Guidebook on Identification of High Pedestrian Crash Locations

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Research, Development, and Technology
Turner-Fairbank Highway Research Center
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Pedestrian and Bicycle Safety

FOREWORD

The overall goal of the Federal Highway Administration's Pedestrian and Bicycle Safety Research Program is to improve safety and mobility for pedestrians and bicyclists. The program strives to make it safer and easier for pedestrians, bicyclists, and drivers to share roadways through the development of safer crosswalks, sidewalks, and pedestrian technologies as well as through the expansion of educational and safety programs.

This report documents a five-step, data-driven process to identify high pedestrian crash locations and to anticipate the locations where pedestrians are most at risk. The output of applying the process is a prioritized list of potential locations on the roadway system where safety countermeasures can have the greatest impact. The research that led to this guidebook is documented in the report *Development of Guidebook on Identification of High Pedestrian Crash Locations*.(1)

This report should be of value to engineers, planners, and other community authorities who share an interest in safeguarding the lives of roadway users, especially pedestrians.

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Director, Office of Safety
Research and Development

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16. Abstract
One of the U.S. Department of Transportation's top priorities is the improvement of pedestrian and bicyclist safety. The Federal Highway Administration promotes safe, comfortable, and convenient walking for people of all ages and abilities. Part of this effort has been to encourage a data-driven approach to identifying and mitigating safety problems. An initial step in reducing the frequency of pedestrian crashes is identifying where they are occurring or where there is a concern that they are likely to occur. This guidebook documents methods and examples used to identify or prioritize high pedestrian crash sites to assist State and local agencies in identifying high pedestrian crash locations such as intersections (points), segments, facilities, and areas. The process of identifying high pedestrian crash locations results in a prioritized list of potential locations on the roadway system that could benefit from safety improvement projects.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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LIST OF ABBREVIATIONS

AADT	average annual daily traffic
APT	ActiveTrans Priority Tool
DOT	department of transportation
EB	empirical Bayes
FHWA	Federal Highway Administration
FDOT	Florida Department of Transportation
GIS	geographic information system
HCM	*Highway Capacity Manual*
HSIP	Highway Safety Improvement Program
HSM	*Highway Safety Manual*
I	Interstate
ISI	Intersection Safety Indices
MassDOT	Massachusetts Department of Transportation
NCHRP	National Cooperative Highway Research Program
RSA	road safety audit
RTM	regression to the mean
SHSP	Strategic Highway Safety Plan
SPF	safety performance function
SRTS	Safe Routes to School
VMT	vehicle miles traveled

EXECUTIVE SUMMARY

One of the U.S. Department of Transportation's top priorities is the improvement of pedestrian and bicyclist safety. The Federal Highway Administration promotes safe, comfortable, and convenient walking for people of all ages and abilities. Part of this effort has been to encourage a data-driven approach to identifying and mitigating safety problems. An initial step in reducing the frequency of pedestrian crashes is identifying where they are occurring or where there is a concern that they are likely to occur. This guidebook documents methods and examples used to identify or prioritize high pedestrian crash sites to assist State and local agencies in identifying high pedestrian crash locations such as intersections (points), segments, facilities, and areas. The process of identifying high pedestrian crash locations results in a prioritized list of potential locations on the roadway system that could benefit from safety improvement projects.

The research team contacted several cities and States to determine the criteria being used to identify and rank high pedestrian crash locations. In all cases, crash data are being used. In some cases, cities and States are considering other variables, especially when developing the list of sites for treatments. For example, Los Angeles, CA, uses a score that considers the age of the pedestrian and a health and equity index in addition to the number of injury crashes and the number of fatal crashes. Several of the cities have created unique lists for intersections, facilities, and areas, recognizing that treatment selection would be different for these element types.

Most agencies now have available the geographic coordinates of crashes, which is resulting in the ability to quickly illustrate visually where crashes are occurring. All of the interviewed agencies are using geographic information systems (GISs) to identify high crash locations. The agencies generally start with identifying high crash intersections and then group the sites into facilities and/or areas. GIS tools are used to aid in the grouping; however, several agencies noted that visually confirming the grouping is how they set the limits for their corridors and areas.

Agencies have considered surrogates, such as activity centers, walk scores, or citizens' comments, to identify locations of concerns. Pedestrian exposure data are rarely used to identify sites because of the lack of good data. The analysis period ranges between 1 and 3 yr. The agencies noted that pedestrian and bicycle crashes are different from motor crashes and require unique efforts.

The skill set needed to work with crash data includes familiarity with GISs and the ability to work with attribute tables and programming. Key lessons learned include the following:

- Analysts with the needed skill set are necessary.
- Partner agencies that share data are better informed and can develop their program more efficiently and effectively.
- Agencies with access to reliable geographic coordinates for crashes can more accurately locate their crashes.
- Agencies with strong support from others within the city can develop and implement stronger programs.

Some of the cities suggested that the list of sites and plans should be shared with the public so that residents know where the city is performing work and how those decisions were made.

Examples of approaches used and lessons learned from previous studies include the following:

- Use several methods to rank sites to ensure consensus.
- Keep in mind that not considering pedestrian exposure in some manner could significantly affect results.
- Consider other measures (e.g., walkability score) along with crash data, since crashes are rare events.
- If evaluating segments, remember that a minimum segment length is needed (suggested as being at least 0.2 mi).
- When evaluating pedestrian crashes, a longer period may be needed due to the relatively small number of reported pedestrian crashes (e.g., 5 yr rather than 3 yr).

The methods used to identify and evaluate sites with a high crash frequency have evolved, in the recent decades, in the following ways:

- The availability of geographic coordinates (latitude and longitude) for crashes has resulted in the ubiquitous use of GIS platforms for displaying the locations and density of crashes on maps.
- Certain map displays are more likely to successfully convey crash density. For example, the use of larger symbols or color-coded symbols (e.g., green–yellow–red scale) seems to be most appropriate for quickly identifying high crash locations. In most cases, showing symbols for individual crashes does not display well because the crash symbols overlap on the map.
- Map displays with zoom capability can be used to quickly identify high crash areas on a citywide scale yet still provide the option to view individual crashes at a particular intersection or street. Maps that display additional information once clicked are ideal for exploring crash patterns or attributes at a detailed level.
- Several different approaches are used to identify and display high crash locations, and often, these approaches are not well documented on the mapping application. In some cases, the mapping software application automatically determines how to group nearby crashes based on view level. In other cases, agencies predetermine how nearby crashes will be grouped and displayed in the mapping software.

When considering approaches other than crashes, recent advances in statistical techniques have provided several methods and tools that can be used to identify locations with concerns for pedestrians. These methods include safety performance functions, the *Highway Safety Manual*, and systemic analyses and provide the opportunity to allow comparisons between a city's data and national trends.[2] The growth of better statistical techniques also permits the profession to better handle regression to the mean and low sample challenges.

CHAPTER 1. INTRODUCTION AND RESOURCES

INTRODUCTION

One of the U.S. Department of Transportation's top priorities is the improvement of pedestrian and bicyclist safety. The Federal Highway Administration (FHWA) promotes safe, comfortable, and convenient walking for people of all ages and abilities. Part of this effort has been to encourage a data-driven approach to identifying and mitigating safety problems.

An initial step in reducing the frequency of pedestrian crashes is identifying where they are occurring or where there is a concern that they are likely to occur. Several approaches have been used to identify locations where a concern exists for pedestrians. Once locations with a large number of pedestrian crashes or with a safety concern for pedestrians have been identified, appropriate treatments can be selected and installed.

PURPOSE

The purpose of this guidebook is to assist communities in identifying high pedestrian crash locations. The guidebook builds on or complements materials provided in other resources, such as those discussed in the following Resources section. The locations can include points (e.g., intersections or midblock crossings), segments, facilities, and areas.

RESOURCES

FHWA and the National Cooperative Highway Research Program (NCHRP) recently sponsored several studies to aid in the identification and prioritization of sites with safety concerns for pedestrians. The materials being developed include the following:

- ***Guidebook on Identification of High Pedestrian Crash Locations*** (this document). The objective of this FHWA research is to document methods and examples used to identify or prioritize high pedestrian crash sites. The process of identifying high pedestrian crash locations results in a prioritized list of potential locations on the roadway system that could benefit from safety improvement projects. Using the information gathered as part of this research, the research team developed a best practice guidebook that can assist State and local agencies in identifying high pedestrian crash locations such as intersections (points), segments, facilities, and areas.(1,3)

- ***Systemic Pedestrian Safety Analysis Guidebook***. As part of NCHRP Project 17-73, a document is being developed to detail the process for conducting systemic safety analyses for pedestrians using analytical techniques to identify pedestrian activities (including behavior), roadway features, and other contextual risk factors, such as land use, that are associated with pedestrian crashes.(4)

Other documents that could be of value in identifying and evaluating pedestrian crash locations include the following:

- **Scalable Risk Assessment Methodology.** A current FHWA project is developing a process or conceptual framework to be used to estimate exposure at multiple geographic scales. A preliminary synthesis is available.[5]

- ***Highway Safety Manual*** **(HSM).** The HSM presents a variety of methods for quantitatively estimating crash frequency or severity at a variety of locations.[2] Volume I provides fundamental information about crashes and the roadway safety process that includes the following suggested steps for conducting a network screening: (1) establish the focus of network screening, (2) identify the network and establish reference population, (3) select network-screening performance measures, (4) select a screening method, and (5) screen and evaluate results.

- **Highway Safety Improvement Program (HSIP).** Information on the HSIP along with resources related to the HSIP are available on the FHWA website. Per the website:

  The Highway Safety Improvement Program (HSIP) is a core Federal-aid program with the purpose to achieve a significant reduction in traffic fatalities and serious injuries on all public roads, including non-State-owned roads and roads on tribal land. The HSIP requires a data-driven, strategic approach to improving highway safety on all public roads with a focus on performance.[6]

Resources for prioritizing locations after they are identified are provided in chapter 5 of this document. Once an agency has selected the locations for treatment, several resources are available to assist in countermeasure selection, including, but not limited to, the following:

- The Pedestrian Safety Guide and Countermeasure Selection System is an online system designed to assist practitioners with the selection of countermeasures. It was updated in 2013 and is available at http://www.pedbikesafe.org/pedsafe/. The online tools provide the user with a list of possible engineering, education, or enforcement treatments to improve pedestrian safety or mobility, or both, based on user input about a specific location.

- As noted on FHWA's Safety website, "Road Safety Audit (RSA) is the formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users."[7] The website also includes examples of pedestrian road safety audits (RSAs). Pedestrian RSAs should include more details on pedestrian safety issues than traditional RSAs, and available prompt lists help to focus the audit team on key pedestrian safety issues. Audit guidelines and prompt lists are available in *Pedestrian Road Safety Audit Guidelines and Prompt Lists*.[8]

- *Non-Motorized User Safety: A Manual for Local Rural Road Owners* presents a process that can be used to evaluate safety of nonmotorized users on noninterstate, local, and rural roads maintained and operated by local agencies.[9] The document includes a list of resources for addressing nonmotorized safety concerns and information on typical engineering countermeasures that may be used to address nonmotorized safety issues on rural roads.

- A State's Strategic Highway Safety Plan (SHSP) can identify the State's key safety needs along with strategies and countermeasures. Additional information on SHSPs is available at https://safety.fhwa.dot.gov/shsp/.

PROCESS TO IDENTIFY HIGH PEDESTRIAN CRASH LOCATIONS

Locations with nonmotorized user concerns are not always identified using a typical network-screening process. The greater number of motor vehicle crashes, as compared to pedestrian and bicycle crashes, may mask locations with specific pedestrian concerns. Another concern is that, because an injured pedestrian or bicyclist may seek emergency medical care as quickly as possible, some of these crashes may not be accurately reported (or even reported at all).

The research team contacted several agencies to gather information on how they are identifying high pedestrian crash locations. This information coupled with findings from a review of the literature generated the process shown in figure 1. Following are the steps along with the chapters in which they will be discussed:

1. Select approach (chapter 2).
2. Gather data (chapter 3).
3. Plan assessment (chapter 4).
4. Conduct assessment (chapter 5).
5. Prioritize locations (chapter 6).

In addition to the glossary, this guidebook concludes with supporting materials grouped within the following sections in chapter 7:

- **Supplemental Material A—Example of Safety Index.** This section provides additional details regarding the index the City of Los Angeles uses.

- **Supplemental Material B—Screening Method Examples.** This section presents examples of several screening methods.

- **Supplemental Material C—Online Maps.** This section presents several examples of online maps being produced by numerous city and State transportation departments and other groups to show pedestrian crash data.

- **Supplemental Material D—Advice From Previous Studies.** This section addresses several previous studies that have documented analyses to identify high crash locations along with different approaches to identify and rank locations.

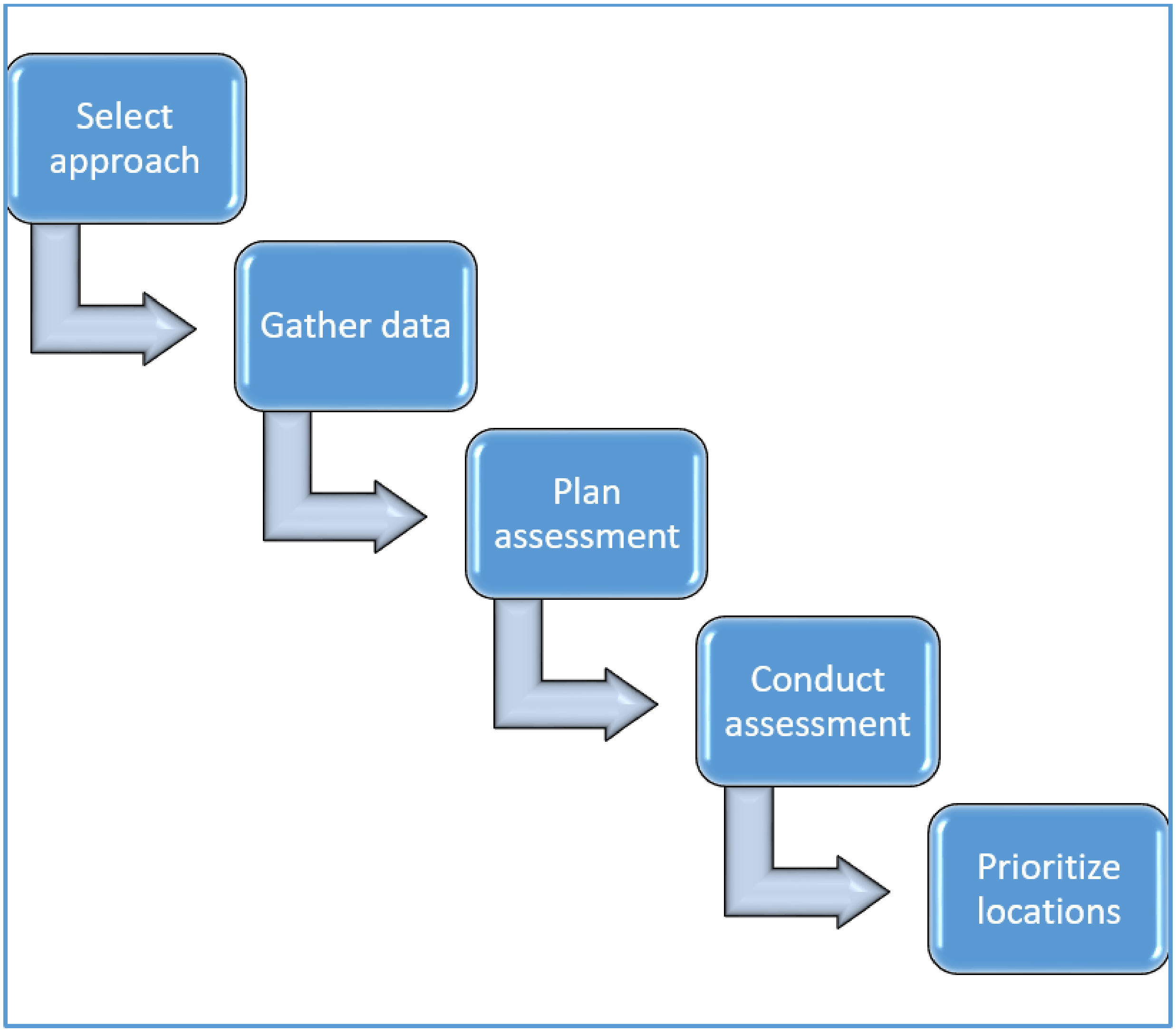

Figure 1. Graphic. Steps to identify high pedestrian crash locations.

CHAPTER 2. SELECT APPROACH

OVERVIEW

The identification of locations that cause concern for pedestrian safety can be accomplished using any of the following approaches, either alone or in combination:

- A **traditional approach** (also known as a "reactive approach") is generally based on an observed or historical crash pattern that suggests a problem exists. These locations have historically been called "hot spots" or "black spots." Existing crash data along with roadway data and perhaps volume data are used to identify the locations. In some cases, an index may be developed to integrate other conditions, such as lack of sidewalks, into the process of identifying these locations of concern.

- A **proactive approach** uses models—such as safety performance functions (SPFs)—to determine the expected number of crashes (or crash frequency) for locations within a set region. These estimates can be used to prioritize the sites that may potentially need treatments. The approach is called proactive because it addresses a potential risk rather than an experienced problem. Treatments installed at locations identified using risk factors or known land uses are additional illustrations of proactive approaches, for example, installing a pedestrian crossing treatment when a bus stop is added to a five-lane arterial across the street from a large apartment complex. SPFs that could be used within a proactive approach are available in the HSM.(2) Another example of a proactive approach that is gaining in use is the **systemic approach**. The FHWA website on the systemic approach notes:

  Rather than managing risk at certain locations, a systemic approach takes a broader view and evaluates risk across an entire roadway system. A system-based approach acknowledges crashes alone are not always sufficient to determine what countermeasures to implement, particularly on low-volume local and rural roadways where crash densities are lower, and in many urban areas where there are conflicts between vehicles and vulnerable road users (pedestrians, bicyclists, and motorcyclists).(10)

  A systemic highway safety improvement uses a particular countermeasure or set of countermeasures implemented on all roadways or roadway sections where a crash type or risk factor is linked with a particular roadway or traffic element. Locations being treated are not based on the frequency or rate of crashes at a location, but on an analysis of which roadways or roadway sections have the given risk factor or crash type that may be mitigated by the improvement.

- A **combination approach** uses characteristics of both a traditional approach and a proactive approach, for example, a composite score that includes crash frequency along with predictions from a safety performance function.

APPROACHES CURRENTLY USED TO IDENTIFY PROBLEM LOCATIONS

NCHRP Synthesis 486, *State Practices for Local Road Safety*, documented the processes being used for identifying locations with local road safety concerns.[(11)] The synthesis considered all crash types and was not limited to pedestrians. The objective of the synthesis was to document State programs and practices that address local road safety. The most frequent response from State departments of transportation (DOTs) regarding problem identification was a combination of both traditional (reactive) and proactive methods. The survey indicated the following as the most frequently applied criterion for prioritizing local safety projects:

- Cost–benefit analyses (28 States).
- Crash history (26 States).
- Available funding (25 States).

The conducted survey found that fatal and serious injury crash numbers and crash rates were the major performance measures used.[(11)]

THIS DOCUMENT

This document focuses on the traditional (reactive) approach to the identification of locations of concern. The *Systemic Pedestrian Safety Analysis*, created as part of NCHRP Project 17-73, provides information on conducting a systemic analysis for pedestrians using a proactive approach.[(4)]

CHAPTER 3. GATHER DATA

OVERVIEW

Roadway safety has been characterized as nominal or substantive. Nominal safety is based on design standards, while substantive safety is based on roadway safety performance. A roadway may be thought to be nominally safe because it meets minimum design criteria; however, it could have higher-than-expected crash experience. The reverse could also be true, where a roadway is not meeting minimum design criteria and yet has a high level of substantive safety. Substantive safety requires an evidence-based approach to estimate the expected safety of a roadway through data and analysis rather than focusing solely on standards. Making decisions with an evidence-based approach underscores the need for quality data and data systems.

DATA

Safety data can be grouped into three broad categories, as shown in figure 2. The following are two types of data primarily needed for a traditional (reactive) safety study:

- **Crash data**, including severity, crash type, characteristics of interest (e.g., age of pedestrian or light condition), and contributing factors. The location of the crash, preferably as latitude and longitude coordinates, is also needed.

- **Roadway characteristics**, such as number of lanes or traffic control devices present.

For a pedestrian safety study, the desired **exposure data** that can improve the process could include the following:

- Vehicle counts.
- Pedestrian counts.
- Turning and crossing movement counts for specific locations.

Crash Data

Generally, crash data are available from State DOTs, State highway patrols, another public agency, or even universities, varying from State to State. Typically, the data are coded and stored in a relational database structure, with separate tables for the crash, unit, and person information. These tables are linked through identifier fields in each table. Before storing and making the final version of the data available for use, DOTs conduct a quality control check that addresses inconsistencies or omissions, as submitted by the investigating law enforcement agency; assigns final coordinates to crashes; and supplements or enhances the crash report based on a review of the crash narrative. Crash data are stored in a centralized database after data have been collected by law enforcement and first responders and submitted to the State.

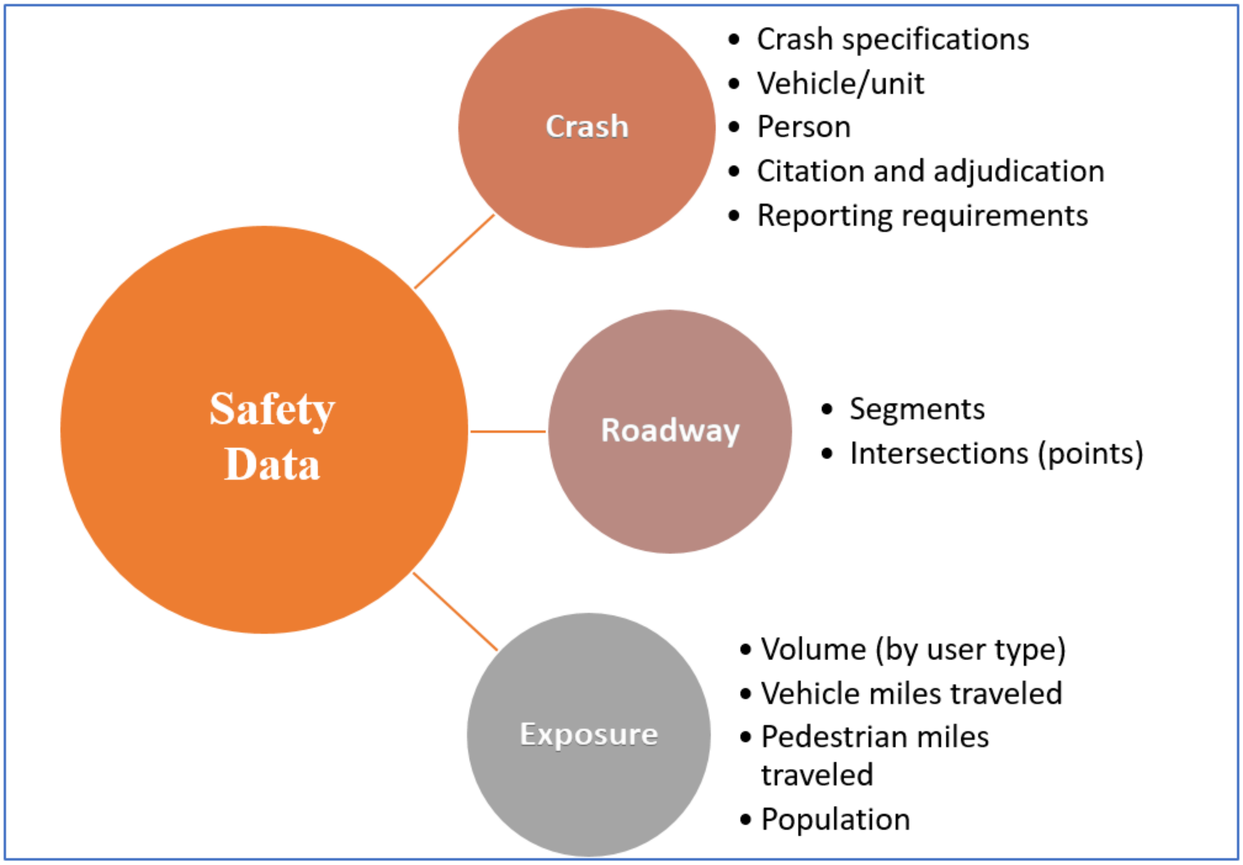

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Figure 2. Graphic. Types of safety data.

Data Dictionaries

Data dictionaries for the crash data provide a description of each data variable in the crash database. The database typically consists of the following three levels of data:

- **Crash-level datasets** contain information about the entire crash, such as crash location, crash date, total fatalities in the crash, and light level.
- **Vehicle- or unit-level datasets** contain information about each vehicle (or unit) in the crash, such as vehicle type and harmful events. Pedestrians and bicyclists (pedalcyclists) are included as nonmotorized vehicles.
- **Person-level datasets** contain information about all people in crashes, such as age and belt usage. The dataset includes one record for each person involved in the crash.

Improvements in Data Collection

The data dictionary for the crash database can provide details needed to interpret the crash data.

Electronic crash reporting is increasingly being used in various States as the preferred method of collecting data at crash scenes. This approach allows for the integration of in-car mapping technologies, which avoid the need to postprocess the location of the crash by later adding a Global Positioning System reading, street address, or distance from an intersection. Instead, in-car mapping allows an officer to click on the crash location on a digital map and have all the necessary location data automatically entered into the crash report.

Additional information on crash data collections is included in the *Highway Safety Improvement Program (HSIP) Manual*.(12)

Roadway Data

The roadway characteristics data may be available from a variety of sources, including electronic databases of roadway features and traffic characteristics, aerial photographs and street views, video logs, and traffic control device inventories. The roadway characteristics could also be collected as part of a field review of the road system at a higher cost. Roadway characteristics might also be collected in a virtual environment with field confirmation, as appropriate.

Many State DOTs and some cities use linear referencing, allowing roadway attributes, such as shoulders or speed limit, to be stored individually and to be defined by the route, along with the start and end points. Crashes can also be referenced in the same system.

Exposure Data

In the safety analysis context, exposure is a measure of the number of potential opportunities for a crash to occur. For motor vehicles, exposure is typically quantified using vehicle miles traveled (VMT), which is the product of an average annual daily traffic (AADT) count and the road segment length for which the count is applicable. For pedestrians, facility-specific exposure has been quantified in many ways, including the following:

- Average pedestrian volume.
- Sum of entering flows (pedestrian and motor vehicle) at intersection.
- Product of pedestrian volume and motor vehicle volume.
- Estimated number of street crossings.
- Estimated total travel distance, in person-miles of travel.
- Estimated total travel time, in person-hours of travel.

Exposure is most often used as a normalization factor (i.e., denominator) to equalize for differences in the quantity of potential crash events in different road environments. Depending on the type of safety analysis, it may or may not be desirable to include exposure. When the number of expected or observed crashes is normalized by exposure, the result is what many consider the individual risk to a pedestrian. This quantity may be useful in some comparisons or analyses. However, in other analyses, the total number of pedestrian crashes or crash frequency is better suited.

Data availability may determine the extent to which exposure can be included in the safety analysis. For example, if exposure data are not readily available, then crash frequency (e.g., number of crashes within a segment for a year) rather than crash rate (e.g., crashes per mile per year) would be the performance measure used. Volume or count data are the primary input data for both motor vehicle and pedestrian exposure, and some exposure measures require supplemental data. For example, segment length is needed for the miles traveled measure, and average travel time or distance is required for person-hours of travel.

Motor vehicle traffic volume data are available for major roads and streets from State DOTs, typically in the form of AADT. Increasingly, State DOTs are also working with city and regional planning staff to routinely collect motor vehicle traffic volumes on lower functional class roads and streets.

Pedestrian count data are less commonly available than motor vehicle count data, but increasingly, many local, regional, and State agencies are routinely collecting pedestrian count data at selected key locations. In some cases, models are being used to estimate pedestrian counts everywhere in a city or region. There are several key resources, including the following, that are intended to promote the widespread collection and estimation of pedestrian count data and, thus, should be consulted if necessary:

- Chapter 4, "Traffic Monitoring for Non-Motorized Traffic" of FHWA's *Traffic Monitoring Guide*, available at https://www.fhwa.dot.gov/policyinformation/tmguide/.(13)

- NCHRP Report 797, *Guidebook on Pedestrian and Bicycle Volume Data Collection*: http://www.trb.org/Main/Blurbs/171973.aspx.(14)

- FHWA-HEP-17-012, *FHWA Bicycle-Pedestrian Count Technology Pilot Project: Summary Report*, available at: https://www.fhwa.dot.gov/environment /bicycle_pedestrian/countpilot/summary_report/.(15)

- NCHRP Report 770, *Estimating Bicycling and Walking for Planning and Project Development: A Guidebook:* http://www.trb.org/Publications/Blurbs/171138.aspx.(16)

- FHWA-SA-17-041, *Synthesis of Methods for Estimating Pedestrian and Bicyclist Exposure to Risk at Areawide Levels and on Specific Transportation Facilities*.(5)

SUPPLEMENTAL DATA SOURCES

Supplemental data that some agencies would like to use in their safety evaluation process include the following:

- Citizens' observations of locations needing attention, either due to maintenance needs or because of a safety concern.

- Law enforcement observations.

- Trauma center data.

- Land use/development plans.

In some cases, a location for consideration of improvements could be identified through the knowledge that a particular development type is being built or based on observations made by local law enforcement or from citizens' comments or complaints. School districts may contact the city requesting assistance with a crossing near their school. Cities with traffic-calming programs may also identify locations of concern for pedestrians based on evaluations of drivers' operating speeds. A sidewalk and curb ramp inventory is another city effort that could identify locations of concerns. Although these techniques are not dependent on crashes, they are examples of identifying locations with the potential for pedestrian crashes and can provide an earlier indication of locations where additional evaluation is needed.

ANALYSIS PERIOD

Number of Years in Analysis

Crashes are random events and naturally fluctuate over time at a given location. The fluctuation over time can make it difficult to determine whether a location has a true safety concern or if it is part of a natural fluctuation. The statistical situation known as regression to the mean (RTM) describes a condition in which crash rates are artificially high during a given period and would be reduced in a later period even without an improvement to the location. Several proactive methods are available to address the RTM concern, including using safety performance functions or a systemic safety analysis.

When using a traditional (reactive) approach, having several years of crash data can also help agencies minimize the likelihood of selecting sites that have a high crash frequency due to being on the higher side of a natural fluctuation. A tradeoff with using a large number of years is that roadway conditions, land use, and/or travel patterns could have changed. In a rapidly developing city, only a few years of data may exist for a site with a specific set of roadway, roadside, or traffic control device characteristics. Having quality geometric and traffic control device data can help to associate crash trends with particular conditions.

The report *How to Develop a Pedestrian Safety Action Plan* states: "When identifying and prioritizing high crash locations, 3 to 5 years of computerized crash data should be used. For prioritizing corridors or other targeted areas, 1 to 3 years of pedestrian data are acceptable."[(17)]

Number of Years to Repeat Analysis

The frequency that a pedestrian safety analysis is updated is typically between 1 and 3 yr. For communities with mature roadway and pedestrian facilities and without the implementation of a major safety treatment program, the crash data trends may only have minimal changes from year to year, resulting in a reasonable analysis update of every 3 yr. For communities with changes in growth or that are implementing a major safety program, updating the analysis annually can help to illustrate the effects of growth or the safety program.

CHAPTER 4. PLAN ASSESSMENT

OVERVIEW

Just as a skilled carpenter measures twice and cuts once, a safety analyst should plan ahead and make key analysis decisions in order to get the most out of the available data. Time spent planning can yield more useful results. A motivation for the analysis could be to identify problems that the community wants to address, for example, improving safety for older or younger pedestrians. For communities with Vision Zero programs, identifying sites for treatment is critical to achieve the goal of eliminating fatal crashes. The planning of the assessment includes the following three substeps as shown in figure 3:

1. Select scale.
2. Select performance measures.
3. Select screening method.

An initial step is to determine the type of the network elements being studied or the scale of the network. This decision could affect how the crash and roadway data are gathered and processed along with the type of performance measure(s) used to identify sites. The preference is to select a performance measure that does not have a known bias or that can minimize known biases. After the performance measure is selected, the type of screening method needs to be identified.

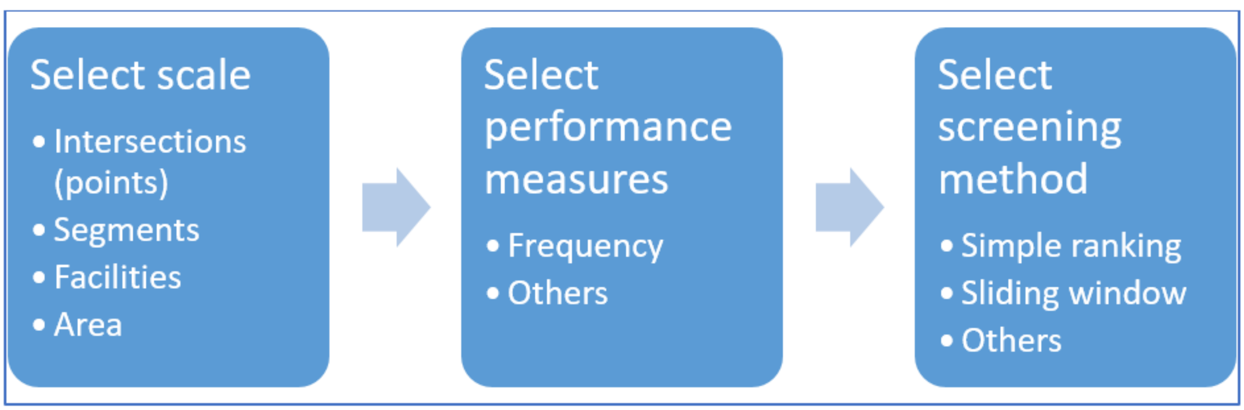

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Figure 3. Graphic. Substeps within plan-assessment step.

SELECT SCALE

The scale of the network being studied along with the type of site(s) for a safety assessment can vary. The scale and type may be related to the anticipated treatment. For example, an advertising campaign regarding driving under the influence may want to target the entire community if the message is being distributed by radio or target select intersections if the message is being distributed using a print medium.

The network element scale may start with the smallest increment, typically an intersection or a marked crosswalk (point), and then be grouped into larger scales to form a facility or an area. In general, a network element is typically one of the following:

- Point (or intersection).
- Segment.
- Facility.
- Area.
- System.

Figure 4 shows examples of the network elements. The following sections provide additional descriptions.

Points (Intersections)

Points are places along a facility where (1) conflicting traffic streams cross, merge, or diverge; (2) a single traffic stream is regulated by a traffic control device; or (3) there is a significant change in the segment capacity (e.g., lane drop, lane addition).

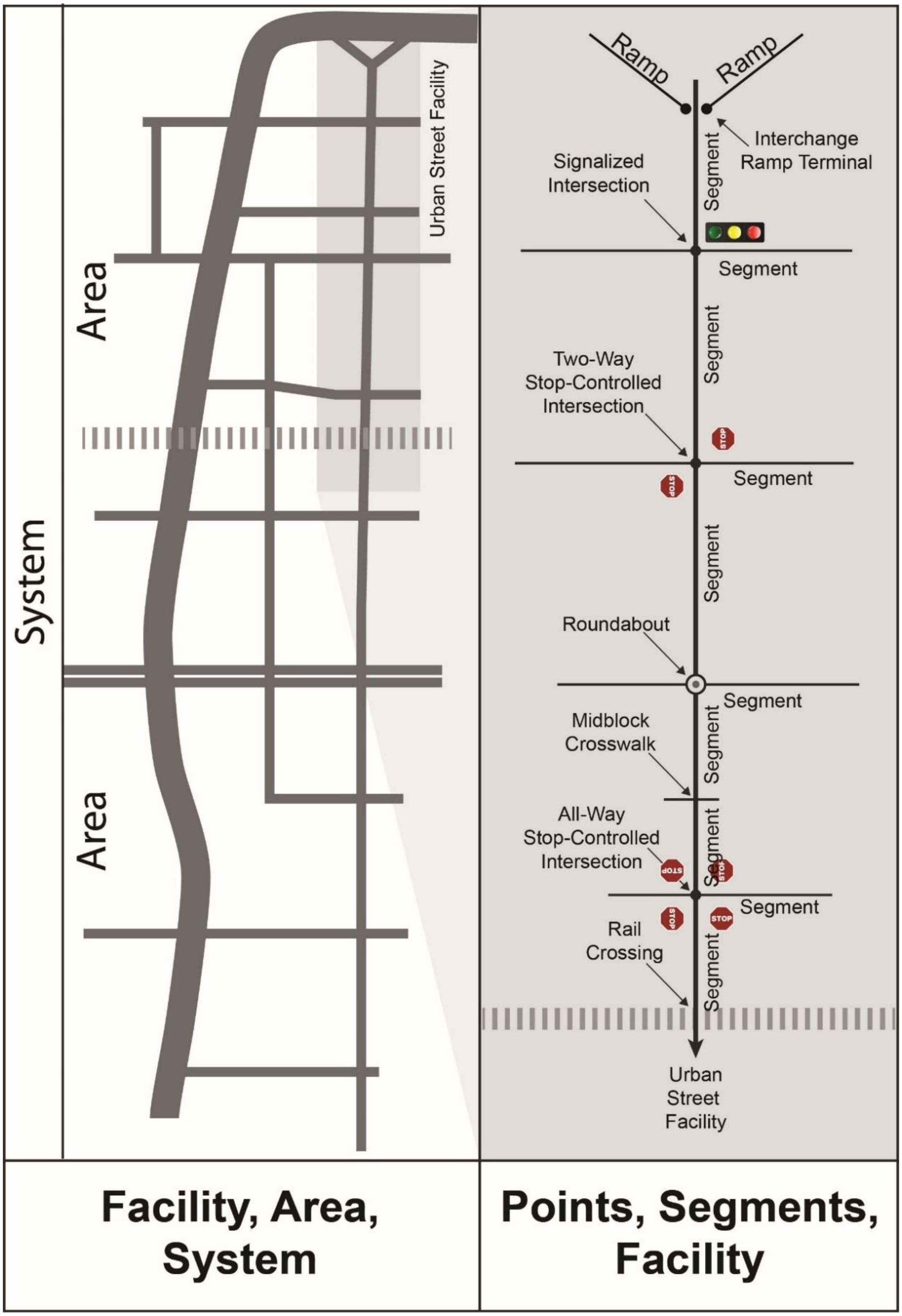
Points (more commonly called intersections) can be subdivided as the following:

- Surface street intersections.
- Signalized intersections.
- Two-way stop-controlled intersections.
- All-way stop-controlled intersections.
- Roundabouts.
- Ramp terminals.
- Rail crossings.
- Midblock crosswalks.

Depending on the variables included in an agency’s database, a crash may be coded as being “intersection related” or “not intersection related.” Such a variable could help determine if the crash should be associated with the characteristics of an intersection or of a segment.

Segments

A segment is the length of roadway between two points with similar geometric, operational, and vehicular characteristics. Traffic volumes and physical characteristics generally remain the same over the length of a segment, although small variations may occur (e.g., changes in traffic volumes on a segment resulting from a low-volume driveway). Segments are generally considered to be the roadway between intersections and are homogeneous throughout the segment; otherwise, the distance would be subdivided. A homogeneous segment includes consistent design characteristics (i.e., cross section) and uniform traffic volumes. Homogeneous segments allow for consistent application of the evaluation and similar countermeasures to be selected.



Source: Inspired by the 2016 *Highway Capacity Manual* Volume I, Exhibit 2-1, but developed to reflect system elements of interest to this document.

Figure 4. Graphic. Examples of system elements.[(18)]

There is no clear definition of road segment length that should be considered as a site within a safety analysis. Segment length does not need to be consistent for the entire dataset; however, the analysis should account for segment length. Using very short segments could result in incorrect assumptions about whether any crashes occurred on the segment or the total crash frequency on the segment, or could result in inflated crash frequency per mile. The segmentation efforts may need additional checks along with flexibility to appropriately consider potentially imprecise location information.

Facilities

Facilities represent multiple points (intersections) and segments. Per the 2016 *Highway Capacity Manual* (HCM), facilities are lengths of roadways, bicycle paths, and pedestrian walkways composed of a connected series of points and segments.[18] The HCM defines freeway facilities, multilane highway facilities, two-lane highway facilities, urban street facilities, and pedestrian and bicycle facilities.

Area

Per the HCM, areas consist of an interconnected set of transportation facilities serving movements within a specified geographic space, as well as movements to and from adjoining areas.[18] The facilities within an area do not need to be parallel to each other.

Because of the limited number of pedestrian crashes at a specific location, areas could be used to identify a section of a community where improvements may be needed. Another advantage to identifying an area rather than unique points or segments is that the appropriate correction for a pedestrian concern, such as increased enforcement or education, may be more appropriate for an area with a particular land use rather than just a single intersection.

System

Per the HCM, systems are composed of all the transportation facilities and modes within a particular region.[18]

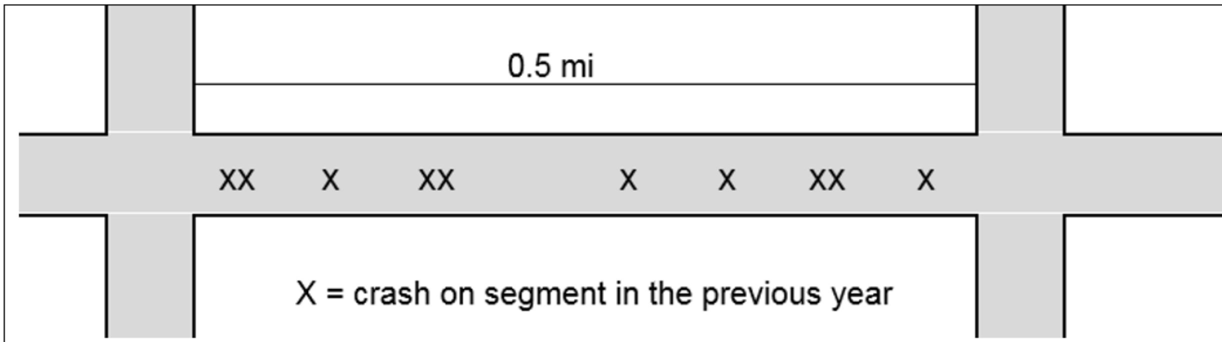
SELECT PERFORMANCE MEASURES

The HSM discusses 13 problem-identification methods, along with each method’s data needs, strengths, and weaknesses.[2] The HSM notes that agencies should use the performance measure that best suits their purpose and/or available data. Interviews with several agencies revealed that, if they were not pursuing a systemic approach, most agencies used pedestrian crash frequency as their measure, with a few combining other performance measures with crash frequency. This guidebook focuses on the most common methods.

Several performance measures are available, and using more than one may provide more certainty in site selection, especially when different performance measures result in the same sites having similar ranks. Measures that are commonly used in pedestrian safety analyses include the following:

- Crash frequency—count.
- Crash frequency—density.
- Crash rate.
- Crash type.
- Crash severity.
- Safety index.

The following sections provide additional details about each of the above performance measures. Figure 5 shows an example of crash frequency and crash rate calculations for a segment.



For segment:

- Crash frequency—count = 10 crashes
- Crash frequency—density = 10 crashes/0.5 mi=20 crashes/mi
- Crash rate (vehicle based) = (10 crashes×100,000,000)/[(10,000 veh/day)×(365 days)×(0.5 mi)]=548 crashes/100 million vehicle miles of travel
- Crash rate (vehicle and pedestrian based) = unknown due to lack of pedestrian volume along segment

Figure 5. Graphic. Examples of performance measures for crashes on a segment.

Crash Frequency—Count

Crash frequency is the total count (or number) of crashes for a given network element (e.g., segment, point/intersection) for a specified time period. Supplemental data, such as exposure or roadway geometry, are not required.

Using only the crash frequency could introduce a bias toward locations with higher volumes, and using volume to generate a crash rate could help to address this bias. The lack of reliable pedestrian volume data, however, limits the ability to calculate crash rates.

Sites are ranked based on the total crash frequency or crash frequency for a particular crash severity or crash type during a given time period. The site with the highest crash frequency is ranked first.

Crash Frequency—Density

Density methods identify high concentration of pedestrian crashes, calculated as pedestrian crash frequency per unit area (e.g., square miles) or unit length (e.g., mile). Density could reflect the selected segment length, resulting in pedestrian crashes per mile as the performance measure, or density could reflect an area. The size of the area could be predetermined and reflect established U.S. Census geographic areas of block, block group, or tract or reflect established geographic regions such as city, county, or metropolitan statistical area. The size of the area could also vary. Several examples on calculating density are available (see the following recent Florida DOT (FDOT) report, *Comprehensive Study to Reduce Pedestrian Crashes in Florida*, for examples), including the simple density method, which uses a circular search area.(19)

Crash Rate

Crash rate is the number of crashes per unit of exposure. It can be expressed as the ratio of the crash frequency to exposure (e.g., traffic volume at a location or population for an area). The crash rate normalizes the crash frequency based on exposure. Crash rate is intuitive, and if traffic volume is known, it can be easy to apply. A typical crash rate calculation is shown in figure 6.

$$CR = C \times 100{,}000{,}000 \div (V \times 365 \times N \times L)$$

Figure 6. Equation. Typical crash-rate equation used with vehicle volume.

Where:

CR = crash rate for the road segment expressed as crashes per 100 million vehicle miles of travel.
C = total number of crashes in the study period.
V = traffic volumes using AADT volumes.
N = number of years of data.
L = length of the roadway segment in miles.

The equation in figure 6 relies on having traffic volume information. For evaluating pedestrian crash locations, exposure should also consider pedestrian volume in addition to vehicle volume. (See additional discussion in the Exposure Data section of chapter 3.) The availability of pedestrian or bicycle volume data, however, is generally rare. An FHWA project is developing the Scalable Risk Assessment Methodology, which will be able to help estimate pedestrian exposure.(5)

For several reasons, the use of crash rate values should be reserved for safety comparisons of locations with similar traffic volumes. For example, a limitation with crash rate is that it has bias toward low-volume locations. The ratio format of crash rate also implies that the relationship between the crash frequency and the crash volume is linear (i.e., the crash rate calculation equates to the slope of a line). Safety research efforts have determined that the sometimes-complex relationship between the crash frequency and traffic volume is usually nonlinear (i.e., the curve generally flattens as traffic volume increases). Additional information regarding these issues are available in the HSM.(2) Other recent research studies have also expands on these concerns.(20–22)

Crash-Type Distribution

Crash type has been used to separate crashes into categories so that a more focused evaluation can be conducted on a given type. Crash type has also been used to compare the distribution (or proportion) of crashes within each crash type.

Crash type reflects the actions of those involved in the crash. Identifying the crash type can help with identifying the problem and then the countermeasures appropriate to address the crash type. An analysis to identify high crash locations may focus on a particular crash type if targeted funding or a specific program is available.

Typical crash types for pedestrian crashes include dart/dash, multiple threat/trapped, through vehicle at unsignalized location, turning vehicle, through vehicle at signalized location, and walking along road. Additional information on pedestrian crash types is available on the Pedestrian and Bicycle Information Center website as part of the Pedestrian and Bicycle Crash Analysis Tool (see http://www.pedbikeinfo.org/pbcat_us/ped_images.cfm).

Another approach for using crash type is to review the proportions of crash type for a specific location to a typical proportion of crash type for similar types of locations. For example, this approach could reveal if a specific signalized intersection is having more crashes involving turning vehicles than other signalized intersections with similar volume and roadway cross section.

Crash-Severity Distribution

The degree of severity for the crash (e.g., injury or fatality rather than property damage only) can be a factor in identifying high crash locations. Because of potential inconsistencies in reporting of property-damage-only crashes between regions, the preference is to focus on the more severe crashes. Due to the low number of pedestrian crashes, however, many agencies include all severity levels in the evaluation.

The distribution of crash severity can also be used to rank sites. Sites with similar characteristics within a region can be compared to a systemwide proportion for similar sites. Figure 7 illustrates the cumulative distribution of pedestrian crashes for a major city as compared to other major cities. In this example, the major city (shown with open circles) appears to have more severe crashes than the reference group of other major cities (shown with closed diamonds). A statistical analysis should be conducted to verify this visual observation (e.g., odds ratio in a contingency table with counts of severe/nonsevere crashes versus major city/other major cities).

The distribution of crash severity could also be used to identify sites (or regions) with the most severe crashes as the method to rank sites. The data in table 1 show the severity distribution for five major cities. The cities with the greatest proportion of severe crashes are city C and city B with 29 and 28 percent of severe crashes (fatal and incapacitating injury), respectively.

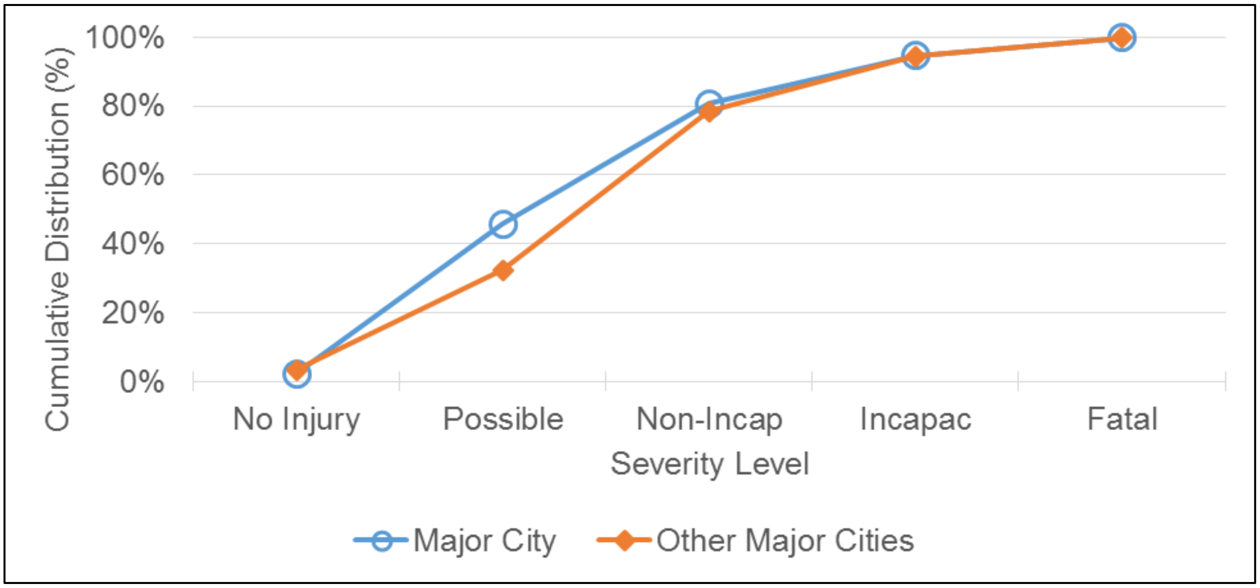


Figure 7. Graph. Example of severity-level differences between a major city and other similar major cities.

Table 1. Distribution of pedestrian crashes by severity levels for several cities.

Scenario[a]	City	Fatal (%)	Incapacitating Injury (%)	Nonincapacitating Injury (%)	Possible Injury (%)	No Injury (%)	Grand Total (%)
I	A	4	14	58	23	1	100
I	B	7	21	41	28	3	100
I	C	7	22	34	33	3	100
I	D	5	14	35	44	2	100
I	E	6	14	41	35	5	100
II	C	29[b]	[b]	34	33	3	100
II	B	28[b]	[b]	41	28	3	100
II	E	20[b]	[b]	41	35	5	100
II	D	19[b]	[b]	35	44	2	100
II	A	18[b]	[b]	58	23	1	100

[a]Scenario I identifies the distribution when considering the percent of crashes by each severity level, while scenario II identifies the distribution by combining fatal and incapacitating injuries to identify cities with the most severe pedestrian crashes.
[b]Represents combined fatal and incapacitating injury crashes.

Safety Index

Different performance measures can be combined to form a safety index. The intent of a safety index measure is to minimize known biases in the analysis procedure. For example, using crash frequencies as a sole method for determining safety needs would introduce a bias toward locations with higher volumes. One suggested index is to combine the following four crash-related attributes: crash frequency, crash rate, crash severity, and/or crash type (excessive proportion of specific type).

Another type of index is when crash data are combined with other data to identify locations of highest concern for the community. An example is other data being used to subdivide the community into geographic regions to ensure that each region receives a similar number of treatment dollars. Another example of other data could be the consideration of where sidewalk gaps exist. An example of an index being used by the City of Los Angeles, CA, is included in Supplemental Material A in chapter 7.

There are several alternatives to handling the bias incurred by only using crash frequency or only using crash rates. Depending on their characteristics and objectives, an agency could (1) develop an SPF for pedestrian crashes using their available exposure data and base the index on that, (2) include both frequency and rate in an index and weight them differently, or (3) include crash frequency or crash rate for various ranges of exposure and then rank within each range.

Challenges with Existing Performance Measures

Concerns with various performance measures include the following:

- Using only the crash frequency could introduce a bias toward locations with higher volumes, and using volume to generate a crash rate could help to address this bias.
- A nonlinear relationship exists between crashes and traffic volume (crash rates usually decrease with traffic volume, so sites with low volumes tend to be selected if crash rate is used as a selection criterion by itself). A potential method to overcome this challenge is to require a minimum crash count for a site before flagging the site as being on a high crash location list. Whether this method completely addresses this challenge is still questionable, since counts (and rates) are subject to random fluctuation.
- Selecting sites based on high crash counts or rates may have bias issues (either RTM or emphasis on sites with low crashes). The empirical Bayes (EB) approach was developed to overcome these issues. EB estimates the expected crash frequency at a site that could be combined with actual crash count. Additional discussion on using a proactive approach for identification of locations is available in the HSM.[(2)]

Grouping Network Elements to Determine Reference Population Norms

Depending on the preferred performance measure, the calculated performance measure of a given site could be compared to a reference population. Establishing a reference population permits the comparison of a particular site with the expected safety of the reference population. The reference population norms could take the form of crash frequency, crash rate (if exposure is known), crash-severity distribution, or crash-type distribution. The comparison of similar elements could help eliminate some of the biases attributed to traffic volume or other characteristics for the element. For example, a comparison between an intersection with four legs (where turning crashes may be more common) and an intersection with three legs (where fewer turning conflicts exist) could result in a missed opportunity to identify a specific safety need. If only intersections with three legs are compared, then those three-legged intersections with a greater proportion of turning crashes involving pedestrians could be identified.

Intersections could be grouped into reference populations based on traffic volume, traffic control, number of approaches (legs), functional class, area type, number of lanes (including the presence of turn lanes), and terrain. Segments could be grouped into reference populations based on traffic volume, area type, number of lanes, functional class, access density, median type and width, operating speed, and terrain.

SCREENING METHODS

Once performance measures have been chosen for the evaluation, the next step is to select the screening method. The screening method can vary depending on whether the focus of the evaluation is on segments or points (e.g., intersections or ramp terminal intersections). Typical screening methods include simple ranking for points and sliding window or peak searching for segments. Other screening methods for a network can include grid and polygons. The selected performance measure can influence which screening method is to be used. Supplemental Material B shows examples of results based on different screening methods.

Simple Ranking

Simple ranking orders the intersections, segments, or facilities based on the numerical value calculated from the selected performance measure. Sites with the highest value are identified for further study.

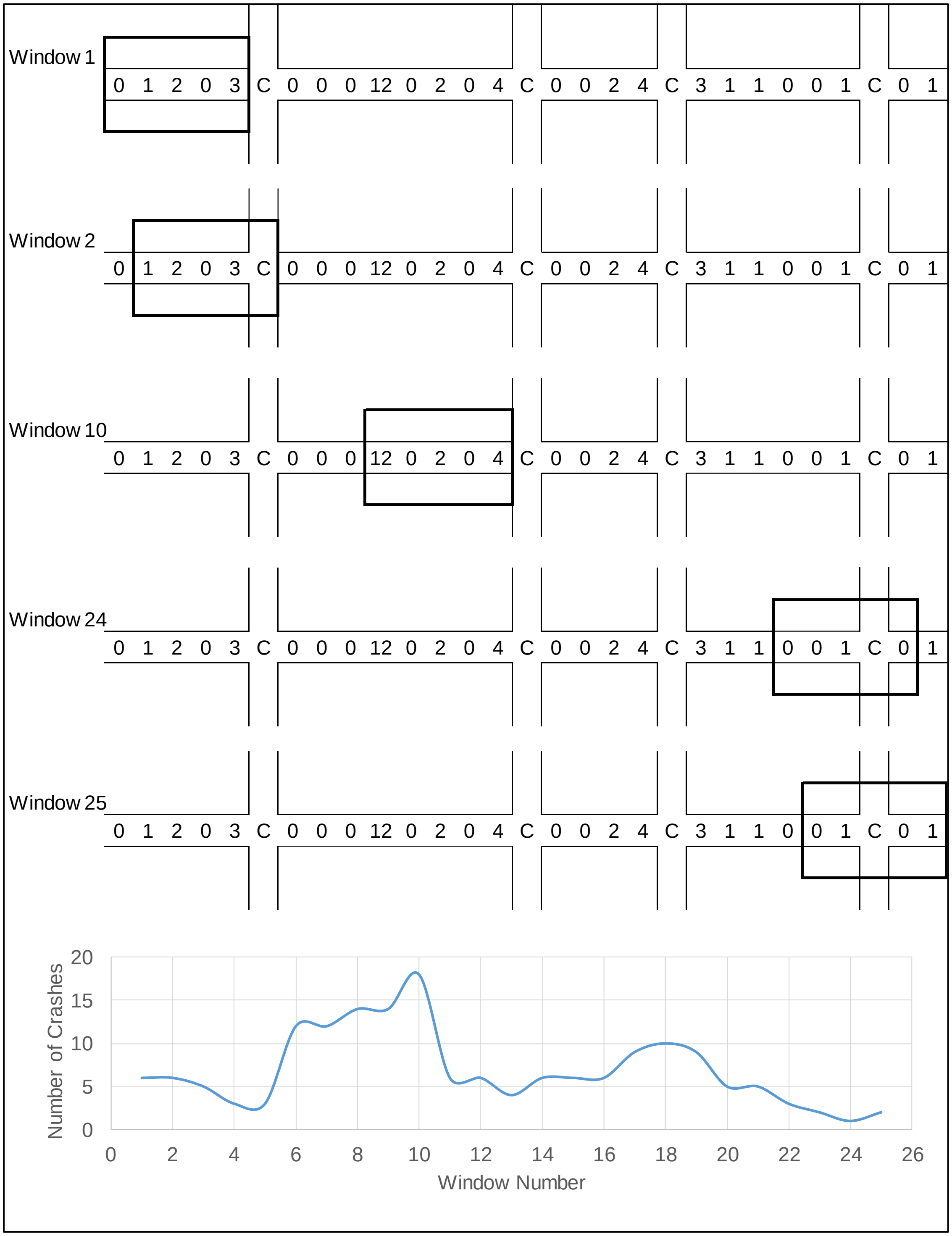
When ranking by crash frequency, a bias may be present for high-volume intersections or segments. Grouping and then ranking within an intersection or segment type could help eliminate some of the biases attributed to traffic volumes. For example, a high-vehicle-volume signalized intersection (where rear-end collisions may be prominent) merits unique evaluation, and a direct comparison between this intersection and a low-vehicle-volume intersection (where angle crashes may be prominent) could mask critical safety enhancement needs. The following are potential categories for intersections:

- Low-volume stop-controlled intersections.
- Moderate-volume stop-controlled or signalized intersections.
- High-volume signalized intersections.
- Interchange terminal intersections.

Sliding Window

Sliding window is only applicable for segment-based screening and is used to identify locations within a roadway facility that show the most potential for safety improvements. The selected performance measure is calculated for a specified segment length (e.g., 0.3 to 0.5 mi), and then the window is moved by specified incremental distance (e.g., 0.1 mi) and the value is recalculated for the next increment. By evaluating an individual location multiple times (for example, the segment between the 0.4- and 0.5-mi location would be evaluated five times), inaccurate crash reporting locations are minimized. The windows with the highest values for the segment or facility are identified. This technique can be automated using geographic information system (GIS) tools or spreadsheet tools.

An example application of this method is illustrated in figure 8. In this example, the increments were assumed to be 0.1 mi and the window length 0.5 mi, resulting in five increments being included in each window. Also assumed was that the width of each intersection was equal to the increment distance (e.g., 0.1 mi) and that there were no segment crashes within those intersections. The number of crashes at an intersection would be screened using another screening tool, such as with the simple ranking method. For the example in figure 8, the window with the highest number of crashes is window 10.



X = number of segment crashes on a 0.1-mi segment; C = intersection.

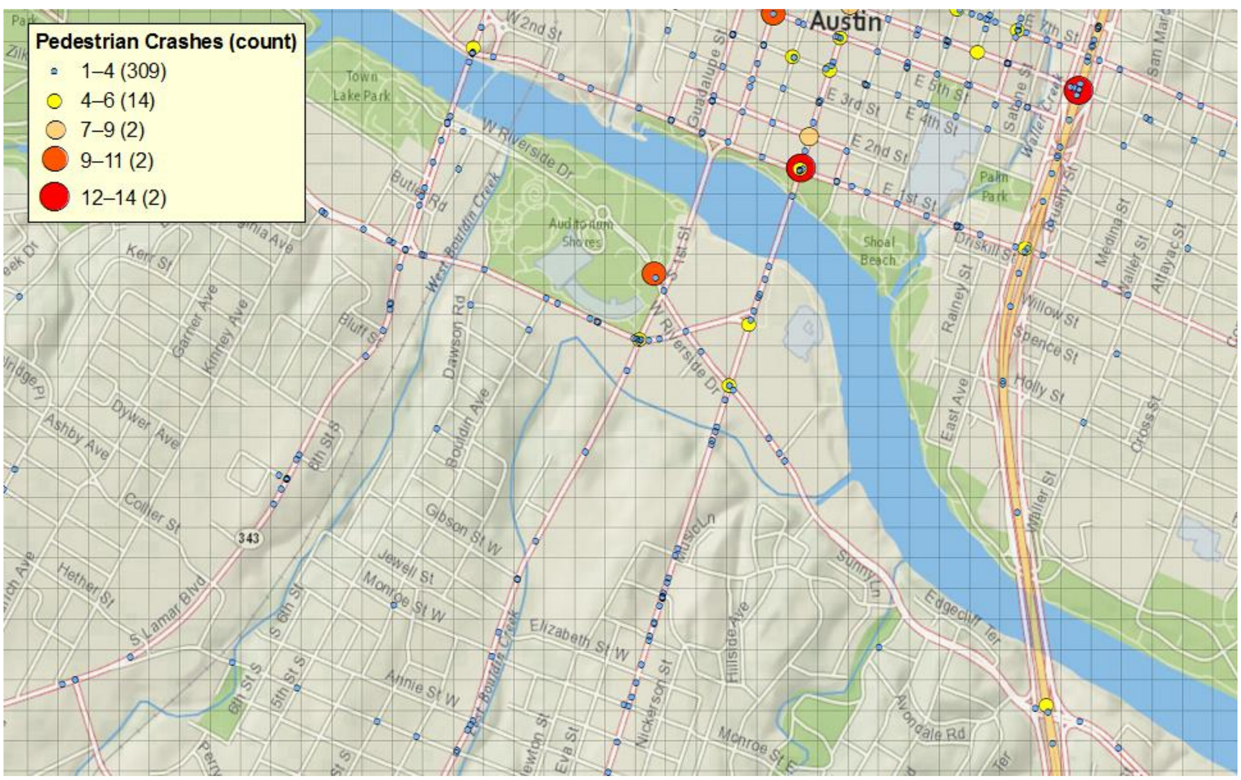
Figure 8. Graphic. Example of sliding window screening.

Peak Searching

Similar to the sliding window, peak searching is only applicable for segment-based screening. In peak searching, the segments are subdivided into windows of similar length, typically 0.1 mi initially, where the windows do not overlap. The performance measures are calculated for each window, and the resulting value is compared to a desired level of precision. If none of the 0.1-mi segments meets the desired level of precision, the segment window is increased, for example, to 0.2 mi, and the process is repeated until a desired precision is reached or the window equals the entire segment length.

Grid

The grid method creates a grid for the entire network. All the crashes could be summed within the cell to create pedestrian crashes per area, or a more detailed approach could be used that assigns a score for each cell. The score could be based on a number of characteristics, such as crash severity, age of pedestrian, or the crash frequency within the cell in combination with the crash frequency in neighboring cells. The scores can be shown as a crash density map, where cells of a given color (e.g., red) are those with higher-than-average crashes and cells of another color (e.g., blue) represent lower-than-average crash conditions. Figure 9 shows the grid superimposed on an area, while figure 10 shows the crash density for that area.



Screen capture ©Texas A&M Transportation Institute using ArcGIS software by ESRI. ArcGIS Desktop: Release 10.4.1. Service Layer Credits: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, METI, NGCC, ©OpenStreetMap. Crash data provided by the Texas Department of Transportation.

Figure 9. Graphic. Example of a grid over Austin, TX.

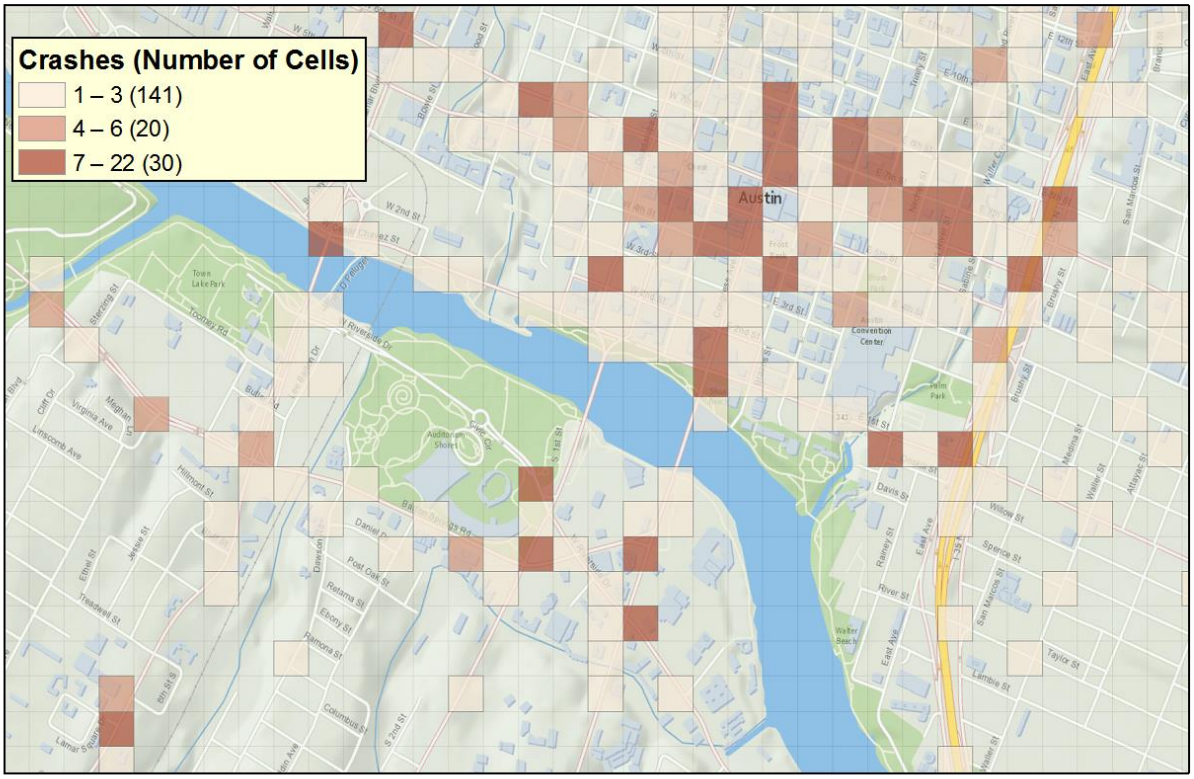


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Figure 10. Graphic. Example of a crash-density grid.

Polygons

Most GIS tools provide a tool to draw proximity polygons (e.g., ArcGIS calls this tool Thiessen Polygons, and QGIS calls it Voronoi Polygons). The use of these tools can help visualize crash concentration more fairly. These tools can be used to easily represent crash density from a layer with crashes. These polygons are defined as the largest area around an event (i.e., crash) where there is no closer event than the event inside the area. Therefore, the smaller the polygon, the higher the concentration of crashes around that area. Given the definition of these polygons, the smaller the area, the closer the adjacent crashes are to the crashes within the polygon. The smallest areas would represent the areas with the highest crash densities.

Proximity polygons can be used when there are a significant number of instances with two or more crashes geocoded to the same latitude and longitude (i.e., “stacked” crashes). To account for those situations, the area of each polygon can be adjusted to represent area per crash: (polygon area)/(crash frequency). Figure 11 shows proximity polygons in the downtown area in Austin, TX, after adjusting for event stacking. Polygons are color coded by the adjusted area (smallest polygons in red, largest polygons in blue).

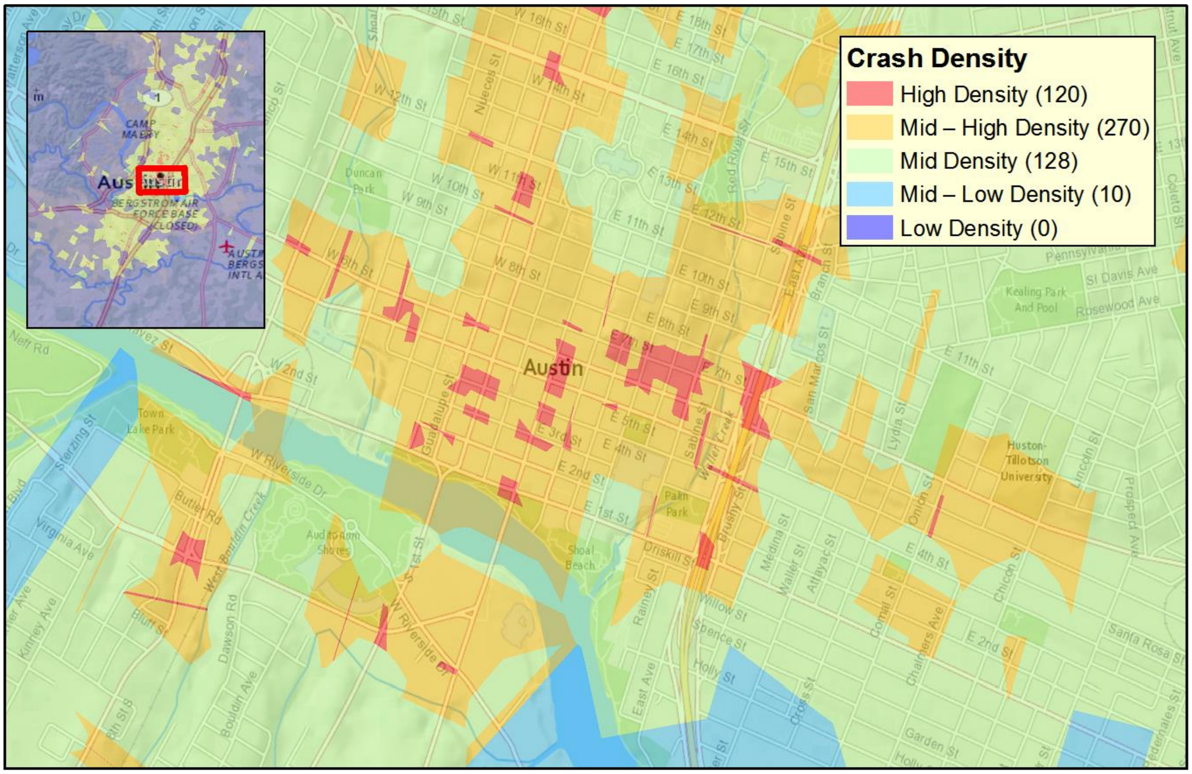

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Figure 11. Graphic. Example of proximity polygons.

Visual

Visualization of locations of concern can be done by reviewing a plot of the crash locations. To adequately account for the crashes that occur at a single location, a technique to provide an appreciation for the multiple crashes is needed. Heat maps are one technique, and different symbols representing number of crashes is another. Figure 12 shows the same Austin data presented in the previous examples to provide an appreciation of locations with the highest crash densities. Heat maps can be prepared in several ways. Most online applications use a kernel smoothing over an uploaded cloud of points. The presentation in figure 12 is based on the proximity polygons discussed in the Polygons section.

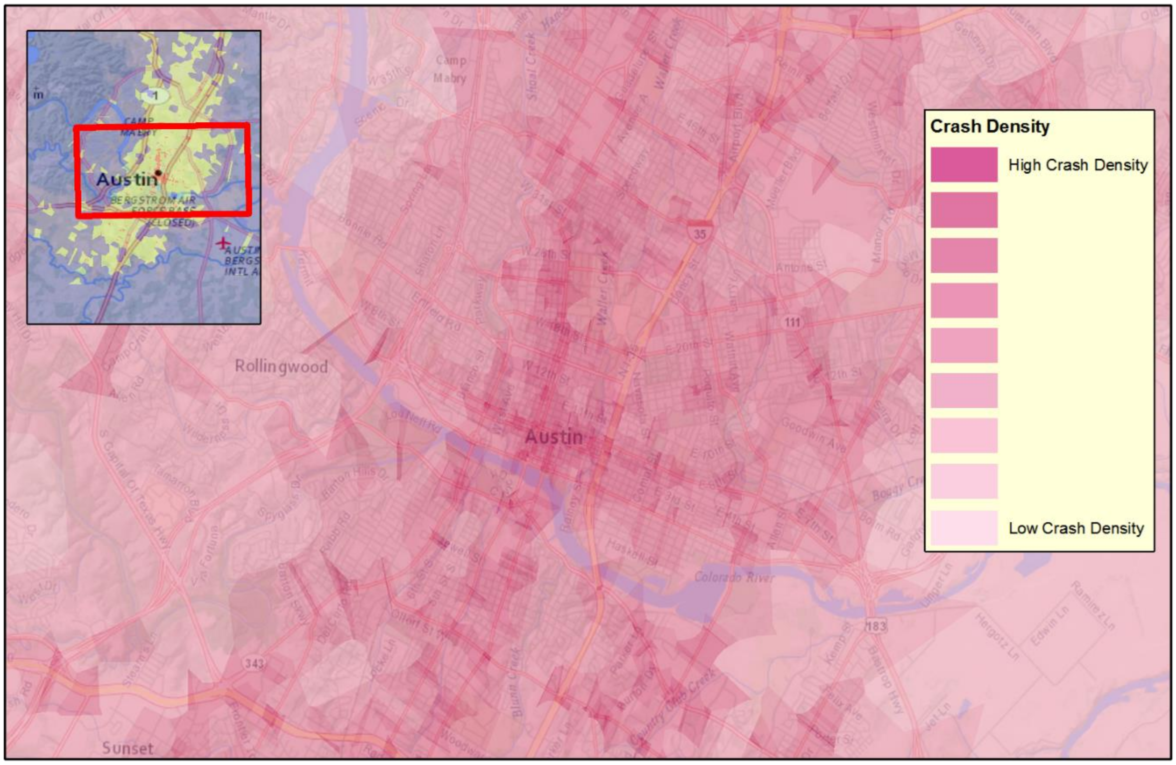

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Figure 12. Graphic. Example of a heat map.

CHAPTER 5. CONDUCT ASSESSMENT

OVERVIEW

Several tools are available to assist in conducting the assessment. Most of the tools have data requirements in addition to crash data and may require additional training before an assessment can be conducted.

AVAILABLE TOOLS

Several tools are available to manage the assessment. These tools can implement a range of performance measures and incorporate different screening techniques to identify locations of concern. Available tools include the following:

- **GISs** are digital systems intended to code, display, and analyze data in relation to their geolocation (i.e., data with geodetic system of coordinates). GISs manipulate layers containing different types of data. For the purpose of safety analyses, GIS tools allow displaying and analyzing a layer with crash data on a map. Depending on the purposes, crashes can be analyzed in terms of their relation to each other, or in relation to other layers containing different types of data, for example, road infrastructure data, census tract data, and land use data.

- **United States Road Assessment Program** has a risk-mapping protocol to demonstrate which roads have the highest and lowest risk of fatal and serious injury crashes.[(23)]

- **Safety Analyst** is a set of software tools used for highway safety management.[(24)] The software automates the six main steps of the highway safety management process, which has as the first step network screening. The other five steps are diagnosis, countermeasure selection, economic appraisal, priority ranking, and countermeasure evaluation. As noted on the related website, "Safety Analyst can be used to proactively determine which sites have the highest potential for safety improvement, as opposed to traditional (reactive) safety assessments done conventionally," and it implements the procedures from part B (Roadway Safety Management Process) of the HSM.[(24,2)]

- NCHRP Report 803, *Pedestrian and Bicycle Transportation Along Existing Roads—ActiveTrans Priority Tool Guidebook*, is a guidebook that presents the **ActiveTrans Priority Tool** (APT), a step-by-step methodology for prioritizing pedestrian and bicycle improvements along existing roads.[(25)] The APT is intended to be used by planners and other agency staff charged with managing a pedestrian or bicycle prioritization effort. It is designed to encourage practitioners to prioritize pedestrian and bicycle improvement locations by establishing a clear prioritization process that is responsive to agency/community values, and it is flexible, transparent, and receptive to the unique needs of pedestrians and bicyclists. The methodology combines the crash data with other data such as demand, connectivity, or equity using weights determined by the user.

Tools that are available for conducting a proactive approach include the following:

- The HSM provides information on available crash prediction models.[(2)] Crash prediction models can be used to determine the expected crash frequency at a location. This information can be used to prioritize the locations that may potentially need treatments. The predicted crash frequency can also be combined with existing crash data to identify expected crash frequency for a location.

- A current NCHRP project (NCHRP 17-73) is developing a process for conducting systemic safety analyses for pedestrians using analytical techniques to identify pedestrian activities (including behavior), roadway features, and other contextual risk factors (e.g., land use) that are associated with pedestrian crashes.[(4)]

While several performance measures along with different screening techniques can be used to identify locations of concern, it appears that the tool being used by most agencies is GIS. GIS provides the opportunity to manage the data in an efficient and productive manner and then visually see the results. Figure 13 displays various conceptual elements of a GIS application. The main components for GIS are a core to host, manipulate, and analyze data (shown in red or as either rectangles or a cylinder); inputs, consisting of data and processing packages (shown in green or as either cards or a barrel); and outputs, consisting of data and information (shown in yellow or as either rounded cards or a rounded parallelogram).

Supplemental Material C in chapter 7 presents several examples of the use of GIS in displaying crash data.

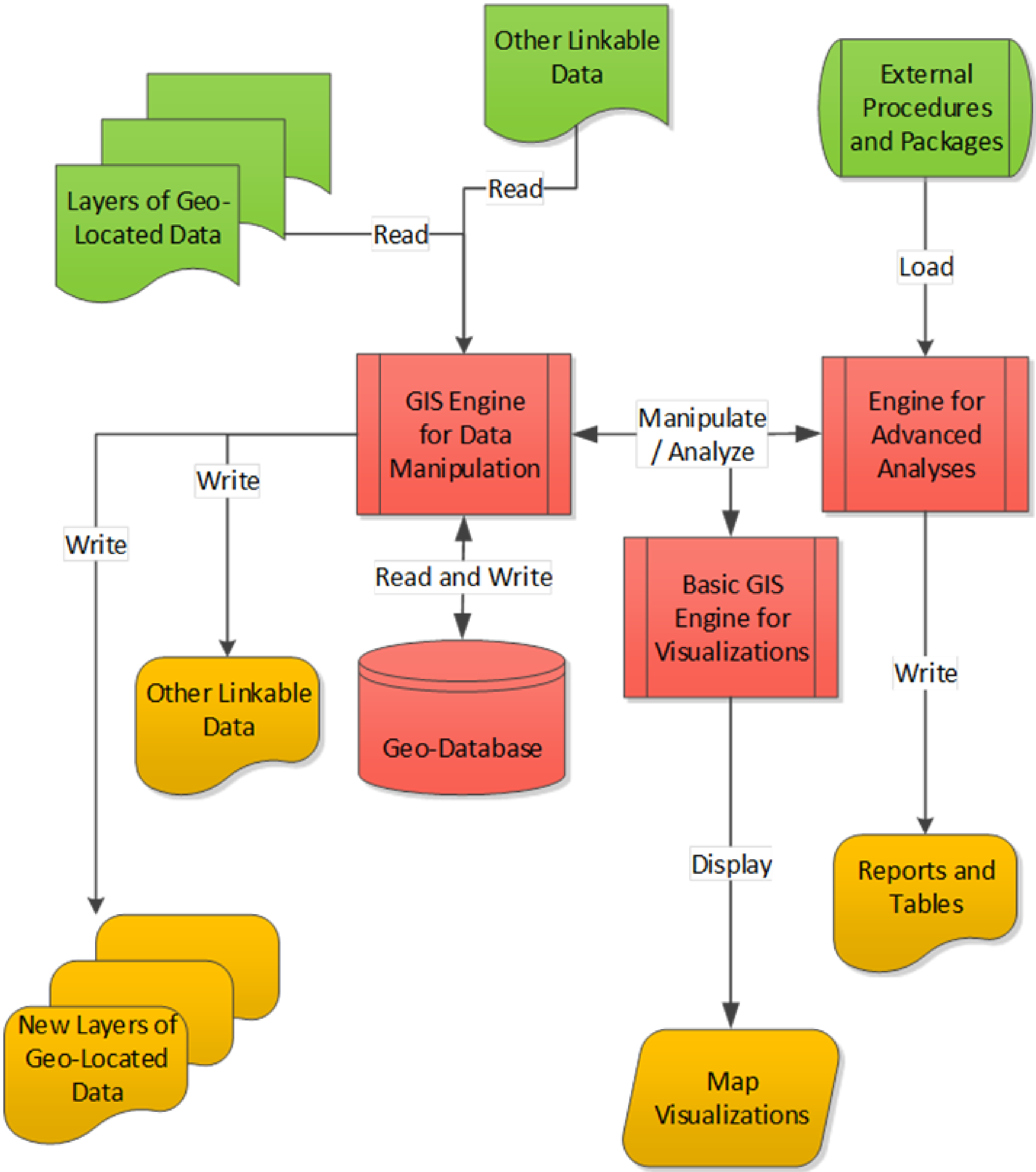

Figure 13. Flowchart. Conceptual elements of a GIS application.

ASSIGNING CRASHES TO NETWORK ELEMENTS

Crash Concentration

With the availability of geographic coordinates (such as latitude and longitude), crashes can be spatially assigned to intersections or segments. Having latitude and longitude available for crashes may boost the sense of confidence of knowing the location of the crash more precisely. However, research with geolocated crash data has shown that the exact location of a crash is not always coded accurately.(26) With that in mind, the following section presents various alternatives to aggregate crashes by their geolocations. In one simple step, the tool "Collect Events" in ArcGIS aggregates points that are perfectly overlapping. The resulting layer of points can then be displayed showing the aggregated crashes, as figure 14 illustrates. The map in figure 14 displays the color and size of the dots proportionally to the crash frequency represented.

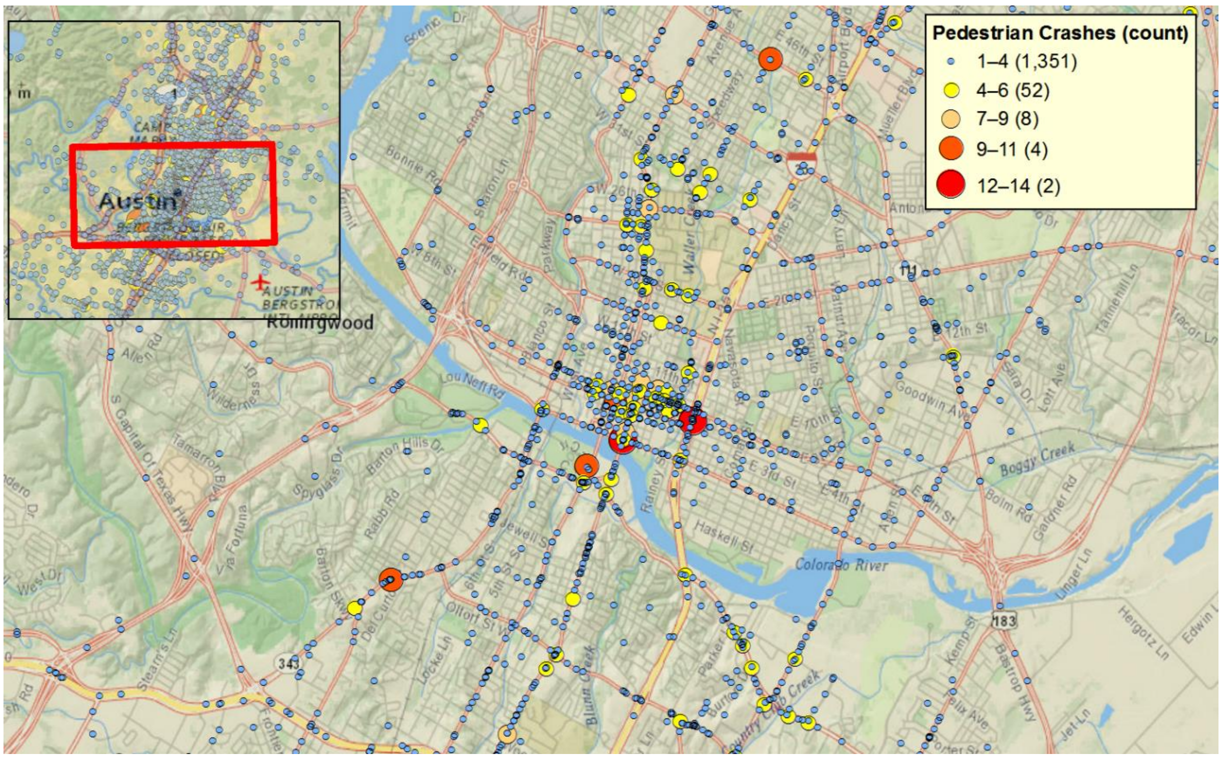

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Figure 14. Graphic. Aggregation of pedestrian crashes.

Intersection Buffer

A basic analysis of intersections should identify crashes that occur in the intersection, along with crashes on approaches that are considered intersection-related crashes for further analysis. If an inventory of intersections is available, the main task is identifying a buffer around the intersections and selecting those crashes within that buffer for further analysis. It is common to set buffers of a specific distance (e.g., 250–300 ft) around an intersection, classify the crashes within as "intersection related," and use only those crashes in the analysis (see figure 15). However, using this method still carries the risk of capturing nonintersection-related crashes or leaving intersection-related crashes out. Therefore, the research team recommends that agencies use the variable that indicates whether the crash is an intersection crash or not, when such information is available.

Research has shown that an average distance of 300 ft around the intersection is appropriate for developing SPFs, or crash frequency prediction equations.[26] If no intersection inventory is available, a layer of intersections can be generated based on the points of intersection between georeferenced road segments, and these intersection locations can then be overlapped with layers of crashes of interest.

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Figure 15. Graphic. Example of buffers around intersections.

CRASHES TO EXPOSURE

The relationship between pedestrian and bicyclist crashes and exposure measures is still the subject of active research.[5] Several exposure measures have been considered, including population, number of trips, and number of pedestrians (crossing or walking along street). In contrast to AADT for other types of crashes, there is no consensus on what measure or combinations of measures of exposure are best to incorporate in these types of analyses, mostly because of availability and strength of correlation.

CHAPTER 6. PRIORITIZE SITES

OVERVIEW

The selected performance measures and screening methods can be applied to the study network, resulting in a list of sites identified with the potential for safety improvement. These sites can then be ordered such that the sites with the most crashes are at the top of the list. Applying multiple performance measures to the same dataset can improve the certainty that the identified sites represent the locations with the most potential for improving pedestrian safety. While a simple ranking of sites by the performance measures will give the potential list of sites to be considered for treatments, the list can be adjusted by several factors.

ADJUSTMENTS

Factors that may be used to adjust the ranking of high crash locations or to select specific sites from a list of high crash locations include the following:

- Input from other stakeholders in the area (e.g., schools or the metropolitan planning organization).
- Planned maintenance (e.g., pavement overlay) that would permit implementation of a countermeasure that could treat the identified safety concern.
- Anticipated work by the State.
- Federal or State mandates.
- Available funding for specific countermeasures (e.g., distracted driving education campaign).

Priorities within a community could also affect the identification of candidate sites. For example, if the community wants to improve walkability, then street classification (e.g., collector streets may be given a higher priority than residential streets) or proximity to pedestrian generators (such as light rail transit stations, schools, parks and parkways, libraries, or neighborhood destinations) may be additional factors to consider. For example, some cities may pair the need to improve pedestrian safety with the need to encourage the community to walk more. Therefore, those cities may consider sites with the greatest potential to increase walkability among all sites with similar potential to improve pedestrian safety.

The process of identifying sites for treatment could include performing additional reviews of the sites. These reviews could use available aerial photographs or in-field reviews that would help identify roadway conditions. The results of these reviews could move a site higher or lower on the ranking list or could remove it from the list.

The prioritizing of sites may be conducted uniquely by location type. The ranking may be performed by geographical regions within a city so that all parts of the city receive some safety and infrastructure improvements rather than have all funding being directed to only one area within a city.

TOOLS

Tools are available to help with the ranking of sites, including the recently published APT (NCHRP Report 803).[25] APT presents a step-by-step methodology for prioritizing pedestrian and bicycle improvements along existing roads. It is designed to encourage practitioners to prioritize pedestrian and bicycle improvement locations by establishing a clear prioritization process.

EXAMPLES

New York City identifies priority lists using three categories: area (crashes/mi^2), facilities (crashes/mi, but facility must be a minimum of 1 mi), and intersections. The city bases its lists on 5 yr of data. When identifying potential locations for treatment, it identifies areas and facilities until it has listed about 50 percent of a borough. The lists are generated per borough (Manhattan, the Bronx, Queens, Brooklyn, and Staten Island) to ensure that each borough receives some improvements. For intersections, the city limits the list to about 15 percent of the borough to obtain a manageable list (about 5,500 intersections for the entire city).

Portland, OR, identified the top 20 high crash streets for driving, bicycling, and walking. The combination of those sites resulted in 30 streets being on the high crash network. The motor vehicle network included the streets with the highest number of people killed or seriously injured for the years between 2004 and 2013. The bicycle and pedestrian networks included streets with the highest crash frequency, regardless of severity, for people bicycling and walking, respectively, in recognition that the difference between a minor and a serious injury for pedestrian or bicyclists is "often random and circumstantial."[27] The number of 20 per mode (30 total) was selected as representing a balance between having enough streets to capture most of the fatal crashes (8 percent of streets capturing 56 percent of traffic deaths) and not having so many that the evaluation and countermeasure implementation steps far exceeded the ability to secure necessary resources.

SURROGATES

Because crashes can be rare events, some agencies have considered surrogates. Surrogates mentioned include the following:

- Location of activity centers.
- Type of land use, including when an apartment complex is across a major street from a grocery store.
- Retail or population density.
- Transit, such as location of bus stop or rail stations with respect to origins or destinations or number of riders (on or off).

- Number of lanes in combination with operating speed.
- Score that reflects the walkability of a street.
- Citizens' comments.

Most surrogates are good indicators of locations with potential for pedestrian crashes because they are also reliable indicators of pedestrian traffic. Therefore, some agencies may collect surrogates not only to identify crashes but also to monitor and anticipate pedestrian volumes as well as to evaluate the walkability of sites.

Although surrogates have been considered, the number of crashes involving pedestrians is the key metric being used because of the emphasis on data-driven decisions.

CHAPTER 7. SUPPLEMENTAL MATERIALS

This chapter presents several supplemental material examples and uses them to illustrate the method undertaken to identify locations of interest. The chapter also includes a discussion of the advantages and disadvantages for the more common assessment methods.

SUPPLEMENTAL MATERIAL A—EXAMPLE OF SAFETY INDEX

Los Angeles uses an index that considers the following:

- Number injured.
- Number of fatalities (with a 1.5 factor).
- Age of the pedestrian (an additional point is assigned for youth and older pedestrians).
- Health and equity index. In the *Health Atlas for the City of Los Angeles* document (table 2, page 179), the components considered in the city's community health and equity index are provided.[28] For example, a weight of 35 points is provided for the variable of hardship index.

SUPPLEMENTAL MATERIAL B—SCREENING METHOD EXAMPLES

Site Identification Analysis

Identification of points or segments is readily available in certain GIS packages, such as ArcGIS. The optimized version of this package analyzes a layer of data (pedestrian crashes in this case), creates a grid to group the data in the context of their extent, and computes the Getis-Ord Gi statistic, which is useful to find areas in the grid with high (and low) representation of a variable of interest (pedestrian crashes in this case). Figure 16 shows the output of running this tool with its default parameters. The area near the center of Austin clearly has more pedestrian crashes relative to the whole county. However, the size of the squares of the grid is relatively large for further, more nuanced decisions.

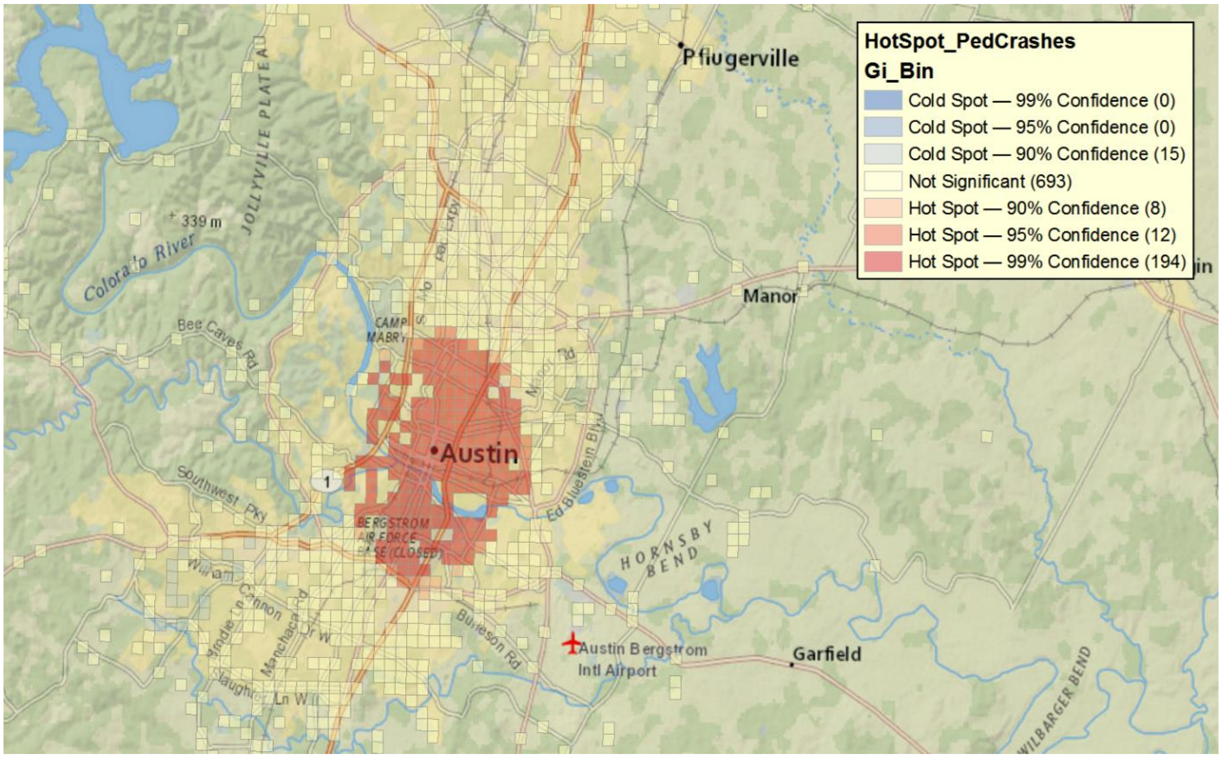

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Figure 16. Graphic. Pedestrian preliminary assessment of Austin-area pedestrian crashes.

A grid of higher resolution can be set for increased detail by limiting the analysis to the area previously identified as being the primary location with a higher number of crashes. In this case, the reduced grid is set to have cells of 328 by 328 ft. Figure 17 shows the distribution of the cells with at least one crash inside. There is a clear concentration of pedestrian crashes in the Austin downtown area and, more specifically, along a west/northwest–east/southeast corridor that includes 6th Street. This visualization presents smaller areas with a high number of pedestrian crashes. To further focus the attention to more problematic subregions, the Getis-Ord Gi analysis can be run again on a different variable: the crash frequency per square. Figure 18 shows the result of this action.

Figure 18 displays two cells whose counts are exactly eight pedestrian crashes in 5 yr, yet one of those cells is flagged as a hot spot (Neches Street and East 7th Street), while the other one is not (South Lamar Boulevard and Lamar Square Drive). The difference between these two sites is their Getis-Ord local statistic. For Neches Street and East 7th Street, that statistic amounts to 3.0598; in contrast, the Getis-Ord statistic is slightly smaller (2.854) for South Lamar Boulevard and Lamar Square Drive.

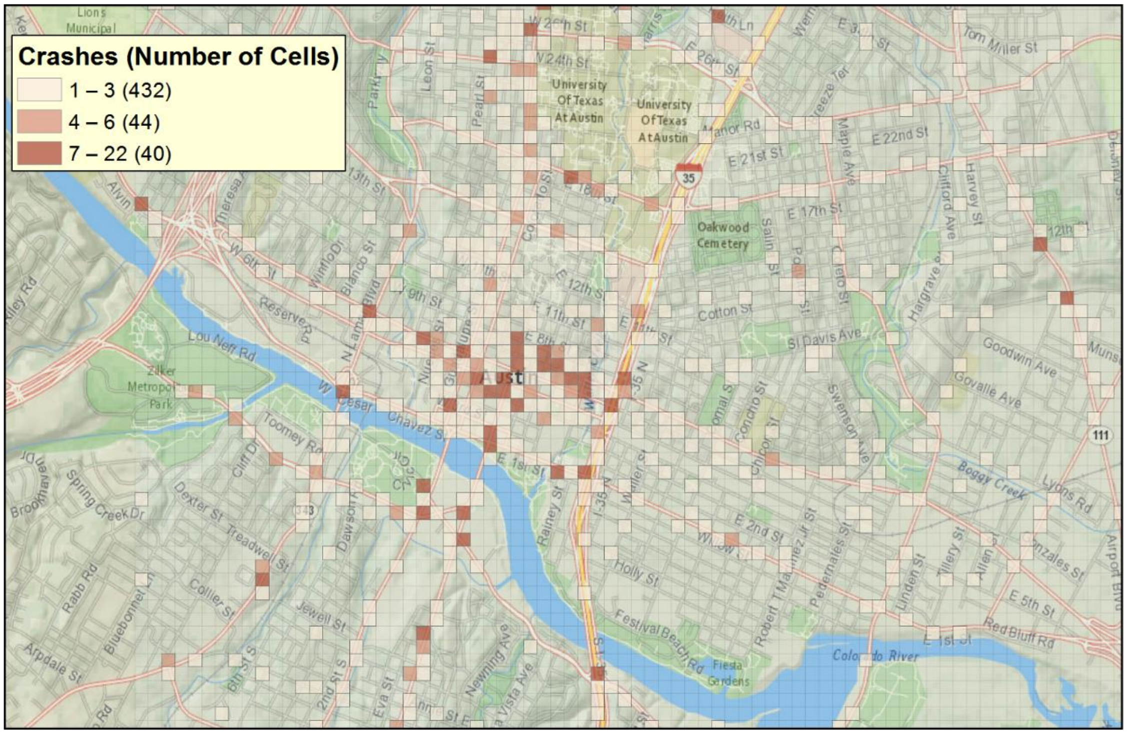

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Figure 17. Graphic. Pedestrian preliminary assessment of area near downtown Austin, TX.

A higher Getis-Ord statistic indicates a higher count of events (crashes) within a context of cells with high counts. Thus, given a high count of crashes, the cell with a lower statistic may be an isolated case of high crashes, but the cell flagged as a hot spot by the higher Getis-Ord statistic indicates overrepresentation of pedestrian crashes at that cell and its neighbor cells. Only a handful of sites were labeled as hot spots after this step (16 cells, as shown in figure 18). Interestingly, 4 out of 16 hot-spot cells are along the axis of 6th Street. The following example utilizes only the crashes on this arterial to demonstrate sliding window crash screening.

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Figure 18. Graphic. Identification of locations of concern using small grids.

Sliding Window Screening for 6th Street

The sliding window approach uses overlapping windows for smoothing any errors in crash location reporting. For this screening method, a window length of 984 ft is selected, performance measures are calculated for that window, the window is then moved for a given smaller offset (e.g., 328 ft), and the analysis is repeated for the shifted window. This procedure is repeated multiple times for as many windows as it takes to cover the complete corridor. An example application of this technique using the 6th Street corridor in Austin, TX, is discussed next.

As shown in figure 19, the corridor of 6th Street between Mopac Expressway and Interstate (I)-35 is roughly 2.2 mi long and had 104 pedestrian crashes between 2009 and 2014. Thirty-seven sliding windows of 984 ft can be defined for this corridor. Figure 20 shows the resulting windows. The crash frequency was computed per sliding window, resulting in the map shown in figure 21.

There are 6 windows with 16 or more pedestrian crashes, as shown in figure 22.

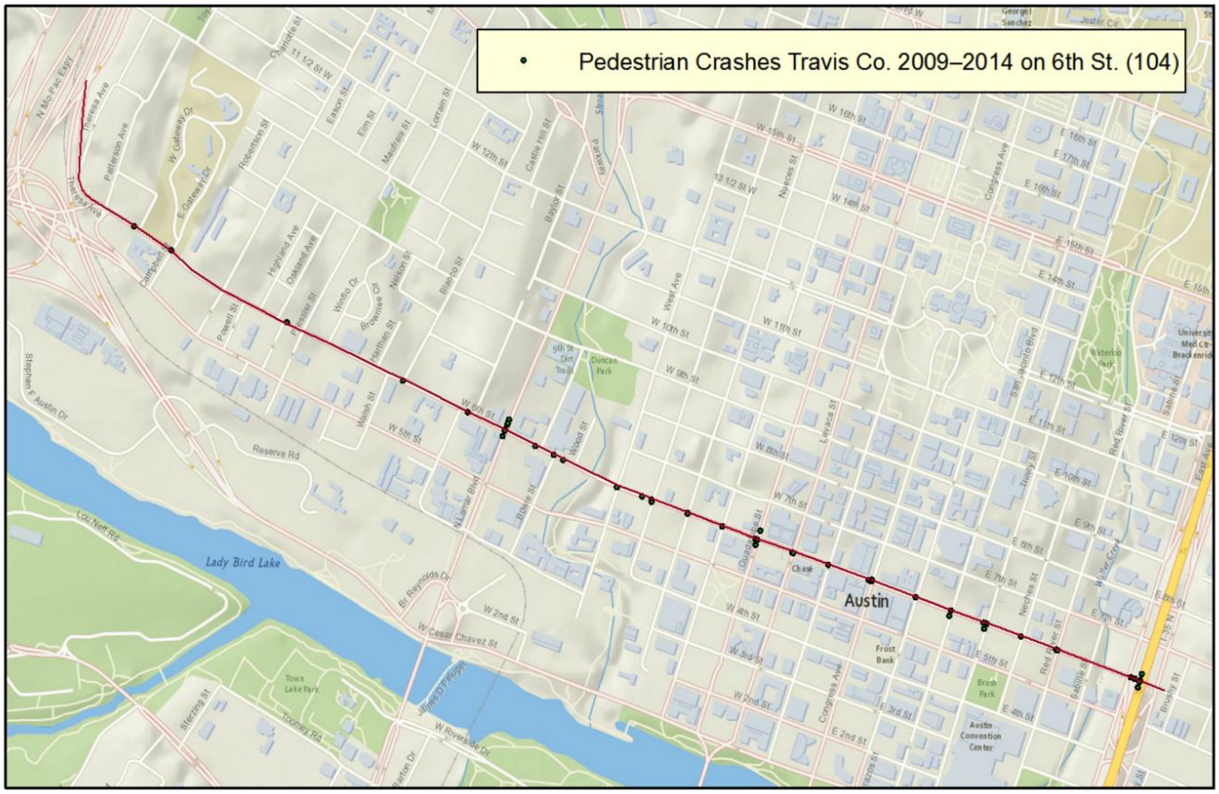

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Figure 19. Graphic. 6th Street corridor area of analysis.

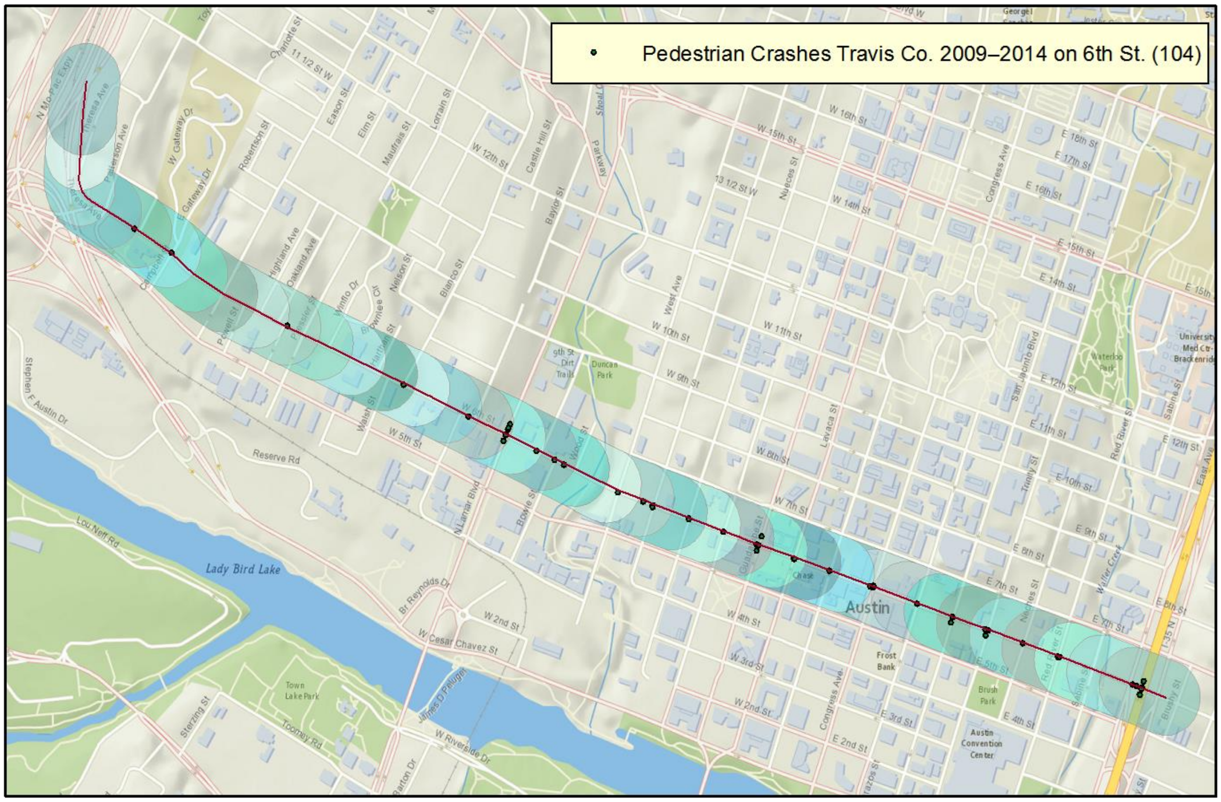

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Figure 20. Graphic. Sliding windows shown as transparent, overlapping oblongs for 6th Street corridor analysis.

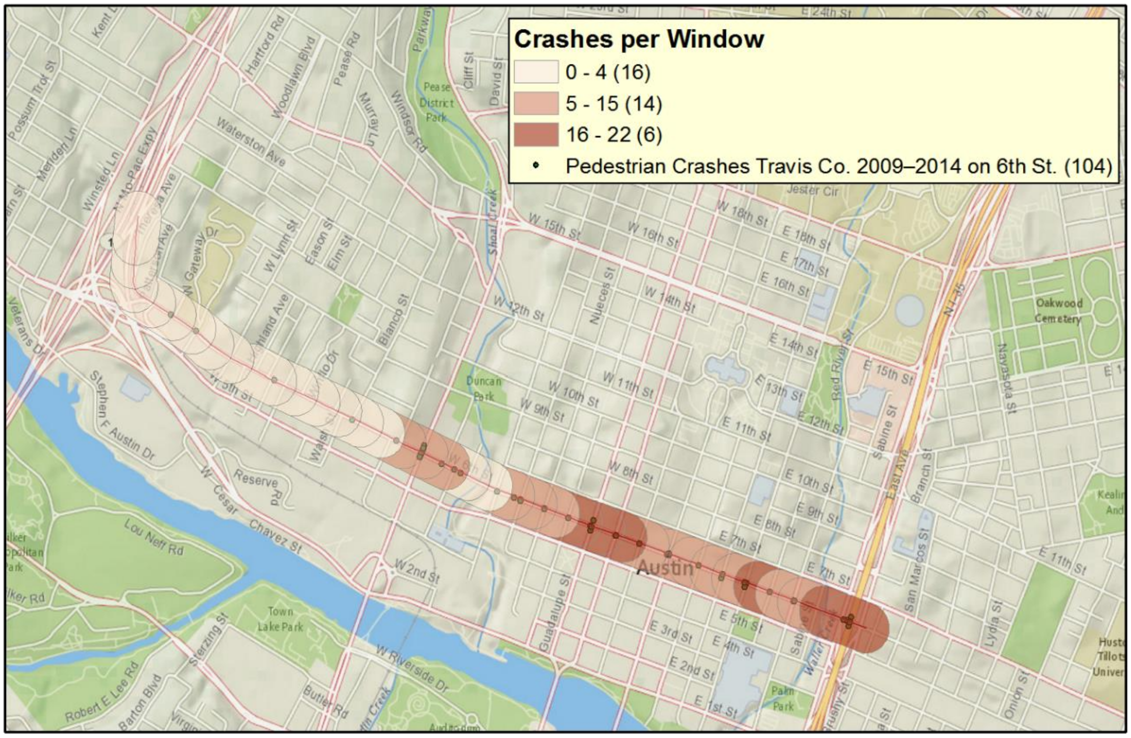

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Figure 21. Graphic. Sliding window analysis results.

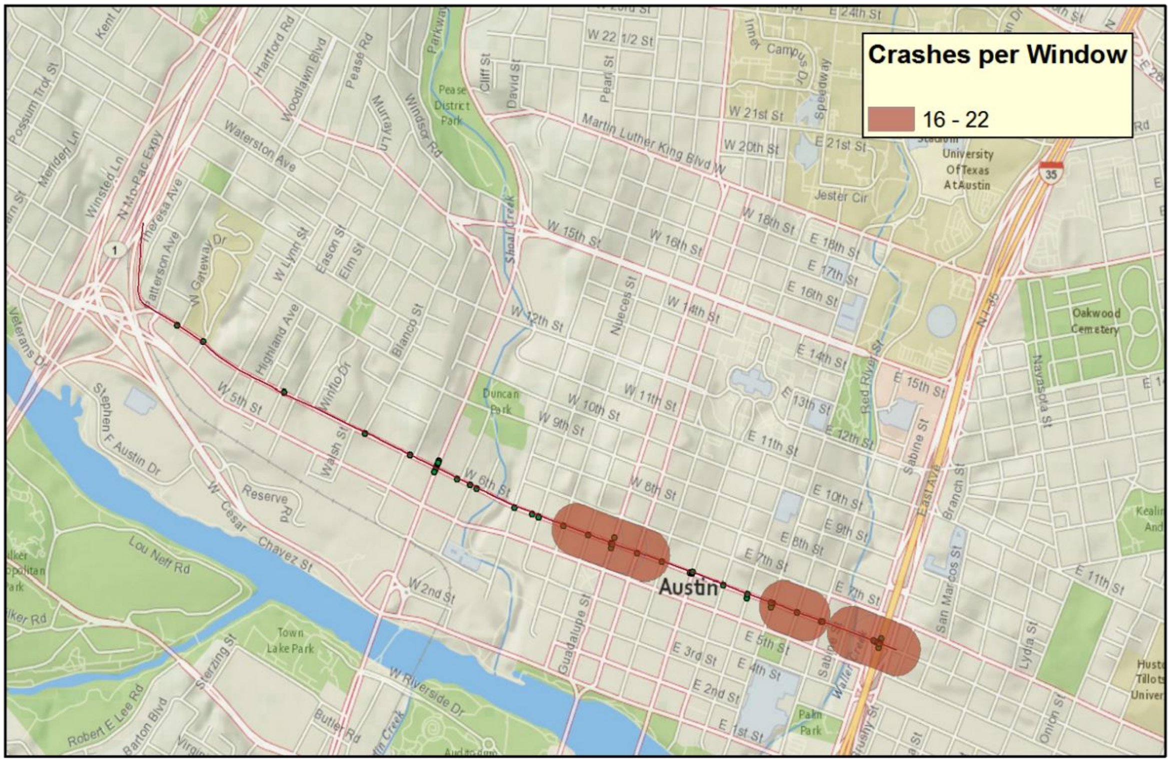

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Figure 22. Graphic. Segments of concern identified from the sliding window analysis.

Since the six critical windows identified overlap, these windows define three areas suited for more granular assessments. Figure 23 shows the first area of concern. This area of interest ranges through five intersections, from Nueces Street to Colorado Street. It is clear from figure 23 that the communality between these three windows is that they all contain the intersection of Guadalupe Street. Incidentally, the previous analysis identified this intersection as one of the top four sites of concern along 6th Street. One can conclude from these two analyses that the intersection of 6th Street and Guadalupe Street has an overrepresentation of pedestrian crashes compared to the rest of the 6th Street corridor (from the sliding window analysis) and that its surroundings also tend to have overrepresentation of pedestrian crashes (from the site identification analysis).

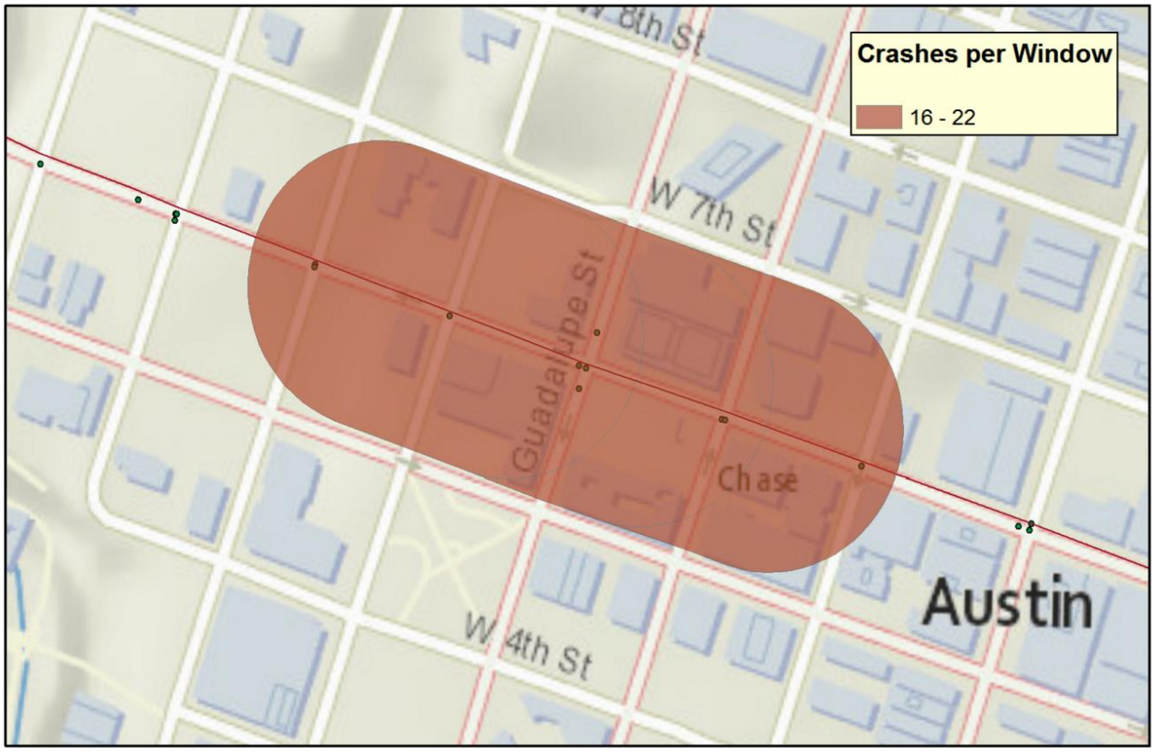

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Figure 23. Graphic. One of the areas of concern—includes critical intersections on 6th Street at Nueces Street, San Antonio Street, Guadalupe Street, Lavaca Street, and Colorado Street.

Figure 24 shows the other two segments identified from the sliding window analysis: the single window from Trinity to Red River Street and the two overlapping windows from Sabine Street to the I-35 Service Road. The site identification analysis identified the latter as a location of concern as well.

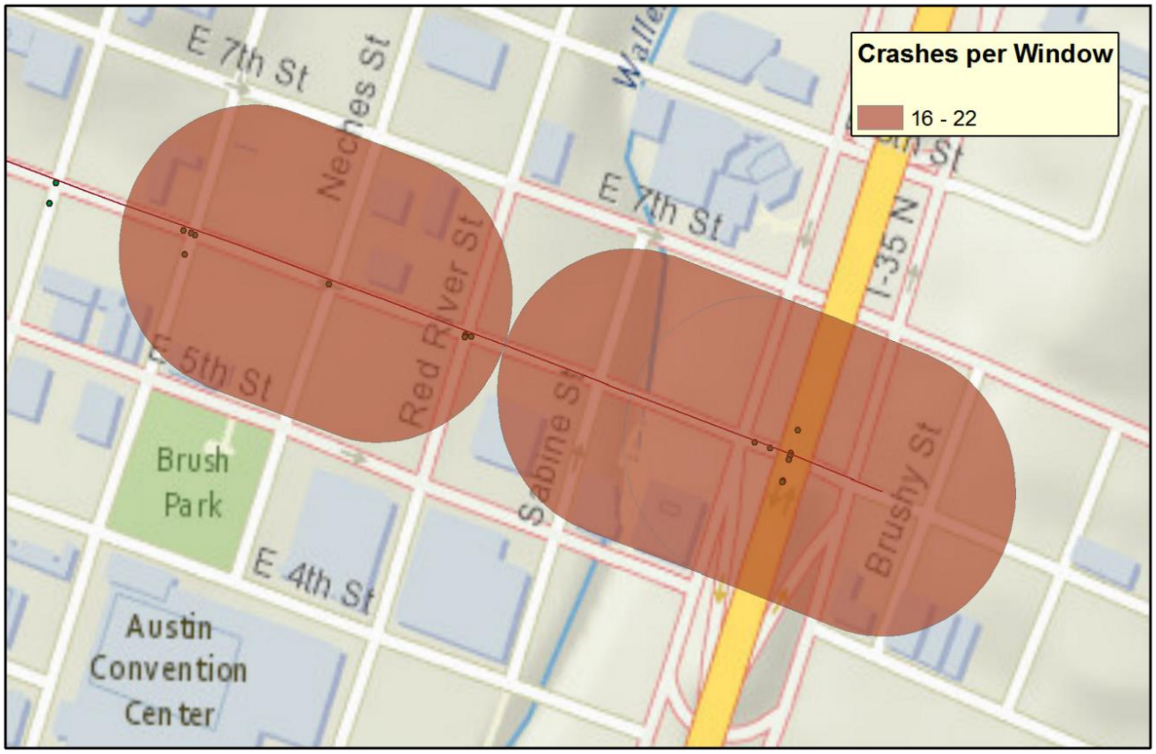

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Figure 24. Graphic. Two segments of interest along 6th Street: Trinity through Red River Street and Sabine Street to I-35 Service Road.

SUPPLEMENTAL MATERIAL C—ONLINE MAPS

Numerous city and State transportation departments along with FHWA are making pedestrian crash data available online through interactive maps. These online maps allow anyone with access to a Web browser to perform a variety of functions with regard to pedestrian crashes, including the following:

- Zoom out to get a citywide view, or zoom in to get a street- or intersection-specific view.
- Display the crash density by grouping crashes that occur close to each other.
- View pedestrian crashes in the context of nearby land use, socioeconomic attributes, or planned street or highway improvements.
- Filter/subset the crashes by year, crash severity, crash cause, and other crash attributes (e.g., gender, day of week, road agency ownership).
- Click on an individual crash or high crash location to get additional information.

The following are examples of such maps:

- The Federal Highway Administration shows pedestrian fatal crashes for 2009 to 2013 on its HEPGIS site: http://hepgis.fhwa.dot.gov/fhwagis/ViewMap.aspx?map=Annual+Fatal+Crashes|Pedestrian+Fatal+Crashes+2009-2013.

- California has funded the development of the Transportation Injury Mapping System to provide data and mapping analysis tools and information for traffic safety–related research, policy, and planning. The mapping system is available at https://tims.berkeley.edu/. Several tools are available, including interactive maps and the ability to query collision data, such as pedestrian-involved collisions.

- As part of the Austin Vision Zero initiative, Vision Zero ATX, which is a local nonprofit organization, created a color-coded map that indicates each fatality's mode of travel (see http://www.visionzeroatx.org/austin-fatality-map/). This map does not group nearby crashes to show crash density but does allow the user to filter by several attributes, including gender, control of road, time of crash, and day of week.

- As part of its Vision Zero initiative, the City of Portland, OR, displays all traffic fatalities and serious injuries on a map that illustrates fatality and serious injury crash density. The map shows 10 yr of crash data (2005 through 2014), displays density with different-sized symbols, allows the user to click on a particular crash for additional information, and allows the user to view pedestrian crashes separately from other crashes. Additionally, under the pedestrian-only crash tab, this map highlights (with a yellow line) the 20 pedestrian high crash corridors as determined by the city's crash analysis. It is available at http://pdx.maps.arcgis.com/apps/MapSeries/index.html?appid=cf122cd3b4ef46f0ac496b2d61d554e9.

- As part of its Vision Zero initiative, the City of Los Angeles, CA, displays its high injury network for people walking and biking who are killed or seriously injured in the context of other variables, such as a community health and equity index.[28] The Los Angeles DOT also used this high injury network to prioritize Safe Routes to School (SRTS) projects. While SRTS prioritization preceded Vision Zero, the city noted that the top 50 schools were all within 0.25 mi of the high injury network. The map is available at http://visionzero.lacity.org/high-injury-network/.

- As part of a pedestrian safety initiative called WalkFirst, the City of San Francisco, CA, displays high pedestrian injury corridors and intersections in a map-based interface. The WalkFirst site has high injury corridors and intersections categorized by crash profiles (i.e., causal crash factors such as low nighttime visibility, left-turning vehicle at signalized intersection, alcohol use, etc.) such that users can click on a certain crash profile to see where that causal factor contributes to a high crash density. The interactive map also uses color-coded lines to indicate crash density on these high injury streets and can be seen at http://walkfirst.sfplanning.org/index.php/home/streets.

- In a separate analysis of pedestrian safety in Los Angeles, CA, the *Los Angeles Times* identified the 817 most dangerous intersections in Los Angeles County using the California Highway Patrol's Statewide Integrated Traffic Records System (http://graphics.latimes.com/la-pedestrians-how-we-did-it/). The *LA Times* analysis considered three factors in designating dangerous intersections:

    - Total number of pedestrian collisions.
    - Proportion of collisions that involved a pedestrian.
    - Proportion of pedestrian crashes that were fatal.

  It is important to note that the resulting map shows the density of dangerous intersections, not the density of actual pedestrian crashes. The intent of the graphical map was to show, from a regional perspective, the location of problem areas (zones with multiple intersections) with respect to pedestrian safety (see http://graphics.latimes.com/la-pedestrians/).

- The North Central Texas Council of Governments, the metropolitan planning organization for the Dallas–Ft. Worth region, has developed static pedestrian crash maps that are available online. The maps show individual crash locations overlaid on a color-coded density map and include pedestrian and bicyclist crashes from 2010 through 2014. An example is available online at http://www.nctcog.org/trans/sustdev/bikeped/BikePedCrashInfo.asp.

- Massachusetts DOT (MassDOT) displays an interactive map of top crash locations for pedestrians and bicyclists. This map groups nearby pedestrian crashes into intersection clusters based on the crash frequency occurring, with the top 200 ranking intersections displayed with a different-colored symbol. There are several different types of cluster displays that can be viewed, depending on the desired year range and type of crash (pedestrian or bicyclist). The map is located at http://gis.massdot.state.ma.us/maptemplate/topcrashlocations.

- The *Houston Chronicle* has compiled and displays pedestrian crash data in an interactive map. The map can be used to show individual crashes and associated attributes, like road, weather conditions, and contributing factors. A heat map that groups nearby pedestrian crashes is also viewable and uses color coding to indicate relative crash density. There are also filters that allow users to focus on a selected crash severity or contributing crash factor. An example of the Houston, TX, map is available at http://www.houstonchronicle.com/default/media/Pedestrian-accident-map-252958.php.

- FDOT has a website crash visualization tool that permits the user to modify year, intersection type, crash harmful event (which permits filtering on pedestrian crashes), and others. An example of a FDOT map is available at https://fdotewp1.dot.state.fl.us/TrafficSafetyWebPortal/FivePercent/LocationList.aspx.

SUPPLEMENTAL MATERIAL D—ADVICE FROM PREVIOUS STUDIES

Several previous studies have documented analyses to identify high crash locations, and these studies have used different approaches to identify and rank locations. Examples of approaches used and lessons learned include the following:

- A study explored different ranking methods to identify high pedestrian crash zones for the Las Vegas Metropolitan area.[(29)] The ranking methods included crash frequency, crash density, and crash rate, as well as composite methods such as the sum-of-the-ranks and the crash score methods. In addition, two density methods (simple method and kernel method) were used within a GIS. Results showed a significant variation in ranking when individual methods were considered, while the rankings of the high pedestrian crash zones were relatively consistent when the sum-of-the-ranks method and the crash score method were used. The authors recommended that composite methods should be used in ranking high pedestrian crash zones.

- A study using data from San Francisco, CA, found that although the pedestrian crash frequency was higher in the vicinity of the central business district, the pedestrian crash rate (crash frequency normalized by pedestrian exposure) was higher in the periphery of the city.[(30)] The authors noted that disregarding pedestrian exposure could significantly affect the results.

- Crash data can be combined with other data to develop a ranked list of locations for safety improvements. For example, Ottawa, Canada, combined crash data with public input and findings from the Intersection Safety Indices (ISI) tool.[(31,32)] Ped ISI allows the ranking of intersections based on their traffic control, number of lanes, 85th-percentile speeds, average daily traffic, and the predominant land use in the area. The combination of crash data with other datasets recognizes that pedestrian crashes are rare compared to vehicle crashes, and the combination of crashes with surrogates permits the consideration of other variables associated with pedestrian activity or situations known to be challenging for pedestrians.

- In a 2013 study in Florida, the authors observed that for small clusters (i.e., roadway segments less than 0.2 mi), normalized crash frequencies were inflated, and these segments were ranked among the highest.[(33)] Clusters were then categorized into intersections and corridors using a 500-ft threshold. Segments shorter than the threshold were identified as intersections, while those longer than the threshold were identified as corridors.

- MassDOT identified top locations where reported collisions occurred between pedestrians and motorists.[(34)] The crash cluster analysis methodology used a fixed search distance (for both pedestrian and bicycle crashes of 328 ft compared to 82 ft for intersection locations) to merge crash clusters together. Because of the relatively small number of reported pedestrian crashes in the crash data file, the clustering analysis used crashes from the 10-yr period from 2005 through 2014, instead of the 3-yr analysis for intersection locations. The actual crash clusters can be viewed on the interactive maps at http://services.massdot.state.ma.us/maptemplate/TopCrashLocations.

GLOSSARY

Term	Definition	Source
Areas	An interconnected set of transportation facilities serving movements within a specified geographic space, as well as movements to and from adjoining areas. The primary factor distinguishing areas from corridors is that the facilities within an area do not need to be parallel to each other.	2016 HCM[18]
Areawide	A generic term that includes all geographic scales that are not facility specific, such as neighborhood, network, system, region, city, State, etc.	Research team
Corridors	A set of parallel transportation facilities designed to move people between two locations. For example, a corridor may consist of a freeway facility and one or more parallel urban facilities.	2016 HCM[18]
Crash frequency (also called "Crash frequency—count" in this document)	The number of crashes occurring at a particular site, facility, or network in a 1-yr period. Crash frequency is measured in number of crashes per year.	2016 HCM[18]
Crash frequency—density	The number of crashes occurring per unit area (e.g., square miles), unit length (e.g., mile), or area (such as an established U.S. Census geographic area of block, block group, or tract or established geographic regions such as city, county, or metropolitan statistical area).	Research team
Crash rate	The number of crashes per unit of exposure. For an intersection, this is typically the number of crashes divided by the total entering AADT; for road segments, this is typically the number of crashes per million VMT on the segment.	2010 HSM[2]
Exposure	The measure of the number of potential opportunities for a crash to occur. This theoretical definition has been quantified or estimated numerous ways in practice.	Research team
Exposure scale	The most granular geographic level for which an exposure measure is desired.	Research team
Facilities	The lengths of roadways, bicycle paths, and pedestrian walkways composed of a connected series of points and segments. The HCM defines freeway facilities, multilane highway facilities, two-lane highway facilities, urban street facilities, and pedestrian and bicycle facilities.	2016 HCM[18]
Network	A geographic scale (mentioned in the original FHWA Statement of Work) that is most comparable to the term "area" as defined in the 2010 HCM.[35]	Research team

Term	Definition	Source
Points	Places along a facility where (a) conflicting traffic streams cross, merge, or diverge; (b) a single traffic stream is regulated by a traffic control device; or (c) there is a significant change in the segment capacity (e.g., lane drop, lane addition, narrow bride, significant upgrade, start or end of a ramp influence area).	2016 HCM[18]
Region	A geographic scale (mentioned in the original FHWA Statement of Work) that is most comparable to the term "system" as defined in the 2010 HCM.[35]	Research team
Risk	The measure of the probability of a crash to occur given exposure to potential crash events. This theoretical definition has been quantified or estimated by dividing the expected or measured number of crashes by exposure.	Research team
Risk factor	Any attribute or characteristic that increases the likelihood of a negative safety outcome (e.g., crash or fatality).	Research team
Segment	The length of roadway between two points. Traffic volumes and physical characteristics generally remain the same over the length of a segment, although small variations may occur (e.g., changes in traffic volumes on a segment resulting from a low-volume driveway).	2016 HCM[18]
System	All the transportation facilities and modes within a particular region.	2016 HCM[18]
Safety index	A measure to minimize known biases in the analysis procedure.	Research team

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