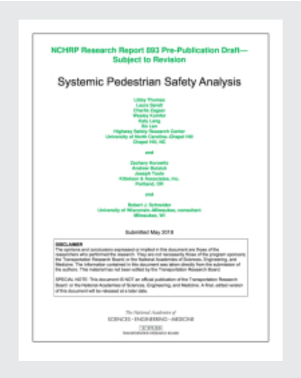
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Systemic Pedestrian Safety Analysis

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DETAILS

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LIST OF ACRONYMS

AADP	Average Annual Daily Pedestrian Traffic
AADT	Average Annual Daily Traffic (Motor Vehicles)
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ADOT	Arizona Department of Transportation
ARTS	All Roads Transportation Safety
Caltrans	California Department of Transportation
CEI	Cost-effectiveness Index; also see glossary
CMF	Crash Modification Factor; also see glossary
DOT	Department of Transportation
EB	Empirical Bayes
FHWA	Federal Highway Administration
GIS	Geographic Information System
HAWK	High-Intensity Activated crossWalK
HSIP	Highway Safety Improvement Plan (or Program)
HSM	*Highway Safety Manual*
LPI	Leading Pedestrian Interval
MPH	Miles per Hour
MPO	Metropolitan Planning Organization
MUTCD	Manual on Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
ODOT	Oregon Department of Transportation
PBCAT	*Pedestrian and Bicycle Crash Analysis Tool*
PBIC	Pedestrian and Bicycle Information Center
PCS	Pedestrian Countdown Signals

PEDSAFE	*Pedestrian Safety Guide and Countermeasure Selection System*
PEDSMARTS	*Pedestrian Systemic Monitoring Approach for Road Traffic Safety*
PHB	Pedestrian Hybrid Beacon
RSA	Road Safety Audit
SDOT	Seattle Department of Transportation
SHS	State Highway System
SHSP	State Highway Safety Plan
SPF	Safety Performance Function (i.e., crash prediction model); also see glossary
SSARP	Systemic Safety Analysis Report Program
TCRP	Transit Cooperative Research Program
TWLTL	Two-Way Left-Turn Lane
UNC-HSRC	University of North Carolina Highway Safety Research Center

GLOSSARY OF KEY TERMS

The following glossary provides definition of key terms, within the context of this Guidebook. Other references or agencies may have different definitions and uses for these terms.

Cost-Effectiveness Index: Estimates the cost to reduce one vehicle-pedestrian crash. It is calculated by dividing project costs by the expected reduction in pedestrian crashes. See Step 6 for details.

Crash Frequency: The number of crashes at a defined location over a defined time period.

Crash Modification Factor (CMF): A numerical estimate of the expected reduction (or increase) in the number of crashes that may result when a countermeasure treatment is implemented.

Crash Type: A variable that typically describes events and maneuvers of the involved parties that led up to a crash. The relative maneuvers of the parties such as road departure (single vehicle), angle crash (between two motor vehicles), or pedestrian crossing at midblock and struck by a vehicle traveling straight (pedestrian-motor vehicle crash type) are examples.

Crash Predictor: Any characteristic of the roadway, environment, vehicle, or population attribute that helps to predict future crashes based on a quantified association with prior crashes (such as in an SPF, see definition below). In other words, these are measured variables that are associated with crash frequencies and are used to estimate risk (see definition below). Crash predictors themselves may not have a causal relation or theoretical basis for increasing risk, but they may serve as surrogate measures for certain risk factors (see definitions of these terms below).

Exposure: Using the Safe States Alliance *Consensus Recommendations for Pedestrian Injury Surveillance* definition, pedestrian exposure is "an observable period or point during which a pedestrian experiences the possibility of suffering an injury related to the act of being a pedestrian." Several constructs—such as counts of pedestrians at crossings—can be used to quantify pedestrian exposure to the risk of a crash or injury. In theory, not all pedestrian trips or activity result in exposure to a vehicle crash, but for the purposes of this guide, the terms pedestrian exposure, volumes, demand, and activity are used interchangeably.

Network: The complete network of streets within a defined area or jurisdiction.

Risk: The probability of a crash between a pedestrian and a motor vehicle at a specific location within a defined period. While true risks are rarely known, the traffic engineering field creates estimates of risk by identifying attributes of locations on a roadway network that are associated with crash frequencies or severities (see crash predictor definition).

Risk Factor: Any attribute, characteristic, or exposure of an individual or roadway that increases the likelihood of a crash or increases the risk of a more severe injury outcome in the event of a crash. Unlike a crash predictor, not all risk factors can be measured from attributes associated with site characteristics (such as states of users at the time of a crash). The mere presence of a risk factor may not be sufficient to cause a crash, but a risk factor should have a plausible association with a contributing circumstance of a crash.

Safety Performance Function (SPF): A statistical model used to predict crashes based on site characteristics. These models always include traffic volume (AADT), and in the case of pedestrian crash SPFs should also always include pedestrian volume (AADP). SPFs may also include other roadway features, and in the case of pedestrian SPFs, characteristics of the built and social environment around the site. Predictions (both adjusted for prior crashes and unadjusted) are used to estimate overall crash risk at a location.

Surrogate Measure: A characteristic or variable that may help to predict crashes by approximating or capturing phenomena associated with a risk factor that may or may not be measured. A common example is the use of household or employment density (available data from the Census) to serve as a surrogate for pedestrian exposure, when the latter is not directly measured.

Systemic Approach: A systemic approach is a data-driven, network-wide (or system-level) approach to identifying and treating high-risk roadway features correlated with specific or severe crash types. Systemic approaches seek not only to address locations with prior crash occurrence, but also those locations with similar roadway or environmental crash risk characteristics.

BASICS: HOW TO USE THIS GUIDEBOOK

This Guidebook was developed to provide a framework for transportation agencies to take the steps needed to advance toward implementing a risk-based, systemic pedestrian safety management process to reduce pedestrian crashes. It aims to:

- Provide rationale and motivation for taking a systemic approach;
- Clarify key terms and definitions;
- Describe the data needs for a systemic process, and offer guidance on how agencies can acquire necessary data;
- Offer guidance for conducting a systemic analysis, as well as provide alternative methods and troubleshooting; and
- Highlight real-world examples that can provide motivation and models for systemic approaches.

The Guidebook was developed as part of the National Cooperative Highway Research Program (NCHRP) project 17-73. The *Systemic Pedestrian Safety Analysis: Technical Report* complements this guidebook and offers more details on the research methods and evidence base. The Technical Report also provides an example of a systemic safety analysis for users that may seek more in-depth information on the analysis process.

INTENDED AUDIENCE

It is intended to serve state department of transportation (DOT) personnel and contractors, including managers and staff in highway safety improvement programs, pedestrian and bicycle programs, and safety data management programs. Its guidance is also applicable for local and regional transportation agencies that may be working independently or in coordination with state DOT staff on safety improvement efforts. The introductory chapter is intended for higher-level decision makers and elected officials.

GUIDEBOOK CONTENTS

The Guidebook is divided into several sections:

- **Introduction:** Provides a high-level overview of the motivation for a systemic pedestrian safety process, clarifies key terms, and describes the seven steps in the process, as laid out in this Guidebook;
- **Steps 1 – 7:** Provides more detailed guidance on each step in the process, as well as examples and alternative methods;
- **Case Examples**: Presents four real-world examples of systemic pedestrian safety processes used by state and local DOTs;
- **Conclusion**: Offers additional considerations and limitations; and
- **Appendix A:** Describes 12 key countermeasures (referenced elsewhere in the Guidebook) that may be implemented to treat risks identified in a systemic pedestrian safety analysis.

GUIDEBOOK FEATURES

Throughout the Guidebook, look for call out boxes designed to bring attention to key definitions, considerations, and noteworthy practices. These are highlighted using the icons below:

Definition

Concise definition of a key term; also found in the glossary.

Looking Ahead

Different steps in the systemic process build on and relate to other steps. These call outs are intended to flag decision points that may have implications for other steps in the process.

Noteworthy Practice

Highlights of real-world practices, many of which are also included in Case Examples.

Troubleshooting

Advice for addressing challenges that may arise during a systemic process.

INTRODUCTION: PURPOSE AND PROCESS OF SYSTEMIC ANALYSIS

In the U.S., while motor vehicle occupant safety has made considerable strides, pedestrian fatalities are on the rise, making up a greater and greater portion of all traffic fatalities each year (see Figure 1, based on data from the National Highway Traffic Safety Administration, or NHTSA). In 2016 alone, 5,987 pedestrians were killed in collisions with motor vehicles (Retting 2018)—making it the deadliest and costliest year for pedestrians in the U.S. in more than 25 years. In more urban states and cities, pedestrian crashes can represent as much as 25 to 45 percent of all traffic fatalities (Williams 2015).

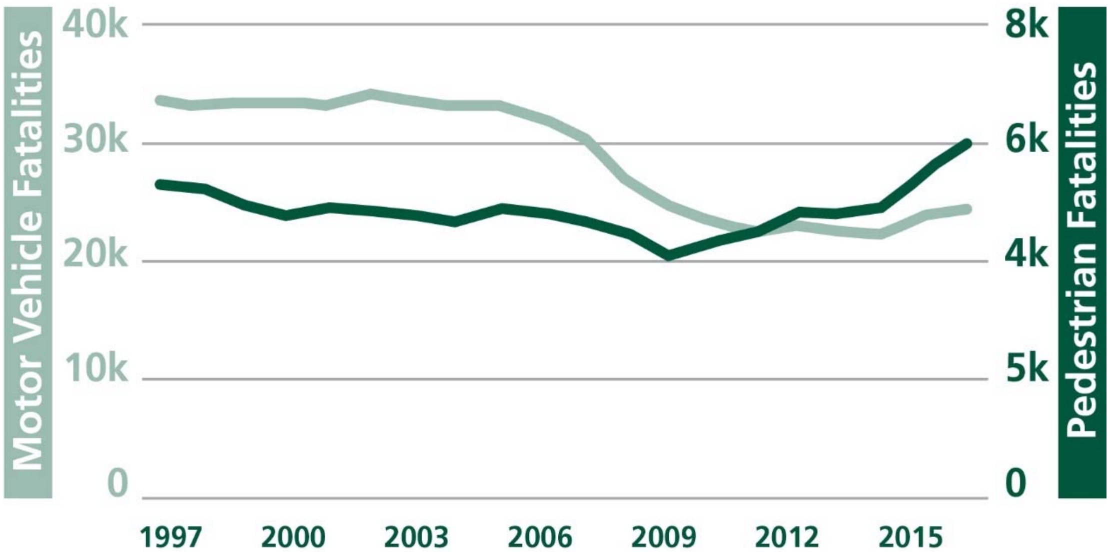

Figure 1. U.S. motor vehicle and pedestrian fatalities between 1997 and 2016.

Addressing pedestrian safety issues and curbing this trend have become a critical mission for both state and local transportation agencies.

ESSENTIALS OF A SYSTEMIC APPROACH

Constrained resources, a perennial challenge for state and local transportation agencies, has motivated many to seek more innovative and data-driven methods to use limited transportation funds in ways that maximize cost-effectiveness and safety impact. In recent years, many states have adopted systemic approaches to safety, which, according to the Federal Highway Safety Administration (FHWA, https://safety.fhwa.dot.gov/systemic/), "helps agencies broaden their traffic safety efforts at little extra cost."

The basic tenets of a systemic safety approach, as outlined in FHWA's *Systemic Safety Project Selection Tool* (Preston et al. 2013), are as follows:

- Identifies a safety concern based on an evaluation of data at the system-level;
- Establishes common characteristics (risk factors) of locations where severe crashes frequently occur;
- Emphasizes deploying one or more countermeasures to address the underlying circumstances at many of the locations experiencing the risk factors; and

- Given high aggregate numbers of target crashes but low average density per site, tends to deploy lower cost countermeasures to many sites to affect a large number of locations.

Definition: Systemic Approach

A systemic approach is a data-driven, network-wide (or system-level) approach to identifying and treating high-risk roadway features correlated with specific or severe crash types. Systemic approaches seek to not only address locations with prior crash occurrence, but also those locations with similar roadway or environmental crash risk characteristics. A systemic approach resides on a spectrum of ways that transportation agencies may address safety issues (see Figure 2 on next page) and is considered a more proactive approach than those that focus only on treating specific locations with a crash history.

MOTIVATION FOR A SYSTEMIC APPROACH

FHWA maintains a website resource that catalogs the practices of states that are taking a systemic approach, found here: https://safety.fhwa.dot.gov/systemic/. At the time of this publication, nearly a dozen states and a handful of cities and regions are implementing systemic approaches to safety. Although few have focused on pedestrian issues, lessons from places that are implementing systemic safety approaches are consistent. The benefits of a systemic approach are:

- **Stronger Basis for Decisions**: Accounts for important factors, such as activity/exposure and randomness that are often excluded from a traditional crash "hot spot" approach when identifying locations for improvement.
- **Effective Use of Resources**: Helps focus resources on crash risks that are most prevalent across the network and guides selection of appropriate treatments and locations to reduce the most serious crashes.
- **Data-Driven Approach**: Provides a data-driven/analytical method and screening tools that can be used to justify funding decisions, even if there is not a specific crash history at a given location. A data-driven process also creates new opportunities to provide an equitable risk-based assessment across a jurisdiction.
- **More Proactive Approach**: Takes a forward-looking approach to address safety issues without waiting for a crash history to develop at any given location.
- **Consistency**: Helps avoid dealing with broad safety issues one project at a time and instead treats risks more widely and consistently.

Ultimately, a systemic approach is intended to lead to more informed decision-making and optimized investment that will result in accelerated safety improvements.

Spot Safety Approach

Makes improvements at individual sites or road segments with relatively high numbers of crashes, without regard to other sites with similar risk factors.

Corridor Retrofit Approach

Makes improvements at several adjacent locations (with possibly similar risk factors), not all of which may have experienced a high number of crashes.

Systemic Approach

Makes improvements at locations with a high predicted crash risk or presence of key risk factors, regardless of actual crash history.

Systematic Approach

Makes improvements at all sites in an area, regardless of predicted crash risk or crash history.

Figure 2. A systemic approach addresses sites with similar risk factors, regardless of crash history; it falls along a spectrum of other approaches to safety that are more or less proactive in treating sites based on risk or prior crash history.

Noteworthy Practice

In 2001, the City of Seattle Department of Transportation (SDOT) identified the need for improvements to pedestrian crossings throughout the City. Crash data had shown that pedestrian crashes accounted for roughly 25 percent of all fatal crashes in the City, and there were signs that number could rise as pedestrian activity increased. SDOT wanted to take a more proactive and comprehensive approach to address risks across the network, rather than only responding to a site after a crash occurred. At that time, there were not a lot of examples of how to go about conducting a systemic pedestrian safety study. An early effort involved inventorying and assessing all unsignalized crosswalk locations using risks identified from a national study. More recently, the City has invested in data improvements and robust, systemic pedestrian safety analyses. Their experience led the way for the development of many of the processes and methodologies presented in this Guidebook. See Case Example 1 for further detail.

STEPS IN A SYSTEMIC PEDESTRIAN SAFETY PROCESS

As outlined in this Guidebook, there are seven key steps in a pedestrian safety systemic process (see Figure 3). While the steps are presented in a linear sequence, some of these steps may occur simultaneously, in different orders, or iteratively, and there is wide latitude for agencies to enter the process at different points.

Figure 3. Steps in a systemic pedestrian safety analysis process.

The steps highlighted in Figure 3 include:

- **Step 1** involves defining the area for analysis, identifying the facility or location type target or focus, and identifying subsets of target crash type(s) for systemic focus. This step sets the stage for all subsequent steps.
- **Step 2** involves compiling the roadway and other location characteristics and crash data that will be needed to identify risk factors in Step 3. All systemic processes require data, and the compiled data will serve as an important foundational database to identify potential treatment sites in Step 4.
- **Step 3** involves analyzing data to determine factors associated with the target pedestrian crash type or location of interest or using alternate approaches from research or local knowledge to identify key risk factors.
- **Step 4** involves identifying an optimal set of sites that have common risk and site characteristics that are suitable for similar packages of treatments, using various screening and ranking methods.
- **Step 5** involves identifying appropriate countermeasures or combinations of measures that could potentially address risks identified. In Step 5, there is also a chance to further refine and prioritize the locations identified in Step 4.
- **Step 6** involves considering additional priorities, performing diagnostics, performing economic assessments, allocating funding, and implementing a systemic treatment plan, including construction of pedestrian safety improvements.
- **Step 7** involves evaluating project and program impacts before starting the process anew.

A systemic process is fundamentally a data-driven process, so a theme throughout this Guidebook relates to how and why agencies can make data more current and complete, accessible, centralized, and linked to support more robust pedestrian safety analysis and implementation.

Agencies familiar with FHWA's *Systemic Safety Project Selection Tool* (available at https://safety.fhwa.dot.gov/systemic/fhwasa13019/sspst.pdf) will recognize many of the same activities, often in a similar sequence. The process detailed in this Guidebook builds on FHWA's established process, but because of the unique needs of pedestrians in terms of crash risks, effective countermeasures, and available data, it provides guidance on key additional steps needed to successfully perform a systemic risk-based analysis focusing on pedestrian safety.

A key question that readers may ask is, "How can this process be incorporated into my agency's highway safety management process?" This process was designed to be highly compatible with the *Highway Safety Manual* (HSM) safety management process, which is used in some form by many DOTs. Table 1 indicates which steps in this guide may be most similar to different phases of the HSM process.

Table 1. Relation of the pedestrian systemic process to the Highway Safety Manual process.

If you are in the HSM process…	Find guidance for incorporating a systemic approach in…
Prior analysis (not shown in HSM's six steps)	Steps 1-3
Network Screening	Step 4
Diagnosis	Step 1 (Section 1.2), Step 3, Step 6 (Section 6.2)
Select Countermeasures	Step 5
Economic Appraisal	Step 6 (Section 6.3)
Prioritize Projects	Step 6
Evaluate	Step 7

The following sections provide in-depth guidance on how to successfully perform systemic pedestrian safety analyses and weave such processes into a broader safety management program.

STEP 1: DEFINE STUDY SCOPE

The introduction makes the case for a performance-based management approach for pedestrian safety and describes the overall steps needed to obtain and utilize the necessary types of data, and to develop the tools and processes to achieve a performance-based practice similar to what is commonly used in road safety management programs for other modes of travel.

The first step of the systemic process is to define the study scope. This step sets the stage for all subsequent steps. This step outlines basic procedures to identify a focus (i.e., a "targeted" risk problem) for a systemic pedestrian safety analysis, regardless of the agency or network size. These include:

- Defining the jurisdiction or network area for analysis;
- Identifying one or more target facility or location types; and
- Identifying subsets of target crash type(s) for systemic focus.

Definition: Network

In this Guidebook, networks refer to the complete network of streets within a defined area or jurisdiction. See the considerations in the following section that may help to determine the network to include in an application of a systemic process.

1.1 IDENTIFY NETWORK FOR ANALYSIS

The jurisdictional focus may be self-evident, depending on who is initiating the process, and how later steps in the process may be shared or divided. For example, a state DOT may initiate a high-level assessment of pedestrian crash issues across the state, or for different geo-political divisions. These analyses can, in turn, be used to inform decisions about regional priorities for further systemic safety analyses.

At a Statewide or regional level, the network of interest (and high-level analysis) might first be subdivided or stratified by ownership or area-type. Examples include the following:

- Urban (municipal) vs. rural locations; or
- State, county, city, and other network divisions.

Rural and urban location and facility types can be analyzed systemically but there may be issues regarding compiling certain types of supplementary data. Compiling crash data from different regions within a state should also be feasible, but there may be more challenges during Step 2 when compiling land use, census, or transit data—types of data that are highly desirable for an analysis of pedestrian risk factors. Also consider differences in regional travel patterns, geographies, development types, and other characteristics when deciding on a network focus.

A state or regional agency may use area-based analyses to help identify higher-risk focus areas for more in-depth systemic analysis. Performance measures such as crash frequencies, crash rates per population, and crash rates derived from travel estimation surveys that capture pedestrian trips or commute mode-shares may be summed and used to compare risk at regional scales. See FHWA's pending *Guide for*

Scalable Risk Assessment Methods for Pedestrians and Bicyclists for more information on performance measures and their use in this type of analysis.

Once the network focus has been determined, the next tasks focus on identifying a target facility and crash type that can be used to assess risks at specific locations for potential treatment. If there is a strong trend of crash-risk at an area scale, such as by distinct neighborhood characteristics, various land uses, or population characteristics (such as older or school-aged pedestrians, impairments, or others), and there is an intention of conducting more field-based diagnoses to identify risk patterns for systemic treatment within zonal areas, an area-based scale could be used for analysis. In general, however, most agencies will prefer a target roadway location type such as intersections or segments, since this allows for identification of risk characteristics associated with specific locations that may warrant treatment.

Looking Ahead

It is a good idea to identify an analysis network that has clear boundaries, within which an agency and partners have the authority to make changes, since the goal is to implement treatments. The data types needed for risk analysis are also more likely to be available and readily compiled for cohesive urban or rural regions or municipalities that tend to compile land use and other types of planning data.

1.2 IDENTIFY ONE OR MORE TARGET LOCATIONS AND CRASH TYPES

The purpose of identifying a specific target crash type or types is to narrow traffic safety efforts down to target crash types that lend themselves to more readily identifying risk patterns and potential treatments. Prioritizing a specific crash type in the context of improving pedestrian safety enables engineers and planners to identify risk factors that influence those specific types of crashes, which can lead to better targeted, systemic treatments.

The target facility and crash type can be informed by prior studies or determined by analyses. Determine if there are pre-existing safety planning documents that have defined key pedestrian focus issues. These may include Strategic Highway Safety Plans (SHSP) or, at a more local level, summary analyses of pedestrian crash problems that may have been developed for pedestrian safety action plans or other planning documents. Otherwise, turn to crash data to help define the target facility and crash types.

Definitions: Crash Type and Crash Frequency

A crash type is a variable that typically describes events and maneuvers of the involved parties that led up to a crash. The relative maneuvers of the parties such as road departure (single vehicle), angle crash (between two motor vehicles), or pedestrian crossing at midblock and struck by a vehicle traveling straight (pedestrian-motor vehicle crash type) are examples.

Crash frequency is the number of crashes at a defined location over a defined time period.

Key Crash Data Elements Needed to Identify Crash Targets

Crash data elements that are key to a systemic pedestrian safety approach include the following:

- **Crash type:** Crash types describe the events leading up to a crash and summarize the conflict type or relative approach angles, positions, and maneuvers that led up to a collision. Crash types for motor vehicle only collisions tend to be well-defined and these provide information relevant to treatment decisions. Many resources treat pedestrian crashes as if they are all the same, but in fact, different circumstances and maneuvers are present at different "types" of pedestrian crashes, just as for motor vehicle only crash types. This information is useful in a systemic pedestrian safety process, as it begins the work of diagnosing patterns that are widespread and potentially treatable, systemically.
- **Location type:** The location type—whether at an intersection or segment location, or potentially another 'location type'—for where the crash occurred is also relevant for a systemic analysis process since this information helps to determine crash context and treatment possibilities. Location information should be available in crash data. Compared to arterial classifications or other potential roadway descriptors that might be used in a motor vehicle-focused approach, focus on location characteristics most relevant for identifying risks and potential systemic pedestrian safety measures.
- **Injury or crash severity:** A systemic approach aims to target treatments to locations with higher potential for severe injury crashes. Thus, pedestrian injury or crash-level injury indicators are also potentially useful. However, as discussed below, any pedestrian crash is potentially severe.

Noteworthy Practices

Arizona coded all pedestrian crash types for crashes that occurred on the state highway system for their pedestrian safety action plan, which included both high crash and systemic/risk-based assessments. See Case Example 3 for details.

In Seattle, pedestrian crash types were unavailable. However, there were separate variables available on the motorists' and pedestrians' pre-crash maneuvers. A cross-tabulation of these two variables was used to generate a pedestrian crash type. This ''type" was used to determine high frequency scenarios for systemic focus. See Case Example 1 for more information.

Troubleshooting

If crash type information is unavailable, here are some options to consider:

- Consider coding crash types for all pedestrian crashes. This data gap can sometimes be solved by using a standard crash-typing system for pedestrian crashes, such as the Pedestrian and Bicycle Crash Analysis Tool (PBCAT).
- Explore whether a combination of variables that are available in the crash database—such as motorist and pedestrian positions, maneuvers, or actions—can be used to characterize key pedestrian crash types.
- If neither of these options is workable, then there may be a need to consider whether improvements can be made in crash reporting for future efforts. Most states collect several separate crash types for motor vehicle only collisions, and this information is useful for systemic safety programs. The goal could be to identify a limited number of pedestrian-motor vehicle crash types that are relevant for identifying conflict patterns and add these to crash reporting. Remember that crash types, like motorist types, describe pre-crash maneuvers and events, and are in addition to any behavioral contributing factors (speeding, failure to yield, impairment, etc.) on the part of either the driver or pedestrian.

Crash Analysis to Identify Focus Types

Ideally, begin the analysis with a careful inspection of crash frequencies and tabulations to identify high-frequency location and crash type combinations. The goal is to narrow down to one or several target crash types for more in-depth risk analysis in Step 3.

At a minimum, you may wish to develop crash frequency tables and cross-tabulations or a crash tree to subdivide or stratify the crash data on factors such as those mentioned above to summarize the frequency and proportions of crashes by:

- Crash location characteristics;
  - Rural or Urban (if relevant);
  - Intersection or Non-intersection (segment);
  - Signalized or Unsignalized crossing location; and
- Crash type (e.g., those involving pedestrians).

Cautions and Considerations

Other elements can be used to further subdivide the data, such as type of traffic control or other roadway characteristics. Use caution, however, when creating subsets with a very narrow focus. If the focus location or crash type is too narrow, the sample of pedestrian crashes and locations may be too small to meaningfully identify risk factors.

Examples of Target Crash Types

Most prior studies have focused on certain types of locations—such as intersections (sometimes only signalized intersections) or segments—and have been less apt to also subdivide by crash types. However, crash type data may be useful to identify risk factors and locations that may be most in need of treatment. The prior tendency to use location types, and not crash types, may be due to the frequent lack of crash type information in pedestrian crash data.

Consider focusing on a few basic crash type descriptors such as:

- Motorist traveling straight and strikes crossing pedestrian;
- Motorist turning left strikes crossing pedestrian;
- Motorist turning right strikes crossing pedestrian;
- Nighttime crashes; or
- Fatal and injury crashes.

Other crash type descriptors besides those listed above could also be used. For example, child pedestrian crashes could potentially be identified as a target crash type. When selecting the systemic focus types, keep in mind whether they relate to application of potential systemic countermeasures, and whether the issue is well-defined in pedestrian crash data.

In terms of pedestrian crash severity, it is recommended that all pedestrian crashes be used, or all injury and fatal crashes. This allows an adequate sample of crashes for analysis. Later, more options are provided on ways to consider risk factors in the analysis that increase potential for severe injuries, as well as when comparing treatment options.

Looking Ahead

In Step 2, roadway characteristics from roadway inventory files will be compiled for analysis. However, if crash and roadway data are already linked, the location characteristics from roadway inventory can be used in this step as well. As crash data are being reviewed, this is also an opportunity to determine the availability, quality, and completeness of specific crash location data. In other words, determine whether detailed location descriptions such as latitude/longitude coordinates, or other spatial linking variables are available to identify the specific roadway locations for where each crash occurred. If latitude/longitude or unique location identifiers are attached to the crash data, bring these variables into the crash database with the location, crash type, and other descriptors you are using to identify the target type. These variables will be used later to count the crashes by location for a network-based risk analysis.

Identifying a target crash type also suggests thinking about the list of potential effective countermeasures, where these might be applied, and the crash types they treat. Step 5 will provide more information about potential countermeasures for a systemic pedestrian safety process.

At a statewide level, the determination of the systemic pedestrian safety focus may begin with categorizing whether crashes occurred within municipalities or outside municipalities and drill down to basic location types. See Figure 4 for an example of a crash tree to identify potential target area, location, and roadway types using data from North Carolina. In this example, non-intersection crashes on two-way, undivided roads are candidate target location types for further systemic analysis for both rural and urban locations statewide. Two-way, divided roads also account for sizable numbers in urban and rural locations.

Other metrics that normalize crash frequencies with an "exposure" denominator (estimates of pedestrian trips, mode share, or others) can also be used to help select a network or networks for further systemic analysis.

Within a city or urban region, the focus could begin by assessing the frequencies or proportions of crashes by location type, then the most prevalent crash types at each location. Consideration can be given to total frequencies and proportions of severe crashes accounted for by each subset. See Case Example 1 for an illustration.

Noteworthy Practice

North Carolina Department of Transportation (NCDOT) sponsored multi-year projects to code pedestrian and bicycle crash types, geo-locate each pedestrian and bicycle crash that is reported statewide, and add these elements to existing crash variables. The crash data are available in a queryable database (the North Carolina Pedestrian and Bicycle Crash Data Tool: http://www.pedbikeinfo.org/pbcat_nc/), so initial systemic analyses can easily be performed to identify crash type and other crash patterns. Crash maps that include crash types and many other crash characteristics are also available for exploration and data are available for local agencies to spatially link and use for safety analysis.

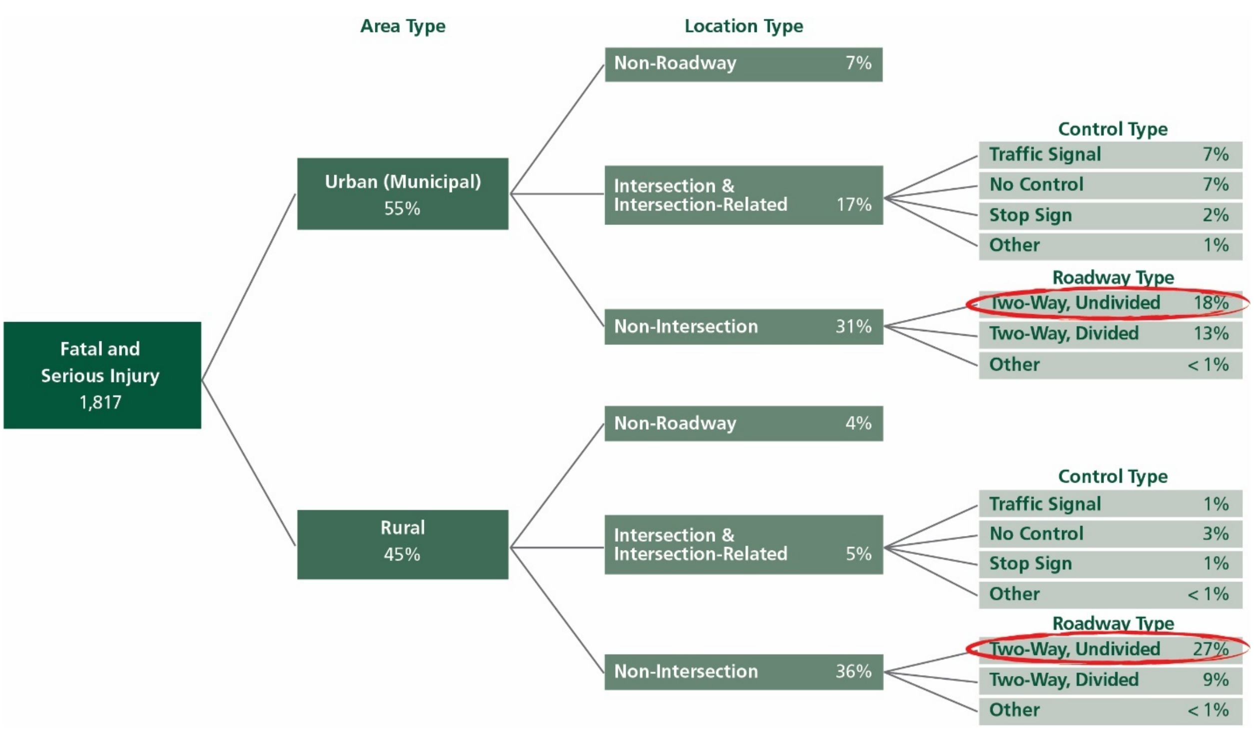

Figure 4. Example tree diagram of pedestrian crash location types using NC crash data.

1.3 FINALIZE AREA AND LOCATION TYPE SCOPE

There may be a need to reassess the network focus extent, road types, or potentially crash types for the risk analysis after compiling the other data types for the risk analysis in Step 2.

For example, there may not be traffic volume data for the whole network within the desired focus area. There may be opportunities to collect or enhance the needed data types or refine the focus for the initial analysis. The process will provide additional lessons and knowledge that will be useful for the next round, and for improving and sustaining the systemic approach to pedestrian safety. Oregon DOT initially planned to focus on both state and local roads, but due to a lack of consistent roadway inventory data for local roads, the list of risk factors identified were for state highways only. See Case Example 2 for details.

In summary, a key first step is to identify combinations of high frequency crash location and crash type characteristics that relate to potential systemic roadway treatments, and to verify the data needs for the project scope. The target location and crash types then form the basis for data collection described in Step 2, and a systemic risk analysis described in Step 3.

1.4 ADDITIONAL RESOURCES

Case Example 1 describes how focus location and crash types were identified for one municipal jurisdiction. These additional resources also offer guidance on ways to identify a network and facility/crash type target for more in-depth analysis.

Resource	Link
FHWA's *Guidebook for Developing Pedestrian and Bicycle Performance Measures*	https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/performance_measures_guidebook/
FHWA's *Guidebook for Scalable Risk Assessment Methods for Pedestrians and Bicyclists*	In progress
FHWA's *Systemic Safety Project Selection Tool*	https://safety.fhwa.dot.gov/systemic/fhwasa13019/sspst.pdf

STEP 2: COMPILE DATA

A systemic approach is inherently data driven, as data are used to identify pedestrian safety risks, locate sites with high-risk features, and evaluate the cost-effectiveness of various treatment alternatives. The purpose of this step is to provide guidance on how to compile the data that will be needed to support all future steps in the process. It also provides options for work-arounds for some commonly-missing data and gives examples of how other agencies approached this step.

This step involves the following tasks, which are further described in the next sections:

- Compile **roadway data**, including traffic and pedestrian volumes (if available), for the relevant target facility type(s);
- Add **land use** and **socio-demographic** data using spatial methods to the specific locations for the relevant facility type; and
- Count the **focus crashes** and add these data to the specific locations. Crash frequencies by location are the dependent (outcome) measures of safety.

Completion of these tasks will result in a database, with a row of data or "observation" for each intersection or segment location, containing variables for all the key data in one place. Table 2 illustrates the basic structure of a database used in a systemic process (Seattle, in this instance). Each site ID is associated with a crash frequency, pedestrian and vehicle volumes, population and land use characteristics, and roadway features (note that only a partial list of sites and variables is shown).

Table 2. Example database compiling key volume, land use, and roadway features for target sites.

Site ID	# of ped crashes	MV AADT	Hourly ped count	% seniors in tract	Distance to university	Median presence	Crosswalk presence	…
1	0	604	6	47	2.4	0	0	
2	0	810	6	06	3.3	0	0	
3	0	1109	7	04	1.2	0	0	
4	1	1897	8	11	0.0	0	0	
5	0	1897	8	11	0.0	0	0	
…								

For more on how these data will be used, read ahead to subsequent steps related to data analysis (Step 3) and site identification (Step 4), or see the Looking Ahead call-out boxes that flag important considerations made in this step that will have implications later in the systemic process.

2.1 COMPILE ROADWAY DATA FOR FOCUS FACILITY TYPE

Based on the target crash types or locations (e.g., intersections, roadway segments, or both) identified in Step 1, build a database conducive to analyzing safety concerns at those locations. Ideally, the database will cover locations across the entire network or jurisdiction of interest. For many agencies, segments and intersections seem to provide the most workable options, but this may depend on how the agency compiles and stores roadway inventory data.

Definitions: Crash Predictors, Risk Factors, and Safety Performance Functions

A crash predictor is any characteristic of the roadway, environment, vehicle, or population attribute that helps to predict future crashes based on a quantified association with prior crashes (such as in an SPF, see definition below). In other words, these are measured variables that are associated with crash frequencies and are used to estimate risk. Crash predictors themselves may not have a causal relation or theoretical basis for increasing risk, but they may serve as surrogate measures for certain risk factors.

Risk factors are any attribute, characteristic, or exposure of an individual or roadway that increases the likelihood of a crash or increases the risk of a more severe injury outcome in the event of a crash. Not all risk factors can be measured from attributes associated with site characteristics (e.g., risk factors such as states of users at the time of a crash). The mere presence of a risk factor may not be sufficient to cause a crash, but a risk factor should have a plausible association with a contributing circumstance of a crash.

Safety performance functions (SPFs) are statistical models used to predict crashes based on site characteristics. These models always include traffic volume (AADT), and in the case of pedestrian crash SPFs should also include pedestrian volume (AADP or average daily pedestrian volume) or suitable surrogate measures. SPFs may also include other roadway features, and in the case of pedestrian SPFs, characteristics of the built and social environment around the site.

Roadway characteristics are key factors to include in database development, as they are used as crash predictors and/or potential risk factors and they can be used in the process to identify and prioritize sites for treatment. State DOTs and local agencies typically maintain many relevant features in roadway inventories. Specific roadway variables to consider are provided in the *Data for Intersections* and *Data for Segments* sections below.

Traffic and Pedestrian Volume Data

Along with the physical characteristics of roadway locations, in a truly systemic, risk-based process, it is important for best results to include two measures to help account for pedestrian exposure to crashes. These measures include:

- Traffic volume data; and
- Pedestrian volume data for each site (collected or estimated).

Both measures have been found to be important predictors of pedestrian crashes, and if they are missing from the analysis, the other factors that appear to be correlated with crashes may be associated with crashes through their correlation with where people most often walk and/or drive. Failure to account for traffic volumes may lead to challenges in identifying the factors that contribute to increased crash risk or lead to incorrect conclusions about their relationship to crashes.

Traffic volume data may be considered an element of roadway inventory, but some agencies may collect and store traffic and/or pedestrian volume data separately. However, traffic volume data should be linkable to roadway locations along with the other features.

Traffic volume data tend to be widely available, with actual counts typically converted to an estimate of average annualized data traffic (AADT). However, AADT data may be less available for non-arterial streets and local network segments in some jurisdictions. Since most agencies find that pedestrian crash and injury problems tend to concentrate on arterial and collector streets, the lack of volume data for local and/or residential streets may be less problematic, or there may be some assumed lower volume categories for local streets. See the additional resources section below for key references on traffic monitoring.

More and more agencies are gathering pedestrian volume and trip data and working on methods to generate appropriate measures of pedestrian activity to use for various purposes. However, many agencies still lack network-wide estimates of pedestrian volumes, scaled to the site level for use in a systemic safety analysis. Many new tools and guides have been developed to support agencies in broadening and improving their pedestrian count data programs, and it is recommended that a pedestrian counting program be undertaken. In the meantime, there are other methods that can be used in a systemic analysis to help account for pedestrian volumes. See the troubleshooting sidebar below and the additional resources section for more information on how to perform these tasks.

Definitions: Exposure and Surrogate Measures

Using the Safe States Alliance *Consensus Recommendations for Pedestrian Injury Surveillance* definition, pedestrian exposure is “an observable period or point during which a pedestrian experiences the possibility of suffering an injury related to the act of being a pedestrian.” Several constructs—such as counts of pedestrians at crossings—can be used to quantify pedestrian exposure to the risk of a crash or injury. In theory, not all pedestrian trips or activity result in exposure to a vehicle crash, but for the purposes of this guide, the terms pedestrian exposure, volumes, demand, and activity are used interchangeably.

A surrogate measure is a characteristic or variable that may help to predict crashes by approximating or capturing phenomena associated with a risk factor that may or may not be measured. A common example is the use of population and/or employment density (available data from the Census) to serve as a surrogate for pedestrian exposure, when the latter is not directly measured.

Noteworthy Practices

Ohio DOT reports that they use a hierarchical approach in assigning traffic volume to the intersection file. First, they use the volume information from the adjacent roadway sections. If that is not available for one or more intersection legs, they obtain any volume information that can be supplied by the Metropolitan Planning Organization (MPO). If that is also not available, they assign a traffic volume value using default values for functional class by county.

Seattle DOT had limited pedestrian count data when it began a systemic pedestrian and bicycle safety analysis project, but short-term counts were available for 50 locations across the City from several sources. Ballpark estimates of pedestrian volume were developed using the count data and characteristics of the 50 count locations. These procedures are explained in Sanders et al. 2017. The predictive model equations used variables such as nearby population density, household density, employment density, presence of schools and university campuses, to estimate pedestrian volumes at intersections across the City. The pedestrian intersection estimates were then parsed to adjacent segments. Due to the limited number of counts and other assumptions made in these estimation procedures, other measures of pedestrian activity were also included in the subsequent crash prediction models to help account for pedestrian exposure. See Case Example 1 for more information. The City also plans to collect more count data to improve future estimates.

Other Roadway Data Needs

Other features that are desirable—but that may be lacking in roadway data for many agencies—include pedestrian-focused facilities such as crosswalks and other crossing improvements. These and some other missing roadway features can sometimes be compiled from online aerial and street-view resources and field checked for accuracy.

Field data collection is also an option. These types of features have not often been available for system-wide analysis. It is worth noting that the presence of pedestrian facilities (e.g., marked crosswalks, median islands, etc.) may reflect pedestrian exposure or where demand is high. These features will be desirable to have during the screening and prioritization process, regardless of whether they are used in the risk analysis.

Traffic speed monitoring data are also highly desirable, but rarely available at a network level. Posted speed limit is typically used as a surrogate measure for traffic speed but may not accurately reflect travel speeds during different times of day (e.g., congested periods versus free-flow conditions).

The following tables offer more suggestions on variables and measurement or ways the data have been aggregated to intersection or segment locations, if the data are not already compiled to the location types of interest. The case examples also describe risk variables that several jurisdictions have used.

Data for Intersections

Table 3 summarizes variables to consider compiling for intersection-focused analyses based on prior studies that have found these variables to be associated with pedestrian crash and injury risk. These variables were identified from the literature on crash risks at intersections, from effective treatments, and risk or conflict principles. Many more variables could be included, and local knowledge of the network and consideration of risk principles should inform the selection of priority variables.

As touched on earlier, some pedestrian features (such as crosswalk markings at an intersection and ADA-accessible curb ramps) have not necessarily been analyzed with respect to pedestrian crash risk, but could prove helpful to include in the database, since this information will allow tracking of features present and may aid prioritization of improvements during the screening and ranking process.

Table 3. Potential pedestrian crash risk variables for intersection analysis.

Intersection-Related Roadway Variables	Measurement Methods
Traffic volume	Typically, ADT or AADT are available for state road networks. Subtypes may include: • Major and minor road volumes (for intersection legs); • Volume assignment by functional classes (surrogate measure); • Turning movement counts; or • Heavy vehicles percentage. May need to collect additional data and develop estimation procedures to generate estimates for network locations not covered by regular traffic monitoring.
Pedestrian volume	• Counts of pedestrians crossing any leg of intersection; or • Average annual daily pedestrians (AADP) crossing at intersection (estimates) based on modeling of a sample of actual counts. Agencies may need to develop a sampling and estimation strategy, coordinate with agencies that have count data, and/or collect additional data to improve estimation accuracy. See the forthcoming FHWA resource: *Guide for Scalable Risk Assessment Methods for Pedestrians and Bicyclists (Turner et al. pending),* and other resources mentioned in Section 2.4 of this Guidebook.
Transit stops	Presence of transit stops. [Note other transit activity measures in the "Other Exposure" measures Table 5. Transit measures have been found to be associated with pedestrian crash risk in both intersection and segment-based analyses.]
Number of traffic lanes	Total number of traffic lanes (all types, all legs); Entering through lanes; Number of lanes on main/largest approach; and Maximum number of lanes pedestrian must cross in one maneuver are all ways traffic lanes have been counted at intersections – all generally have been positively associated with increasing crash risk.
Number of intersection legs	Count the total number of legs entering an intersection. (Short distance offset legs may be included.)
Crosswalk length	Maximum crosswalk length; major/ minor road crosswalk lengths.
Traffic control type	Signalized; Four-way Stop-control; Two-way Stop-control; and No traffic control, yield control, other.
On-street parking	Presence of parking on one or more legs; and Proportion of all legs/sides with parking.
Commercial driveways	Presence or number of commercial driveways within X distance.

Intersection-Related Roadway Variables	Measurement Methods
Leading pedestrian interval	Presence (or amount of time) of leading interval.
Pedestrian signals and detection	Presence of pedestrian countdown signal heads (PCS) on all legs; and Type of activation (active, passive, Puffin).
Unrestricted/restricted turn phasing	Presence of protected pedestrian crossing phase (no left turns during pedestrian walk phase); and Presence of all red during walk phase.
Turning lanes	Presence of one or more lanes dedicated to right or left turning movements.
Speed limit	Highest entering speed limit of any leg; and Major and minor road speed limits. Actual traffic speed monitoring data may be preferable, but no prior studies have been identified that included actual measured traffic speeds.
Intersection skew (Angle > 90 degrees)	Presence of one or more angles with angle > 90 degrees. [No identified pedestrian studies included this measure, but it has been found to be associated with motor vehicle crash types; may affect sight lines and turning speeds.]
Crosswalk markings and type (high visibility or standard)	Presence or proportion of legs with crosswalk markings.
Sidewalk coverage	Proportion of all legs/sides of intersection with sidewalks.
ADA-accessible curb ramps	Proportion of landing areas with ramps that meet accessibility guidance.
Others	Other facility/roadway/or relevant environmental variables as locally determined (e.g., walk signal timing per pedestrian walking speed).

Data for Segments

If focusing on non-intersection or segment crash issues, consider compiling the variables in Table 4. These variables were also identified from the literature on crash risks, effective treatments at uncontrolled locations, and risk principles described in Step 3.

Table 4. Potential pedestrian crash risk variables for segment analysis.

Segment-related Roadway Variables	Measurement
Traffic volume	Typically, ADT or AADT are available for state road networks. Subtypes may include: • Major and minor road volumes (for intersections); • Volume assignment by functional class (surrogate measure); • Heavy vehicles percentage. Data may be less available for non-arterial streets and local networks. Agencies may need to develop a sampling strategy to cover all street /area types and follow standard practices to generate annualized average daily traffic volume estimates for the entire network.
Pedestrian volume	It is challenging to account for pedestrian volumes crossing a length or segment of roadway. Ideally, counts of pedestrians walking along the roadway and of pedestrians crossing anywhere along a segment could be included. It may be feasible to collect counts of pedestrians crossing at non-intersection marked crosswalk locations. AADP for pedestrians walking along segments were included in the analyses of segment-related data for this report and found to help predict where pedestrian crashes occurred. In addition to 'walking along' measures of pedestrian volume, many of the measures in Table 5 were included to capture risks associated with potential pedestrian attractors or areas of pedestrian activity that could contribute to midblock crossings.
Transit	Presence of stops within X distance of segment midpoint or endpoints; Number of stops along segment. [Note additional potential transit activity measures in the "Other Exposure" measures in Table 5. Transit measures have been found to be associated with pedestrian crash risk in both intersection and segment-based analyses.]
Total thru lanes	Number of through lanes (average, either end of segment; midpoint number of through lanes; or number proportionally weighted).
Median with / without crossing facilities	Presence of a continuous raised (not painted or two-way left-turn lane, TWLTL) median.
Median islands with pedestrian crossing	Count of raised median islands with pedestrian pass through / refuge along segment; and could consider median island presence at intersection.
Two-way Left-Turn Lane	Presence of two-way, continuous left turn lane; and
Midblock crosswalks	Presence or count of marked crosswalks with unsignalized approaches along a segment.
On-street parking	Presence (any, one or both sides) or proportion of segment covered by striped parking.
Pedestrian Hybrid Beacon	Presence or count of the facility type along a segment.
Rectangular Rapid Flashing Beacon	Presence or count of the facility type along a segment.
High Visibility crosswalk markings	Presence or count of the facility type along a segment.
Advance Stop/Yield markings and signs	Presence or count of the facility type along a segment.
Speed limit	Posted speed limit or weighted average speed limit along segment.
Segment length	Length of segment; may be estimated from spatial data.
Sidewalk coverage	Presence of sidewalks along 0, 1, or both sides, or proportional coverage from front frontage data.

Segment-related Roadway Variables	Measurement
Distance to nearest signalized crossing or activated beacon along same road	As described.
Right or left turn lanes at adjacent intersections	Presence or counts of different lane types at adjacent intersection.
Signals at adjacent intersections	Proportion or number of adjacent intersections with traffic signals.

There are potentially many more variables that may be important, including risks that have not been thought about or included in prior studies. However, it is also important to be realistic in developing the database. Consider basic risk principles of volumes of users, speed, distance, conflict points, and other features of the trafficway and roadside that could potentially affect pedestrian crash risk. (See the risk concepts at the beginning of Step 3.) Varied networks may also have different data needs, depending on design and operational factors. Therefore, it is important to think through the data that are important for the jurisdiction. With those cautions in mind, consider including many of the factors mentioned above that were identified from prior studies.

2.2 ADD OTHER PEDESTRIAN CRASH EXPOSURE MEASURES TO FACILITY DATA

As described, for a systemic process that aims to identify locations most at risk of future collisions and treat the factors that increase risk, it is important to account for both traffic volume and pedestrian volume in risk analysis and prioritization. In addition, other built and social environment measures have been found to be important crash predictors with respect to where crashes have tended to occur. These data types are described in this section.

Looking Ahead

Whether or not pedestrian exposure measures are used to identify risk factors, they will almost certainly be needed to evaluate the suitability of candidate sites for treatment (in Step 4), to help with selecting appropriate countermeasures (Step 5), and ultimately, for evaluating cost-effectiveness and justifying the treatment plan to be implemented later (in Step 6). For example, a location that has certain roadway-related risk factors for pedestrians (i.e., multiple lanes, higher speed limits, no median islands) may lack the land uses to generate pedestrian trips and may not warrant treatment given other potential priorities. Thus, investment in gathering and including roadway, land use, and travel volume data earlier in the process will pay off in later steps of the process.

Potentially Important Pedestrian Crash Exposure Measures

Each jurisdiction and network are different, and therefore the specific measures that may be compiled and used to understand pedestrian crash risk will likely vary. However, it may be helpful to consider types of data and variables that have been used and found to help predict where pedestrian-motor vehicle crashes tend to occur. For example, varied measures of transit activity, commercial land uses, and population measures such as average income, and younger and older ages, have been found to be associated with increased pedestrian crash risk in some analyses, even when traffic and pedestrian volumes were also accounted for in the analysis. Such measures should be considered for inclusion in the database, in addition to traffic and pedestrian volumes.

Other built environment and demographic measures have been identified as being associated with pedestrian crashes primarily through their linkage to pedestrian activity. Such measures as population and employment density measures, household density, mode-share, and others, could serve as potential "surrogates" for pedestrian volume data, if these data are not yet available. However, note that these surrogate measures may not serve as adequate substitutes for actual pedestrian volume data if volume estimates are not included at all.

Troubleshooting

Both traffic and pedestrian volumes are needed for systemic safety analysis. If pedestrian volume data are not available for the entire network, consider one or more of these alternatives:

- If count data are available for some locations, use modeling to estimate volumes for the network based on existing long and short term or annualized counts.
- Collect count data at a representative sample of locations, then use these to estimate volumes at other locations across the network.
- Use alternative/additional surrogate measures of the roadway, built, and social environment (see Table 5 below).
  However, note that multiple measures may be needed, and surrogate measures of pedestrian activity (populations, numbers of households, employment density, land uses, etc.) may not fully or accurately represent pedestrian volumes. This could potentially lead to incorrect interpretations of analyses.

Table 5 summarizes variables that may be useful, along with traffic and pedestrian volume, to account for potential pedestrian crash exposure associated with the built and social environment.

Table 5. Other variables to account for pedestrian crash exposure at any location type.

Exposure-Related Variables	Measurement
Roadway functional class	Functional classification is usually available in roadway inventory. This measure is included here, as it may help to account for traffic volume if network-wide traffic volume data are not available.
Transit activity measures	• Numbers of buses stopping within X distance of facility location (intersection/ segment) or along a segment; and • Potentially other measures of transit activity (e.g., boarding/alighting data).
Commercial land uses; Mixed, residential land use	• Number or square footage of commercial properties aggregated in spatial reference to facility location; and • Similar measures of other land use types (residential, mixed, institutional).
Area population	• Total population (average of census blocks) within X distance of facility location.
Employment density	• Numbers of employed persons working within distance of facility.
Household density	• Numbers of households within X distance of facility.

Exposure-Related Variables	Measurement
Area population income	• Mean/average income of residents within X distance of facility; and • Percent of residents below the poverty line within distance of facility.
Area population age groups	• Proportion of population 65+ years; and • Proportion of population < 18 years.
Area population vehicle ownership and/or mode share percentages	• Mean/average percentages of residents without access to a motor vehicle / or that walk to work, within X distance of facility location.
Other urban density measures	• May take the form of local planning variables; building volumes; commercial building volumes within distance of facility.
Alcohol vending establishments	• Number or density of alcohol establishments with distance of facility location.
Universities, Schools	• Density of (within X distance) or distance to nearest institutions from facility location.
Slope/grade	• Change in slope or grade on segments or intersection approaches may be associated with pedestrian crash risk. If elements capturing slope or change in grade are not present in roadway data, data can be obtained from the National Elevation Dataset from the U.S. Geological Survey.
Other pedestrian/traffic generators	• Examples include shopping centers, stadiums, theme parks, recreational facilities, hospitals, large parking lots, and others.

Other Considerations

The scale or measurement of a variable may affect its association with crashes. In analyses performed for this project, the versions of variables scaled at closer buffer distances to the facility location provided a stronger association to pedestrian crashes than the greater distance versions. For example, the number of buses stopping within 150 feet of an intersection or midblock location was a stronger predictor than the number of buses stopping within 500 feet. It is reasonable to collect such measures at several scales for testing with local data. The exact way these variables are scaled or measured may be less important than that they are included.

2.3 COUNT TARGET CRASH TYPES BY LOCATION AND ADD TO DATABASE

The final task in compiling data will be to count the target crash types (identified in Step 1) by location and add these counts to the analysis database. These crash frequencies are the dependent variables in the analysis (described further in Step 3) and will also likely be useful at least for reference during the treatment site identification process. Besides the crash types selected for systemic focus, it may be desirable to count total pedestrian crashes, other crash subsets, and bicycle and auto-oriented crashes and add them to the database. The crash database developed in Step 1 can be used to determine the frequencies of focus crash types by location.

The database should now be complete and will form the basis for risk analysis in Step 3 and network screening and ranking to identify and prioritize treatment sites in Steps 4 and 6. See the next section for additional resources on developing the necessary data types to account for pedestrian exposure to potential crashes.

2.4 ADDITIONAL RESOURCES

Chapters 2 and 3 of the Technical Report provide more details on data sources and risk-related variables from prior research that agencies may consider compiling. Below are additional resources on data collection and volume estimation.

Resource	Link
FHWA's *Synthesis of Methods for Estimating Pedestrian and Bicyclist Exposure to Risk at Areawide Levels and on Specific Transportation Facilities*	https://safety.fhwa.dot.gov/ped_bike/tools_solve/fhwasa17041/index.cfm
FHWA's *Guidebook for Scalable Risk Assessment Methods for Pedestrians and Bicyclists*	In progress
FHWA's Traffic Monitoring Guide (TMG)	https://www.fhwa.dot.gov/policyinformation/tmguide/
NCHRP Report 797: Guidebook on Pedestrian and Bicycle Volume Data Collection, Project 07-19	http://www.trb.org/Main/Blurbs/171973.aspx

STEP 3: DETERMINE RISK FACTORS

The purpose of this step is to identify treatable crash risk factors that can be used to identify locations across the network for potential systemic treatments. Using the database developed in Step 2, the next step is to analyze the data to identify factors associated with the focus pedestrian crash types. A sound risk analysis is also needed to help agencies to reliably estimate future crashes, select appropriate countermeasures, and perform economic analyses on treatment options. This will support a data-driven process that will maximize the expected safety benefits from investment in a systemic program.

As this section will show, there will be an opportunity to compare risk identification approaches that take into account activities in later steps in the systemic process—such as location prioritization. Readers are encouraged to keep in mind basic risk concepts as they work through the various stages of the systemic process. The following are roadway conditions that are generally perceived (and established in the literature) to increase risk of a pedestrian crash:

- High volumes of vehicles, but infrequent interaction with pedestrians, which may lead to lower driver expectancy (such as a rare pedestrian crossing on a high-volume road in a suburban area);
- High volumes of pedestrians;
- Long time or distance that pedestrians are exposed to on-coming traffic (such as when crossing multiple lanes);
- Conflict points in roadway design and operations (such as when a vehicle crosses a sidewalk at a driveway or crosswalk at an intersection to make a turn);
- Lack of separation (in space and/or time) between pedestrian and motor vehicle paths (such as when a pedestrian walk signal is concurrent with motor vehicles permissive left turn signal);
- Higher speed traffic (particularly roads with speed limits posted 30 MPH or higher) on roads with significant pedestrian activity (such as near bus stops);
- Dark or sparsely-lit roads or inconspicuous crossing location; and
- Long distances (e.g., block lengths) or wait times (due to signal timing) between roadway crossing opportunities (which may lead pedestrians to misuse or ignore available facilities).

Definition: Risk

Risk is the probability of a crash between a pedestrian and a motor vehicle at a specific location within a defined period. While true risks are rarely known, the traffic engineering field creates estimates of risk by identifying attributes of locations on a roadway network that are associated with crash frequencies or severities. See the definitions for crash predictors, their relationship to risk factors, and how crash predictors are used in Safety Performance Functions in Step 2.

3.1 SELECT APPROACH TO DETERMINE RISK FACTORS

Prior crash histories, unadjusted for the "normal" expected crashes for similar facilities, have not always proven to be reliable indicators of what will happen in the future, particularly for pedestrian crashes or other crash types that tend to be widely dispersed. This is a key reason a systemic approach is necessary—to be more proactive about identifying where crashes may occur without waiting for them to happen in high numbers. If crash histories are not very reliable for predicting the future, how *does* an agency prioritize locations for treatment that have not necessarily experienced any prior crashes? The *Highway Safety Manual* established procedures to help address these challenges, and to produce reliable estimates of crash potential that could be used to prioritize locations for treatment.

In a nutshell, the HSM recommends the development of model equations known as safety performance functions (SPFs; a definition was provided in the Glossary and in Step 2). These mathematical models estimate relationships of risk-related variables (or crash predictors) to crash frequencies and can be used to produce estimates of potential crashes based on the modeled relationships. These estimates have been found to be more reliable than observed prior crash frequencies alone (because of the tendency of crashes to move around) by accounting for traffic volume and other potential measures of crash exposure that vary across the network.

The crash estimation values that can be derived from predictive models will come into play further in Steps 4 and 6 but are important to consider for a systemic pedestrian safety process, or any safety program, that aims to cost-effectively apply resources where they may do the most good. Without good estimates of the potential contribution of each risk factor and the overall crash potential posed by a variety of risks (including those that are associated with crashes but cannot necessarily be treated), it can be challenging to determine which sites are more important to treat and to select cost-effective treatment scenarios for a systemic program.

Ideally, the two objectives of 1) identifying treatable risk factors, and 2) prioritizing locations for systemic treatment can be accomplished by adapting the HSM procedures and developing safety performance functions, also known as crash count prediction models. If SPFs cannot be developed for the network, there are lists of high-risk factors shown later in the Guidebook (Tables 7 and 8) that may be considered for use in performing other types of analyses, or for screening the network for locations of potential higher risk.

Many states are familiar with developing and using SPFs for road safety decision-making, especially regarding motor vehicle only crash types. Traffic volume is essential for SPF development. SPFs have been less widely developed and used for pedestrian safety. Traffic *and* pedestrian volumes are highly desirable for developing pedestrian SPFs. Pedestrian volume data, until recently, has tended to be less available. Other roadway and site characteristics that are useful for identifying pedestrian crash factors and locations can be included in the analysis, ideally allowing for identification of important treatable risk factors, while also aiding the prioritization and evaluation processes.

This Guidebook recommends adapting the *Highway Safety Manual* method of estimating SPFs for use in a systemic pedestrian safety process. Important data types for potential inclusion in the analysis database were already described in Step 2. The following section provides more information on the benefits and challenges of other major methods for determining risks. In reality, the method agencies use may be some combination of these different basic approaches.

Risk Determination from Crash Count Models of Jurisdictional Data (SPF method)

Developing SPFs by use of Negative Binomial regression modeling has been widely used and tested and is a defensible method to model variables' relationship to crash frequencies.

Other analysis approaches are also available to perform predictive modeling of crash frequencies. Some analysts have, for example, performed regression tree modeling (using methods such as Random Forest or Conditional Random Forest) to identify risk factors. These analysis methods provide an alternate to Negative Binomial modeling for systemic process as they can be used to identify factors that have an independent risk relationship to crashes, but there may still be a need for baseline SPFs or other weighting methods to use in prioritization.

Regardless of the specific analysis approach selected, it is necessary to have **traffic and pedestrian volume data**, or valid surrogate measures, to perform these types of analyses. Exposure measures, surrogate measures, and caveats were described in Step 2.

The **roadway descriptors** of interest to pedestrian safety are also needed—in particular, factors that may play a role in crash occurrence and potential treatment for the focus location and crash types.

Finally, **land use, transit measures** (if transit is present in the jurisdiction) and other measures of the **built and social environment** (typically available in census, land use, and business type databases) have been found to be important predictors of pedestrian crashes in several prior studies, even though they may in part be correlated with pedestrian and traffic volumes. These measures, as mentioned in Step 2, should also be considered for the analysis, whether or not volume data are available.

Troubleshooting

Another option to developing SPFs is also available. Agencies may consider calibrating a model developed with data from other jurisdictions for use in assessing risks, such as those included in the first edition of the HSM (for signalized intersections only). Calibration of models with a limited set of predictive factors could be used primarily for crash estimation purposes for use during prioritization, similar to an approach used by Oregon DOT (Case Example 2). If such models are used for estimating crash potential, then one of the methods in this step will still be needed to identify risk factors. Consult the additional resources in Section 3.3 for more information on SPF calibration. The Technical Report, Appendix B references additional pedestrian studies that produced SPFs for different location and crash types. A model from a similar jurisdiction could also be considered for calibration, but it would be necessary to develop the same data elements.

Table 6 compares three different basic approaches to determining pedestrian crash risk factors, which can then be used to identify sites for potential safety improvement needs. The first approach is the one just described, to develop SPFs by modeling crash counts using network-wide data and a meaningful set of traffic, roadway, land use and other characteristics to determine risks. The other two methods are 1) determining risk factors from a combination of prior research and local knowledge, and 2) using system-wide crash data to identify locations in the network where target crash types have occurred and the prevalent characteristics of those locations. These methods are described in depth after the table.

Table 6. Comparison of methods for determining risks to use in a systemic pedestrian safety process.

	Strengths	**Limitations**
Count Models (SPFs)	• Uses network data. • Provides estimates that can be used to determine high-potential crash locations (as well as higher-risk locations) specific to the jurisdiction. • Identifies risks while controlling for other important factors such as traffic and pedestrian volume. • Data determines risks based on crash prediction. • Provides 'weights' of variable importance within model. • Provides ability to estimate crashes for prioritization, economic analysis, and treatment evaluation.	• Requires effort during Step 2 to compile or estimate pedestrian volume data from different sources (roadway, crash, and other). Otherwise, data needs are similar to other methods. • Requires more modeling expertise than other methods. • May provide misleading identification of risk factors or a biased list of sites if important variables are missing from the data and modeling.
Research/ Local Judgment	• Does not require local crash data matched to locations. • Uses local roadway characteristics for screening. • May be simple to perform initially. • Does not require initial use of pedestrian volume data. • Smaller jurisdictions could assess risks through Road Safety Assessments (RSAs).	• Assumes risk factors are similar to those from other studies or jurisdictions. • Requires local knowledge and expertise to determine risk factors. • Still requires compiling relevant data types to screen the network for risks. • May require more effort at later steps to compile additional data (to account for pedestrian demand / exposure) to prioritize zero-frequency crash locations (Step 6), if these measures are not included in the initial risk screening. • May require judgment to apply weighting factors for prioritization. • Does not produce crash estimates for project evaluation or economic analysis. • Does not produce SPFs that can be used to evaluate treatments.
Frequency-based Method	• Uses network data. • May seem more intuitive to apply. • May make *a priori* determinations of crash types and roadway factors that are 'treatable' for use in identifying systemic issues.	• Expert judgment needed to make determinations of conditions relevant for countermeasures application (e.g., traffic volume and speed). • Is not built on analysis of risk factors that may contribute to crashes across the network while controlling for other factors such as traffic volume. • May not account for regression-to-the mean / random effects. • Disaggregation may obscure risks for pedestrians, especially if based on vehicle concerns. • May identify sites having features correlated with high traffic and high pedestrian volumes, but potentially miss other locations with elevated risk. • May require more effort at later steps to compile additional data (to account for pedestrian demand / exposure) to prioritize zero-frequency crash locations (Step 6) (if these measures are not included in the initial risk screening). • Does not produce crash estimates to evaluate projects (economic analysis) or treatments.

Risk Determination Based on Prior Research and Expert Knowledge

It is most desirable to model crash relationships using roadway, land use, and population data for the network under consideration since risk relationships and crash factors may vary by jurisdiction. Many land use and roadway factors, while intercorrelated, also vary considerably across different urban forms, geographies, and roadway networks and thus it can be difficult to isolate factors that contribute to increased risk.

If modeling network crashes is not an option, an agency may consider determining risk factors from a combination of prior research and local knowledge. An important caveat with this approach is to exercise local judgment and expertise to be sure to consider other factors that have been previously identified or appear to be associated with pedestrian crash types within the network.

A potential challenge in using this approach is to determine how to weight different risk characteristics, either in site identification or during prioritization steps. See Table 6 for these and other limitations.

Looking Ahead

Additional work may be needed at other steps in the process if SPFs are not developed to identify risk factors. There may be a need to consider additional data on the built environment, populations, or land uses, to help determine which locations may warrant treatment. Subjective weighting factors may also need to be developed to help with prioritization. See Case Example 3 for an example of how Arizona dealt with these issues. Oregon DOT used a blended approach in their initial systemic effort. They identified crash risks from a mix of expert judgement and analysis, and then developed SPFs based on crash and pedestrian volumes to help prioritize locations based on SPF-predicted crashes. See Case Example 2 for this approach.

Risks from Prior Research for Consideration

If despite the challenges, using a set of pre-determined risk factors is the best option, Table 7 provides a summary of factors that have been found (at the time of this publication) to have consistent relationships in the expected direction to crashes. These factors might be considered, among other locally-determined factors, for risk-based screening. Again, agencies should ensure they are considering relevant characteristics for their network and focus crash types. For example, if crashes involving left-turning vehicles are an issue, it is important to identify locations that lack turn restrictions or leading pedestrian intervals (LPIs), since these measures have been associated with improved safety. Conversely, their lack would be a factor associated with increased crash potential.

Table 7. Potential roadway risk factors identified from prior research and relationship to pedestrian crashes ('+' = positive, '-'= negative correlation with crashes).

Variable / Risk Factor	Intersections	Segments
Traffic volume	+ (generally pos., but not linear)	+ (generally pos., but not linear)
High turning volumes	Unknown threshold	n/a
Functional classes - arterials and collectors compared with local streets	+	+
Proportion of truck/bus traffic in traffic stream	+ (crash severity)	+ (crash severity)
Proportion of local streets at intersection *(potential surrogate for AADT)*	-	n/a
Pedestrian volume	+ (but not linear)	+ (but not linear)
Number of legs > 3 (may also be partial traffic surrogate)	+	n/a
Total lanes on largest leg (5+)	+	n/a
No median/ median island	+ (less certain than for segments)	+
Presence / number of transit stops	+	+
Presence of on-street parking	+	+
Presence/number of driveways	+	Unknown (theoretically yes)
Presence of signal	+ with crash frequencies - with crash severity	n/a
Lack of separate turning movements from walk phase (all red walk phase, or walk and restricted turn phase) (signalized intersections)	+	n/a
Lack of Leading pedestrian interval (signalized intersections)	+	-
Presence of 4 or more through lanes; Higher numbers of total lanes	theoretically	+
Presence of TWLTL	n/a	+
Speed limit > 25 miles per hour (mph)	n/a	+ with crash severity; + with frequency in a few studies
Vehicle speed	+ with severity	+ with severity

Table 8 summarizes conditions associated with increasing pedestrian injury severity. In general, the evidence for some of these measures associations with pedestrian or crash injury severity are quite strong, as there have been many crash-based studies analyzing relative severity outcomes.

As discussed in Step 2, some of these risk factors may be captured to some extent through roadway and built environment data. For example, speed limits, and proportion of truck/ bus traffic are included in the list of potential roadway data needs in Tables 3 and 4. Others could potentially be measured to some extent through land use and population-based measures as shown in Table 5.

Table 8. Roadway, crash, and person factors associated with increasing injury severity in pedestrian crashes.

Variable	Category (if relevant)	Relationship	Evidence*	Potential Data source
Light conditions	Dark, with and without street lighting or unspecified	+	Strong	Crash data
Speed limit	Higher speed limits (> 25 mph)	+	Strong	Roadway data
Traffic Control type	Other than signal (stop sign) or no control	+	Moderate	Roadway data
Vehicle type	Varied - larger comp. to smaller, esp. trucks/buses	+	Strong	Crash data; Traffic data (% heavy vehicles)
Pedestrian age	~65 years and higher	+	Strong	Crash data or census data (area population %)
Pedestrian impairment	Pedestrian under influence, alcohol use suspected/detected	+	Strong	Crash data; Locations of alcohol vendors - may be available in GIS as a potential population-level surrogate
Pedestrian action	Pedestrian crossing roadway (with / without signal or at midblock)	+	Moderate	Crash / crash type data

**Strong = 6 or more studies with consistent direction of effect.*
Moderate = 5 - 6 studies with consistent direction of effect.

Risk Factor Estimation Based on Cross-tabulations or Frequency-based Methods

The most basic approach to identify potential risk factors is to simply use historical crash data for the entire system to identify types of locations across the network where target crash types have occurred, and then to identify prevalent characteristics of those locations. This method is basically an extension of the crash tree or matrix methods used initially to identify focus crash types in Step 1. Mapping and spatial analysis techniques may also be used. FHWA's *Systemic Safety Project Selection Tool* (Preston et al. 2013) describes these types of approaches, which again, depend on an ability to link crashes to location characteristics.

The assumption is that roadway characteristics most prevalent for high frequency crash types represent elevated risk. However, recall that crash frequencies, unadjusted for volumes of users and crash trends for similar types of facilities, may give misleading results about risk factors. In addition, this method still leaves questions for how to prioritize zero crash locations. This method may potentially lead to identification of location types that are predominantly high motor vehicle and pedestrian traffic areas, especially if data for only high-crash locations are used.

The crash type frequency method may be appealing based on its apparent simplicity and offers agencies a choice for a method for risk factor identification that does not depend on modeling. However, this method may not be fully risk-based, if it does not properly account for the influence of traffic and pedestrian volumes. Furthermore, the data needs can be similar to the data needs for modeling. Many of the same data types, including crash types, traffic volume, and roadway location descriptors are important to have on hand to identify risk relationships, and to identify specific locations with the risk characteristics. Land use, census, and other spatial data types may also be used. This method may also still require a significant amount of expertise to determine the crash and location type subsets or combinations that are most likely to represent treatable risk patterns. See the summary of strengths and limitations of this approach in Table 6.

Noteworthy Practices

Case Example 3 provides an example of the process for determining risk factors to use in identifying treatable sites from prior research and expert knowledge, and additional steps carried out for prioritization.

Case Example 4 describes an example of the application of a frequency-based method to identify potential systemic risk patterns.

3.2 PERFORM ANALYSES AND IDENTIFY RISK FACTORS

If analyzing network data (developing SPFs, performing another type of modeling or analysis), this step describes a few considerations for performing those analyses. If risks are being identified using prior research and other means, then there may be useful information in this section on risk factors to potentially use in screening the network to identify sites for treatment.

Perform Analysis

Depending on methods used and numbers of variables available for analysis, the analysts may wish to perform initial data mining analysis prior to SPF development. For example, Random Forest or Conditional Random Forest methods have been used to narrow down the list of potentially important crash predictors to test in regression models. Such methods could also be used to identify potentially important crash types and location characteristics, and to confirm or revisit decisions made in Step 1.

The primary goal of the analysis is to identify treatable risk factors; but, it is also important to generate models that are reliably predictive. SPFs that have too many factors, even if they are statistically significant, can reduce crash prediction efficiency by including more random 'noise' in the model. The resources referenced at the end of this Step provide more information on modeling statistics that can help to reduce the chances of over-specifying the model while including important crash predictors (defined in Section 2.1).

Determine Risk Factors for Use in Subsequent Steps

In examining the model results, agencies will want to particularly consider the variables found to have strong positive associations with crash frequencies (i.e., crash predictors and/or risk factors). If any of the variable associations do not conform to expected relationships, additional steps may be needed to revisit the model building steps and discuss how those variables should be interpreted or applied in subsequent steps in the systemic process.

At this point, agencies will need to determine which of the model variables associated with higher crash frequencies are to be considered *treatable* risk factors (meaning there is an associated countermeasure that could be applied systemically; see Table 15 for some options). For example, if a model identifies the presence of midblock crosswalks as a crash predictor, sites with this feature can then be identified and treated systemically. The subset of relevant variables selected by the model will be applied in Step 4 to screen the network to identify candidate sites for treatment; several examples are provided.

Variables that aren't necessarily treatable still have value in a systemic process in that they help to improve the predictive ability of the model to better estimate where crashes are more likely to occur. These crash estimates raise the priority of those sites for further treatment consideration. Variables such as urban density/development type and traffic volume, regardless of whether they were included in the model, also provide important context for selecting appropriate countermeasures.

Example

Table 9 summarizes variables found to be associated with two types of pedestrian crashes at roadway segments (motor vehicle traveling straight and pedestrian crashes under dark conditions) based on analyses described in Chapter 3 of the Technical Report using Seattle, Washington data.

Table 9. Variables predicting pedestrian-motor vehicle crashes on roadway segments in Seattle, WA.

Predictive factor	Variable and/or Category	Motor Vehicle Traveling Straight at Segment	Pedestrian crashes under Dark conditions at segment
Traffic volume	Log transformation of pred_ada predicted ADT	Positive	n/a
	Pred_rfr predicted ADT/10000	n/a	Positive
Pedestrian volume	Logarithmic term of AADP_MB	Negative	Negative
	Midblock pedestrian volume	Positive	Positive
Built environment/ surrogate exposure measures	No. of buses stopping nearby	Positive	Positive
	Commercial property density	Positive	Positive
	Mean Income area residents/10000	Negative	Negative
	Light poles per 100 ft on segment	Positive*	Positive*
	'Urban Village' development intensity category – with increasing intensity	Positive	Positive
Roadway factors	Midblock crosswalks	Positive	Positive
	Two-way left-turn lane Presence	Positive	Positive
	Four or more (5+) lanes compared with one lane	Positive	none detected
	Striped Parking lanes (1 or 2 +)	Positive	none detected
	Speed limit category (30 or 35 compared with 25; positive trend for higher speeds)	none detected	Positive
	One-way traffic flow	none detected	Negative
	Presence of right-turn-only lanes at one adjacent intersection	Positive	none detected

* light poles are a potential surrogate for other traffic, design, or built environment features or an inadequate measure of lighting quality

Based on the model results shown in Table 9, an agency might select the following variables to be used in identifying potential treatment locations (all were significant for one or both models) and treatments

- Presence of a midblock crosswalk;
- Presence of a two-way left-turn lane;
- Presence of four, five, or more through lanes;
- Presence of on-street, striped parking;
- Speed limits above 25 mph;
- One-way traffic flow; and
- Presence of right-turn only lanes at an adjacent intersection.

Steps 4, 5, and 6, will build on these results to demonstrate how these variables could be used to identify potential treatment sites and countermeasures, and to prioritize systemic safety projects using economic analyses.

3.3 ADDITIONAL RESOURCES

Case Example 1 in this Guidebook, and Chapters 3 and 4 of the Technical Report, provide more information and a detailed example analysis using the SPF development method. Tables 11 and 12 in the Technical Report, along with Appendix B, provide more details on specific variables that have been analyzed. Below are additional resources on SPF development and systemic safety practices.

Resource	Link
Crash Modification Factor Clearinghouse website	http://www.cmfclearinghouse.org/resources_spf.cfm
FHWA's *Safety Performance Function Decision Guide: SPF Calibration vs. SPF Development*	https://safety.fhwa.dot.gov/rsdp/downloads/spf_decision_guide_final.pdf
FHWA's *Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs*	https://safety.fhwa.dot.gov/rsdp/downloads/spf_development_guide_final.pdf
NCHRP's *User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors*	http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-07(332)_FinalGuide.pdf
FHWA's *Systemic Safety Project Selection Tool*	https://safety.fhwa.dot.gov/systemic/fhwasa13019/
FHWA's *Reliability of Safety Management Methods; Systemic Safety Programs*	https://safety.fhwa.dot.gov/rsdp/downloads/fhwasa16041.pdf
FHWA's *Evaluation of Four Network Screening and Performance Measures*	https://safety.fhwa.dot.gov/rsdp/downloads/fhwasa16103.pdf

STEP 4: IDENTIFY POTENTIAL TREATMENT SITES

In this Step, the goal is to identify candidate sites across the entire roadway network with the greatest potential for future crashes that an agency would want to address. These should bear relation to the crash types or locations of interest (from Step 1) and have key risk factors present (identified in Step 3).

As previously indicated, this step relies heavily on data about the roadway and related characteristics that can be used in screening for the presence of key risk factors. Agencies with incomplete data may find the need to gather additional information for particular sites, potentially through aerial imagery or field visits.

4.1 CONSIDER ELIMINATING LOW CRASH POTENTIAL SITES

An initial task may be to determine whether any locations within the focus network should be eliminated from consideration, particularly if the sites have low expected or predicted crashes, where feasible countermeasures do not exist, or where there are pending or planned projects. It may require more in-depth knowledge of the network or looking at sites more closely to make this determination, which can also be done during Step 6.

Noteworthy Practice

Arizona DOT screened their network for high-risk locations based on risk factors identified from prior research by an expert team. They did not have pedestrian volume estimates, so to help prioritize which sites with risk factors may benefit most from treatment, they conducted additional reviews using street and aerial view online mapping tools to examine characteristics of the site that would help determine pedestrian activity or exposure. ADOT subsequently eliminated from further consideration some high apparent risk—but zero prior crash—locations that were determined to not be in areas where pedestrians would likely walk. See Case Example 3 for more information.

4.2 GENERATE INITIAL LIST OF SITES

Site Identification Based on Risk Factor Presence

One approach, which can be used regardless of how risk factors were identified in Step 3, is to filter the list of sites to identify those with similar risk factors that can be further evaluated for treatment options. Filtering and sorting tools are easy to use if the data are in a spreadsheet-type database (like the one shown in Table 2), or in a spatial format that allows querying.

Recall the example in Section 3.2, which identified a list of treatable roadway factors associated with pedestrian crashes at segments (i.e., midblock locations). Here, the risk factors shown in Table 10 are used to narrow down a list of potential treatment sites from 196 (where there was a midblock crossing) to 12 sites that had multiple treatable risk factors present, including four or more through lanes and on-street parking. Observed prior crashes and SPF-predicted crashes from the model are summed for each subset of sites and shown in the table, along with the relative SPF-predicted rankings of the sites in each group. These data will come in handy for economic analyses and ultimate site prioritization.

Table 10. Example 1: Identification of potential sites using risk factors.

Risk Factors	Number of Sites	Total Prior Obs. Crashes (8 yrs.)	Total SPF-Pred. Crashes (8 yrs.)	Range of SPF-rankings (of ~23,000 segments)
1) Presence of Midblock Crosswalk (1 or more)	196	50	50.1	4-20,870
2) AND 4 or 5+ Thru Lanes	26	24	19.2	4-2228
3) AND On-Street Parking	12	10	14.6	9-2228

This is also an opportunity to consider relevant treatments, and whether a treatment or set of treatments related to the risk factors has been identified. Then, the data can be further filtered to identify sites that have the appropriate context (such as number of lanes or traffic volumes) for countermeasure application.

Consider a second example in Table 11, in which an agency has identified that streets having four or more through lanes had higher risk of crashes. They want to take a systemic approach to identify high crash potential road segments suitable for road diets—which might address the risk to pedestrians in crossing multiple lanes—from their network of 23,000 road segments.

An initial list of potential sites, filtered only by the number of through lanes, still identifies 1405 potential sites, far too many to treat, and likely including many with inappropriate volumes for the treatment of interest. The agency has a 25,000 ADT treatment threshold for considering road diets, which further filters the potential sites. The presence of two-way, center turn lanes was an additional risk factor identified, and when this filter is applied to the previous two, it reduces the candidate site list down to a more feasible 131 segments, about 13 miles of roadway. Of course, the adjacency of road segments along a corridor would also be a consideration. In this example and the one before, the sites can be further sorted and ranked or prioritized using other data available, whether it be prior or predicted crashes or other considerations, to refine a treatment plan.

Table 11. Example 2: Identification of potential sites using risk factors and countermeasure context.

Risk Factors	Number of Sites	Total Prior Obs. Crashes (8 yrs.)	Total SPF-Pred. Crashes (8 yrs.)	Range of SPF-rankings (of ~23,000 segments)
1) Presence of 4, 5+ Thru Lanes	1405	302	296.8	1 - 9409
2) AND < 25,000 ADT	939	171	175.2	1 - 9409
3) AND TWLTL present	131	27	27.5	7 - 3866

Looking Ahead

Step 5 describes the process of identifying potentially appropriate countermeasures and provides an initial list of countermeasures that may be suitable for systemic application. It is relevant here, as sites identified for systemic treatment must have some relationship to countermeasures that can be used systemically. Refer to Step 5 while performing this screening step, particularly Tables 15-17. In Step 6, there will be additional work to prioritize locations and treatments, considering community priorities as well as cost-effectiveness data.

Site Identification Based on Estimated Crash Rankings

Another way to identify potential sites—suitable for agencies that have taken the approach in Step 3 to determine risk factors using a model-based approach—is to make use of SPF or EB predictions from the model to identify highest predicted crash sites first, and then perform the filtering techniques described in the previous section. This method may be well-suited for an agency wanting to focus on the sites with the highest potential for crashes regardless of the specific treatable risk factors identified.

Table 12 provides an illustration of this approach. Here, combinations of risk factors can be presented and considered in terms of the numbers of predicted or prior observed crashes and relevant sites for locations that are first ranked by overall crash predictions: in this example, the top 200 locations.

Table 12. Example 3: Identification of potential sites using predicted crashes and risk factors.

Risk Factors or Combinations among top 200 ranked by SPF-prediction	Total predicted crashes for all sites	Total prior crashes for all sites	Number of relevant sites
4 or 5+ Thru Lanes	106	93	146
Striped on-street parking present	72	50	85
TWLTL present	35	39	56
Combination of 4 – 5+ Thru lanes and TWLTL	32	31	51
Right-turn lane present at adjacent intersection	31	32	40
Combination of 4 – 5+ Thru lanes and Right-turn lane present at adjacent intersection	18	26	25

Identifying sites for systemic treatment requires careful consideration of risk factors, overall crash potential, and the existence of relevant countermeasures for treatment. Steps 5 and 6 provide additional opportunities for revision and refinement of sites for potential treatment based on countermeasure availability and prioritization considerations. There are many pragmatic considerations as well, such as just how easily different countermeasures may in fact be implemented, what staff and other departments or agencies are involved, and others.

Looking Ahead

In Step 6, the list of sites and treatments will be further refined based on cost-effectiveness and other considerations. As agencies develop their list of sites, they will want to include associated crash prediction estimates (if developed), prior crash history, and risk variables and any other site characteristics that can aid in future decision-making, regardless of whether these factors were identified as risk factors or used in initial screening.

4.3 ADDITIONAL RESOURCES

The Technical Report has additional background relevant to this step, especially in Chapter 4. See also the resources listed under Steps 3 and 5.

STEP 5: SELECT POTENTIAL COUNTERMEASURES

Now that risk factors have been determined (in Step 3), and locations having these risk factors have been identified (Step 4), the next step is to identify appropriate countermeasures or combinations of measures that could potentially address risks identified. In Step 5 and 6, there is also a chance to further refine and prioritize the locations and treatments.

5.1 ESTABLISH A FRAMEWORK FOR SELECTING COUNTERMEASURES

To aid agencies in jump-starting their countermeasures selection process, this Guidebook provides some general criteria to use when considering options:

- **Relation to systemic program focus or target crash types or locations**: The first phase in the countermeasures selection process may begin even as the systemic safety scope is being determined (see Step 1). If the systemic pedestrian analysis is focused only on intersections or only on segments, then the countermeasures considered in this Step should be relevant to those locations.
- **Safety effectiveness**: There should be some crash-based evidence that a countermeasure can reduce pedestrian crashes. If CMFs or crash-based studies are not available, there should be significant research or well-documented studies showing safety-related benefits (e.g., improved yielding, slowed vehicle speeds, etc.) or that the treatment itself has design features related to conflict or exposure reduction (e.g., reduce crossing width, low design speed, etc.).
- **Cost**: Cost is a concern for systemic safety measures, and agencies will need to consider absolute cost (including installation and maintenance), cost-effectiveness or cost benefit, as well as the funding available. Absolute cost should not necessarily over-ride cost-effectiveness, as more costly design changes may sometimes have greater, more consistent, and potentially longer-lasting benefits than lower-cost markings and signs, and may be justified through life expectancy and potential safety benefits for pedestrians and other road users (Gross et al. 2016a).
- **Feasibility**: The feasibility of implementing countermeasures should also be considered. Step 6 discusses considerations such as political concerns, community priorities, the need for public input or stakeholder engagement, equity concerns, etc. that may impact whether a treatment is feasible to implement at one or more locations. There is also the need to consider feasibility from a technical standpoint: whether the treatment will require additional right of way, how it relates to the Manual on Uniform Traffic Control Devices (MUTCD) recommendations and standards, as well as state or local design guidance or other policies or restrictions affecting potential treatments.

Many states already identify a list of preferred countermeasures, or selection criteria, based on previous experience or state-sponsored research, so that may be a good starting place.

5.2 DEVELOP INITIAL LIST OF POTENTIAL SYSTEMIC COUNTERMEASURES

Table 13 provides a list of a dozen pedestrian countermeasures (each further described in Appendix A) that were identified through research conducted to develop this Guidebook. These countermeasures meet some of the basic criteria—safety effectiveness, cost, and feasibility—described in Section 5.1. These measures may serve as a starting point for agencies as they apply their own criteria to identify countermeasures suitable for systemic implementation in their jurisdictions.

Table 13. List of pedestrian crash countermeasures for potential systemic application.

Suitable for Signalized Intersections Only (or where signal is added)	Suitable for Unsignalized Locations (midblock or intersection) only	Suitable for Either Signalized or Unsignalized Crossing Locations (including midblock)
• Leading pedestrian interval • Longer pedestrian phase • Restricted left turn (protected crossing phase)	• In-Roadway Yield-to-Pedestrian (R1-6) sign / Gateway • Advance Stop/Yield Bar and R1-5/5a Sign • Pedestrian Hybrid Beacon	• High visibility crosswalk • Traffic calming (raised device) • Median crossing island • Reduce number of lanes / road diet • Curb extension and parking restriction • Location-specific lighting improvement

The treatments in the **first column** of Table 13 are treatments that can help address crash types at signalized locations, especially those resulting from conflicts with turning vehicles, inadequate crossing time (which may also result from interactions with turning vehicles), or long delays for pedestrians that may lead to noncompliance.

The treatments in the **second column** can help address crash types involving pedestrians trying to cross at high demand crossing locations along segments or at unsignalized intersections. These treatments primarily aim to help create gaps in traffic on higher volume roads (i.e., Pedestrian Hybrid Beacon or PHB) or encourage motorists to yield at locations where traffic speeds are lower, and the locations do not meet warrants for a traffic signal.

The treatments in the **third column** may help to address additional risk factors relating to crossing distance or numbers of lanes, a lack of pedestrian conspicuity or visibility, and traffic speed. These treatments can be used to enhance pedestrian safety at any type of crossing, whether signalized or unsignalized.

Appendix A provides summaries and images of these treatments, including purpose, use, and systemic application considerations. The remaining sections in Step 5 also frequently reference these countermeasures and provide more information on how they relate to crash risks, crash types, and expected crash reduction benefits. More information about the criteria for selection is included in the Technical Report, Chapter 5. While each countermeasure has a stand-alone description in this Guidebook, it is not necessarily the intent that they be implemented as stand-alone treatments. In many cases, there may a need to package complementary countermeasures to maximize the safety benefits. For example, high visibility crosswalk markings alone may be insufficient to address certain risk factors but could be implemented along with other treatments, such as medians, advance stop bars, PHBs, or others.

Additional Considerations

Treatments such as general warning signs were not included in the suggested systemic countermeasures list. While general warning signs are typically low-cost and meet that criterion for systemic application, the safety benefits for warning signs are inconclusive and signs may need to be used more judiciously than in a systemic process (Zegeer et al. 2013).

Beyond the 12 treatments listed, there are certainly other treatments known to be effective that could be considered in a systemic approach. Additional resources are listed in section 5.4 for agencies that wish to consider a broader set of potential treatments. Many effective treatments, whether systemic or not, could also be used systematically—implemented system-wide as part of a standardized policy or design practice. For example, pedestrian countdown signals are now standard practice for all *new* signalized intersections with pedestrian signals, per the MUTCD (2009).

5.3 SELECT COUNTERMEASURES

The next step in the process involves identifying which treatment options are most applicable to address the characteristics or risk factors identified in previous steps. Countermeasures identification in a systemic process remains similar in some respects to selecting countermeasures for high-crash sites, but this is done for sites across a network with similar risk features and relies in part on understanding patterns across the system from the data analysis. Typically, in high crash implementations, diagnosis is done primarily after sites are identified. For effective systemic application:

- Countermeasures should target the risks identified; and
- Treatments should be otherwise appropriate for the site conditions or context.

The package of treatments selected may also need to target multiple types of risks, in order not to 'partially' treat a site or sites known to have multiple risks.

To get started on the process of matching treatments to risks and location types, consider the example in Table 14, which illustrates one way to consider the risk factors at an identified set of locations and potential countermeasure options. Building upon the example from Step 4 (Table 10) on midblock crosswalks, there are sites with a (partial) set of characteristics shown. In the first table row, the presence of a midblock crosswalk does not provide much information to aid in countermeasure selection, except that there is likely to be high pedestrian demand for crossing at the location. Considering other risk factors (such as whether the roadway has factor of four or more through lanes, in row 2, and on-street parking, in row 3) significantly narrows the list of sites and, also offers additional information to help refine the list of potential countermeasures. The data compiled in Step 2 can be used in this Step to consider the risk factors present and refine the list of countermeasures appropriate for the full spectrum of risks and site conditions identified.

Table 14. Potential countermeasures for segments with midblock crosswalks and other risk factors.

Risk Factors	Number of Sites	Potential Countermeasures
1) Presence of Midblock Crosswalk (1 or more)	196	High visibility crosswalk and potentially many others
2) AND 4 or 5+ Thru Lanes	26	Advance Stop/Yield Bars & Signs, Median Islands with refuge; and a treatment to increase yielding - potentially PHBs OR In-Roadway Yield signs; and potentially others
3) AND On-Street Parking	12	Above list, as well as curb extension/parking restrictions

To further aid in this process, Table 15 provides an evidence-based summary of the relationship of the countermeasure to risk factors, crash types, and the relevant location types for the 12 countermeasures highlighted in this Guidebook. PEDSAFE is another tool that agencies can use to help match potential countermeasures to crash types and other safety issues, and to narrow down the selection of appropriate countermeasures for traffic and roadway context.

Noteworthy Practices

Some agencies—such as NCDOT (Schroeder et al. 2015) and Boulder, Colorado—have produced their own decision guides for countermeasure selection based on research, the MUTCD, and other jurisdictional factors for making these decisions. See Chapter 1 of the Technical Report for more on the NC example.

Table 16 provides information based on research and expert guidance on suitable contexts for the 12 countermeasures, though this is not meant to replace local engineering judgment. Ultimately, engineers need to investigate the sites to ensure the appropriateness of the treatments.

Table 17 provides information on the pedestrian safety effects of the 12 countermeasures (described in terms of CMFs), as well as any other safety benefits that could be documented. (Appendix A of this Guidebook provides a more nuanced discussion.) Keep in mind when considering the safety evidence summarized in this table that some crash effects are based on studies from a single jurisdiction, and benefits can vary in practice and when applied systemically. See the CMF Clearinghouse for star quality ratings and other information that helps to put the CMFs into context.

Table 15. Countermeasures in relation to risk factors, crash types, and location types.

Countermeasure	Related Risk Factor(s)	Related Crash Type(s)	Location Type
High Visibility Crosswalk	Conspicuity (driver failure to notice); Compliance with crosswalks (motorist and pedestrian)	Any occurring at crossing locations	Signalized or Unsignalized *
Traffic Calming (raised crosswalk / speed table)	Traffic Speed; Conspicuity / pedestrian visibility (pos.); Non-compliance with crosswalks	Through vehicle, pedestrian crossing at signalized/ unsignalized location; Turning vehicle, pedestrian crossing; Pedestrian dart-outs and dashes; Unique midblock crossing/ pedestrian in roadway types; Speeding-related	Signalized or Unsignalized *
Median Crossing Island	Number of traffic lanes; Number of lanes crossed in one maneuver; Traffic speed (possibly if roadway narrowed); Turning speed at intersections (possibly, if restricts turning radius/corner cutting)	Through vehicle, pedestrian crossing at signalized/ unsignalized location; Turning vehicle, pedestrian crossing roadway; Pedestrian dart-outs and dashes; Possibly nighttime crashes if replaces two-way, center turn lane	Signalized or Unsignalized *
Road Diet	Number of lanes; Number of conflict points associated with driveways/ junctions; Traffic speed	Through vehicle, pedestrian crossing at unsignalized location; Pedestrian dart-outs and dashes; Potentially pedestrian walking along the roadway or other pedestrian in roadway types if sidewalks provided; Speeding-related/ potentially all types; Motorist types including rear-end & sideswipe/angle	Signalized or Unsignalized *
Curb Extension with Parking Restriction	Parking presence; Visibility/conspicuity; Width of crossing	Through vehicle, pedestrian crossing at unsignalized location; Pedestrian dart-outs and dashes; Multiple threat; Turning vehicle at intersection; Waiting to cross	Signalized or Unsignalized *
Improve Lighting	Conspicuity (driver failure to notice); Darkness	Nighttime pedestrian crashes	Signalized or Unsignalized *
In-roadway Yield to Pedestrian Sign (R1-6)	Conspicuity; Traffic Speed; Traffic volume / gap availability	Pedestrian crossing - through vehicle at unsignalized location; Multiple threat; Motorist failure to yield	Unsignalized *
Advance Stop/Yield Marking and R1-5/R1-5a Sign	Number of traffic lanes (> 1 by direction); Conspicuity / sight lines	Pedestrian crossing - through vehicle at unsignalized location; Multiple threat; Motorist failure to yield	Unsignalized *
Pedestrian Hybrid Beacon (PHB)	Traffic volume; No traffic signal/ stop sign; Multiple traffic lanes (possibly)	Through vehicle at unsignalized location; Motorist failure to yield; Multiple threat; Bus-related	Unsignalized *
LPI	Conflicts at signalized locations; Motorist failure to yield when turning	Pedestrian crossing – vehicle turning left or right	Signalized
Longer Pedestrian Phase	Conflicts at signalized locations; Insufficient crossing time	Pedestrian crossing – through vehicle; Pedestrian crossing – vehicle turning left or right; Pedestrian failure to yield types, dashes	Signalized
Protected Crossing Phase	Conflicts with turning traffic; Pedestrian delay (due to turning traffic)	Pedestrian crossing - vehicle turning left; Motorist failure to yield when turning	Signalized

*Unsignalized locations include midblock crossings lacking signal control.

Table 16. General traffic considerations and context for countermeasures.

Countermeasure	Speed (Limits or General Operating Speed)	Volume	Number of Lanes
High Visibility Crosswalk	Any; consider need for additional treatments at higher speeds	Any; consider need for additional treatments at higher volumes	Any; consider need for additional treatments on multi-lane roads
Traffic Calming Device (raised crosswalk / speed table)	Low Generally </= 30mph	Low to moderate (< ~10,000 to 25,000 ADT)	Any
Median Crossing Island	Any	Any	2 or more through lanes; Minimum space need of 4 feet but ideally 8 feet
Road Diet	Any	Up to 20,000 – 25,000 ADT (consider potential trade-offs at volumes around 20,000 AADT and up)	3-4 lanes; 5+ lanes before treatment (most research based on conversion of undivided four-lane to two regular traffic lanes plus TWLTL and bike lanes or parking)
Curb Extension with Parking Restriction	Potentially any speed on road where parking is present	Any volume	Any; consider bicycle facility type; consider large vehicles/transit effective turn radius
Improve Lighting	Any	Any	Any
In-roadway Yield to Pedestrian Sign (R1-6)	Lower speed (</= 30 mph) (Van Houten and Hochmuth 2017) (Yield treatments may be insufficient at higher speed sites.)	Low to moderate pedestrian volume Low to moderate ADT (< 12,000) (Van Houten and Hochmuth 2017)	2 to 4 total lanes (most recommended for 2-lane roads); Median islands provide protection for signs (Van Houten and Hochmuth 2017)
Advance Stop/Yield Marking and R1-5/R1-5a Sign	Any locations reliant on yield with multiple lanes could be considered. (Yield treatments not recommended for higher speed roads.)	Low to High ADT (consider need for additional treatments on higher vol.)	2+ lanes per approach direction, especially at uncontrolled crossings
PHB	Moderate to moderately-high speeds.	Low to med. high ADT (<10,000 -25,000) – depending on other treatments	2 + lanes per direction
LPI	Low to moderate (</=45mph)	Moderate to high (10,000 - >25,000)	1 or more lanes
Longer Pedestrian Phase	Any	Higher pedestrian volumes Low to high motor vehicle volumes (< 10,000 to > 25,000)	Multiple lanes at intersection (including turn lanes)
Protected Crossing Phase	Any	Higher pedestrian volumes High volumes of left-turning traffic	Multiple lanes with dedicated turn lanes

Table 17. Summary of CMFs and other safety benefits of systemic countermeasures.

Countermeasure	CMFs and other Estimated Pedestrian Safety Benefits	Motor Vehicle CMFs and Crash Types Effects
High Visibility Crosswalk	0.52 urban locations (Chen et al. 2013); 0.63 for high visibility yellow/ green markings in urban school zones (Feldman et al. 2010) - both replacing standard parallel markings	0.81 for Angle, Head on, Left turn, Rear end, Rear to rear, Right turn, Sideswipe (CMF Clearinghouse citing Chen et al. 2012)
Traffic Calming Device Raised crosswalk / speed table	0.55 (CMF Clearinghouse citing Elvik & Vaa 2004 for area-wide traffic calming)	0.70 serious, minor, & possible injuries (CMF Clearinghouse citing Elvik & Vaa 2004)
Median Crossing Island	0.68 (Zegeer et al. 2017a,b); 0.54 to 0.69 range (multiple CMFs available; CMF Clearinghouse citing Alluri et al. 2012, 2013; Zegeer et al. 2002)	0.71 – 0.74 (Zegeer et al. 2017a)
Road Diet	Reducing trend in NYC study of 460 sites; No pedestrian crash CMFs yet available. Injury crash reductions expected due to lower travel speeds, fewer lanes, and other potential enhancements (Thomas et al. 2016).	0.71 average urban/suburban roads; 0.53 (suburban area); 0.81 (urban area) – all types, all severity (Harkey et al. 2008)
Curb Extension with Parking Restriction	0.7 for parking removal to off-street (Toolbox citing Gan et al. 2005); No CMFs yet available for curb extension. Curb extensions reduce pedestrian exposure to crossing distance; Improve visibility between pedestrians and motorists. May reduce turning speeds.	Unknown / No CMFs yet available for limited parking restrictions or curb extensions.
Improve Lighting	0.58 nighttime, pedestrian (CMF Clearinghouse, CMF ID 436 citing Elvik and Vaa 2004, for adding lighting, non-specified location types)	0.77 total injury crashes (Harkey et al. 2008; Many CMFs available for various crash types on CMF Clearinghouse
In-roadway Yield to Pedestrian Sign (R1-6)	No CMFs yet available. Motorist yielding has been highest with gateway configuration. Speed reductions in some applications. (Van Houten 2017; Van Houten and Hochmuth 2017)	Unknown / No CMFs yet available.
Advance Stop/Yield Marking and R1-5/R1-5a Signs	0.75 pedestrian crossing crashes; 0.64 to 0.86 range (Zegeer et al. 2017a, b)	0.89 total crashes; 0.80 rear end and sideswipe crashes (Zegeer et al. 2017)
PHB	0.31 (Fitzpatrick & Park 2010); 0.45 (Zegeer et al. 2017a,b); 0.43 PHB + Adv Stop/Yield (Zegeer et al. 2017a,b)	0.71 total crashes; 0.85 fatal, serious injury (Zegeer et al. 2017a,b)
LPI	0.41 to 0.95 range (ITE 2004; Fayish & Gross 2010; Brunson 2017)	Unknown / No CMFs available
Longer Pedestrian Phase	0.50 (CMF Clearinghouse citing Chen et al. 2014)	0.98 – all multi-vehicle crashes (Chen et al. 2013)
Protected Crossing Phase	0.61 urban intersections and 0.49 Barnes Dance (CMF Clearinghouse citing Chen et al. 2014)	0.01 left-turn crashes for restricted left (Harkey et al 2008); Other CMFs also available

5.4 ADDITIONAL RESOURCES

See Appendix A for images and descriptions of the twelve pedestrian crash countermeasures listed in this chapter and their application in a pedestrian systemic process.

Pedestrian safety treatments are continually being developed and evaluated, so other countermeasures with potential for systemic application are likely to be identified by agencies now and in the future. Following are key resources related to pedestrian crash countermeasures, effectiveness, and selection.

Resource	Link
FHWA's *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines*	https://www.fhwa.dot.gov/publications/research/safety/04100/
NCHRP Synthesis 498: Application of Pedestrian Crossing Treatments for Streets and Highways	http://www.trb.org/Publications/Blurbs/175419.aspx
PBIC's Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research	http://www.pedbikeinfo.org/cms/downloads/PedestrianLitReview_April2014.pdf
FHWA's *PEDSAFE: Pedestrian Safety Countermeasure Selection System*	http://www.pedbikesafe.org/PEDSAFE/
NCHRP Report 674: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities	http://www.trb.org/Publications/Blurbs/164715.aspx
TCRP 112/NCHRP 562: Improving Pedestrian Safety at Unsignalized Crossings	https://nacto.org/wp-content/uploads/2010/08/NCHRP-562-Improving-Pedestrian-Safety-at-Unsignalized-Crossings.pdf
ITE's Designing Walkable Urban Thoroughfares: A Context Sensitive Approach	https://www.ite.org/css/
FHWA's Crash Modification Factor Clearinghouse	http://www.cmfclearinghouse.org/
NHTSA's *Countermeasures That Work*	https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/812202-countermeasuresthatwork8th.pdf
FHWA's *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations*	https://www.fhwa.dot.gov/innovation/everydaycounts/edc_4/guide_to_improve_uncontrolled_crossings.pdf

STEP 6: REFINE AND IMPLEMENT TREATMENT PLAN

As acknowledged previously, the steps in this Guidebook are not always followed consecutively, and there is ample room for reflection and returning to earlier steps in an iterative way. This may be particularly true for Step 6, as the process of refining a treatment plan may require revisiting the actions, assumptions, and decisions made in prior steps.

In general, the process to refine, and implement a systemic treatment plan will involve these activities:

- Consider additional community priorities;
- Perform additional diagnostics;
- Perform economic assessments; and
- Allocate funding and implement projects.

The method of execution of these activities can vary widely based on procedures developed for project selection, inter-agency coordination, and others. There are ample resources available describing how to perform these activities in general, and links to key resources are provided at the end of this section. Thus, the following guidance will focus on key systemic safety considerations to make during these activities, which may differ in some ways from traditional safety management practices.

It is important to note, however, that at the time this Guidebook was produced, few agencies have completed a systemic pedestrian safety process to this extent, and best practices surrounding prioritization and implementation of systemic pedestrian safety projects are still in the early stages. As more agencies go through the process, it will be essential to evaluate systemic projects and systemic programs in terms of both processes and outcomes. The next step in this Guidebook outlines evaluation considerations and activities.

6.1 CONSIDER ADDITIONAL COMMUNITY PRIORITIES

Guidebook Step 4 provided guidance on identifying—and to some degree prioritizing—sites for treatment based on risk, using several different methods. The results from that step are dependent on the quality and completeness of the risk data available, including how well pedestrian exposure to traffic is accounted for, and the robustness of the analysis and screening and ranking procedures used. During this step in the process, there should be an opportunity to reflect upon the results from Step 4 and consider additional information from outside the systemic process, as well as engage key stakeholders. For example, it may be important to consider additional community priorities or opportunities, such as geographic balance, equity, installation and maintenance issues, or other considerations, especially if resource constraints limit the opportunity to treat all similarly ranked and economically viable locations.

Noteworthy Practices

Equity was an important consideration for the City of Seattle. They chose to stratify their initial list of locations by geographic area of the City, and then prioritize locations for treatment within each area, to ensure that there was strong geographic distribution of their systemic treatments.

The N*CHRP Report 803: Pedestrian and Bicycle Transportation Along Existing Roads, and ActiveTrans Priority Tool* (Lagerwey et al. 2015) may be a useful resource to think through and complete the final prioritization steps in a systemic process. The tool could be used to supplement the initial risk-based ranking and to consider additional risks or roadway constraints, as well as factors such as equity, compliance with existing guidance, or others. Once these determinations are made, weights may be assigned to factors to complete the prioritization. The result will be a well-documented process, that may also be used iteratively, and to help identify areas where data improvements or other changes in the process are desirable.

6.2 PERFORM ADDITIONAL DIAGNOSTICS

It may also be important to gather additional data needed to make final decisions. No general safety management process can cover all situations that may be encountered, including risks that remain unmeasured and unidentified in prior studies or in analyses using local data. Also, no guide is a substitute for experience and a thorough diagnosis of conditions before finalizing a treatment package. Thus, it remains important to conduct diagnoses and conduct field visits such as Road Safety Audits (RSAs) to identify potentially unobserved safety issues that should be considered, to verify those risks that seem indicated by the data, and to help ensure that the systemic countermeasures considered for application are appropriate and will not have unintended adverse consequences on other types of crashes or users.

6.3 PERFORM ECONOMIC ASSESSMENTS

All agencies are likely to be interested in maximizing cost-effectiveness of systemic projects. Since systemic treatment sites are identified because they have high-risk characteristics, but may not yet have experienced crashes, this may make them less-suited for a traditional benefit/cost analysis, which relies heavily on crash estimates, unless SPF data are available. Since safety performance functions aim to predict expected crashes in the absence of treatment, they provide a useful tool and metric in the absence of crash data, or to complement crash data. To determine expected benefits from treatments, it is also necessary to have quantifiable information on expected crash effects of treatments, or crash modification factors, to apply to expected or predicted crashes. Since systemic countermeasures are typically lower cost, expected crash benefits per site may be lower and still achieve cost-effectiveness overall, especially if a longer-time frame is considered.

In a traditional benefit/cost analysis, values are typically assigned to crashes, lives, or injuries as well as to the treatments to perform the assessment. The data types needed include: 1) costs of countermeasures, 2) estimates of expected crashes without treatment, 3) crash reductions expected from the countermeasures to be applied, and 4) crash or injury cost estimates (many states have their own), which may include various estimates by crash severity of the economic value of a statistical life (Hauer 2011). Other considerations in an economic assessment include the number of treated locations, expected life span of each treatment, and determinations of the numbers of years to be used in estimating potential benefits. The CMF Clearinghouse guidance also describes how to apply costs and normalize them to the current or investment year in a traditional benefit/cost analysis.

As mentioned in Section 3.1, there is a need to be able to estimate where crashes may occur to perform an economic assessment, and to determine how crashes might change with treatment. This presents a challenge in a systemic process that might identify many locations with no observed prior crashes. To address this need, agencies have used two basic approaches:

- Bundled high risk sites with similar high crash sites for benefit/cost or cost-effectiveness assessment and treatment (see Case Example 3); or
- Used metrics derived from SPFs to estimate potential crash savings (see Case Example 2).

An advantage of developing SPFs to determine risk factors is that the models can also be used to generate SPF-predicted crashes, and empirical Bayes (EB) estimated crashes. SPF-predicted crashes represent the average risk for locations having the set of factors in the model. EB-estimates are weighted by crash history, which helps to account for crash factors that may not have been included in the model or are specific to a given site. In the absence of crashes, SPF-predicted crashes may be the best estimate of crash potential for a given location. The higher of EB-estimated or SPF-predicted crashes could be used in prioritization.

Considering the difficulty in assigning costs to human lives and injuries and value judgments implied (Hauer 2011), some agencies such as those with Vision Zero programs, may prefer a cost-effectiveness approach. The cost-effectiveness approach does not assign values to lives and injuries, but simply attempts to estimate which projects will provide the largest expected reduction in crashes or injuries per expenditure.

Noteworthy Practice

A lack of crash frequency often excludes segments and corridors with few prior crashes, but high crash potential, from being selected using a crash-based benefit/cost analysis. To account for this, after corridors for potential treatment were identified for improvements through an initial risk-based screening and ranking process, Oregon DOT predicted combined vehicle-pedestrian and vehicle-bike crashes using the available safety performance functions, and the Part C Predictive Method of the HSM. For prioritization, the number of predicted crashes were compared with the number of observed prior crashes, and the higher value was used in the cost-effectiveness analysis. See Case Example 2 for details.

Definition: Cost Effectiveness Index

The Cost Effectiveness Index (CEI) estimates the cost to reduce one vehicle-pedestrian crash. It is calculated using the equation below:

$$CEI = \frac{Project\ cost}{Expected\ reduction\ in\ pedestrian\ crashes}$$

Table 18 offers a hypothetical example for how to apply a cost effectiveness index to a selection of 26 potential treatment sites identified in Step 4, using model-derived SPFs and established CMF and countermeasure cost data. Site 1 represents the site with the highest predicted crash risk based on the SPF model, as indicated by the relatively high number of predicted crashes (column A); inversely, Site 3 represents the lowest risk site. The values in the second column (A) are derived from an SPF model created for the City of Seattle to predict crashes involving pedestrians and motor vehicles traveling straight at midblock locations and are provided here for illustration purposes only. These SPF values have been multiplied by the expected countermeasure lifespan (in this case assumed to be 10 years). The countermeasure options (B) show three countermeasures recommended for midblock crossing locations that have established CMFs (C) and costs (D) (see table footnotes). The values for (E) are the expected number of crashes that would be prevented over the assumed 10-year period if the site is treated with the countermeasure. Dividing the cost of the treatment (D) by this number produces the cost effectiveness index, or the cost (in thousands) to reduce one crash.

Table 18. Example cost-effectiveness analysis for different treatment scenarios.

Site	Predicted # of Crashes (A)	Countermeasure Option (B)	CMF (C)*	Countermeasure Cost per Site (D)^	Expected Crash Reduction if Treated (E) = A - (A x C)	Cost Effectiveness Index, in thousands (F) = D/E
1	3.6	High vis X -walk	0.63	$2,540	1.33	2
		Median island (MI)	0.69	$13,520	1.12	12
		High vis X-walk and MI	0.44[&]	$16,060	2.02	8
		PHB	0.53	$57,680	1.69	34
2	1.36	High vis X-walk	0.63	$2,540	0.50	5
		Median island (MI)	0.69	$13,520	0.42	32
		High vis X-walk and MI	0.44	$16,060	0.76	21
		PHB	0.53	$57,680	0.64	90
3	0.45	High vis X-walk	0.63	$2,540	0.17	15
		Median island (MI)	0.69	$13,520	0.14	97
		High vis X-walk and MI	0.44	$16,060	0.25	64
		PHB	0.53	$57,680	0.21	273
Other 23 sites	18.51	High vis X-walk	0.63	$2,540	6.85	9
		Median island (MI)	0.69	$13,520	5.74	54
		High vis X-walk and MI	0.44	$16,060	10.37	36
		PHB	0.53	$57,680	8.70	152
All 26 sites	23.98	High vis X-walk	0.63	$2,540	8.87	7
		Median island (MI)	0.69	$13,520	7.43	47
		High vis X-walk and MI	0.44	$16,060	13.43	31
		PHB	0.53	$57,680	11.27	133

* CMFs provide here are the highest (most conservative) value from Table 17 in Step 5; see Technical Report for details

^Average cost estimates from *Costs for Pedestrian and Bicyclist Infrastructure Improvements*, Appendix D table on page 42-44, available at: http://www.pedbikeinfo.org/cms/downloads/Countermeasure%20Costs_Report_Nov2013.pdf.

[&] Assuming multiplicative effects on crashes (0.63 x 0.69) for High vis X-walk and median island (multiply CMFs).

The CEI value can be used to explore the cost-effectiveness of different treatment scenarios. For example, there is high cost-effectiveness (as demonstrated by the low CEI value of 2) in treating Site 1 with a high visibility crosswalk, but similar cost-effectiveness (CEI value of 7) in treating all 26 sites with high visibility crosswalk markings. Since there is still some uncertainty about which sites will actually experience future crashes (in the absence of treatments), the more sites that can be treated, the more opportunity to reduce crashes that may occur at some sites. On the other hand, there is much lower cost-effectiveness in treating only the lowest predicted risk site (Site 3) in this group with a more expensive PHB treatment. Similarly, it may be more cost-effective to treat more higher-risk sites with multiple countermeasures (to address more types of risk) than to treat lower ranking sites. This is illustrated by the estimates for combining high visibility crosswalk markings and median islands. Other considerations (as described in Section 6.1) may certainly come into play, but this example illustrates one method in current use by a state DOT to take cost-effectiveness into account (see Case Example 2).

The CEI example is one way to approach cost-effectiveness without monetizing the cost of a crash, injury, or fatality. It can easily be extended to a benefit/cost analysis by applying crash cost estimates to the predicted prevented crashes and comparing these to the costs of treatment. For an extended example of a more traditional benefit/cost analysis approach, please see pages 41-50 of ADOT's *Pedestrian Safety Action Plan* section on Benefit Cost Evaluation, found here: http://www.azbikeped.org/downloads/ADOT-Pedestrian-Safety-Action-Plan.pdf.

Regardless of which method is used, it is important in a systemic approach to perform the economic assessment for all locations anticipated to be treated with a similar package of treatments. The sum of "predicted" crashes or combined expected crashes and risk estimates across many locations can help to justify the treatment cost and to determine the balance of investment and number of sites for different types of systemic projects, as well as with high crash/high cost treatments.

CMF Caveats in Cost-Effectiveness/Benefit Analyses

A unique challenge for pedestrian safety is that there are fewer pedestrian CMFs available for use in estimating benefits of treatments. In an ideal world, high quality CMFs would be available for each pedestrian treatment and would be calibrated using local data to provide more precise estimates of potential effectiveness. However, there may be insufficient data to calibrate crash effect estimates of pedestrian crash type countermeasures in a given jurisdiction. Further, there is very little research on synergistic or multiplicative effects of applying multiple countermeasures to a site. Thus, the estimates available in the Guidebook (Table 17 in Step 5) and from the CMF Clearinghouse and other sources may serve as the best available estimates.

Oher Effectiveness Assessments

Since crash effect estimates may be lacking or not appropriate for the locations considered, agencies could also consider estimates of behavioral or operational effects—such as documented speed reductions—to estimate crash effects. For example, the HSM provides CMF estimates for changes in baseline speeds on total fatal or injury crashes; additional assumptions are that effects on pedestrian crashes may be similar. These crash effect estimates, adjusted for local experience or conditions, can aid agencies that wish to perform a benefit/cost analysis. Other resources that detail methods and metrics for performing economic assessments with different data limitations are listed in the Additional Resources section.

6.4 ALLOCATE FUNDING

State and local agencies may need to change or adapt existing policies to allocate funds to systemic safety projects. For some states, this may require an adjustment in how projects are prioritized (see sections above) to allocate safety funding to sites based on risk if, for example, crash prediction estimates are unavailable, and only crash histories are available to estimate future crashes.

Additionally, agencies may wish to balance expenditures across high-crash or hotspot treatment projects and systemic safety implementation projects, particularly if data to drive confidence in one process over another is lacking.

As mentioned above, compared to the traditional crash hotspot approach where economic decisions may be made on a per-site basis until funding limits are reached, systemic applications may be decided based on expected crash savings across a group of sites, including those with low or no prior crashes, but potential crashes based on crash predictions or estimates or other risk assessment. While expected crash savings may be low at many individually-treated systemic sites, investment risk is also typically low (for lower cost, but effective treatments). By treating many locations with similar risk, a positive benefit/cost ratio can be achieved. Conversely, treating a few more sites with high cost treatments may quickly become un-economic as the numbers of expected crashes or injuries decrease on a per site basis.

Figure 5, from FHWA's *Reliability of Safety Management Methods: Systemic Safety Programs* provides a framework for how agencies might optimize the balance of funding between the high crash and systemic treatment approaches (Gross et al. 2016b). A similar approach may be used in assessing allocation of funding by enforcement and educational options if funds may be transferred among program types. (See the highlighted example from Caltrans below.) Some assumptions may have to be made when applying this approach, for example, if there is uncertainty about crash effects of treatments. The FHWA *Systemic Safety Programs* Guide (Gross et al. 2016b) also mentions that there is a need to test this framework for allocating funds under real-world conditions and scenarios.

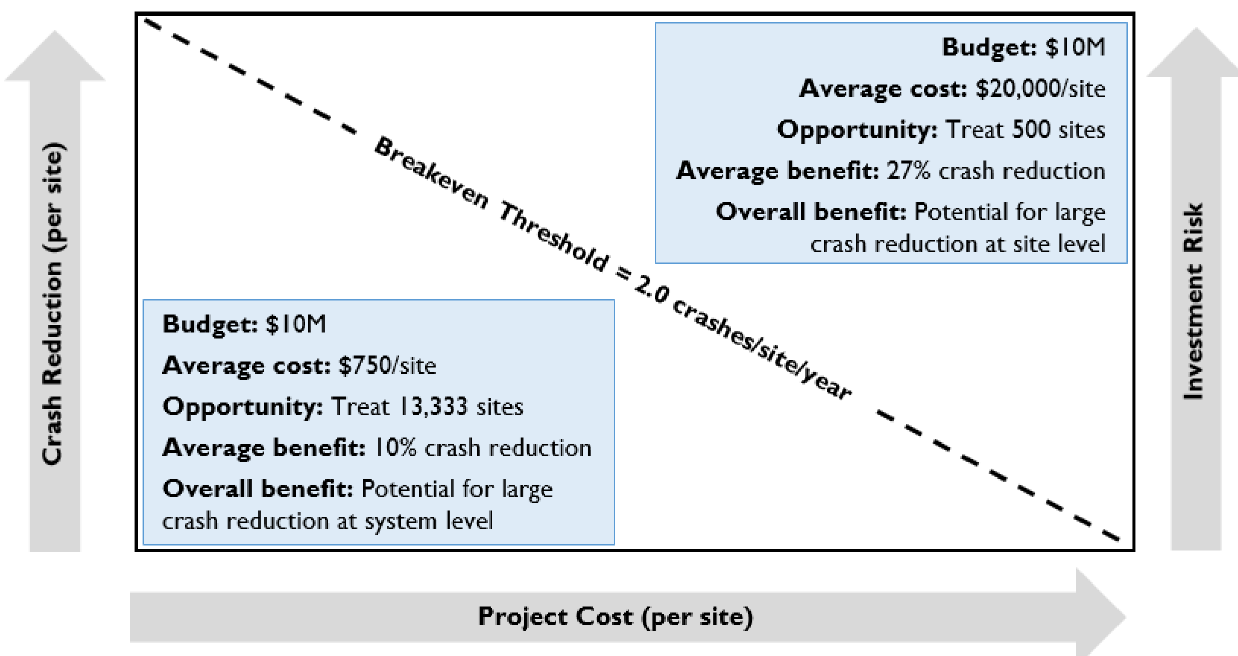

Figure 5. Optimizing investment in high-cost and low-cost (systemic) improvements (Source: FHWA Systemic Safety Programs guide by Gross et al. 2016, Fig. 12).

Noteworthy Practices

There are several examples of how states and cities are allocating funding toward systemic safety programs. Caltrans set aside $10 million from the Highway Safety Improvement Program (HSIP) and established the Systemic Safety Analysis Report Program (SSARP). The state funding for the SSARP program was made available by exchanging the locally available HSIP funds for State Highway Account (SHA) funds. Caltrans has issued two rounds of calls for all types of systemic safety project funding applications by local agencies.

Oregon DOT's All Roads Transportation Safety (ARTS) program splits its available funding (primarily Highway Safety Improvement Program funds) evenly between two project prioritization types: hotspot and systemic analyses. Funding for systemic projects is further disseminated into three emphasis areas identified by Oregon's Strategic Highway Safety Plan, which include roadway departure, intersection, and pedestrian/bicycle safety improvements. Together, these three emphasis areas account for approximately 90 percent of the fatal and injury crashes in Oregon.

Seattle is pursuing HSIP funds based on crash-based screening and EB estimates. According to Seattle DOT staff, Washington DOT is allowing prediction models to be used to justify treating sites that have not yet experienced crashes. The Seattle crash prediction models were based on crash data from previous years, but a recent review of more current crash data showed that sites predicted to have crashes based on the model did in fact experience a pedestrian crash later.

6.5 ADDITIONAL RESOURCES

Additional considerations are provided in Chapter 5.3 and Chapter 6 of the Technical Report. The following resources offer guidance on ways to prioritize treatments and evaluate different scenarios.

Resource	Link
FHWA's *Systemic Safety Project Selection Tool*	https://safety.fhwa.dot.gov/systemic/fhwasa13019/
NCHRP's *ActiveTrans Prioritization Tool* and NCHRP Report 803, *Pedestrian and Bicycle Transportation Along Existing Roads—ActiveTrans Priority Tool Guidebook*	http://www.pedbikeinfo.org/planning/tools_apt.cfm
FHWA's *CMFs in Practice, Introduction to Safety Performance Functions*	https://safety.fhwa.dot.gov/tools/crf/resources/cmfs/pullsheet_spf.cfm
FHWA's *CMFs in Practice, Quantifying Safety in the Roadway Safety Management Process*	https://safety.fhwa.dot.gov/tools/crf/resources/cmfs/
AASHTO's *Highway Safety Manual*	In-print only
FHWA's *Reliability of Safety Management Methods: Systemic Safety Programs*	https://safety.fhwa.dot.gov/rsdp/downloads/fhwasa16041.pdf
FHWA's *Guidebook for Developing Pedestrian and Bicycle Performance Measures*	https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/performance_measures_guidebook/

STEP 7: EVALUATE PROJECT AND PROGRAM IMPACTS

Evaluation and monitoring is a key part of a systemic process. The purpose of this chapter is to describe the final step in the systemic process, which involves evaluating project and program impacts before starting the process anew.

7.1 EVALUATE SYSTEMIC PROGRAMS

There are several actions that can be taken to judge the progress and outcomes of a systemic pedestrian safety program. To start, agencies may consider looking at various process measures to determine if the systemic analysis and prioritization process has been implemented as planned. This could involve:

- Determining if each of the other six steps in the systemic process has been carried out;
- Documenting what barriers to implementation arose and what additional measures are needed, such as: data improvements, changes to policies or funding structures, training, additional tools, coordination across agencies, etc.; and
- Summarizing how many locations in the system were identified as high-risk, and what percentage of the high-risk locations had specific countermeasures recommended and implemented through the process.

Going a step beyond process evaluation, systemic projects and their documentation may play a role in broader performance monitoring. This could involve examining the program not only from the safety perspective, but in terms of how it supports connectivity, reliability, and other pedestrian transportation goals. For example, many performance measures documented in FHWA's *Guidebook for Evaluating, Establishing, and Tracking Pedestrian and Bicycle Performance Measures* may be applicable to a systemic pedestrian safety program benchmarking. The FHWA Guide describes measures at the local, MPO, state, and national level, for tracking safety and other pedestrian transportation goals such as connectivity, mobility, health, and equity. These performance measures could be considered when evaluating a systemic program.

Several specific aspects of the systemic program will also need evaluation and/or validation. Depending on the type of program initially established, the types of evaluation and program renewal activities may vary. For example, if an agency developed SPFs to use in risk identification and screening, there is likely a need to validate the risks identified in the model using engineering judgment. This type of validation could be accomplished through field investigations or road safety audits (RSAs) at sites having risk characteristics and may include observing conflicts and conditions at a sample of sites.

Noteworthy Practice

Seattle performed some additional field assessment and model validation activities after initial intersection SPFs were developed, since there was a need to better understand the risks associated with signalized intersections. Through this process, the agency also determined it would be valuable to collect additional data on turning movements and phases at intersections to help improve the next round of systemic analysis.

If SPFs are used for ranking sites for systemic treatments, agencies may also wish to validate how well the model predicts, on average, where crashes occurred using updated data. If rankings are developed through other/expert weighting procedures, a similar assessment may be performed.

7.2 EVALUATE SYSTEMIC PROJECTS

Systemic projects—and ideally all types of safety projects—should be evaluated to determine the safety impacts. It is important to evaluate the impacts across all treatment sites where similar treatments were implemented, because crashes would be expected to be low at any one site. Again, if SPFs were developed for screening and ranking, these models can be used to predict baseline expected crash rates for the facility and location types without the treatment(s) to compare to effects with the treatment. However, given the average low propensity for crashes for many sites included in systemic projects, the potential effects on crashes may be difficult to detect unless data can be pooled for many sites and a number of years. State or regional agencies may be able to facilitate the development of robust evaluation datasets for both initial risk identification and evaluation, by pooling roadway and project data across several jurisdictions, thereby increasing potential for significant findings.

There are also alternative measures of impacts that may be assessed in the shorter term. Measures such as operating speed and other surrogate safety measures may indicate whether the treatments are working as expected. For example, if leading pedestrian intervals were implemented at signalized intersections, are pedestrians able to establish presence in the crosswalk before motorists begin turning? Are conflicts reduced? Do motorists yield? Are there certain locations where the treatments seem to work better than others? How do those locations differ? The use and efficacy of surrogate-based safety evaluations is an area of active research. Qualitative evaluations, including actively engaging the public to see how the new treatments are serving traveler's needs and are being used, are also important.

To make these program and project assessments, it is important to consider these needs before treatments are implemented so observations may be conducted before and after. Plan ahead so that the relevant types of observations for each treatment type as well as the need for comparison locations, can be planned in conjunction with location and countermeasures selection.

7.3 RENEW ANALYSES

At this point in time, there is no clear research-based guidance on the time frame for renewing SPF development or other risk analyses. Consider the extent of changes to the roadway network (including the systemic projects previously implemented), changes in traffic and pedestrian volumes and land use, or the availability of new and improved data to add to the analysis.

Noteworthy Practice

Seattle made the decision to update SPF-predictions with new data after three years using the same models. They planned to develop new SPF models, with new data, after five years.

7.4 ADDITIONAL RESOURCES

Below are additional resources on pedestrian safety planning and management.

Resource	Link
FHWA's *How to Develop a Pedestrian and Bicycle Safety Action Plan*	https://safety.fhwa.dot.gov/ped_bike/ped_focus/docs/fhwasa17050.pdf
NACTO's *Urban Street Design Guide*	https://nacto.org/publication/urban-street-design-guide/
NACTO's *Urban Bikeway Design Guide*	https://nacto.org/publication/urban-bikeway-design-guide/
FHWA's *Incorporating Safety into the Planning Process*	https://safety.fhwa.dot.gov/tsp/presentation/tsp_presentation120114.pdf
FHWA's *Safety Focused Decision-Making Framework*	https://safety.fhwa.dot.gov/tsp/fhwasa13034/fhwasa13034.pdf
FHWA's *Applying Safety Data and Analysis to Performance – Based Transportation Planning*	https://safety.fhwa.dot.gov/tsp/fhwasa15089/

CASE EXAMPLE 1: SEATTLE DEPARTMENT OF TRANSPORTATION

Key Takeaways

- Used network-wide data for all intersections to develop pedestrian SPFs for different crash types;
- Applied crash predictions from model estimation to identify high-risk sites;
- Conducted additional field investigations to identify and supplement missing data types; and
- Planned LPIs at several intersections to address risks identified; crash predictions were used to help prioritize sites without prior crashes.

BACKGROUND AND MOTIVATION

To help realize its Vision Zero goal, Seattle DOT (SDOT) developed a series of pedestrian safety performance functions to help establish a more comprehensive approach for reducing pedestrian crashes throughout the City. Prior to the development of these SPFs, SDOT employed a series of traditional crash-frequency based approaches to identify “hotspot” locations experiencing a high number of pedestrian crashes. The efficacy of these approaches, is, however, often limited by the failure to account for “regression to the mean,” in which crash frequency at high crash locations would be expected to decrease towards the average frequency for similar sites. These frequency-based approaches also are not based on factors contributing to pedestrian crashes across the network; and as a result, they may fail to identify the underlying factors that contributed to increases in pedestrian crashes. Therefore, SDOT set out to create a series of SPFs that included parameters that could help identify locations with potential for systemic pedestrian (and bicycle) safety improvements.

STEP 1: DEFINE STUDY SCOPE

Intersection crashes were selected as the initial focus for the first round of systemic analyses. Intersections of all types accounted for 69 percent of total crashes and 59 percent of fatal and serious injury pedestrian crashes in the City (Figure 6). Types in which the motor vehicle was going straight through the intersection (no turns) had a higher severity percentage, but crashes involving motorist turning left occurred more often. However, because this was a new effort, City staff and analysts decided to analyze all types of pedestrian crashes at intersections in lieu of left-turning only crashes, as well as the more severe subset of crashes involving motorists traveling straight through.

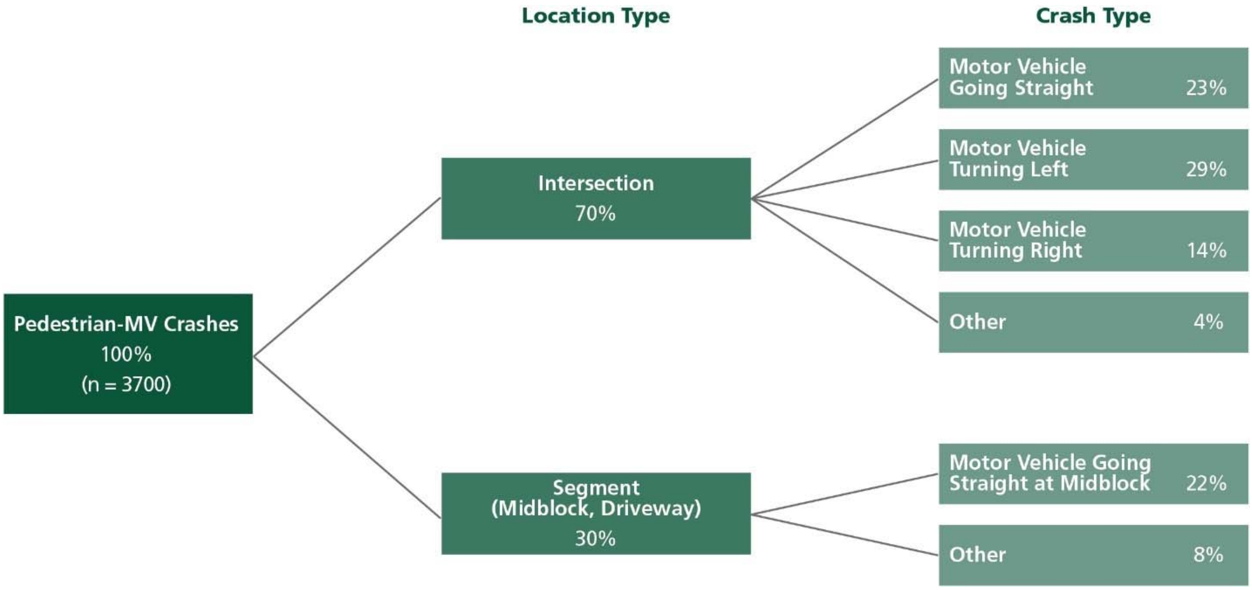

Figure 6. Pedestrian crash distributions by location type and crash type, based on data from 2008-2014 (Source: Adapted from Fig. 12 in SDOT 2016).

STEP 2: COMPILE DATA

To develop its SPFs, SDOT relied on a comprehensive relational crash and roadway database that incorporates spatial linkages between crashes, and roadway segments, or intersections. Much of the crash and roadway data (e.g., lane types, lane widths, traffic control type) were data SDOT and many DOTs already collect and maintain. Building on the spatially-referenced roadway inventory data, an intersection database for the entire network was compiled that joined crash counts per intersection with spatial data from transit agencies, land use, and census sources that could be useful in accounting for pedestrian activity exposure, social and built-environment and land-use-related pedestrian crash risks. Table 19 provides a summary of the data sources used to develop the variables to use in analyzing the crash relationships through modeling.

Table 19. Data and corresponding sources for variables tested in pedestrian crash risk SPFs.

Data	Source
Comprehensive crash database	City of Seattle
Roadway network geodatabase	
Generalized land use	
Building footprints	
University locations (volume estimate model only)	
Schools	
Short-term, quarterly, and continuous user count data used in pedestrian volume estimation	
Census blocks and demographic/employment data	U.S. Census Bureau
National elevation dataset	U.S. Geological Survey
Transit stop location and schedule data	Google Transit Feed Specification, Sound Transit

STEP 3: DETERMINE RISK FACTORS

Limited pedestrian count data were available prior to the analysis but short-term counts were available for about 50 intersections across the City. Ballpark pedestrian and bicycle volume estimates were developed by modeling the count data and associated location characteristics. The mode was then used to generate estimates for all intersections, which were then parsed to segments as well. The estimates were annualized using factors derived from a prior study in a city with similar amounts of walking and developed infrastructure (San Francisco). These procedures are explained in Sanders et al. 2017. The model equations, based on short-term counts at 50 locations in Seattle, used variables such as nearby population density, employment density, numbers of households, and others. The variables that were included in the best-fitting pedestrian volume model included number of households within 0.25 mi of intersection/10,000, number of commercial properties within 0.25 mi of intersection, and whether the intersection was within 0.25 mi of a university. The Pseudo R^2 (a measure of the amount of variation in the count data accounted for by the model) was 0.76 (Sanders et al. 2017). Because the models were developed based on a limited number of short-term counts, primarily from arterial locations, and there was a need to make other assumptions, it was important to also consider other measures of pedestrian activity to help account for potential biases in these estimates.

Negative binomial regression modeling was used to test variables relationships to crashes for two intersection crash types–all pedestrian crashes at intersections, and crashes involving crossing pedestrians struck by a through motor vehicle at an intersection. Variables that were significant in the final model, or Safety Performance Function, were used as the basis for a Geographic Information System (GIS) based tool that would allow SDOT to conduct screenings using various crash type predictions and ranking methods to infer future crash potential. The tool also allows filtering by various location characteristics that were correlated with crashes to help prioritize locations for further assessment.

Variables that were positively associated with increasing pedestrian crashes at intersections included pedestrian volume (although a threshold volume was estimated when the relationship changed direction). Roadway-related variables included the presence of traffic signals, higher arterial classes, the numbers of entering legs, numbers of lanes at the intersection, and the presence of parking. Some of these variables were likely correlated with traffic volume, which was not available for much of the network and so was not used in the analysis. Prior analyses had suggested that arterial class served as a fair proxy for traffic volume, so arterial class was included in the analyses. A recent modeling effort to estimate traffic volumes at counted locations across the network found that arterial class was in fact highly correlated with traffic volumes. At the time this model was interpreted, it was thought that the number of legs and numbers of lanes, as well as traffic signals likely also correlated with volume-related risk and so the relationship of these crash predictors was interpreted cautiously (Thomas et al. 2017). In addition, increasing transit/buses stopping nearby was positively associated with crashes, as were commercial land uses. Mean income of area residents had a negative correlation with pedestrian crashes.

STEP 4: IDENTIFY POTENTIAL TREATMENT SITES

Several SPF and empirical-Bayes ranking metrics generated from the model results were available to help identify high-priority locations for potential treatment. While the SPF-predicted crashes come directly from the model equation and coefficients, the EB-estimate comes from a weighted blend of the SPF-prediction and prior observed crashes. Given the uncertainties around the estimates of pedestrian volume and the lack of traffic volume data for this first analysis, the City is putting more weight on the EB-estimates when prioritizing sites, since this estimate helps to account for missing variables. These estimates are described in Step 6 in the main text.

The data and ranking metrics were turned into a map-based tool that also allows SDOT to visualize highly-ranked locations and compare the outputs from various ranking methods, including prior crash frequency ranking (see the map in Figure 7). These predictive outputs, along with all the variables, can also be exported to a spreadsheet tool to be used in screening and ranking sites for potential improvement. (Note that Figure 7 is for illustration purposes only, and safety needs for specific locations have not been verified.)

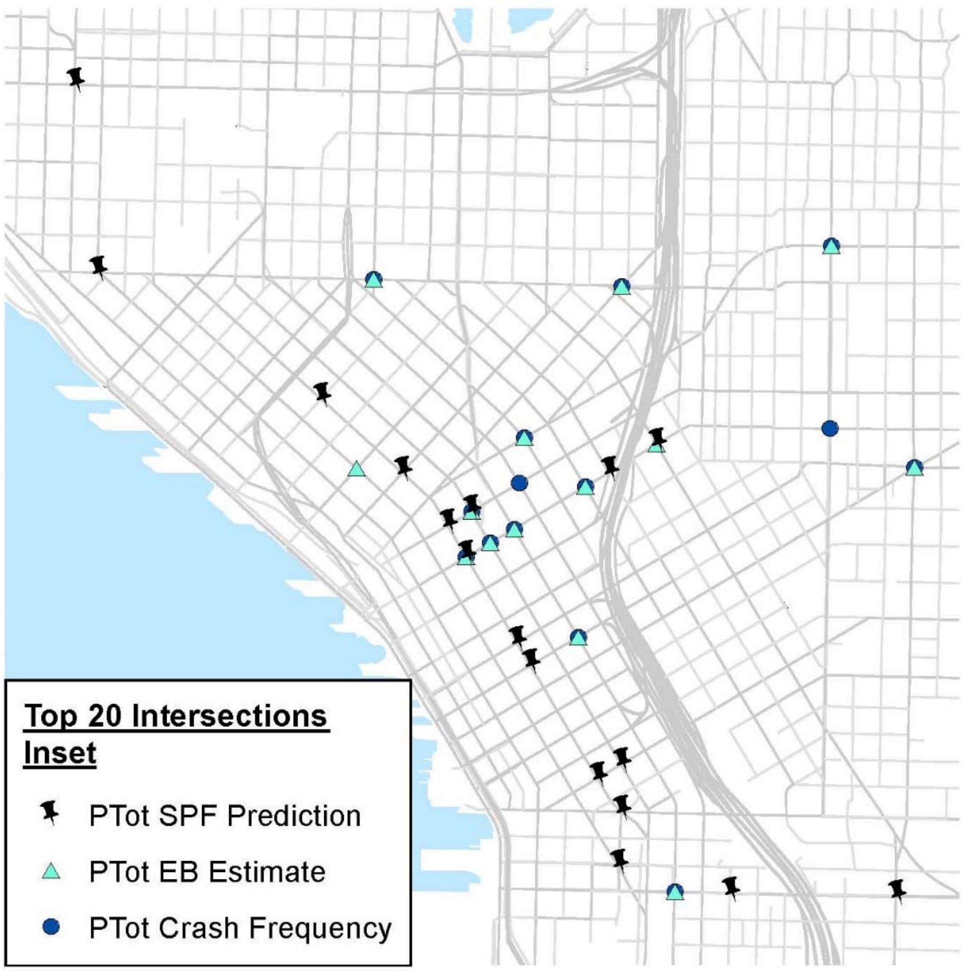

Figure 7. Illustration of highly-ranked intersections from SPF-based calculations, compared to prior observed high-frequency crash sites (Source: Thomas et al. 2017).

Some of the significant roadway factors from the model could also be used for initial screening. The top 20 intersections, for example, were overwhelmingly signalized, four or 5+ leg intersections, and involved major arterials spanning at least four lanes across the largest leg. However, due to the data limitations, further field diagnoses were carried out at highly-ranked sites to further diagnose the potential conflicts and risks. Traffic volume and unrestricted turning movements were identified as a risk factors for many of the signalized intersections. In addition, traffic signals are also typically placed to control movements where conflicts and volume is high, so these considerations suggest that signals are not necessarily the source of increased risk. Nevertheless, the factor is useful to identify locations that may be at increased risk of pedestrian crashes.

OTHER STEPS AND LESSONS LEARNED TO DATE

The model-derived estimates (SPF and EB) for potential for crashes have also been used to help justified multi-modal treatments. For example, by considering estimated bicycle crashes (from similar bicycle models) at one intersection where a bicycle path entered, the City was able to justify implementing turning restrictions at an intersection that did not quite meet the City's warrants for this improvement based on auto crashes alone.

Seattle is working on various data improvements, including improvements to both traffic and pedestrian volume data and hopes to improve other potential risk measures including signal operations. These improvements should allow for improved identification of treatable risk factors in future analyses. Although current data limitations created some challenges in interpreting how some of the roadway features contributed to risk, the supplemental census and land use data elements contributed to the estimation of activity-based risk. Results were also generally intuitive and useful for diagnosing potential solutions, and the model results have been used to rank and identify sites that may have potential for future crashes, even if those sites have not experienced prior crashes. In the interim, engineers visited highly ranked sites to identify "missing" data types and found a common risk factor at signalized intersections involved turning traffic conflicts with pedestrians. Thus, several similar locations were identified for leading pedestrian intervals.

The City is pursuing a mix of local and state Highway Safety Improvement Program funds to help implement leading pedestrian intervals (LPIs) at around 150 intersections—about 50 per year over the next few years. The City has used observed crashes to prioritize about 35 locations, and with the state's approval, is using the crash prediction estimates (EB estimates) derived from the SPFs to justify about 115 others. In this case, the City used EB estimates as the primary ranking metric, which relative to the SPF-predictions helps to better account for missing variables (such as the missing traffic volume data). Nevertheless, many locations with no prior crashes in the past eight years were identified based on the EB estimates.

Anecdotally, staff have observed crashes occurring at predicted crash locations since the period covered by the analysis. City staff also mentioned that while the initial data compilation was time-consuming, the cost was not that high, and the resulting knowledge and tools were well worth the investment. Interns, for example, coded the initial eight years of crash locations. The City plans to update the SPF predictions with new data using the current models within three years, and to develop new models in approximately five years. As data improvements are made, including network-wide traffic estimates, the relationships identified from future models may be better able to isolate treatable factors that have been associated with prior crashes. In addition, the SPF and related empirical-Bayes based ranking methods are very useful in prioritizing the locations that may be most likely to experience future crashes, as well as to weed out those with low potential for pedestrian crashes.

For more information, see the 2016 City of Seattle *Bicycle and Pedestrian Safety Analysis*, available at https://www.seattle.gov/Documents/Departments/SeattleBicycleAdvisoryBoard/presentations/BPSA_Draft_Public_093016.pdf and Thomas et al. 2017. Seattle DOT staff also assisted with information for this case example.

CASE EXAMPLE 2: OREGON DEPARTMENT OF TRANSPORTATION

Key Takeaways

- Complemented a hot-spot analysis approach with a systemic analysis approach;
- Used a set of risk factors established by an expert panel and applies weights to produce a high-risk score;
- Used sophisticated GIS-based techniques to create a high-risk score for individual roadway segments and corridors along the entire state highway system; and
- Prioritized projects using a cost-effectiveness index.

BACKGROUND AND MOTIVATION

The Oregon Department of Transportation (ODOT) created a systemic safety method to inform their Statewide Bicycle and Pedestrian Safety Implementation Plan with a goal to identify and prioritize candidate project corridors through a data-driven process to reduce fatal and severe-injury pedestrian and bicycle crashes on all public roads (regardless of jurisdiction) throughout Oregon. At the time of this research, ODOT was collecting additional data hypothesized to influence pedestrian and bicycle crash risk and is anticipated to revise their list of pedestrian and bicycle crash risk factors.

Currently, ODOT's All Roads Transportation Safety program splits its available funding (primarily Highway Safety Improvement Program funds) evenly between two project prioritization types: hotspot and systemic analyses. Funding for systemic analyses is further disseminated into three emphasis areas identified by Oregon's Strategic Highway Safety Plan, which include roadway departure-, intersection-, and pedestrian/bicycle safety improvement projects. Together, these three emphasis areas account for approximately 90 percent of the fatal and injury crashes in Oregon.

While projects targeting roadway departure and intersection crashes can readily be prioritized based on traditional benefit-cost analyses, applying these methodologies to pedestrian safety is more challenging because of general low frequencies of vehicle-pedestrian crashes at specific locations. Improvement projects would likely result in the exclusion of many sites without reported crashes, but potential for crashes, from funding consideration. To help alleviate this concern, ODOT applied the predictive methods of the *Highway Safety Manual* and cost-effectiveness analysis to identify or help prioritize pedestrian and bicycle safety improvement projects without relying only on existing crash data. The cost-effectiveness method also does not rely on monetizing pedestrian and bicycle crashes to prioritize projects.

STEP 1: DEFINE STUDY SCOPE

ODOT initially planned to focus on both state and local roads, but due to a lack of consistent roadway inventory data for local roads, risk factors were identified for state highways only.

STEP 2: COMPILE DATA

ODOT had a history of using network screening for motor vehicle crashes and had compiled relevant roadway inventory for the state-owned road system. Pedestrian risk factors identified in the next section were available or added to the inventory. Crash counts were also added.

STEP 3: DETERMINE RISK FACTORS

ODOT formed an expert panel to help identify key risk factors (see Table 20) to use in subsequent steps in the analysis. Each risk factor was assigned a point value (between 1 and 4) depending on certain conditions, and a weight value relative to other risk factors.

Table 20. ODOT-identified pedestrian risk factors.

Pedestrian Risk Factors	PMT Relative Weight	Risk Factor Score
Proximity to Signal	1	1 point if at least 1 signal is located on the segment or within 100' of the segment
Proximity to Transit Stop	2	1 point for segments with 1 transit stop located on the segment or within 100' of the segment; 2 points for 2 or more transit stops
Pedestrian-Activated Beacons or Flashers	2	1 point subtracted (rewarded) for the presence of an enhanced midblock crossing
Posted Speed Limit	3	2 points for posted speed limit of 35 or 40 mph; 4 points for posted speed limits above 40 mph
Undivided 4-Lane Segment Characteristic	3	2 points if segment is an undivided 4-lane segment
Number of Non-Severe Injuries and Pedestrian Involved but Not Injured in Crashes	4	2 points awarded if a non-severe injury or pedestrian-involved crash was reported within 100'; 1 additional point for each additional injury or pedestrian involved
AADT	4	2 points for AADT between 12,000 and 18,000; 4 points awarded for AADT above 18,000
Number of Severe Injuries Resulting from Pedestrian-Involved Crashes	5	4 points awarded if a severe injury was reported; 2 additional points awarded for each additional severe injury
Number of Fatalities Resulting from Pedestrian-Involved Crashes	5	4 points awarded is a fatality was reported

STEP 4: IDENTIFY POTENTIAL TREATMENT SITES

ODOT staff screened the network to identify potential treatment sites by applying a two-pronged approach: a crash-based approach and a risk-based approach. Under the crash-based approach, priority corridors were identified for both pedestrian and bicycle improvements using crash frequency and severity over a five-year period. Under the risk-based approach, a similar list of corridors was developed by identifying the presence of the risk factors described in Table 20. Due to lack of local road data, the risk-based approach was only applied to state-maintained roadways.

The statewide network was divided into 0.10-mile segments to identify locations where risk factors are present. The scores in Table 20 were applied to 9,490 0.10-mile segments on the state network. Rural segments (as defined by the Census Urbanized Areas), freeways and interstates, and connectors and frontage roads (based on the highway name) were excluded because the risk factors did not apply to those facilities. A segment's score represents the sum of points awarded for all risk factors present. The higher the score, the greater the risk of a pedestrian or bicycle crash.

The prioritized individual segments were grouped into longer candidate project corridors where one or more countermeasures could be applied to reduce crash frequency and severity; this allowed for efficiency for project development and construction. To establish candidate project corridor boundaries around the highest scoring individual segments, the segments were screened again to establish an additional score for each segment that accounts for the scores of upstream and downstream segments. This resulted in a unique "corridor" score for each 0.10-mile segment, calculated as the average score for segments on the same roadway within one-half mile in each direction.

The analysis was conducted using a spatial analysis model developed with ArcGIS 10.1 Model Builder. The spatial analysis selects and aggregates the scores of each segment of the network. The corridor aggregate score was divided by the number of segments resulting in a score for each segment that reflects the average risk per mile long corridor.

STEP 5: SELECT POTENTIAL COUNTERMEASURES

A variety of countermeasures were identified to address the crash patterns and risk factors identified through crash analysis. The countermeasures were evaluated to identify documented effectiveness, ease of implementation, and relative construction costs. A list of priority countermeasures was then identified and a "Countermeasure Toolbox" was developed to assist in selecting the appropriate set of countermeasures for each project corridor, based on the effectiveness indicated by quantitative CMFs developed by empirical studies. Most of these identified countermeasures carried over into the HSIP "Approved Crash Reduction Factor" list.

STEP 6: REFINE AND IMPLEMENT TREATMENT PLAN

After the potential project corridors were identified for improvements through the risk-based network screening process (described in Step 4), combined vehicle-pedestrian and vehicle-bike crashes were predicted based on the available safety performance functions using the Part C Predictive Method of the HSM. For prioritization, the number of predicted (HSM SPF-derived) crashes were compared with the number of observed (historical crash data) crashes, and the higher value was used in the analyses.

Projects were prioritized using a cost-effectiveness index (CEI), which compares the reduction in number of crashes due to the implementation of the countermeasure to the project cost, as shown below:

$$CEI = \frac{Project\ cost}{Expected\ reduction\ in\ pedestrian\ or\ bicycle\ crashes}$$

The expected reduction in pedestrian crashes would be determined by the difference in the expected crashes without treatment and the expected crashes with treatment. This ratio estimates the cost to reduce one vehicle-pedestrian crash. The projects with the *lower* CEIs were selected for implementation. A CEI is the inverse of benefit/cost analysis (where the *higher* benefit/costs are selected for implementation), therefore, a lower value indicates a better performing alternative. By applying this cost-effectiveness approach, rather than the traditional benefit-cost approach, ODOT was able to select 28 pedestrian improvement projects using a systemic and data-driven process.

OTHER STEPS AND LESSONS LEARNED TO DATE

Since this study, ODOT has continued these efforts and undertaken additional analyses to identify risk factors and develop SPFs to apply in their systemic process. See Monsere et al. 2017 and Siddique et al. 2017 for more information.

CASE EXAMPLE 3: ARIZONA DEPARTMENT OF TRANSPORTATION

Key Takeaways

- Used a set of risk factors established by prior research and applied some weighting criteria to these to produce a high-risk score;
- Used existing GIS-based roadway data along with state roadway file to score and map roadway segments and intersections;
- Performed additional visual scan of high-scoring sites to refine potential treatment sites (using on-line street viewing resources) and select candidate countermeasures; and
- Developed groupings of similar high-crash and high-risk sites with similar recommended countermeasures, which allowed for computing benefit/cost ratios of high-risk and high-crash sites.

BACKGROUND AND MOTIVATION

In addition to analyzing high crash locations, the Arizona Department of Transportation (ADOT) developed a crash risk assessment methodology to proactively identify state highway segments and intersections where investment can help to cost-effectively lower the risk of pedestrian crashes. This methodology considers roadway, environmental, and other risk factors that are frequently identified as contributing factors to pedestrian crashes on their state highway system.

STEP 1: DEFINE STUDY SCOPE

Arizona's overall strategic pedestrian safety action plan aimed to reduce the greatest number of severe injury and fatal pedestrian-motor vehicle crashes on the Arizona State Highway System (SHS). The systemic program was one part of that overall plan. The state undertook to identify both high crash and high-risk locations that may not have experienced crashes.

STEP 2: COMPILE DATA

Arizona's process relied upon existing data sources that have been spatially linked. See tables in Step 3 for a list of data sources for each risk factor used. Arizona DOT also crash typed all pedestrian crashes on the SHS using the FHWA PBCAT software. These data were not used in the initial risk assessment but were available for diagnosing potential conflicts at sites that had prior crashes.

STEP 3: DETERMINE RISK FACTORS

Arizona DOT uses risk factors established from prior research in its approach, divided into three categories:

- Existing Conditions: factors relating to the lack of pedestrian accommodations;
- Pedestrian Demand: factors estimating pedestrian exposure; and
- At-Risk Groups: factors in the degree of safety concern that the absence of facilities creates.

Table 21 lists the risk factors used by ADOT to help identify locations with high crash risk for pedestrian crashes and their respective data source.

Table 21. Pedestrian crash risk factors and corresponding data sources.

Risk Factor Category	Risk Factor	Data Source
Existing conditions	Posted Speed Limit	ADOT GIS
	Operating Environment/Number of Lanes/ Roadway Width	
	Missing Sidewalk Link	
	Paved Shoulder Width	
	Prior Crashes	
	Traffic Volume	
	Signalized Intersection Spacing	
Pedestrian Demand	Population Density	U.S. Census Bureau
	Attractors (e.g., convenience stores, schools, parks)	Land Use Maps and Visual Inspection (Corridor-level only)
	Land Use (commercial and high-density housing)	
At-Risk Groups	% Households in Poverty	U.S. Census Bureau
	% Households with No Vehicle	Land Use Maps and Visual Inspection (Corridor-level only)
	At-Risk Groups (Children, Elderly, and Handicapped)	

Like the ODOT example, ADOT created a method for developing a risk score for each state highway roadway segment, based on the risk factors shown in Table 21, and weighted values for the presence (or lack) of these factors. The point system was developed subjectively and incorporated research results from the latest pedestrian safety literature. For ease of ranking and scoring, ADOT converted the continuous variables into categorical variables. For example, the width of roadway and posted travel speed variables are broken down as follows:

- Width of Roadway
  - 6-Lane Highway = 6 points
  - 4- or 5-Lane Undivided Highway = 3 points
  - 2- or 3-Lane Undivided Highway = 2 points
  - 2- or 3-Lane Divided Highway = 1 point
- Posted Travel Speed
  - >45 miles-per-hour (mph) = 6 points
  - 35 to 45 mph = 4 points
  - 25 to 35 mph = 2 points
  - <25 mph = 0 points

STEP 4: IDENTIFY POTENTIAL TREATMENT SITES

ADOT uses the GIS-based risk scoring tool to identify potential treatment locations on the state highway system. Roadway segments are ranked by the total number of points earned, and high-risk locations— those with more than 32 total points based on all category variables, some not included in Table 21—are mapped using GIS (see Figure 8). These locations were further evaluated visually using

Google Earth or other resources to make assessments based on the segment's area-wide elements such as sidewalk connectivity, signalized intersection spacing, and presence of pedestrian attractors. This step either maintains the segment's status as being high-risk or screens-out the location if there seems little potential for pedestrian activity. Then, sites were grouped with others that shared high-risk features and where the same countermeasure(s) were proposed. This allowed for computing of a benefit-cost ratio for each of these site groupings, so that the benefits of treatments could be measured across sites with similar risk factors but different crash histories.

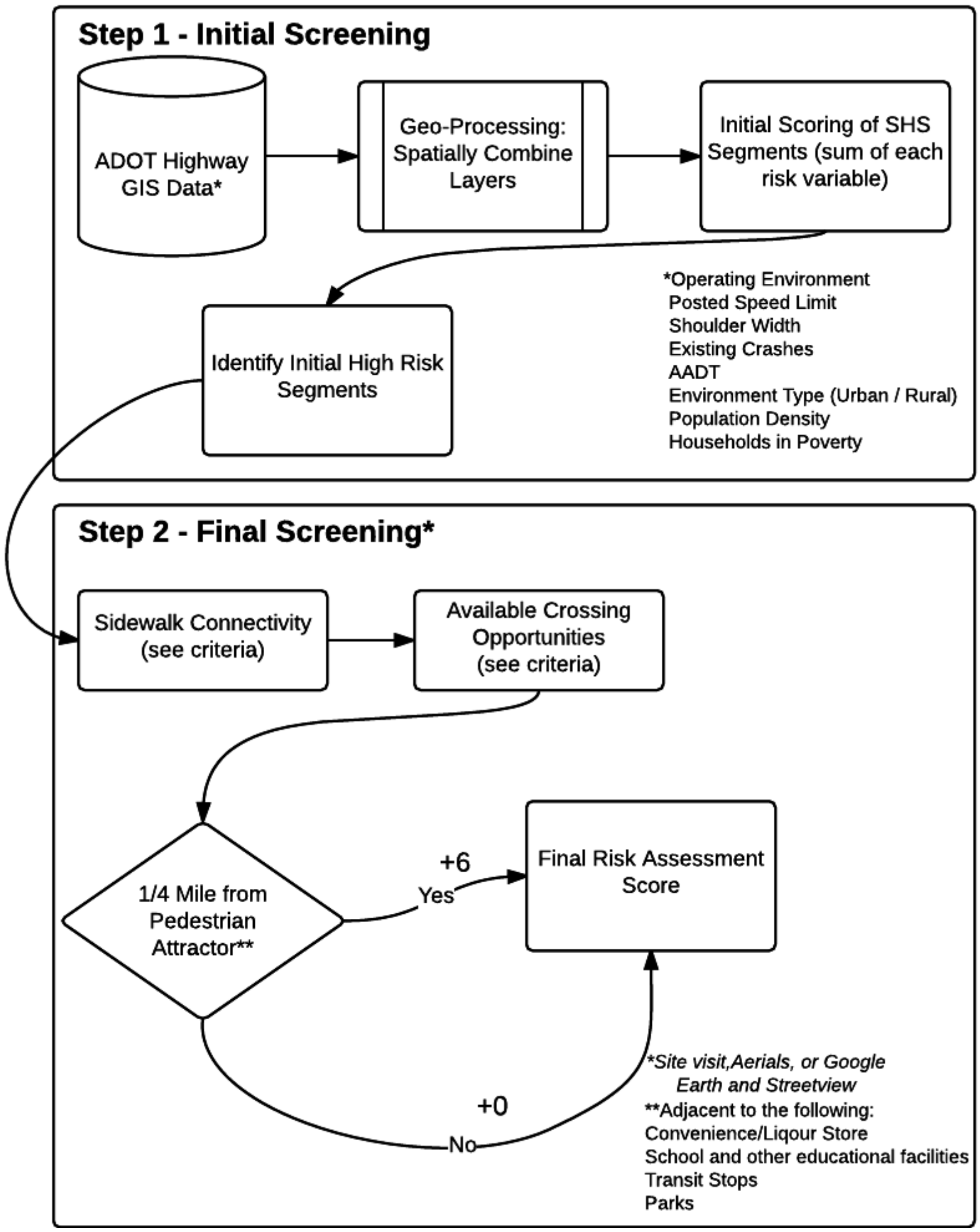

Figure 8. Arizona process to identify high-risk segments for potential treatment (Source: Kimley Horn et al. 2017).

STEP 5: SELECT POTENTIAL COUNTERMEASURES

ADOT identified a set of effective pedestrian countermeasures and select other countermeasures that may help to address pedestrian crash types along the state highway system from research. Since the state developed both the high-crash and high-risk plan simultaneously, both high cost measures and lower to moderate cost measures were included. Chapter 5 from ADOT's *Pedestrian Safety Action Plan* (Kimley-Horn et al. 2017) describes the process and countermeasures selected. Some of the most common countermeasures that were recommended include:

- Improving shoulders (e.g., shoulder widening and paving);
- Installing lighting, where nighttime pedestrian crashes were a problem;
- Establishing a pedestrian crossing, usually to include high-visibility crosswalks, pedestrian hybrid beacons, and advanced stop lines with pavement markings;
- Installing raised median islands;
- Providing signalized crossing improvements, such as leading pedestrian intervals and/or extending the walk interval;
- Adding pedestrian warning signs at some rural, high-crash areas; and
- Developing police enforcement plans for many of the sites.

In addition, recommendations were made to conduct road safety audits at many of the locations to finalize treatment selection.

STEP 6: REFINE AND IMPLEMENT TREATMENT PLAN

For the high-crash and high-risk locations that were identified from the analysis, candidate countermeasures were assigned a benefit/cost ratio in a similar process recommended in the *Highway Safety Manual*. Since many of the high-risk locations had few or no pedestrian crashes during the analysis period, a procedure was developed to allow for them to also be included in the economic analysis. To accomplish this, sites that were similar in terms of risk factors and with identical countermeasure recommendations were grouped together. Thus, similar high-crash and high-risk sites were combined. This allowed for the use of the total combined pedestrian crash number for the group and the crash modification factor for the treatment type in computing the expected crash benefit. The combined cost of the countermeasures at all treatment sites in the group was the basis of the cost value in the B/C calculation.

OTHER STEPS AND LESSONS LEARNED TO DATE

This risk assessment methodology has allowed ADOT to identify segments or corridors that have high crash experience, and sites that may not necessarily appear on a high-crash location list but possess the conditions to be high-risk for crashes in the future. By proactively implementing the appropriate countermeasures (after completing a benefit-cost analysis and ranking the results) at the locations identified through this methodology, ADOT aims to help mitigate their high-crash risk and potentially prevent the locations from appearing on a list of high frequency crash sites.

ADOT applied a benefit/cost analysis to high crash and high-risk sites. Due to variability in potential injury outcomes for each crash based on individual crash factors (e.g., age and health of the pedestrian who was struck, etc.), the state applied crash costs based on the average severity outcome by crash type for all of the prior crashes on the SHS. Their report also describes how they assigned a service life and annual operating costs, as well as initial construction costs, to each potential countermeasure to be used in the benefit/cost calculations.

With less data on pedestrian environments and exposure available for the initial screening process, more work was needed following initial identification of sites with risk factors to identify locations to potentially remove from the pool of sites if they lacked pedestrian demand characteristics.

Arizona DOT assisted with information for this case example. The full *Arizona Pedestrian Safety Action Plan* final report (Kimley-Horn et al. 2017) can be found at: www.azbikeped.org/downloads/ADOT-Pedestrian-Safety-Action-Plan.pdf.

CASE EXAMPLE 4: CALIFORNIA DEPARTMENT OF TRANSPORTATION

Key Takeaways

- Employs a matrix of facility types and crash types to identify high crash frequency scenarios across a roadway network; and
- Connects each high-crash scenario (or matrix cell) to a potential countermeasure for further consideration.

BACKGROUND AND MOTIVATION

To help compliment their traditional hotspot analysis, California DOT (Caltrans) has developed a quasi-systemic safety approach for identifying high-risk crash locations. The approach, dubbed the Pedestrian Systemic Monitoring Approach for Road Traffic Safety (PEDSMARTS), focuses on developing strategies to reduce pedestrian and bicycle injuries along urban arterials. Caltrans sought to use this program as a means for more effectively incorporating pedestrian and bike projects into their safety funding, as these roadway users were typically underrepresented through traditional hotspot analyses due to lack of exposure.

PEDSMARTS takes a holistic approach to safety by screening the entire state highway system (~15,000 miles) and focusing on facility types of interest, rather than locations of interest. The systemic analyses matrix tool seeks to represent key roadway types and crash types in a single table to inform the decision-making process; this helps to provide a big-picture snapshot of the issues rather than one focused on a single area or facility type.

STEP 1: DEFINE STUDY SCOPE

The Caltrans process was initiated to complement the traditional hotspot analysis and focused on high-risk locations along urban arterials.

STEP 2: COMPILE DATA

This approach uses primarily crash data and basic roadway data, including presence of traffic signals, number of lanes, and AADTs.

STEP 3: DETERMINE RISK FACTORS

The process started by defining specific facility types of interest, in addition to crash types. Crash count data is used to identify facility types with high crash frequencies. The roadway characteristics were predetermined by the UC Berkeley team and Caltrans from prior analyses and included:

- Signalized or unsignalized location;
- Number of lanes for both main and cross streets;
- AADT for both main streets; and
- AADT for cross streets.

Risk factors are inferred using a matrix tool that reflects the combinations of crash types and facility types that have the highest crash counts (see Figure 9). The matrix includes categories for location type across the horizontal axis and crash types across the vertical axis, where cell (i, j) represents the number of crash type i experienced at locations of type j [e.g., In cell 3,3 for example (Figure 9), there were 98 Type 3 crashes at locations of Type 3].

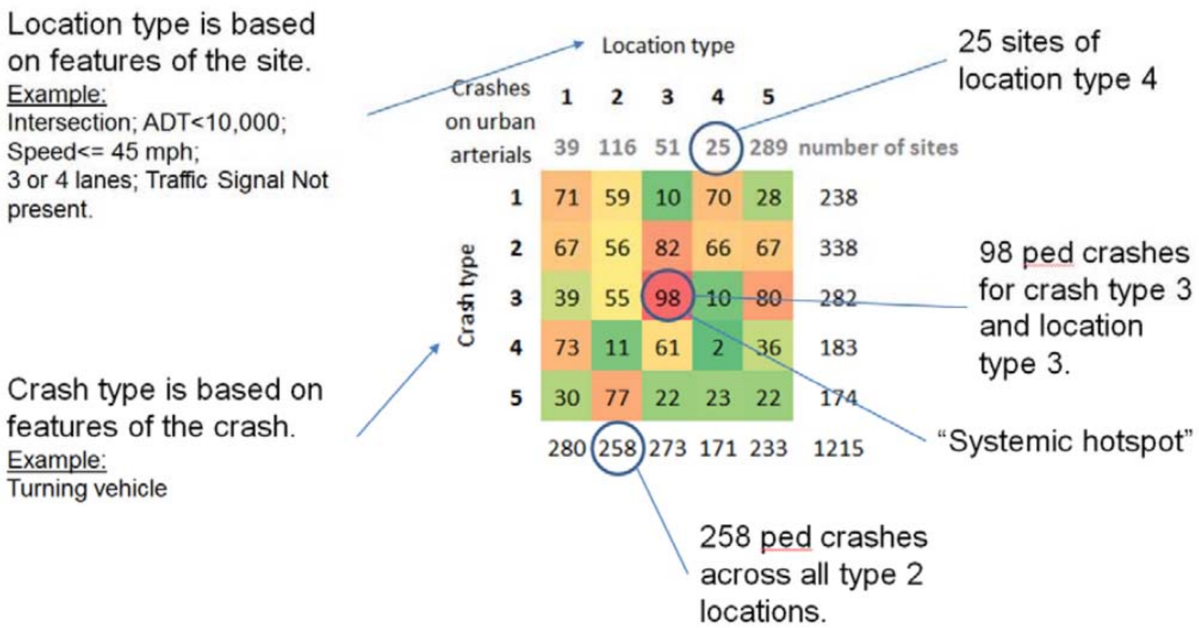

Figure 9. Example of systemic hot spot identification matrix (Source: Grembek et al. 2013).

The matrix cell with the highest number of crashes represents a "systemic hotspot" type, and the corresponding location type and crash type are entered into a systemic countermeasures matrix (see Step 5).

STEP 4: IDENTIFY POTENTIAL TREATMENT SITES

Each of the "systemic hotspot" cells are associated with a set number of sites. For example, the 98 crashes identified in the red cell in Figure 9 occurred at 51 different sites at Location Type 3. However, all sites with the set of characteristics of Location Type 3 are potential candidates for treatment of this crash type. Additional work (in the field, using local knowledge or aerial imagery, or some combination of these) would be required to identify which subset of these sites, which include many locations with zero prior crashes, are priorities for treatment.

STEP 5: SELECT POTENTIAL COUNTERMEASURES

Figure 10 shows an example systemic countermeasure matrix. This consists of countermeasures specifically identified to potentially reduce the crash type i for location type j in Caltrans' Countermeasure Toolbox. The matrix identifies countermeasures 2 and 4 as the most applicable to address crash Type 3 at locations of Type 3). Once a countermeasure is selected, safety practitioners can then implement the countermeasure across all locations of that type (e.g., across all 51 locations of Type 3), or across a subset (identified in Step 4).

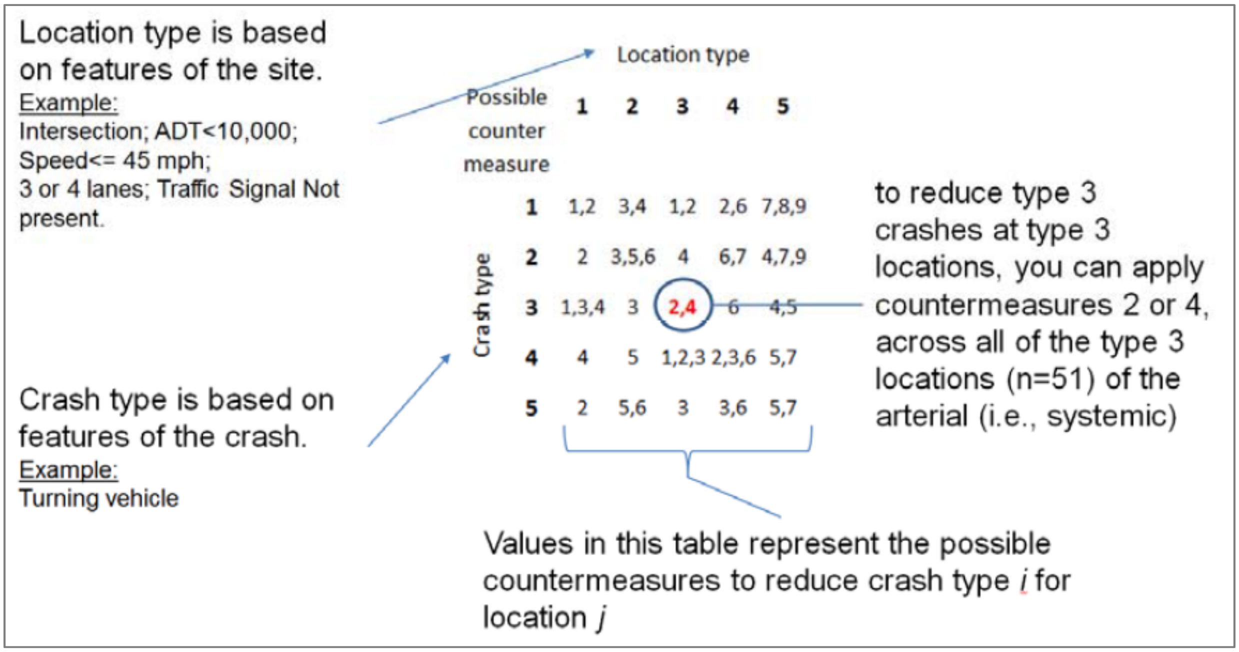

Figure 10. Example of systemic countermeasure matrix (Source: Grembek et al. 2013).

The methodology includes consideration of dozens of countermeasure options, and lists countermeasures linked to specific pedestrian crash types. Some of the countermeasure options include:

- Roadway lighting;
- Raised median island;
- Traffic calming treatments (e.g., curb extensions, mini-circles);
- Countdown signals;
- Right turn on red restrictions;
- Advanced stop bar;
- Overpass/underpass;
- Pedestrian hybrid beacon;
- Crosswalk marking and enhancements;
- Transit stop improvements;
- Roundabouts; and
- Curb ramps.

OTHER STEPS AND LESSONS LEARNED TO DATE

The inherent challenges with this approach lie in performing expert analyses to develop the crash type and location type matrices, and then in accounting for differences in pedestrian activity/exposure across different facility types as they pass through different area types during prioritization. Since the matrix does not take these types of data or pedestrian volume into account in the initial analysis, more work must go into Step 4 to assess the appropriateness of each site for treatment. However, this research has been ongoing since 2013 and Caltrans is continually seeking to modify and improve the procedures for their systemic program. This methodology has allowed Caltrans to more readily incorporate systemic projects into its annual safety programming and to develop a more comprehensive safety improvement plan. An article related to this methodology (Grembek et al. 2013) can be found at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.448.85&rep=rep1&type=pdf. Caltrans staff also assisted with information for this case example.

CONCLUSION: CONSIDERATIONS AND LIMITATIONS

A robust process has been outlined in this Guidebook: one in which agencies can put to use high quality data to analyze pedestrian safety risks, identify the types of locations most associated with those problems, and select appropriate countermeasures for systemic implementation. The anticipation is that the Guidebook can provide concrete guidance, real-world examples, and links to key additional references to help motivate and support agencies to gather the minimum level of data and technical expertise needed to perform the steps in a systemic process. Other steps may involve putting partnerships in place (e.g., with data stakeholders, other state and or local staff) to support the communication and collaboration that surrounds the analytic steps.

The reality is that many agencies will need to continue to work to develop the data, skills, and methods for a systemic pedestrian safety process. This work will likely require strong inter-jurisdictional collaboration, particularly for processes led by state DOTs. For example, different agencies may manage roadway inventories according to ownership, and many of the data types needed for a robust systemic pedestrian safety analysis may be lacking or in the purview of others. The quality and completeness of pedestrian facilities—and the rate at which improvements are made—varies largely by community, and some agencies may fail to timely document when changes are made. Establishing processes—both at the state and local level—for project documentation and inventories will benefit many aspects of safety and system management.

Another key consideration is whether an agency has in place a sound strategy to collect pedestrian counts at representative locations and develop accurate volume estimates that can be used in risk analysis as described in Step 3. Traffic volume data improvements may also be needed. For example, some localities collect traffic volume data only on arterial streets, making it difficult to account for the relationship between traffic volume and pedestrian crashes across the entire network.

An additional limitation is that states typically standardize crash reporting elements that may omit important crash type information when pedestrians are involved. State agencies compile crash data statewide, but the quality and availability of complete and accurate data depends on timely and accurate reporting from local law enforcement agencies. In most states, police reported crash data are rarely linked to medical data, which could be used to further enhance analyses to understand risks associated with pedestrian injury severity.

The above types of challenges are unlikely to become less pronounced over time (although there is a potential for improving knowledge regarding the use of surrogate risk measures), and many of these issues are relevant to prioritizing projects in all types of multi-modal safety programs. While the Guidebook offers some ways to address or work around these challenges, additional coordination and funding may be needed to enhance the data quality and completeness that underlies a truly data-driven systemic process for identifying focus crash types, analyzing risks, prioritizing locations and identifying appropriate types of systemic pedestrian safety improvements. Consider whether it makes sense to begin now to collaborate to enhance the processes for acquiring the needed types of data and develop the structures, spatial linkages (ideally ones in which demographic and land use data can be aggregated), and partnerships across agencies to accomplish safety objectives.

In the meantime, beginning the systemic process with existing data should prove quite informative of needs for improvements to data and process, if the experiences of some of the early adopters (see case examples) are an indication.

CONTINUING RESEARCH NEEDS

The case examples outline four systemic or quasi-systemic approaches that state and local agencies have begun, using different levels of data, risk screening methods, and philosophical approaches towards prioritizing locations and countermeasures. However, the application of a systemic approach to pedestrian safety is still in its infancy, and it will be important to monitor the success of these different types of applications of the process as these efforts mature through the later steps of implementation and evaluation.

Follow-up research on this guidance and process are important. Specifically, there is a need to conduct additional implementation assessment to determine which types of systemic methods are adopted, continuing barriers to adoption, and which processes work best for agencies. A data-driven process and use of reliable safety performance metrics is desirable and thought to be most effective for spending safety funds wisely. But questions remain on whether there is a point of diminishing return, and if it is possible to achieve similar safety results taking a more pragmatic approach based on risk principles, land use types, and sound engineering judgment. This may be a particular concern in smaller communities or others in which data quality (or quantity) is less than ideal and data shortcuts or surrogate measures are not reliable alternatives. Chapter 8 in the Technical Report provides further discussion of data and research needs.

Agencies that are implementing systemic processes and treatments have a role to play in advancing research, particularly around project evaluation. There is a possibility that crash reductions at systemically-treated sites may be different than those expected based on CMFs that may have been developed using actual higher crash sites rather than predicted high crash risk sites. There is also concern about some treatments—such as signs, which are low cost and easily implemented in a systemic process—being overused, diminishing their overall effectiveness. Evaluation of systemic projects is ideally something that each jurisdiction implementing a systemic approach will do, but, there may be a need for collaboration, pooled funds, or pooled data across state and local agencies to perform more robust evaluations. Such collaborations could enhance all types of safety programs, not only systemic programs.

As more studies are conducted, there may also be a need to consider how factors that increase the severity of a crash, in addition to the likelihood of a crash, can be measured and best be incorporated into systemic analyses. For example, how can travel speeds be measured in meaningful ways to assess pedestrian (and other road user) safety risk across the network or at different times, and how can such measures be incorporated into analyses to identify and prioritize risks by location?

These and other issues provide fertile grounds for continuing research around systemic pedestrian safety practices and outcomes that could enhance future editions of this Guidebook.

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APPENDIX A: POTENTIAL COUNTERMEASURES

In this section are 12 pedestrian countermeasures that could be considered during a systemic pedestrian safety analysis process. Each summary describes the purpose, current use of the treatment, available safety evidence, and considerations for application within a systemic framework.

State or local agencies may choose to expand this list of treatments, or limit the list based on local conditions and concerns (such as prior agency studies of effectiveness, political considerations, etc.) as well as the degree to which measures are being implemented systematically or as a matter of policy.

COUNTERMEASURES FOR SIGNALIZED OR UNSIGNALIZED CROSSING LOCATIONS

High Visibility Crosswalks

Figure A-1. Midblock crosswalk with high visibility pavement markings in Bellevue, WA (Source: www.pedbikeimages.org/Dan Burden).

Purpose and Use

High visibility crosswalks use continental (ladder) or bar-pair pavement markings to increase the conspicuity of pedestrian crossings (relative to traditional transverse pavement markings) for both pedestrians and motorists. While the use of high visibility crosswalks has become pervasive throughout the U.S., the implementation strategies across states and local agencies may differ. Some agencies have installed them systematically at every marked crossing location, while others install them only at priority risk locations (e.g., unsignalized crosswalks, roadways with high pedestrian volumes, high speeds, or school zones).

Effectiveness

High visibility crosswalks can provide safety benefits including crash reductions, as motorists detect them sooner than standard parallel line crosswalk markings during daytime and nighttime (Fitzpatrick et al. 2011). They also may help increase motorist yielding, especially when paired with other countermeasures such as highly visible 'pedestrians present when active' types of devices such as Pedestrian Hybrid Beacons or Rectangular Rapid Flashing Beacons.

Other potential benefits have been noted including increased pedestrian scanning behavior and fewer pedestrians stranded in the middle of the street while crossing (Pulugurtha et al. 2012). Potential effects on motorist speeds are unclear.

Systemic Application

Systemic application focuses on the use of high visibility markings of any type to replace standard crosswalk markings or to implement a crosswalk once a thorough assessment has been made of the suitability of a location for a marked crosswalk. A full engineering and safety study should be conducted to assess pedestrian need, sight distance, safety, and operational suitability of an uncontrolled location for a new crosswalk and/or a crosswalk combined with other treatments.

For a systemic approach, agencies may wish to consider application of high visibility markings to help address identified risks including the following: poor conspicuity of pedestrian crossings or unexpected locations (such as midblock), failure of drivers to slow or yield, lack of pedestrian compliance or use of crosswalks, and conflicts with turning vehicles at signalized intersections. High-visibility crosswalks alone are not sufficient to treat high-volume, high speed, multi-lane roads or inadequate lighting.

Traffic Calming (Raised Devices)

Figure A-2. Raised midblock crosswalk (Source: www.pedbikeimages.org/Dan Burden).

Purpose and Use

Raised roadway devices (i.e., speed tables, raised crosswalks, and speed humps) aim to calm traffic and improve the pedestrian environment by reducing vehicle speeds and the need for pedestrian ramps. These treatments may be applied at either intersection or midblock crossings to slow vehicle speeds on local and collector roadways in urban/suburban environments; they also may be applied in other specialized locations experiencing a high volume of pedestrians (e.g., airport pick-up/drop-off zones or college campuses) (Mead et al. 2014, Thomas et al. 2016). State DOTs have been slow to implement raised devices on their networks (only 17 percent reported they used raised crosswalks or speed tables often), but local agencies use them with greater frequency (Thomas et al. 2016).

Effectiveness

The extant literature has found traffic-calming treatments, specifically raised devices, provide an effective means of reducing vehicular speeds (Engineering Speed Management Countermeasures 2014; Strong and Kumar 2006). In turn, several studies have shown these reduced vehicle speeds can reduce the frequency and severity of pedestrian crashes (Elvik and Vaa 2004; *Toolbox of Countermeasures and Their Potential Effectiveness for Pedestrian Crashes* 2013, citing Bahar et al.). While the low frequency of pedestrian crashes where these devices are typically employed (low-speed environments) have made these findings somewhat difficult to replicate, a reduction in vehicle speeds may still serve as a surrogate measure of pedestrian safety and comfort.

Systemic Application

Traffic calming may be implemented through a variety of means, including special programs involving neighborhood requests to reduce speeding on local streets. These types of programs typically establish specific criteria and procedures for implementation and often require neighborhood support of the measure. If accepted for implementation at a jurisdiction-wide basis, raised traffic calming treatments can also be implemented through a risk-based systemic process at appropriate locations. However, they are most appropriate on relatively low-speed roads and have special considerations for application to ensure that problems do not “migrate” elsewhere.

Median Crossing Islands

Figure A-3. Median crossing island in Santa Cruz, CA (Source: www.pedbikeimages.org/Dan Burden/ 2006).

Purpose and Use

Median crossing islands are raised areas intended to protect pedestrians crossing at intersections or midblock locations by providing a refuge area to wait for a gap in traffic before beginning the second leg of the crossing (Thomas et al. 2016). Also referred to as pedestrian median islands, center islands, and refuge islands, these treatments can be used at both uncontrolled and signalized crossings, and may be used with curb extensions to further reduce crossing distance (Mead et al. 2014, Thomas et al. 2016). Median crossing islands have been used extensively by both state and local agencies on roadways with high volumes, high speeds, and multiple lanes (Thomas et al. 2016).

Effectiveness

Median crossing islands have been shown to reduce pedestrian-motor vehicle crashes (Zegeer et al. 2017 a, b). Median islands appear to help increase the frequency of motorist yielding and reduce motorist speeds (Pulugutha et al. 2012, Elvik 2001, Kamyab et al. 2003). This treatment may also reduce multiple-threat crash risk, dash and dart-out crashes, crashes caused by motorist or pedestrians failing to yield the right-of-way, and crashes at unique midblock crossings. Several studies suggest that median crossing islands encourage safer crossing behaviors by pedestrians, including scanning and compliance in crossing at the marked crosswalk (Pulugutha et al. 2012, Strong and Kumar 2006).

Systemic Application

Crossing islands may be applied at signalized and unsignalized intersections as well as at midblock locations on both high- and low-speed roadways. However, FHWA recommends their use for areas with less than 12,000 AADT for vehicles and high pedestrian volumes, as well as roadways with moderate to high travel speeds.

Lane Reduction (Road Diet)

Figure A-4. Road diet in Orlando, FL (Source: https://safety.fhwa.dot.gov/road_diets).

Purpose and Use

A road diet reduces the number of motorized traffic lanes along a street in conjunction with a reallocation of that space to other uses such as sidewalks, bicycle lanes, parking, or transit. Also known as “road conversions,” these projects commonly involve converting a four-lane undivided road into a three-lane road with two through lanes and a center turn lane (i.e., TWLTL) and bike lanes, but medians may also be used. Road diets benefit pedestrians by reducing the number of lanes to cross, allowing for medians or median islands and other treatments to be added to the road to assist in crossing, and by creating space for walkways, bike lanes, or additional buffers from traffic Knapp et al. 2014, Thomas 2013) Almost three-quarters of states and local agencies surveyed reported using road diets in locations with excess capacity or to provide additional space for bicyclists and pedestrians (Thomas et al. 2016).

Effectiveness

Road diets have been found to reduce total crashes from 19 to 47 percent and reduce motor vehicle speeds, which is expected to have pedestrian safety benefits. The larger range of effect was found for main roads through small towns and suburban areas, with the lower range of effect in large urban areas (Harkey 2008, FHWA 2013). Road diets can also reduce travel speeds and New York City observed a downward trend in pedestrian crashes after evaluating effects of 460 road diets (Thomas et al. 2016).

Systemic Application

As with all types of applications, diagnosis and additional screening are needed to ensure that locations are appropriate for the measure. FHWA’s *Road Diet Informational Guide* provides information on the safety benefits and potential trade-offs of road diets, performing a feasibility assessment (including traffic volume considerations, number of driveways and junctions, and intersection function), designing a road diet conversion, and evaluating a road diet (Knapp et al. 2014). Road diets are generally considered feasible for roads with lower to moderate traffic volumes (less than 25,000 ADT). The Iowa Department of Transportation developed a statewide screening system for candidate sites for 4- to 3-lane road conversion that is useful for understanding how existing roadway databases and geographic information systems (GIS) data can be used in a streamlined screening approach (Statewide Screening for Potential Lane Configuration 2017).

Curb Extensions and Parking Restrictions

Figure A-5. Curb extension and parking restriction at midblock crosswalk approach (Source: www.pedbikeimages.org/Andy Hamilton).

Purpose and Use

Curb extensions (also known as bulb-outs or neckdowns) and parking restrictions near an intersection or other crossing are two countermeasures that frequently appear together to reduce crossing distance and improve sight lines between motorists and pedestrians. Curb extensions extend the sidewalk and the curb line into the roadway on streets that have on-street parking. The removal of parking adjacent to crossing locations is sometimes referred to as "daylighting." Guidance suggests that, at a minimum, vehicles should not be parked within 20 feet of an intersection or other crosswalk, with longer restrictions if speeds are greater than 25 mph (Blackburn et al. 2017).

Effectiveness

A curb extension and parking restriction combination should reduce pedestrian exposure by shortening crossing distance or width of the street, enhance conspicuity of pedestrians to drivers, and allow pedestrians to better view oncoming traffic. On their own, curb extensions may not improve motorist yielding but may help to improve yielding in combination with other treatments such as median islands and advance stop/yield markings and signs (Thomas et al. 2016). Curb extensions may also slow turning traffic at intersections since vehicles must navigate a narrower turning radius. Traffic may be slowed on segments if the roadway is sufficiently narrowed. One study (King 1999) found that curb extensions lowered pedestrian crash severity at four out of six locations, possibly indicating a speed lowering effect. Another benefit is that installing a curb extension is an opportunity to install an ADA-accessible curb ramp that may not have previously existed.

At present, the effects on crashes of curb extensions are not known, but at least one study has found pedestrian crash reductions on the order of 30 percent for removal of on-street parking to off-street (Toolbox of Countermeasures and Their Potential Effectiveness for Pedestrian Crashes 2013, citing Gan et al. 2005).

Systemic Application

Curb extensions and parking restrictions, along with high-visibility crosswalks, improved nighttime lighting, advance yield signs and lines, and in-street pedestrian crossing signs are all part of FHWA's STEP countermeasure "crosswalk visibility enhancements" at uncontrolled locations. Curb extensions are recommended for use on 2-4 lane roads with and without medians and for any speed (Blackburn et al. 2017).

Curb extensions and parking removal may help to address almost all crash types that occur at crossing locations, including midblock or unsignalized intersection crossing crashes involving thru vehicles, turning vehicle crashes (at intersections), pedestrian dashes and dart-outs, and multiple threat types, especially if sight lines are obscured by parking. However, curb extensions on their own, may not induce drivers to yield to pedestrians more often, and speed effects are not guaranteed, so multiple lane crossings on higher volume, higher speed roads may need additional treatments to help create safe gaps for pedestrians at unsignalized locations. Curb extensions should only be used where there is an existing parking lane and where bicycles and transit vehicles can be accommodated in the through lanes. Curb extensions also provide an opportunity for additional pedestrian landing/waiting space, curb ramps, and potentially landscaping and street furniture. Parking restrictions can also be considered at any crossing location. Oregon DOT, for example, uses parking restrictions in conjunction with curb extensions, lighting, medians, and leading pedestrian intervals (at signalized intersections) (Thomas et al. 2016).

Site Specific Lighting Improvements

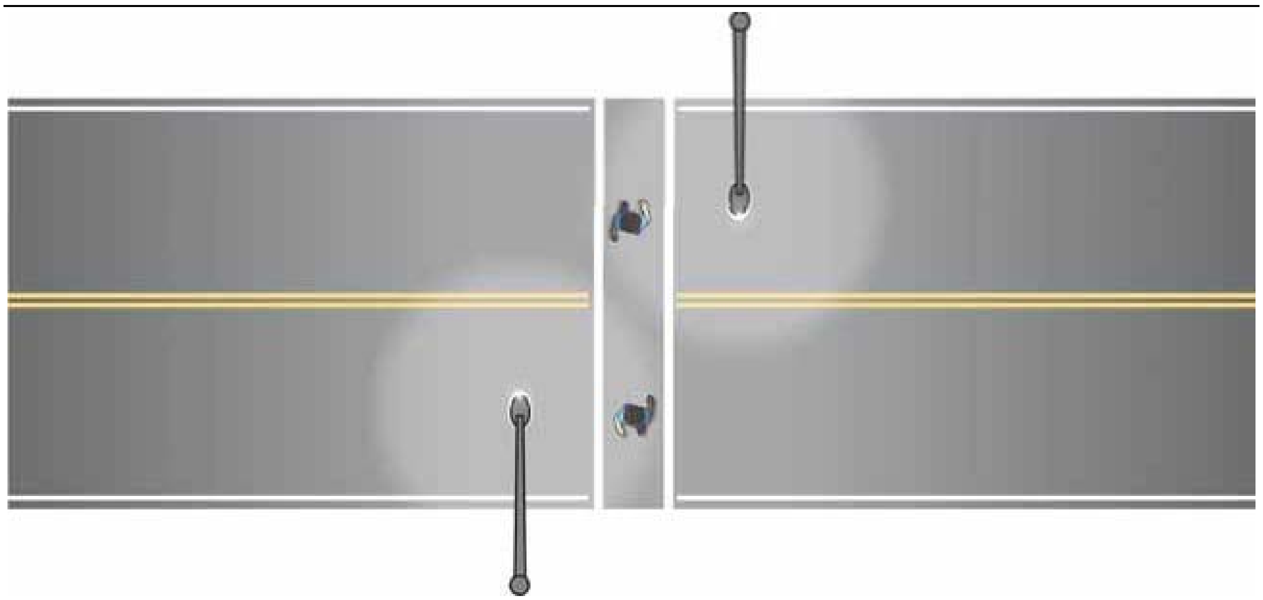

Figure A-6. Recommended lighting configurations for midblock pedestrian crossings (Source: Gibbons et al. 2008, p.13, figure 12).

Purpose and Use

Crosswalk and roadway illumination is intended to enhance the visibility of pedestrians crossing or walking along roads at night. Illumination may take the form of overhead lighting, automated detection systems with enhanced lighting, and bollard luminaries. Pedestrian crossing areas should have additional, brighter lighting on approaches to and directly at crosswalks (Zegeer 2013, Thomas et al.

2016). Approximately three-quarters of surveyed states and local agencies sometimes provide enhanced crossing illumination (Thomas et al. 2016). Nationally, nearly three-fourths (73 percent) of pedestrians killed from 2014-16 were struck under various dark conditions (FARS data, NHTSA).

Effectiveness

Illuminating crossing locations has been found to increase both motorist yielding and the distance at which motorists yield. Illumination improves pedestrian visibility and decreases the time needed for motorists to detect and react to a pedestrian. Enhanced lighting at crosswalks may also increase the percentage of pedestrians using crosswalks instead of crossing at other unmarked locations (Nambisan et al. 2009).

Providing enhanced illumination is expected to reduce the severity and number of all types of crashes at night and has been shown to have a reduction on nighttime pedestrian crashes (Chu 2006, Elvik and Vaa 2004, Kump et al. 2016, Mead et al. 2014, Wang 2017). Crash reduction for nighttime pedestrian crashes has been estimated at 42 percent for the provision of intersection illumination (Elvik and Vaa 2004). Bollard luminaries are a promising lighting treatment that has been found to improve visibility of pedestrians at midblock crosswalks and intersections and reduce the identification time needed to detect pedestrians when compared with other lighting treatments (Bullough et al. 2012, Gibbons et al. 2008).

Systemic Application

Lighting is appropriate at both intersection and midblock locations and roadways of low to high speeds. It is also appropriate for all land use types, although light spillover and energy costs may be issues to be considered. Crash-based effectiveness evidence for pedestrians comes mostly from studies of intersections.

Implementation of lighting to improve pedestrian safety should ensure that pedestrian walkways and crosswalks are well lit. Lighting should be installed on both sides of wide streets and streets in commercial districts. Uniform lighting levels should be used along corridors with enhancements at risk locations.

Lighting to enhance pedestrian environments generally could also be considered as a systematic countermeasure and may be addressed through land use and safety planning and policy development. Some states may leave lighting initiatives up to municipalities due to maintenance, energy costs, and dark skies initiatives at the local level (Thomas et al. 2016).

COUNTERMEASURES FOR UNSIGNALIZED LOCATIONS (MIDBLOCK OR INTERSECTION)

In-Roadway “Yield-to-Pedestrian” Signs (R1-6)

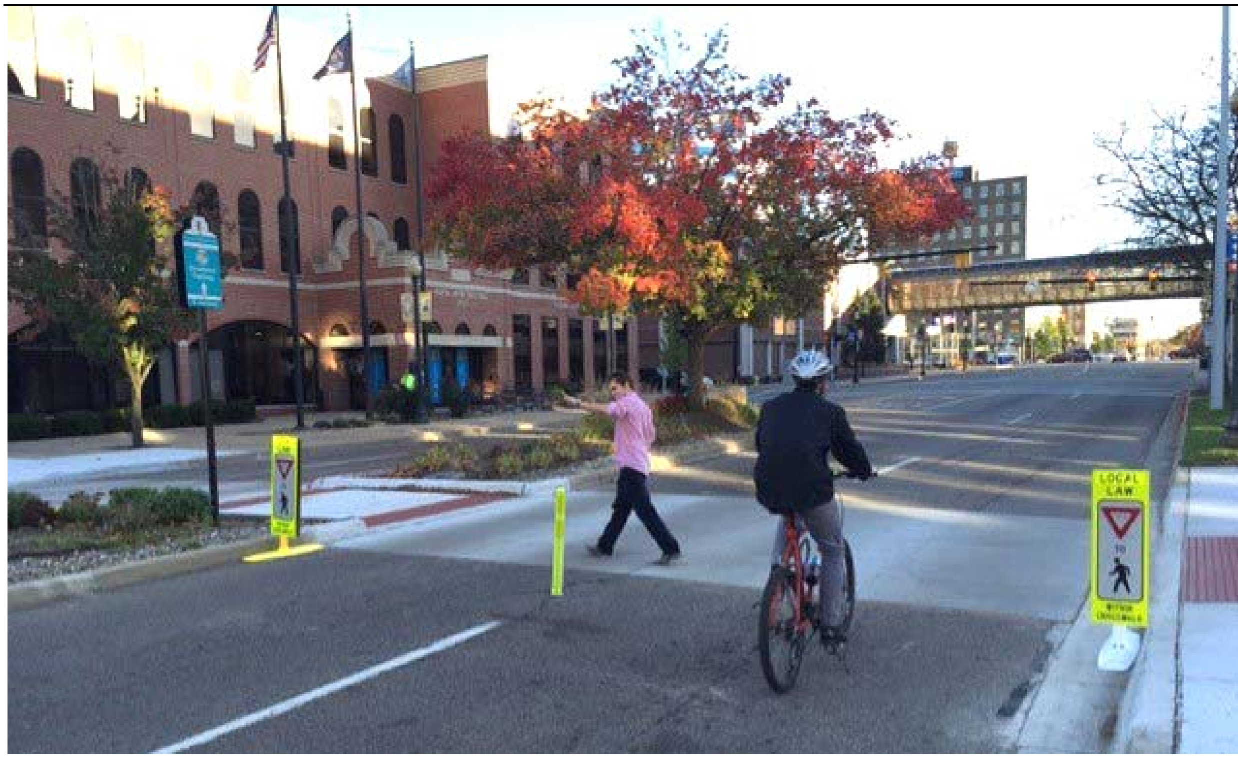

Figure A-7. In-roadway pedestrian signs and center line bollard installed at a mid-block crosswalk in the “gateway” configuration (Source: Ron Van Houten).

Purpose and Use

In-roadway “Yield to Pedestrian” (R1-6) signs are installed at uncontrolled crosswalks to encourage motorist yielding. They are often installed at unsignalized crosswalks on lower-speed, two-lane roads. These are sometimes combined with crossing islands and other treatments on larger or higher speed roads. Almost 70 percent of state and local agencies reported using this treatment on occasion (Thomas et al. 2016).

Effectiveness

In multiple behavioral studies, in-roadway “Yield to Pedestrians” signs have been shown to increase motorist yielding substantially, particularly on lower-speed, lower-volume roads.

The rates of motorist yielding have increased for both rural and urban locations, and regardless of whether the sign or multiple signs were placed in advance of or directly at the crosswalk (Ellis et al. 2007). The highest yielding rates of the standard treatment (one sign in the middle of the road) seem to peak around 75 to nearly 80 percent (Thomas et al. 2016). Studies of configurations, referred to in reports as a “gateway” configuration, show that applying the signs in between lanes on both the outside (curb edge) and inside (yellow) lane line can improve yielding and, in some cases, contribute to driver speed reductions (Van Houten 2017). Motorist yielding has been higher on roads with posted speeds of

30 mph or lower, including on some multilane installations. Sign placement may also be used to encourage yielding further in advance of the crosswalk (Van Houten and Hochmuth 2017).

Systemic Application

Before selecting this treatment for specific locations, agencies should consider the typical motorist yielding rates within the jurisdiction, and that both speeds and motorist yielding rates may be affected by speed limits, number of lanes, and the extent of 'narrowing' achieved by the signs placement. Other researchers have also documented that higher travel speeds and platooning effects may reduce motorist yielding (Bertulis and Dulaski 2014, Gårder 2004, Strong and Kumar 2006). Maintenance of the signs may also be a challenge; placement of signs on a curb mount and use of flexible attachments has helped reduce damage and keep signs in service longer (Van Houten 2017; Van Houten and Hochmuth 2017).

Advance Stop/Yield Bars and R1-5/5a signs

Figure A-8. Advance Stop or Yield bars and R1-5 signs help improve sight lines between motor vehicles and pedestrians at multi-lane crossings (Source: www.pedbikeimages.com/Toole Design Group).

Purpose and Use

Advanced stop/yield pavement markings with "Stop/Yield Here" (R1-5/5a) signs are a low-cost treatment that has been widely implemented at multi-lane, uncontrolled crosswalks. State and local agencies often use the treatment in combination with other countermeasures to help reduce the crash risk associated with motorists failing to yield the right-of-way to pedestrians. In particular, advanced stop/yield bars and R1-5/5a signs are implemented in locations where the motorist's view of a pedestrian in the crosswalk is obscured by stopped or slowing motor vehicle in an adjacent lane (Thomas et al. 2016, Zegeer et al. 2017).

Effectiveness

Crash reductions in the range of 14 to 36 percent and behavioral improvements have been associated with this treatment (Zegeer et al. 2017a,b). Multiple behavioral studies have found this treatment to be associated with increases in the distance motorists stop from an uncontrolled crosswalk. This increased stopping distance provides improved sight lines between vehicles approaching in an adjacent lane to a stopped or slowing vehicle and crossing pedestrians, and substantially decreases conflicts (Thomas et al. 2016, Zegeer et al. 2017a).

Systemic Application

Advance stop/yield markings and signs could be considered a baseline treatment for unsignalized intersections or uncontrolled, midblock locations on multilane roads to help address risks associated with multiple lanes such as “Motorist-Failed-to-Yield” and “Multiple Threat” crash types. Bus stops placed in advance of uncontrolled crosswalks are another location that could be screened for potential application, if the bus stops cannot be relocated. Other treatments should be considered as needed to address potential risks associated with speed, darkness, and motorists’ failure to yield.

Pedestrian Hybrid Beacons

Figure A-9. Pedestrian Hybrid Beacon signal installation in Tucson, AZ (Source: www.pedbikeimages.org/Sree Gajula/2009).

Purpose and Use

Pedestrian Hybrid Beacons are a device that combines features of warning beacons with stop-control for uncontrolled crosswalks. Also known as High-Intensity Activated crossWalK (HAWK) beacons, these treatments are located on mast arms over the major approaches, with two red lenses above a single yellow lens, which are dark when the beacon is not activated. Overhead signs labeled “Crosswalk: Stop on Red” accompany the beacon. Once activated, the beacon displays flashing yellow, followed by steady yellow, and then steady red with a “walk” signal for pedestrians. Because the steady red changes back to an alternating flashing red pattern during the pedestrian clearance interval, drivers can proceed if pedestrians have cleared their lanes (and no others have begun crossing). Consequently, there may be less vehicle delay than with a standard stop and go signal. However, since driver judgment is allowed during the flashing red phase, there is still a potential for conflicts and multiple-threat type events. Pedestrian Countdown Signals installed as part of the PHB package seem to enhance intuitiveness of the signals and provide added benefits to pedestrians (Road User Behaviors at Pedestrian Hybrid Beacons 2016). Marked crosswalks should also be present. The original PHB design, which places the beacon over the crosswalk, is preferred to modified designs with an offset beacon.

Effectiveness

Pedestrian Hybrid Beacons have been associated with safety improvements at uncontrolled pedestrian crossings, with increased motorist yielding and pedestrian crash reductions as the main safety benefits. Pedestrian crash reductions have been estimated in the range of 47 to 69 percent (Zegeer et al. 2017a,b; Fitzpatrick & Park 2010b).

Compared to sites with no treatment and/or with other warning type devices, motorist yielding studies report higher rates of yielding behavior - ranging from 61 to 98 percent at sites with PHBs. PHBs' effect on increasing motorist yielding seems to hold true for wide crossings, roads with higher speed limits (40 to 45 mph), and high-volume roads (Road User Behaviors at Pedestrian Hybrid Beacons 2016, Fitzpatrick et al. 2006). In cities where PHBs are used often, driver yielding rates also appear to be higher, possibly due to familiarity with the treatment (Fitzpatrick et al. 2014), although other causes cannot be ruled out.

Systemic Application

PEDSAFE recommends PHBs for unsignalized intersections and midblock crosswalks on both low and high speed (defined as greater than 45 mph) roadways to address pedestrian needs for a gap to cross and/or lack of motorist yielding.

Part of the screening process for systemic application might include whether or not the pedestrian volume or other warrant conditions are met (such as older or younger populations in the area served or expected demand); however, engineers may want to consider some of these factors during field investigations if not all relevant data types are available during initial screening.

PHBs may not be for all areas; urban cores and other locations where pedestrian volumes are high or routinely expected may be better served by regular traffic signals. It may also be important to consider driving culture, enforcement, and motorist yielding compliance rates when considering installing these, especially on higher speed roadways.

COUNTERMEASURES FOR SIGNALIZED INTERSECTIONS

Leading Pedestrian Interval

Figure A-10. LPIs to reduce conflicts between turning traffic and pedestrians at a signalized intersection in La Mesa, CA (Source: www.pedbikeimages.org/Dan Burden).

Purpose and Use

Leading Pedestrian Intervals (LPIs), also known as Pedestrian Head Start or a Delayed Vehicle Green, gives pedestrians at signalized intersections a few seconds head start (typically three to seven seconds per PEDSAFE) to cross before parallel-path traffic receives the green signal. This is intended to allow pedestrians to establish presence in the crosswalk, make pedestrians more visible to turning vehicles, and thus increase motorist yielding (Mead et al. 2014, Thomas et al. 2016). LPIs are used by about two-thirds of states and local agencies, primarily on a case-by-case basis, but typically for intersections with heavy turning volumes and high pedestrian volumes, or other identified pedestrian safety improvement locations (Thomas et al. 2016). However, at least one state uses LPIs at locations where motorists are turning "aggressively" and pedestrian volumes are not high enough to command the right-of-way. An audible pedestrian signal alerts visually impaired pedestrians as to when they have the walk indication.

Effectiveness

LPIs have been found to reduce pedestrian conflicts with turning vehicles. Several crash-based studies have also found pedestrian crash reductions to be associated with the treatment.

LPIs are considered to be an effective countermeasure for reducing left and right-turn-related conflicts and pedestrians ceding right-of-way to turning vehicles, particularly in urban areas (Hua et al. 2009, Van Houten et al. 2000). However, at intersections where right turn volumes are very high, or drivers are turning aggressively, especially outside of urban cores or areas where pedestrians may be less expected, restrictions on RTOR might be needed to supplement LPIs in order to enable pedestrians to leave the curb and capture the crosswalk during the leading interval (Hubbard et al. 2008).

At urban, high pedestrian volume sites where LPIs have been studied, LPIs have been deemed to reduce pedestrian crash rates and crash severity (King 1999; Brunson et al. 2017; Fayish and Gross 2010; ITE 2004).

Systemic Application

For systemic applications, if crash / crash type data are lacking, observations of pedestrian crossings and percentages of crossings compromised by motorists failing to yield right-of-way to pedestrians could serve as a potential surrogate measure of risk. As mention, right turn on red restrictions may be needed as a companion measure in some traffic conditions. Lighting enhancements and other measures such as high visibility crosswalk markings could also be considered.

Extending/Longer Pedestrian Phase

Figure A-11. Pedestrians crossing on the "Walk" signal In Walnut Creek, CA (Source: www.pedbikeimages.com/Dan Burden/2006).

Purpose and Use

Extending the pedestrian walk phase is a method of adjusting signal timing so that pedestrians have more time to cross at a signalized crossing. However, walk time must be balanced with pedestrian and motorist (including transit and trucks) wait times with respect to overall cycle length (Van Houten et al. 2007). In general, pedestrian level of service (LOS) is improved through shorter overall cycle lengths (wait time) but longer pedestrian crossing times. Some agencies also use PUFFIN pedestrian detection technologies to extend pedestrian walk phases when pedestrians have not cleared the intersection.

Effectiveness

Implementing a longer phase or extending the “walk” phase using pedestrian detection have not been studied extensively, but the research suggests that reducing the amount of time that pedestrians must wait, and giving them additional time to cross, may reduce crashes and may improve pedestrian compliance.

A longer pedestrian phase was estimated in one study to reduce the pedestrian crash rate in a study of 244 NYC intersections where pedestrian crossing time was increased by increasing the overall cycle length; both large main roads and side streets were given more green time, which included more time for pedestrians to cross both streets (Chen et al. 2014). The average pedestrian crash rate fell by 50 percent at the 244 intersections where pedestrian crossing time was increased and decreased by only 29 percent at the control intersections.

Systemic Application

Signals should allow adequate crossing time for pedestrians to complete their crossing. Current guidance recommends a crossing and clearance interval based upon a maximum walking speed of around 3.5 ft/s, or a slower speed (typically 3.0 ft/s) in areas with high elderly or younger pedestrians (Zegeer 2013; Gates et al. 2016). If pedestrians are frequently stranded in the crosswalk, there may be insufficient crossing time. Observations may be needed to determine if clearance intervals are insufficient or if pedestrian crossings are being compromised for reasons such as high volumes of pedestrians, slower walking speeds, or turning vehicles not yielding right-of-way to crossing pedestrians resulting in pedestrian delay.

When implementing a longer pedestrian phase, care must be taken to balance the wait times for pedestrians and motorists, so as not to inadvertently reduce compliance by either mode. Pedestrian signal compliance could, for example, be high in the types of NYC locations where the treatment was implemented, even with long overall wait times, because the large main roads with high traffic volumes may reduce pedestrians’ temptation to violate the signal. These behavioral factors (pedestrian compliance), and others should be considered in screening and further diagnosis of locations where risks related to pedestrian volumes, crossing distance and crossing time needs may suggest consideration of this treatment. Additional diagnosis of issues and traffic characteristics is essential.

Restricted Left-Turns (Fully Protected Pedestrian Walk Phase)

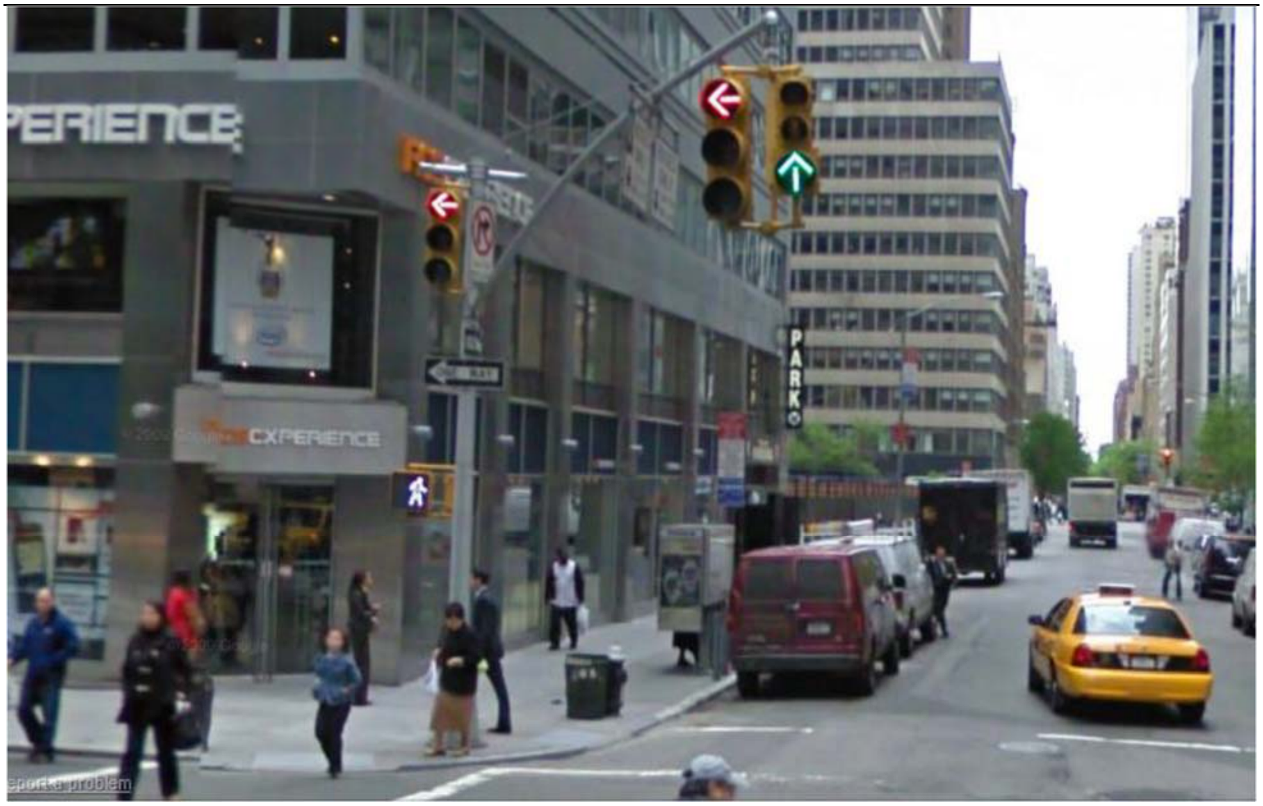

Figure A-12. Pedestrians crossing at an intersection with restricted left-turn phasing in New York, NY (Source: Chen et al. 2014).

Purpose and Use

Fully protected/restricted left-turn phases only permit left-turning vehicles to turn while a green arrow is displayed. Typically, an exclusive left-turn lane is provided with this phasing. The FHWA Traffic Signal Timing Manual recognizes this protected left-turn phasing as the safest left-turn operation, although notes that it may increase overall intersection delay (Koonce 2017). Studies of permissive phasing and flashing yellow arrows recommend protected left phasing when pedestrians are present (Hurwitz and Monsere 2013, Steyn et al. 2013).

Effectiveness

The implementation of a protected left-turn phase decreases motor-vehicle angle crashes at signalized intersections and reduces pedestrian crashes. Decreases in crashes come primarily from a reduction in crashes with left-turning vehicles (FHWA 2013, Harkey 2008, De Pauw et al. 2015).

Restricted left turn and fully protected pedestrian phasing also appear to reduce pedestrian crashes at intersections (Chen et al. 2014; Strauss et al. 2014).

Systemic Application

Protected left-turn phasing addresses the risk of conflict between pedestrians and motor vehicles, specifically parallel-path left-turning vehicles at signalized locations. Implementation of a protected left-turn phase would be appropriate at signalized intersections with exclusive left turn lanes and high turn volumes and conflicts with pedestrians. If these conditions are not present, the implementation would include installing a left turn arrow signal and exclusive left turn lanes (which also helps to decrease rear-end motor vehicle crash potential).

This treatment may require longer cycle lengths and impact signal system coordination, which can be addressed through performing an intersection capacity analysis. Less restrictive measures, such as time-of-day left turn restrictions or leading pedestrian intervals, may be an option for locations lacking separate turn lanes or lower but still impactful turning volumes.