribal roadways. However, TTP grant awards distributed between 2013 and 2019 show that only 12 percent of grant funding was awarded for infrastructure projects targeting roadway departure crashes (FHWA, n.d.). FHWA felt this funding disparity was partially due to the difficulty for demonstrating the need for a low-cost countermeasure in the absence of crash data. Given the widespread nature of the roadway departure problem and limited crash data, the TTP decided to use the systemic approach to promote implementation of low-cost roadway departure countermeasures at higher risk sites. To standardize the risk assessment, FHWA created risk assessment forms allowing the Tribes to make funding requests which can be prioritized using documented risk factors (FHWA, 2024b). Applicants enter geometric, traffic, and other data to demonstrate the risk of a crash on these system elements. Selecting risk factors based on known correlations allowed the TTP to overcome crash and roadway data limitations which would have otherwise hindered some Tribes from accessing roadway departure grant funding. Figure 15 shows the data that Tribes may provide for the TTP to assess risk at a subject site.



Systemic Roadway Departure Countermeasure Request Form

Click to Add Photo

(optional)

Location Information

Route Name

NTTFI Route

NTTFI Section

Segment Length

Alignment ☐ Curve(s) ☐ Tangent(s)

Surface Type

Risk Data

Traffic Volume

Speed Limit

Lane Width

Paved Shoulder Width

What additional data indicates a high risk for roadway departure crashes here?

Countermeasures	Existing	Requested	Requested Funding
a. Horizontal alignment warning signs (see MUTCD Section 2C.06)	☐	☐	
b. Delineators (flexible or post mounted) as described in Chapter 3F of the MUTCD	☐	☐	
c. Center line and edge line markings (Maintenance is not eligible. TTPSF can fund striping where it does not exist or upgrades in line width or material type.)	☐	☐	
d. Rumble strip or rumble stripes (Please attach a design detail drawing, if available)	☐	☐	
e. Mitigation of roadside hazards to establish or widen clear zone (specify improvement in project narrative)	☐	☐	

Notes (Optional)

Add Another Location

Figure 15. Graphic. Roadway departure risk assessment form (Source: FHWA, 2024).

Option 4 – Local Knowledge

Agencies can use the knowledge of local stakeholders to provide qualitative assessments of roadway risk. Common stakeholders include engineers, emergency responders (e.g., fire, Emergency Medical Technician, and law enforcement), school bus drivers, transit operators, and maintenance workers. Agencies can solicit information from stakeholders using digital surveys, online maps, or even in-person workshops with physical maps. Given the qualitative nature of this approach, it is important to establish a consistent framework for the stakeholders to perform their assessment and ensure broad representation to gather data for the entire study area. One option is to establish limited inputs for categories, such as "low, medium, or high" for traffic volume or "narrow, average, or wide" for lane or shoulder width. Another option is to give each stakeholder 10 stickers to identify the 10 highest-risk sites on a map based on their opinion.

Local Risk Assessment in Kentucky

Boyle County, Kentucky used systemic safety analysis to inform an LRSP. Unfortunately, limited data were available to identify risk factors. After working with the University of Kentucky, the Kentucky Transportation Cabinet (KYTC), and FHWA, the County decided to use local knowledge to assess risk within the system, called the "Qualitative Hazard Identification Program". Initial data review identified roadway departure crashes as the focus crash type and "County Collector" roadways[5] as the focus facility type. The team selected and ranked roadway segments using the following as risk factors:

- Sharp horizonal curves.
- Vertical curvature.
- Operating speed.
- Daily traffic volume.
- Clear zone.
- Roadway width.
- Crash history.

These were "qualitative" in that participants in the data review assigned a qualitative score for each of these categories, whether this was "present" or "not present" for curvature, or "low", "medium", or "high" for factors like traffic volume and clear zone.

[5] As defined in the County's LRSP – not as defined using Federal functional classification.

When using the local knowledge approach, it is important to consider representation in the stakeholder group. In addition to traditional stakeholders, agencies should solicit input from underrepresented and underserved communities, population groups, and roadway users. This could include advocacy groups, such as pedestrian and bicycle advocates, but also advocates for disability rights and racial and socioeconomic equity. Research has repeatedly shown that Black and Native communities are disproportionately harmed by traffic deaths and serious injuries (Sanders & Schneider, 2022). Meaningfully engaging with these communities to identify and fix high risk locations can help redress past harms.

Selecting a Risk Factor Methodology

How should an agency select an appropriate risk factor methodology? This decision is based on many factors, including desired scale and level of effort, data availability and sophistication, and analysis capabilities and sophistication.

Table 10 shows how the methodologies fall on the scale of analysis and data sophistication. Similarly, figure 16 is a decision tree which agencies can use to select the appropriate methodology. NCHRP Research Report 955 also provides information to assist with selecting tools for risk factor analysis (National Academies of Sciences, Engineering, and Medicine, 2020a). Note that agencies can combine risk factor methodologies to identify risk factors for their systemic program – they should not feel limited to one option.

Table 10. Matrix showing risk factor methodology by data and analysis sophistication.

Sophistication Level	High Analysis Sophistication	Low Analysis Sophistication
High Data Sophistication	Statistical Modeling	Overrepresentation, Established Findings
Low Data Sophistication	Established Findings	Established Findings or Local Knowledge

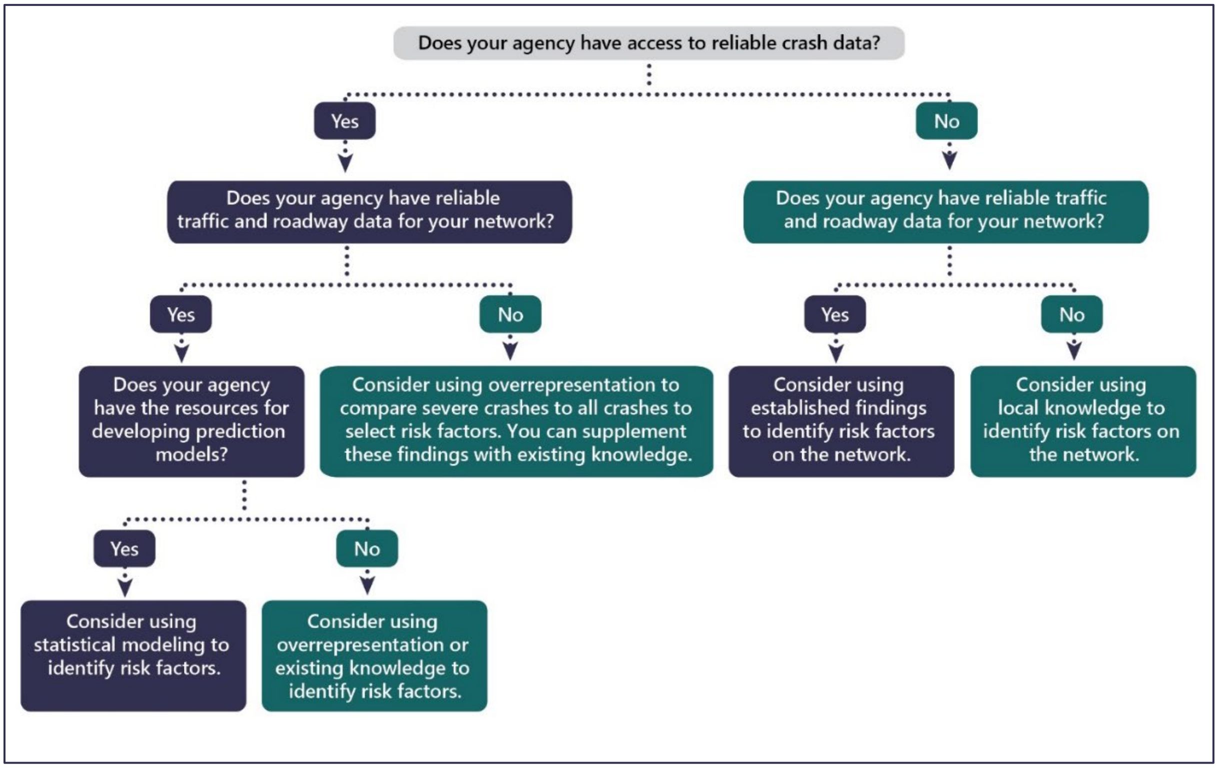


Figure 16. Graphic. Decision tree used to guide the selection of risk factor methodologies (Source: FHWA).

Innovation in Risk Factors

Several agencies have used innovative approaches and data sources to select risk factors. Agencies should consider these factors and data sources in their own analysis.

Safe System Approach: Safe System applications such as the Safe System Approach for Intersections (SSI) (Porter et al., 2021) and the Design Flag Assessment in NCHRP Report 948 *Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges* (National Academies of Sciences, Engineering, and Medicine, 2021) represent qualitative and quantitative Safe System metrics which can be incorporated as risk factors. Additionally, Post-Crash Care is an element of a Safe System. Agencies may consider distance to a trauma center and other "Golden Hour"-related characteristics as potential risk factors.

Equity: Along with the Safe System Approach, the USDOT encourages the consideration of equity in transportation. Agencies can use equity measures, including those in the Census (US Census Bureau, 2022a) and American Community Survey (US Census Bureau, 2022b), as well as Environmental Justice (EJ) (US Environmental Protection Agency, 2022) indicators as risk factors to incorporate equity into systemic safety analysis. MassDOT found several correlations between severe crash frequency and the EJ indicators, including the number of indicators flagged in a town or census tract, as well as if a specific flag (e.g., income, minority population, non-English speaking population) was present (MassDOT, 2021a).

Health: VDOT (2023), to inform their Pedestrian Safety Action Plan (PSAP), incorporated the Virginia Health Opportunity Index (HOI) as a risk factor for pedestrian crashes—corridors adjacent to areas with a low HOI score showed an elevated risk of pedestrian and bicyclist crashes and propensity for activity. Virginia's HOI is based on 13 social determinants of health.

Pedestrian & Bicycle Demand: The Michigan DOT identified the need for an understanding of pedestrian and bicycle demand to inform systemic safety analysis. With a lack of volume counts for those users across the system, the DOT estimated exposure models for both types of users, which were used as traffic volume risk factors in their systemic safety models (Hampshire et al., 2018).

Example Risk Factors

The Washington State DOT requires an LRSP for local agencies to receive HSIP funds. Each LRSP includes roadway characteristics, roadside characteristics, and other factors identified using safety data analysis. Figure 17 shows the wide range of characteristics and factors used by cities and counties in Washington State. Additionally, the figure shows the difference in factors considered based on the jurisdiction—cities included several factors related to pedestrian and bicycle safety and demand, while counties focused on roadside and other factors that influence roadway departure crash frequency and severity.

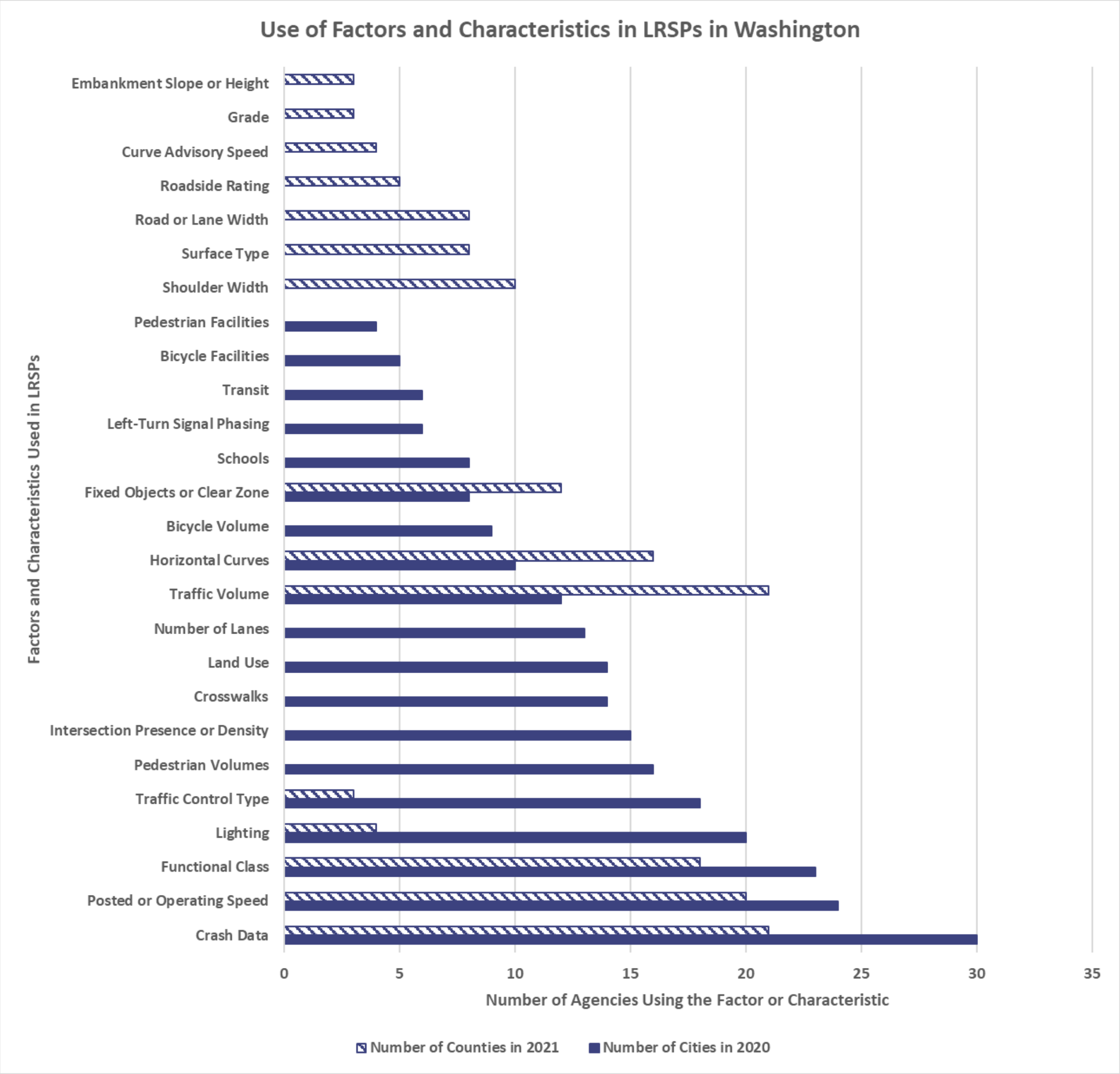


Figure 17. Graphic. Distribution of factors and characteristics used in Washington State LRSPs by cities and counties. Source: FHWA[6].

[6] Project team created the graphic based on data shared as an example of a noteworthy systemic safety practice from the WSDOT.

FHWA (Saleem et al., 2020) used the Highway Safety Information System data to investigate contributing factors for several focus crash type and facility type combinations. The analysis used statistical models to identify correlations on roadways and intersections in California, Ohio, and Washington. Table 11 and table 12 show infrastructure risk factors which were identified in the report. The report provides further details on the risk factors and correlations identified in the analysis: https://www.fhwa.dot.gov/publications/research/safety/20052/20052.pdf. There is also a shorter "Quick Reference" guide available: https://www.fhwa.dot.gov/publications/research/safety/20053/20053.pdf.

Table 11. Summary of risk factors for intersection focus crashes and facility types identified by Saleem et al. (2020).

Risk Factors	Angle Crashes, Rural Two-Lane Roads, 4-Leg Stop- Control	Angle Crashes, Urban Two-Lane Roads, 4-Leg Stop-Control	Angle Crashes, Rural Two-Lane Roads, 3-Leg Stop- Control	Angle Crashes, Urban Divided Multi-Lane Roads, 4-Leg Signalized	Angle Crashes, Urban Undivided Multi-Lane Roads, 4-Leg Signalized	Angle Crashes, Rural Multi-Lane Roads, 4-Leg Stop-Control
Larger mainline AADT	●	◊	●	●	◊	◊
Larger cross street AADT	●	◊	◊	◊	◊	●
Smaller curve radius	--	--	◊	--	--	--
Wider lane width	●	--	◊	◊	--	--
Wider median width	--	--	--	◊	--	◊
Absence of mainline left-turn channelization	◊	--	--	--	--	--
Absence of cross-street right-turn channelization	--	--	--	--	◊	--
Design speed/higher speed limit	●	●	◊	●	◊	--

Note: "●" = risk factor in multiple States, "◊" = risk factor in one State, "--"= not a risk factor in any State.

Table 12. Summary of risk factors for non-intersection focus crashes and rural two-lane facility types identified by Saleem et al. (2020).

Risk Factors	Run Off Road, Curves	Run Off Road, Tangents	Lane Departure, Curves	Lane Departure, Tangents	Head On, Curves	Head On, Tangents	Angle, Tangent	Rollover or Overturn, Curve	Rollover or Overturn, Tangent
Larger AADT	●	●	●	●	●	●	●	●	●
Smaller percentage of trucks	◊	◊	◊	◊	◊	◊	--	◊	◊
Larger percent grade	◊	◊	●	●	◊	◊	--	●	●
Smaller curve radius	●	N/A	●	N/A	●	N/A	N/A	●	N/A
Narrower surface width	◊	◊	◊	◊	◊	◊	--	◊	◊
Narrower shoulder width	●	●	◊	◊	◊	--	◊	◊	◊
Unpaved shoulder	--	◊	--	◊	--	◊	--	--	--
Higher speed limit	◊	◊	◊	◊	◊	◊	--	◊	◊
Narrower lane width	--	--	--	◊	--	--	--	--	--
Mountainous terrain	--	--	--	--	--	--	--	--	◊

Note: "●" = risk factor in multiple States, "◊" = risk factor in one State, "--"= not a risk factor in any State, "N/A" = not applicable.

Typical Risk Factors

Agencies have used an extensive range of risk factors for systemic safety projects, including:

- Aberrant behavior (e.g., seat-belt surveys, distracted driving surveys).
- Access control.
- Area type (urban or rural).
- Bicycle facility type and presence.
- Bicyclist volume.
- Citations.
- Crosswalks.
- Demographic factors.
- Distance to trauma center.
- Edge drop-offs.
- Equity measures.
- Facility type.
- Friction availability or demand.
- Functional class.
- Geographic area.
- Horizontal curve geometry.
- Intersection skew angle.
- Lack of common countermeasures (e.g., lack of pavement markings, curve warning signage, stop bars at intersections).
- Land use.
- Lane or surface width.
- Lighting presence or type.
- Likelihood of associated crash types (e.g., impaired crashes for lane departure crashes, unbelted driving crashes for young driver crashes).
- Median type.
- Median width.
- Number of access points.
- Number of lanes.
- Pedestrian volume.
- Pedestrian facility type and presence.
- Posted speed limit.
- Presence of a visual trap.
- Proximity to interchange.
- Roadway ownership.
- Shoulder type.
- Shoulder width.
- Sidewalk presence.
- Slopes (roadside and median).
- Socioeconomic factors.
- Target crash frequency, severity, density, etc.
- Terrain.
- Traffic volume.
- Transit stops.
- Trip generators.
- Truck traffic.
- Vertical geometry.
- Weather data.

Table 13 summarizes several special, focused considerations when identifying risk factors for roadway departure crashes, intersection crashes, pedestrian crashes, bicycle crashes, and speeding crashes.

Table 13. Risk factor considerations for select emphasis areas.

Roadway Departure Crashes	Intersection Crashes	Pedestrian and Bicycle Crashes	Speed-related Crashes
Roadway departure risk is most often correlated with roadway cross-section and geometric features. For instance, if a motorist does not correct their vehicle path or adjust their speed for an alignment change, they may leave the traveled way. If there is no shoulder and a tree near the edge of the roadway, the driver has little recovery area to avoid striking the tree. Example roadway departure risk factors to investigate include: • Horizontal curvature and side friction demand. • Roadway width, including lane and shoulder width. • Clear zone width. • Roadside conditions, including slopes, presence of fixed objects, and presence of edge drop-offs.	Several factors can contribute to crash frequency and severity at an intersection. Brush may obstruct or limit sight distance, while little to no delineation and traffic control signage may confuse drivers to reduce their awareness of an upcoming conflict. Additionally, high-speed approaches may increase the likelihood of a severe crash. Potential risk factors for intersections include: • Presence of skew angle more than 10 degrees. • Speed limit on one or more approaches being 55 mph. • Lack of intersection lighting. • Lack of stop bar. • Lack of dedicated left-turn lanes. • Poor traffic control device visibility.	Pedestrians and bicyclists are two of the most vulnerable road users. As such, numerous factors should be considered when assessing risk of a severe crash. Potential risk factors include: • Pedestrian and bicycle demand and trip generators. • Intersection geometry. • Crossing distance and the presence of a median. • Social factors, such as demographics and equity indicators. • Medium or high motorist speed. • Long distance between signalized crossings. • Multilane arterials.	Along with roadway characteristics, speed data can indicate risk at a focus facility element. Potential speeding risk factors include: • Difference between operating speed and statutory/regulatory speed limit. • Lack of appropriate advisory speed warning signs. • Percentage of motorists exceeding the speed limit. • Number of speeding traffic citations.

Helpful Hints and Considerations

Can I use crash data as a risk factor?

Yes, several agencies have used crash data as a risk factor. Crash-based risk factors can include target crash frequency, density, or rate, both as the actual number (weighted) or compared to a threshold value. VDOT has even integrated their crash-based network screening results, using the potential for safety improvement as a risk factor (Cho et al., 2020). However, it is important to remember that crash history is not necessarily indicative of future crash risk, so crash history should not be the sole risk factor used in systemic safety analysis.

How can I test a characteristic if it is not part of a dataset?

Several of the methodologies discussed provide methods to test such a characteristic. One such method is to use existing risk factor or CMF research as justification for inclusion of the feature as a risk factor. Another method is to work with stakeholders to identify the specific risk factor for a feature based on their experience. Finally, agencies can use desktop or windshield surveys to collect data at sample sites to test the characteristic.

How many risk factors should I select?

Agencies can select as many risk factors as they would like. A minimum of three risk factors is recommended because it allows for variance in the scoring and the prioritization. Generally, more risk factors produce more variance in prioritization and better predict the likelihood of a severe focus crash.

Should potential risk factors be combined during the evaluation process?

Consider combining risk factors where individual evaluations do not produce expected risk factor relationships. For instance, an analysis may find little correlation between narrow shoulder width and narrow lane width with increased severe crash probability. However, combining the two to produce a total paved surface width may produce a valid risk factor.

Can you still identify risk factors without traffic volume information?

Agencies should look for methods to incorporate traffic volume records for all modes into their risk factor analysis. Ideally, AADT is included directly to find the correlation or bins of traffic volumes which result in higher-than-expected focus crash frequency. If count data are not available, consider classifying sites into qualitative categories, such as high, medium, or low, to identify a traffic volume risk factor. Activity generators or proxies and dedicated facilities can be used as surrogates for pedestrian and bicyclist volumes. Finally, agencies can consider using center line mileage or lane mileage to calculate exposure rates per facility in the absence of AADT or non-motorized volumes.

Should I consider how the risk factor can be used when implementing the results?

The ultimate use of the risk factors is for scoring and prioritizing sites. As such, agencies should consider how risk factors will be used when scoring and prioritizing sites. When using a regression model to identify risk factors, will the dependent variables be scored on a continuous range? Binary? Ordinal? It is important for agencies to think about the planned scoring procedure when finalizing risk factors.

Am I limited to one method for identifying risk factors in my analysis?

No, agencies can use one or more methods to identify risk factors. For instance, an agency may have limited data for analysis and only identify a few risk factors through modeling. However, agencies can add risk factors based on published research, data summarization, and local knowledge.

Outcome

Agencies should have three outcomes from this step:

1. A focus crash type (or types) for the systemic analysis.
2. A focus facility type (or types) for each focus crash type.
3. Risk factors on each focus facility type for each focus crash type.

Agencies should consider documenting these in some manner, whether through a memorandum, report, or slide deck.

Frequently Asked Questions

Is there a minimum number of crashes on a system to provide credible results?

Generally, the risk factor analysis should include at least 100 crashes to provide reasonable results. In smaller jurisdictions or rural areas, it may be necessary to make an exception and accept a smaller minimum number of crashes, especially for pedestrian or bicyclist crashes. In these cases, the practitioner is encouraged to incorporate established findings about risk factors to supplement the results of the crash analysis. Further, there should be at least five observations for any risk factor categories created for analysis. In general, it is useful to create categories or bins, especially for continuous variables. The number of categories should be based on practical considerations, but fewer categories is generally preferable to help increase individual sample sizes.

What if my data system cannot provide the ideal level of data?

The methodologies described in this chapter are adaptable and scalable based on the level of data available. Additionally, there are several options for agencies to improve data availability and quality for systemic safety analysis, including windshield surveys, desktop data collection, and seeking to use HSIP funds for data collection. Agencies can ask the Local Technical Assistance Program (LTAP), State DOT, MPOs, and FHWA for help identifying resources or receiving technical assistance. Finally, agencies should think outside of the box and get creative with their identification of potential data sources.

What if my jurisdiction has developing areas for which land use patterns are changing and traffic volumes are growing?

The systemic safety analysis process should reflect the current conditions of the system. If parts of the system are anticipated to experience significant changes in land use, traffic volume, or other changes which will significantly affect travel demand, the analysis may not be as useful in those conditions, and agencies should carefully consider whether the results of the analysis will still be applicable under those conditions. Another option is to perform the systemic analysis using historical data and then apply the results to the system using the expected future conditions to assign risk scores and prioritize locations for potential treatment. Finally, consider incorporating systemic countermeasures and risk-based safety improvements into development policies. For example, if a development is being planned adjacent to a pedestrian risk corridor without a sidewalk, agency policy might require the developers to install a sidewalk.

Chapter 2 – Screen and Prioritize Candidate Locations

This is the second step of the systemic safety process. **The objective of this step is to use risk to develop a prioritized list of sites for systemic safety improvements.** Essentially, an agency is trying to identify the elements of their system which are at most risk of a severe focus crash, then prioritize them for safety improvements. The process includes identifying the system elements which will be analyzed, assigning a risk score to those elements, and prioritizing the elements based on the total risk scores. Figure 18 shows the tasks in this step.

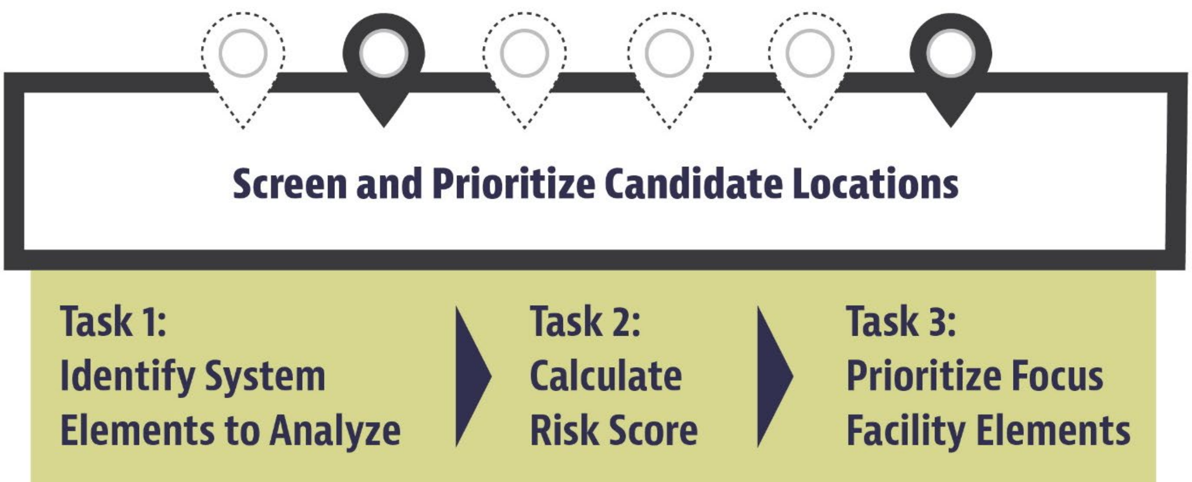


Figure 18. Graphic. Tasks to screen and prioritize candidate locations (Source: FHWA).

Data

The screening and prioritization process requires an integrated dataset, including the focus facility type system elements (e.g., intersection, horizontal curves, tangents) and the features assigned to each of those elements which will allow the agency to produce a risk score. The best practice for integrating and preparing the data for this step is to use spatial or tabular data tools, such as GIS or spreadsheets. Particularly, the spatial data capabilities in GIS tools provide ample opportunities for agencies to integrate various sources of spatial and tabular data, increasing the ability to include all features needed for scoring can be added to the system elements.

Task 1 – Identify System Elements to Analyze

In this task, agencies should identify the system elements from the focus facility type that are at higher risk of severe focus crashes using the risk factors identified in Chapter 1. There are several options for defining system elements, including tangent segments, horizontal curves, corridors, and intersections. Segment elements (e.g., tangents, curves, corridors) should include consistent design features, especially with regards to cross-section and features used in the risk factor analysis.

All system elements should have the features associated with each risk factor. If needed, agencies can consider using spreadsheets, GIS, and other tools to integrate data. Agencies can use a spreadsheet to organize the system elements in tabular format, collecting relevant uniform data in each column. GIS offers more sophisticated analysis options to create system elements.

For example, MassDOT used GIS to create consistent segments for each of their systemic safety analyses (MassDOT, 2021a). The default GIS road inventory file used for MassDOT's safety analysis is an aggregation of several event layers, resulting in a feature class that is segmented for every "event" (i.e., change in roadway characteristic) along the roadway. MassDOT found that the disaggregated file does not produce useful system elements for a systemic network screening map. As a result, MassDOT elected to use GIS to create segments that have uniform characteristics based on the risk factors. For instance, if shoulder width was a risk factor, adjacent segments with the same value for shoulder width were dissolved (i.e., joined together) to create a uniform continuous segment. Figure 19 provides a visual example of this process, including seven segments with individual attributes. The systemic safety analysis found AADT, average shoulder width, and degree of curvature as risk factors, so the segments were combined where those attributes were equal, condensing the original seven segments to four segments after the dissolve.

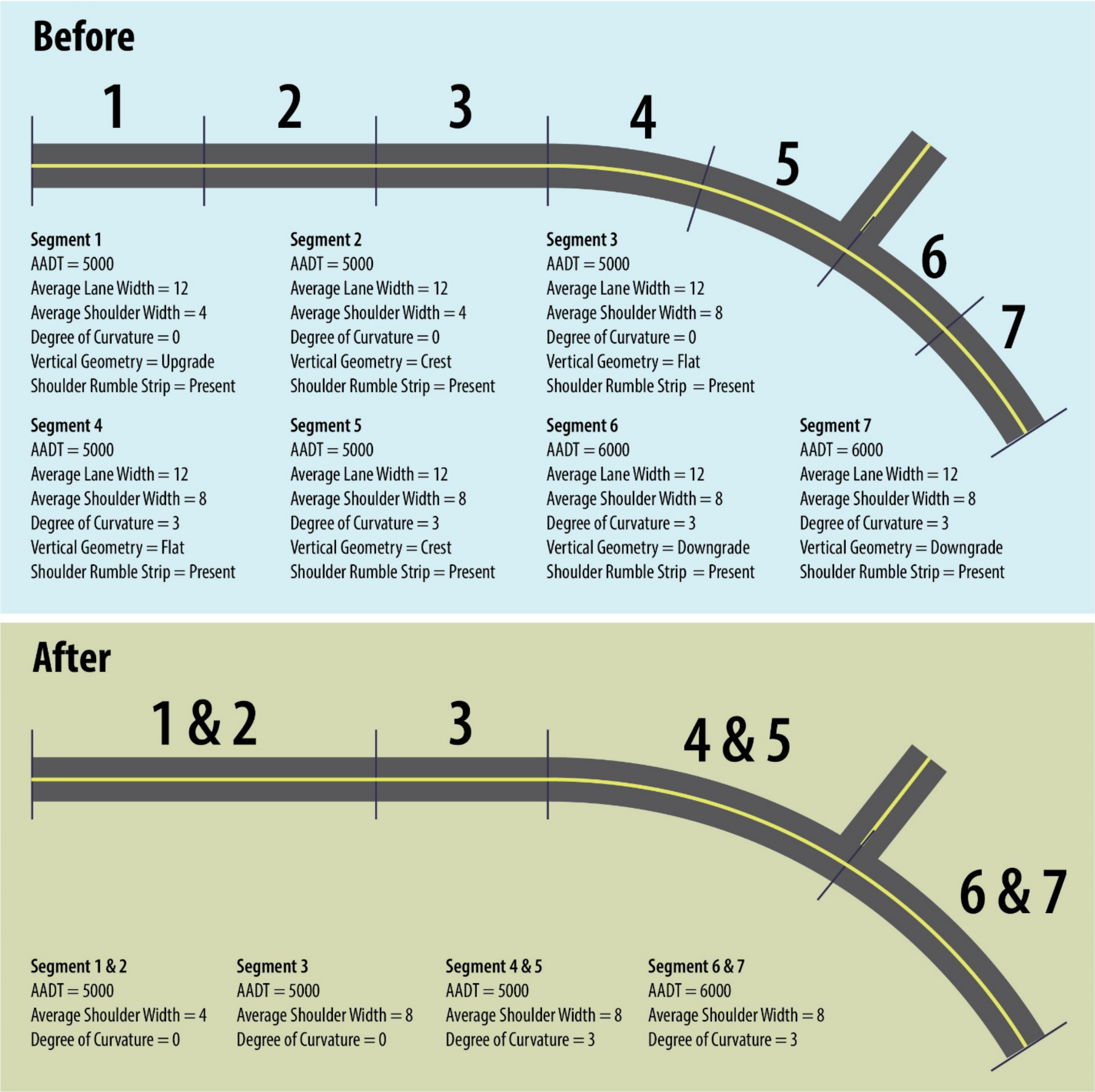


Figure 19. Graphic. Example creation of segment elements through dissolve. (Source: FHWA).

Helpful Hints and Considerations

What other data should be collected when reviewing locations for risk factors?

When collecting and integrating data for system elements, agencies should be cognizant of the full systemic process—what data are needed to complete each step? As such, agencies should include data in prioritization, countermeasure selection, and even future project development efforts. For instance, regardless of whether an agency includes shoulder width as a risk factor for roadway departure crashes, knowing shoulder width is helpful for determining if shoulder rumble strips are an eligible countermeasure. While these data may not be readily available, collecting or integrating them while doing the work for risk factors is an efficient practice.

Task 2 – Calculate Risk Score

This task involves calculating the "risk score" for each system element. In this context, the "risk score" is the quantitative assessment based on the presence and weight of risk factors for the element. The risk score is ultimately used for prioritization of the system elements.

Agencies should begin this task by determining whether each risk factor is present at each site within the focus facility type. For instance, is the shoulder width within the defined range of 0 to 2 ft? Are there no intersection approaches with left-turn lanes? If the risk factor is binary, as is the case in those examples, agencies can simply flag the presence of the risk factor with a "1" and the lack of a risk factor with a "0". Agencies may also assign weight to a risk factor based on the relative effect on severe crash likelihood to other risk factors (e.g., 0.25, 0.5). This is done by multiplying the binary risk factor indicator (1/0) by the assigned weight. A risk factor could also be continuous, applying to a range of values. These can also be normalized or assigned a weight. For example, an agency may elect to model curve radius as a continuous risk factor, assigning a range of values from 0 for the flattest curve to 1 for the sharpest curve. After assigning the weighted score for each risk factor, an agency sums the individual risk factor scores for a total "risk score" for each site.

Risk Scores for Minnesota LRSPs

The Minnesota DOT prepares LRSPs for each county in the State (called County Road Safety Plans). The standard approach used for these LRSPs is the binary indication of the presence of a risk factor, typically using a star symbol. One example of this application is the LRSP for Otter Tail County (Otter Tail County, 2021). For rural segments, Otter Tail County identified criteria for five risk factors for single-vehicle crashes:

- Speed limit is 55 mph or greater.
- AADT is 500 to 2,500 vehicles/day.
- 7 to 18 access points along segment.
- 1+ horizontal curve per mile.
- Qualitative edge risk assessment of 2 (no shoulder or steep side slopes) or 3 (no shoulder, steep side slopes, or fixed objects).

After identifying these risk factors, Minnesota DOT and the County chose to weight each risk factor equally. They then scored each segment along the County State-Aid Highway (CSAH) system. Table 14 is an example scoring table derived from the County's LRSP. A star indicates the presence of a risk factor on the segment.

Table 14. Prioritization table for rural segments in Otter Tail County, Minnesota (Otter Tail County, 2021).

Segment ID	Route Number	Segment Start	Segment End	Length (mi)	Average Daily Traffic [ADT] (veh/day)	Speed Limit	ADT Rural Single-Vehicle	ADT Rural Multi-Vehicle	Access Density	Curve Density	Edge Risk	Total Risk Score
17.002	17	Vergas Corp Lmts	Becker County Line	6.2	1,550	★	★	★	★	★		★★★★★
24.005	24	Erhard Corp Lmts	CSAH 3	4.8	535	★	★		★	★	★	★★★★★
3.001	3	CSAH 10	CSAH 24	8.4	530	★	★		★	★	★	★★★★★
35.001	35	US Trunk Highway (USTH) 59	CSAH 82	5.8	560	★	★		★	★	★	★★★★★
35.005	35	Underwood Corp Lmts	CSAH 1	6.0	1,070	★	★		★	★	★	★★★★★
41.001	41	CSAH 35	MNTH 108	6.0	550	★	★	★	★	★	★	★★★★★★
5.003	5	Clitherall Corp Lmts	CSAH 16	4.7	580	★	★		★	★	★	★★★★★
1.004	1	CSAH 10	CSAH 35	5.9	2,440	★	★		★			★★★
10.004	10	USTH 10	Becker County Line	0.7	1,000	★	★		★	★		★★★★
14.001	14	CSAH 1	CSAH 49	7.8	600	★	★		★		★	★★★★

Risk Score Calculations in Virginia

VDOT chose to use a weighted scoring approach for the systemic analysis described in their PSAP (VDOT, 2023). This plan used risk factors to assess pedestrian safety risk on corridors throughout the State. VDOT identified several risk factors, including traffic volume, posted speed limit, cross-section information, demographics, crash history, land use, and alcohol sales. Table 15 shows the risk factor scoring used in the PSAP. The risk factors are divided into four groups which are each assigned a total weight which is multiplied by a normalized score:

1. Roadway normalized out of 30 – 50 percent.
2. Built Environment normalized out of 30 – 25 percent.
3. Community normalized out of 50 – 20 percent.
4. Crash normalized out of 10 – 5 percent.

Table 15. Risk factor scoring system for the Virginia PSAP (VDOT, 2023).

Risk Factor	Risk Factor Group	Category Scores
AADT [vehicles/day]	Roadway	• Less than 500 = 2 • 500 – 1,499 = 4 • 1,500 – 6,999 = 6 • 7,000 – 19,999 = 8 • 20,000 – 40,000 = 10 • More than 40,000 = 8
Roadway Configuration	Roadway	• 1 lane = 2 • 2 lanes, divided = 4 • 2 lanes, undivided = 6 • 3 or 4 lanes = 8 • More than 4 lanes = 10
Posted Speed Limit [mph]	Roadway	• 25 or less = 1 • 30 – 35 = 5 • 40 – 55 = 10 • 60 or more = 5
Transit (Bus Stops)	Built Environment	• Present within ¼ mile = 10 • Not present within ¼ mile = 1
Schools & Universities	Built Environment	• School is present within ¼ mile OR College is present within ½ mile = 10 • School is not present within ¼ mile AND College is not present within ½ mile = 1
Parks	Built Environment	• Present within ¼ mile = 10 • Not present within ¼ mile = 1
Virginia HOI	Community	• 81st to 100th percentile = 2 • 61st to 80th percentile = 4 • 41st to 60th percentile = 6

		• 21st to 40th percentile = 8 • 1st to 20th percentile = 10
Proportion of Zero Vehicle Households	Community	• 1st to 10th percentile = 1 • 11th to 20th percentile = 2 • 21st to 30th percentile = 3 • 31st to 40th percentile = 4 • 41st to 50th percentile = 5 • 51st to 60th percentile = 6 • 61st to 70th percentile = 7 • 71st to 80th percentile = 8 • 81st to 90th percentile = 9 • 91st to 100th percentile = 10
Employment Density	Community	• 1st to 10th percentile = 1 • 11th to 20th percentile = 2 • 21st to 30th percentile = 3 • 31st to 40th percentile = 4 • 41st to 50th percentile = 5 • 51st to 60th percentile = 6 • 61st to 70th percentile = 7 • 71st to 80th percentile = 8 • 81st to 90th percentile = 9 • 91st to 100th percentile = 10
Urban Area	Community	• Urban = 10 • Rural = 1
Population Density	Community	• 1st to 10th percentile = 1 • 11th to 20th percentile = 2 • 21st to 30th percentile = 3 • 31st to 40th percentile = 4 • 41st to 50th percentile = 6 • 51st to 60th percentile = 8 • 61st to 70th percentile = 10 • 71st to 80th percentile = 10 • 81st to 90th percentile = 10 • 91st to 100th percentile = 8
Pedestrian and Bicycle Crash History	Crash	• At least one crash occurred within 250 feet = 10 • No crash occurred within 250 feet = 1

Table 16 provides a sample risk score for a segment in Virginia using the scoring criteria in table 15. These scores are combined to produce group risk scores as follows:

1. Roadway = 24.
2. Built Environment = 12.
3. Community = 36.
4. Crash = 10.

Figure 20 shows how these scores are combined to produce a weighted risk score for the sample Virginia segment.

$$
\begin{aligned}
Examples\ Weighted\ Risk\ Score &= \frac{Roadway}{30} * 0.5 + \frac{Built\ Environment}{30} * 0.25 + \frac{Community}{50} * 0.2 + \frac{Crash}{10} * 0.05 \\
&= \frac{24}{30} * 0.5 + \frac{12}{30} * 0.25 + \frac{36}{50} * 0.2 + \frac{10}{10} * 0.05 = 0.64
\end{aligned}
$$

Figure 20. Equation. Calculation of weighted risk score for sample Virginia segment.

Table 16. Weighted risk score calculations for sample Virginia segment.

Risk Factor	Segment Value	Risk Score
AADT [vehicles/day]	7,500	8
Roadway Configuration	2 lanes, undivided	6
Posted Speed Limit [mph]	45	10
Transit (Bus Stops)	1 within ¼ mile	10
Schools & Universities	No facilities present nearby	1
Parks	No facilities present nearby	1
Virginia HOI	54^{th} percentile	6
Proportion of Zero Vehicle Households	65^{th} percentile	7
Employment Density	23^{rd} percentile	3
Urban Area	Urban	10
Population Density	75^{th} percentile	10
Pedestrian and Bicycle Crash History	1 pedestrian and 1 bike crash within 250 feet	10

Empirical Bayes and Systemic Safety

An alternative approach to estimating a risk score is directly using an SPF, either created specifically for the systemic analysis using statistical modeling or a published SPF selected from established findings. Using this approach, the SPF is directly applied to each system element, and the resulting risk score is the estimated crash probability or frequency. As described in the City of Seattle case study, SDOT used expected crashes, based on observed crash history and the SPF, to assess the risk score for pedestrian and bicycle crashes.

Observed crashes can be integrated into the risk score using the EB approach (see Srinivasan et al., 2016), which combines modeled crashes from an SPF and observed crashes in a weighted manner to calculate an expected crash frequency for a site. When using the EB approach in a systemic application, expected crashes can influence a risk score based on a threshold (e.g., expected crashes or excess expected crashes exceed 2.0 per mile) or can be used directly for the score (e.g., risk score for expected crashes is 2.4 expected crashes). To make sure the systemic approach is proactive and not overly reactive based on crash history, agencies should balance the weight of the expected crash risk score with that of other identified risk factors. Both Marin County, California (County of Marin, 2018) and the City of Seattle applied this approach for various focus crashes (SDOT, 2016; SDOT, 2020a).

Noteworthy Practice

Organizing system elements in a tabular format, whether in a spreadsheet, GIS, or another form, makes the scoring process simple and repeatable.

Task 3 – Prioritize System Elements

After calculating risk scores, this task includes the prioritization of system elements. The task begins with a simple ranking of system elements from highest risk score to lowest. Agencies can set thresholds for priority elements to help focus on a manageable number of sites or miles. For instance, VDOT selected the top 1.0 percent of sites by risk score as priority elements (VDOT, 2022a). As another example, MassDOT identifies sites in the top 5 percentile of risk scores as *primary* risk sites, and sites in the next 10 percentile as *secondary* risk sites (MassDOT, 2021a). Figure 21 is an example of how MassDOT visualizes the primary and secondary risk sites for roadway departure crashes.

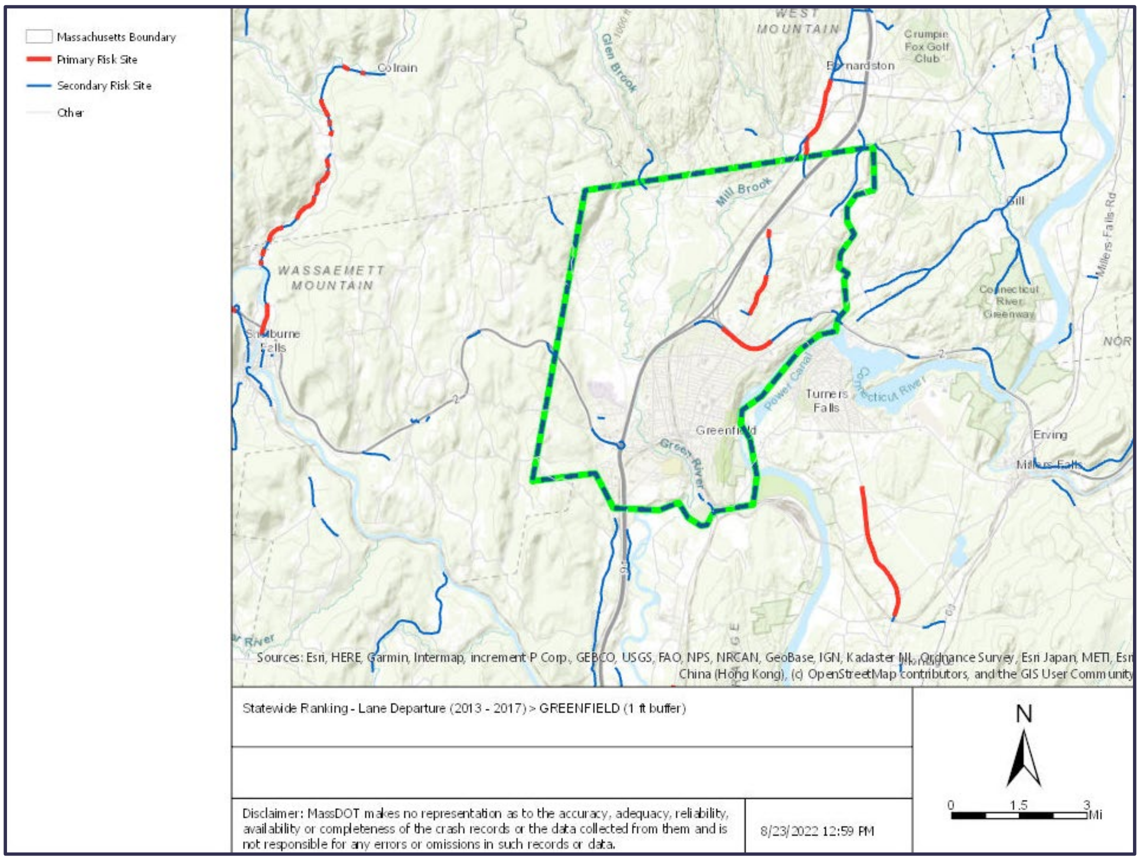


Figure 21. Graphic. Primary and secondary roadway departure risk sites in Greenfield, Massachusetts (Source: MassDOT, 2022).

In some cases, the prioritization may include system elements scored using different risk factor criteria, meaning, for instance, one set of elements may be scored from a total of nine risk factors, and another scored from a set of seven risk factors. For these scenarios, agencies need a way to compare the risk scores across the different criteria. To do so, agencies can assign normalized risk scores to each element by dividing the assigned risk score by the total potential risk score. The system elements can then be ranked and prioritized using the normalized risk score. MassDOT used such an approach to prioritize system elements (MassDOT, 2021a). Table 17 is an example set of site data which are prioritized using a normalized risk score.

Table 17. Example systemic risk scores highlighting normalization.

Site ID	Risk Score	Maximum Risk Score Possible	Normalized Risk Score	Priority Rank
1	6	7	86%	3
2	1	7	14%	7
3	4	7	57%	4
4	8	8	100%	1
5	7	8	88%	2
6	5	9	56%	5
7	2	9	22%	6

Outcome

After completing the tasks of this chapter, agencies should have the following:

1. A list, map, or other set of system element data.
2. Calculated risk scores for each system element.
3. A prioritized order of system elements.

Frequently Asked Questions

What if I do not have enough data to either document the characteristics of locations with crashes or to conduct the risk assessment of focus facilities?

The goal of this task is to determine the risk score of each system element. As such, agencies should use available information and, to the extent possible, identify efficient means to collect additional data necessary for calculating risk score. Agencies can collect data from free online aerial and street-level imagery. Open-source data can be a good starting point. Local knowledge is the most useful approach in these scenarios, even if the work includes manually identifying sites on a paper map.

How do I know if the characteristics I select really represent an increased level of risk?

The methodologies described in Chapter 1 justify how the results of each method produce valuable risk factors—whether proven through statistical analysis or professional judgement. However, it is worth reiterating that some risk factors may function as surrogates, such as the presence of left-turn lanes functioning as a surrogate for heavy left-turn volumes. For a quantitative check, agencies can compare the average target crash rate (i.e., target crashes per mile or per million VMT for the sites with that risk score) by risk score, expecting the highest risk sites to have the highest crash rate.

How many locations should I select in my initial prioritized list?

The number of selected sites should be guided by planned funding and implementation goals. Agencies can make a rough estimate of an average cost per site, determine how many sites can be addressed within that budget, then select that number of sites. If the initial selection did not identify enough sites, the agency can add more to the list.

What if a risk factor is present for each system element?

If a risk factor is present for all system elements, it is not useful as a risk factor. Agencies should remove the risk factor from scoring and prioritization and can either disregard it or add the factor as a feature of the focus facility type. However, there is value in documenting such a risk factor. For instance, speeds 30 mph and above can kill a pedestrian, but that may be nearly every street in a city with a statutory 30 mph minimum speed. Using this as a risk factor does not help prioritize locations but documenting it can help build the case for lowering the policy-set speed.

Chapter 3 – Identify and Select Countermeasures

The third step of the systemic safety process is to identify and select countermeasures for deployment. The process consists of developing the library of potential countermeasures, then determining which countermeasures should be assigned at each site. With the purpose of the systemic approach being to develop system-wide projects, it is important to focus on identifying low-cost countermeasures for this step.

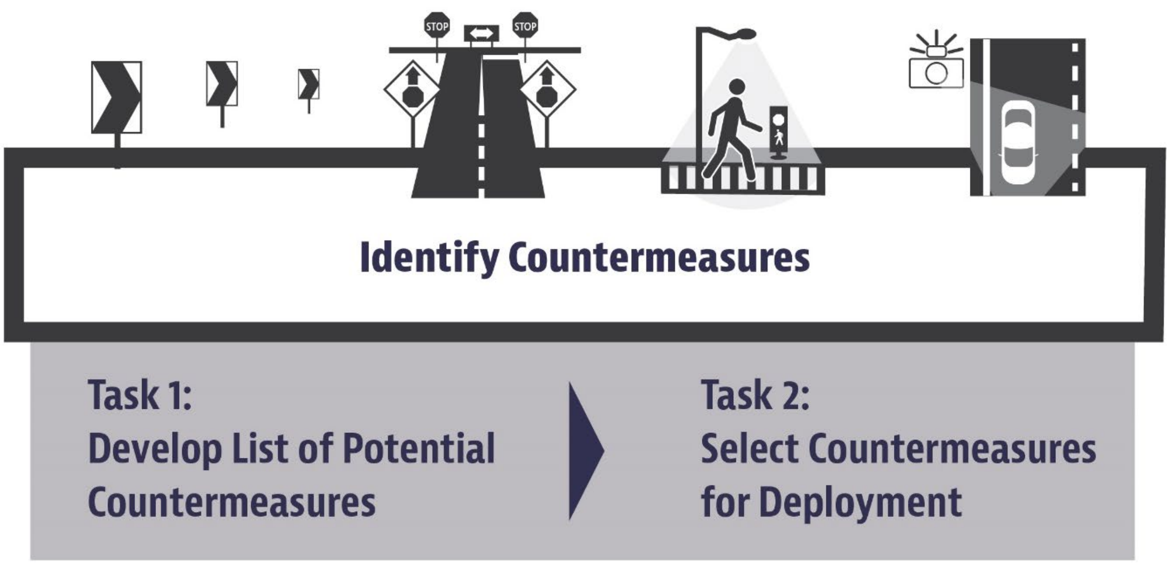


Figure 22. Graphic. Tasks to identify countermeasures (Source: FHWA).

Data

The two tasks in this chapter require individual sources of data. The first task requires data to curate a countermeasure list, including information on potential for crash reduction, average implementation and maintenance costs, service life, and installation context. The second task requires the data needed to determine eligibility of a system element for a countermeasure.

Task 1 – Develop List of Potential Countermeasures

In this task, agencies should compile a list of potential countermeasures for the program. There are many resources for this task, including those listed below. Agencies should use (or develop) a preferred list of CMFs, the resources below, and other resources available to compile data for each selected countermeasure.

- **General**:
    - FHWA Proven Safety Countermeasures: https://highways.dot.gov/safety/proven-safety-countermeasures.
    - State CMF Lists: http://www.cmfclearinghouse.org/stateselectedlist.cfm.
    - FHWA Countermeasure Service Life Guide: https://highways.dot.gov/safety/hsip/countermeasure-service-life-guide. https://safety.fhwa.dot.gov/hsip/docs/FHWA-SA-21-021_Countermeasure_Serv_Life_Guide.pdf.
    - FHWA Low-Cost Safety Improvement Video Series: https://www.youtube.com/user/USDOTFHWA/videos.
    - FHWA LRSP Choose Proven Solutions Webpage: https://highways.dot.gov/safety/local-rural/local-road-safety-plans.
    - Highway Safety Manual 1st Edition, Part D.
    - CMF Clearinghouse: http://www.cmfclearinghouse.org/.
    - Manual on Uniform Traffic Control Devices: https://mutcd.fhwa.dot.gov/.
    - NCHRP Report 500 series: https://www.trb.org/Main/Blurbs/152868.aspx.
    - NHTSA Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices Eleventh Edition, 2023: https://www.nhtsa.gov/book/countermeasures/countermeasures-that-work.
- **Intersection**:
    - FHWA Intersection Safety Strategies: https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/fhwasa15085.pdf.
    - FHWA Intersection Safety Resources Webpage: https://highways.dot.gov/safety/intersection-safety/resources.
    - Institute of Transportation Engineers Unsignalized Intersection Improvement Guide: https://toolkits.ite.org/uiig/.
- **Pedestrian and Bicycle**:
    - Bicycle Safety Guide and Countermeasure Selection System: http://www.pedbikesafe.org/bikesafe/countermeasures.cfm.
    - FHWA Safe Transportation for Every Pedestrian (STEP) Resources: https://highways.dot.gov/safety/pedestrian-bicyclist/step/resources. https://safety.fhwa.dot.gov/ped_bike/step/resources/.
    - NCHRP Research Report 926 – *Guidance to Improve Pedestrian and Bicyclist Safety at Intersections*. https://www.trb.org/Main/Blurbs/180624.aspx.

    - Pedestrian Safety Guide and Countermeasure Selection System: http://www.pedbikesafe.org/pedsafe/countermeasures.cfm.
- **Roadway Departure**:
    - FHWA Focus on Reducing Rural Roadway Departures Webpage: https://highways.dot.gov/safety/RwD.
    - FHWA Rural Roadway Departure Countermeasure Pocket Guide: https://highways.dot.gov/safety/rwd/forrrwd/rural-roadway-departure-countermeasure-pocket-guide.

There are several factors and pieces of data which agencies should collect when building their list. Recommended characteristics include:

- **Target crashes and risk factors** – it is important for agencies to select countermeasures which will directly or indirectly target the focus crash type and underlying risk factors.
- **Safety effectiveness** – safety countermeasures should have a documented history of reducing targeted crashes. Agencies can identify CMFs to determine the effect.
- **Agency policies, practices, and experiences** – agencies may have policies which limit the use of countermeasures to certain contexts. When considering a countermeasure for a systemic purpose, agencies should verify that the proposed use is compliant with policy. If a countermeasure is new to an agency, practitioners may consider emulating noteworthy practices adopted by their peers to guide demonstration projects.
- **Alignment with Safe System principles** – as agencies move toward a Safe System Approach, it is important to identify countermeasures which align with Safe System principles. Consider how each countermeasure points towards a Safe System principle and where the countermeasure may fall within the Safe System elements.
- **Implementation costs** – agencies should understand the up-front costs required for implementation of a countermeasure, including any preliminary engineering costs. This is the first opportunity to document potential cost savings which can be achieved using different project delivery mechanisms.
- **Operational effects** – some systemic countermeasures, such as mini roundabouts, flashing yellow arrows (FYAs), RRFBs, pedestrian hybrid beacons (PHBs), and LPIs, produce (often beneficial) changes to traffic operations which should be taken into consideration.
- **Maintenance costs and responsibilities** – once countermeasures are implemented, regularly scheduled maintenance is important to maximize their effectiveness. Agencies should document the anticipated maintenance frequency, costs, and responsibilities for each proposed countermeasure.
- **Countermeasure service life** – this is the time period for which a countermeasure may have a measurable impact (Himes et al., 2021). This information is needed to assess the lifecycle costs of a systemic countermeasure.
- **Expected BCR** – the BCR measures the expected economic effectiveness of a countermeasure. At the planning-level, agencies can estimate lifecycle costs using data

described above and the benefits using a CMF, crash costs, and an average crash reduction.

- **Countermeasure score** – the average cost for a countermeasure to produce a 1-percent reduction in fatal and serious injury crashes (Gross et al., 2021). This metric can be modified as needed, for instance, by modifying the metric to reflect the average cost to produce a 1-percent reduction in target crashes. Like BCR, this score serves as a measure of economic effectiveness.
- **Equitable transportation outcomes** – outcomes that occur when projects redress past and current harms of the transportation system for disadvantaged neighborhoods and communities.

After compiling potential countermeasures, agencies should refine the list to produce the final list of countermeasures for the systemic program. Several agencies reported using workshops to refine their countermeasure list. Agencies should ask the following questions when refining the list:

Will our partner agencies and stakeholders support the installation and maintenance of this countermeasure?

It is important to have buy-in from stakeholders to implement countermeasures in a systemic manner. These stakeholders can help influence public opinion, support project development and delivery, and become ambassadors for the systemic safety program. The public may also be involved in this process. Questions like the following can help to identify appropriate stakeholders based on the scope and context of the project:

- Is the State DOT asking locals to install a countermeasure systemically?
- Is a local agency seeking HSIP funding for their systemic program for a countermeasure that may not be typical?
- Is it a National Environmental Protection Act (NEPA)-related issue where a transportation agency needs to convince a permitting agency to allow projects that implement a certain countermeasure?

It is important that stakeholder involvement, especially solicitation of input from the public, be done in an equitable manner. To learn more about strategies and tools to conduct equitable community involvement, review the resources available at https://highways.dot.gov/safety/zero-deaths/engage-community-representatives.

Can maintenance staff reasonably maintain this countermeasure?

Systemic safety countermeasures can only continue to be effective over time with proper maintenance. As such, agencies should work with the appropriate maintenance staff to explain maintenance needs and, if needed, help to develop a maintenance plan to ensure continued effectiveness.

Does this countermeasure move us towards a Safe System by providing redundancy?

One of the principles of a Safe System is "Redundancy is Crucial," which means that there should be additional components preventing a severe crash when one component of the system fails. For instance, the combination of an attentive driver, edgeline markings, shoulder rumble strips, and barriers work together to create a redundant system for preventing a roadway departure crash—if one component fails, the next is there to assist in reducing the likelihood or severity of the crash. Agencies should verify that the list of preferred countermeasures has the potential to increase redundancy in the system. Consider the countermeasures included in figure 23 which provide a redundant system for preventing roadway departures.

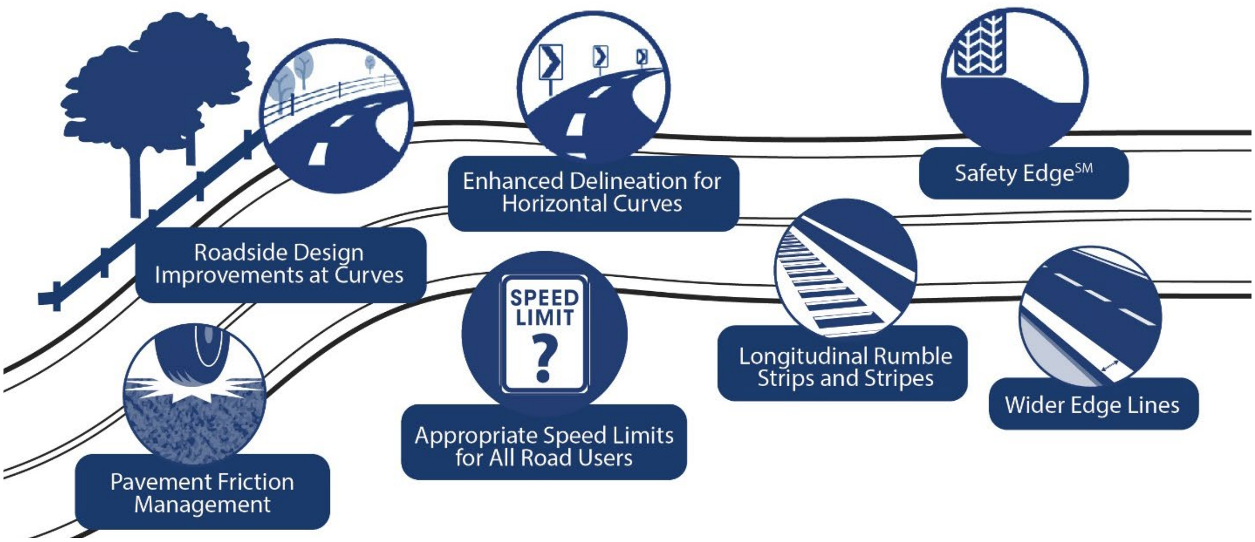


Figure 23. Graphic. A series of roadway departure countermeasures which provide redundancy for reducing the likelihood of a roadway departure crash (Source: FHWA).

Will the program include countermeasures that improve safety for all road users?

A Safe System should provide safe transportation for all road users. To incorporate the Safe System Approach into a systemic safety program, agencies should include countermeasures that improve safety for all those who use the road, including people walking, biking, rolling, driving, and riding on the system. Some pedestrian and bicyclist safety countermeasures may lack CMFs (e.g., curb extensions are on the CMF Clearinghouse's "Most Wanted" list); alternate approaches to evaluate the benefits of these countermeasures can be considered. Potential alternative approaches include the change in exposure to motor vehicle traffic and the distance from through traffic.

Through what types of projects can these countermeasures be implemented?

Traditionally, systemic countermeasures are implemented through bundled safety projects, which include a portion of installations within a designated geographic area. However, a systemic program can be enhanced by incorporating systemic safety countermeasures into other projects. For instance, agencies should consider whether a countermeasure can be implemented as part of a rehabilitation project, such as resurfacing, 2R, or 3R projects at a site with risk factors present (see NCHRP Report 1036 for guidance on countermeasure trade-offs during roadway cross-sectional reallocation; National Academies of Sciences, Engineering, and Medicine, 2023). Another method of implementation is directly through maintenance forces, which has the potential to reduce implementation costs. Agencies should document the various methods for implementing systemic countermeasures.

Traffic Safety Culture

A strong traffic safety culture will prioritize safety in all transportation system decisions (National Academies of Sciences, Engineering, and Medicine, 2024). As noted in the Introduction of this Guide, the Safe System Approach requires proactive safety applications, calling on the need to adopt a systemic approach to safety. While the systemic safety approach is commonly discussed and applied with infrastructure solutions in mind, an effective traffic safety culture will allow for the adoption of a wider range of countermeasures to address systemic risk. For example, the initial reaction to address impaired driving may be to solely implement a high-visibility law enforcement campaign targeting drunk driving; this may only produce a short-term, localized reduction in risk and should be carefully considered to ensure it is an equitable solution. With a well-developed traffic safety culture, transportation stakeholders may expand the options to reduce this risk such as reconsidering community design and providing resources such as free transportation or designated drivers to accommodate the transportation needs for those who are impaired. Agencies may also work with their partners to develop equitable anti-impaired driving campaigns and resources.

A key component of traffic safety culture is acknowledging that community design can greatly influence traffic safety, and adjustments to the community via changes in zoning policy, licensing policies, and other actions can produce traffic safety improvements as well as address transportation inequities (Webber et al., 2023; Serrano et al., 2022). Transportation stakeholders should remain open to these options to reduce systemic risk in the transportation system.

Education campaigns can also help agencies produce a Safe System. These campaigns can be launched in several media forms, address different issues (e.g., unsafe driving behaviors, how to interact with a safety countermeasure), and target the affected population(s) as needed. One noteworthy example is the “It’s Your Turn” education campaign developed by the City of San Francisco to reduce pedestrian crashes involving left-turning motorists (Osorio, 2021). This campaign includes numerous strategies, including grants and multiple media campaigns, to raise awareness of the safety issue. The campaign also has a website to raise awareness: https://www.saferleftturns.org/. Systemic safety analysis may be used to determine what communities are most in need of targeted campaigns. Education can also be used internally among transportation stakeholders, helping to advance a Traffic Safety Culture, promote awareness and acceptance of the Safe System approach, and advocate for a systemic safety approach. Internal campaigns may also help arm stakeholders with the knowledge and resources needed to discuss these strategies and actions with the public.

Enforcement in the Systemic Approach to Safety

Many agencies are likely interested in “enforcement” to assist with reducing risk. The purpose of enforcement is to ensure that road users comply with traffic safety laws, which is an important element to ensure redundancy in a Safe System Approach and prevent or reduce severe crashes. Traditionally, enforcement focused on law enforcement strategies, including both passive strategies (e.g., parking a cruiser along a busy road to deter speeding) and active strategies (e.g., rolling speed patrols) (FHWA, 2023b). In some cases, agencies employ high-visibility enforcement campaigns, which enhance the visibility and communication of the enforcement campaign to raise public awareness (NHTSA, 2024b). Any enforcement campaigns should be preceded by educational campaigns to enhance effectiveness and acceptance (NHTSA, 2023).

However, enforcement can extend beyond law enforcement and include self-enforcing roadways and speed safety cameras (SSCs). Self-enforcing roadways are planned and designed to encourage drivers to select operating speeds in harmony with the posted speed limit (Donnell et al., 2018). SSCs use speed measurement devices to detect speeding and capture photographic or video evidence of vehicles that are violating a set speed threshold. Some SSC technology can detect motorists that are exceeding the speed limit and alert them in real time via a display. SSC applications have been shown to reduce roadway fatalities and injuries by 20 to 37 percent (FHWA, 2023b). Self-enforcing roadways and SSCs, when implemented equitably, could be applied systemically. Practitioners should analyze what types of traditional enforcement strategies have been used and evaluate their effectiveness or lack of effectiveness in improving road safety (FHWA, 2023b). Practitioners can consider applying more systemic self-enforcing roadway strategies and SSCs to achieve safer roads and safer road users.

Task 2 – Select Countermeasures for Deployment

After developing the list of countermeasures for the systemic safety program, agencies should assign countermeasures to prioritized system elements. This task should be done in a consistent format. To encourage consistency, agencies should consider developing tools such as decision trees, worksheets, or matrices for standardized countermeasure selection.

After documenting and standardizing the decision process, agencies can apply the approach to the prioritized system elements. This will produce a list of recommended safety projects with one or more countermeasures assigned to the prioritized system elements. Agencies should review the site conditions at each location to confirm the applicability of the countermeasure. If no countermeasures are applicable to a priority site, agencies should document the reason and consider identifying other countermeasures to address the underlying safety issue(s). After selecting countermeasures at each site, agencies should generate cost estimates to support project prioritization in the next step of the process.

The following sections describe various tools agencies have developed for selecting and standardizing countermeasures for deployment.

The Importance of a Standardized Approach

Consistency is key across a transportation system. Drivers know what to do when they see a red octagon sign—stop. Agencies can encourage more predictable behavior for all road users through the consistent deployment of systemic countermeasures. A standardized approach or decision process will help promote consistent deployment of countermeasures with relation to risk, especially if multiple people are responsible for developing projects. Additionally, this standardized approach provides justification for proposed countermeasures to the public and other stakeholders.

Route consistency is also an important factor to consider when deploying countermeasures. For instance, if a corridor has several curves of varying priority with risk factors present, and one or two curves are selected for high priority improvements, agencies should use their judgement as to whether the remaining curves may also require some improvements. As such, agencies can balance considerations for route consistency against the overuse of systemic treatments and spending too much of the budget on low-risk sites.

For example, analysts identifying potential improvements for the high and primary risk sites identified on the corridor in figure 24 may also consider targeted improvements on the horizontal curves between the prioritized curves and cleaning safety hardware present on adjacent curves.

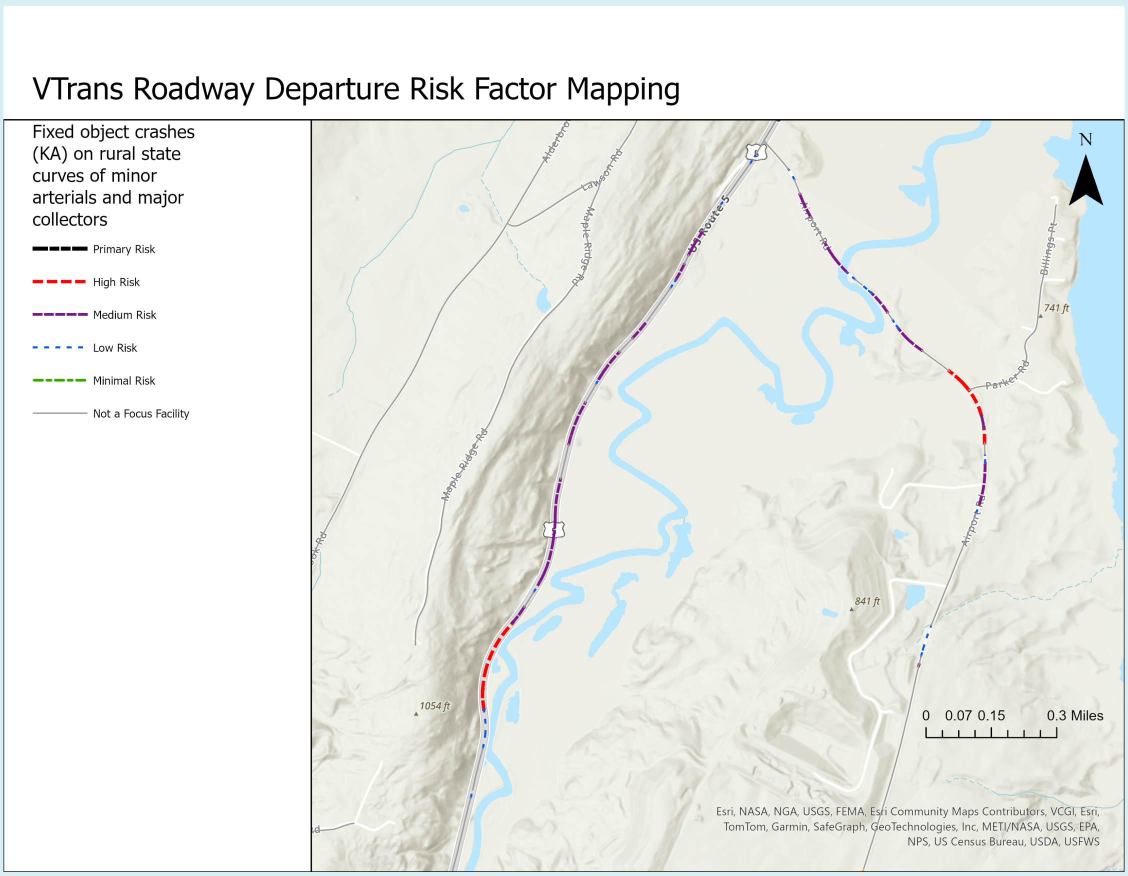


Figure 24. Graphic. Example Vermont Agency of Transportation horizontal curve risk assessment (Source: Vermont Agency of Transportation, 2023)

Decision Trees

Decision trees are standardized flow charts which agencies can use to determine appropriate countermeasures for a prioritized location. As part of their LRSP, Palm Beach County, Florida developed a decision tree to identify improvements for urban and suburban signalized intersections. The decision tree includes several steps, including checking site conditions, assessing signal hardware, reviewing crash data for driver compliance issues, reviewing signal timing and phasing, checking access points, and considering non-motorist needs (Palm Beach County, 2019). Figure 25 is one of the decision trees created for this LRSP. As another example, the City of Boulder, Colorado, also used decision trees to select pedestrian crossing countermeasures (City of Boulder, 2011). To select a countermeasure, analysts began by completing the evaluation worksheet pictured in figure 26 and figure 27. After completing this worksheet, analysts can use the organized data to complete the decision tree in figure 28.

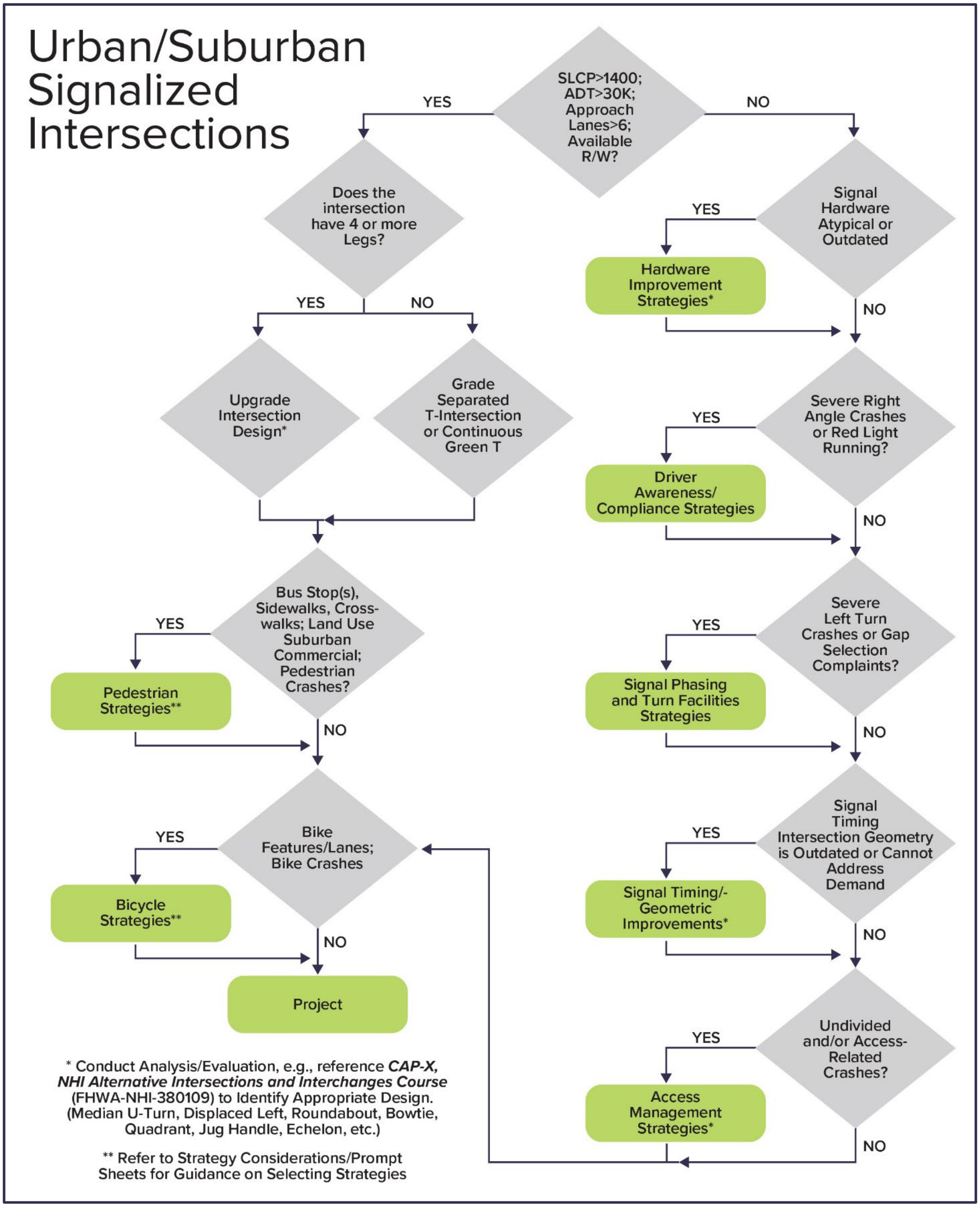


Figure 25. Graphic. Urban and suburban signalized intersection decision tree for Palm Beach County (Source: Palm Beach County, 2019).

City of Boulder Pedestrian Crossing Treatment Installation Guidelines

Crossing Location Evaluation Worksheet

Rev. 11/2/11

STEP 1 - LOCATION DESCRIPTION

Major Street: ____________________ Crossing Location: ____________________

Is this a multi-use path crossing? ☐ Yes ☐ No Posted Speed Limit: ______ mph

Existing Traffic Control: ☐ Stop Sign ☐ Traffic Signal ☐ Uncontrolled

Existing Crossing Treatments (if any): ____

____

Nearby Pedestrian Generators (School, transit stop, commercial, etc.): ____________________

____

STEP 2 - PHYSICAL DATA

Roadway Configuration:
- ☐ 2-Lane
- ☐ 3-Lane w/Striped Median
- ☐ 3 Lane w/Raised Median
- ☐ 4 Lane
- ☐ 5 Lane w/Striped Median
- ☐ 5 Lane w/Raised Median
- ☐ 6 Lane
- ☐ Other: ______________

Crossing Distance By Direction: _______ ft total _______ ft to median *(if applicable + note direction)* _______ ft to median *(if applicable + note direction)*

Nearest Marked or Protected Pedestrian Crossing: ______________ Distance to: _______ft

(*For uncontrolled location only*) Stopping Sight Distance (SSD) = _______ ft _______ ft.

Is SSD ≥ 8x Speed Limit? ☐ Yes ☐ No If No, are improvements to SSD feasible? ☐ Yes ☐ No

STEP 3a - TRAFFIC DATA

Pedestrian Crossing Volumes / Bicycle Crossing Volumes:

	AM	Mid-Day	PM	Other
Time:	to	to	to	to
Date/Day of Week:	/	/	/	/
Major Street Vehicular Volume (**Hourly**):				
# of Transit Boardings (if applicable)				
# of Young Peds / Bicyclists	/	/	/	/
# of Elderly Peds				
# of Disabled Peds				
# of Non-Y/E/D Peds / Bicyclists	/	/	/	/
TOTAL PEDS (Actual) (Include All Bicyclists in Total Sum)				
TOTAL PEDS (**Adjusted** for 2x Y/E/D				

Major Street Vehicular Volume (**Daily**): ADT = ______________ veh/day

Evaluation Worksheet Page 1 of 2

Figure 26. Graphic. Page 1 of the evaluation worksheet used by the City of Boulder to collect data for pedestrian crossings (Source: City of Boulder, 2011).

City of Boulder Pedestrian Crossing Treatment Installation Guidelines

Crossing Location Evaluation Worksheet *(Continued)*

STEP 3b - OPERATIONAL OBSERVATIONS

Nearest Intersection (Direction #1): Cross Street Name: ______________________

Located _______ ft to the ☐N ☐S ☐E ☐W of crossing location

Signalized? ☐Y ☐N Distance from Crossing _______ ft

	AM	Mid-Day	PM	Other
How many times per hour did the downstream vehicle queue back up into pedestrian crossing?				
If multiple lanes per direction, are queue lengths approximately equal?	Y N	Y N	Y N	Y N
If NO (above), which lane is longer (inside, outside, middle) and by how much (feet)?				

Nearest Intersection (Direction #2): Cross Street Name: ______________________

Located _______ ft to the ☐N ☐S ☐E ☐W of crossing location

Signalized? ☐Y ☐N Distance from Crossing _______ ft

	AM	Mid-Day	PM	Other
How many times per hour did the downstream vehicle queue back up into pedestrian crossing?				
If multiple lanes per direction, are queue lengths approximately equal?	Y N	Y N	Y N	Y N
If NO (above), which lane is longer (inside, outside, middle) and by how much (feet)?				

STEP 4 - APPLY DATA TO FIGURE 1 and TABLE 1

Recommended Treatment(s): ____

____

____

Evaluation Worksheet Page 2 of 2

Figure 27. Graphic. Page 2 of the evaluation worksheet used by the City of Boulder to collect data for pedestrian crossings (Source: City of Boulder, 2011).

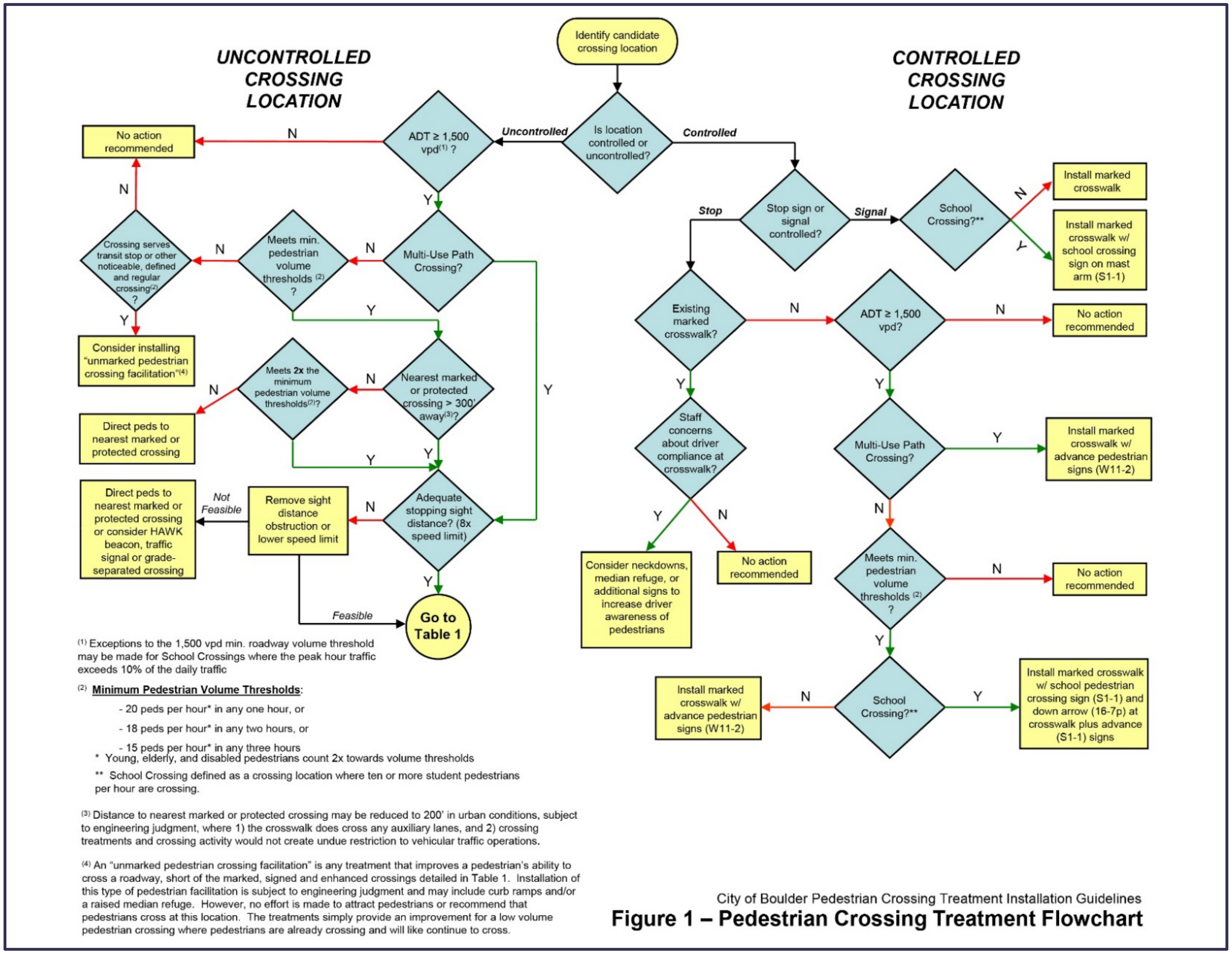


Figure 28. Graphic. City of Boulder pedestrian crossing countermeasure decision tree (Source: City of Boulder, 2011).

Matrices

Another way to organize and standardize the countermeasure selection process is using a matrix. Figure 29 shows an FHWA matrix created for rural roadway departure countermeasures (FHWA, 2021b). For each countermeasure, the matrix indicates target crashes, estimated cost, and the context under which the countermeasure should be considered.

Countermeasure Summary Table by Roadway Departure Objective

Objective	Countermeasure	Target Crash Types				Cost H-M-L	Option on Narrow Roads*	Option on Unpaved Roads	More Details on Page
		Head-On	Roll over	Fixed Object	Curve				
Keep Vehicles in Lane	Edge Line Markings		●	●	●	L	✓		5
	Center Line Markings	●			●	L			5
	Curve Warning Signs		❍	❍	●	L	✓	✓	7
	Delineators		❍	❍	●	L	✓	✓	9
	Shoulder Rumbles		●	●	❍	L			11
	Center Line Rumbles	●			❍	L			11
	HFST				●	M	✓		10
Reduce Potential for a Crash	Shoulder Widening	❍	●	●	●	M-H	✓		13
	SafetyEdge℠	●	●		●	L	✓		15
	Center Line Buffer Area	●				L			17
	Remove Fixed Objects			●	❍	L-H	✓	✓	14
	Slope Flattening		●		❍	M-H	✓	✓	18
Minimize Severity	Roadside Barriers		●	●	❍	M-H	✓	✓	19
	Breakaway Features		❍	●	❍	L	✓	✓	21

*For the purpose of this guide, narrow roads are defined as a two-way road with less than 20 feet of total traveled way.

Table Key

● *Primary countermeasure for this type of crash*

❍ *Countermeasure to consider*

L: *Low-cost – up to $5,000 per mile or per curve/location*

M: *Medium-cost – $5,000 to $50,000 per mile or per curve/location*

H: *High-cost – More than $50,000 per mile or per curve/location*

Figure 29. Graphic. FHWA roadway departure countermeasure matrix for rural roads (Source: FHWA, 2021b).

Resources

FHWA has created several resources to assist agencies with countermeasure selection:

- *Proven Safety Countermeasure Filter Tool* allows agencies to describe issues through a questionnaire and receive recommended proven safety countermeasures: https://highways.dot.gov/safety/proven-safety-countermeasures/search.
- *STEP Studio* provides guidance for selecting and implementing countermeasures for pedestrian crossing safety: https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/step_studio.pdf.
- *Rural Roadway Departure Countermeasure Pocket Guide* describes the context under which several roadway departure countermeasures can be implemented to reduce the frequency and severity of those crashes on rural roads: https://highways.dot.gov/safety/rwd/forrrwd/rural-roadway-departure-countermeasure-pocket-guide.
- *Reliability of Safety Management Methods: Countermeasure Selection* recommends several practices to increase agency confidence in the selection of countermeasures: https://rosap.ntl.bts.gov/view/dot/42828.

Outcome

After completing the tasks in this chapter, agencies should have the following as an outcome:

- List of countermeasures which can be used for the systemic safety program.
- Targeted countermeasures selected for prioritized system elements.

Frequently Asked Questions

Should I seek input from others when screening countermeasures?

Yes. It is important to get the support of safety stakeholders when selecting a countermeasure for a systemic program. For instance, staff responsible for pavement management can provide valuable support for rumble strips, and pedestrian advocates can be effective messengers for RRFBs. It is important to seek input from non-traditional stakeholders as well. Additionally, regional staff, including district and local engineers and planners, are knowledgeable of what may or may not be effective on roads in their jurisdiction.

Is there an optimum number of countermeasures for my agency's countermeasure list?

No. But agencies should consider the balance between too few and too many. Too few countermeasures can limit the flexibility of the process and can limit the number of potential safety projects. Too many countermeasures may complicate the project identification process. Meanwhile, the countermeasure list should have sufficient redundancy to maximize the number of candidate sites which can be addressed with a countermeasure.

Why would I want to remove countermeasures from my agency's list?

There is an extensive range of countermeasures available to target almost any focus crash type. However, some may not meet the wide list of requirements for your agency's systemic program, including cost-effectiveness, ease of installation, stakeholder support, and other factors. Additionally, as addressed in the previous question, too many countermeasures can complicate the project identification process, so there is added motivation to pare down the countermeasure list.

Are the CMFs developed for high-crash locations applicable to a systemic implementation?

While CMFs in the CMF Clearinghouse present the best information available to date, it is important to recognize that some CMFs may be developed from before-after studies conducted when the countermeasure was implemented at a high-crash location. Despite the use of statistical methods to account for treatments installed at high-crash locations, it is unknown whether the same results will be achieved when implementing these countermeasures on a systemic basis. It is possible that systemic application (i.e., deployment at some locations with no crash history) may not achieve as high of an average percentage reduction in crashes as applications at high-crash locations. Therefore, agencies are encouraged to conduct follow-up evaluations to determine the effect of systemic countermeasures.

How should we incorporate countermeasures without CMFs?

Some countermeasures may be new or semi-experimental, and thus do not have sufficient data to estimate a CMF. Agencies should not view this as an impediment to incorporating the countermeasure into their systemic safety program. One method is to use professional judgement to assess the potential impact of a countermeasure. This can be informed from a Safe System perspective—does the countermeasure:

- Reduce speeds?
- Reduce crash probability?
- Separate modes?
- Reduce the number of potentially severe conflicts?
- Reduce crash severity?
- Provide redundancy?

Agencies are encouraged to apply innovative and emerging treatments and conduct follow-up evaluations as described in the previous answer. Peer agencies, LTAP centers, professional organizations, and FHWA can provide technical guidance and networking for new and emerging practices. Agencies using experimental treatments are encouraged to evaluate the performance of these treatments, document the results, and share them with their peers.

Chapter 4 – Prioritize Systemic Projects

Ideally, an agency can implement every project proposed in the previous step. In reality, these projects are typically programmed within a fixed budget. To maximize the effectiveness of that budget, agencies prioritize the proposed safety projects. This chapter describes the task to prioritize safety projects. The term "projects" includes dedicated safety projects as well as safety improvements implemented as one component of a traditional construction or maintenance project (e.g., resurfacing), or as part of routine maintenance efforts.

The FHWA guide *Selecting Projects and Strategies to Maximize Highway Safety Improvement Program Performance* (Gross et al., 2021) is one resource for assisting agencies with this step. Figure 30 describes the recommended tasks to complete this step. The following tasks are based on the guidelines provided in that document.

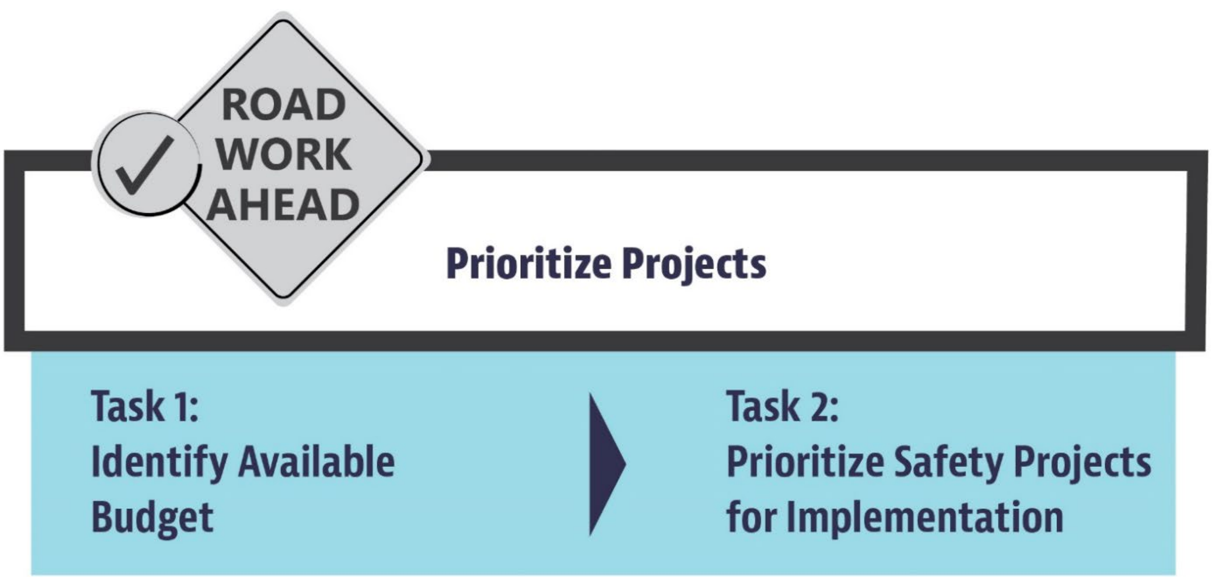


Figure 30. Graphic. Tasks to prioritize projects (Source: FHWA).

Data

The information needed to support the project prioritization process includes a basic understanding of an agency's priorities, practices, and policies as they relate to project and program development. In addition, defining specific safety projects requires current information about countermeasure implementation costs and estimated effectiveness. Finally, this requires an understanding of the total budget available for safety improvement projects.

Task 1 – Identify Available Budget

The first task involves understanding the budget available for systemic safety projects. Agencies can consider putting all projects in a selection pool, regardless of the approach to project development (site-specific, systemic, systematic). Thus, all projects would compete on the same merits such as BCR and other factors that agencies use to score projects. While some agencies prioritize systemic safety projects alongside site-specific safety projects, others use a dedicated set-aside for systemic projects. In these cases, the budget available for the systemic program is equivalent to the set-aside. VDOT uses this approach and dedicates 80 percent of safety funding to systemic improvements (Commonwealth of Virginia, 2019).

A modified approach to budgeting is to create set-asides by emphasis area. For instance, roadway departure crashes may account for 65 percent of fatalities and serious injuries, so the set-aside for roadway departure projects could be 65 percent of safety funds. An agency may deploy either method—prioritize all projects together or create a systemic set-aside—to dictate the budget available for systemic safety projects.

Task 2 – Prioritize Safety Projects for Implementation

The second task involves prioritizing the proposed safety projects for implementation. Agencies should consider several factors when prioritizing safety projects. The following sections describe those factors and how they should be incorporated into the project prioritization process.

Expected Safety Performance

The purpose of the systemic safety approach is to reduce the frequency and severity of severe crashes. As such, it is critical to estimate the potential change in safety performance for each proposed project. Data-driven safety analysis is commonly employed to estimate the potential change in safety performance associated with a countermeasure (FHWA, 2023c). This requires estimating the future safety performance with no countermeasure and then again with one or more countermeasures implemented to estimate the reduction in crashes after countermeasure installation.

Agencies can employ both simple and statistically rigorous methods for estimating future safety performance. For instance, the MassDOT *Safety Alternatives Analysis Guide* (MassDOT, 2021c) describes three methods for estimating future safety performance based on the data and resources available. As an example, figure 31 shows MassDOT's decision process to select the appropriate method.

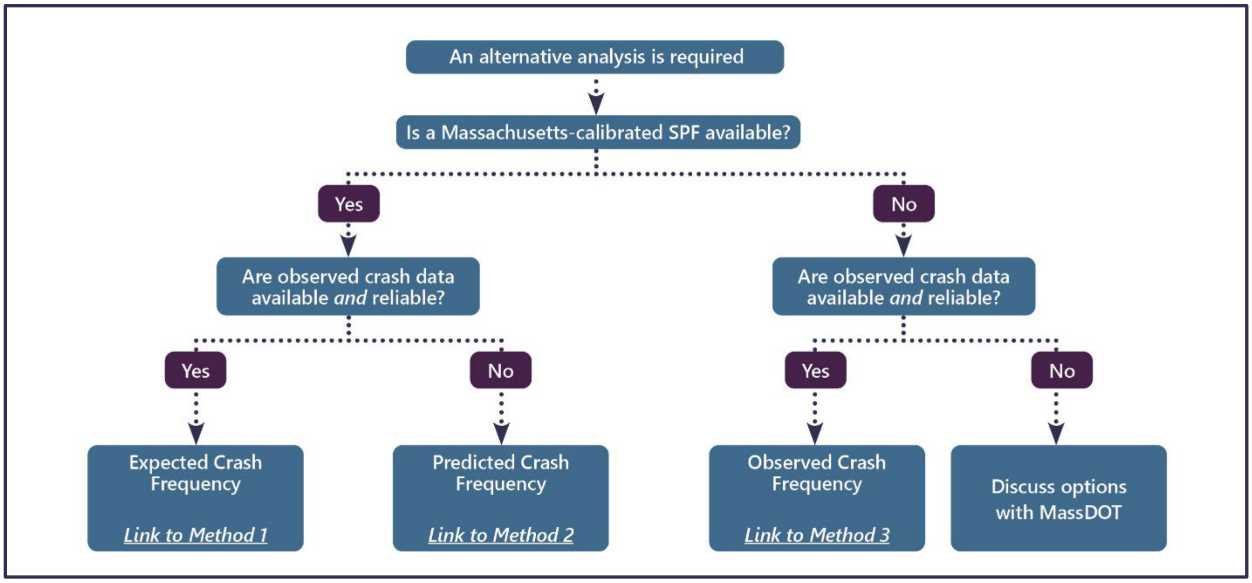


Figure 31. Graphic. Guidance for the selection of safety analysis methodology by MassDOT (Source: MassDOT, 2021c).

Per MassDOT's workflow, agencies can use the EB approach to estimate the expected future safety performance of a project location, apply a CMF, then estimate the annual crash reduction and aggregate the estimated reduction over the service life of the countermeasure(s).

Where crash data are not available or reliable, but a calibrated crash prediction modelis available, agencies should predict future crashes using the crash prediction model and apply the CMF. If crash data are available and reliable but there is no calibrated crash prediction model, agencies should use several years of historical data to estimate an average crash rate, grow that rate to future years, and then apply the CMF to expected crashes based on the rate. Figure 32 shows how the change in safety performance can be calculated using expected safety performance and a CMF.

$$Annual\ Crash\ Reduction = Expected\ Crashes * (1 - CMF)$$

Figure 32. Equation. Calculating the expected change in safety performance using a CMF.

One issue that is specific to the systemic approach is that often, sites are identified with no crash history because they are prioritized based on the presence of risk factors. A direct application of the crash rate method will predict no future crashes to reduce. However, agencies should consider applying an average crash rate for the applicable facility type based on historical crash frequency across the system. This can serve as an adequate future estimate of safety performance based on observed rates across the system.

The HSM and FHWA's *Scale and Scope of Safety Assessment Methods in the Project Development Process* (Atkinson et al., 2016) provides guidance for using predictive methods for safety analysis.

Where a CMF is not available, agencies may consider surrogate measures of safety. These can be viewed from a Safe System perspective—does the countermeasure reduce speeds, reduce conflict frequency and angle, or separate modes? Professional judgement of surrogate measures should inform the analysis.

Ultimately, while prioritization of improvements is an important step in the systemic approach, agencies with limited existing data should not be concerned if they lack ideal data to fully distinguish and rank locations by risk. A simple "number of risk factors" approach or other qualitative assessment has worked well for agencies to get started with implementing countermeasures where needed.

Expected Benefit-Cost Ratio

There are several methods to compare safety benefits to project costs. The BCR is the preferred method for prioritizing projects because it identifies those that offer the greatest reductions in fatalities and serious injuries per dollar invested. FHWA's *Highway Safety Benefit Cost Analysis Guide* (Lawrence et al., 2018) describes the methodology for calculating the BCR. The key assumption for this analysis is that crashes can be converted to a monetary amount using average crash costs. Many agencies have developed or adopted average crash cost values for benefit-cost analysis. If not, FHWA also provides average crash cost values in the *Crash Costs for Highway Safety Analysis* publication (Harmon et al., 2018).

In the systemic approach, agencies can estimate the benefit by converting the expected change in safety performance to monetary benefits using average crash costs. The denominator—installation and maintenance costs—should be estimated based on typical cost estimation procedures that reflect local material and labor costs. FHWA's *Synthesis of Countermeasure Cost User Guide* (Smith and Signor, 2017) is a useful resource for producing a cost estimate if none is available, while *Countermeasure Service Life Guide* (Himes et al., 2021) includes methods for accurate cost estimation using service life. Agencies can reduce costs through project bundling and other innovative project delivery approaches, as discussed in chapter 5.

What if crash data are not available to quantify the potential crash reduction and BCR? This should not be a hinderance for agencies to program and prioritize systemic safety projects. Factors agencies can use to overcome this challenge include:

- How many risk factors does a countermeasure address at each site? Projects addressing several risk factors can be elevated in the prioritization process.
- Can the traffic or safety characteristics of the site be classified qualitatively (e.g., high, medium, low)? Consider elevating the priority based on these qualitative measures.
- Is BCR for a countermeasure quantified elsewhere? For instance, use an average BCR calculated by a neighboring agency or published in the literature.
- Does the countermeasure have a proven history of safety effectiveness, like FHWA's Proven Safety Countermeasures? Agencies may consider streamlining projects including proven countermeasures, bypassing BCR calculation for those projects (FHWA, 2023d).
- Is there a cost estimate and CMF available to calculate a Countermeasure Score (Gross et al., 2021)?
- How does the countermeasure rank on the Safe System Roadway Design Hierarchy (Hopwood et al., 2024)? Consider increased priority ranking for countermeasures in higher tiers.

No BCR? Try Countermeasure Score

Countermeasure Score (CM Score) is a measure of the cost efficiency for a proposed improvement, calculated as the cost to produce a 1-percent reduction in a target crash type and severity (Gross et al., 2021), as shown in figure 33 for crash type *T* and severity *S*. The lower the CM Score, the more cost efficient the proposed improvement and higher it should be prioritized.

$$CM\ Score_{T,S} = \frac{Project\ Costs}{\left(1 - CMF_{T,S}\right) * 100}$$

Figure 33. Equation. Calculation of CM Score for a given crash type (T) and severity (S).

This metric could be used for prioritization when data are unavailable to estimate benefits and BCR. For example, an agency is considering four potential systemic mid-block crossing projects, each addressing 100 locations: High-Visibility Crosswalk Markings, RRFBs, PHBs, and Median Refuge Islands. Table 18 shows the calculation of CM Score for each proposed project, focused on vehicle-pedestrian crashes of all severities. Based on CM Score, the High-Visibility Crosswalk markings would be the highest prioritized project, followed by RRFB, Median Refuge Islands, and PHB.

Table 18. Example CM Score Calculations for Prioritization

Countermeasure	Target Crash Type	CMF (CMF Clearinghouse ID)	Total Project Cost	CM Score
High-Visibility Crosswalk Markings	Vehicle-Pedestrian	0.6 (4123)	$800,000	$20,000
RRFB	Vehicle-Pedestrian	0.53 (9024)	$1,700,000	$36,170
Median Refuge Island	Vehicle-Pedestrian	0.69 (8799)	$1,900,000	$61,290
PHB	Vehicle-Pedestrian	0.45 (9020)	$3,500,000	$63,636

Calculating BCR with Spreadsheet Tools in Missouri

The Missouri DOT (MoDOT) developed spreadsheet tools to estimate BCRs for systemic treatments, including median cable barrier, shoulder widening, and chevron applications (MoDOT, 2019). Figure 34 is a screenshot of the chevron cost to benefit calculator. Users input project documentation, treatment level, number of planned installations, service life, and unit or total project costs. The tool calculates several metrics, including:

- BCR.
- Fatal and serious injury crashes avoided as a result of the treatment.
- Number of lives to be saved.
- Number of persons prevented from experiencing disabling injuries.

This tool can be useful for low data environments, as applicants only need to know roughly the order of magnitude for traffic volume and are not required to provide site-specific crash data.

Chevrons in Curves or Turns, Cost to Benefit Calculator:

B/C of adding to curves or turns that do not yet have chevrons. B/C may also apply to ramp curves advised at 35 mph or less.

Project documentation:

		Comments:
District:	St. Louis	
County:	St. Louis	
Route		
Project:	Rural Chevrons	

Select the Level: Level 1: AADT 1,000 or more, advisory speed plaque of 35 mph or more. (High volume curve.) v

Where:	CMF	
Level 1	0.840	Level 1: AADT 1,000 or more, advisory speed plaque of 35 mph or more. (High volume curve.)
(no Level 2)		No Level 2.
Level 3	0.840	Level 3: AADT less than 1,000, advisory speed plaque of 35 mph or more. (Low volume curve.)
Other	0.840	Other: Any AADT, advisory speed plaque of 30 mph or less. (Any volume turn.)

FHWA report estimates 16% reduction for chevrons (where none) on fatal and injury crashes. (See FHWA booklet.)

A MoDOT adaptation of a federal study estimates the total, direct and indirect crash costs of : (See FHWA study.) (See MoDOT Crash Costs.)

Fatal	Disabling
$ 9,962,900	$ 577,700

$ 19,311 benefit estimate, per year, per curve.

Data Entry:

Estimate number of curves or turns signed:

400 **Curves / Turns** — $ 7,724,228 benefit estimate, per year.

Estimate how long the signs will last (life), usually 10 years:

10 **years** — $ 77,242,279 benefit estimate for life of the signs.

Estimate a cost of adding chevrons or arrows.

$ total or (If a value is entered in "total," then it will be used.)

2,500 **$ per curve, usually $2,500.** — $ 1,000,000 total cost estimate.

Results:

Calculated Benefit per Cost ratio (B/C), where higher is better and < 1 is undesirable.

77.24 **B/C**

Estimated crashes and persons for project length and life.

6.533	**F Crashes avoided.**	21.041	**SI Crashes avoided.**
27.574	**F & SI Crashes avoided.**		
7.095	**Lives saved, people.**	20.865	**Disabling injuries avoided, people.**

Figure 34. Graphic. MoDOT spreadsheet tool to calculate BCR for systemic chevron installations (Source: MoDOT, 2019).

Other Programmed Projects

As discussed previously, systemic safety improvements can be incorporated into non-safety projects. If an agency is planning a project that includes a prioritized site from the systemic list, the agency should look for opportunities to add systemic safety countermeasure(s) to that project. This can often come at a reduced cost, as mobilization is already accounted for as part of the larger project.

Equitable Transportation Outcomes

Transportation safety projects have the opportunity to redress past and current harms of the transportation system for disadvantaged neighborhoods and communities. Agencies may consider raising the priority of systemic projects which aid in this goal. To learn more about strategies and tools to implement safety improvements equitably, review the resources available at https://highways.dot.gov/safety/zero-deaths/implement-safety-improvements-equitably.

Need for Public Outreach

Systemic safety may present some confusion to the public and stakeholders. To some, the systemic safety approach may seem counterintuitive, as it may involve spending money at locations where there have been no crashes. For an effective systemic project, agencies need to be prepared to defend and justify the project to the public. Agencies should estimate the need for such efforts and plan accordingly when prioritizing systemic safety projects.[7] As in all safety projects, newer and innovative analysis methods and countermeasures may need to be accompanied by education campaigns to help the public understand expected behavior and countermeasure benefit.

Environmental and Right-of-Way Constraints

Most systemic countermeasures are low-cost treatments which will have limited impact on the immediate surroundings. However, there is still some potential for incursion into environmentally-sensitive areas. The same considerations apply to right-of-way acquisition—many systemic, low-cost countermeasures have minimal impact on the surrounds, and often do not exceed available right-of-way.[8] Agencies should monitor the potential for such impacts and consider the effects the countermeasure could have on planning, permitting, and other project development steps.

[7] While this is a challenge, it should not be viewed as an impediment to implementing a systemic safety project or program.
[8] Note that safety projects are often considered a Categorical Exclusion.

Prioritization

After performing the relevant calculations and collecting data for other considerations, agencies should develop the final prioritized list of proposed safety projects. It is up to the agency how they weigh the factors considered. Table 19 provides an example of project prioritization data. In this application, the agency elected to prioritize improvements based on BCR. One can also quantify the effectiveness of dollars spent in a systemic project. One method would be to provide either a cost per location improvement, crash modification per mile, or site per dollar for a systemic project using an average crash reduction across many sites.

Outcome

The outcome from this task includes:

- The budget available for systemic safety projects.
- A prioritized list of systemic safety projects.

Table 19. Sample project prioritization data.

Project ID	Project Type	Description	Environmental or Right-of-Way Impacts	Lives Saved and Serious Injuries Prevented	Cost	BCR	Priority Order
45784	Systemic	Chevrons on two-lane rural horizontal curves in District 2	None	30	$800,000	31	1
33699	Site-specific	Roundabout at Main Street and Route 104	Moderate	6.1	$2,100,000	8.1	2
85142	Systemic	RRFBs at urban mid-block pedestrian crossings in South MPO	Minimum	2.1	$650,000	4.1	3
33559	Systematic	Shoulder rumble strip installation on rural four-lane divided highways that meet criteria	None	1.9	$1,200,000	2.2	4
64741	Site-specific	Road diet on Liberty Avenue in the central business district	Moderate	0.5	$700,000	1.9	5
17458	Systemic	Median cable barriers on unprotected divided freeway segments	None	1.2	$2,450,000	0.9	6
98585	Site-specific	Horizontal and vertical realignment of Route 993 S-curve.	Significant	0.4	$3,000,000	0.2	7

Frequently Asked Questions

What do I do if I cannot implement a countermeasure at a candidate location?

Agencies should build redundancy into the countermeasure selection process so that if a primary countermeasure is not viable at a site, there are secondary countermeasures for consideration. In the rare situation where no countermeasures are viable at a priority location, consider developing a site-specific project to address safety issues at that location (e.g., a capital project with alignment changes or other geometric improvements could be needed).

We have identified more projects than the available funding – is this a problem?

No, the systemic safety planning process should not be limited by fiscal constraints. Agencies make the decision regarding which projects get funded in future steps. Additionally, agencies will inevitably encounter obstructions or barriers when implementing a countermeasure that may make a particular project at least temporarily unviable, so a backlog of additional candidate projects is a useful resource to help meet planned systemic safety obligations.

My high-priority sites are ranked in a specific order. Do the suggested safety projects need to be implemented in that exact order?

No. As discussed in the next chapter, the project prioritization process considers a range of inputs, not solely a candidate site's priority risk ranking. Incorporating a variety of factors into project prioritization can result in a more efficient systemic safety program than simply implementing directly from the risk ranking.

Are data gathered to implement systemic safety projects admissible in evidence?

Sometimes. Under 23 U.S.C. 407 (previously codified as 23 U.S.C. 409), reports, surveys, schedules, lists, or data compiled or collected for the purpose of identifying, evaluating, or planning the safety enhancements of potential accident sites, hazardous roadway conditions, or railway-highway crossings pursuant to the Railway-Highway Crossing Program (RHCP), National Bridge and Tunnel Inventory and Inspection Standards (NBI), or HSIP, or for the purpose of developing any highway safety construction improvement project which may be implemented utilizing Federal-aid highway funds, is not subject to discovery and cannot be admitted into evidence in any Federal or State court proceeding in any action for damages arising from any occurrence at a location mentioned or addressed in those reports, surveys, schedules, lists, or data.

Under *Piece County, Washington v. Guillen*, 537 U.S. 129 (2003), the reports, surveys, lists, or data must be actually compiled or collected for the stated purposes as part of the RHCP, NBI, or

HSIP to be covered by 23 U.S.C. 407. 537 at 144-46. The statute covers not just information that an agency generates for protected purposes but also any information that an agency collects from other sources for protected purposes. *Id.* at 145. The statute, however, does not cover information compiled or collected for unprotected purposes and held by agencies that are not pursuing covered objectives. *Id.* at 145-46. For example, a crash report collected only for law enforcement purposes and held by a law enforcement agency would not be covered by 23 U.S.C. 407 in the hands of that law enforcement agency. *See id.* at 144. However, that same crash report would be covered by 23 U.S.C. 407 in the hands of a local safety agency, so long as the agency first obtained the report for HSIP purposes or other purposes covered under the statute. *See id*.

Chapter 5 – Deliver Systemic Projects

This is the fifth step of the systemic safety process. The objective of this step is to deliver systemic projects as efficiently as possible. There are several key components to the successful and efficient delivery of systemic projects. First, it is important to have plans that sufficiently describe the proposed countermeasures. Once plans are ready, agencies should select the appropriate method for delivering projects. Because of the low-cost nature, agencies are encouraged to use innovative mechanisms that are better tailored to delivering a large quantity of safety improvements in a cost-efficient manner. Finally, agencies should track implementation. Large-scale projects that involve numerous locations can be difficult to monitor—documenting installation dates, change orders, and specific locations. A standardized tracking approach will improve the possibility of tracking and evaluating systemic safety projects.

Project Delivery Mechanisms

Agencies can select from a range of mechanisms for delivering systemic safety projects. When selecting an approach, agencies should consider what improvements are being implemented, agency policies and procedures, and which methods can fit within the program budget. The following sections highlight several project delivery mechanisms for systemic safety projects. Agencies may use some or all of these approaches for the most efficient implementation of the safety program.

Project Bundling

The most common method of delivering systemic safety projects is through project bundling. This delivery mechanism includes the aggregation of several individual yet similar safety projects within a geographic area to be delivered through one contract. Project bundling provides many benefits over simple, individual contracts, including (FHWA, 2022b):

- **Expedited Project Delivery** – grouping the sites can allow for the production of a single plan set (as opposed to many plan sets), combined environmental and right-of-way documentation, and the use of standard drawings for implementation.

- **Reduced Unit Cost** – the bundling of individual installations into one project increases the cost efficiency of mobilization and can reduce the unit cost of materials due to bulk purchases. Additionally, labor costs per installation may reduce as the staff responsible for installation becomes more efficient.
- **Contracting Efficiency** – bundling individual projects into one contract produces several savings on the contractual side, including reduction in time to prepare and bid the contract (as opposed to several individual contracts) and cost savings related to procurement and project management.

FHWA highlighted the use of project bundling as an Every Day Counts initiative for bridge projects (FHWA, 2022b). However, several agencies have employed this approach for systemic safety project delivery, including those highlighted below.

Pennsylvania

The Pennsylvania Department of Transportation (PennDOT) has used project bundling for several systemic safety countermeasures, including center line, edge line and shoulder rumble strips, high-friction surface treatments, delineation (signage, pavement markings, other devices), high-tension cable median barrier, and lighting (Hershock, 2020). The agency creates a list of multiple locations by improvement type and batches the locations into district-wide or county-wide contracts. The plans include basic location and detailed quantity tabs. Adding to the efficiency, the proposed improvements do not require right-of-way, include straightforward environmental clearances, and have no issues with utilities or rail crossings.

Gulf Region

The Gulf Regional Planning Commission (GRPC) in southern Mississippi developed a list of systemic roadway departure projects on horizontal curves within their jurisdiction (Yarrow, 2020). The GRPC used a consultant for Plans, Specifications, and Estimates (PS&E) development and then created a bundle of projects for each of the three counties in the MPO. The GRPC then handed off the contracts to the counties to bid and implement. The projects included a mix of rumble strips, shoulder treatments including gravel or SafetyEdge^{SM}, painted and raised pavement markings, pavement improvements, advanced warning and chevron signs, and barriers. Phase I of the project was delivered at an average cost of $80,000 per location, with Phase II implemented at an average cost of $40,000 per location. The GRPC and partner counties reduced mobilization costs in Phase II by selecting locations that were geographically closer together than in Phase I.

Ohio

The Ohio Department of Transportation's (ODOT's) Pedestrian Safety Improvement Program (PSIP) included intersection and mid-block pedestrian crossing improvements in eight cities (FHWA, 2020d). ODOT bundled the projects into one contract per District for each of the six Districts involved. This bundled application included, for each contract, a table of proposed locations including the proposed work, a link to a map of the locations, and notes indicating whether there are proposed impacts for the following environmental screening factors:

- Historical district (roughly 25 percent of locations were in a historical district).
- Ground disturbance, including whether this may affect drinking water resources.
- Deep excavation involving 6 or more ft, which are only for pole installations.
- Adjacent to significant public parks, recreation areas, or significant historic sites (i.e., section 4(f) resources).
- Vegetation removal.
- Parking impacts.
- Floodplain based on the Federal Emergency Management Agency Flood Insurance Rate Map.

Additionally, ODOT shifted some responsibility for assessing utility risk to the contractor (FHWA, 2020d).

Minnesota

Counties in Minnesota are recommended to have a current County Road Safety Plan to be eligible for the State's HSIP funding. To implement low-cost improvements in an economic efficient manner, several counties may join together to bundle low-cost safety improvement installations, such as rumble strips or signage (Preston et al., 2018). Bundling together provides several benefits for the counties, including:

- Reduced mobilization costs.
- Reduced administrative burden, as one county typically takes care of administration for the bundle.
- Reduced material costs because by combining quantities, the per unit costs are likely to decrease.

Indefinite Delivery and Indefinite Quantity (ID/IQ) and On-Call Contracts

ID/IQ contracts allow an agency to maintain the services of a contractor for a set amount of time with an unknown quantity of services. The contract includes predetermined labor rates and often general rates for estimated quantities of individual items. Agencies then use work orders to issue individual assignments to contractors. In some cases, agencies may have several contractors available through an ID/IQ and will place work orders up for bid. ID/IQ contracts can be combined with project bundling. Benefits of ID/IQs include reduced contracting and labor costs, time savings, and reliable material costs through pre-set unit prices.

Push Button Contracts in Florida

District 7 of the Florida Department of Transportation (FDOT) further innovated on the traditional ID/IQ contract to develop a Design-Build "Push Button" contract to implement low-cost safety improvements. After selecting design build teams in the ID/IQ, the District proceeds with implementing improvements. The District identifies safety needs, generates a cost estimate, generally submits for NEPA Categorical Exclusion, obligates Federal safety funds, then proceeds to "push the button" for the design build team to design and implement the safety concept. This mechanism reduces average design and implementation time for low-cost safety improvements from 3-5 years to 3-9 months, producing significant reduction in costs (FDOT, 2021).

Material Procurement

State agencies often use material procurement contracts to support local agencies' systemic safety efforts. With this approach, agencies purchase a large quantity of a specific countermeasure, such as an RRFB or curve warning signs. The bulk purchase allows for a reduced unit cost, achieving savings which can be then transferred to local agencies. State agencies can allow local agencies to either purchase materials from them or transfer them at no cost.

Material Procurement by MaineDOT

MaineDOT uses material procurement contracts for several countermeasures, including RRFBs, dynamic speed feedback signs, signage, and other delineation improvements (FHWA, 2018). Local agencies are eligible to obtain these materials for free from MaineDOT if they receive training for installation and have a record of installing the countermeasures within 36 months of receipt. Additionally, MaineDOT will offer additional funds to local agencies if a countermeasure requires updating a facility to meet ADA requirements.

Quick-Build Applications

Several agencies deploy “quick-build” applications, which are low-cost, quickly implementable safety improvements that require simple materials such as pavement markings, delineators, flexible posts or crashworthy bollards, and other items to produce a safety countermeasure. These are often installed as temporary measures until a more permanent safety solution can be implemented. Systemic countermeasures that can be implemented via quick-build applications include crosswalks, curb bulb outs, separated bicycle facilities, and even roundabouts. Quick-build applications are typically implemented using maintenance staff.

These applications are often highlighted in municipal Vision Zero plans. The City of San Francisco, California and the San Francisco Municipal Transportation Agency (SFMTA) include projects such as pavement marking, signage, delineation, parking adjustments, signal timing modifications, and transit stop or route improvements (SFMTA, 2021). The City revisits sites for evaluation and consideration for more permanent changes within 24 months of construction. The City of Burlington, Vermont produced *Quick Build Design and Materials Standards*, which describe the materials and procedures employed by the City to quickly implement temporary safety solutions (City of Burlington Public Works, n.d.). Formal documentation of the process ensures consistency across the system as more quick-build applications are installed.

The primary benefits of quick-build applications, especially in a systemic context, are cost-savings and the speed at which safety countermeasures can be implemented. Upon selection of the countermeasure for a location, a quick-build approach can have the countermeasure implemented within weeks or months, rather than months to years through a more traditional process.

Systemic Safety and Maintenance

Some agencies employ maintenance forces for the installation of systemic safety countermeasures. This mechanism offers significant potential for cost savings, as the salary of maintenance forces are already accounted for in an agency's budget, so additional costs would only be derived from materials acquisition. Additionally, the lack of a contract bid and letting process speeds up the timeline of countermeasure installation.

Maintenance is also important for the continued effectiveness of safety countermeasures. Signs need to be cleaned to maintain retroreflectivity and pavement markings need to be regularly applied to delineate the travel lane. Vegetation clearing is needed to maintain sign visibility, to improve sight distance at curves/intersections, and to prevent new trees from growing and becoming roadside obstacles within the clear zone. Agencies should work with the appropriate maintenance staff to ensure the new countermeasures will be maintained regularly. When implementing systemic countermeasures on local roads, the Tennessee Department of Transportation (TDOT) requires a maintenance agreement to be established with the local agency before delivering the project.[9]

Finally, systemic safety analysis can inform maintenance practices. The Indiana LTAP recommends local agencies prioritize high-risk corridors for maintenance activities (Slusher, 2021). For example, if a corridor is at high risk for wet road crashes, maintenance staff are encouraged to prioritize reviewing the corridor to identify and remove drainage clogs, remove excess shoulder material, maintain and clear debris from ditches and culverts, and deepen ditches as needed.

Integrating Systemic Safety into Other Projects and Policies

Agencies should look for opportunities to integrate the systemic approach into other projects and policies. Primarily, agencies should include a check for the presence of risk factors, or the status of a site as a priority risk, at all project locations, regardless of whether it is a safety project or not. If this is the case, agencies should encourage the addition of targeted, low-cost safety countermeasures in the project. Agencies can consider making this a policy, requiring the incorporation of systemic analysis results into 3R, Federal Aid, and other non-safety projects.

[9] TDOT shared this information with FHWA as an example of a noteworthy systemic safety practice.

Atlanta, Texas System Safety Checklist

The Atlanta District of the Texas Department of Transportation (TxDOT) maintains a "System Safety Checklist" which design engineers are required to apply to their projects (TxDOT, 2021). The list includes a series of roadway features which guide the design review. The list is incorporated into the Design Summary Report process in the District. The following are factors included on the checklist:

✓ **Crash data:**
- Check priority safety project lists.
- Check with maintenance for safety issues or recurring problems.

✓ **Signage:**
- Check standards.
- Check font size.
- Reduce oversized signs.
- Chevron criteria.

✓ **Safety end treatments:**
- Driveways – extend pipes if needed.
- Cross drainage.
- Side road pipe extension to eliminate a 4-inch or greater vertical protrusion.

✓ **Lighting:**
- Upgrade to light-emitting diode (LED).
- Add lighting on intersections between two State roads.

✓ **Cross-section elements:**
- Front slopes.
- Back slopes.
- Sidewalks.

✓ **Textured pavement markings.**

✓ **Mailbox turnouts.**

✓ **Superelevation rates.**

✓ **Pavement width.**

✓ **Bridge rails.**

✓ **Tree trimming and brush growth.**

✓ **Guardrail:**
- As needed, install, upgrade, or remove if slopes can be flattened, structures can be extended, or fixed objects can be removed.
- Check clear zone and length of need.

✓ **Tree removal:**
- Present within clear zone.
- Outside of clear zone but a potential issue.
- Within right-of-way.
- Check "no mow" areas.
- Consider public involvement issues.

✓ **Geometric alignment:**
- Add turn lanes or deceleration lanes.
- Improve intersection geometry.

✓ **Pedestrian elements:**
- Update push buttons to be audible.

✓ **Delineation:**
- Upgrade and standardize guardrail delineators.
- Standard delineators.
- Check for appropriate stickers.

Plan Development

Despite the typical low-cost, low-impact nature to the surrounding area, it can be useful to develop plans for systemic projects. At a minimum, plans for systemic improvements should communicate the quantity of materials needed, accurate locations of installations, and standard installation information. Some agencies produce formal PS&E documents, using planning level topography data rather than survey data. Others use simpler documents, which reduce the cost of preliminary and final engineering.

Systemic Safety Project Plans in Tennessee

TDOT often uses "No Plans Contracts", which relay the proposed improvements to implementation staff using markups overlaid on an aerial image of locations.[10] These documents are used when no right-of-way or in-depth design is required. The documents are let-to-contract through a contractor bid process. This contract allows TDOT to deliver low-cost safety improvements in a streamlined manner. Before a No Plans Contract is let, TDOT and an in-house consultant review the following elements:

- Countermeasure constructability.
- Accurate description of improvements.
- Accurate and complete estimated quantities.
- Presence of the appropriate general notes on TDOT Standard Drawings.
- Accurate and complete sign schedule.

Figure 35 provides a screenshot of a page from one of TDOT's No Plans Contracts for local road safety improvements in Tipton County.[11]

Figure 35. Graphic. Sample No Plan Contract plan from TDOT (Source: TDOT[11]).

[10] TDOT shared this information with FHWA as an example of a noteworthy systemic safety practice.

[11] TDOT shared this resource with FHWA as an example of a noteworthy systemic safety practice.

Agency policy dictates what type of plan documents can and cannot be used for systemic safety projects. In the event agency policy significantly increases the costs associated with plan development and hinders the economic effectiveness of a systemic project, agencies should work internally to revise or develop a process that reduces the burden and provides sufficient economic effectiveness.

Material Procurement in Ohio

Beale et al. (2018) summarized the systemic safety program developed by ODOT and the Ohio LTAP to improve safety on local roads. After working together with the local agencies, the Ohio DOT decided to develop a Sign Grant program, where eligible townships can apply for grants for up to $50,000 in new signage which can be installed in a systemic or systematic manner. To overcome financial burdens for the agencies, ODOT purchased the signs using HSIP funds, meaning the local agencies receive the signs at zero cost. To reduce the administrative burden, the agencies could only install signs within existing right-of-way and where the project was classified as a categorical exclusion, and would only receive materials from ODOT (which prevented the need to track and document labor costs for reimbursements from ODOT). To receive signs through this program, agencies must qualify and attend a training course for proper installation. Finally, to close out the project, local agencies must submit confirmation of installation to ODOT. Given the structure of the program, financial, administrative, and engineering burdens are minimized for local agencies.

The delivery method may also affect what plans are used. As with TDOT, agencies using maintenance staff can likely prepare much simpler plan documents than those using a formal letting process. Less detailed design plans are also applicable for material procurement and quick-build applications.

Project Tracking

As projects are identified and implemented, agencies are encouraged to track their progress. Project tracking is valuable to agencies for numerous reasons. First, it allows agencies to monitor implementation for systemic programs. Second, it sets the stage for evaluations by tracking location and installation information. Finally, it allows agencies to track project spending, assisting with paying invoices to contractors.

FHWA published guidelines for tracking HSIP projects, including systemic projects, in the *HSIP Evaluation Guide* (Gross, 2017). Figure 36 shows the project tracking timeline, including what data should be collected at various stages of the project development process.

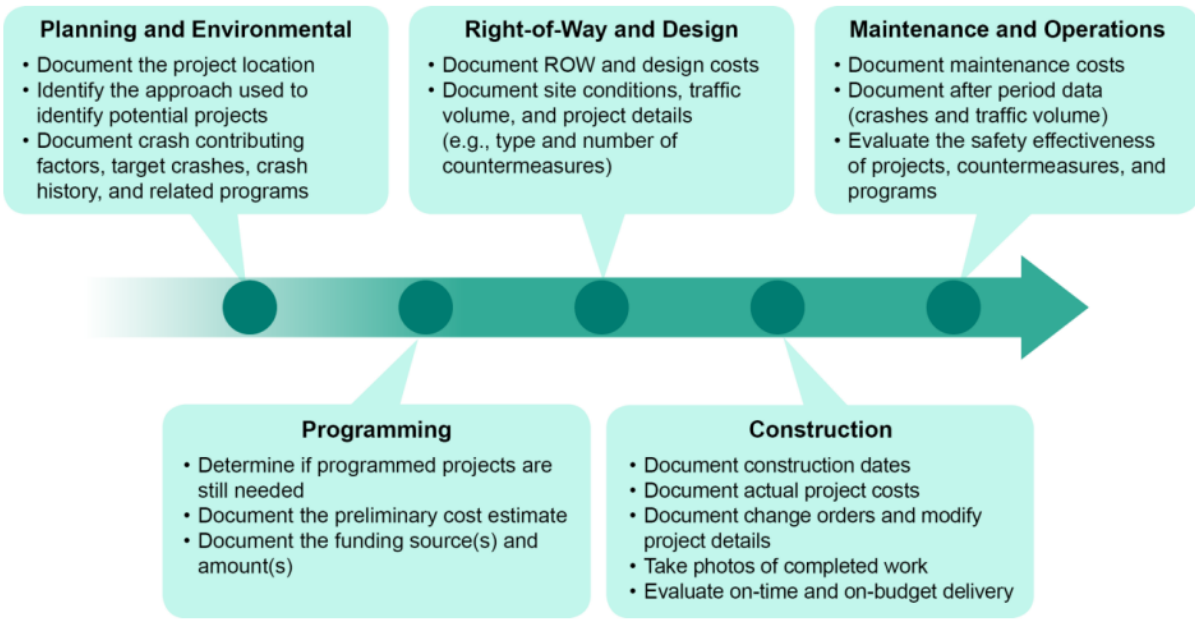


Figure 36. Graphic. The HSIP project tracking timeline (Source: Gross, 2017).

VDOT uses a Microsoft PowerBI tool for tracking implementation of systemic safety initiatives (VDOT, 2022). VDOT uses the tool to track countermeasure installations by district, including a comparison of planned and actual installations to date. This also includes details on the status of the projects (i.e., preliminary engineering, construction, and completion), funding expended to date, and planned expenditures. Figure 37 is a screenshot of the tracking dashboard, which shows the tables, charts, and maps tracking installations. The dashboard also includes a GIS Story Map which provides location and status data.

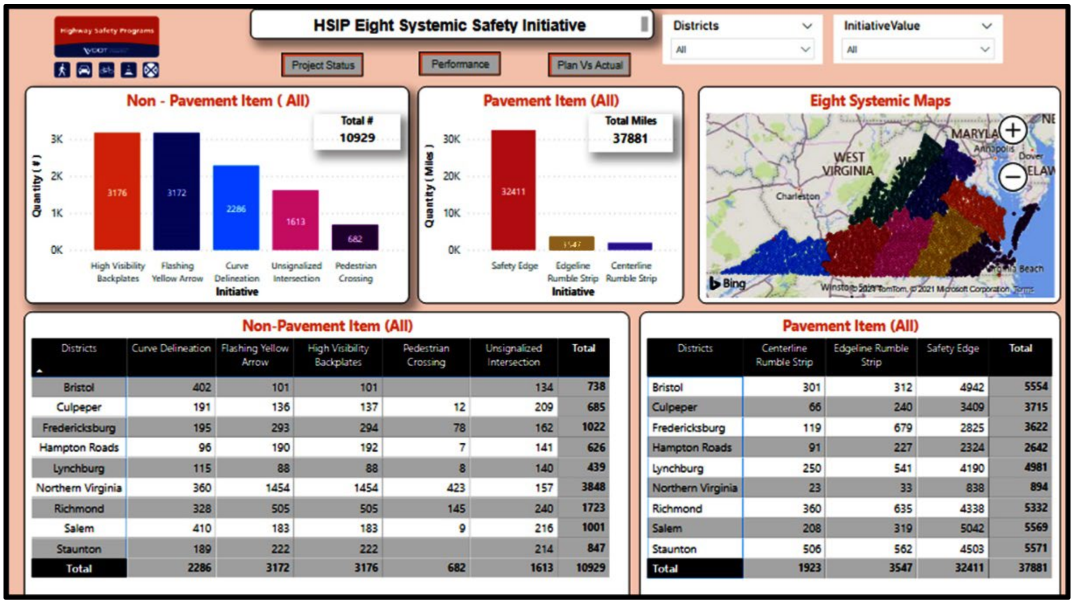


Figure 37. Graphic. Screenshot of the VDOT PowerBI systemic tracking dashboard (Source: VDOT, 2022).

Outcome

The outcome of this chapter includes:

- Plans for the implementation of a systemic project.
- Delivery mechanism selected for the implementation of a systemic project.
- Tracking the implementation of systemic projects.

Frequently Asked Questions

How can my agency verify there are no right-of-way impacts for bundled projects?

Even when installing low-cost, low-impact countermeasures, agencies should work to avoid impacts outside of existing right-of-way. Ideally, this would be verified with accurate records or survey, but given the low costs driving the benefits of systemic safety, surveys at all locations would hinder the economic effectiveness of a systemic project. In lieu of survey, agencies typically use planning-level right-of-way maps in GIS to perform a desktop review. If there are significant concerns of right-of-way impacts at a location, agencies can perform a field survey to confirm, consider relocating or changing the countermeasure, or dropping the location from the project.

How do I prevent scope creep in systemic projects?

Agency practices are typically oriented towards site-specific projects. If the typical approach is applied to bundled systemic safety improvements, such as installing an FYA or adding a pedestrian signal, a complete re-evaluation of signal warrants and upgrading all hardware at an intersection might be required. If systemic improvements are bundled, this would lead to an exponential increase in costs from full engineering reviews of each signalized intersection in a project. To avoid this significant impact on scope and cost, those charged with implementing a systemic program should work with partners and stakeholders within their agency to highlight the benefits of bundled, low-cost systemic improvements and develop a separate process or waivers for such projects.

Can I use HSIP funds to supplement regular funding sources for reconstruction?

Federal regulation (23 CFR 924.5) states that improvements to safety features that are routinely provided as part of a broader Federal-aid project should be funded from the same source as the broader project. Agencies should address the full scope of their safety needs and opportunities on all roadway categories by using all available funding sources. For example, as mentioned before, if a resurfacing or other form of rehabilitation project includes a site with elevated risk, safety improvements should be incorporated into those projects using the funding source already identified for that project.

Chapter 6 – Evaluate Systemic Safety Results

This is the sixth and final step of the systemic safety process. Given the cyclical nature of the systemic safety approach, it is important for agencies to learn from their experiences. That does not only include effectiveness of individual projects, but countermeasures, programs, and the systemic safety process as a whole.

HSIP Evaluation in Law
The HSIP requires States to establish an evaluation process to analyze and assess results achieved by the program of highway safety improvement projects [23 CFR 924.13(a)(1)].

FHWA published the *HSIP Evaluation Guide* (Gross, 2017) with extensive guidance for agencies regarding the evaluation of safety projects, countermeasures, and programs. This chapter is based on the recommendations in that guide.

Benefits of Evaluation per HSIP Evaluation Guide (Gross, 2017)

Understanding the Return on Investments

Evaluations can demonstrate the value of investment in systemic projects by documenting the benefits achieved for each dollar spent.

Inform Future Decisions

The average safety reduction and cost effectiveness identified in evaluations can inform future investments in systemic safety projects.

Improve Processes

The insights from evaluations of a systemic program can improve future systemic cycles at all steps, including network screening, project selection, and project delivery.

Demonstrate Accountability

Transportation agencies are stewards of public funds. As such, evaluation results can allow agencies to justify systemic safety investments to the public.

Meet Federal Requirements

States are required to evaluate their HSIP on an annual basis (23 U.S.C. 148(h); 23 CFR 924.15). As such, States need to evaluate any systemic programs funded through the HSIP to meet Federal HSIP requirements.

Several forms of data are necessary for a thorough and insightful evaluation. **Crash data** for the before and after period should include, at a minimum, date, location, severity, and crash type (Gross, 2017). It is preferable to include detailed crash types (e.g., pedestrian struck in crosswalk by left-turning motorist) as opposed to general crash types (e.g., pedestrian crash), and whether the crash was a focus crash type. **Project data** should include installation location, date, capital costs, and maintenance costs. Additional data may be necessary based on the sophistication of the desired evaluation approach (Gross, 2017). Agencies should consider organizing these data using a tracking method as described in the previous chapter.

Agencies can evaluate systemic safety at the project-, countermeasure-, and program-level. The following sections describe the evaluations at each level, guided by questions for agencies to ask through the evaluation process.

Project-Level Evaluations

A project-level evaluation refers to the aggregated evaluation of all individual site improvements within a bid contract or project. Agencies can answer several questions using a project-level evaluation, including:

1. Were all planned countermeasures successfully installed at each site?
2. Was the project delivered at the estimated cost and schedule?
3. Did the site improvements successfully reduce fatal and serious injuries related to the focus crash type?
4. Did the site improvements positively impact safety, comfort, access, or convenience for all roadway users?
5. Conversely, did the site improvements produce any adverse effects, such as increasing crashes involving pedestrians or bicyclists or decreasing pedestrian and bicyclist comfort or travel?
6. Did the safety benefit exceed the cost of improvements?

Agencies can answer questions 1 through 4 using project installation and crash data. An agency can use one of several methodologies ranging in statistical sophistication to compare safety performance at project locations before and after installation. Additionally, agencies can compute monetary benefits by converting the reduction in crash frequency to a dollar amount using average crash costs[12]—these can be compared to the cost of the project to see if the BCR exceeds 1.0. Agencies should compare the change in safety performance and BCR to the expected values calculated in the planning and project development process. If the crash reduction or BCR were less than expected, the agency should investigate why this may have happened. While waiting for crash data to perform evaluations, agencies can use surrogate measures to assess the potential safety improvements, such as decreased motor vehicle speed or increased compliance with traffic control (National Research Council, 2023).

Agencies can answer questions 5 and 6 using construction documentation, such as diaries from the resident engineer and change orders. The agency should investigate why any installations were modified or cancelled and if the project went over cost or schedule, then identify solutions to implement in future projects of similar nature.

[12] If crash costs are not readily available, consider reviewing FHWA's *Crash Costs for Highway Safety Analysis* guide.

Countermeasure-Level Evaluations

Countermeasure-level evaluations are similar to project-level evaluations, but rather than evaluating all sites within a project, the agency evaluates all sites which received a certain countermeasure. Countermeasure-level evaluations may include site improvements across multiple projects and even across multiple years. Countermeasure-level evaluations will help agencies answer the following questions:

1. Did the countermeasure installations successfully reduce fatal and serious injuries related to the focus crash type?
2. Did the countermeasure installations positively impact safety, comfort, access, or convenience for all roadway users?
3. Conversely, did the countermeasure installations produce any adverse effects for any roadway users, such as increasing crashes involving pedestrians or bicyclists or decreasing pedestrian and bicyclist comfort or travel?
4. Did the aggregated safety benefit from the countermeasures exceed the cost of improvements?
5. Were all planned countermeasures successfully installed?
6. Were the countermeasures installed within the expected budget?
7. Were there differences in the budget, schedule, or installation performance of the countermeasure across geography or contract mechanisms?

Agencies can answer questions 1 through 6 using the same process described in the previous Project-Level Evaluations section. The only difference is rather than aggregating data for the sites within a given contract, the agency would aggregate data for all sites which received a specific countermeasure.

If an agency has a sufficient number of sites and crash data, they can develop a CMF. CMFs typically require more rigorous statistical approaches. The *HSIP Evaluation Guide* (Gross, 2017), *A Guide to Developing Quality Crash Modification Factors* (Gross et al., 2010), and *Recommended Protocols for Developing Crash Modification Factors* (Carter et al., 2012) describe state-of-the-practice techniques for estimating and documenting CMFs. Again, while waiting for crash data, agencies can use surrogate measures for short-term assessments of safety performance (National Research Council, 2023). To answer question 7, an agency should review the aggregate performance of each project included in the countermeasure evaluation. The agency should look for potential reasons why any budget, schedule, or installation issues arose and identify ways the issue can be avoided in future projects.

Evaluating South Carolina's Systemic Intersection Improvements

The South Carolina Department of Transportation (SCDOT) deployed a range of low-cost systemic safety improvements at signalized and stop-controlled intersections throughout the State. FHWA evaluated the effort through the Evaluation of Low-Cost Safety Improvements Transportation Pooled Fund (Le et al., 2017). The evaluators used the EB before-after methodology to compare observed crashes in the after period to expected crashes. The evaluation included several crash types (all, angle, rear end, and nighttime) and severity categories (all, fatal and injury), including aggregated results as well as disaggregated results by area type (rural and urban) and facility type (three-leg and four-leg, number of lanes on approaches). Table 20 summarizes the CMF and BCR results (Le et al., 2017). SCDOT used these CMFs to inform future systemic projects of this nature. Note this approach can be used for both project-level and countermeasure-level evaluations.

Table 20. Summary of evaluation results from SCDOT systemic low-cost intersection improvements (Le et al., 2017).

Crash Type	Signalized Intersection CMF (Percent Reduction)	Stop-Control Intersection CMF (Percent Reduction)
All Crashes	0.96 (4%)	0.92 (8%)
Fatal and Injury Crashes	0.89 (11%)	0.90 (10%)
Rear-End Crashes	0.97 (3%)	0.93 (7%)
Right-Angle Crashes	0.88 (12%)	0.94 (6%)
Nighttime Crashes	0.97 (3%)	0.85 (15%)
BCR, All Crashes	4.1	12.4

Program-Level Evaluations

A program-level evaluation reviews the overall performance of a systemic safety program. There are several forms of systemic programs, including:

- Full systemic safety program.
- Crash-based systemic safety program, such as those targeted to crashes involving roadway departures or pedestrians.
- Geography-based systemic safety program, such as for a district or region.
- Ownership-based systemic safety program, such as for State roads or local roads.

Along with crash-level and implementation-level questions, a program-level evaluation should consider performance and cost compared to program goals. Program-level evaluations can answer several questions, such as:

1. Was there a reduction in fatalities and serious injuries related to the focus crash type?
2. Was there a reduction in fatalities and serious injuries on the focus facility type?
3. Were any unexpected safety benefits or adverse consequences observed?
4. Were investments distributed as intended?
5. Were the preferred countermeasures successfully selected for most candidate locations?
6. Did the program successfully implement the planned number of improvements?
7. Did the program implement the proposed countermeasures on time?
8. How did the actual program costs compare to the planned costs?
9. Were the contracts executed as planned?

To answer the crash-based questions, agencies should aggregate the results of project-level or countermeasure-level before-after evaluations—comparing the expected crashes in the after period to the observed crashes in the after period. For investment-level questions, agencies can simply compare the actual countermeasure implementations and expenditures to the planned distribution. Finally, the program-level evaluation should include a thorough review of all projects delivered within the program. While waiting for crash data, agencies can review surrogate safety measures to provide short-term feedback.

For example, to evaluate their previously mentioned PSIP, ODOT will be evaluating several metrics, including the construction performance compared to schedule, speed reduction at implementation sites, and the changes in crash frequency and severity.[13]

[13] ODOT shared this information with FHWA as an example of a noteworthy systemic safety practice.

Systemic Program Evaluations in Missouri

MoDOT was looking for methods to 1) evaluate their horizontal curve chevron program and 2) easily communicate the program effectiveness. To do so, MoDOT created a plot showing trends of roadway departure fatalities and serious injuries compared to the number of chevrons installed (MoDOT, 2021). Figure 38 shows MoDOT's program evaluation through 2020. The results show that while severe roadway departure injuries fluctuated on major roads, the increase in chevrons correlated with a consistent decrease in severe roadway departure injuries on those roads.

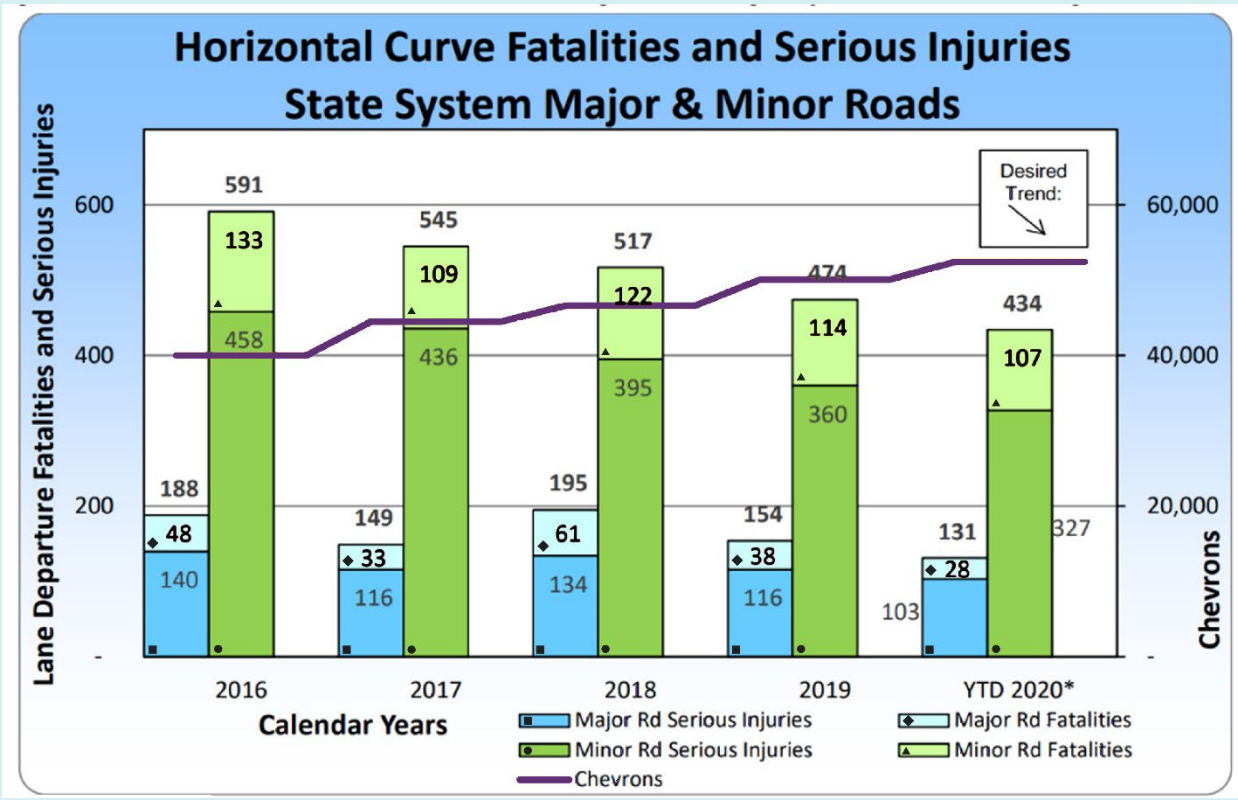


Figure 38. Graphic. System-wide program evaluation of the MoDOT chevron program (MoDOT, 2021).

Equity Considerations in Evaluation

Agencies should also consider the performance of projects, countermeasures, and programs from an equity perspective. The following are several questions to ask for different levels of evaluation, including (FHWA, 2023e):

- What data or metrics were, are being, or can be collected and analyzed to evaluate safety and equity improvements?
- Is our agency evaluating and reducing the impact of unintended consequences from social trends, including aging, gentrification, displacement, and over-policing?
- Did this project adversely affect a specific group? If yes, is there a plan in place to remediate the adverse effects?
- Did this project benefit a particular group? If yes, was that group historically underserved? If not, are there plans in place to invest in historically underserved communities?
- What limitations impact our agency's ability to evaluate all aspects of our projects, including equity impacts? Do missing data present obstacles to a full evaluation?
- What processes are in place to report evaluation results to the community and provide access to the data?

Along with the safety metrics described elsewhere in this chapter, agencies interested in an equitable evaluation may also consider examining accessibility and mobility metrics (e.g., increased walking or bicycling, transit on-time performance, improved access for underserved communities), health impact metrics (e.g., air quality, emergency response and access, access to active transportation opportunities), and community perception and feedback metrics (e.g., phone surveys, public forums, wheelchair audits/assessments) (FHWA, 2023e).

To learn more about strategies and tools to evaluate safety improvements equitably, review the resources available at https://highways.dot.gov/safety/zero-deaths/evaluate-safety-improvements-equitably.

Using Evaluation Results

Evaluation results provide several benefits to an agency. First, agencies can use the results to improve future systemic safety efforts. Agencies can use crash-based results to inform future countermeasure selection and project prioritization efforts. Countermeasure-based results can inform future project prioritization and implementation efforts. Program-level and system-level results can inform systemic safety planning, particularly related to setting program goals.

Second, documenting the effectiveness of systemic safety efforts can increase agency and stakeholder support for future systemic projects. This support is valuable for several reasons. While agency leadership may be hesitant to support a safety program that does not target historical crash locations, evidence that systemic programs are successful can generate support.

Additionally, many systemic countermeasures require regular maintenance for continued effectiveness. Showing that these countermeasures produce the desired safety effects can motivate maintenance staff to perform the necessary upkeep of the systemic countermeasures. Positive results can also encourage partner agencies to undertake systemic safety improvements for roadways under their jurisdiction.

Systemic safety, like all safety management practices, is cyclical, and evaluation should inform future efforts. This is reinforced by the systemic safety graphic in figure 39.

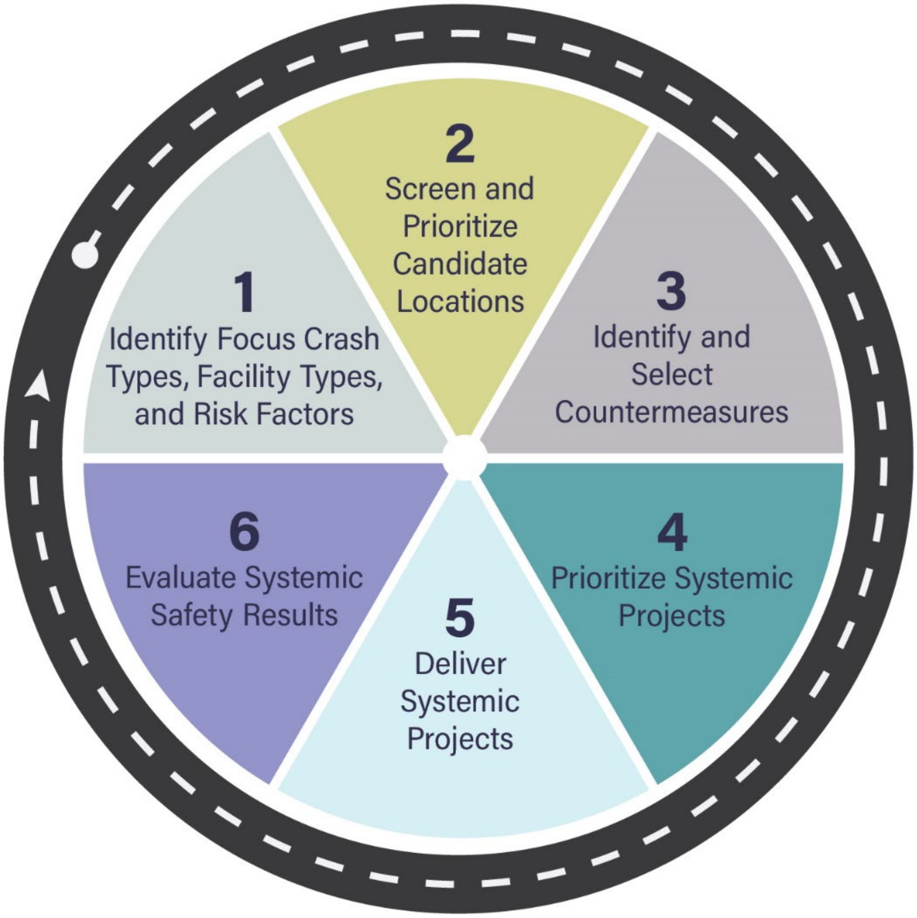


Figure 39. Graphic. The systemic safety process is cyclical, evaluation results should feed into future efforts (FHWA).

Outcome

The outcomes from systemic safety evaluations include documentation of the performance of:

- Systemic projects.
- Systemic countermeasures.
- Systemic programs.

Frequently Asked Questions

How do I know if my evaluation results are reliable?

One way to increase the confidence in your evaluation is to compare the results to other literature. For instance, if you are performing a project-level or countermeasure-level evaluation of rumble strips, you can review highly-ranked studies in the CMF Clearinghouse to compare those results to yours. In a similar fashion, you can assess your results using the CMF Clearinghouse star-rating developed in NCHRP Project 17-72 and available here: http://cmfclearinghouse.org/sqr.cfm.

If observed crashes increase after implementation, does this mean the project, countermeasure, or program is unsuccessful?

An increase in observed crashes in the after period does not necessarily mean the project, countermeasure, or program was not effective. There are several reasons why crashes might increase in the after period and it is important to further evaluate these instances to understand why and whether there is a need for additional measures. For instance, a countermeasure may be installed to reduce specific, high-severity crash types but may also result in an increase in less severe crashes. A roundabout is one such countermeasure – Bagdade et al. (2011) documented a 41.7 percent reduction in injury crashes despite a 34.6 percent increase in total crashes. While a high-level review of total crashes may suggest converting an intersection to a roundabout is unsuccessful, a more detailed evaluation by crash severity would help to uncover any differential effects. A reduction in severe crashes would indicate success from a Safe System perspective.

Crashes may also increase due to increased exposure or induced demand. For instance, the addition of a bike lane may attract more bicycle traffic to the road, which may lead to an increase in crashes. However, the crash rate per cyclist often declines, indicating a safety improvement on a per-bicyclist basis. Other reasons for a short-term increase in observed crashes may be adaptation effects or regression-to-the-mean. Regarding adaptation, there may be a short-term increase in crashes after installation, followed by the desired decrease in crashes as users adjust to the treatment. Sacchi et al. (2015) documented such an effect with the installation of pedestrian signals, showing the crash benefits increasing as the number of years since installation increases. Regression-to-the-mean reflects short-term variability in observed crashes, which can present the illusion of increases (or decreases) in crashes if not properly accounted for. Rigorous statistical techniques such as the EB method can help to account for regression-to-the-mean and reveal a more accurate picture of the long-term safety effects. Finally, a countermeasure may just not be successful at a few, some of, or many of the sites selected for implementation. In this case, as well as the other cases discussed, agencies should perform a post-evaluation diagnosis to understand what crashes are occurring in the after period, why they may be occurring, how the sites may be remedied, and what changes can be made to policies or procedures to prevent a similar problem in the future.

How many years of data should I include in my evaluation?

Generally, evaluations should include three to five years of before data and three to five years of after data. The *HSIP Evaluation Guide* (Gross, 2017) provides specific recommendations for project-level, countermeasure-level, and program-level evaluations.

How can I evaluate systemic efforts if I don't know the exact project locations?

Though agencies would prefer to accurately track systemic project locations, complications can arise, and the data may be lost or not created in the first place. While this is inconvenient, it does not preclude an agency from evaluating systemic safety efforts. One solution is to track focus crash frequency and rates in the before and after period within the geographic area affected by the project or program. This may not provide detailed results but can provide some level of feedback assuming there were sufficient project locations in the area.

Bringing it All Together

This Guide presents a six-step process for applying the systemic approach to safety. This chapter presents an example using the systemic safety approach to perform a system-wide risk assessment and implement a systemic program to reduce fatalities and serious injuries.

Example

After a State experienced an increase in fatal and serious injury crashes for three consecutive years, the State transportation agency (STA) recognized the need to perform a risk assessment of their State highway system and implement a program to address the high risk sites identified in the assessment. The purpose of the risk assessment is to identify the sites on the system at most risk for a fatal or serious injury crash. The following sections describe the STA approach to deploying the six-step process for the system-wide risk assessment.

Step 1 – Identify Focus Crash Types, Facility Types, and Risk Factors

Recognizing the challenge in addressing risk on the entire State highway system, the STA begins with narrowing the focus of fatal and serious injury risk. After reviewing their SHSP, the STA identified four general focus crash types that account for more than 95 percent of traffic fatalities in the State:

- Roadway departure crashes – 62 percent.
- Multi-vehicle intersection crashes – 21 percent.
- Vehicle-pedestrian crashes – 11 percent.
- Vehicle-bicycle crashes – 3 percent.

Per the SHSP, no other crash type exceeded 1 percent.

Task 1 – Identify Focus Crash Types

By using the SHSP to guide their decision making, the STA used Option 1 (Overrepresentation) and Option 3 (Established Findings) described above to dictate their focus crash types, which are:

- Roadway departure crashes.
- Multi-vehicle intersection crashes.
- Vehicle-pedestrian crashes.
- Vehicle-bicycle crashes.

The STA queried the fatal and suspected serious injury crashes which occurred on the State system by crash type and found the following distribution, which was similar to the SHSP:

- Roadway departure crashes – 54 percent.
- Multi-vehicle intersection crashes – 25 percent.
- Vehicle-pedestrian crashes – 12 percent.
- Vehicle-bicycle crashes – 3 percent.

Given the similar distribution, the STA felt confident moving forward with these categories as their focus crash types for the system-wide risk assessment.

Task 2 – Identify Focus Facility Types

To further focus the risk assessment, the STA selected general focus facilities, acknowledging the various contexts under which these focus crashes occur. Given the goal of covering the full system, the STA opted to keep the focus facilities general. The STA used crash trees to identify focus facilities for each crash type. Figure 40 is the STA-developed crash tree for roadway departure crashes. Generally, the STA selected focus facilities that are similar in nature and have experienced at least 70 focus crashes (based on engineering judgement), though they reduced this threshold in some cases. For example, the STA combined urban divided interstates, freeways, and expressways as a focus facility, despite being below the threshold, because of the importance of these facilities to system coverage. Ultimately, the STA selected the following focus facilities:

- Rural divided highways.
- Rural two-lane undivided highways.
- Rural multilane undivided highways.
- Urban divided interstates, freeways, and expressways.
- Urban divided arterials.
- Urban two-lane undivided highways.
- Urban multilane undivided highways.

Table 21 summarizes the STA-selected focus facilities for each crash type. Note that the STA used Option 1 for selecting the focus facilities – choosing the facilities which account for the most crashes.

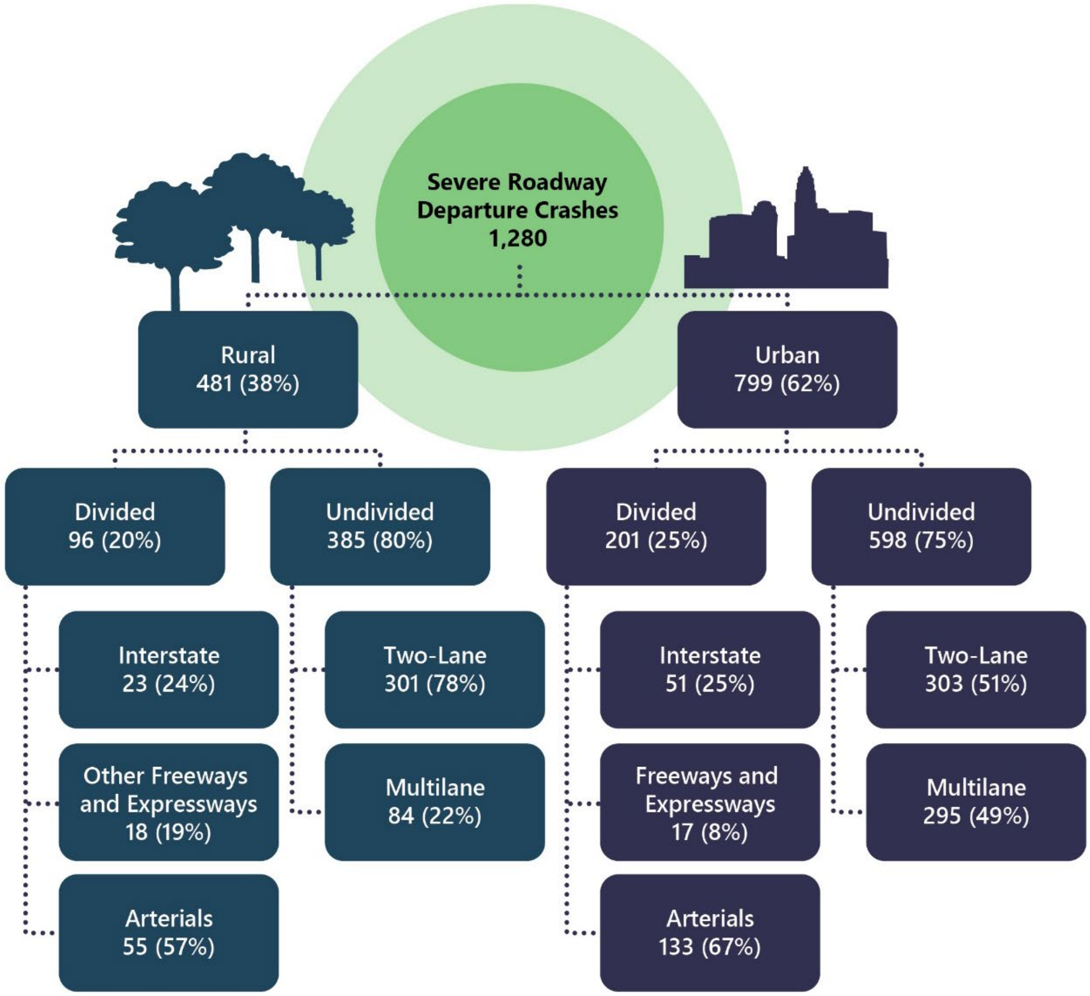


Figure 40. Graphic. Roadway departure crash tree developed for system-wide risk assessment (Source: FHWA).

Table 21. Focus facilities by crash type for the systemwide risk assessment.

Focus Facility Types	Roadway Departure Crash	Multi-Vehicle Intersection Crash	Vehicle-Pedestrian Crash	Vehicle-Bicycle Crash
Rural divided highways (excluding full access-control roads).			●	●
Rural divided highways.	●		●	●
Rural multilane undivided highways.	●		●	●
Rural signalized intersections.		●	●	●
Rural stop-controlled intersections.		●	●	●
Rural two-lane undivided highways.	●			
Rural undivided highways.			●	●
Urban divided arterials.	●		●	●
Urban divided highways (excluding full access-control roads).	●		●	●
Urban divided interstates, freeways, and expressways.	●			
Urban multilane undivided highways.	●		●	●
Urban signalized intersections.		●	●	●
Urban stop-controlled intersections.		●	●	●
Urban undivided highways.	●		●	●
Urban two-lane undivided highways.	●		●	●
Rural intersections – other traffic control.		●	●	●
Urban intersections – other traffic control.		●	●	●

Task 3 – Identify Risk Factors

With the selected focus areas, the STA had 33 combinations of focus crash type and facility type for which they identified risk factors. The STA reviewed available staff and financial resources to perform analysis, ultimately adopting the following approaches:

- Roadway departure crashes – used in-house staff to perform overrepresentation analysis.
- Multi-vehicle intersection crashes – used in-house staff to identify relevant risk factors from established findings in the literature.
- Vehicle-pedestrian crashes – contracted with a consultant to perform statistical modeling and identify risk factors.
- Vehicle-bicycle crashes – used in-house staff to identify relevant risk factors from established findings in the literature. Supplemented these risk factors with additional risk factors based on stakeholder input.

After completing these reviews and analysis, the STA summarized the risk factors applicable to the 33 combinations of focus crash type and facility type. Table 22 summarizes some of the risk factors identified by the STA for a sample of focus crash and facility type combinations.

Table 22. Example risk factors.

Roadway Departure Crash on Rural Two-Lane Undivided Highways	Multi-Vehicle Intersection Crash at Urban Stop-Controlled Intersections	Vehicle-Pedestrian Crashes on Urban Undivided Highways	Vehicle-Bicycle Crashes at Urban Signalized Intersections
• Shoulder width narrower than 3 ft. • Lane width narrower than 11 ft. • Clear zone narrower than 10 ft. • Presence of a horizontal curve with radius of 570 feet or sharper. • AADT less than 3,000 vehicles per day. • Presence of pavement edge dropoff. • 85th-percentile speed at least 10-mph above the posted speed limit.	• Total entering volume (continuous risk), vehicles per day. • Intersection skew angle greater than 10 degrees. • Major road speed limit is at least 45 mph. • Presence of horizontal curve on major road approach. • Presence of crest vertical curve on major road approach. • Presence of transit stop within 0.25 mi of intersection. • Presence of parking on minor road approach.	• No marked crosswalk present along segment. • Posted speed limit is at least 35 mph. • At least 4 through lanes present on the segment. • No sidewalk present along the segment. • Transit stop present along the segment. • At least 2 alcohol sales establishments within a quarter mile of the segment. • At least 1 school within a quarter mile of the segment.	• Major road approach is at least 4 lanes. • Major road speed limit is at least 35 mph. • Minor road speed limit is at least 30 mph. • Transit stop present within a quarter mile of the intersection. • At least 2 alcohol sales establishments within a quarter mile of the intersection. • At least 1 school within a quarter mile of the intersection. • No shoulder present on the major approach. • No shoulder present on the minor approach.

The example in table 22 primarily includes binary risk factors; however, the STA identified several continuous risk variables (such as total entering volume at intersections). After completing the analysis, the STA proceeded with Step 2.

Step 2 – Screen and Prioritize Candidate Locations

The STA is executing this project with the purpose of a system-wide risk assessment of the State highway system. As such, this step is crucial for the completion of the assessment.

Task 1 – Identify System Elements to Analyze

The STA reviewed the State highway system to identify the system elements for analysis. Ultimately, the STA settled on individual intersections for intersection elements and 0.10-mi segments for roadway segment system elements. The STA created the system elements and verified that the data necessary for risk scoring are present at all locations. The STA obtained the data from a variety of sources, including their MIRE data, traffic counts, GIS data from their Asset Management and Planning groups, and socioeconomic data from the US Census Bureau, American Community Survey, Environmental Protection Agency, and the State's Department of Health.

Task 2 – Calculate Risk Score

The next task is to calculate the risk score. The STA elected not to apply any weights to individual risk factors as they were concerned about introducing unintentional bias to their results. The STA calculated the individual element risk scores based on the presence (for binary factors) and value (for continuous factors) of relevant risk factors. Given the different number of risk factors included in each focus crash type and facility type combination, the STA calculated normalized risk scores—the location-specific risk score divided by the maximum potential risk score for that element. This task produced a roadway departure, vehicle-pedestrian, and vehicle-bicycle risk score for each segment and a multi-vehicle intersection, vehicle-pedestrian, and vehicle-bicycle risk score for each intersection. Table 23 is an example risk calculation for vehicle-pedestrian crashes on urban undivided highways. Note that the risk score is increased by 1 for each risk factor present. The STA then calculated a normalized risk score (0.57) by dividing the score for this location (4) by the total number of risk factors for this element (7).

Table 23. Example risk score calculation for vehicle-pedestrian crashes on urban undivided highways.

Risk Factor	Site Feature	Risk Score
No marked crosswalk present along segment	Marked crosswalk present on the segment	0
Posted speed limit is at least 35 mph	45 mph	1
At least 4 through lanes present on the segment	2 lanes	0
No sidewalk present along the segment	Sidewalk present	0
Transit stop present along the segment	Transit stop present	1
At least 2 alcohol sales establishments within a quarter mile of the segment	4 alcohol licenses	1
At least 1 school within a quarter mile of the segment	1 school	1
	Total Score:	4
	Normalized Score (out of 7):	0.57

Task 3 – Prioritize System Elements

After assigning risk scores to each element, the STA ranked the system elements by normalized risk score. The STA created two assessment maps: crash-specific risk assessment maps and total risk assessment maps. For the crash-specific risk assessment maps, the STA simply sorted the sites by the relevant crash type normalized risk score. For the total risk assessment, the STA summed the normalized risk scores across the focus crash types, and then sorted the sites based on the total risk score. For example, if the crash-specific normalized risk scores for an urban signalized intersection included 76 percent for multi-vehicle intersection crashes, 25 percent for vehicle-pedestrian crashes, and 43 percent for vehicle-bicycle crashes, then the total risk score for the intersection would be 144. Table 24 shows an example of the normalized and total risk score for five intersections. Note the maximum total risk score for a site is 300 (100 for each of the three individual focus crash types).

Table 24. Example normalized and total risks scores for intersections.

Intersection ID	Normalized Multi-Vehicle Intersection Risk Score	Normalized Vehicle-Pedestrian Risk Score	Normalized Vehicle-Bicycle Risk Score	Total Risk Score
15143	76%	25%	43%	144
98431	24%	44%	7%	75
26265	37%	32%	68%	137
77433	71%	21%	25%	117
21212	64%	76%	63%	203

The STA then assigned percentile ranking to the normalized risk scores, so the top 3 percent of sites by normalized risk score were assigned a percentile ranking from 97 to 100, because they ranked higher than 97 to 100 percent of sites. Finally, for prioritization purposes, the STA developed tiers of sites based on their percentile ranking. Table 25 describes the risk tiers used for the risk assessment, including the name, range of normalized risk scores, and percentile ranking range. The top tier, "Primary Risk Sites" includes the top 3 percent of sites and accounts for normalized risk scores from 0.95 to 1.00. The remaining tiers include "High-Risk Sites," "Medium-Risk Sites," "Low-Risk Sites," and "Minimal-Risk Sites." Note that though "Primary Risk Sites" only account for 3 percent of sites, those sites account for 21 percent of severe injuries on the STA's system. Figure 41 is an example map of a small town with intersections visualized by risk tier.

Table 25. Example risk tiers for the statewide risk assessment.

Risk Tier	Range of Normalized Risk Score	Percentile Ranking Range	Percent of Severe Injuries
Primary Risk Sites	0.95 to 1.00	97 to 100	21%
High-Risk Sites	0.85 to 0.95	90 to 97	15%
Medium-Risk Sites	0.50 to 0.85	70 to 90	14%
Low-Risk Sites	0.25 to 0.50	50 to 70	17%
Minimal-Risk Sites	0 to 0.25	0 to 50	33%

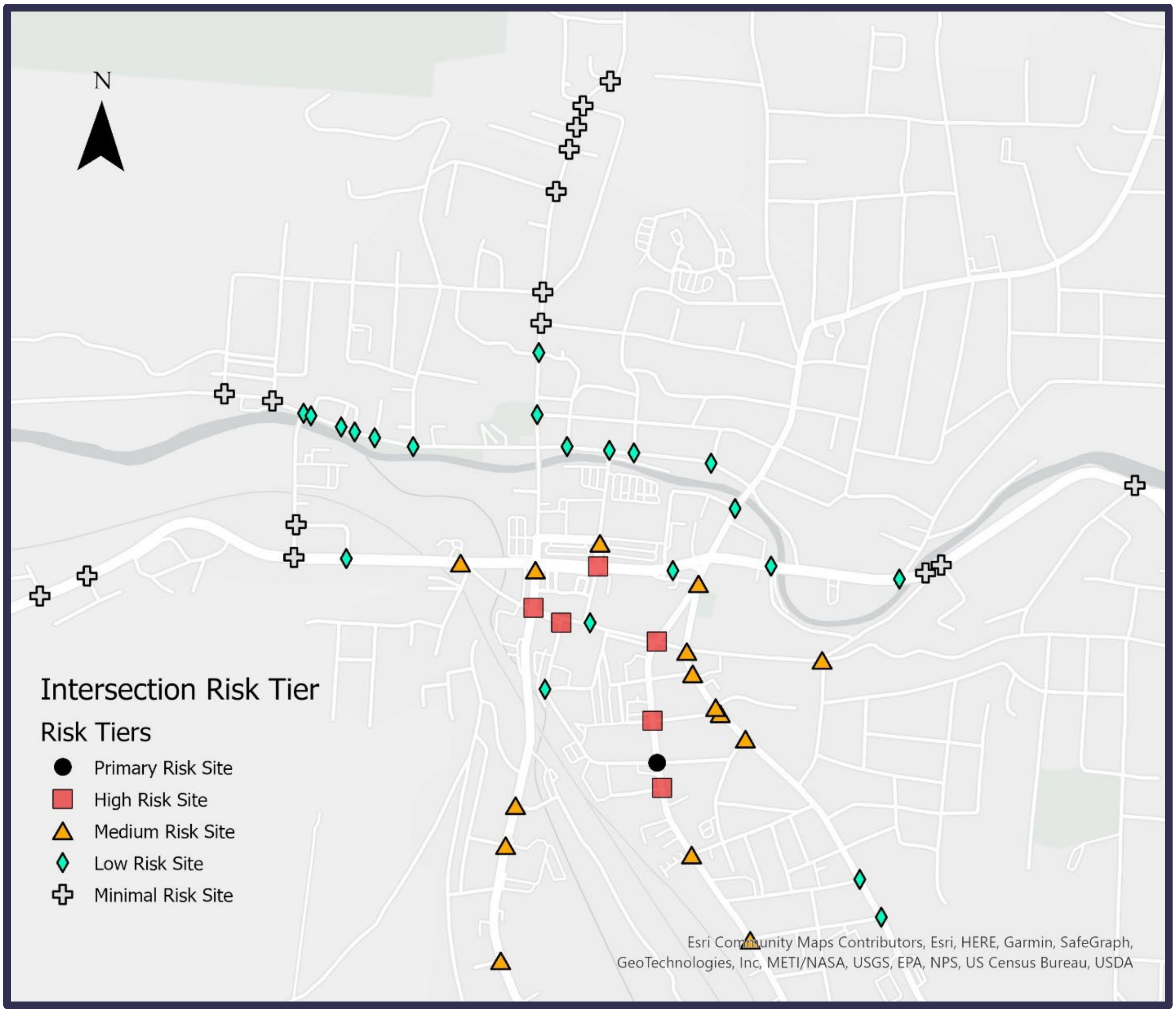


Figure 41. Graphic. Example intersection risk tier map. (Source: FHWA).

Step 3 – Identify and Select Countermeasures

After completing the risk assessment, the next step is to identify systemic countermeasures for installation. For each focus crash and facility type, the STA developed a plan to systemically deploy safety countermeasures. For example, the STA selected pedestrian safety countermeasures at urban mid-block crossings to address vehicle-pedestrian crashes on urban undivided road segments. The remainder of Step 3 and Step 4 focus on this specific example.

Task 1 – Develop List of Potential Countermeasures

The STA began with a review of the following pedestrian safety literature to identify potential countermeasures to address vehicle-pedestrian crashes on urban undivided road segments:

- FHWA's CMF Clearinghouse (FHWA, 2023fc).
- FHWA's Proven Safety Countermeasures (FHWA, 2023db).
- FHWA's STEP Resources (FHWA, 2023gd).
- NCHRP Research Report 926 – *Guidance to Improve Pedestrian and Bicyclist Safety at Intersections* (Sanders et al., 2020).
- Pedestrian Safety Guide and Countermeasure Selection System (FHWA, 2023he).
- The National Association of City Transportation Officials (NACTO) *Urban Street Design Guide* (NACTO, 2013).

Task 2 – Select Countermeasures for Deployment

After reviewing the potential countermeasures, the STA and their stakeholders elected to implement countermeasures at uncontrolled crossings consistent with the approach outlined by the FHWA countermeasure matrix published in the *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* (Blackburn et al., 2018), which is provided as figure 42.

Roadway Configuration	Posted Speed Limit and AADT																										
	Vehicle AADT <9,000									Vehicle AADT 9,000-15,000									Vehicle AADT >15,000								
	≤30 mph			35 mph			≥40 mph			≤30 mph			35 mph			≥40 mph			≤30 mph			35 mph			≥40 mph		
2 lanes (1 lane in each direction)	1^*	2		1^*			1^+			1^*			1^*			1^+			1^*			1^+			1^+		
	4	5	6		5	6		5	6	4	5	6		5	6		5	6	4	5	6		5	6		5	6
				7		9	7^*		9^*				7		9	7^*		9^*	7		9	7		9			9^*
3 lanes with raised median (1 lane in each direction)	1^*	2	3	1^*		3^*	1^+		3^*	1^+		3	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*
	4	5			5			5		4	5			5			5		4	5			5			5	
				7		9	7^*		9^*	7		9	7^*		9^*	7^*		9^*	7		9	7^*		9^*			9^*
3 lanes w/o raised median (1 lane in each direction with a two-way left-turn lane)	1^*	2	3	1^*		3^*	1^+		3^*	1^+		3	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*
	4	5	6		5	6		5	6	4	5	6		5	6		5	6	4	5	6		5	6	5	6	
	7		9	7		9			9^*	7		9	7^*		9^*			9^*	7		9			9^*			9^*
4+ lanes with raised median (2 or more lanes in each direction)	1^*		3^*	1^*		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*
		5			5			5			5			5			5			5			5			5	
	7	8	9	7	8	9		8	9^*	7	8	9	7^*	8	9^*		8	9^*	7^*	8	9^*		8	9^*		8	9^*
4+ lanes w/o raised median (2 or more lanes in each direction)	1^*		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*	1^+		3^*
		5	6		5	6^*		5	6^*		5	6^*		5	6^*		5	6^*		5	6^*		5	6^*		5	6^*
	7	8	9	7	8	9		8	9^*	7	8	9	7^*	8	9^*		8	9^*	7^*	8	9^*		8	9^*		8	9^*

Given the set of conditions in a cell,

Signifies that the countermeasures is a candidate treatment at a marked uncontrolled crossing location.

* Signifies that the countermeasure should always be considered, but not mandated or required, based upon engineering judgement at a marked uncontrolled crossing location.

+ Signifies that crosswalk visibility enhancements should always occur in conjunction with other identified countermeasures.

The absence of a number signifies that the countermeasure is generally not an appropriate treatment, but exceptions may be considered following engineering judgement.

1 High-visibility crosswalk markings, parking restrictions on crosswalk approach, adequate nighttime lighting levels, and crossing warning signs.

2 Raised crosswalk

3 Advance Yield Here to (Stop Here For) Pedestrian sign and yield (stop) line

4 In-Street Pedestrian Crossing sign

5 Curb extension

6 Pedestrian refuge island

7 Rectangular Rapid-Flashing Beacon (RRFB)

8 Road Diet

9 Pedestrian Hybrid Beacon (PHB)

Figure 42. Graphic. STEP Countermeasure matrix for uncontrolled crossings (Source: Blackburn et al., 2018).

This matrix included targeted countermeasure recommendations for sites based on traffic volume, posted speed limit, and cross-section characteristics. The STA utilized a team of engineers and planners to review the eligible countermeasures for each site on the Prioritized List. The team assigned relevant countermeasures to each location. The STA then began discussion of prioritization and implementation. To do so, the STA bundled the proposed improvements geographically (e.g., Region 1, Region 2, Region 3, and Region 4).

Step 4 – Prioritize Systemic Projects

Task 1 – Identify Available Budget

The STA elected to implement the urban mid-block systemic projects as part of their overall safety program, meaning that the projects would enter the pool of all safety projects to determine priority for funding. As such, the STA did not feel the need to apply any limitations to the scope or level of effort for the potential project.

Task 2 – Prioritize Safety Projects for Implementation

The STA uses expected BCR to prioritize safety projects. As such, the STA calculated the BCR for each bundled project. The general approach is to estimate the safety performance for future no-build conditions at the identified sites using crash history. The STA then applies a CMF for the proposed countermeasure(s) to estimate the reduction in crashes. The STA multiplies the reduction in crashes by crash costs to calculate project benefits. Finally, the STA calculates BCR by dividing the benefits by capital and maintenance costs. The following is an example specific to the projects implementing the pedestrian countermeasures described previously:

- A review of crash data for the previous five years showed that the uncontrolled crossings designated as primary risk averaged 0.25 pedestrian crashes per year. Based on the severity distribution of those crashes, one pedestrian crash carried an average cost of $630,000.
- The STA assigned a CMF to each countermeasure included in the program. The CMFs were taken from a review of the CMF Clearinghouse. For instance, the STA applied a CMF of 0.31 for RRFBs.[14]
- The STA calculated the expected reduction in crashes for each crossing by multiplying the expected crash frequency by the Crash Reduction Factor (CRF) for the service life of the treatment. For an RRFB with a 15-year service life, this calculation was 0.25 crashes per year * 0.69 * 15 years for a total reduction of 2.6 pedestrian crashes over service life.
- The STA then converted the crash reduction to monetary benefits by multiplying the estimated crash reduction by the average crash cost of $630,000. Continuing the RRFB example, multiplying the total reduction of 2.6 crashes by $630,000 per crash produced a total monetary benefit of $1.64 million.
- The STA summed this benefit for each proposed improvement in the bundle, then divided by the total bundle cost. For Region 1, the total benefit was calculated as $32.3 million with a project cost of $412,000, producing a BCR of 78.4. Regions 2, 3, and 4 had BCRs of 16.1, 45.2, and 33.6 respectively. The STA funded the four projects estimated in this example.

[14] https://www.cmfclearinghouse.org/detail.php?facid=11158

Step 5 – Deliver Systemic Projects

Project Plans

To keep project costs down and given the fact that all proposed improvements were within the right-of-way, the STA elected to produce "No Plan" plan sets using the STA's design team. These featured aerial imagery of each project location with mockups indicating where each proposed countermeasure would be implemented.

Project Delivery

As stated previously, the STA prepared bundled improvements for each region. These were ultimately advertised and let as construction projects in individual contracts for each region's bundle. To encourage quick implementation, the STA included monetary incentives for every week the contractor completed the work earlier than a previously established date. Additionally, the STA included responsibility of the contractor for identifying and working around utility complications in the contract.

Project Tracking

As part of the overall risk assessment program, the STA created a systemic project tracking tool which could be incorporated into their overall HSIP program. The tool lived in a cloud GIS environment and project managers were responsible for entering countermeasure installation locations and dates.

Step 6 – Evaluation

The project and effort associated with the risk assessment program was a significant investment for the STA, partially funded by the HSIP. In accordance with 23 CFR 924.15, the STA performed an evaluation of the individual projects, countermeasures, and overall program. Three years after completion of the projects, the STA returned to their project tracking program to prepare an evaluation dataset. Table 26 summarizes the methodology and performance measures used by the STA for each evaluation level. To balance resources, the STA performed the project-level and program-level evaluations internally while contracting with a local university partner to perform the countermeasure evaluations using the EB before-after method.

Table 26. Evaluation methodologies.

Evaluation Level	Methodology	Performance Measures
Project	Simple Before-After	• BCR • Target crash frequency • Target crash severity
Countermeasure	EB Before-After	• BCR • CMF for total crashes • CMF for injury crashes • CMF for target crashes
Program	Naïve Before-After	• BCR • Lives saved and serious injuries prevented • Target crash frequency • Target crash severity

Data Preparation

The STA used a GIS environment to prepare the evaluation data, starting with the geolocated project information and installation dates. The STA then added geolocated crash data for the three years before installation and the three years after installation to the GIS environment and used spatial analysis tools to assign crashes to individual project locations. Next, the STA added historical traffic volume maps to the GIS environment and used spatial analysis tools to add AADTs in the before period and after period to each project location. This produced an integrated dataset for evaluation. Table 27 is an example of the dataset collected for the evaluation. Each entry is an individual systemic project location with sufficient information for analysts to aggregate the data at the project, countermeasure, and program level.

Table 27. Example disaggregated project-level data for evaluation.

Program	Project Name	Contract #	Project Countermeasure(s)	Project Location	Before Crashes	After Crashes	Before AADT	After AADT
Urban Unmarked Crossings	District 1 Unmarked Crossing Improvements	329456	Crosswalk Markings, RRFB, Signage	SR 28, MP 1.4	9 Total 6 FI 1 Pedestrian	6 Total 2 FI 0 Pedestrian	5,000	5,100
Urban Unmarked Crossings	District 1 Unmarked Crossing Improvements	329456	Crosswalk Markings, PHB, Signage	SR 35, MP 17.4	3 Total 2 FI 0 Pedestrian	1 Total 1 FI 1 Pedestrian	3,400	3,300
Rural Undivided Rumble Strips	Western State Rumble Strips	329012	Center line rumble strips, edgeline rumble strips	SR 129, MP 1.1 to 7.5	17 Total 12 FI 13 Lane Departure 2 Head On	23 Total 6 FI 4 Lane Departure 0 Head On	2,100	2,700
Rural Stop-Control Intersection Improvements	Eastern State Intersection Delineation Improvements	329016	Double Stop Signs, Stop Bars, Intersection Warning Signs	SR 32 & CR 855	1 Total 0 FI 1 Angle	2 Total 0 FI 0 Angle	600	800

Note: SR = State route; MP – milepost; CR = County route; and FI = fatal and injury crash.

Project-Level Evaluations

The STA used a simple before-after approach to evaluate the systemic projects. To do so, they aggregated crash and exposure data (i.e., VMT for segments and entering vehicles for intersections) for each site improvement in a project using the contract number. The STA then calculated an average crash rate across all sites for the before condition by summing the crashes in the before period and dividing by the summed exposure during that period. The STA then estimated the crashes without treatment by multiplying the average crash rate in the before period by total exposure in the after period. Finally, the STA compared the observed crashes with treatment to the estimated crashes without treatment. The STA repeated this process for total crashes, fatal injury (FI) crashes, and the appropriate target crash type(s) for each project. Table 28 is an example of the simple before-after calculations for total crashes for the bundled pedestrian projects. Note that the calculations included total reduced crashes in the after period as well as annualized results. The STA produced similar tables for FI crashes and target crashes. These tables were used to directly measure the change in target crash frequency performance measure.

The table output was also used to calculate BCR. For each project, the STA compiled the total annual crash reduction, FI annual crash reduction, and PDO annual crash reduction. The STA then converted the annual reductions to crash cost savings by multiplying the annual reduction by the average cost of a FI crash and PDO crash on the STA's road system. The STA then calculated the service life benefit by multiplying the annual benefit by the service life of the project. Finally, the STA calculated the BCR by dividing the service life benefit by the project cost and anticipated maintenance costs. Table 29 summarizes the BCR calculations for the vehicle-pedestrian project bundles discussed in previous examples. Note that while all projects returned a significant return on investment, some were much more successful than others. Additionally, the STA compared the BCR results to the estimated results described in Step 4, Task 2, and noted that the projects produced different results than expected.

The STA noticed the BCR for the Region 3 unmarked crossing improvements project was lower than both the expected BCR from Step 4, Task 2 and the BCR observed in other Regions. This led the STA to perform a deep dive into the Region 3 installations. After comparing the "after" period crash data in Region 3 to the other regions, the STA found a higher proportion of crashes at night in Region 3. Based on this result, the STA is programming a second round of improvements targeting the Region 3 locations to improve nighttime visibility and delineation at the crossings.

Finally, the STA reviewed the before and after crash data to compare the change in average crash severity for each project. They did so by calculating the average crash cost in the before period and average crash cost in the after period for target crashes. The STA calculated costs using crashes at each KABCO severity level.

Table 28. Example aggregated project-level before-after calculations.

Project & Contract #	Before Crashes, All	Before Exposure (MVMT or MEV)	After Crashes, All	After Exposure (MVMT or MEV)	Before Crash Rate	Estimated Crashes in After Period	Reduced Crashes in After Period	Annual Reduced Crashes in After Period
Region 1 Unmarked Crossing Improvements - 329456	121	273.8	88	284.8	0.44	125.3	37.3	12.4
Region 2 Unmarked Crossing Improvements - 329457	548	659.7	475	646.5	0.83	536.6	61.6	20.5
Region 3 Unmarked Crossing Improvements – 329458	274	1,026.6	298	1,149.8	0.27	310.4	12.4	4.1
Region 4 Unmarked Crossing Improvements - 329459	68	124.6	41	145.6	0.55	80.1	39.1	13.0

Note: MVMT = million vehicle miles traveled; MEV = million entering vehicles.

Table 29. Example project BCR calculations.

Project & Contract #	Annual FI Crash Reduction	Annual PDO Crash Reduction	FI Crash Cost	PDO Crash Cost	Annual Crash Savings	Service Life	Service Life Benefits	Total Cost	BCR
Region 1 Unmarked Crossing Improvements - 329456	4.2	8.2	$423,400	$17,000	$1,917,680	15	$28,765,200	$412,000	69.8
Region 2 Unmarked Crossing Improvements - 329457	10.5	10	$423,400	$17,000	$4,615,700	15	$69,235,500	$423,000	163.7
Region 3 Unmarked Crossing Improvements – 329458	0.4	3.7	$423,400	$17,000	$232,260	15	$3,383,900	$360,450	9.4
Region 4 Unmarked Crossing Improvements - 329459	6.2	6.8	$423,400	$17,000	$2,740,680	15	$41,110,200	$147,980	277.8

Countermeasure Evaluations

As stated previously, the STA contracted with a local university to perform EB before-after evaluations of several countermeasures. The STA transferred the data from the previously prepared project evaluation dataset. Additionally, the university reviewed the system to identify and collect data for comparison sites for each countermeasure. For each comparison site, the university also collected crash and traffic data in the before and after period.

Following the prescribed EB procedure, the university used the comparison sites to estimate SPFs and correction factors for each year in the before and after period. The university then followed the EB methodology to calculate expected crashes with and without treatment. Finally, the university calculated the CMF for each countermeasure by dividing the expected crashes with and without treatment. This process was completed for total crashes, FI crashes, and target crashes.

The university also calculated a BCR for each countermeasure by converting the reduction in crash frequency to costs and comparing that to the cost of the countermeasure installations.

Program Evaluations

Finally, the STA completed five program evaluations as part of the risk assessment effort:

- Total risk assessment program.
- Pedestrian risk program.
- Intersection risk program.
- Roadway departure risk program.
- Bicycle risk program.

These evaluations were performed using a similar approach as the project-level evaluations. Rather than aggregating the site results at the project level, the STA aggregated at the program level. This produced the BCR, target crash frequency, and target crash severity performance measures.

For lives saved and serious injuries prevented, the STA looked at the average proportion of KABC crashes which included a fatality or serious injury and multiplied that proportion by the reduced KABC crashes. For example, prior to implementing the lane departure program, 3 percent of KABC lane departure crashes result in a K injury (i.e., a fatality), while 12 percent result in an A injury (i.e., a suspected serious injury). The lane departure program reduced an average of 150 KABC lane departure crashes per year, thus saving 4.5 lives (3 percent of 150) and preventing 18 A injuries (12 percent of 150) per year. Aggregating results at the focus crash level for each program helps align the program results with the SHSP, and inform future safety performance target setting exercises.

Outcomes

The STA produced a proactive safety program based on the results of a system-wide risk assessment. The initial effort included the identification of focus crash types, focus facility types, and risk factors to describe the crashes, facilities, and conditions associated with the highest risk of fatalities and serious injuries on the system.

The STA proceeded to develop several targeted programs and projects which delivered low-cost safety countermeasures to the highest risk sites across the system. To verify effectiveness of the approach, the STA evaluated the projects, countermeasures, and programs and found that their approach produced noteworthy reductions in lane departure, intersection, pedestrian, and bicycle fatalities and serious injuries across the State system.

With the approach proven effective, the STA elected to continue this process on a five-year cycle; where the STA produces a new risk-assessment every five years, then develops safety programs around those results to implement during that period. The STA also encouraged the application of the risk results outside of the HSIP and safety program, incorporating targeted low-cost safety countermeasures on all Federal-aid projects which fall on or near a “Primary,” “High,” or “Medium” risk site.

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Case Studies

The following are a select group of case studies which highlight notable systemic safety efforts. Note that these case studies highlight a variety of approaches to implementing systemic safety. Some case studies follow the process described in this Guide closely, while others show how the process is adapted to their needs.

Thurston County, Washington

The Washington State Department of Transportation (WSDOT) operates a County Safety Program as part of its HSIP (WSDOT, 2023). For counties to be eligible for funding under this program, they must document their safety issues through an LRSP. Thurston County has published several of these plans—the most recent, titled the *Thurston County Transportation Safety Plan*, was published in 2018 and updated in 2021 (Thurston County, 2021). The County used systemic safety analysis to identify focus crash types, focus facility types, and risk factors to guide their safety plan. This case study describes Thurston County's systemic safety process.

Source

The source for this case study is the *Thurston County Transportation Safety Plan*, published in June 2018 and updated in 2021 (Thurston County, 2021).

Objective

The objective of the safety plan is to achieve progress towards Washington's vision of zero deaths and serious injuries by 2030.

Data

Thurston County relied on data from more than 700 crashes on the county road system from 2012 through 2015. These data were obtained through the County Road Administration Board's (CRAB) MOBILITY system (Thurston County, 2021). The County supplemented these data with additional fatal and serious injury crashes from 2011, producing a sample of 36 fatalities and 123 serious injuries for analysis. Thurston County also pulled roadway data for the county from the CRAB MOBILITY system. Table 30 lists the roadway data elements in the Thurston County database.

Table 30. Roadway data elements for Thurston County.

Segments (Excluding Curves)	Curves
Segment Length	Curve Radius
Average Daily Traffic (ADT)	Curve Length
Number of Lanes	ADT
Posted Speed Limit	Number of Lanes
Center Turn Lane	Posted Speed Limit
Lane Width	Lane Width
Shoulder Type	Shoulder Type
Shoulder Width	Shoulder Width
Shoulder Surface Type	Shoulder Surface Type
Median Type	Roadside Rating
Median Width	Center Line Rumble Strips
Roadside Rating	Edge Line Rumble Strips
Center Line Rumble Strips	Shoulder Rumble Strips
Edge Line Rumble Strips	Visual Trap
Shoulder Rumble Strips	Intersection in Curve
Parking	Advance Curve Signing
Sidewalks and Trails, and Bike Lanes	Advisory Speed Limit
Land Use	Curve Delineation
Access Points and Access Management	Arrow Boards
Crash Frequency by Severity	Crash Frequency by Severity
Crash Frequency by Type, All Severity	Crash Frequency by Type, All Severity
Crash Frequency by Type, Severe Crashes	Crash Frequency by Type, Severe Crashes

Step 1, Task 1 – Focus Crash Types

Thurston County reviewed the crash data to identify those crashes which accounted for the greatest number of fatalities. These data are summarized in figure 43. Based on these results, Thurston County selected the following focus crashes:

- Fixed object.
- Head-on.
- Left-turn.
- Angle.
- Overturn.
- Rear-end.

Combined, these crashes accounted for 33 of the County’s 36 county road fatalities (92 percent) and 98 of the County’s 123 county road serious injuries (80 percent).

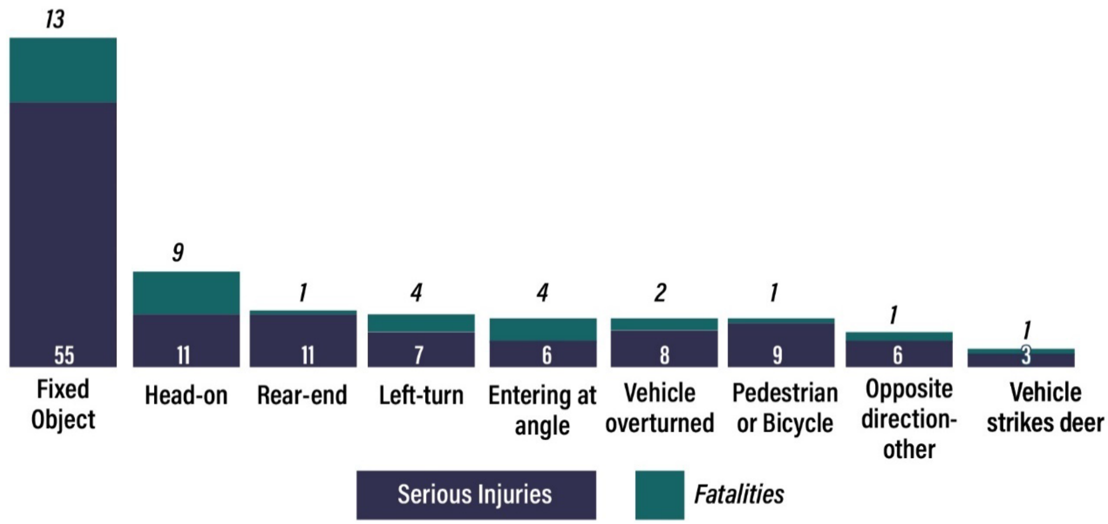


Figure 43. Graphic. Fatality and serious injury crashes by crash type 2011-2015 (Source: Thurston County, 2021).

Step 1, Task 2 – Focus Facilities

Thurston County reviewed several roadway factors when considering focus facility types. This included the distribution of fatal and serious injury crashes, center line miles, and VMT by functional class, posted speed limit, horizontal curvature, and vertical curvature. The severe crashes were distributed as follows:

- 42 percent on rural major collectors and arterials.
- 38 percent on rural roads at horizontal curves.
- 10 percent on urban other principal arterials.

Rather than using a crash tree, Thurston County used bar charts to compare severe crash frequency with exposure (measured via center line miles and MVMT) to identify which facilities the County should focus on. Figure 44 is one pair of bar charts used by the County—in this case, the facilities were based on functional class. Note that, for instance, rural major collectors account for a larger proportion of severe crashes compared to center line miles and MVMT.

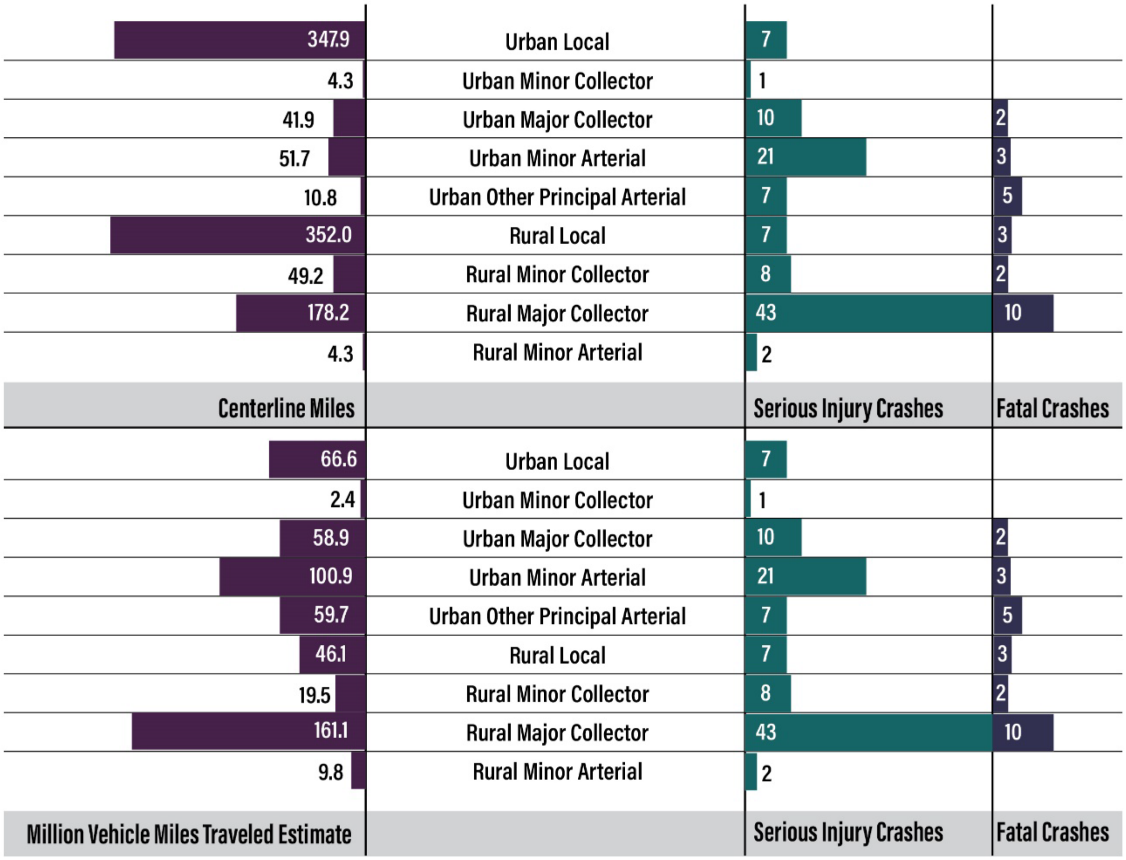


Figure 44. Graphic. Comparison of severe crash frequency and exposure in Thurston County (Source: Thurston County, 2021).

Based on these findings, the County selected the following focus facility types:

- Rural Major Collectors and Arterials.
- Urban Other Principal Arterials.
- Urban 35 mph Posted Speed Limits.
- Rural Curves.

Step 1, Task 3 – Risk Factors

Thurston County proceeded to prepare the data for risk factor analysis. This included segmenting the roadway system, associating crash and roadway data with each roadway segment, and calculating crash severity, weighted crash rate, and crash frequency for each segment. Thurston County then selected risk factors by comparing the safety metrics to the exposure for each roadway feature. Thurston County identified “primary” and “secondary” risk factors based on the strength of the correlation between safety performance and exposure. Table 31 summarizes the risk factors for Thurston County.

Table 31. Primary and secondary risk factors by focus facility.

Focus Facility Type	Primary Risk Factors	Secondary Risk Factors
Rural Major Collectors and Arterials	• Private access density, 15-25 points per mile. • Shoulder with ≥ 3 ft. • Roadside risk rating of 3.[15] • Four or more curves per mi.	• None.
Urban Other Principal Arterials	• ADT ≥ 20,000 vehicles per day.	• Posted Speed Limit is 50 mph and ADT < 20,000 vehicles per day. • Private access density ≥ 60 points per mile.
Urban 35 mph Posted Speed Limits	• ADT between 3,500 and 6,000 vehicles per day.	• Private access density between 30 and 50 points per mile.
Rural Curves	• Curve radius ≤ 850 ft. • Advisory speed limit of 40 mph where radii < 850 ft. • No advisory sign present.	• Absence of curve delineation.

Step 2 – Screen and Prioritize Candidate Locations

To complete step 2, Thurston County identified system elements, calculated the risk score for each element, then prioritized those elements. The system elements were identified in the previous step when Thurston County segmented the system for analysis. When calculating risk scores, Thurston County assigned a full point for each primary risk factor present and a half point for each secondary risk factor present. Finally, Thurston County ranked the sites by risk score and selected scoring thresholds for each focus facility type. Table 32 summarizes the prioritized candidate locations in Thurston County.

[15] Using an internal roadside assessment scale out of three based on the presence of edge drop off, fixed object locations, and sideslope.

Table 32. Summary of prioritized candidate locations for Thurston County.

Focus Facility Type	Scoring Threshold	Mileage and Crashes	Percent of Mileage Selected for Projects	Percent of Crashes on Selected Mileage
Rural Major Collectors and Arterials	2	115 mi, 9 severe crashes, 1,013 total crashes	51%	60% of severe crashes, 56% of total crashes
Urban Other Principal Arterials	1	11 mi, 5 severe crashes, 545 total crashes	66%	83% of severe crashes, 65% of total crashes
Urban 35 mph Posted Speed Limits	1	13 mi, 5 severe crashes, 388 total crashes	34%	100% of severe crashes, 47% of total crashes
Rural Curves	3	162 curves, 6 severe crashes, 180 total crashes	41% of curves	26% of severe crashes, 44% of total crashes

Step 3 – Identify and Select Countermeasures

Thurston County reviewed the risk factors to identify potential countermeasures for each safety issue. The County then refined the list based on input from the Thurston County Public Works Department and stakeholders at a workshop for the safety plan. Table 33 summarizes the proposed segment countermeasures in Thurston County. The County estimated a total cost of $28 million to implement these countermeasures at candidate locations.

Table 33. Summary of segment countermeasures for Thurston County.

Safety Issue	Segment Countermeasures
Reduce Lane Departure Crashes	• Edge line and center line rumble strips. • Widen or pave shoulders. • Enhance or widen edge line markings. • Enhance corridor lighting.
Reduce Speeding	• Provide shoulder widening for traffic enforcement. • Implement portable speed feedback signs with power enhancements. • Narrow lanes, LED speed limit signs, and review passing zones.
Improve the Roadside	• Clear roadside and/or delineate guardrail. • Flatten slopes and/or install or upgrade guardrail.
Reduce Crashes in Urban Areas	• Conduct studies, including road diets, access management, spot analysis, and area analysis. • Narrow lanes. • Implement LPI and upgrade lighting to LED. • Install curb extensions and/or upgrade lighting. • Install raised crosswalks. • Construct roundabouts.
Basic Improvements	• Add 8-inch edge lines.

Similarly, table 34 summarizes the proposed countermeasures for horizontal curves. Thurston County estimated these improvements across the candidate locations to cost $8 million for 161 horizontal curves.

Table 34. Summary of curve countermeasures for Thurston County.

Safety Issue	Curve Countermeasures
Reduce Curve Crashes	• Install chevrons, advanced curve warning signs, advisory speed plaques, and 8-inch edge lines. • Clear roadside and/or delineate guardrail. • Clear roadside, flatten sideslope, and/or install or delineate guardrail. • Pave 2-ft shoulder and installed profiled pavement markings. • Install dynamic LED chevrons. • Install high-friction surface treatment. • Add lighting on curves with dashed edge line through intersections. • Add post delineators to existing signs.

Along with the risk score threshold, Thurston County applied additional criteria to limit the sites included in the project list, including (Thurston County, 2021):

- Roadway departure projects will be implemented on segments with at least four roadway departure crashes per mile.
- Speeding projects will be implemented on segments with a least two speeding crashes per mile.
- Roadside improvement projects will be implemented on segments with a roadside rating of two or three.
- Urban roadway projects will be installed on any segments functionally classified as urban.

Thurston County developed decision trees to determine which countermeasures to apply based on the characteristics of the site. Figure 45 is an example of one of these decision trees for speeding projects. Note that if the site does not meet crash history criteria, the site can be treated with a portable speed feedback sign. If the site does meet the crash threshold, the countermeasure is based on the cross-section. If the roadway has 2 lanes and 40 ft of paved surface width, then a median buffer is recommended. Otherwise, several countermeasures are used, including portable speed feedback signs, lane narrowing, LED speed limit signs for speed transition zones, and a review of and potential removal of passing zones.

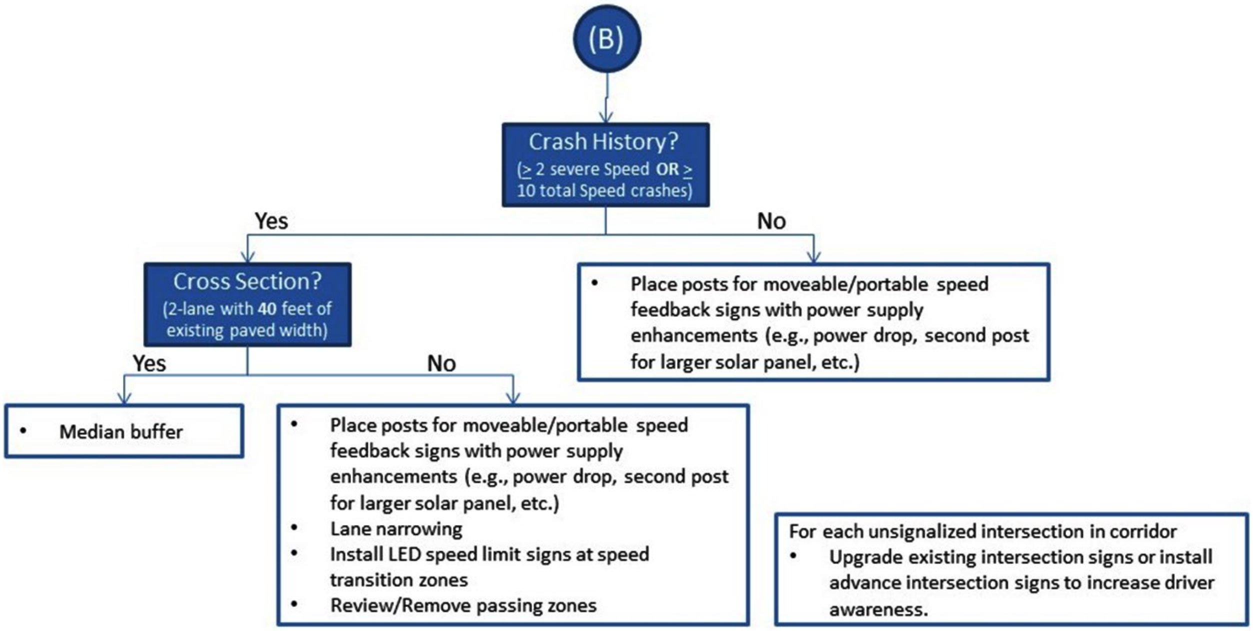


Figure 45. Graphic. Thurston County decision tree for systemic speeding countermeasure selection (Source: Thurston County, 2021).

Step 5 – Project Delivery

Thurston County has experience delivering systemic safety improvements on County roads. As a result, the County delivered the projects as contracted force HSIP projects (e.g., on-call contracts, push-button contracts, force account contracts).

Step 6 – Evaluation

This is not Thurston County's first LRSP. The County has regularly used the systemic approach to improve safety on their roads. The Thurston County Public Works Department performs annual high-level crash reviews to evaluate the successes and failures of their programs (Thurston County, 2021). For instance, the County reviewed fatal and severe crashes on horizontal curves after implementing a horizontal curve safety program in 2011. This simple before/after evaluation showed a 35-percent reduction in those crashes between the before period (2006 to 2010), in which 80 severe crashes occurred, and the after period (2012 to 2016), in which 52 severe crashes occurred.

Key Takeaways

Key takeaways from this case study include:

- Systemic safety analysis is a valuable resource for supporting LRSPs.
- Focus facility types can range from general (rural curves) to specific (urban streets with 35 mph speed limits).
- Agencies do not need a lot of risk factors to conduct a systemic analysis.
- Crash data can be used to refine systemic project prioritization either as part of the risk factor analysis (as a risk factor) or afterwards (this case).
- Stakeholder input is valuable to refine the potential countermeasure list.

City of Seattle Pedestrian Models

SDOT uses systemic safety analysis to identify high priority areas for pedestrian and bicyclist safety (SDOT, 2016; SDOT, 2020a). This is accomplished through a multi-phase effort that includes the development of pedestrian and bicycle SPFs for several specific crash types. The results of the analysis are updated periodically, and the outputs are used to identify and prioritize candidate locations for proactive countermeasure implementation. This case study shows how Seattle has used the systemic safety process as part of their Vision Zero program, with particular emphasis on three data-driven steps: identifying focus crash types, facility types, and risk factors; screening and prioritizing candidate locations; and evaluating systemic safety results.

Source

This case study is based on SDOT reports describing the two phases of their Bicycle and Pedestrian Safety Analysis:

- SDOT City of Seattle Bicycle and Pedestrian Safety Analysis, Phase I, published in 2016.
- SDOT City of Seattle Bicycle and Pedestrian Safety Analysis, Phase II, published in 2020.

Objective

Seattle's Vision Zero program aims to end traffic deaths and serious injuries for all road users by 2030, to eliminate racial disparities in traffic safety, and to achieve 90-percent zero-emission person trips by 2030 (SDOT 2016; SDOT 2020a). The *Bicycle and Pedestrian Safety Analysis* is one facet of the Vision Zero program; this advanced data-driven program is designed to help SDOT *proactively prevent* deaths and serious injuries for people walking, biking, and rolling on all of Seattle's streets.

Data

SDOT used a variety of crash, roadway, transit, land use, demographic, and other contextual datasets to complete the analyses that inform project identification and prioritization. Roadway data included, among other attributes, the number and configuration of lanes, signalization including left-turn phasing patterns, functional class, presence of on-street parking, and presence and type of bicycle facilities; SDOT maintains these data. SDOT used known motor vehicle counts in conjunction with purchased motorist AADT data from a third-party vendor. Additionally, SDOT obtained free demographic data from the U.S. Census Bureau. SDOT maintains a robust pedestrian and bicyclist counts program, with a mix of permanent counter reference sites and short duration counters; SDOT used these data to estimate system-wide volume or exposure models (Schoner et al., 2021) that played a role in the development of Seattle-specific SPFs.

Step 1 – Identify Focus Crash Types, Facility Types, and Risk Factors

SDOT used descriptive analyses of bicyclist and pedestrian crashes to identify the top crash types and facility types for each mode. For both pedestrians and bicyclists, a majority of fatal and serious injury crashes happened at intersections (compared to segment or midblock locations). Among these intersection crashes, crash types were constructed using combinations of the motorist's and pedestrian's or bicyclist's movements. Figure 46 shows the basic crash tree SDOT used in Phase I to identify the highest priority facility and crash types.

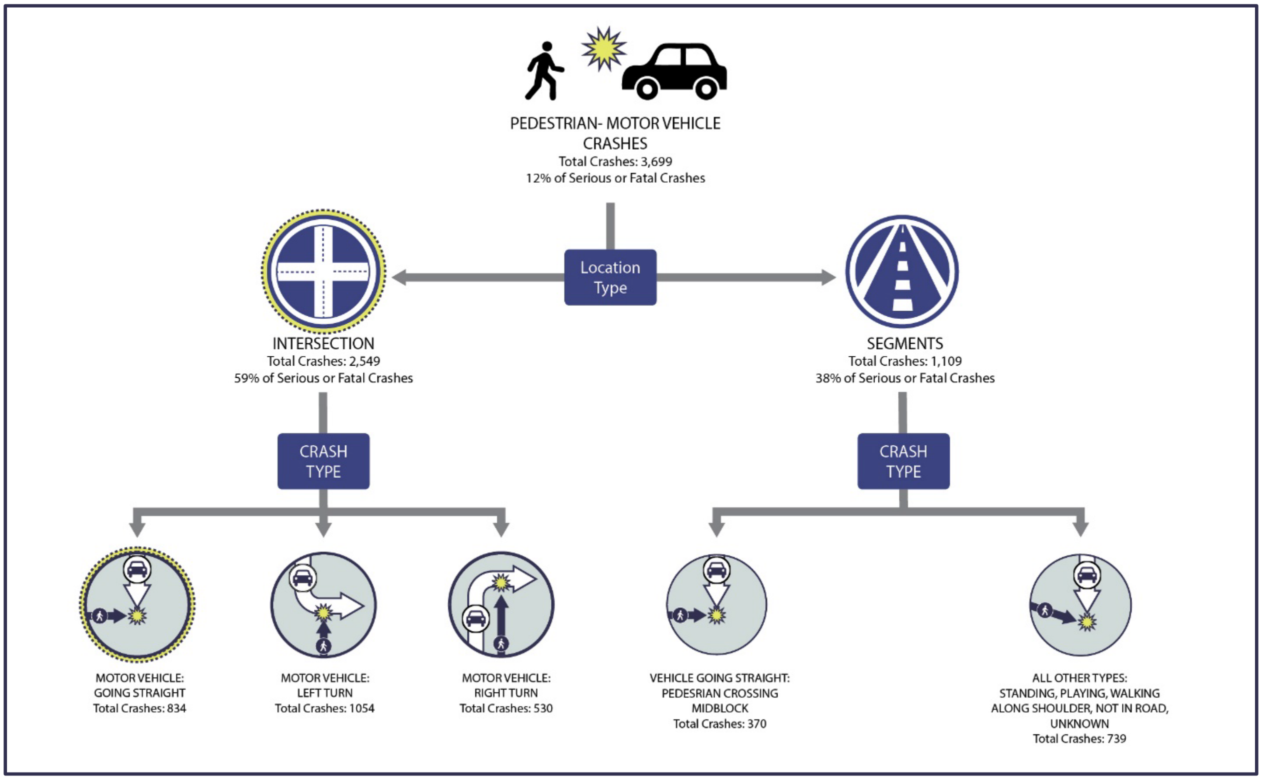


Figure 46. Graphic. Pedestrian priority location types and crash types in SDOT's *Bicycle and Pedestrian Safety Analysis, Phase I* (reproduced from SDOT 2016; figure 12, pg. 20).

Seattle also used descriptive analysis to initially evaluate what risk factors to consider, and then estimated SPFs for several pedestrian and bicycle crash types to help screen the system on the most impactful risk factors. The SPF models were first estimated in Phase I and then revised in Phase II, when additional important risk factor data became available (namely, motor vehicle volume data). The Phase II models were estimated for seven different crash types, illustrated in figure 47 and figure 48.

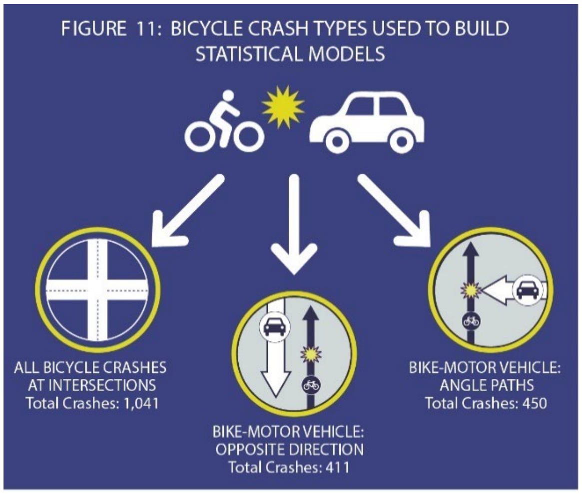


Figure 47. Graphic. Priority bicyclist crash types used to build SPFs (reproduced from SDOT 2020; figure 11, pg. 14).

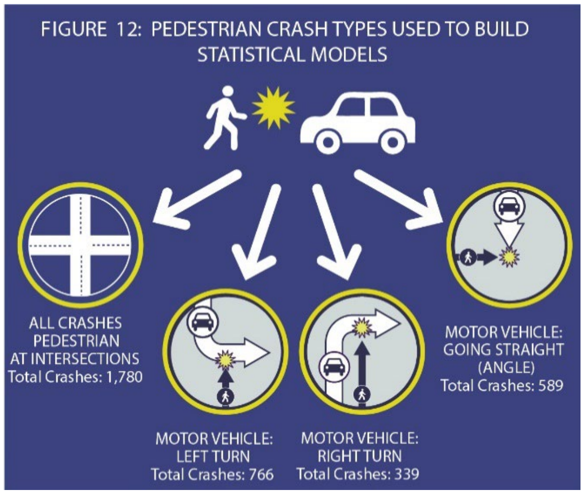


Figure 48. Graphic. Priority pedestrian crash types used to build SPFs (reproduced from SDOT 2020, figure 12; pg. 17).

An exploratory analysis used descriptive statistics to identify risk factors with a high concentration or overrepresentation of pedestrian and bicyclist crashes—particularly those resulting in death or serious injury. Figure 49 shows an example of this from Phase 1.

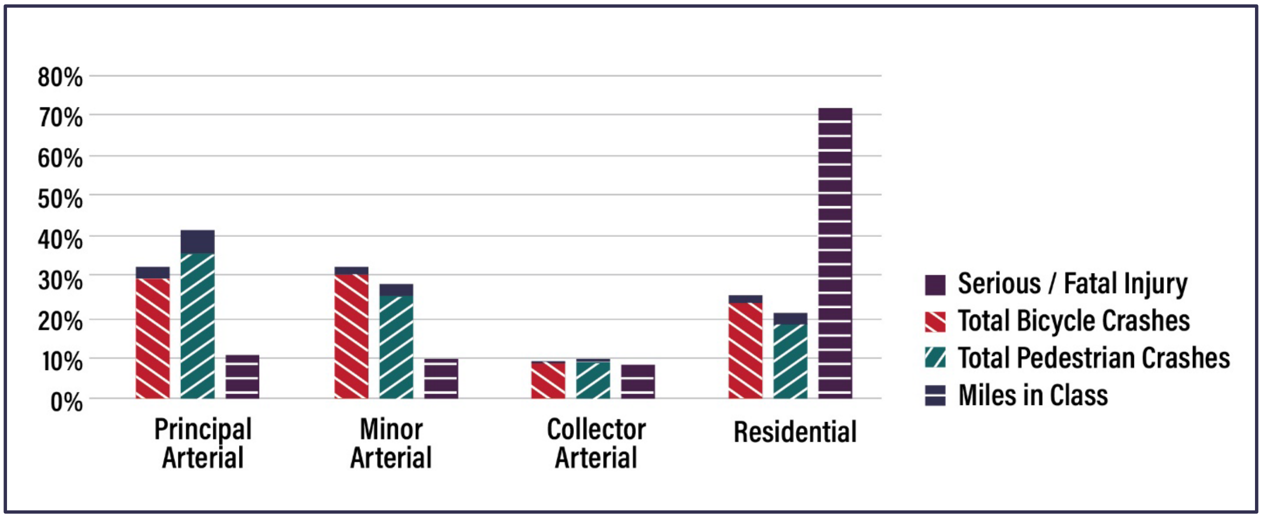


Figure 49. Graphic. Distribution of pedestrian and bicyclist crashes and roadway miles by functional class (reproduced from SDOT 2016; figure 7, pg. 7).

Step 2 – Screen and Prioritize Candidate Locations

SPFs are a powerful tool for screening and prioritizing candidate locations. The coefficients of the statistical model effectively “weight” the included risk factors by their relative impact on crash outcomes. The SPF equation scores each location on the estimated number of crashes. This output is further refined using an EB adjustment, which blends the modeled output with crash history to estimate the “expected” number of crashes. Figure 50 shows summary results of the top risk factors identified via SPF for opposite direction bicyclist—motorist crashes. Examples of full SPF models were provided in table 9.

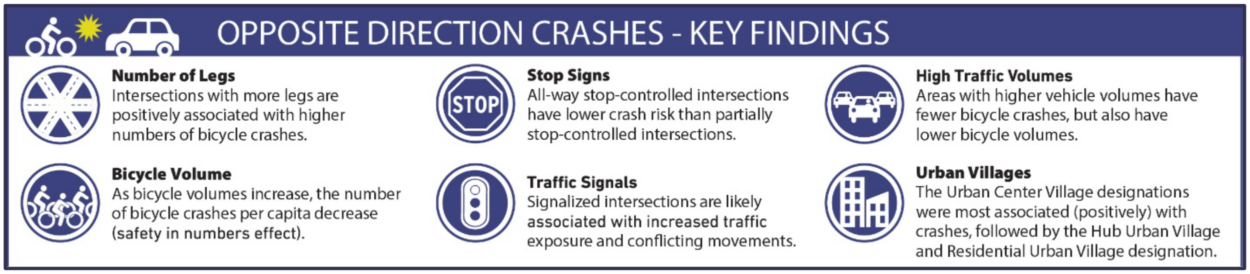


Figure 50. Graphic. Summary of key findings for bicycle—motorist opposite direction crashes (reproduced from SDOT 2020a, pg. 15).

The result of screening every location via SPF on each of the modeled crash types was a ranked and prioritized list of all intersections in the City. This list can be used to identify the top priorities for future projects subset by geography (e.g., Council district, as shown in figure 51, or by demographics to further Seattle’s [Race and Social Justice Initiative [City of Seattle, 2023]]). SDOT prepared separate rankings for bicyclist and pedestrian crashes at intersections, based on the modeled crash types.

After this initial screening and ranking, SDOT staff visited top scoring locations for a field investigation and to gather additional information that can inform future projects. Additionally, SDOT required any projects that overlap priority locations to be reviewed for the potential to incorporate bicycle or pedestrian focused safety improvements and countermeasures to their project scope.

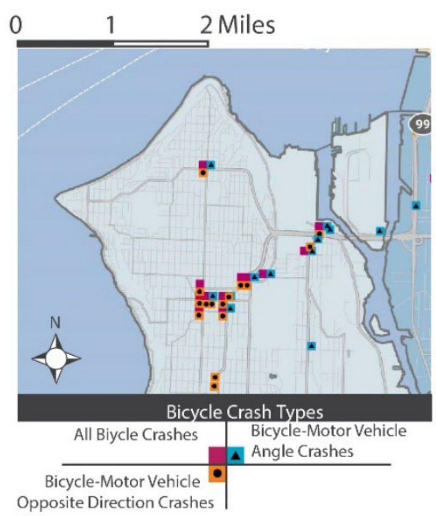


Figure 51. Graphic. Top 20 priority bicyclist crash locations in each Council District (reproduced from SDOT 2020a; figure 13, pg. 24).

Step 3 – Identify and Select Countermeasures

SDOT maintains a suite of countermeasures that includes several FHWA proven safety countermeasures known to increase safety for all road users. For example, the following countermeasures are spotlighted on the City's Vision Zero website (SDOT, 2023a):

- Hardened center lines.
- LPIs.
- Protected bike lanes.

SDOT staff use both a data-driven understanding of the problem and community input to select the most appropriate countermeasure for the identified issue.

Step 4 – Prioritize Projects

SDOT staff use a variety of metrics to prioritize projects, including safety rankings from the systemic analysis and priorities previously identified via multiple other City efforts (e.g., Vision Zero, ADA, Transportation Equity, and Safe Routes to School). Cost effectiveness and available funding also influence prioritization but are secondary to overall safety and community need.

Step 5 – Deliver Systemic Projects

Seattle has delivered a wide variety of systemic countermeasure projects following the analyses described here. For example, after seeing the effectiveness of LPIs using a systemic prioritization approach, Seattle developed a policy recommending the implementation of LPIs at many signalized intersections across the city, following certain selection criteria, whenever any changes were made to the intersection that provided an opportunity (SDOT, 2023b). LPI deployment is now widespread throughout the city. This countermeasure targets crash types and risk factors identified through their *Bicycle and Pedestrian Safety Analysis*. SDOT has also undertaken multifaceted efforts to lower motorist speeds throughout the City (SDOT, 2023c). These efforts have included both citywide policy (lowering statutory speed limits), targeted speed limit changes in urban villages (a risk factor identified in the *Bicycle and Pedestrian Safety Analysis*), and design changes to reduce operating speeds on identified High Injury Streets (SDOT, 2023c).

Systemic projects are implemented through a variety of mechanisms depending on whether they are capital projects or can be implemented through operations. Vision Zero and bicycle and pedestrian projects tend to be the latter type. Smaller projects, especially quick-build projects not requiring construction, are bundled for internal crews to implement. This bundling can accommodate a variety of smaller projects or a larger-scale implementation of a systemic countermeasure. Larger capital projects and corridor-scale work tend to be sent out for bid.

Step 6 – Evaluate Systemic Safety Results

Seattle has continued to evaluate safety results at the program, countermeasure, and project level, as well as refine their analytical and prioritization methods over time to respond to better data and changing conditions.

At the **program** level, Seattle publishes regular Vision Zero progress update reports (such as this report published in 2019) that look at overall severe crash trends and patterns over time (SDOT, 2019).

At the **countermeasure** level, Seattle evaluated protected bike lanes as part of Phase II of the *Bicycle and Pedestrian Safety Analysis* (SDOT, 2020a). Given a crash-based analysis would take years to complete, the City in the meantime chose to get more immediate results through a short-term evaluation. Seattle used a surrogate safety analysis in which video data were collected and analyzed to observe how motorist-bicyclist conflicts changed in response to the new facilities. Seattle continues to evaluate systemic pedestrian and bicycle countermeasures in future efforts.

At the **project** level, Seattle regularly publishes before-after evaluations of their flagship Vision Zero safety projects. These evaluations include both direct outcomes (measured reduction in crashes) as well as surrogates (e.g., motorist speeds and pedestrian and bicyclist volumes). For example, an evaluation of the Northeast 65th Street Redesign Project showed that the treatments implemented were associated with increased pedestrian and bicyclist volumes, decreased motorist speeds, decreased overall collisions in the corridor, and even an elimination of fatal and serious injury crashes in the year following implementation (SDOT, 2020b). Table 35 summarizes the results of the evaluation.

Table 35. Evaluation results for the Northeast 65th Street rehabilitation project (SDOT, 2020b).

Crash Type	Before Crashes, West Segment	Interim Crashes, West Segment	After Crashes, West Segment	Percent Change, West Segment	Before Crashes, East Segment	Interim Crashes, East Segment	After Crashes, East Segment	Percent Change, East Segment
Angle	4	3	4	0%	7	4	0	-100%
Bike	3	2	3	0%	1	2	1	0%
Head On	0	0	0	0%	0	0	0	0%
Left Turn	6	8	0	-100%	2	2	2	0%
Other	1	1	0	-100%	1	1	0	-100%
Parked Car	5	1	0	-100%	2	1	1	-50%
Pedestrian	3	6	1	-67%	1	1	1	0%
Rear End	4	3	1	-75%	3	1	1	-67%
Right Turn	1	2	0	-100%	1	1	0	-100%
Sideswipe	0	3	0	0%	1	0	1	0%
Total	27	29	9	-67%	19	13	7	-63%

Key Takeaways

- While the data input requirements are high, SPFs provide a data-driven way to rank and prioritize all intersections for systemic and systematic countermeasures.
- Agencies can use a variety of tools, ranging from corridor-scale projects to system-wide policies (e.g., speed changes or widespread deployment of LPI), to address local safety problems.
- Specifically addressing pedestrian and bicyclist safety is a key component of creating an equitable, sustainable transportation system—with safety benefits for motorists, as well.
- Many systemic safety countermeasures can be implemented by city public works staff through the use of paint, bollards, and signal retiming.
- Ongoing analysis and evaluation helps agencies monitor progress and keep abreast of changing patterns.
- SDOT used their Vision Zero Plan and systemic safety analysis to apply for and receive a Safe Streets and Roads for All Grant (USDOT, 2023).

Brown County, Wisconsin

Brown County, Wisconsin made a budgetary commitment to low-cost safety improvements after the development of a County Road Safety Plan (CRSP), driven by systemic safety analysis, described the strategies needed to make a serious reduction in severe injuries on the County's roads. This case study describes the systemic safety process used by Brown County to develop their CRSP.

Source

The source for this case study is the Brown County – County Road Safety Plan, published in 2018 and available at: https://www.browncountywi.gov/i/f/files/Public-Works/brown_county_crsp_20181107_final(1).pdf (Brown County, 2018).

Objective

Brown County used systemic safety analysis to prioritize safety improvements on county roads with the goal of reducing fatal and serious injury crashes. To achieve this objective, Brown County followed the process described in figure 52.

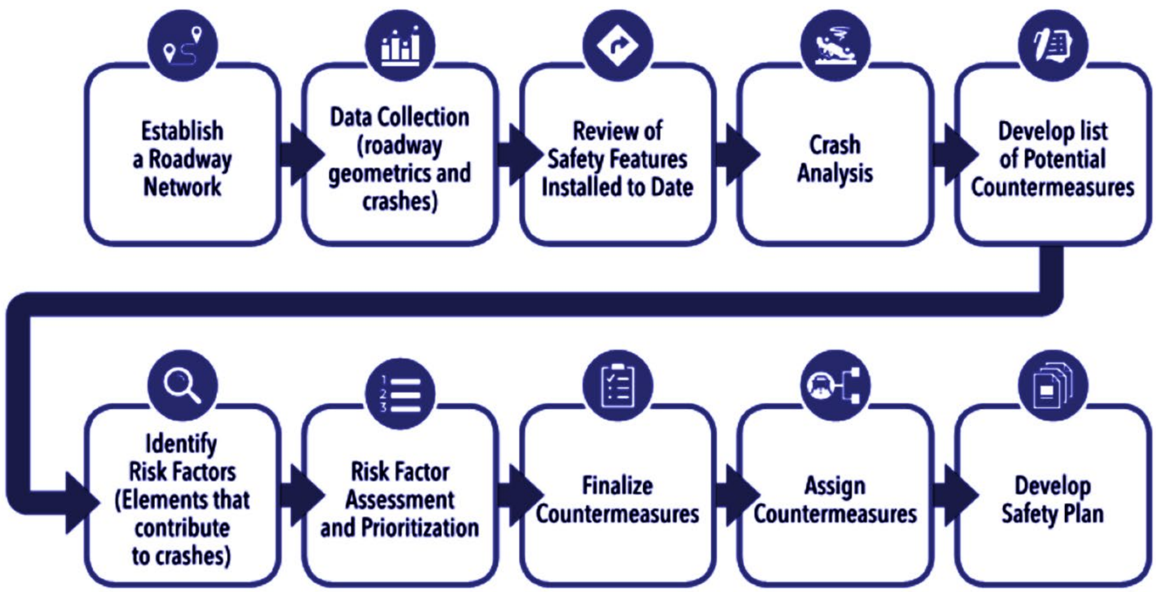


Figure 52. Graphic. Brown County CRSP approach (Source: Brown County, 2018).

Data

Brown County created a GIS database with 363 miles of County Trunk Highway. Table 36 summarizes the number of system elements included in the GIS database.

Table 36. Number of system elements in the Brown County GIS database (Brown County, 2018).

System Element	Rural	Urban	Total
Segments	79	87	166
Horizontal Curves	115	128	243
Intersections	83	103	186

Brown County collected several roadway data elements for each set of system elements. Table 37 summarizes those roadway elements, which the County collected from a variety of resources, including County staff, the Wisconsin Information System for Local Roads, aerial photography, and street photography.

Table 37. Data elements collected for systemic analysis by Brown County (Brown County, 2018).

Segment Data Elements	Curve Data Elements	Intersection Data Elements
Facility type	Radius	Intersection configuration
Median type and width	Curve length	Intersection design type
Lane width	Existing curve signing	Traffic control
Shoulder width and material	Intersection presence	Lighting
Center line, edgeline, and transverse rumble strips	Visual trap presence	Major approach speed
Edge and center line width	Curve isolation	Facility type
Shoulder width	--	Speed limits
Curb and gutter	--	Approach leg ADTs
Edge risk	--	Near a curve
Speed limit	--	Adjacent trip generator
Access density	--	Railroad crossing presence
Curve density	--	Approach legs with previous stop greater than five miles
ADT	--	Severe crash data
Severe crash rate	--	--
Pavement age	--	--

Finally, Brown County obtained data for 1,449 crashes on county roads from 2013 through 2017 from the Wisconsin DOT—the total number of crashes for all roads, including State, City, and County roads, in the County was 18,859. They then proceeded with the analysis.

Step 1 – Identify Focus Crash Types, Facility Types, and Risk Factors

Task 1 and 2 – Identify Focus Crash Types and Focus Facility Types

Brown County used a crash tree to summarize crash data with the intention of selecting focus crash types and investigating focus facility types. Figure 53 is a recreation of that crash tree, which includes crashes of all severity as well as KA crashes. The County initially reviewed area type and found that 95 percent of the severe crashes were on rural roads. The County then investigated deer crashes and found that only 3 percent of severe crashes involved striking a deer. The County then analyzed KA crashes at intersections, which was 38 percent of the remaining KA crashes. Of those, 84 percent were right-angle crashes. For non-intersection crashes, 90 percent of KA crashes involved a roadway departure (note that the County uses the Lane Departure terminology in figure 53), with most involving running off the road. Of the 19 severe roadway departure crashes, 9 occurred on horizontal curves.

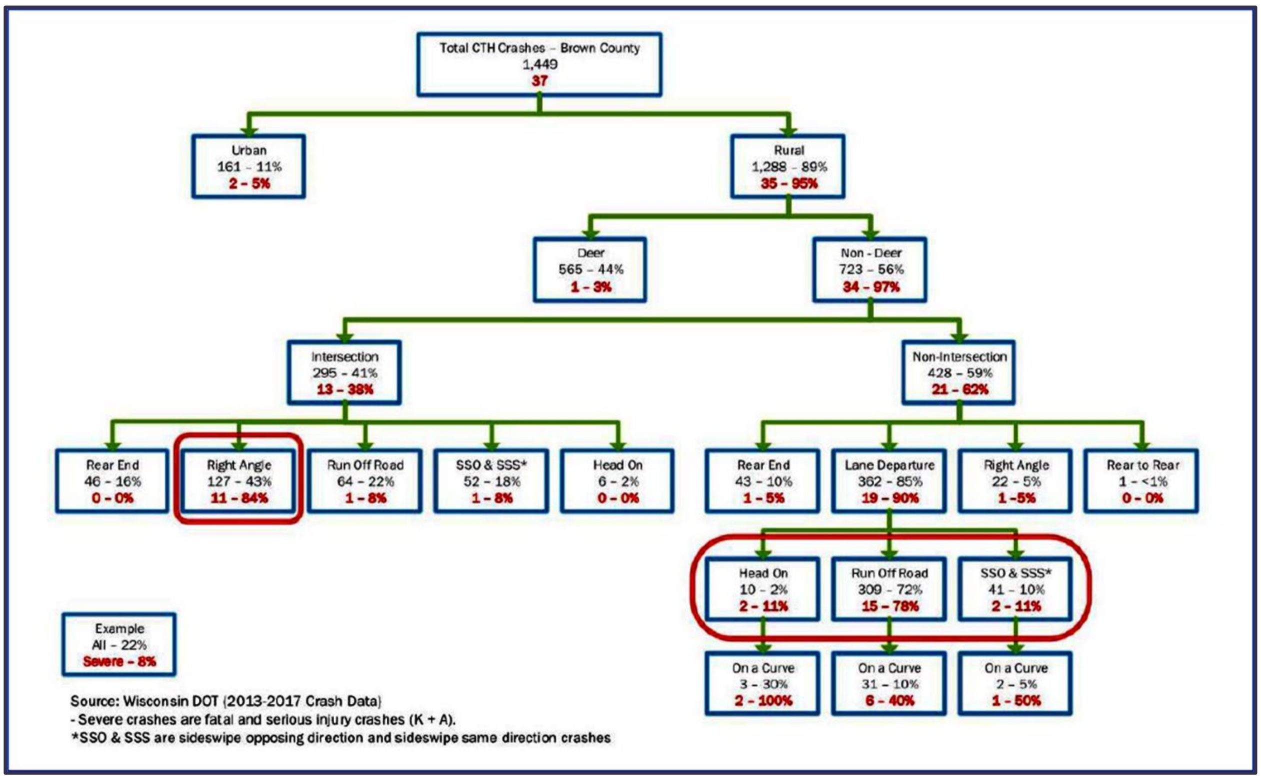


Figure 53. Graphic. Crash tree summarizing all severity and KA crashes on county highways in Brown County (Source: Brown County, 2018).

Based on this analysis, Brown County selected Intersection crashes and Roadway Departure crashes as focus crash types and did not narrow focus facility types beyond the default system elements.

Task 3 – Identify Risk Factors

Brown County used the overrepresentation method to identify risk factors, comparing the percentage of severe crashes with an attribute to the percentage of total crashes and the percentage of roadway length. Figure 54 is the overrepresentation plot used to select the ADT risk factor. Note the elevated proportion of severe crashes at the ADT range from 500 to 2,000 vehicles per day compared to total crashes and mileage.

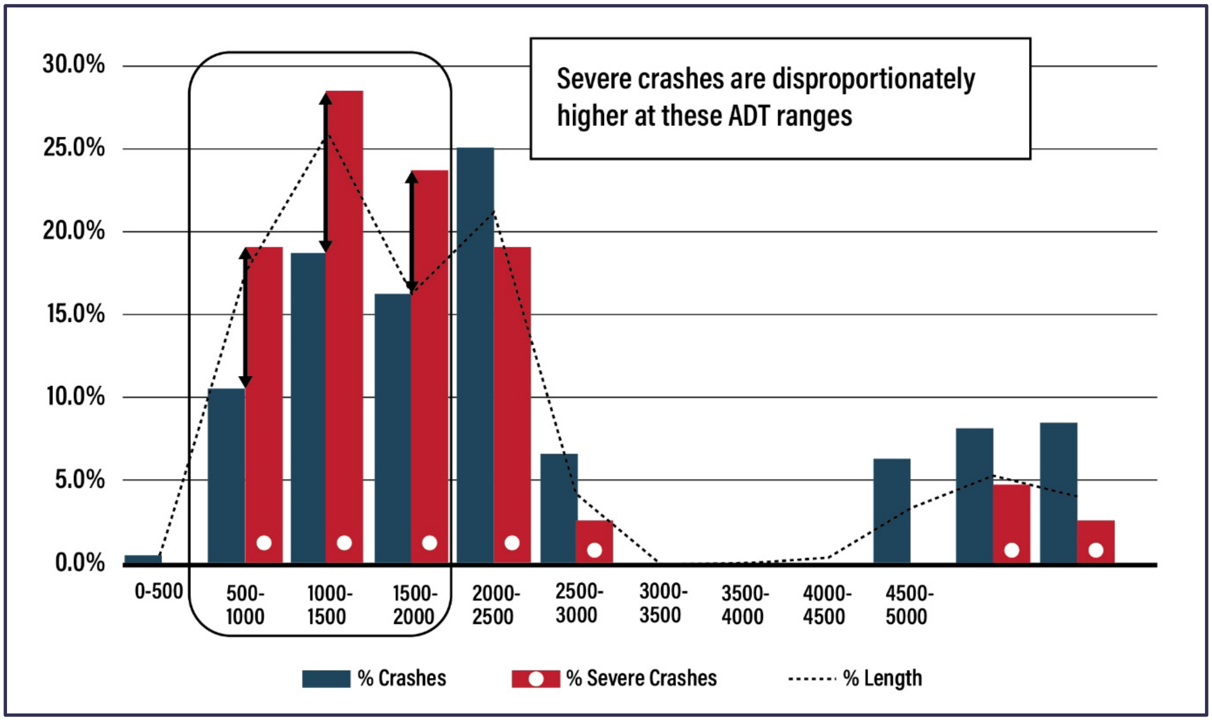


Figure 54. Graphic. Brown County overrepresentation analysis for rural non-intersection severe crashes (Source: Brown County, 2018).

The County identified risk factors for each element. Table 38 summarizes the risk factors for segments.

Table 38. Segment risk factors for rural highways in Brown County (Brown County, 2018).

Risk Factor	Value or Range
ADT	500 to 2,000 vehicles per day
Access Density	15 or more access points per mile
Roadway departure Crash Density	More 0.4 roadway departure crashes per mile per year
Critical Radius Curve Density	More than 0.13 critical radius curves per mile
Edge Risk	Assessed an edge risk score of 2C[16], 2S[17], or 3[18]
Shoulder Width	Less than 4 ft

Table 39 summarizes the risk factors for horizontal curves, and table 40 summarizes the risk factors for intersections. Note the risk factors include a mix of infrastructure, crash, traffic, and trip generation elements.

Table 39. Horizontal curve risk factors for rural highways in Brown County (Brown County, 2018).

Risk Factor	Value or Range
Curve Radius	250 ft to 1,250 ft
ADT	Greater than 750 vehicles per day
Adjacent Intersection	The curve is on or near an intersection
Visual Trap	Present
Total Crashes	At least one KA crash between 2013 and 2017

Table 40. Intersection risk factors for rural highways in Brown County (Brown County, 2018).

Risk Factor	Value or Range
ADT	The cross product of the approaches is greater than 2,000,000
Skew Angle	15 degrees or more
Adjacent Curve	Intersection is on or near a horizontal curve
Adjacent Trip Generator	Commercial development is present in at least one quadrant
Railroad Crossing	Railroad crossing is present on a minor approach
Previous Stop	One approach is 5 or more mi from an adjacent stop-control approach
Total Crashes	At least one KA crash between 2013 and 2017

[16] Usable shoulder but inadequate clear zone.
[17] No usable shoulder but adequate clear zone.
[18] No usable shoulder and inadequate clear zone.

Step 2 – Screen and Prioritize Candidate Locations

Task 1 – Identify System Elements to Analyze

Brown County selected three sets of system elements—segments, horizontal curves, and intersections. Table 36 summarized the number of system elements. However, the County removed sites with the following characteristics from the data because they have a reduced likelihood of severe crashes:

- Segments and horizontal curves with a posted speed limit less than 45 mph, as these are low-speed facilities.
- Curves with a radius larger than 3,000 ft.
- Intersections that are roundabouts.
- Intersections where the speed limits for both approaches are less than 45 mph.

Task 2 – Calculate Risk Scores

Brown County elected to use binary scoring of risk factors, where each risk factor has a weight of 1. As a result, the maximum score for a segment was 6, for a horizontal curve was 5, and for an intersection was 7.

Task 3 – Prioritize Focus Facility Elements

Brown County considered the sites with the highest number of risk factors present in "High Priority Elements." They created maps and tables to show the high priority segments, curves, and intersections. Figure 55 is an example of a Brown County high priority intersection map (Brown County, 2018).

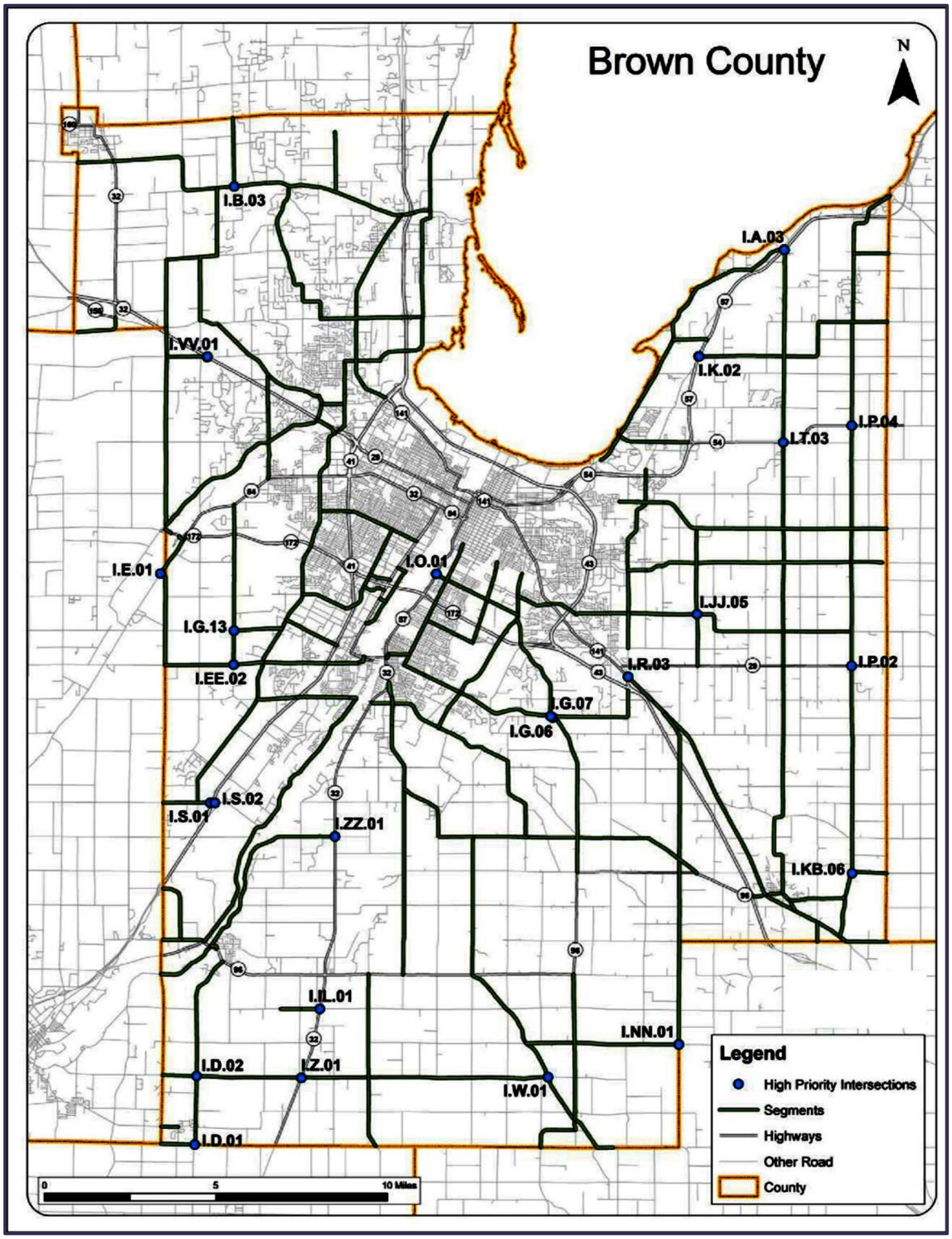


Figure 55. Graphic. High priority intersections in Brown County (Source: Brown County, 2018).

Step 3 – Identify and Select Countermeasures

Task 1 – Develop List of Potential Countermeasures

Brown County used the NCHRP Report 500 series (Transportation Research Board, 2014) and FHWA's CMF Clearinghouse (FHWA, 2023e) to develop a potential list of safety strategies. After reviewing those resources, Brown County organized selected countermeasures into a table. Table 41 is a recreation of the developed table, including the safety strategy as well as the standard crash reduction and average cost for each strategy (Brown County, 2018).

Table 41. Safety strategies for the Brown County CRSP (Brown County, 2018).

Segment Element Type	Countermeasure or Safety Strategy	Crash Reduction Factor (%)	Average Cost
Segment	Clear Zone Maintenance	35% to 40% all crashes	$50,000-$500,000 per mile
Segment	Enhance Edgeline	10% to 45%, rural severe crashes	$2,000 per mile
Segment	Shoulder Rumble Strip	20%, run-off-road crashes	$5,850 per mile
Segment	Two-Foot Shoulder Paving & Safety Edge	20% to 30%, run-off-road crashes	$54,000 per mile
Segment	Center Line Rumble Strips	40%, head-on and sideswipe-opposite direction crashes	$3,600 per mile
Horizontal Curve	Upgrade or Install Chevrons	20% to 30% all crashes	$3,960 per curve
Horizontal Curve	Two-Foot Shoulder Paving	20% to 30%, run-off-road crashes	$54,000 per mile
Horizontal Curve	Shoulder Rumble Strips	20%, run off road crashes	$5,850 per mile
Horizontal Curve	Advanced Curve Warning, Speed Advisory Sign	20% to 30% all crashes	$1,440 per curve
Intersection	Roundabout	20% to 50%, all crashes;	$1,000,000 per intersection
Intersection	All-Way Stop-Control	N/A	$1,000 per intersection
Intersection	Lighting	25% to 40%, nighttime crashes	$6,000 per light
Intersection	Upgrade Signs and Markings	40%	$2,640 per approach
Intersection	Reconstruct to a Single-T Intersection	N/A	$150,000 per intersection
Intersection	Transverse Rumble Strips	39%, severe crashes	$2,500 per intersection
Intersection	Safety Strategies to Improve Visibility	Varies	Varies

Task 2 – Select Countermeasures for Deployment

To standardize the countermeasure deployment decision process, Brown County created decision trees for segments, curves, and intersections. Figure 56 is the decision tree developed by the County for segments (Brown County, 2018). Note that clear zone maintenance is included in any case where the edge risk is assessed a score of 2C or 3. After this, the County's decisions are based on traffic volume, shoulder type, and noise sensitivity.

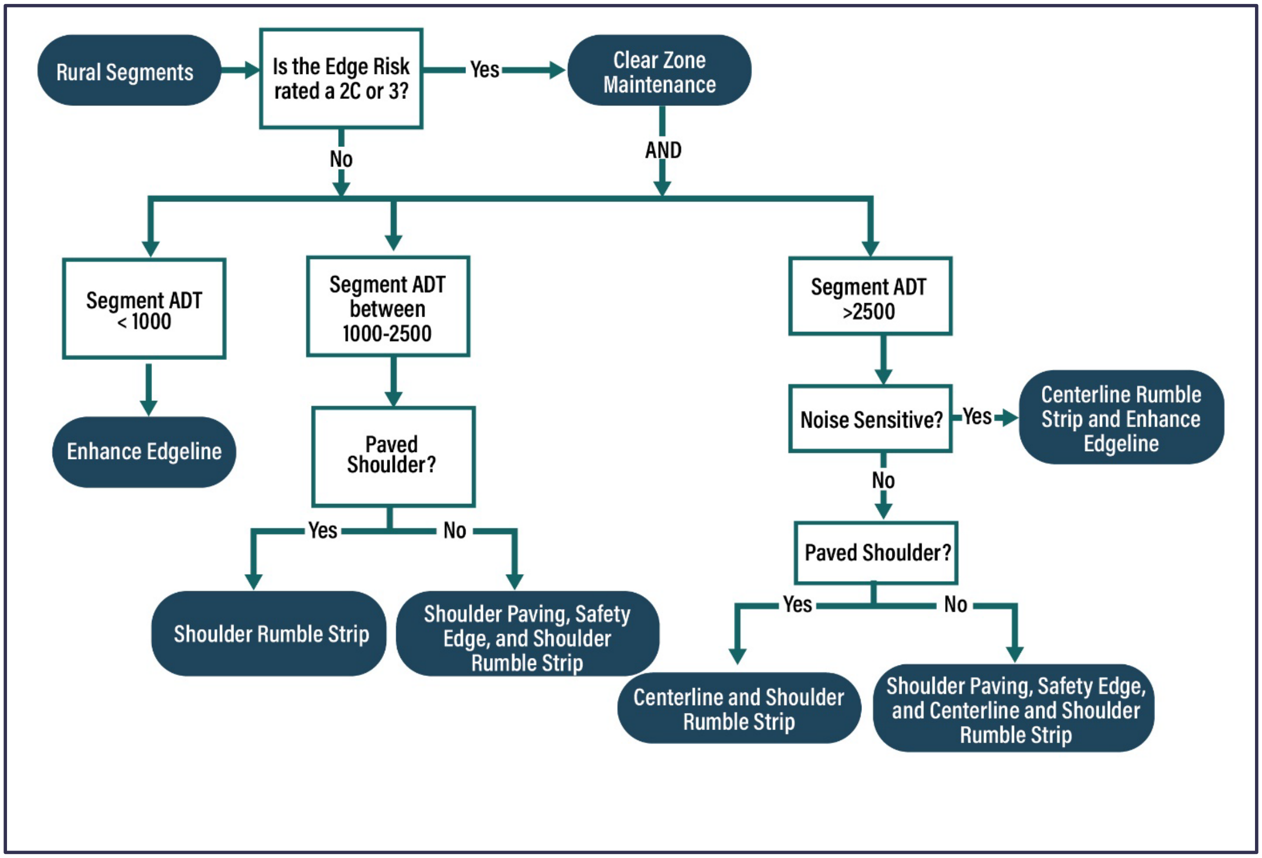


Figure 56. Graphic. Decision tree for safety countermeasures on segments in Brown County (Source: Brown County, 2018; figure 21).

Steps 4 and 5 – Prioritize and Deliver Projects

Finally, Brown County identified several safety improvements projects across the County. Table 42 summarizes the proposed safety improvements by number of sites and mileage for each strategy. Note that most of the proposed improvements are clear zone maintenance and shoulder rumble strips.

Table 42. Proposed improvements at high-priority sites in Brown County (Brown County, 2018).

Segment Element Type	Countermeasure or Safety Strategy	Number of Sites	Total Miles
Segment	Clear Zone Maintenance	33	128.9
Segment	Enhance Edgeline	15	28.9
Segment	Shoulder Rumble Strip	21	105.1
Segment	Two-Foot Shoulder Paving & Safety Edge	8	40.7
Segment	Center Line Rumble Strips	2	6.6
Segment	Enhanced Edgeline in Noise Sensitive Corridors	1	0.5
Horizontal Curve	Upgrade or Install Chevrons	37	N/A
Horizontal Curve	Two-Foot Shoulder Paving	22	4.1
Horizontal Curve	Shoulder Rumble Strips	49	8.7
Horizontal Curve	Advanced Curve Warning, Speed Advisory Sign	49	N/A
Intersection	Roundabout	1	N/A
Intersection	All-Way Stop-Control	0	N/A
Intersection	Lighting	21	N/A
Intersection	Upgrade Signs and Markings	23	N/A
Intersection	Reconstruct to a Single-T Intersection	0	N/A
Intersection	Transverse Rumble Strips	19	N/A
Intersection	Safety Strategies to Improve Visibility	5	N/A

Key Takeaways

- Systemic safety analysis is useful for guiding LRSPs.
- It is feasible for local agencies to prepare GIS databases for systemic safety analysis.
- Decision trees are useful for standardized application of systemic improvements.
- A well-planned systemic safety program can generate political enthusiasm and result in additional funding for highway safety.

Boyle County, Kentucky

Boyle County, Kentucky developed an LRSP in partnership with FHWA, KYTC, and the LTAP at the University of Kentucky to improve transportation safety in the County. The Boyle County LRSP provided "a framework for identifying, analyzing, and prioritizing roadway safety improvements that can be used to reduce fatalities and serious injuries on the local road network" (Boyle County, 2021; page 1). This case study describes how Boyle County used local knowledge to inform their systemic safety program.

Source

The sources used in this case study are:

- Boyle County Local Road Safety Plan (2021) available at (Boyle County, 2021): https://www.flipsnack.com/ukkyt2/boyle-county-lrsp/full-view.html
- The Kentucky LTAP Technology & Transfer Program Presentation available at (Kirk, 2021): https://www.youtube.com/watch?v=iAE9LlQc4yQ&t=1079s

Objective

The objective of the Boyle County LRSP is to reduce fatalities on local roads. Boyle County worked towards this objective using systemic safety analysis, identifying focus facilities, risk factors for those facilities, a prioritization process, and proposing countermeasures for the candidate sites.

Data

Boyle County obtained five years of statewide crash data (2015-2019) from the Kentucky Crash Database. On the county roadway system, there were 92 crashes during the 5-year period, with 16 of those crashes resulting in injuries and one crash resulting in 2 fatalities.

Step 1 – Identify Focus Crash Types, Facility Types, and Risk Factors

Boyle County summarized the county road crash data and found that the majority of crashes (54 percent) were single-vehicle crashes, which also accounted for 63 percent of injury crashes. However, the County did not limit their systemic safety analysis to a focus crash type.

To identify focus facilities, the County reviewed 147 miles of county-owned roadways (all classified as local) to identify a "County Collector" system—roads which are important to the County, operate similar to collector roadways, may serve as a connection between or to State routes, have relatively high traffic volumes for the roadway system, or serve large population or employment centers. The County ultimately focused on a system of 15 roadways that accounted for 35 miles, 65 percent of all crashes, and 75 percent of injury crashes. Figure 57 shows the roadways selected by the County.

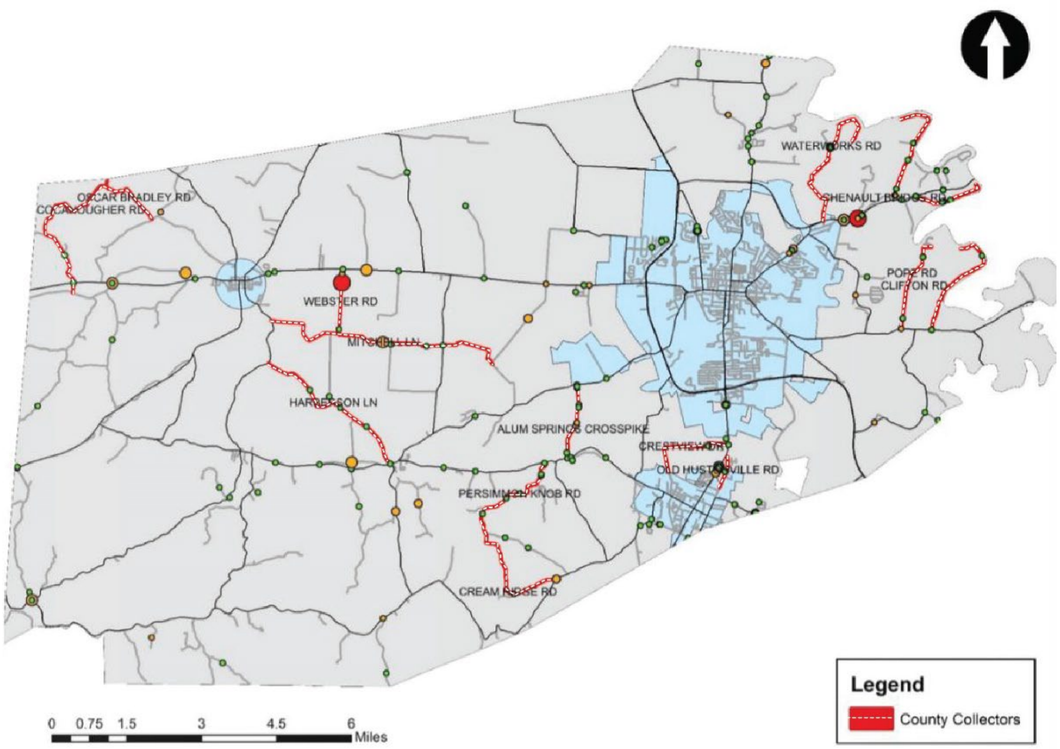


Figure 57. Graphic. Boyle County "County Collector" system for systemic analysis (Source: Boyle County, 2021).

Finally, Boyle County needed to assess the risk for each corridor in the system. With a small crash sample size and limited data, the County elected to use local knowledge—soliciting input from the:

- County Judge Executive.
- County Engineer.
- County Sheriff.
- County Emergency Medical Services.
- School Transportation Supervisor.

The participants reviewed and assessed the risk along the corridor for several features, including:

- Sharp horizontal curves.
- Vertical curvature.
- Operating speed.
- Traffic volume.
- Clear zone.
- Roadway width.

For each risk factor, the participants assigned a score of 1 (minimal risk), 2 (moderate risk), or 3 (high risk).

Step 2 – Screen and Prioritize Candidate Locations

Boyle County identified system elements as part of the selection of focus facility types. For this analysis, each roadway was a system element. The County proceeded to calculate the risk score for each corridor using the scores assigned by individuals in the previous step. The final risk score for each corridor was the consensus score among the participants. Table 43 shows the risk score and rank assigned to each roadway.

Table 43. Boyle County "Qualitative Hazard Rating" analysis ranking (table 2; Boyle County, 2021).

Road Name	Horizontal Curve	Speed	ADT	Vertical Curve	Clear Zone	Road Width	Qualitative Hazard Score	Qualitative Hazard Rank
Alum Springs Crosspike	3	3	3	2	3	2	16	1
Harberson Lane	3	3	2	3	2	2	15	2
Waterworks Road	3	3	2	2	3	2	15	2
Oscar Bradley Road	3	3	1	3	2	2	14	4
Cocanougher Road	3	3	1	2	2	3	14	4
Godbey Lane	1	3	2	3	2	2	13	6
Pope Road	2	3	3	2	1	2	13	6
Cream Ridge Road	3	2	1	2	2	2	12	8
Chenault Bridge Road	2	1	1	2	3	3	12	8
Wells Landing Road	2	2	2	2	2	2	12	8
Mitchell Lane	2	2	1	3	2	2	12	8
Persimmon Knob Road	3	2	1	2	2	2	12	8
Clifton Road	2	2	2	2	2	2	12	8
Old Hustonville Road	2	2	2	2	2	2	12	8
Crestview Drive	2	3	1	1	2	2	11	15

Boyle County then included an Equivalent Property Damage Only (EPDO) crash analysis and the risk score to produce a final ranking of sites. The EPDO method uses severity weights to assess the safety of a corridor based on crash frequency and severity. Boyle County used a weight of 10 for fatal crashes, 5 for injury crashes, and 1 for PDO crashes. Table 44 displays the number of crashes by severity level for each roadway in the analysis system, the EPDO values, and the ranking.

Table 44. Boyle County EPDO analysis ranking (table 1; Boyle County, 2021).

Road Name	Fatal	Injury	PDO	EPDO	EPDO Rank
Alum Springs Crosspike	0	3	7	22	1
Godbey Lane	1	1	4	19	2
Cream Ridge Road	0	2	3	13	3
Chenault Bridge Road	0	1	4	9	4
Harberson Lane	0	1	4	9	4
Wells Landing Road	0	1	3	8	6
Mitchell Lane	0	1	2	7	7
Pope Road	0	1	2	7	7
Persimmon Knob Road	0	0	7	7	7
Waterworks Road	0	1	1	6	10
Crestview Drive	0	0	3	3	11
Clifton Road	0	0	2	2	12
Oscar Bradley Road	0	0	2	2	12
Cocanougher Road	0	0	2	2	12
Old Hustonville Road	0	0	1	1	15

After performing the EPDO and qualitative hazard rating analyses, Boyle County developed a composite ranking based on the relative rankings from both analyses, shown in table 45, to identify roadways for further investigation. That table reflects the prioritized list of focus facility elements.

Table 45. Boyle County final roadway ranking (table 3; Boyle County, 2021).

Road Name	EPDO Rank	Qualitative Hazard Rank	Final Rating	Final Ranking
Alum Springs Crosspike	1	1	2	1
Harberson Lane	4	2	6	2
Godbey Lane	2	6	8	3
Cream Ridge Road	3	8	11	4
Chenault Bridge Road	4	8	12	5
Waterworks Road	10	2	12	5
Pope Road	7	6	13	7
Wells Landing Road	6	8	14	8
Mitchell Lane	7	8	15	9
Persimmon Knob Road	7	8	15	9
Oscar Bradley Road	12	4	16	11
Cocanougher Road	12	4	16	11
Clifton Road	12	8	20	13
Old Hustonville Road	15	8	23	14
Crestview Drive	11	15	26	15

Key Takeaways

- Systemic safety analysis can be performed even with limited data.
- Local knowledge is useful for assessing safety risk.
- Agencies can combine risk data and crash data to prioritize system elements for systemic safety improvements.

MassDOT Behavioral Crash Analysis

Agencies typically employ systemic safety analysis to plan infrastructure improvements. However, the process can also be used to plan and prioritize non-infrastructure improvements. MassDOT used systemic safety analysis to prioritize locations for behavioral safety campaigns. This case study describes MassDOT's systemic safety analysis of impaired driving, distracted driving, and occupant protection crashes.

Objective

MassDOT used systemic safety analysis to prioritize locations for distracted driving, impaired driving, and unbelted occupant countermeasures.

Source

This case study is based on MassDOT's *IMPACT Phase II – Identification of Risk Factors for SHSP Emphasis Areas* reports.[19] The individual reports are available at the following links:

- Impaired Driving (MassDOT, 2021d).
- Distracted Driving (MassDOT, 2021e).
- Occupant Protection (MassDOT, 2021f).

Data

MassDOT elected to use statistical modeling at the town level. As such, MassDOT created an integrated town-level database. The following lists the data used in the systemic safety analysis:

- Geolocated crash data from 2013 to 2017 (obtained from the Massachusetts Registry of Motor Vehicles).
- Roadway mileage (obtained from MassDOT Road Inventory).
- VMT (obtained from MassDOT Road Inventory).
- Town-level citation data (2017-2020).
- Driver's License data (2013-2015).
- Alcohol sales license location data.
- Schools, college, and university count by town.
- County-level seat belt use survey data.
- County-level cell phone use survey data.

[19] MassDOT. *Network Screening Methodology Reports.* https://www.mass.gov/lists/network-screening-methodology-reports#reports-.

- EJ flags at the town-level. The State determined thresholds and flagged communities that are above the threshold for proportion of population which are non-English speaking, low income, and/or minority.

Step 1, Tasks 1 and 2 – Identify Focus Crash Type and Facility Type

MassDOT selected impaired driving, distracted driving, and occupant protection as emphasis areas in the 2018 SHSP. As part of their efforts, MassDOT elected to include each of these as focus crash types. After consideration, MassDOT did not further define focus facility types, as these behaviors can lead to severe crashes on all roads.

Step 1, Task 3 – Identify Risk Factors

With large samples, MassDOT elected to produce crash frequency models at the town-level. The dependent variable was the number of focus crashes observed over five years in a town, and the predictive variables included proposed risk factors. The results of the analysis identified proposed town-level risk factors for the behavioral emphasis areas.

The following are risk factors found for impaired driving severe crashes (MassDOT, 2021d):

- High population density (exceeding 1,500 residents per square mile) was associated with a 46-percent increase in crash frequency.
- A low availability of alcohol licenses (less than 4 per 1,000 residents) was associated with a 94-percent increase in crash frequency compared to more than 4 per 1,000.
- Where more than 1 person out of 1,000 in a community was enrolled in an Operating Under the Influence (OUI) class, crash frequency in the town had an average increase of 62 percent.
- If there were more than 4 OUI citations per 1,000 residents in a town, severe impaired driving crash frequency increased 32 percent.
- Finally, in a measure of general risk-taking rather than impaired driving, towns with more than 50 total traffic citations per 1,000 residents were associated with an increased crash frequency of 46 percent.

The following are risk factors found for distracted driving severe crashes (MassDOT, 2021e):

- Total population was found to be positively correlated with crash frequency, where towns with a population between 35,000 and 74,999 people experienced 25-percent more crashes and towns with 75,000 or more residents experienced 2.59 times as many crashes as towns with fewer than 35,000 residents.
- Distracted driving crashes were also found to occur at a higher frequency in towns with a low-income EJ flag—crash frequency was 29-percent higher in those communities compared to others.

- Towns with fewer than 0.1 colleges or universities per square mile were found to have 94-percent more crashes than those with a higher density of higher-education institutions.
- Towns with a relatively high proportion of urban or rural principal arterial and urban minor arterial or rural major collectors had an increased severe distracted driving crash frequency, with increases of 29 percent and 32 percent, respectively.
- Finally, several citation variables were included as surrogate measures of risky driving behaviors in a town.
    - If impaired driving citations per center line miles in a town was between 0.25 and 0.75, crash frequency increased by 42 percent.
    - If impaired driving citations per center line miles in a town was greater than 0.75, crash frequency was 2.39 times as high as towns where that metric was less than 0.25.
    - If total annual traffic citations exceeded 10 per center line mile, crash frequency in the town was 27-percent higher.
    - Where distracted driving citations per center line mile exceeded 0.25, crash frequency was 49-percent higher than baseline towns.

The following are risk factors found for unbelted occupant severe crashes (MassDOT, 2021f):

- The proportion of licensed drivers in the town aged 29 or younger was found to be positively correlated with severe unbelted crash frequency—a 1.0-percent increase in the proportion results in an average of a 0.44-percent increase in crashes.
- There was significant correlation between EJ communities and severe unbelted occupant crashes—if a town was flagged for all three EJ indicators, the crash frequency was 49-percent higher than other towns.
- Because unbelted occupants are at more risk of injury when traveling at higher speeds, the model included thresholds for the proportion of center line mileage that is higher speed roads—if the interstate proportion was greater than 0.06, crash frequency was 50-percent higher, and if the principal arterial proportion was greater than 0.05, crash frequency was 52-percent higher.
- Also related to speed, towns where the weighted average speed limit (based on roadway mileage) was higher than 35 mph had crash frequency elevated by 30 percent.
- Additionally, towns with a population density greater than 500 person per square mile had elevated crash frequency—88-percent higher when the density was between 500 and 2,000 persons per square mi, 2.24-times higher when the density was between 2,000 and 3,500 persons per square mi, and 74-percent higher when density was greater than 3,500 persons per square mile. The spike in the coefficient for medium density towns was unexpected. One potential explanation is higher density communities have more public transit options, which may change the travel behaviors of those who otherwise would travel unbelted.

- Finally, unbelted occupant traffic citations functioned as a surrogate measure for the behavior—towns where the proportion of unbelted citations to total citations was greater than 0.025 had an elevated crash frequency of 60 percent.

After identifying the town-level risk factors, MassDOT further refined segment risk by identifying roadway characteristics which were overrepresented when comparing severe (i.e., fatal and serious injury crashes) to all crashes. Table 46 summarizes the segment-level risk factors selected by MassDOT.

Table 46. Summary of segment-level risk Factors for MassDOT behavioral crashes (MassDOT, 2021d; MassDOT, 2021e; MassDOT, 2021f).

Risk Factor	Distracted Driving	Impaired Driving	Unbelted Occupants
Functional Class	Urban Collector or Rural Minor Arterial	N/A	Interstate, Rural Principal Arterial, or Urban Principal Arterial
Roadway Jurisdiction	N/A	MassDOT highway.	N/A
Access Control	N/A	Full or partial access control.	N/A
AADT	AADT is between 15,000 and 60,000 vehicles per day.	AADT is between 500 and 1,999 vehicles per day.	AADT is 40,000 vehicles per day or greater.
Curbing	Curb is present.	No curb is present.	No curbing is present or is only present on the primary direction.
Right Shoulder Width	3 ft or wider	1 to 2 ft.	3 ft or wider
Median Type	Divided with barrier	N/A	Divided with barrier
Posted Speed Limit	40 to 65 mph	N/A	40 to 55 mph, 60 to 70 mph
Crash Risk	N/A	Risk of a Roadway departure Crash and Risk of a Pedestrian Crash	N/A

Step 2 – Screen and Prioritize Candidate Locations

After identifying the focus crash types, focus facility types, and risk factors for behavioral crashes, MassDOT proceeded to identify their candidate locations for improvements.

Task 1 – Identify System Elements to Analyze

MassDOT wanted to identify the corridors with the highest risk of behavioral crashes. MassDOT began by joining the town-level risk factors to each segment in the road inventory. Therefore, the road inventory had each risk factor present for each segment. MassDOT used the GIS Dissolve function to create corridors uniform in basic roadway characteristics, such as the town and route name, as well as the relevant risk factors, for each focus crash type. This process created a database of uniform system elements from the raw road inventory data.

Task 2 – Calculate Risk Score

After identifying the system elements, MassDOT proceeded with assigning a risk score to each corridor. The agency began by assigning weights to individual risk factors. MassDOT started with a binary scale, where the maximum weight assigned to a risk factor was 1.0. However, they allowed for values between 0 and 1 to be applied based on the correlations observed in the risk factor identification process. This resulted in three potential scoring schemes for a risk factor:

- Binary – 1 if the risk factor is present; 0 otherwise.
- Ordinal – fixed values are assigned between 0 and 1 (e.g., 0 if the population is less than 35,000 persons; 0.5 if the population is between 35,000 and 75,000 persons, and 1.0 if the population is greater than 75,000).
- Continuous – risk score is function of the risk factor (e.g., risk score is 0.02 * Posted Speed Limit -0.30 if the posted speed limit is between 40 and 65 mph). The functions typically produce a linear scale with a maximum of 1.0 and a set minimum somewhere between 0 and 1.0.

For an example, table 46 describes the scoring criteria used to calculate the risk score for system elements in the Distracted Driving focus area. Note the range of scoring strategies MassDOT applied for this model. The maximum potential score for a corridor when assessing distracted driving risk is 14. The maximum potential score for impaired driving was 12, while the maximum for unbelted occupants was 14.[20] MassDOT proceeded to calculate the total risk score for each system element for the three focus crashes.

[20] The scoring methods used for Impaired Driving and Unbelted Occupants are available in the respective reports linked previously.

Table 47. Distracted driving risk scoring for MassDOT (MassDOT, 2021e).

Risk Factor Level	Risk Factor	Scoring
Town	Town Population	• 0 if population is less than 35,001. • 0.5 if population is between 35,001 and 75,000. • 1.0 if population is greater than 75,000.
Town	Environmental Justice	• 1 if the town is flagged with the EJ – Income indicator. • 0 otherwise.
Town	College and Universities per Square Mile	• Risk score is equal to 1-5 * Density if density is less than or equal to 0.1. • 0 otherwise.
Town	Proportion of Town's Center Line Mileage that is Urban or Rural Principal Arterial	• Risk score is equal to 2.692 * Proportion + 0.3654 if proportion is greater than or equal to 0.05. • 0 otherwise.
Town	Proportion of Town's Center Line Mileage that is Urban Minor Arterial or Rural Major Collector	• Risk score is equal to 2.027 * Proportion + 0.0946 if proportion is greater than or equal to 0.20. • 0 otherwise.
Town	Annual Impaired Driving Citations per Center Line Mile in Town	• 1.0 if greater than 0.75 citations per mile. • 0.5 if ratio is between 0.25 and 0.75 citations per mile. • 0 if less than 0.25 citations per mile.
Town	Annual Total Traffic Citations per Center Line Mile in Town	• 1.0 if greater than 10 citations per mile. • 0 otherwise.
Town	Annual Distracted Driving Citations per Center Line Mile in the Town	• 1.0 if greater than 0.25 citations per mile. • 0 otherwise.
Segment	Functional Class	• 1.0 if functional class is urban collector or rural minor arterial. • 0 otherwise.
Segment	AADT	• 1.0 if AADT is between 40,000 and 60,000 vehicles per day. • Risk score is equal to 0.00002 * AADT + 0.2 if AADT is between 15,000 and 40,000 vehicles per day. • 0 otherwise.
Segment	Curbing	• 1.0 if no curbing is present. • 0 otherwise.
Segment	Right Shoulder Width	• 1.0 if right shoulder width is 3 feet or wider. • 0 otherwise.

Risk Factor Level	Risk Factor	Scoring
Segment	Median Type	• 1.0 if divided with barrier. • 0 otherwise.
Segment	Posted Speed Limit	• Risk score is equal to 0.02 * Posted Speed Limit – 0.30 if posted speed limit is between 40 and 65 mph. • 0 otherwise.

Task 3 – Prioritize Elements

After assigning risk scores, MassDOT needed to prioritize the system elements to identify potential candidate locations. They began by normalizing the risk score for each corridor—dividing the corridor risk score by the total risk score available for each focus crash type. MassDOT then produced two sets of prioritized lists—a statewide prioritization and MPO prioritization.

For the statewide list, MassDOT ranked each corridor in the State by the normalized risk score then assigned a percentile to each corridor describing how many corridors the subject corridor has a higher risk score than (e.g., the corridor with the highest risk score received a percentile ranking of 100, indicating that this corridor ranks higher than 100 percent of the other corridors). MassDOT identified the top 5 percentile corridors—those with a percentile score between 95 and 100—as "Primary Risk Sites". The next 10 percentile corridors—those with a percentile score between 85 and 95—were labelled "Secondary Risk Sites".

The same procedure was performed within each MPO for prioritization. The same labels were applied as well, though in this case the percentile ranking and labels were relative to other corridors in the MPO. After assigning these labels, MassDOT created maps visualizing the "Primary Risk Sites", "Secondary Risk Sites", and remaining system elements.

Figure 58 shows the distracted driving priority map using statewide rankings, while figure 59 shows the distracted driving priority map using MPO ranking. These maps, as well as the impaired driving and occupant protection maps, are available through the MassDOT IMPACT tool at: https://apps.impact.dot.state.ma.us/sat/NetworkEmphasisArea (MassDOT, 2022).

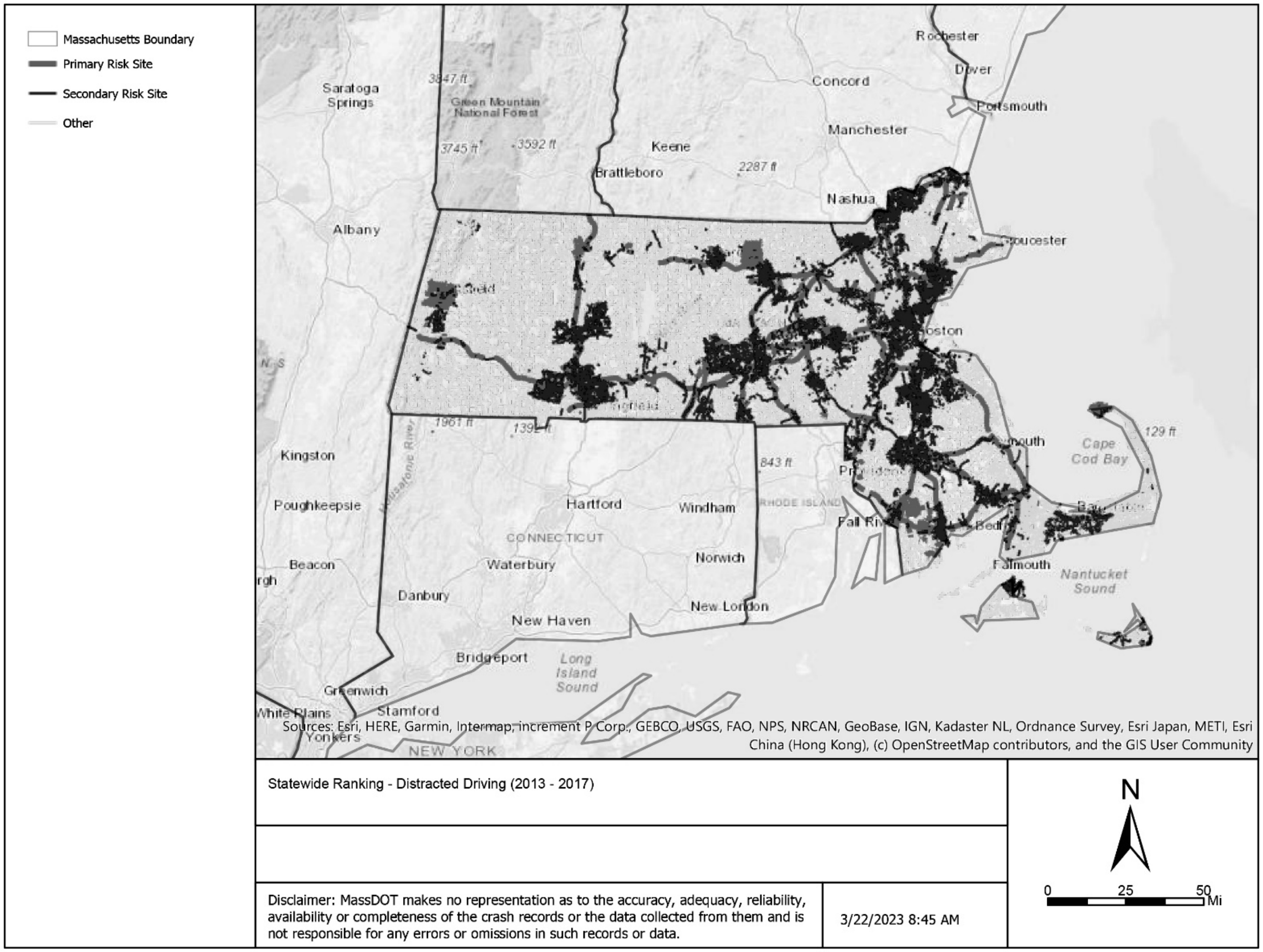


Figure 58. Graphic. Statewide ranking map for Distracted Driving (Source: MassDOT, 2022).

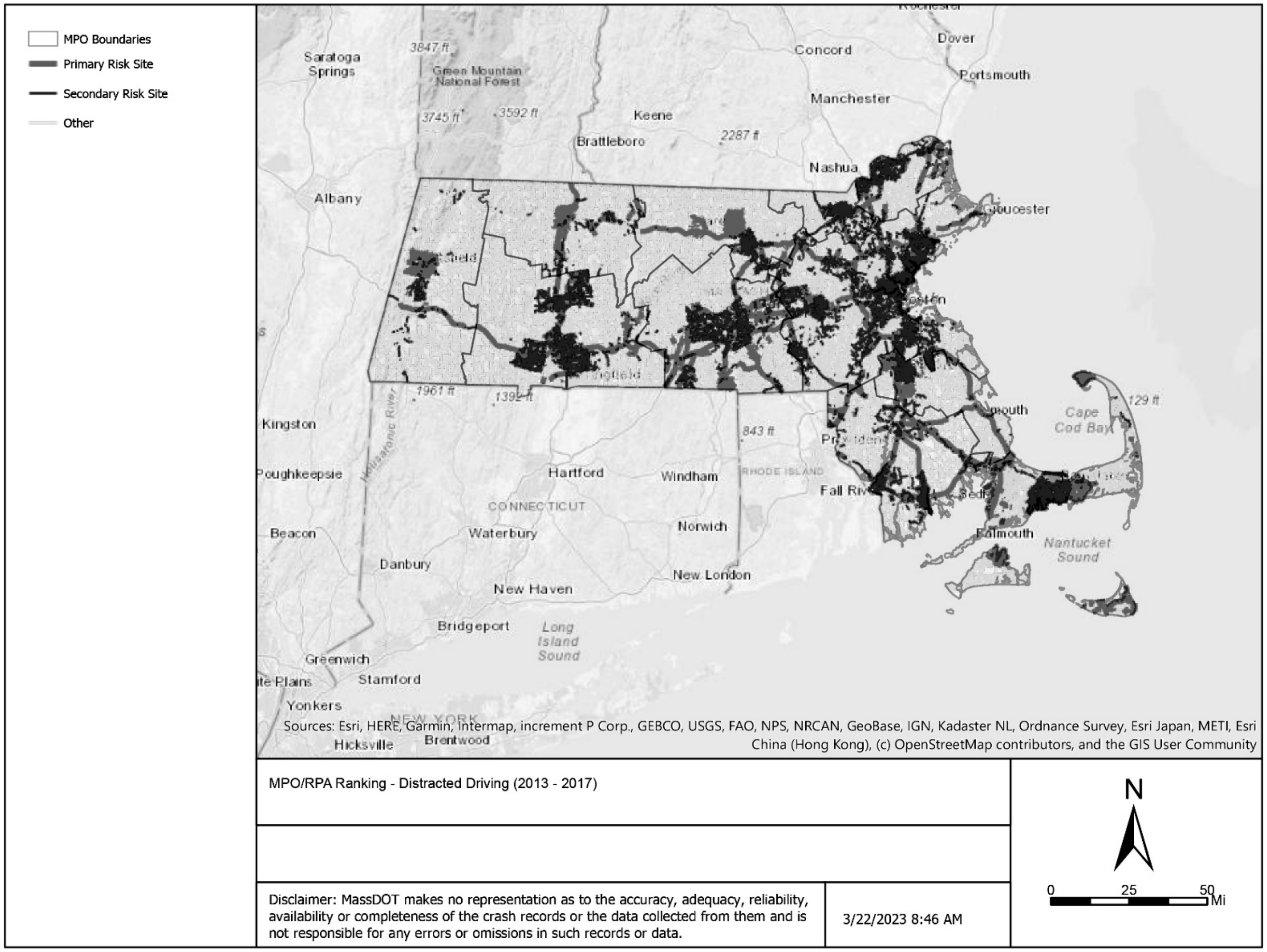


Figure 59. Graphic. MPO ranking map for Distracted Driving (Source: MassDOT).

Key Takeaways

- Systemic safety analysis is a useful process for behavioral crash analysis.
- Systemic safety analysis can use a mix of risk factor identification methodologies and risk score weighting methods.
- Systemic safety analysis can be applied to geographic areas (such as cities and towns), not just roadway elements.
- Visualizations can help communicate the highest risk components of the system to stakeholders and the public.

Key Terms

This section provides definitions specific to this Guide for relevant terms.

BCR – benefit-cost ratio represents the ratio of expected safety benefits to the cost of the project. This calculation can be modified to include other benefits (e.g., operational, environmental, etc.) and specific individual cost components (e.g., HSIP, state-funding, etc.).

Countermeasure – an infrastructure improvement, behavioral or enforcement program, or other implementation which is meant to reduce the frequency and or severity of crashes.

Crash tree – a diagram which shows the breakdown of crashes by data elements and attributes.

Evaluation – a review of the performance of a project, countermeasure, or improvement after installation.

Focus crash type – the crash type around which a systemic program is built, defined using crash, roadway, person, and other data elements as needed. Typically, the crash type accounts for the largest proportion of severe crashes, is most overrepresented in terms of severe crashes, or is derived from a safety plan.

Focus facility type – the facility type around which a systemic program is built. Typically, the facility type on which the largest proportion of focus crashes occurs, on which focus crashes are overrepresented, or derived from another program or safety plan.

Highway Safety Improvement Program (HSIP) – the Highway Safety Improvement Program is a core Federal-aid program with the purpose to achieve a significant reduction in traffic fatalities and serious injuries on all public roads, including non-State-owned roads and roads on tribal land (23 U.S.C. 148(b)(2)). This also includes the State HSIP, which is the actual planning, implementation, and evaluation of the safety program funded by the HSIP and other funding sources.

Indefinite Delivery/Indefinite Quantity (ID/IQ) – a method of contracting that allows an indefinite quantity of services for a fixed time. This method is used when a contracting agency anticipates a recurring need but has not determined, above a specified minimum, the precise quantities of services that it will require during the contract period. Contractors bid unit prices for estimated quantities of standard work items, and work orders are used to define the location and quantities for specific work (23 CFR 635.602).

Material procurement – a project delivery method in which the State Transportation Agency acquires safety countermeasure equipment and distributes the equipment to local agencies for implementation.

Overrepresentation – the comparison of the proportional distribution of a set of subject data to a set of comparison data with the goal of identifying attributes for which the subject data account for a notably larger proportion than the comparison group.

Project bundling – typically used for bridges, it is "a procurement process where a single contract is used for the rehabilitation or replacement of multiple projects" (FHWA, 2022b). In a safety context, this typically includes the bundling of similar safety improvements at several sites within a geographic area for delivery under one contract.

Quick-build – a project delivery method in which projects are implemented rapidly, often within a year of ideation, and built using flexible yet durable materials, typically using maintenance forces, with the purpose of getting a safety countermeasure in the ground quickly.

Risk – a qualitative or quantitative measure of the likelihood of a severe crash relative to typical conditions.

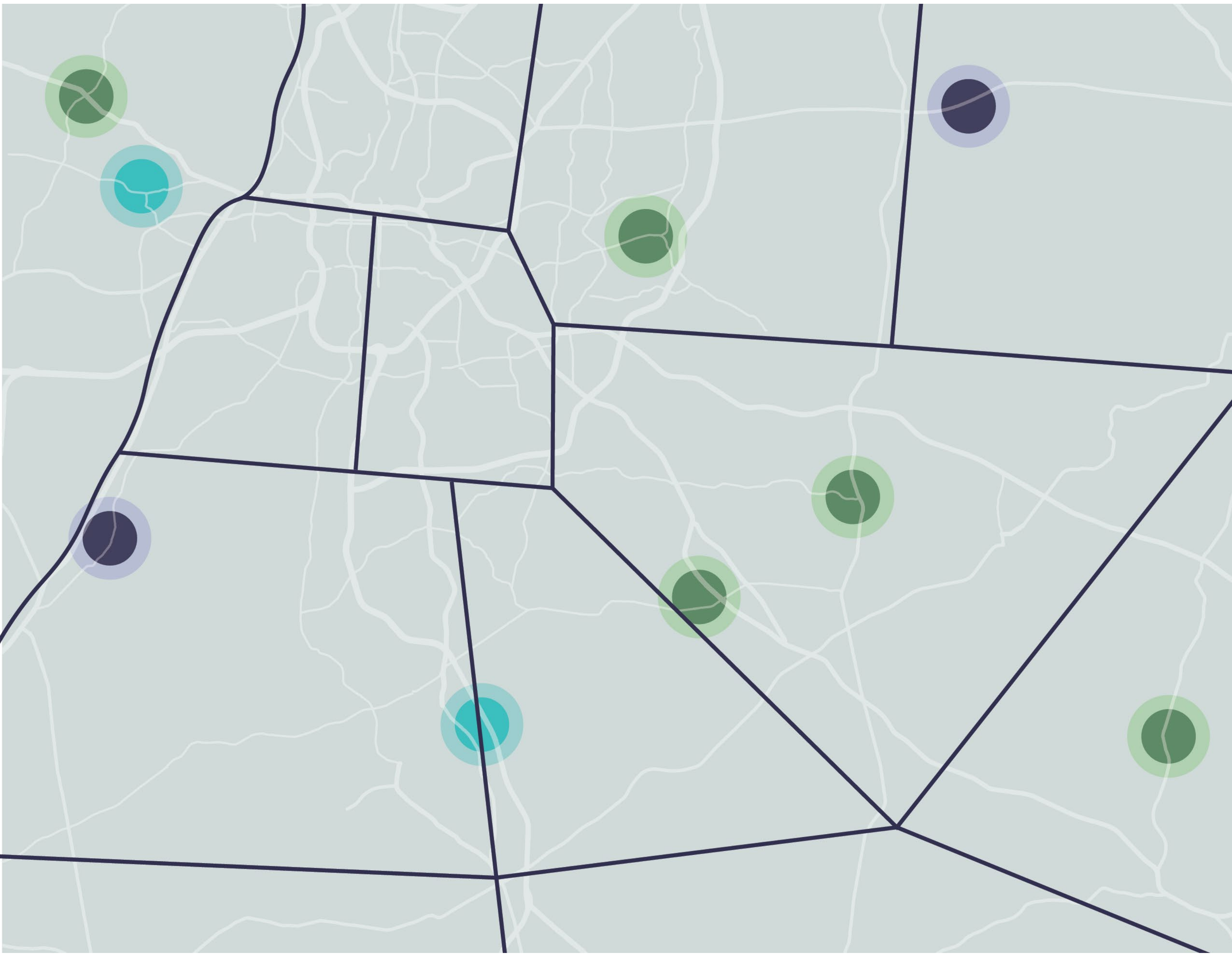
Risk factor – characteristics of a site which have been found to elevate the risk of a severe crash relative to typical conditions. Risk factors can be binary, ordinal, or even continuous, in which the risk is measured as a function of the risk factor.

Site – the system element at which analysis and projects are considered, can be a segment, curve, intersection, corridor, block group, community, or anything as defined by the systemic safety program.

Site-specific safety – a reactive form of safety management in which agencies develop targeted safety projects at locations based on their crash history.

Systematic safety – a proactive form of safety management in which agencies install safety countermeasures at locations which meet a predefined set of criteria.

Systemic safety – a proactive form of safety management in which agencies install safety countermeasures at locations which are prioritized based on their relative level of risk.



U.S. Department of Transportation
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