Identification of High Pedestrian Crash Locations

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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 the research into identifying a process to identify high pedestrian crash locations. The *Guidebook on Identification of High Pedestrian Crash Locations*, prepared based on research documented in this report, was developed to present a five-step process to assist State and local agencies in identifying high pedestrian crash locations, such as intersections (points), segments, facilities, and areas.[(1)]

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

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16. Abstract An initial step in reducing the frequency of pedestrian crashes is identifying where they occur or where there is a concern they are likely to occur. As part of a Federal Highway Administration project, the *Guidebook on Identification of High Pedestrian Crash Locations* was developed to present a process to assist State and local agencies in identifying high pedestrian crash locations such as intersections (points), segments, facilities, and areas.(1) This document summarizes the research efforts to develop the five-step process. Several cities and States were contacted to establish the criteria used to identify and rank high pedestrian crash locations. In all cases, crash data are being used. In some cases, other variables are considered, especially when developing the list of sites for treatments. For example, Los Angeles 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 create unique lists for intersections, facilities, and areas, recognizing that treatment selection would be different for these element types. The methods used to identify and evaluate sites with a high crash frequency have evolved in recent decades. The availability of geographic coordinates (latitude and longitude) for crashes has resulted in the ubiquitous use of geographic information system platforms for displaying the locations and density of crashes on maps.			
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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
ADT	average daily traffic
APT	ActiveTrans Priority Tool
CS	crash score
DOT	department of transportation
EB	empirical Bayes
FHWA	Federal Highway Administration
GIS	geographic information system
HCL	high crash location
HSIP	Highway Safety Improvement Program
HSM	*Highway Safety Manual*
LRS	linear referencing system
MPO	metropolitan planning organization
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
ODOT	Oregon Department of Transportation
PBCAT	Pedestrian Bicycle Crash Analysis Tool
PEDSMARTS	Pedestrian Systemic Monitoring Approach for Road Traffic Safety
RTM	regression to the mean
SPF	safety performance function
SR	sum-of-the-ranks
SRTS	Safe Routes to School
TAP	Technical Advisory Panel
TIMS	Transportation Injury Mapping System
USDOT	U.S. Department of Transportation
usRAP	United States Road Assessment Program
V2P	vehicle-to-pedestrian

CHAPTER 1. INTRODUCTION

BACKGROUND

One of the U.S. Department of Transportation's (USDOT'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 occur or where there is a concern they are likely to occur. 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.

RESEARCH OBJECTIVE

The objective of this FHWA research was to document methods used to identify or prioritize high pedestrian crash sites or areas. Using the information gathered as part of this research, the research team developed a best practice document, *Guidebook on Identification of High Pedestrian Crash Locations* (henceforward referred to as "the *Guidebook*"), which can assist State and local agencies in identifying high pedestrian crash locations, corridors, and zones.(1)

APPROACH

The research was conducted in a series of tasks as follows:

- **Task 1—Hold Kickoff Meeting and Organize Technical Advisory Panel (TAP):** The research team met with FHWA staff to discuss the project direction, scope, and work plan. Following that meeting, the research team worked with FHWA on identifying a TAP.
- **Task 2—Develop Literature Review:** The research team reviewed the literature to identify how high pedestrian crash locations are currently identified. The review also found issues and tools associated with identifying high crash locations (HCLs).
- **Task 3—Conduct Agency and Industry Interviews:** The research team conducted several interviews with governmental agencies and industry representatives.
- **Task 4—Develop Draft Best Practice Guide:** The research team developed the *Guidebook*.
- **Task 5—Conduct Webinar Workshop and Final Briefing Meeting:** A final briefing meeting was held in May 2017 that included FHWA, members of the research team, and the panel. Following the briefing, the research team conducted a webinar workshop on the draft *Guidebook*. Comments from the webinar workshop were used to refine the *Guidebook*.

- **Task 6—Develop Documentation:** The research team developed the final deliverables, which include this comprehensive technical report that documents all aspects of the project's activities and findings, along with a TechBrief.[(2)]

REPORT ORGANIZATION

This report includes the following chapters:

- **Chapter 1. Introduction.** The introduction presents general background information and the research objectives.

- **Chapter 2. Literature Review.** This chapter presents information on the tools and methods currently being used to identify HCLs with an emphasis on what is being used with pedestrian crashes.

- **Chapter 3. Interviews With Governmental Agencies.** This chapter summarizes interviews held with governmental agencies that explored how high pedestrian crash locations are identified.

- **Chapter 4. Interviews About Pedestrian Collision Warning Systems.** This chapter summarizes interviews that explored the potential of using pedestrian collision warning systems to identify locations of concern.

- **Chapter 5. Development of the *Guidebook* and Webinar Workshop.** This chapter provides an overview of the webinar workshop that was developed based on the *Guidebook*.

- **Chapter 6. Summary/Conclusions and Future Research Needs.** This chapter provides a summary and the conclusions of the research and presents future research needs.

CHAPTER 2. LITERATURE REVIEW

TOOLS OR METHODS AVAILABLE

Approaches to Problem Identification

An initial step in reducing the frequency of pedestrian crashes is identifying where they occur or where there is a concern they are likely to occur. 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. Identification of locations can be accomplished using one of the following approaches:

- A **reactive approach** (also known as a “traditional approach”) is generally based on an observed or historical crash pattern that suggests a hot spot (sometimes called a “black spot”) and the need for a countermeasure to improve safety at that location.

- A **proactive approach** uses models—such as crash prediction models—to determine the expected number of crashes for locations within a set region. These estimates can be used to prioritize the locations that may potentially need treatments. The approach is called “proactive” because it addresses a potential risk rather than an experienced problem. An example of a proactive approach is the **systemic approach**. The FHWA website notes the following about the systemic approach:

  …involves widely implemented improvements based on high-risk roadway features correlated with specific severe crash types. The approach provides a more comprehensive method for safety planning and implementation that supplements and compliments traditional site analysis. It helps agencies broaden their traffic safety efforts and consider risk as well as crash history when identifying where to make low cost safety improvement locations.[(3)]

The 2016 National Cooperative Highway Research Program (NCHRP) Synthesis 486 identified the current process for identifying locations with local road safety concerns. The synthesis considered all crash types and was not limited to pedestrians.[(4)] The objective of the synthesis was to document State programs and practices that address local road safety. The most frequent response from State DOTs concerning problem identification was a combination of both reactive and proactive methods. The survey indicated the following as the most frequently applied criteria for prioritizing local safety projects:

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

The survey found that fatal and serious injury crash numbers and crash rates were the major performance measures used. Table 1 provides additional findings from the synthesis.

Table 1. Problem identification methods as identified in NCHRP Synthesis 486.[(4)]

Problem Identification Process	Method	States and Description
A combination of both reactive and proactive methods (25 responses)	Crash data analysis (reactive) and systemic approach to determine high-risk roadway (proactive)	Examples include the following: • **Florida:** The DOT has initiated efforts to combine its identification methods through the District 7 Local Agency Project Funding Program and Intersection Safety implementation in Districts 2 and 3. • **Indiana:** The DOT conducts an annual screening of State and local roadway networks for apparent safety risks. All intersections, road segments, and interchange ramps undergo a comparison of multiyear crash frequency data to nominal risk calculated for two indices. The Index of Crash Frequency measures the relative risk of all crashes, and the Index of Crash Cost measures the relative risk of severe crashes. The results can be used to conduct road safety audits for both reactive spot safety improvement projects and for planning proactive systemic safety projects. • **Oregon:** The DOT uses crash-based analysis for network screening purposes for both State highways and local roads using the Safety Priority Index System, a numerical value based on the combination of crash rate, crash frequency, and crash severity. The Oregon DOT has launched a newly developed All Roads Transportation Safety program and plans to apply HSM SPFs for some areas. • **Washington:** Spot locations are primarily addressed through the City Safety Program (reactive), and risk locations over widespread areas (systemic safety) are addressed in both the City Safety Program and the County Safety Program (proactive).
Reactive method (14 responses)	Crash frequency analysis	11 DOTs
Reactive method (14 responses)	Crash rate analysis	8 DOTs
Reactive method (14 responses)	Surrogate analysis	2 DOTs
Reactive method (14 responses)	Other	• **Arkansas:** The Arkansas State Highway and Transportation Department uses a reactive method based on complaints from the people it serves. • **California:** California identifies projects on local roads in a reactive manner through a benefit–cost analysis. • **Wisconsin:** Wisconsin uses the input of DOT staff, local officials, and the public to identify problems on local roads.
Proactive method (3 responses)	Road safety audit	3 DOTs (Nevada, New Hampshire, and North Dakota)
Proactive method (3 responses)	Risk factor analysis	2 DOTs (Nevada and North Dakota)

Note: Adapted from table 9 of NCHRP Synthesis 486.
HSM = *Highway Safety Manual;* SPFs = safety performance functions.

Techniques

General Knowledge

In some cases, a location for consideration of improvements could be identified through recommendations made by local law enforcement or from citizens' comments or complaints. School districts may contact the city requesting assistance with crossings near their schools. 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 concern. While these techniques are not dependent on crashes, they can provide an earlier indication of locations where additional evaluation is needed.

Suggested Techniques From the **Highway Safety Manual**

Several techniques are used to identify HCLs, including the following list of performance measures from the *Highway Safety Manual* (HSM) (see table 4-2, pp. 4–9, in volume 1):[(5)]

- Average crash frequency.
- Crash rate.
- Equivalent property-damage-only average crash frequency.
- Relative severity index.
- Critical rate.
- Excess predicted average crash frequency using the method of moments.
- Level of service of safety.
- Excess expected average crash frequency using safety performance functions (SPFs).
- Probability of specific crash types exceeding threshold proportion.
- Excess proportions of specific crash types.
- Expected average crash frequency with empirical Bayes (EB) adjustments.
- Equivalent property-damage-only average crash frequency with EB adjustments.
- Excess expected average crash frequency with EB adjustments.

The most common methods include identifying intersections or midblock crossings with the highest number of crashes in a specific time period (i.e., frequency) or the highest number of crashes after adjusting for exposure (i.e., crash rate).

Given the limited number of pedestrian crashes, other data or approaches may be necessary to appropriately identify the locations where pedestrian safety is a concern. For example, identifying zones prone to pedestrian crashes—rather than a single intersection or marked crosswalk—could identify crashes where pedestrians are not crossing at a specific intersection or at a signed and marked midblock crossing.

Zones

Because of the limited number of pedestrian crashes at a specific location, zones can be used to identify a land area where improvements may be needed. In 1998, the National Highway Traffic Safety Administration (NHTSA) developed a guide that describes what zoning is and explains how to design and use pedestrian safety zones to increase the efficiency and effectiveness of pedestrian safety programs.[6] "Zoning" is defined as a relatively small geographic area where a relatively large proportion of the problem occurs. The NHTSA guide highlights examples of successful pedestrian safety zone programs and includes charts, checklists, and the following steps to define and use zones:

- Step 1. Select the crash problem.
- Step 2. Map the pedestrian crashes.
- Step 3. Define zones.
- Step 4. Calculate the efficiency measure and select final zones.
- Step 5. Evaluate zones and identify resources.
- Step 6. Select program activities.
- Step 7. Implement program activities.
- Step 8. Monitor program activities.

NCHRP Synthesis 295

NCHRP Synthesis 295 presents a discussion about the methodology for identifying hazardous locations.[7] The synthesis was published in 2001 and contains dated material; however, the authors discuss key concerns that are still relevant. They make the following points:

- Techniques based on high crash counts or rates may have regression-to-the-mean (RTM) issues.

- The EB approach was developed to overcome RTM. EB estimates the expected number of crashes at a site rather than the crash count.

- Another approach is to rank sites by their potential for safety improvement.

- A common thread in recent research is a departure from the use of crash rates.

The authors also comment that current procedures try to overcome the difficulty of the nonlinear relationship between crashes and traffic volume (crash rates usually decrease with traffic volume, and therefore, sites with low volumes tend to be selected if crash rate is used as a selection criterion by itself) by requiring a minimum crash count for a site to be flagged. The authors note that the extent to which this refinement overcomes the problem is unclear because counts (and rates) are subject to random fluctuation.

United States Road Assessment Program

The United States Road Assessment Program (usRAP) has the following goals and objectives as documented on the usRAP website:[8]

- To support iRAP [International Road Assessment Programme] and its vision of a world free of high-risk roads, by ensuring that ALL highway authorities have access to a robust and cost-effective tool for data-driven safety analysis.

- To provide a unique, innovative, and proactive means of enhancing the safety of the built road environment, so that hazardous designs and risky locations can be assessed and corrected even before a death or serious injury occurs.

- To reduce death and serious injury on U.S. roads through a program of systematic assessment of risk that identifies major safety shortcomings, which can be addressed by practical road improvement measures.

- To ensure that limited resources are efficiently allocated so that the greatest safety gains can be made within existing constraints.

- To forge partnerships among those responsible for a safe road system.

usRAP has a risk-mapping protocol to demonstrate which roads have the highest and lowest risk of fatal and serious injury crashes. The usRAP protocol includes four basic risk maps based on the following safety performance measures:

- Map 1—crash density (fatal and serious injury crashes per mile).

- Map 2—crash rate (fatal and serious injury crashes per 100 million vehicle miles [veh mi] of travel).

- Map 3—crash rate ratio (the ratio of the fatal and serious injury crash rate for an individual road section to the average crash rate for similar roads).

- Map 4—potential crash savings (the annual number of fatal and serious injury crashes that would be reduced if the crash rate for an individual road section could be lowered to the average crash rate for similar road sections).

The road sections on each risk map are color coded to indicate the risk level for fatal and serious injury crashes on that road section. The following distribution is used:

- Highest risk—5 percent of highway system length, shown in black.
- Medium-high risk—10 percent of highway system length, shown in red.
- Medium risk—20 percent of highway system length, shown in yellow.
- Medium-low risk—25 percent of highway system length, shown in light green.
- Lowest risk—40 percent of highway system length, shown in dark green.

According to the American Automobile Association website, risk maps have been prepared for Iowa, Michigan, Florida, and New Jersey. The following States were added in phase 3: Illinois, Kentucky, New Mexico, and Utah.(9) Highway agencies interested in having additional maps generated can seek information from the developer of usRAP. Examples of risk maps include those created using Kentucky data for speed-involved crashes, alcohol-involved crashes, aggressive-driving crashes, and lane-departure crashes. These maps were developed as part of phase 3 of the research project.(10) Phase 3 also explored pedestrian star ratings. The authors concluded that the crash frequencies for pedestrian and bicycle crashes proved to be too low to assess the star ratings.

The data needed to develop the four basic usRAP risk maps are listed in table 2. Only crashes that involve fatalities or serious injuries are used in risk mapping. Other typical approaches include (1) using mainline roadways and excluding interchange ramps, (2) combining both directions of travel on a divided highway even if the highway agency linear referencing system (LRS) treats the two directions of travel as separate segments, and (3) normally conducting the analysis using crash data for a 5-yr period.

Table 2. Data requirements for usRAP.

Characteristics	Data Needed
Crash	• Crash location (latitude and longitude). • Crash location (route and milepost or route, county, and milepost; these should already be in the database or derivable from latitude and longitude using an LRS). • Crash location (direction of travel for crashes on divided highways). • Crash severity (fatal, serious injury, and minor injury). • Crash date (year of crash occurrence).
Roadway	• Route type (e.g., interstate route, U.S. route, State route, county road, or other local road). • Route number or road name. • County. • AADT volume (veh/day). • Posted or legally applicable speed limit (mph). • Area type (rural/urban). • Number of through travel lanes. • Presence of median (undivided highway/divided highway). • Access control (freeway/nonfreeway). • Location (milepost/milepoint/log point) of—and data to derive—the segment length between points of change in the preceding roadway characteristics that can be used as a basis for dynamic segmentation.

AADT = average annual daily traffic; mph = miles per hour.

Safety Analyst

Safety Analyst is a set of software tools used for highway safety management. The software automates the six main steps of the highway safety management process: network screening, diagnosis, countermeasure selection, economic appraisal, priority ranking, and countermeasure evaluation.[11] As noted on the website, "Safety Analyst can be used to proactively determine which sites have the highest potential for safety improvement, as opposed to reactive safety assessments done conventionally," and it implements the procedures from part B ("Roadway Safety Management Process") of the HSM.[11,5] The program is designed for more than just identifying HCLs, and its applicability to identifying high pedestrian crash locations would need additional investigation. The minimum data elements are listed in table 3.

Table 3. Data requirements for Safety Analyst.[11]

Characteristics	Data Needed
Crash	• Crash location. • Date. • Collision type. • Severity. • Relationship to junction. • Maneuvers by involved vehicles (straight ahead, left turn, right turn, etc.).
Roadway	• Segment number. • Segment location (in a form that is linkable to crash locations). • Segment length (miles). • Area type (rural/urban). • Number of through traffic lanes (by direction of travel). • Median type (divided/undivided). • Access control (freeway/nonfreeway). • Two-way versus one-way operation. • Traffic volume, AADT.
Intersection	• Intersection number. • Intersection location (in a form that is linkable to crash locations). • Area type (rural/urban). • Number of intersection legs. • Type of intersection traffic control. • Major-road traffic volume (AADT). • Minor-road traffic volume (AADT).
Ramp	• Ramp number. • Ramp location (in a form that is linkable to crash locations). • Area type (rural/urban). • Ramp length (miles). • Ramp type (on-ramp, off-ramp, freeway-to-freeway ramp). • Ramp configuration (diamond, loop, directional, etc.). • Ramp traffic volume (AADT).

AADT = average annual daily traffic.

Prioritizing Improvements Using ActiveTrans Priority Tool

NCHRP Report 803 is a guidebook that presents the ActiveTrans Priority Tool (APT), a step-by-step methodology for prioritizing pedestrian and bicycle improvements along existing roads.[12] 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 meets the following criteria:

- Responsive to agency/community values: Transportation agencies often make decisions based on a defined set of goals or values of the communities they serve.

- Flexible: Rather than being a rigid, one-size-fits-all tool, the APT is flexible and allows practitioners to choose the most appropriate approach that reflects agency/community values and resource availability.

- Transparent: The APT is designed to facilitate transparency by breaking the prioritization process down into a series of discrete steps, each of which can be easily documented and explained to the public.

- Responsive to the unique needs of pedestrians and bicyclists.

Crash Prediction or Planning Models/Systemic Approach

An approach for being proactive is to use crash prediction models to determine the expected number of crashes at a location and to use this information to prioritize the locations that may potentially need treatments. FHWA has suggested several potential risk factors that States may want to consider. These factors, which are not specific to pedestrian crashes, are listed in table 4.[13]

Table 4. FHWA potential risk factors for a systemic approach.[13]

Category	Potential Risk Factor
Roadway and intersection features	• Number of lanes. • Lane width. • Shoulder surface width/type. • Median width/type. • Horizontal curvature, delineation, or advance warning. • Horizontal curve and tangent speed differential. • Roadside or edge hazard rating (potentially including side-slope design). • Driveway density. • Presence of shoulder or centerline rumble strips. • Presence of lighting. • Presence of on-street parking. • Intersection skew angle. • Intersection traffic control device. • Number of signal heads versus number of lanes. • Presence of backplates. • Presence of advance warning signs. • Intersection located in/near horizontal curve. • Presence of left-turn or right-turn lanes. • Left-turn phasing. • Allowance of right turn on red. • Overhead- versus pedestal-mounted signal heads. • Pedestrian crosswalk presence, crossing distance, and signal head type.
Traffic volume	• ADT volumes. • Average daily entering vehicles.
Other features	• Posted speed limit or operating speed. • Presence of nearby railroad crossing. • Presence of automated enforcement. • Adjacent land use type, such as schools, commercial, or alcohol-sales establishments. • Location and presence of bus stops.

ADT = average daily traffic.

A current NCHRP project (NCHRP 17-73) will develop a process for the following:[14]

- 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.

- Identifying appropriate and cost-effective systemic pedestrian safety improvements to address their associated risk factors.

- Enabling transportation agencies to prioritize candidate locations for selected safety improvements based on risk.

The NCHRP 17-73 research results will aid transportation agencies in more effectively allocating resources for pedestrian safety improvements.[14] The research builds on element 1 of the FHWA Office of Safety's Systemic Safety Project Selection Tool and focuses on existing countermeasures within the 4E framework—**E**ducation, **E**nforcement, **E**ngineering, and **E**mergency response—and will not include developing a software solution.

Jermprapai and Srinivasan provided an example of using crash prediction models by applying their models to calculate the expected number of crashes for census block groups within Florida that had no observed crashes.[15] They noted that if safety assessments are made purely based on crash history, all the locations with zero observed crashes should be deemed equally safe. Their results are summarized in table 5.

Table 5. Example of predicted crashes for Florida census block groups.[15]

Statistical Measure	All Crashes	Severe and Fatal Crashes	Fatal Crashes	Nighttime Crashes (6 p.m.–6 a.m.)
95th percentile	3.97	0.48	1.5	1.81
Mean	1.78	0.2	0.6	0.78
Variance	7.29	0.04	0.35	0.59
Count of block groups with no observed crashes	3,164	6,549	9,449	6,048

Note: Reproduction of a portion of table 6 in Jermprapai and Srinivasan.

The predictive model highlighted that there is significant variability in crash risk across these locations because of differences in land use and socioeconomic patterns. They noted that these types of findings could be used to allocate statewide safety funds and prioritize safety projects. They concluded with the following:

> It is envisioned that future studies will develop similar models for other states to determine the transferability of the empirical findings from the models in this study. Further, the predictive ability of the models could be improved with additional explanatory variables and advanced, flexible modeling methods. With additional explanatory variables, the challenge lies in finding consistent spatial data at a fine spatial resolution for the entire state and the effective treatment of multicollinearity among the variables. An important future effort would also seek to perform rigorous comparative assessments of the application of alternate methods to quantify the benefits obtained from advanced models.[15]

Grembek et al. developed a systemic approach for identifying sites where there is potential for significant reductions in pedestrian and bicyclist injuries in California.[16] They applied their method to a 16.5-mi section of San Pablo Avenue (State Route 123) in the San Francisco East Bay.

The authors developed the Pedestrian Systemic Monitoring Approach for Road Traffic Safety (PEDSMARTS). The procedure involves the following steps:

1. Estimate the number of a specific type of crash at a specific type of facility.

2. Present the data in a matrix to map the distribution of crash types across all facility types.

3. Identify the systemic hot spots in the matrix.

4. Identify the corresponding countermeasures for each cell to identify which one could be implemented for the specific crash type occurring at the specific location type.

5. Select the appropriate countermeasure that can be implemented throughout all similar locations.

The authors recommended that the California DOT use the method proposed in the research to study pedestrian/bicycle crashes on State arterial roadways.

Whether the suggested PEDSMARTS method is transferable to other regions would need to be investigated.

Integrated Method That Includes Crashes, Conflict, and Subjective Risk

Pešić et al. discuss a proactive method of identifying and ranking danger spots for pedestrians that incorporates the following:(17)

- Objective risk based on the analysis of traffic crashes.
- Potentially objective risk based on the subjective conflict technique.
- Subjective risk based on the analysis of participants' attitudes to traffic.

Further, using this method to rank identified spots helps officials set priorities in allocating resources.

Iterative Process to Group 1-Mi Segments

A 2003 paper discussed a study conducted to provide the framework for the systematic identification of pedestrian HCLs on the Florida highway system as part of the Highway Safety Improvement Program (HSIP).(18) The authors noted that the then-current methodology to identify HCLs as part of Florida's HSIP did not identify the location where most pedestrian crashes occur. The study considered roadways with continuous sidewalks on both sides in Miami-Dade County using data from 1997 to 1999. The methodology used crash data available from the Florida DOT and did not consider pedestrian exposure data. It used an iterative process to group 1-mi roadway segments with similar roadway characteristics, such as the presence of sidewalk and facility type. The iterative process was needed because different groupings may be needed before a Poisson process can model the actual pedestrian crash frequencies. The study had to omit the crashes within Miami Beach because of significantly higher levels of pedestrian activity in the area. The authors noted that a larger data sample may allow the grouping of a significant number of segments with much higher levels of pedestrian activities. They also noted that development type (i.e., urban or suburban) may be an additional criterion for further segregation of the data. With a confidence level of at least 90 percent and for 1-mi segments, a pedestrian crash frequency was called "abnormally high" for four-lane divided facilities with three or more crashes and for six-lane divided roadways with four or more crashes. From these thresholds, 22 1-mi segments were identified as pedestrian HCLs.

Geographic Information System

A geographic information system (GIS) is a digital system intended to code, display, and analyze data in relation to their geolocation (i.e., data with a geodetic system of coordinates). A GIS manipulates layers containing different types of data. For 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, such as road infrastructure, census tract, and land use. The complexity of the types of analyses that can be performed with GIS data varies significantly depending on the purpose of the analysis.

Pulugurtha et al. used the following steps with a commercial GIS software program to identify high pedestrian crash zones:(19)

- Step 1. Geocode pedestrian crash data.
- Step 2. Create a crash concentration map.
- Step 3. Identify zones and their shapes and sizes.

In their 2013 report, Scopatz et al. assessed the state of the practice of GIS tools used for safety by State and local agencies.(20) An important element moving toward widespread use of a GIS is the *Moving Ahead for Progress in the 21st Century Act* legislation signed in 2012 requiring statewide base maps and an LRS that include all public roads by June 2014. At the time of that report, about two-thirds of the States had base maps for local roads, but it was not clear what proportion had an LRS in place. The most widely available data to be used in a GIS are crash records, traffic volume, and roadway inventory information.

Although several agencies use GIS tools for visualization of crashes on a Web platform, the most common type of further analysis is the identification of hot spots for crash frequency. Scopatz et al. report that 33 States were implementing HSM methods, 12 were implementing Safety Analyst, and 6 were implementing the Interactive Highway Safety Design Model.(20)

Visualization Tools

As identified earlier, the simplest and most widely used types of GIS tools are those that provide crash visualizations. In general, crashes can be displayed using variables as filters or as criteria to display the data. Several agencies offer visualization tools for their crash data using a Web-based interface. An example of such maps is available from several sources. For example, the Florida DOT shows its pedestrian and bicycle crashes at https://fdotewp1.dot.state.fl.us/TrafficSafetyWebPortal/FivePercent/LocationList.aspx.

Visualization and analysis tools are available to analyze crashes. In addition to tools specifically for processing layers of data prior to safety analyses, modules offer the construction of the following four types of risk maps to visualize crash data:

- **Crash density map**—highlights road segments by the proportion of severe crashes.

- **Crash rate map—**highlights road segments by the magnitude of their crash rates (crashes per average annual daily traffic (AADT), vehicle miles traveled, or other measures of exposure).

- **Crash rate ratio map—**highlights segments by the relative size of their crash rates with respect to the mean of other segments of similar characteristics.

- **Potential crash savings map—**displays the difference between the crashes per mile in a segment and the average number of crashes per mile at a group of segments of similar characteristics.

While the first two types of maps are basically visualization tools that also yield some ranking of hot spots, the last two maps carry a further analysis of the data to provide a ranking based on a comparison of each segment and other similar segments.

Advanced GIS Analyses

A GIS with evaluation tools allows safety analyses beyond visualization, depending on the amount of data available. This section highlights a subset of those possible analyses.

Identifying Intersection-Related Crashes

One basic analysis consists of identifying intersection-related crashes for further analysis. If an inventory of intersections is available, the main task is identifying an area around the intersection and selecting those crashes within that area for further analysis. Research has shown that an average distance of 300 ft around the intersection is appropriate for developing SPFs or crash frequency prediction equations.[21] If no intersection inventory is available, a layer of intersections can be generated based on the points of intersection between georeferenced road segments. These intersection locations can then be overlapped with layers of crashes of interest.

Relationships With Exposure Measures

The relationship between pedestrian and bicyclist crashes and exposure measures is still the subject of active research. Contrasted with AADT for other types of crashes, there is no consensus on what measure of exposure is best to incorporate in these types of analyses, mostly because of availability and strength of correlation.

Development of Safety Routes

A state-of-the-practice evaluation in Alabama presents a variety of GIS-based analyses. One interesting technique identified in that document is the development of "safety routes," potentially useful for defining school routes.[22] This procedure combines the LRS defined for the road inventory layer and the geolocations of crashes. The procedure develops different paths based on the shortest path between two nodes of interest and the recommended path based on reduced probability of crashes.

NHTSA's Advancing Pedestrian and Bicyclist Safety: A Primer for Highway Safety Professionals

NHTSA recently published *Advancing Pedestrian and Bicyclist Safety: A Primer for Highway Safety Professionals.*[23] The report provides examples for geocoding crashes. In the geocoding crash method, crashes are coded with geographic location such as latitude and longitude and are presented in map format and/or spatially analyzed in relation to factors of interest, such as roadway types, destinations (e.g., schools), and sociodemographic information.

Conflicts

The behaviors of motorists, bicyclists, and pedestrians at intersections could be an indication of the potential for crashes at those conflict areas. "Conflict" is described as a sudden action taken by either party to avoid a collision. "Avoidance maneuvers" are defined as any change in speed or direction in response to the presence of another party. A conflict exists when it is believed that the absence of a change in action would result in a collision, while an avoidance maneuver would not necessarily result in a collision. An example of an avoidance maneuver is when a pedestrian changes course to walk around a vehicle.

In 2006, Carter et al. presented a pedestrian intersection safety index that can prioritize intersection crossings given macro-level site characteristics.[24] The analysis incorporated behavioral data in the form of conflicts and avoidance maneuvers and subjective data in the form of expert safety ratings. The final model included consideration of the presence of traffic control signal or stop-sign controlled crossing, the number of through lanes, 85th-percentile speed of the street being crossed, traffic volume on the street being crossed, and predominant lane use in the surrounding area.

There is ongoing debate about the validity of using near misses as a surrogate for vehicle crashes. Guo et al. analyzed near crashes (termed "safety critical events") in naturalistic driving data and concluded that near crashes could be used as a surrogate for actual crashes.[25] Knipling challenges the "near-crash as surrogate for crash" by arguing that near crashes and crashes are two different types of events that have only a weak correlation.[26] Knipling does concede that, with proper sampling and validation, certain types of near crashes can be used as crash surrogates.

Interactive Pedestrian Crash Map Websites

Numerous city and State DOTs 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 for 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., driver or pedestrian gender, day of week, road agency ownership).

- Click on an individual crash or HCL to get additional information.

Several examples of these interactive pedestrian crash maps are shown and described in this section.

FHWA 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 a Transportation Injury Mapping System (TIMS) to provide data and mapping analysis tools and information for traffic-safety-related research, policy, and planning. The TIMS is available at https://tims.berkeley.edu/. Several tools are available, such as interactive maps and the ability to query collision data, including pedestrian-involved collisions.

With consideration for the Vision Zero initiative, Vision Zero ATX, a local nonprofit organization, created a color-coded map that indicates each fatality's mode of travel. The map is available at http://www.visionzeroatx.org/austin-fatality-map/. It 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, Portland, OR, shows all traffic fatalities and serious injuries on a map that displays fatality and serious injury crash density. This map shows 10 yr of crash data (2005 through 2014), displays density with different-sized symbols, and allows users to click on a specific crash for additional information and view pedestrian crashes separately from other crashes. Additionally, when viewing 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. The map is available at http://pdx.maps.arcgis.com/apps/MapSeries/index.html?appid=cf122cd3b4ef46f0ac496b2d61d554e9.

As part of its Vision Zero initiative, 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. 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, interestingly, the top 50 schools are all within 0.25 mi of the high injury network. The high injury network in Los Angeles can be viewed at http://visionzero.lacity.org/high-injury-network/.

As part of a pedestrian safety initiative called WalkFirst, San Francisco, CA, displays high pedestrian injury corridors and intersections in a map-based interface. The WalkFirst site categorizes these high injury corridors and intersections by crash profiles (i.e., the causal crash factor, such as low nighttime visibility, a left-turning vehicle at a signalized intersection, alcohol use, etc.) so that a user 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 is available 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 *Los Angeles Times* analysis considered the following three factors in designating dangerous intersections:

- The total number of pedestrian collisions.
- The proportion of collisions that involved a pedestrian.
- The proportion of pedestrian accidents that were fatal.

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. For more information, see http://graphics.latimes.com/la-pedestrians/.

The North Central Texas Council of Governments, the metropolitan planning organization (MPO) for the Dallas–Fort 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 at http://www.nctcog.org/trans/sustdev/bikeped/BikePedCrashInfo.asp.

The Massachusetts DOT displays an interactive map of "Top Crash Locations" for pedestrians and bicyclists. The map groups nearby pedestrian crashes into intersection clusters based on the number of crashes occurring, with the top 200 ranking intersections displayed with a different-colored symbol. Several different types of cluster displays can be viewed, depending on the desired year range and type of crash (pedestrian or bicyclist). The map is available at http://gis.massdot.state.ma.us/maptemplate/topcrashlocations.

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

PREVIOUS STUDIES

Chicago, IL

Chicago used descriptive and spatial analyses in 2011 to identify crash trends.[27] As documented in the NHTSA report, the city evaluated injury frequency and severity for different age groups (e.g., children and seniors) as well as for various crash types and contributing environmental factors.[23] The spatial analysis presented crash density citywide by ward as well as near schools. The findings will be used to develop the Chicago Pedestrian Plan, identify engineering treatments throughout the city, and aid ongoing pedestrian safety education efforts.

Oregon

The NHTSA report states that the Oregon Department of Transportation (ODOT) Traffic-Roadway Section decided to focus limited resources on locations that have the greatest potential for crash reductions.[23] In 2013, ODOT set out to match infrastructure countermeasures with potential locations for improvements by identifying key patterns of behavior and roadway conditions that cause locations to be high risk. The NHTSA report noted that "this approach is promising, but ODOT expressed that the analysis was constrained by the limited availability of roadway information such as bicyclist and pedestrian volumes, the presence of a crossing treatment, presence of a turn lane, driveway activity, and sight distances."[23]

San Francisco, CA

San Francisco's WalkFirst (see http://walkfirst.sfplanning.org/) combines public engagement with technical and statistical analysis of where and why pedestrian collisions occur on San Francisco's streets and updates the knowledge of effectiveness and costs of various engineering measures. The first phase included identifying high-demand and high-risk corridors and intersections based on a history of severe or fatal injuries. The crash analysis found that just 12 percent of San Francisco streets account for over 70 percent of all severe and fatal crashes.

North Carolina

As documented in the NHTSA report, the North Carolina DOT Division of Bicycle and Pedestrian Transportation provides a suite of tools (see http://www.ncdot.gov/bikeped/researchdata/) designed to help practitioners understand pedestrian and bicycle crash issues, including the following:[23]

- A database of crash-typed data that can be queried.
- An interactive map.
- Detailed summary reports on pedestrian and bicyclist crash trends and common crash types.

The NHTSA report states that these tools are used to inform decisionmaking when developing the State Highway Safety Improvement plan and by local agencies receiving planning grants.[23]

San Francisco, CA; Las Vegas, NV; and Miami, FL

FHWA awarded grants to San Francisco, Las Vegas, and Miami in 2002 to examine pedestrian crashes and then to evaluate pedestrian safety countermeasures within the identified high crash zones. The goal of the project was "to demonstrate how a city could improve pedestrian safety by performing a detailed analysis of its pedestrian crash problem, identifying and evaluating high crash locations, observing factors such as driver and pedestrian behavior, and deploying various lower cost countermeasures tailored to the site."[28] The HCLs were identified by reviewing police reports.[29]

Factors Associated With Pedestrian Crashes

Understanding those roadway, traffic control devices, and traffic factors that affect pedestrian crash severity or are associated with pedestrian crashes could lead to an approach for identifying potential locations that might have a crash concern.

A 2015 study identified significant factors affecting pedestrian crash injury severity at signalized and unsignalized intersections using a mixed logit model.[30] The study used 3 yr of pedestrian crash data from Florida (2008–2010) and included 3,038 pedestrian crashes. Of those crashes, 2,360 occurred at signalized intersections, and 678 occurred at unsignalized intersections. The study only included State roads, and the authors recommended additional research for local roads.

For signalized intersections, the following were associated with higher pedestrian severity risk:

- AADT.
- Speed limit.
- Percentage of trucks.
- Very old pedestrians (age ≥ 80 yr).
- At-fault pedestrians.
- Rainy weather.
- Dark lighting conditions.

The authors provided the following examples:

- A 1-percent higher truck percentage increases the probability of severe injuries by 1.37 percent.

- A 1-mph higher speed limit increases the probability of severe injuries by 1.22 percent.

At unsignalized intersections, the following were associated with higher pedestrian severity risk:

- A pedestrian walking along a roadway.
- Middle-aged and very old pedestrians (age ≥ 80 yr).
- At-fault pedestrians.
- Vans.
- Dark lighting conditions.
- Higher speed limit.

Standard crosswalks were associated with a 1.36-percent reduction in pedestrian severe injuries for unsignalized intersections. (The standard crosswalk was shown in a figure to be a crosswalk with two transverse lines. The crosswalk marking type was a binary categorical variable: 1 when transverse lines were present and 0 otherwise.) This variable was not found to be significant for signalized intersections.

Haleem et al. reviewed several previous studies that conducted pedestrian injury severity analyses.[30] Table 6 and table 7 summarize the variables that were found to be significant in the various studies.

Table 6. Summary of significant variables identified from pedestrian injury severity analyses, part 1 of 2.[30]

Study	Key Characteristics	Significant Variables
Zajac and Ivan, 2003[31]	Rural Connecticut	• Roadway width. • Vehicle type. • Alcohol involvement. • Pedestrian age.
Mohamed et al., 2013[32]	New York City and Montreal, Canada	• Presence of heavy vehicles. • Absence of lighting. • Prevalence of mixed-lane use.
Oh et al., 2005[33]	Korea	Collision speed
Garder, 2004[34] Strandroth et al., 2011[35] Zhao et al., 2013[36]	Several studies	Collision speed
Sarkar et al., 2011[37]	Bangladesh (1998–2006)	• Elderly pedestrians (older than 55 yr). • Young pedestrians (younger than 15 yr). • Pedestrians who crossed compared to those who walked along the street. • Trucks, buses, and tractors as compared to cars. • Locations with no control or stop control compared to signalized intersections.
Tarko and Azam, 2011[38]	Linked police and hospital crash data	• Male. • Older. • Rural and high-speed urban roadways, especially for pedestrians crossing the roadway. • Crossing between intersections (i.e., midblock). • Size and weight of vehicle.

Note: Material in this table is based on results documented in Haleem et al. (2015).

Table 7. Summary of significant variables identified from pedestrian injury severity analyses, part 2 of 2.[30]

Study	Key Characteristics	Significant Variables
Al-Shammari et al., 2009[39]	Riyadh, Saudi Arabia, 3 yr	• Men. • Crossing.
Nasar and Troyer, 2013[40]	Data from U.S. Consumer Product Safety Commission and hospital emergency rooms (2004–2010)	• Mobile-phone-related injuries among pedestrians increased relative to total pedestrian injuries. • Pedestrian injuries related to mobile phone use were higher for males and people under 31 yr.
Byington and Schwebel, 2013[41]	Conducted in a simulator	Pedestrian behavior was considered riskier while simultaneously using mobile device and crossing the street than when crossing the street with no distraction.
Lee and Abdel-Aty, 2005[42]	Intersections in Florida (1999–2002)	• Pedestrian age. • Weather. • Lighting conditions. • Vehicle size.
Jang et al., 2013[43]	San Francisco, CA (2002–2007)	Alcohol involvement, cell phone use, age (below 15 or above 65 yr), nighttime, weekends, rainy weather, larger vehicles
Kim et al., 2010[44] Kim et al., 2011[45]	North Carolina (1997–2000)	Darkness without streetlights, trucks and sport utility vehicles, speeding involvement, freeway sections, increase in pedestrian age

Note: Material in this table is based on results documented in Haleem et al. (2015).

In 2014, Jermprapai and Srinivasan reported on a planning-level model for assessing pedestrian safety.[15] They noted that their review of the literature found that past research had focused on specific cities or counties with census tracts as the unit of analysis. Their study used a larger study area (the entire State of Florida) at a finer spatial resolution (census block groups rather than tracts). Crash data from 2005 to 2009 and land use data from the entire State of Florida were used in developing four models: total crashes, severe and fatal crashes, fatal crashes, and nighttime crashes. Their results generally reaffirmed other studies concerning the relationship between crashes and socioeconomic, land use, and transportation characteristics. One of their findings was that a low-income location in a higher income county is riskiest. They also concluded that locations with a larger volume of conflicting vehicular and pedestrian movements make the locations riskier. Table 8 through table 10 summarize the findings from the Jermprapai and Srinivasan study for severe and fatal crashes along with their findings from a review of the literature.[15]

Table 8. Summary of results from literature on planning-level models (socioeconomic).[15]

Variable	Abdel-Aty et al., 2012[46] and Siddiqui and Abdel-Aty, 2012[47]	Ukkusuri et al., 2012[48] and Ukkusuri et al., 2011[49]	Green et al., 2011[50]	Cottrill and Thakuriah, 2010[51]	Chakravarthy et al., 2010[52]	Wier et al., 2009[53]	Loukaitou-Sideris et al., 2007[54]	Noland and Quddus, 2004[55]	LaScala et al., 2000[56]	Jermprapai and Srinivasan, 2014[15]
Population (or density)	+	+	o	+	+	o	+	+	+	+
Minority	+	+	+	o	o	o	+	o	o	o
Income	–	o	o	–	–	–	o	o	o	–
Population below poverty	o	o	o	o	o	o	o	o	o	+
Education	o	o	o	o	–	o	o	o	o	–
Non-English speaker	o	o	o	o	+	o	o	o	o	+
Proportion of transit users	+	o	o	o	o	o	o	o	o	o
Proportion who walk	+	o	+	+	o	o	o	o	o	o
Median age	o	o	o	o	o	o	o	o	o	+
Median household income	o	o	o	o	o	o	o	o	o	–

+ = increased pedestrian crashes; – = decreased pedestrian crashes; o = not part of study.

Note: The final column is based on results documented in Jermprapai and Srinivasan (severe and fatal crashes); the rest of the table is based on table 2 in Jermprapai and Srinivasan.[15]

Table 9. Summary of results from literature on planning-level models (land use—environment).[15]

Variable	Abdel-Aty et al., 2012[46] and Siddiqui and Abdel-Aty, 2012[47]	Ukkusuri et al., 2012[48] and Ukkusuri et al., 2011[49]	Green et al., 2011[50]	Cottrill and Thakuriah, 2010[51]	Chakravarthy et al., 2010[52]	Wier et al., 2009[53]	Loukaitou-Sideris et al., 2007[54]	Noland and Quddus, 2004[55]	LaScala et al., 2000[56]	Jermprapai and Srinivasan, 2014[15]
Housing density	+	o	o	o	o	o	o	o	o	o
Residential area	o	o	o	o	o	o	+	o	o	+
Industrial area	o	+	o	o	o	o	o	o	o	–
Commercial areas	o	+	o	o	o	+	+	o	o	–
Total employment	+	o	o	o	o	+	+	o	o	o
Number of schools	o	+	o	+	o	o	o	o	o	–
Crime	o	o	+	+	o	o	o	o	o	o
Alcohol availability	o	o	o	o	o	o	o	+	+	o
Distance from big city	o	o	o	o	o	o	o	o	o	+

+ = increased pedestrian crashes; – = decreased pedestrian crashes; o = not part of study.
Note: The final column is based on results documented in Jermprapai and Srinivasan (severe and fatal crashes); the rest of the table is based on table 2 in Jermprapai and Srinivasan.[15]

Table 10. Summary of results from literature on planning-level models (traffic and transportation system).[15]

Variable	Abdel-Aty et al., 2012[46] and Siddiqui and Abdel-Aty, 2012[47]	Ukkusuri et al., 2012[48] and Ukkusuri et al., 2011[49]	Green et al., 2011[50]	Cottrill and Thakuriah, 2010[51]	Chakravarthy et al., 2010[52]	Wier et al., 2009[53]	Loukaitou-Sideris et al., 2007[54]	Noland and Quddus, 2004[55]	LaScala et al., 2000[56]	Jermprapai and Srinivasan, 2014[15]
Traffic volume	+	o	o	+	o	+	+	o	+	o
Local roads	o	+	o	o	o	+	o	o	o	o
Access-controlled roads	–	–	o	o	o	o	–	o	o	–
Number of intersections	+	+	+	o	o	o	o	o	+	–
Stations or bus stops	o	+	o	o	o	o	o	o	o	o
Total weekly work trips	o	o	o	o	o	o	o	o	o	–

+ = increased pedestrian crashes; – = decreased pedestrian crashes; o = not part of study.
Note: The final column is based on results documented in Jermprapai and Srinivasan (severe and fatal crashes); the rest of the table is based on table 2 in Jermprapai and Srinivasan.[15]

Previous Evaluation of Methods

Vasudevan et al. evaluated the following methods used to identify pedestrian HCLs:[(57)]

- Crash index based on crash frequency method. The HCL with the highest number of crashes is ranked 1, and the remaining HCLs are then ranked in a descending order of their numbers of crashes.

- Crash index based on weighted frequency method. This method was based on the severity and frequency of pedestrian crashes and accounted for the density of crashes.

- Crash index based on vehicular traffic volume. This index is defined on the basis of the number of pedestrian crashes and the average daily traffic (ADT).

- Crash index based on pedestrian age group. This index considered the number of crashes for each age group, the population for each age group, and weights to consider the pedestrians' inexperience and other characteristics.

- Sum-of-the-ranks (SR) method. The SR method combines the previous methods into a single rank value.

- Crash score (CS) method. The CS method considers crash frequency, weighted factors, traffic volume, and pedestrian exposure that are normalized.

The authors used data for 30 pedestrian HCLs in Las Vegas to illustrate the methods and to conduct statistical analyses using Spearman's correlation coefficient of ranking. Crash data between 1996 and 2001 were available. They concluded that, although any of the methods could be used to identify pedestrian HCLs, the simple-frequency-based or weighted-frequency-based methods would be adequate as a first step.

Pulugurtha et al. used Las Vegas, NV, crash data from 1998 to 2002 to evaluate several of the methods listed previously along with a GIS method.[(19)] The GIS method was used to help quantify the concentration of crashes and reduce the degree of subjectivity involved in identifying high crash zones. It resulted in 22 linear zones and 7 circular zones. Pulugurtha et al. evaluated the following methods for those 29 zones:[(19)]

- Crash frequency.
- Crash frequency based on severity.
- Crash density based on area.
- Crash rate based on vehicular volumes.
- Crash rate based on population.
- SR method.
- CS method.

The authors concluded that, because the rankings obtained for each zone were relatively consistent for the SR and CS methods compared to the individual methods, the composite methods are more robust. They recommended the CS method over the SR method, since it also helps identify the cause of the safety problem.

CHAPTER 3. INTERVIEWS WITH GOVERNMENTAL AGENCIES

BACKGROUND

Researchers contacted representatives from a variety of State, regional, and local agencies to gain insights into how they identify high pedestrian crash locations. The goal was to determine at least the following:

- What criteria are being considered to identify high pedestrian crash locations?
- What tools are being used to identify high pedestrian crash locations?

QUESTIONS

Criteria used to select agencies included the following:

- Whether they are a focus city or State (Arizona; Austin, TX; Los Angeles, CA; Miami-Dade, FL; New York City, NY; and Phoenix, AZ).
- Whether they have a pedestrian action plan (Arizona and Phoenix, AZ).
- Whether they have adopted a Vision Zero policy (Portland, OR; Austin, TX; and Los Angeles, CA).
- Whether they have a pedestrian emphasis area within their Strategic Highway Safety Plan (New York City, NY).

Preference was also given to talking to those agencies that did not participate in the NCHRP 17-73 survey to avoid contacting the same individuals with similar questions.(14) Table 11 lists the questions used with the government representatives.

Table 11. Discussion questions for government representatives.

No.	Question	Potential Answers/Prompts/Comments
1	What are the focus areas within your safety programs?	Lane departure, pedestrians, etc. If pedestrians are not one of their focus areas, thank them for their time.
2	What is your current method for identifying high pedestrian crash locations?	Reactive/hot spots (based on crashes) or proactive/systemic (based on something else)
3	How do you identify the locations of concern (where you will develop potential countermeasures)?	Potential criteria: count of pedestrian crashes, rate of pedestrian crashes, severity, etc.
4	What tools are you using to assist in the identification of high pedestrian crash locations?	Spreadsheets, Safety Analyst, usRAP, ArcGIS®, open-source tools, OpenStreetMap™.
5	Do you consider exposure? If so, how?	ADT, vehicle miles traveled, pedestrian counts, etc.

No.	Question	Potential Answers/Prompts/Comments
6	Have you used or considered surrogates?	Conflicts
7	Do you cluster your pedestrian crashes to identify hot zones?	Rely on a software app.
8	If yes, what criteria are you using?	Distance between the crashes, severity level for the crashes, density, age of the pedestrian, weights (by distance to school), equity (avoid lower income being overburdened)
9	What skill sets are needed to conduct these studies? Do you have those skill sets in-house, or do you contract?	If you contract, who usually does the work?
10	How frequently do you conduct the analysis? How frequently should it be conducted?	Looking to compare what they do and what they think they should do
11	Can you provide examples of what needs to be done to go from your crash records to a final list of sites needing treatments?	Protocol for assigning crashes (latitude/longitude or street names)
12	What are your lessons learned or takeaway you would offer from your experience?	Looking for general comments
13	Do you have any other comments?	This question provides the opportunity to cover items not previously discussed.

The following sections summarize the findings from the interviews.

What Are Focus Areas Within Your Safety Programs?

All the agencies participating in the interviews have a pedestrian focus within their safety efforts. Portland, Austin, and Los Angeles are implementing a Vision Zero policy with very aggressive goals for reducing crashes. Another community with a Vision Zero policy is San Francisco, CA, which maintains a pedestrian–vehicle injuries and high injury corridor interactive map on its website.(58) Los Angeles announced in August 2015 the goal of reducing citywide traffic deaths by 20 percent by 2017 and eliminating all traffic deaths by 2025.(59) Portland also has a goal of eliminating all serious and fatal crashes by 2025.

What Is Your Current Method for Identifying High Pedestrian Crash Locations? How Do You Identify the Locations of Concern (Where You Will Develop Potential Countermeasures)?

All the agencies interviewed are primarily using crashes to identify high pedestrian crash locations. They use GIS tools to identify the HCLs. Some agencies focus more on corridors, while others use intersections. After the crash histories for specific locations are identified, the agencies use a variety of techniques to develop a shorter list of sites where treatment will be identified. The crashes at the priority locations are then investigated further to help define which countermeasures to select.

Several agencies noted that the selection of a site for treatment may be the result of an opportunity to treat a site that is also undergoing needed maintenance, such as an overlay. The occurrence of a high-visibility crash or fatality may also affect whether a site is considered for improvements.

Miami-Dade uses GIS crash density maps to identify locations and segments with clusters of crashes. After identifying the initial list of candidate locations, three factors were used to develop the final list of locations: input from MPO staff, information in the Florida DOT work program, and review of aerials.(60) They also consider anecdotal data for injury crashes that do not generate a crash report.

In addition to the consideration of crashes, Austin would like to have a method to integrate public comments into its procedure.

Phoenix has Global Positioning System coordinates for all crashes and plots within a GIS to identify hot spots. Phoenix also considers the distance between points to identify corridors and noted that plotting makes it easy to identify hot spots. The Arizona DOT identifies HCLs using GIS density tools. The locations are separated into highway segments, intersections, and interchanges, with subsequent visual review to identify appropriate and logical end points to the segments. The Arizona DOT also uses a risk assessment methodology to identify segments and intersections where investment can help to lower the risk of pedestrian crashes. The methodology is modeled after those documented in NCHRP Report 803 and a risk assessment tool used by the Washington State DOT.(12,61) Application of the methodology occurs in the following two steps:

- Step 1. Identify and screen potential locations where pedestrian facilities should be considered.

- Step 2. Rank the proposed pedestrian facility improvement locations (e.g., roadway segments or intersections) to determine a rank order for funding and/or implementation. This step also incorporates a benefit–cost analysis, which will be developed in subsequent tasks of the study.

New York City identifies priority lists using the following three categories:

- Area.
- Corridors (must be a minimum of 1 mi).
- Intersections.

New York City bases its lists on 5 yr of data. When identifying potential locations for treatment, the city identifies areas and corridors for approximately 50 percent of the borough. For intersections, the city limits the locations to about 15 percent of the borough to obtain a manageable list (about 5,500 for the entire city).

Los Angeles uses a score that also considers the number of injured, the number of fatalities (multiplied by a 1.5 factor), the age of the pedestrian (an additional point is assigned for youth and older pedestrians), and a health and equity index.(62) Having the ability to also integrate public comments, work requests such as sidewalk repairs, and trauma data was suggested as another method to identify locations of concern that are not currently integrated into the method but could be considered in the future. The locations are generally identified as either intersections, corridors, or areas.

Portland identified the top 20 high crash streets for driving, bicycling, and walking. The combination of those sites resulted in 30 streets being on their high crash network. The motor vehicle network includes the streets with the highest number of people killed or seriously injured between 2004 and 2013. The bicycle and pedestrian networks include streets with the highest number of crashes, regardless of severity, for people on bikes and walking, respectively, in recognition that the difference between a minor injury and a serious injury for pedestrians or bicyclists is "often random and circumstantial."(63) The number of 20 high crash streets per mode (30 total) was selected as representing a balance between having enough streets to capture most of the fatal crashes and not having so many as to make the subsequent evaluation and countermeasure implementation steps exceed available resources.

What Tools Are You Using to Assist in the Identification of High Pedestrian Crash Locations?

All the agencies are using a GIS to identify high pedestrian crash locations. Some of the agencies are also using database software to help manage the data. The Arizona DOT imports the crashes into a Google® Fusion™ table/map that assists with the visual review of locations. Using this tool gives the analyst the capability to customize a data table with key crash attributes and to spatially evaluate these attributes associated with the pedestrian crash by running queries or filters. Another advantage is the ability to visually inspect the specific crash location with Google® Street View™ to determine roadway characteristics that cannot be identified with satellite imagery.

Do You Consider Exposure? If So, How?

Several agencies commented that they are not considering pedestrian volume exposure because of the lack of good data or because they are focusing on reducing the overall number of crashes rather than reducing a crash rate. They may consider distance (e.g., per mile) when comparing corridors of different lengths. Several agencies noted that they may collect pedestrian volume data on a project basis when needed during countermeasure identification.

Have You Used or Considered Surrogates?

Some agencies have considered surrogates, including the following:

- The location of activity centers.
- The 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 stops or rail stations with respect to origins or destinations or number of riders (on or off).

- The number of lanes in combination with operating speed.
- A score that reflects the walkability of a street.
- Citizens' comments.

In most cities, the number of crashes involving pedestrians is the key metric.

The Arizona DOT is using the FHWA Pedestrian Bicycle Crash Analysis Tool (PBCAT) to crash-type each crash on the State highway system. PBCAT identifies the events leading up to the crash.

Do You Cluster Your Pedestrian Crashes to Identify Hot Zones? If Yes, What Criteria Are You Using?

The interviewed agencies do review their data to identify clusters of crashes. Typically, they generate corridors that include multiple intersections. The Miami-Dade MPO noted that it has used age-group crash clusters to show areas where crashes involving juveniles are prevalent.

Los Angeles considers corridors rather than just intersections (similar to New York City and San Francisco). Visual review is used to find the clustering of intersections because the locations are obvious after the plotting of the data.

The Arizona DOT noted that it identifies locations based on GIS density/cluster analysis. The DOT does not have defined criteria (e.g., a certain number of crashes within a given distance) but is discussing potentially developing such criteria. Because of the dispersed nature of the State highway system and the random pattern of crashes, identifying clusters according to specific set criteria is difficult. A visual confirmation of the density locations identified in the GIS has been its approach, which, the DOT noted, would be difficult in a denser urban environment with a denser street network.

What Skill Sets Are Needed to Conduct These Studies? Do You Have Those Skill Sets In-House, or Do You Contract?

The skill sets needed to work with crash data include familiarity with a GIS, the ability to work with attribute tables, and programming skills. Understanding how to identify appropriate crash types and interpreting crash data are also valuable skills.

Many of those interviewed commented that they have gone outside of their immediate department to obtain the needed skill sets.

How Frequently Do You Conduct the Analysis? How Frequently Should It Be Conducted?

The analysis period ranged between 1 and 3 yr. Those locations with a higher number of pedestrian crashes (e.g., New York City and Los Angeles) tend to use a longer update cycle. Those agencies commented that minimal change occurs with a 1-yr increment for their region. Some of the agencies noted that the analysis period can be affected by the availability of crash data because they have to wait until the State releases the data to them.

Can You Provide Examples of What Needs to Be Done to Go From Your Crash Records to a Final List of Sites Needing Treatments?

Each of the agencies noted that problems and/or mistakes exist within the crash datasets they use, which requires them to clean the data. Having the geocodes for each crash results in the ability to identify problem locations faster and with greater confidence. In previous decades, the agencies would pull data for select intersections to determine crash patterns. The availability of geocodes allows the consideration of the entire city or State. There are concerns about the accuracy of the geocodes, especially when trying to determine if a specific crosswalk at an intersection needs attention. The Miami-Dade MPO noted that the Florida DOT has begun to supply local agencies with crash data shapefiles, which eliminates the labor-intensive process of address matching and data entry. New York City commented that local police are experimenting with new equipment that will permit geocoding of the crash location in the field.

What Are Your Lessons Learned or Takeaway You Would Offer From Your Experience?

Observations on lessons learned from their experiences include the following:

- Data sharing between partner agencies is important.
- Having access to crash report shapefiles is critical for problem identification.
- Pedestrian and bicycle crashes are different from motor crashes and require a special effort.
- It is good to break the analysis down into three groups: area, corridor, and intersection.
- Lists of sites and plans should be shared with the public so that people know where the city is working and why.
- New York City solicited observations from citizens to identify problems such as speeding and double parking; however, New York City found that most of the information came from areas that were more educated or wealthy, thus creating a bias within the data. The city commented that outreach is important to help shape the development of treatments for a site or for confirming trends and patterns found in the data analysis but not in prioritizing locations.
- The Vision Zero process can move very quickly, perhaps faster than some in a city will be used to.
- Having additional analyst(s) with the needed skill sets is very important.

Do You Have Any Other Comments?

An additional comment made at the conclusion of the interview by several agencies is the desire to be able to better identify unreported collisions.

New York City noted that Los Angeles and San Francisco are also including an equity focus to ensure that locations in poor or predominately one-race locations are being considered for treatment upgrades.

CHAPTER 4. INTERVIEWS ABOUT PEDESTRIAN COLLISION WARNING SYSTEMS

INTRODUCTION

The existing process for identifying unsafe locations for pedestrians is often based on accumulating pedestrian–motor vehicle crashes over several years until a high crash pattern emerges at specific locations. But what if engineers and planners did not have to wait until too many crashes happen to be able to identify these unsafe locations? What if engineers and planners had the ability to quickly (within weeks or months) identify where a lot of near crashes occur between pedestrians and motor vehicles, without waiting for years for high numbers of pedestrian crashes to occur?

Automated pedestrian collision warning systems in newer cars have the potential to dramatically improve the way engineers and planners identify unsafe locations for pedestrians. These warning systems use advanced sensors to detect when pedestrians are in proximity to a car's trajectory and then provide a warning to the driver. In some collision warning systems, the car brakes may be automatically activated to avoid a collision with the pedestrian.

Conceptually, these near-crash collision warning events could be logged by a car's computer system and then communicated to a centralized database. If these near-crash events are accumulated over all vehicles with pedestrian collision warning systems, there is the potential to have a citywide view of near crashes. If near crashes are an adequate surrogate for actual crashes, unsafe locations for pedestrians could be easily identified within weeks or months rather than years.

Research conducted by Leidos, Inc., for FHWA in 2014 and 2015 identified numerous vehicle-to-pedestrian (V2P) technologies that are capable of providing warnings to motor vehicle drivers or pedestrians of impending pedestrian–vehicle crashes.[64] The in-vehicle pedestrian collision warning systems described earlier are termed "unilateral pedestrian detection and driver notification" because the collision warning is provided only to the driver. This FHWA V2P effort resulted in the development of a Research Implementation Plan in May 2015.[65] However, none of the FHWA V2P documents presented the concept of using pedestrian collision warning events as surrogates for actual pedestrian crashes.

IN-VEHICLE SYSTEMS

Several new car models come equipped with collision avoidance systems that include pedestrian detection. These warning systems use advanced sensors to detect when pedestrians are in proximity to the car's trajectory and then provide a warning to the driver. In some collision warning systems, the brakes may be automatically activated to avoid a collision with the pedestrian. Consider the following examples:

- Toyota has a precollision system with pedestrian detection.
- Ford has precollision assist with pedestrian detection.
- General Motors has front pedestrian braking.

- BMW’s Driving Assistant includes a pedestrian warning.
- Honda is working on a pedestrian collision mitigation steering system.

RESEARCH APPROACH

In task 3 of this project, the research team contacted three industry representatives to discuss the feasibility of logging warning events from pedestrian collision warning systems for use in pedestrian safety analyses. The following three companies were contacted:

- Mobileye ™, a manufacturer of machine vision and pedestrian detection systems.

- Toyota ™, a global auto manufacturer.

- HERE ™, an information services company that provides advanced driver assistance systems.

The following section summarizes the findings from these three companies.

INTERVIEWS

Mobileye

Mobileye is a global leader in vision-based driver assistance and collision avoidance systems, and its machine vision products can be found in many common production car models.(66) Mobileye also works with a number of tier 1 partners that supply automotive components to other car manufacturers. They also have an aftermarket single-camera system suitable for trucks and passenger cars that can provide alerts and hot spots when connected to select devices.

In addition to its car-based collision avoidance systems, Mobileye has developed a pedestrian and bicyclist collision avoidance system for trucks, buses, and commercial vehicles called Mobileye Shield+™.(67) The Mobileye Shield+™ system uses similar machine vision technology to detect and track pedestrians and bicyclists in proximity to large vehicles. However, Mobileye Shield+™ differs from most auto-based collision avoidance systems in that it uses several strategically placed cameras to “see” in blindspots at the rear of these large vehicles. The Mobileye Shield+™ system has been installed by several transit authorities and other fleet vehicle operators in an effort to reduce pedestrian and bicyclist collisions.

These two types of collision avoidance systems—consumer-auto based and fleet-vehicle based—are addressed separately in this discussion. Fleet-vehicle-based collision warning systems represent the most feasible near-term implementation for logging and analyzing collision warning system events. Fleet vehicle operators have a strong vested interest in analyzing and understanding collision warning events in which their drivers are involved and in using this information to improve both fleet vehicle and roadway safety and operation. For consumer-auto-based systems, most consumers tend to be more concerned about their individual privacy and are hesitant to voluntarily provide data about their driving patterns, especially events such as collision warnings.

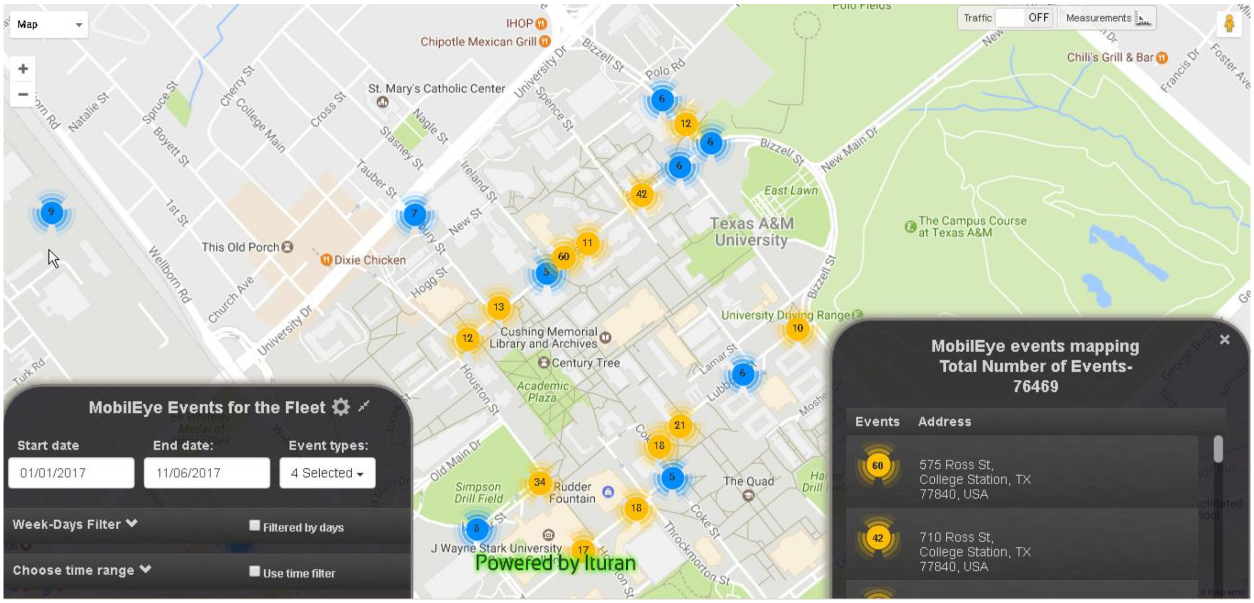
For Mobileye's consumer-auto-based systems, it is not currently feasible for Mobileye to log collision warning events generated by its machine vision technology in consumer autos. Essentially, Mobileye is a parts supplier for automakers and other tier 1 parts suppliers and does not currently have a communication mechanism with new consumer autos equipped with advanced collision warning systems. If a consumer auto does have a communication mechanism (e.g., connected car), it could be with the automaker that sells the car or with an information services provider that offers location-based services (e.g., real-time navigation or travel time information). In these cases, the consumer who purchases the car must agree to terms and conditions that permit data to be retrieved from the onboard computer systems. However, these terms and conditions are often buried in long user agreements that few consumers actually read or fully understand (i.e., similar to lengthy software user agreements on desktop computers or smartphones). In summary, Mobileye is not currently involved in connected car communication with consumer autos equipped with its collision avoidance technology, thereby making it currently infeasible for Mobileye to log pedestrian collision warning events from consumer autos.

For Mobileye's fleet-vehicle-based systems, it is feasible for Mobileye to log collision warning events. Mobileye has developed an analytics platform for summarizing these Mobileye Shield+™ collision warning events. The primary reason for differences of warning system data availability between consumer autos and fleet vehicles is that Mobileye sells the Mobileye Shield+™ system directly to the fleet vehicle operator and is, therefore, in the position to provide the communication mechanism needed to retrieve warning system event data from each equipped fleet vehicle. In fact, Mobileye markets the Mobileye Shield+™ system to include a "…full telematics system which tracks the vehicle and reports all warnings made by the Mobileye System to your fleet management system, providing fleet managers with valuable information about their drivers' daily driving behavior."(66)

Several transit agencies have already conducted pilot evaluations of the Mobileye Shield+™ system, including the Metropolitan Transit Authority in New York and King County Metro in Seattle, WA. As part of USDOT's Smart City Challenge, Mobileye is planning to equip 300 transit buses in Columbus, OH, with the Mobileye Shield+™ system.

In partnership with another laboratory, the researchers also conducted a pilot evaluation of the Mobileye Shield+™ system on one of the busiest routes on the Texas A&M campus. The evaluation of the Mobileye Shield+™ system was conducted from January to March 2016. During this period, the equipped bus was in active service for 27 d and accumulated 41 pedestrian collision warnings (based on an estimated time to collision of 1.5 s). These pedestrian collision warnings were issued to the bus driver using both visual and audio alerts. These warnings and other sensor events were also communicated to a central repository and saved for historical analysis. This Mobileye Shield+™ evaluation illustrates the near-term feasibility of logging and analyzing collision warning system event data.

Since the exact location of each collision warning event was logged by the Mobileye system, the events could be easily mapped to show the frequency of these events. Mobileye had already created a hot spot locator that enabled a crash frequency map to be generated in a point-and-click Web browser interface (figure 1). These hot spot locations were shared with the Texas A&M bus operators and dispatchers, who confirmed they were known locations where bus–pedestrian–bicyclist conflicts were common.



Source: Evaluation of Mobileye Shield+TM.

Figure 1. Screenshot. Mobileye interface for mapping warning event hot spot locations.

This Mobileye system for fleet vehicles serves as a proof of concept for saving and analyzing pedestrian collision warning events. However, the limitation to fleet vehicles may restrict the representativeness of the data gathered. For transit systems, the warning event data are limited to the bus routes driven by equipped buses. For other fleet vehicles, the warning events may be unique to that type of fleet vehicle and not indicative of normal consumer cars and trucks.

Toyota

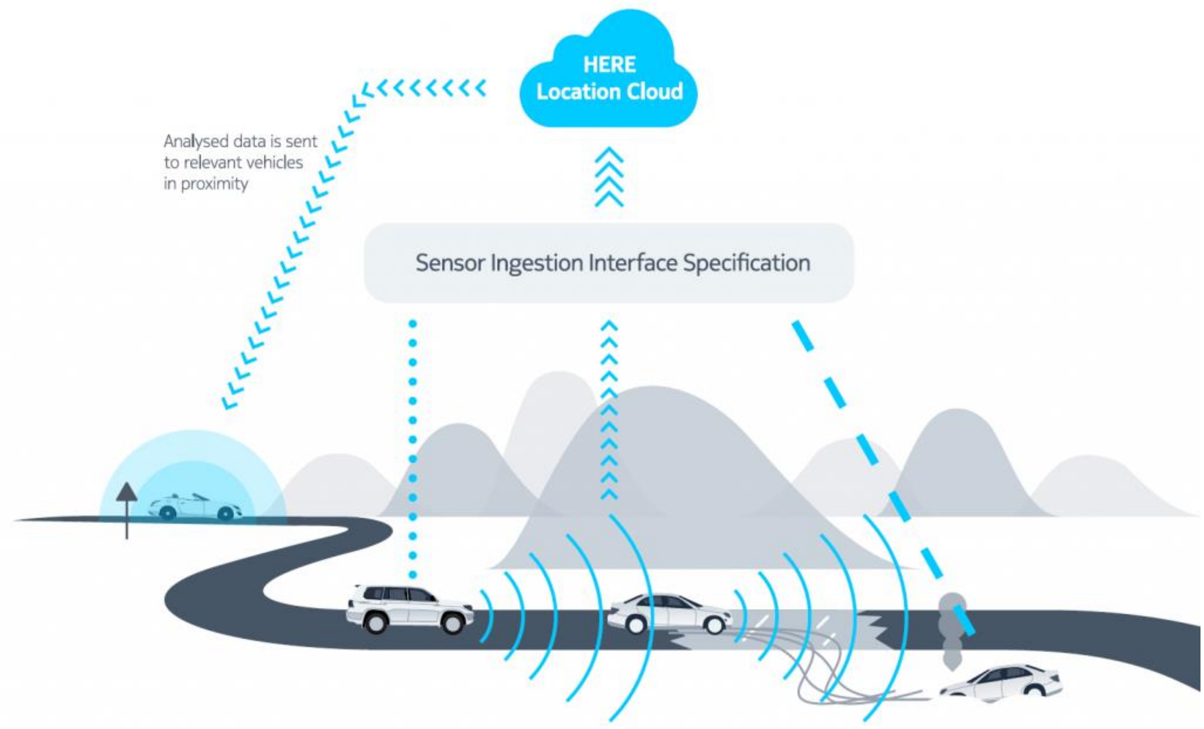
Toyota is a global auto manufacturer that produces several car models with its precollision system with pedestrian detection function.[68] According to the Toyota representative, Toyota does not have access to the warning system data generated by its precollision system. That is, Toyota does not currently have the communication mechanism in place to permit the routine logging of pedestrian collision warning events. In actual crash situations, Toyota Motor Sales investigators may retrieve data from the in-vehicle computer system, but this data retrieval is performed onsite on a case-by-case basis, and the data gathered in this situation are considered confidential.

The Toyota representative indicated that the Insurance Institute for Highway Safety's Highway Loss Data Institute has gathered postcrash data from onboard collision warning systems (i.e., forward crash and lane departure) in an effort to estimate the value and benefits of collision warning systems.[69] However, this effort is not systematic across the entire equipped vehicle fleet (i.e., it includes only vehicles in crashes that have an insurance claim) and has not been performed for pedestrian collision warning systems yet due to their very low vehicle fleet penetration.

HERE

HERE is a global location-based data services company that also provides mapping technology used in advanced driver assistance systems. HERE gathers and systematizes location content (e.g., road networks, buildings, parks, points of interest, and traffic patterns) and then sells or licenses this location content to carmakers, various other businesses, and government entities.

Of particular interest in this discussion are the connected vehicle services that HERE currently provides (or plans to provide) to several carmakers. To provide these information services to consumer cars, HERE must maintain a communications mechanism that enables two-way data flow. That is, HERE first gathers various sensor data from the connected cars of several automaker brands; second, HERE anonymizes, aggregates, and analyzes the data to develop actionable information; and third, HERE communicates the actionable information to the relevant connected cars via the cellular network or short-range communications networks. For example, for a temporary road hazard where some drivers are using hard braking (figure 2), HERE would gather these hard-braking events, and HERE's location analytics platform would infer that something is causing an unexpected slowdown at that location. HERE would then communicate a targeted traffic disruption/slowdown warning to the automaker's connected cars that are approaching the location.



Source: http://360.here.com/2015/06/23/here-sensor-data-ingestion/, ©HERE.

Figure 2. Graphic. Simplified concept of HERE's car-to-cloud data transmission specification.(70)

This simple example can be extended to all types of events that might occur in a connected car, including a pedestrian collision warning event. All that is required (from a technical perspective) is a real-time communications mechanism that can be used to gather event data from the onboard car computer system. Of course, from a business perspective, there must be some value in gathering and aggregating connected car data. New car models have extensive sensor systems that can generate terabytes of data per day, which requires extensive communications bandwidth and data disk storage. To maintain a sustainable business model, companies like HERE will have to make tough decisions about which connected car data are most valuable to collect and aggregate in a centralized database.

For confidentiality reasons, the HERE representative was not able to discuss specific company plans or actions about gathering pedestrian collision warning events and making them available for historical/analytic purposes. However, in the public realm, HERE has recently been working with the entire automotive industry on standardizing the information that is gathered from connected cars so that interoperability among various car models and information service providers is possible. In June 2015, HERE published a vehicle-to-cloud data specification that is intended to standardize the data that are transmitted from connected cars to centralized cloud-based databases.(71) This HERE data specification does address pedestrian and bicyclist detection from onboard car sensors but does not address warning system events. The following data attributes are included in version 2.0.2 of HERE's data specification:

- Object detection types (section 2.17): Two possible values of detected objects are "MOVING_BIKE" and "MOVING_PERSON."
- The path of the detected pedestrian or bicyclist ("movingVector_mps").
- The size of the detected pedestrian or bicyclist ("objectSizeVector_m").
- Any associated media (image or video) of the detected pedestrian or bicyclist ("mediaID").

In June 2016, HERE submitted the design for a standardized data format for connected car sensor data to a European public/private partnership for intelligent transport systems, which has agreed to continue as an innovation platform to evolve the design into a standardized interface specification for broad use across the automotive industry. Recently, HERE announced it will be using this car-to-cloud data specification to gather sensor data from various car manufacturers.(72) Although the initial scale of this HERE activity could be modest (in terms of numbers of connected cars involved), it is considered the early steps on a path toward much greater levels of sensor data collection from connected cars.

CHAPTER 5. DEVELOPMENT OF THE *GUIDEBOOK* AND WEBINAR WORKSHOP

OVERVIEW

The findings from the literature and interviews were incorporated into the *Guidebook on Identification of High Pedestrian Crash Locations* and a 90-min webinar workshop.(1)

DEVELOPMENT OF *GUIDEBOOK ON IDENTIFICATION OF HIGH PEDESTRIAN CRASH LOCATIONS*

Background

One of USDOT's top priorities is the improvement of pedestrian and bicyclist safety. 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 occur or where there is a concern they are likely to occur. As part of an FHWA project, the *Guidebook on Identification of High Pedestrian Crash Locations* was developed to assist State and local agencies in identifying high pedestrian crash locations such as intersections (points), segments, facilities, and areas.(1) 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.

Process to Identify High Pedestrian Crash Locations

Several agencies were contacted to gather information on how they identify high pedestrian crash locations. This information coupled with findings from a review of the literature generated the process shown in figure 3. The steps are as follows:

1. **Select approach.** The *Guidebook* focuses on the traditional (also known as "reactive") approach. If a proactive approach is preferred, the *Guidebook* gives suggestions on other reference documents.

2. **Gather data.** The typical data needed consist of crash data (including severity, crash type, contributing factors, and, importantly, the location of the crash preferably as latitude and longitude coordinates) and roadway characteristics (e.g., the number of lanes or traffic control devices present). Exposure data in the form of vehicle counts, pedestrian counts, and/or turning and crossing movement counts for specific locations may also be desired.

3. **Plan assessment.** The substeps are to select scale (e.g., intersections, segments, or area), performance measures (e.g., crash frequency or crash rate), and screening method (e.g., simple ranking or a more complex approach that requires software).

4. **Conduct assessment.** Several tools are available to assist in conducting the assessment, with most having data requirements in addition to crash data. Some of the tools can require additional training or a skill set in a GIS before an assessment can be conducted.

5. **Prioritize locations**. After the selected performance measure(s) and screening method(s) are applied to the study network, the resulting list of sites can be arranged using a simple ranking or by considering adjustments or community priorities.

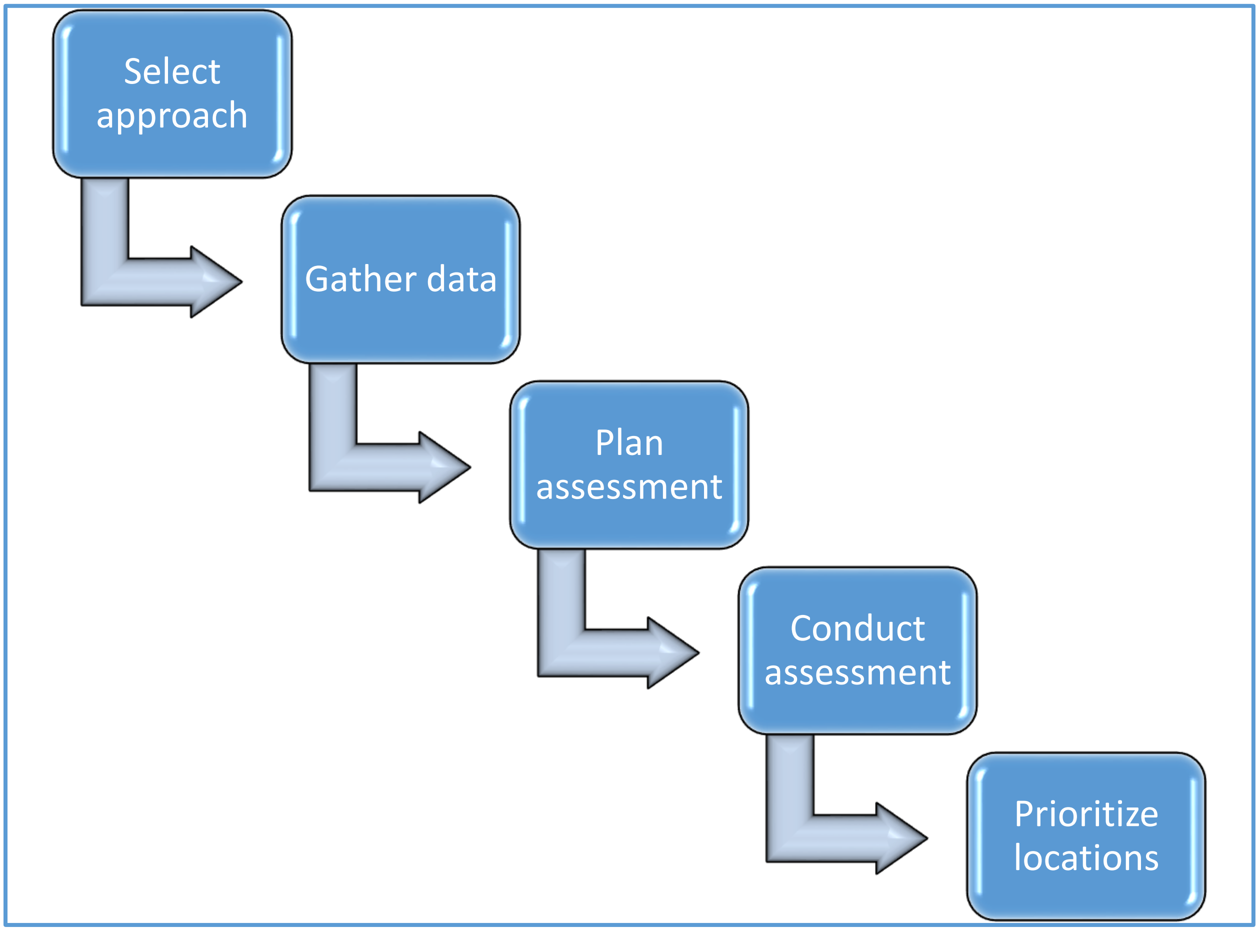


Figure 3. Flowchart. Steps to identify high pedestrian crash locations.

Details about completing each of these steps are discussed in the *Guidebook*. The *Guidebook* concludes with supporting materials grouped within the following sections:

- **Supplemental Material A—Example of Safety Index:** provides additional details about the index the City of Los Angeles uses.
- **Supplemental Material B—Screening Method Examples:** presents examples of several screening methods.
- **Supplemental Material C—Online Maps:** presents several examples of online maps being produced by numerous city and State DOTs to show pedestrian crash data.

- **Supplemental Material D—Advice From Previous Studies:** discusses several previous studies that have documented analyses to identify HCLs along with different approaches to identify and rank locations.

- **Supplemental Material E—Glossary:** provides a list of definitions relevant to the document.

Lessons Learned During Development of the *Guidebook*

Most agencies now have available the geographic coordinates of crashes, which results in the ability to quickly illustrate where crashes occur. All the interviewed agencies use a GIS to identify HCLs. 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 to identify locations of concern, such as activity centers, walk scores, or citizens' comments. Pedestrian exposure data are typically not used to identify sites because of the lack of good data for significant portions of their network. The analysis period ranges from 1 to 3 yr. The agencies noted that pedestrian and bicycle crashes are different from motor vehicle crashes and require unique efforts.

The current skill sets needed to work with crash data include familiarity with a GIS, the ability to work with attribute tables, and programming skills. Key lessons learned include the importance of 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 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:

- Several methods should be used to rank sites to ensure consensus.

- Not considering pedestrian exposure in some manner could significantly affect results.

- Other measures (e.g., walkability score) should be considered along with crash data, since crashes are rare events.

- If evaluating segments, a minimum segment length is needed (suggested as at least 0.2 mi).

- During evaluation of 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. The use of larger symbols or color-coded symbols (e.g., green–yellow–red scale) seems to be most appropriate for quickly identifying HCLs. 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 at a citywide scale yet still provide the option to view individual crashes at a specific 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 HCLs, 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 techniques include SPFs, the HSM, and systemic analyses.(5) The techniques provide the opportunity to allow comparisons between a city's data and national trends. The growth of better statistical techniques also permits the profession to better handle RTM and low-sample challenges.

WEBINAR WORKSHOP

FHWA hosted a webinar workshop in May 2017 for FHWA staff and panel members. The webinar workshop had the following three objectives:

- Provide lessons learned about the identification of high pedestrian crash locations.

- Present the features of the developed *Guidebook.*

- Provide examples of the screening process using a real dataset to overview the *Guidebook* and demonstrate its use.

The webinar workshop covered the following:

- Overview and objectives.
- Advice and lessons learned.
- Process of identifying locations of interest.
- Overview of available GIS technologies.
- Demonstrations.
- Discussion.
- Closure.

Previous sections of this chapter summarize the information presented about the initial three bullets covered during the workshop. The portions of the workshop that focused on a GIS and the demonstration illustrated the steps of the process to identify locations of interest (i.e., locations with high pedestrian crashes). Emphasis was placed on the use of a GIS in identifying locations of interest, given the wide availability of appropriate data and the growing interest and use of a GIS for such data analysis platforms.

The diagram in figure 4 summarizes the basic structure of a GIS. The main components for a GIS are a core to host, manipulate, and analyze data (shown in red or as rectangles or a cylinder); inputs consisting of data and processing packages (shown in green or as cards or a barrel); and outputs consisting of data and information (shown in yellow or as rounded cards or a rounded parallelogram).

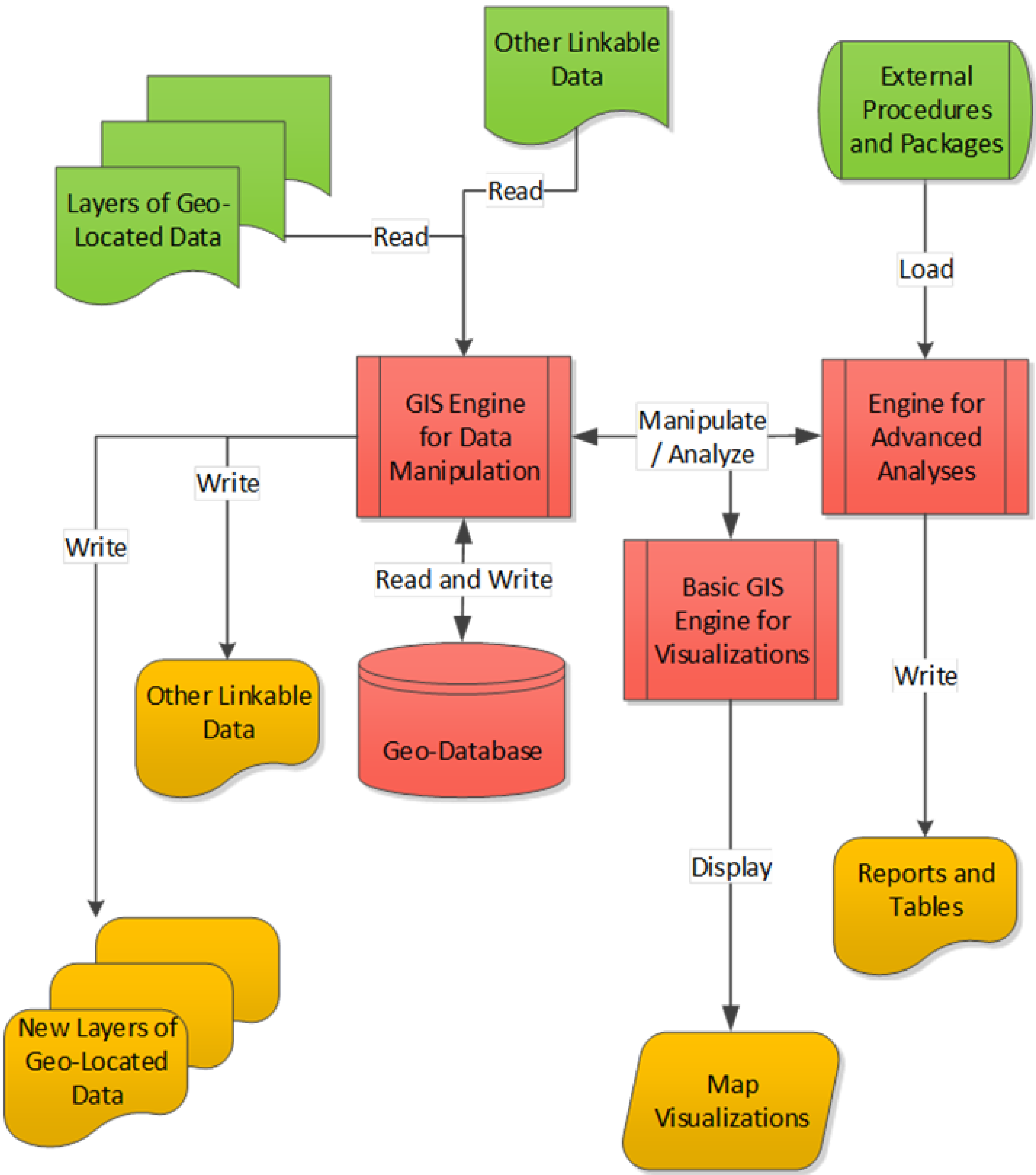


Figure 4. Flowchart. Conceptual elements of a GIS application.

During the webinar workshop, prerecorded steps were shown to demonstrate the use of a GIS package to implement one of the screening methods to identify locations of interest. The scenario for demonstration was the application of the sliding window method to identify locations of interest along a corridor in Austin, TX. The inputs for the analysis were two layers of data: one with corridor crashes and one with the segment representing the analysis corridor, as shown in figure 5.

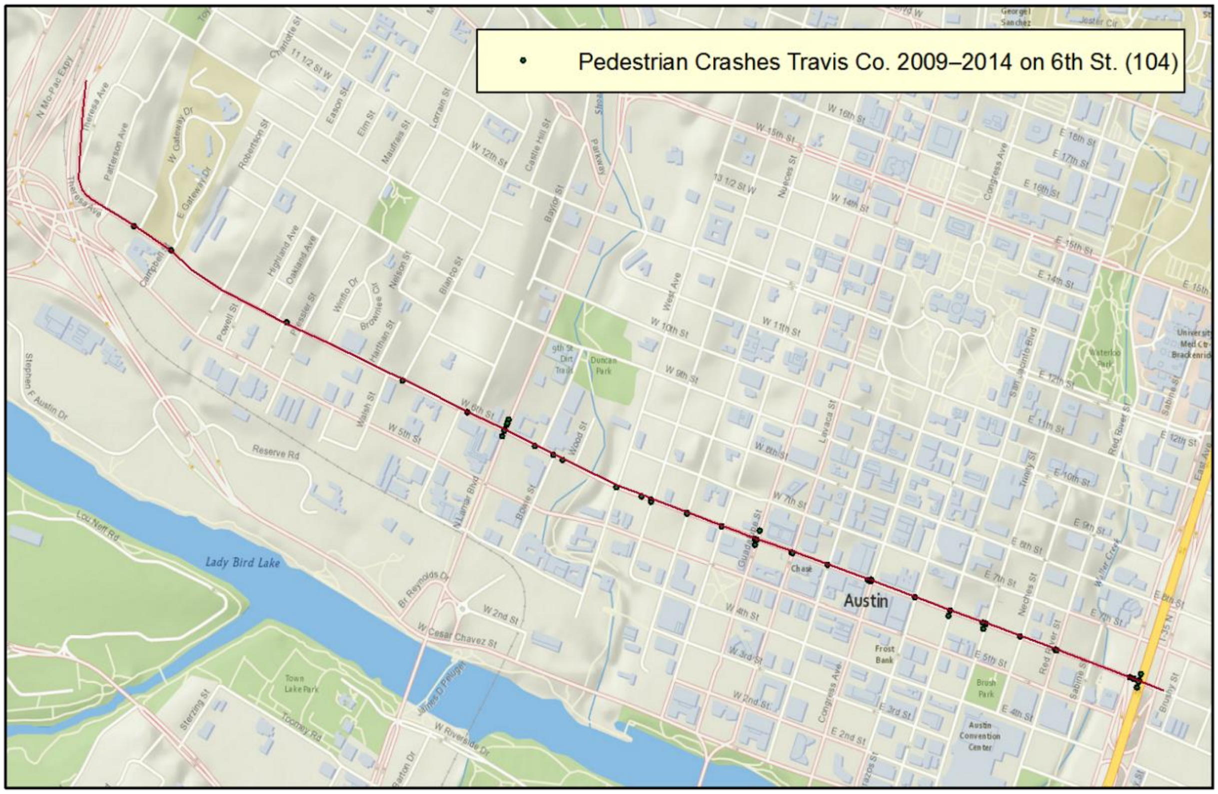


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Figure 5. Graphic. Corridor and crashes for analysis in webinar workshop demonstration.

The corridor main segment was split into subsegments, and buffers were created around each subsegment, each buffer representing a sliding window for analysis (shown in figure 6).

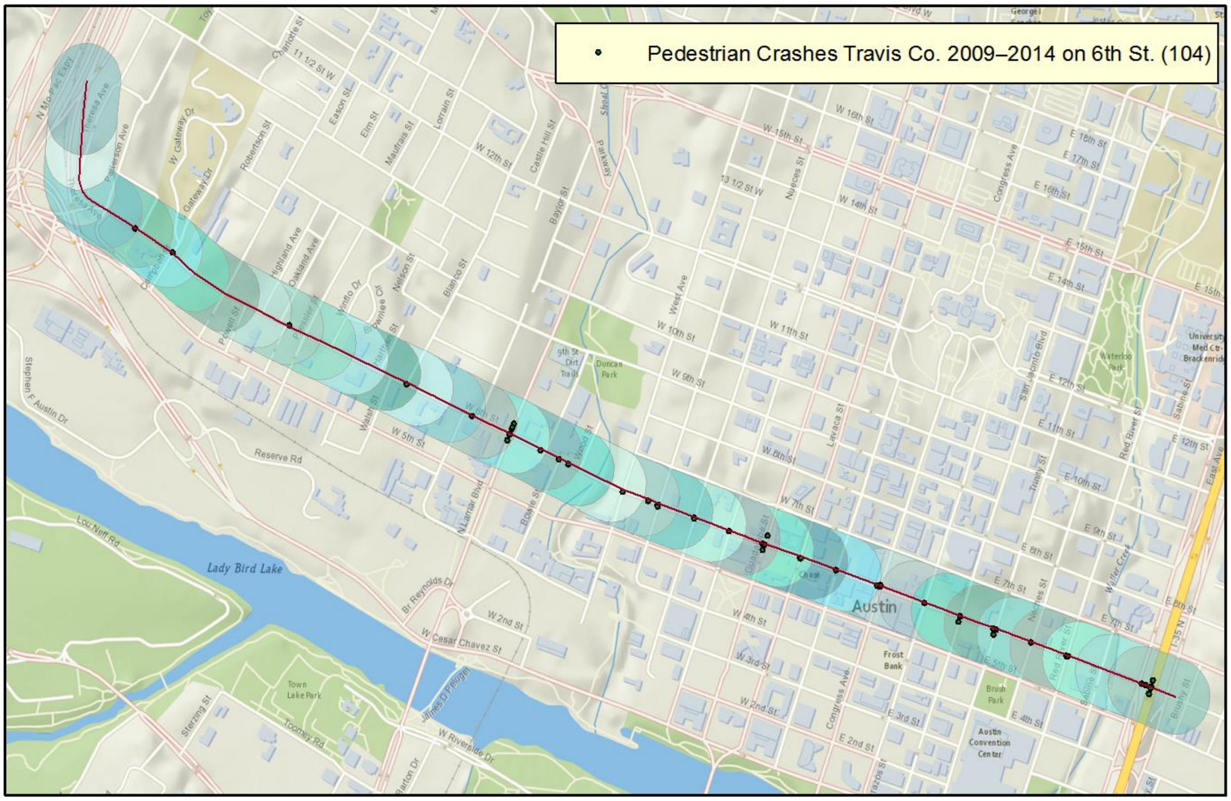

Figure 6. Graphic. Creation of sliding windows shown as transparent overlapping oblongs for analysis.

The data in the crash layer were then merged into each sliding window to collect the crash frequency per window. The crash frequency per window displays how crash frequency varies along the corridor using a color scale (as shown in figure 7).

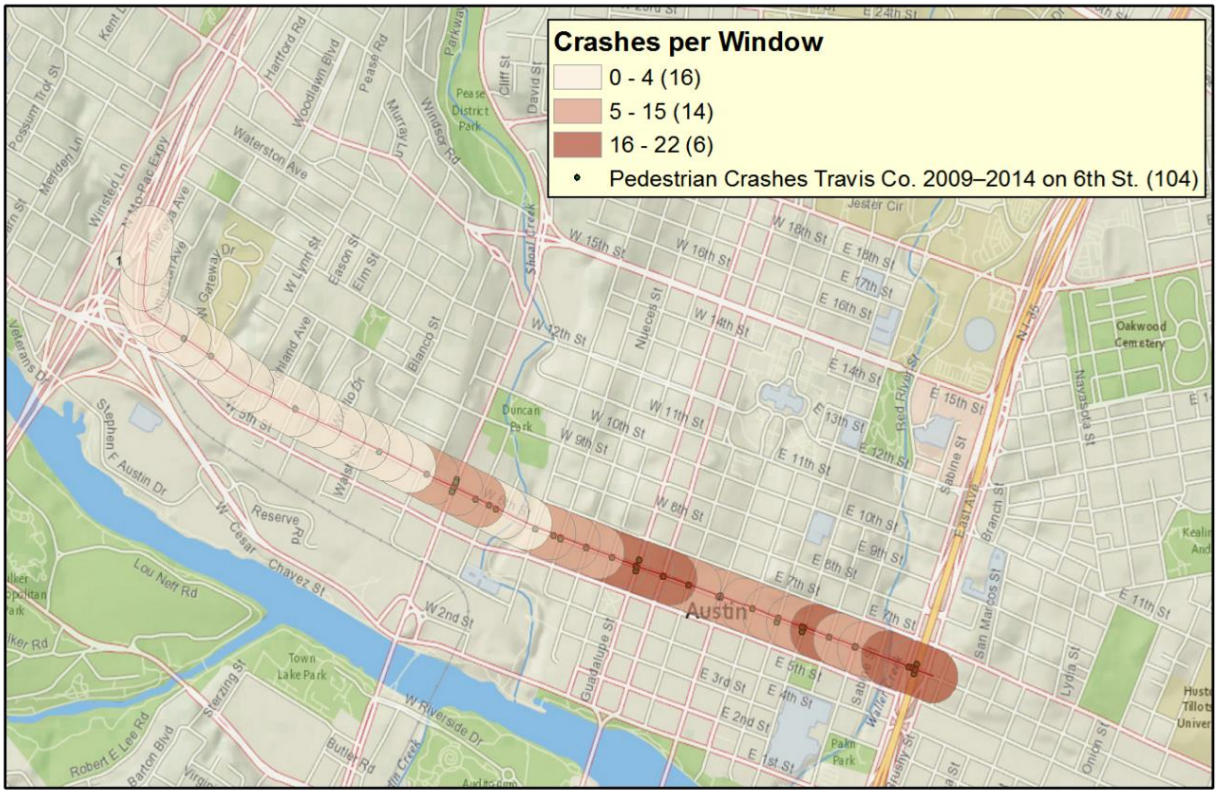

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Figure 7. Graphic. Merging sliding windows and crashes.

Finally, the layer with the results of the sliding window analysis was extracted and exported to a spreadsheet for further analysis and graphics as necessary (a plot from the exported data is shown in figure 8). The webinar workshop was closed by taking questions and comments from participants.

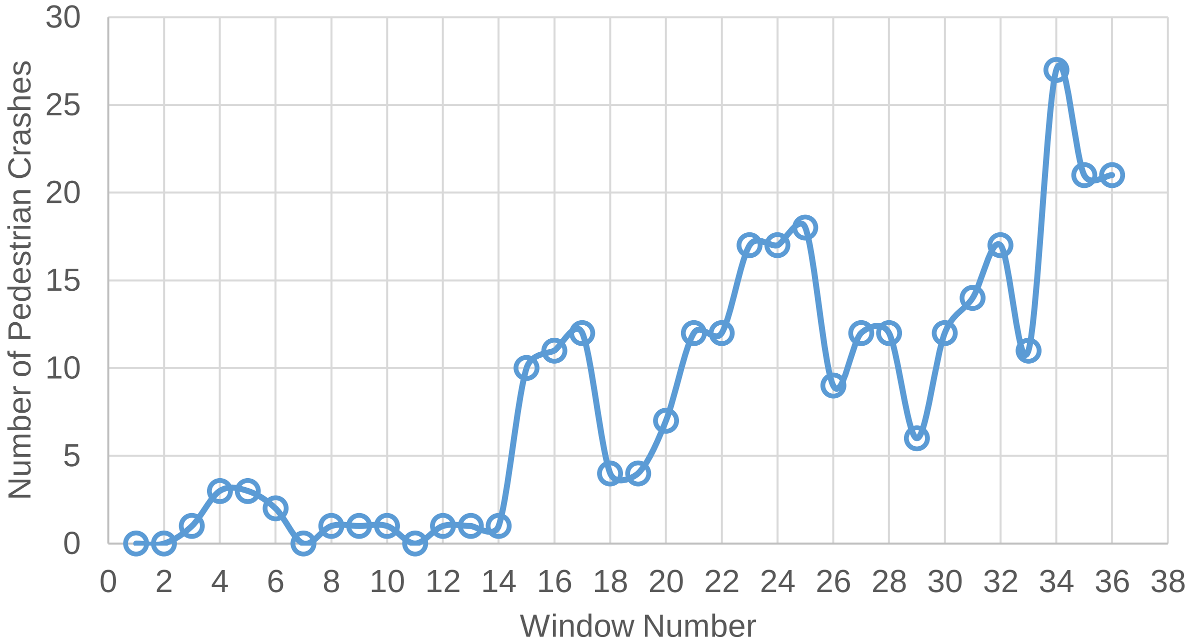

Figure 8. Graph. Sliding window analysis results exported to a spreadsheet.

CHAPTER 6. SUMMARY/CONCLUSIONS AND FUTURE RESEARCH NEEDS

OVERVIEW

This chapter provides summaries and conclusions along with a discussion of the implications of the findings of each study. The chapter concludes with a list of future research needs.

SUMMARY/CONCLUSIONS

Literature Review

Key findings and conclusions for this literature and state-of-the-practice review include the following:

- With the growth of improved statistical techniques, the profession is better able to handle RTM and low-sample challenges.

- The development of new techniques—such as SPFs, the HSM, or systemic analyses—and new computer programs (e.g., ArcGIS® or usRAP) allows relatively easy comparison between a city's data and national trends.

- Several different approaches are used to identify and display HCLs, and often, these approaches are not well documented in 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.

- Certain map displays are more likely to successfully convey crash density. The use of larger symbols or color-coded symbols (e.g., green–yellow–red scale) seemed to be most appropriate for quickly identifying HCLs. 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 at a citywide scale yet still provide the option to view individual crashes at a specific intersection or street. Maps that display additional information once clicked are ideal for exploring crash patterns or attributes at a detailed level.

Interviews With Governmental Agencies

Several cities and a State were contacted to determine the criteria that are being used to identify and rank high pedestrian crash locations. In all cases, crash data are used. In some cases, other variables are considered, especially when developing the list of sites considered for treatment. For example, Los Angeles 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.

Agencies are now geocoding the location of their crashes, which is resulting in the ability to quickly illustrate visually where crashes are occurring. All the interviewed agencies are using a

GIS to identify HCLs. The agencies generally start with identifying high crash intersections and then cluster the sites into corridors and/or areas. GIS tools are used to aid in the clustering; however, several agencies noted that visually confirming the clustering is how they set the limits for their corridors and areas.

Agencies have considered surrogates to identify locations of concern, such as activity centers, walk scores, or citizens' comments. Pedestrian exposure data are not used to identify sites because of the lack of good data. The analysis period ranges from 1 to 3 yr.

The skill sets needed to work with crash data include familiarity with a GIS, the ability to work with attribute tables, and programming skills. Key lessons learned include the importance of having analysts with the needed skill sets, sharing data between partner agencies, having access to reliable geocodes for the crashes, and having strong support from others within the city.

Interviews About Pedestrian Collision Warning Systems

In this effort, the research team contacted three industry representatives to discuss the feasibility of logging warning events from pedestrian collision warning systems for use in pedestrian safety analyses. The most feasible near-term approach is available through fleet-vehicle-based systems such as Mobileye's Shield+™ system. In fact, Mobileye has already developed and demonstrated an analytics platform for identifying safety hot spots from pedestrian collision warning event data. The technical feasibility for consumer-auto-based collision warning systems depends entirely on whether a carmaker or information services provider has communications capability. Toyota indicated that it does not currently have this capability. As part of their operating model, information service providers such as HERE have two-way communications capability with cars and do intend to gather various sensor data if it suits their business purposes. However, these efforts at gathering sensor data from connected cars are in early stages, and any pedestrian collision warning event data will likely not be available on a systematic basis within the next few years.

Guidebook and Webinar Workshop

The draft *Guidebook* was developed and distributed for review. After revisions were made, the research team held a webinar workshop with FHWA and the panel to present the process developed to identify high pedestrian crash locations. Comments made during the webinar workshop were used in the development of the final version of the *Guidebook.*

FUTURE RESEARCH NEEDS

Several future research needs were identified, with the following having the highest support by the panel:

- Explore alternative methods to identify locations of concern for pedestrians that can supplement or expand pedestrian crash data, such as hospital data, conflict data, or citizens' concerns.

- Investigate the sensitivity of exposure data—both pedestrian and vehicle—in affecting the ranking of locations of concern for pedestrians.

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The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear in this report only because they are considered essential to the objective of the document.

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