PEDESTRIAN DETECTION SYSTEMS FOR IMPROVED SAFETY

FINAL REPORT

January 2022

ENTERPRISE TRANSPORTATION POOLED FUND STUDY TPF-5(359)

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16. Abstract
A significant increase in traffic-related pedestrian fatalities has been experienced in the United States since 2009. Detection-based pedestrian safety technologies have the potential to improve safety for pedestrians. This research was completed to improve ENTERPRISE members' understanding of pedestrian traffic safety issues and explore recent advancements in detection-based pedestrian safety technologies. The project conducted a literature search to provide context for pedestrian safety issues and trends, completed an industry scan of detection-based pedestrian safety technologies, and identified potential future research for consideration by ENTERPRISE or other research entities. The literature search revealed several factors and conditions that have been found to contribute to higher rates of pedestrian fatalities and serious injuries, which can help agencies as they consider technology-based solutions. The industry scan identified numerous examples of detection-based technologies that are commercially available or being researched. While there is some evidence of deployments and testing, many technologies appeared to be in early stages of planning or implementation. Future research could consider investigating the effectiveness of signage or other alerts for pedestrians; demonstrating and evaluating commercially available pedestrian safety technologies, or research to correlate crash or conflict causes with appropriate safety technologies.

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Project Champion

Ben Flanagan, Pennsylvania Department of Transportation, was the ENTERPRISE Project Champion for this effort. The Project Champion serves as the overall lead for the project.

ENTERPRISE Members

The ENTERPRISE Board consists of a representative from each of the following member entities.

- Illinois Department of Transportation
- Iowa Department of Transportation
- Kansas Department of Transportation
- Michigan Department of Transportation
- Minnesota Department of Transportation
- Ontario Ministry of Transportation
- Pennsylvania Department of Transportation
- Texas Department of Transportation
- Wisconsin Department of Transportation

Project Input

ENTERPRISE would like to thank the following entities that provided input for this project:

- City of Bellevue, Washington
- Michigan Department of Transportation
- Minnesota Department of Transportation
- Texas A&M Transportation Institute

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1.0 Introduction

A significant increase in traffic-related pedestrian fatalities has been experienced in the United States since 2009. From 2009-2018, pedestrian fatalities in the United States increased by 53 percent (from 4,109 deaths in 2009 to 6,283 deaths in 2018) while other traffic deaths increased by only 2 percent (Retting, 2020). Detection-based pedestrian safety technologies that are commercially available or being researched hold the potential to improve safety for pedestrians. These detection-based technologies can provide real-time alerts or offer data collection and analysis platforms to help agencies identify issues and prioritize locations for safety improvements.

The objective of this research was to improve ENTERPRISE members' understanding of pedestrian traffic safety issues and explore recent advancements in detection-based pedestrian safety technologies. The project conducted a literature search to provide context for pedestrian safety issues and trends (including at signalized intersections), completed an industry scan of detection-based pedestrian safety technologies, and identified potential future research for consideration by ENTERPRISE or other research entities.

This report includes the following sections:

- 2.0 Project Approach – Describes the research approach and how information was gathered.
- 3.0 Literature Search – Provides findings from a literature search that summarizes issues and trends related to pedestrian safety, both in an overall context as well as exploring pedestrian safety data at signalized intersections.
- 4.0 Industry Scan – Presents an overview of detection-based pedestrian safety technologies that are commercially available or being researched.
- 5.0 Project Interviews – Summarizes information gathered from selected agencies that are deploying and testing detection-based pedestrian safety technologies.
- 6.0 Potential Future Research – Offers suggestions for potential research that could be considered by ENTERPRISE or other research entities to be conducted in the future.
- 7.0 Summary – Presents a summary of key project findings.

2.0 Project Approach

This project completed the following steps to understand pedestrian safety issues and explore recent advancements in detection-based pedestrian safety technologies:

- **Literature Search** – A literature search was conducted to summarize issues and trends related to pedestrian safety, to provide context for safety issues that could potentially be addressed by detection-based pedestrian safety systems. The literature search explored trends in pedestrian fatalities and crashes, to improve ENTERPRISE members' understanding of contributing factors.
- **Industry Scan** – An online industry scan was completed to compile a summary of detection-based technologies (commercially available and being researched) that aim to improve pedestrian safety. The industry scan focused on detection-based technologies with real-time alerts and detection-based technologies with data collection and analysis platforms.
- **Project Interviews** – This step completed phone interviews with selected agencies and entities that are deploying or testing detection-based pedestrian safety technologies. Information was gathered to document deployment conditions, technology type, evaluation approach, and lessons learned such as benefits or challenges encountered.
- **Potential Future Research** – Based on findings from the literature search, industry scan, and agency interviews, ideas for potential future research were identified.

Figure 1 presents an overview of the research approach.

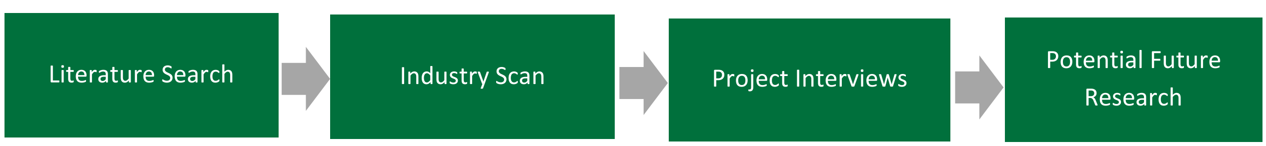

Figure 1: Overview of Research Approach

3.0 Literature Search

The literature search summarized in this section provides an overview of data, trends, and contributing factors associated with pedestrian fatalities and pedestrian-involved crashes.

At the onset of the project, the ENTERPRISE Board expressed an interest in understanding overall data and trends as well as pedestrian safety at signalized intersections. This literature search section is therefore presented as such, with Section 3.1 summarizing selected literature that offers overall insight on issues and trends related to pedestrian fatalities at a national level, and Section 3.2 summarizing available publications related to pedestrian fatalities and crashes at signalized intersections. A summary section (Section 3.3) contains key findings from the literature search.

3.1 Pedestrian Safety Issues and Trends

This section summarizes selected publications that offer overall insight on issues and trends related to pedestrian fatalities and serious injuries, at a national level. These publications provide historical data and trends, as well as conditions and factors that may contribute to pedestrian fatalities and crash severity. After conducting an online search, these publications were chosen to provide overall context for this project because they provide national level data, offer concise summary information, and draw extensively from previous literature to summarize potential contributing conditions and factors.

> The publications summarized in this section provide national level data for pedestrian fatalities and other safety-related trends, offer a concise summary information, and draw extensively from previous literature.

The following publications are summarized in this section:

- ***Pedestrian Traffic Fatalities by State – 2019 Preliminary Data*** (Retting, 2020)[1] and ***Pedestrian Traffic Fatalities by State – 2020 Preliminary Data*** (Retting, 2021)[2] – Published annually by the Governors Highway Safety Association (GHSA), these reports offer a summary of state and national trends in pedestrian fatalities.
- ***Toward a Shared Understanding of Pedestrian Safety - An Exploration of Context, Patterns, and Impacts*** (Pedestrian and Bicycle Information Center, 2020)[3] – This document, published by the Pedestrian and Bicycle Information Center (PBIC) at the University of North Carolina, provides context on pedestrian safety issues, crash patterns, contributing factors and resulting impacts.
- ***NCHRP Research Report 893: Systemic Pedestrian Safety Analysis*** (Thomas et al., 2018)[4] - This report provides a safety analysis method that can be used to proactively identify sites for potential safety improvements based on specific risk factors for pedestrians.

When reviewing these publications, special attention was given to include key findings that may impact state transportation agency decisions around selecting and deploying detection-based pedestrian safety technologies.

3.1.1 Pedestrian Traffic Fatalities by State – 2019 Preliminary Data (Retting, 2020)

This report offers a summary of United States (U.S.) national and state trends in pedestrian traffic deaths, including data for 2018 and preliminary data for 2019.

Selected key highlights from this publication:

- From 2009 to 2018, the number of pedestrian fatalities in the United States increased by 53% (from 4,109 deaths in 2009 to 6,283 deaths in 2018). See Figure 2. During this same time period, the combined number of all other traffic deaths increased by 2%.

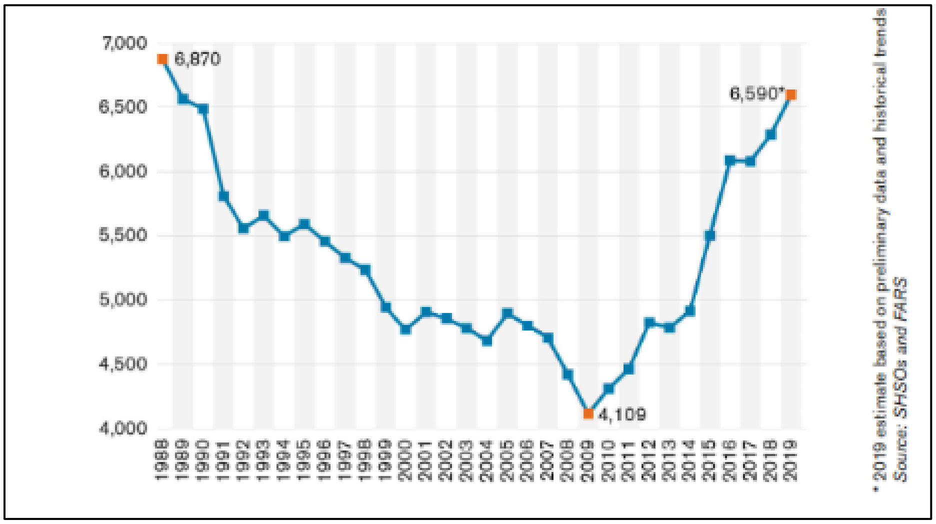

Figure 2: U.S. Pedestrian Fatalities 1988-2019 (Source: Retting, 2020)

- The number U.S. states with 2.0 or more pedestrian fatalities per 100,000 population has continued to rise from 2014 to 2018.

- National data summarized for pedestrian fatalities in 2018 showed that:
  - ***Roadway Function Class***: Most pedestrian fatalities occurred on non-freeway arterials (59%), followed by collectors and local streets (22%), and freeways (18%). See Figure 3.
  - ***Intersections versus non-intersections:*** 74% pedestrian fatalities were not at intersections. See Figure 4.
  - ***Lighting Conditions***: 76% of pedestrian fatalities occurred after dark. In addition, nighttime pedestrian fatalities are increasing at a much higher rate than daytime fatalities. See Figure 5.
  - ***Impairment***: Alcohol impairment, for the driver and/or pedestrian, was reported in about half of traffic crashes that resulted in pedestrian fatalities in 2018.
  - ***Vehicle Type***: Pedestrians struck by a large sport utility vehicle (SUV) are twice as likely to die as those struck by car.

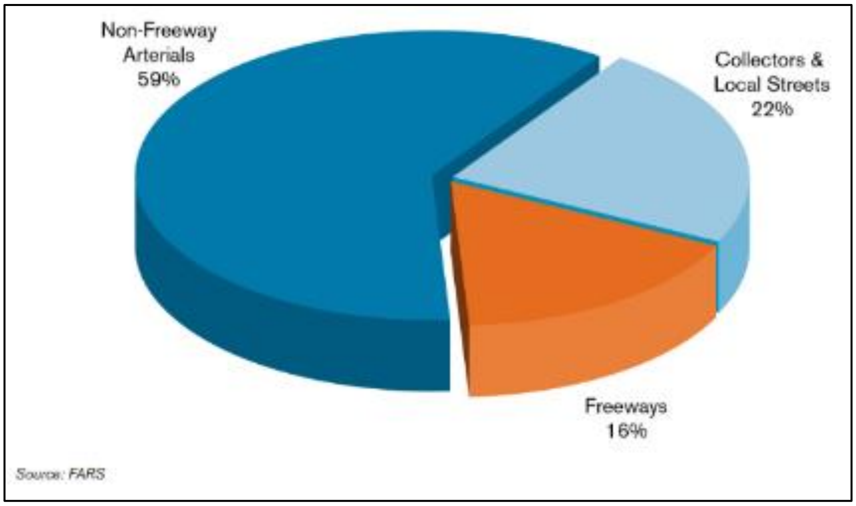

Figure 3: Pedestrian Fatalities by Roadway Function Class (Source: Retting, 2020)

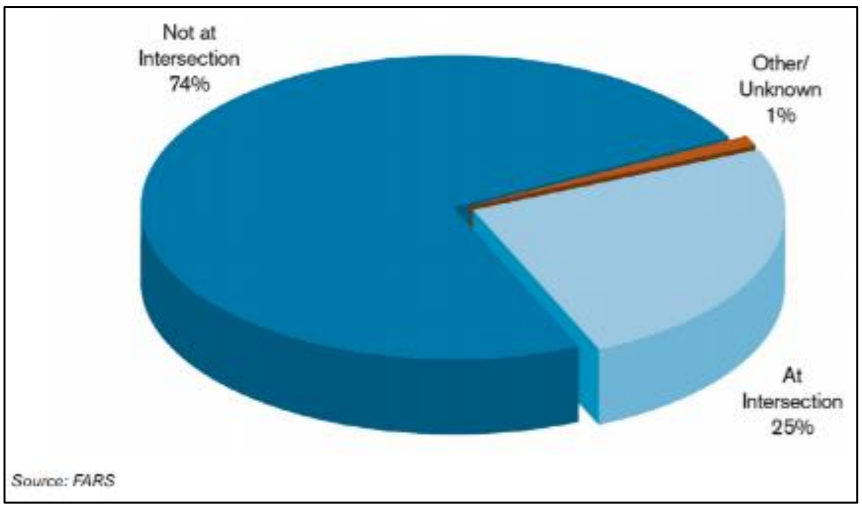

Figure 4: Pedestrian Fatality Locations: 2018 (Source: Retting, 2020)

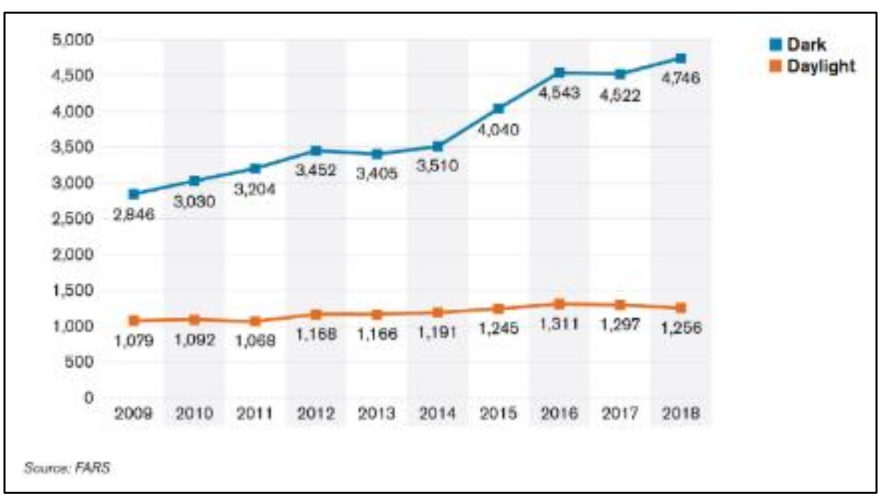

Figure 5: Pedestrian Fatalities by Light Condition: 2009-2018 (Source: Retting, 2020)

3.1.2 Pedestrian Traffic Fatalities by State – 2020 Preliminary Data (Retting, 2021)

This report offers a summary of U.S. national and state trends in pedestrian traffic deaths, including data for 2019 and preliminary data for 2020.

Selected key highlights from this publication:

- The Governors Highway Safety Association (GHSA) projects 2957 pedestrian fatalities for the first six months of 2020, which closely mirrors the number of pedestrian fatalities reported in first six months of 2019 (2951).
- Nationwide, three out of every four (75%) pedestrian fatalities in 2019 occurred ***after dark.***
- Most pedestrian fatalities in 2019 (74%) occurred at ***non-intersection locations***.
- More than half of all pedestrian fatalities in 2019 (63%) occurred on ***non-freeway arterials,*** with 21% on collectors and local streets, and 16% on freeways.
- ***Alcohol impairment*** (for the driver and/or pedestrian) was reported in about half of traffic crashes that resulted in pedestrian fatalities in 2019.
- Although passenger cars accounted for a larger number of pedestrian deaths, ***the number of pedestrian fatalities involving SUVs increased at a greater rate*** (69%) from 2010 to 2019, compared to fatalities involving passenger cars (46%).
- For 2015-2019, the percentage of total pedestrian fatalities ***by race and total population by race*** was examined. As shown in Figure 6:
    - People classified as White/Non-Hispanic accounted for a considerably smaller proportion of pedestrian fatalities than expected based on their respective share of the population.
    - Black, Indigenous, and People of Color (using Office of Management and Budget (OMB) guidelines for race) accounted for a larger proportion of pedestrian fatalities than expected based on their respective share of the population.

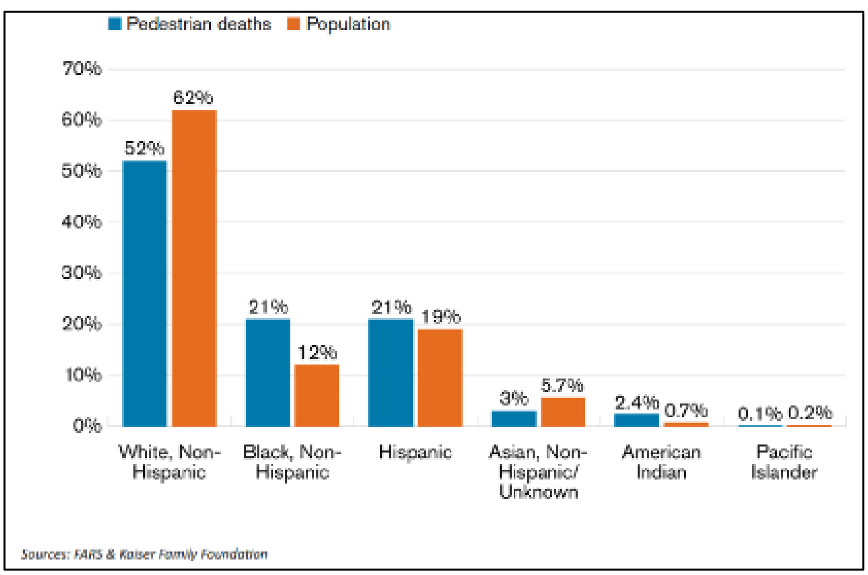

Figure 6: Percent of Total Pedestrian Fatalities and Population by Race, 2015-2019 (Source: Retting, 2020)

3.1.3 Toward a Shared Understanding of Pedestrian Safety - An Exploration of Context, Patterns, and Impacts (Pedestrian and Bicycle Information Center, 2020)

The goal of this document was to provide context on pedestrian safety issues, crash patterns and contributing factors, and resulting impacts that may help orient readers from diverse sectors to identify shared concerns and opportunities to make a difference.

Selected key highlights from this publication:

- ***Pedestrian fatalities*** – According to the Fatality Analysis Reporting System (FARS), pedestrian fatalities increased by 53 percent from 2009 to 2018, while other traffic deaths increased by only 2 percent.
- ***Measuring crash exposure*** – There is a lack of data measuring how often people are exposed to the risk of a crash, or "exposure data." Funding for pedestrian counting programs is limited and there are no pedestrian exposure measurement systems at a statewide or national level that meet basic level data quality standards for road safety.
- ***Marginalized populations and historically underserved communities*** – Marginalized populations or historically underserved communities experience a disproportionate share of crashes while also experiencing conditions less favorable for walking.
- ***Age of Pedestrians and Drivers***
    - ***Older pedestrians*** – Older adults are overrepresented in pedestrian fatalities and the proportion of fatalities involving pedestrians age 65 and older has been increasing.
    - ***Older drivers*** – The age of drivers involved in fatal pedestrian crashes has been rising. There has also been a steady increase in the total number of fatal pedestrian crashes involving older drivers (age 65 and older). See Figure 7.

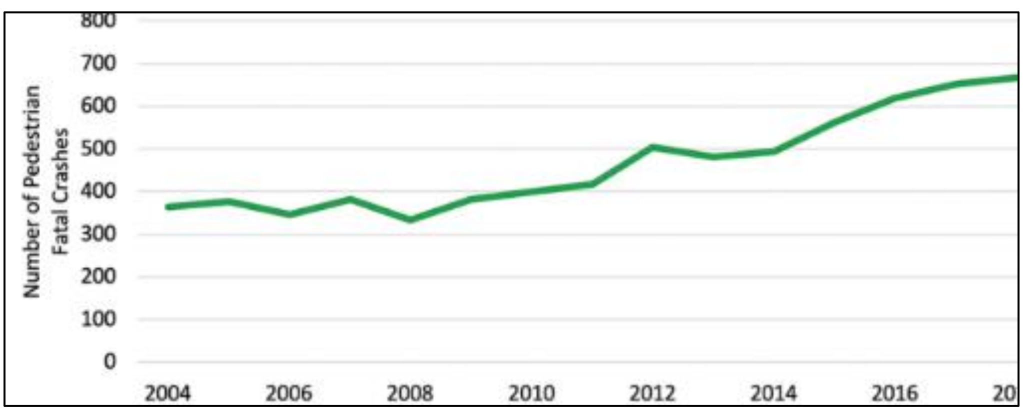

Figure 7: Fatal Pedestrian Crashes involving Older Drivers age 65 and Older from 2004-2008 (Source: PBIC using FARS data)

- ***Younger Drivers*** – Analysis of pedestrian crashes in one state (North Carolina) indicates that younger drivers (under the age of 25) may be overrepresented in events causing non-serious and serious injury to pedestrians.

- ***Impairment and Distraction***
    - Prescription drugs, fatigue, distraction, and other factors can lead to impaired driving skills that affect a driver's ability to perceive and react to pedestrians in shared spaces.
    - There is little research that quantifies the behavior changes in impaired pedestrians (e.g., making the decision to cross the street), but research indicates that alcohol use is associated with worse injury outcomes for pedestrians.
    - Research has shown that distraction can affect the behavior of pedestrians crossing the street, but direct links to pedestrian involved crashes have not been established.
- ***Vehicle Speed and Mass***
    - Higher vehicle speeds (measured by posted speed limit or estimated speed at time of impact) increase the likelihood and severity of a crash.
    - Increased use of sport utility and larger-sized vehicles, when combined with higher speed, has contributed to a national rise in pedestrian fatalities.
    - Figure 8 outlines risk of serious injury or fatality for a pedestrian as vehicle speed increases. It also shows the narrowing visual field and ability for drivers to scan the peripheral for pedestrians as speed increases.

Figure 8: Average Risk of Pedestrian Fatalities and Injuries at Increasing Speeds and Cone of Vision (Source: Porter et al.[5])

- ***Lighting conditions*** – Between 2000 and 2018, fatal pedestrian crashes have continued to increase at nighttime and in dark conditions.
- ***Pedestrian Crash Context/Environment***
    - The largest growth in pedestrian fatalities in recent years has been seen in more urbanized locations.
    - From 2009 to 2018 the largest increase in pedestrian fatalities have occurred on principal and minor arterial roadways.
    - Most pedestrian fatalities nationally occur at non-intersection locations. See Figure 9.

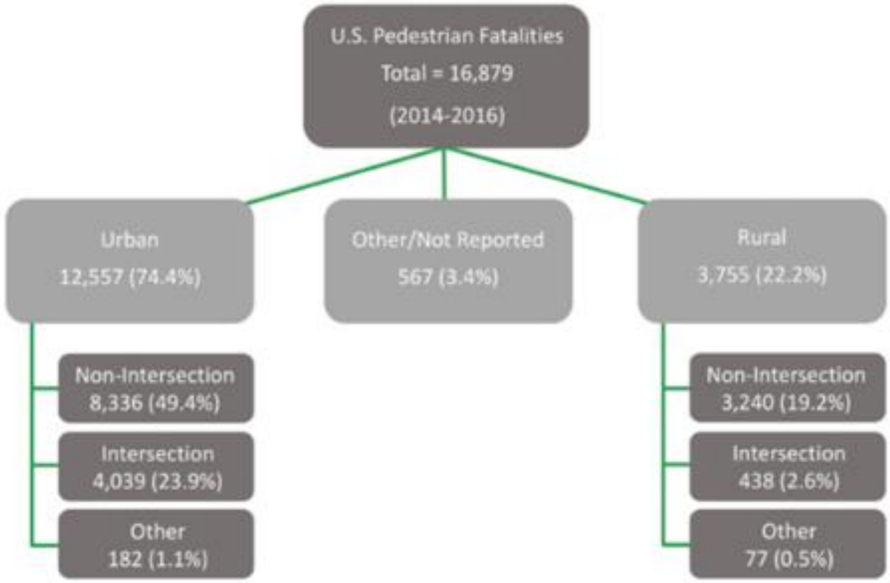

Figure 9: US pedestrian fatality distribution by location and intersection characteristics, 2014-2016 (Source: PBIC, n.d. [6])

3.1.4 NCHRP Research Report 893: Systemic Pedestrian Safety Analysis (Thomas et al., 2018)

This report provides a safety analysis method that can be used to proactively identify sites for potential safety improvements based on specific risk factors for pedestrians. The guidance is based on research that used data on roadway characteristics, pedestrian crashes, and measures of exposure to develop new risk factors for pedestrian-related crashes.

Selected key highlights from this study:

- ***State of Practice*** – The state of practice and knowledge is evolving rapidly regarding identifying risk factors for pedestrian-related crashes.
- ***Data Collection*** – Many state and local jurisdictions struggle with collecting, compiling, and analyzing data needed for pedestrian safety purposes, especially estimating pedestrian volumes.
- ***Roadway, Crash and Person Factors*** – Table 1 provides an overview of roadway, crash and person factors associated with increasing pedestrian injury severity. These factors include dark lighting conditions, higher speed limits, traffic control other than signal (stop sign) or no traffic control, larger vehicle types, older age of pedestrian (approximately 65 and older), pedestrian impairment (alcohol), and pedestrian crossing the roadway.

Table 1: Roadway, crash, and person factors associated with increasing injury severity in pedestrian crashes (Source: Thomas et al., 2018)

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

Note: Strong = six or more studies with consistent direction of effect; moderate = five to six studies with consistent direction of effect.

- ***Roadway Risk Factors*** – Table 2 provides a summary of roadway risk factors that have been found (at the time of *NCHRP Research Report 893: Systemic Pedestrian Safety Analysis* publication) to have consistent relationships in the expected direction to crashes, for intersections and roadway segments.

Table 2: Potential roadway risk factors identified from prior research and relationship to pedestrian crashes (Source: Thomas et al., 2018)

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

Note: Positive and negative denote correlations with crashes.

3.2 Pedestrian Crashes and Fatalities at Signalized Intersections

This section summarizes an online literature search by highlighting the findings, crash risks of pedestrian crashes and fatalities at signalized intersections, and factors unique to signalized intersections and intersections in general. Key findings from the following resources are highlighted within this section:

- **Pedestrian Safety at Signalized Intersections** (Alluri et al., 2014)[7] – This publication researched vehicle-pedestrian crashes that occurred at signalized intersections on state roads in Florida from 2008-2010.
- **Analyzing pedestrian crash injury severity at signalized and non-signalized locations** (Haleem et al., 2015)[8] – This paper identifies and compares the significant risk factors affecting pedestrian crash injury severity at signalized and unsignalized intersections in Florida.
- **Pedestrian safety at signalized intersections: Modelling spatial effects of exposure, geometry and signalization on a large urban network** (Stipancic et al., 2020)[9] – This document models the effects of exposure, geometry, and signalization on pedestrian injuries at urban signalized intersections in Montreal, Quebec.
- **A Bayesian spatial Poisson-lognormal model to examine pedestrian crash severity at signalized intersections** (Munira et al., 2020)[10] – This study examined pedestrian crashes, including traffic characteristics, road geometry, built environment features, and pedestrian exposure volume at intersections and models pedestrian crash severity to examine the significant factors influencing the fatal, incapacitating injury (or suspected serious injury), and non-incapacitating injury pedestrian crashes at 409 signalized intersections in the Austin, Texas area.
- **Influencing Factors on Conflicts of Turning Vehicles and Pedestrians at Intersections** (Xu et al., 2015)[11] – This Nevada Department of Transportation (NDOT) report looks at the relationship between driver observation behavior and pedestrian crash type/frequency and includes findings from a literature review on the impact of intersection and roadway segment characteristics on pedestrian safety.
- **Saving Lives with Safe Streets** (City of Portland, 2019)[12] – This Vision Zero 2-year update published by the City of Portland describes lessons learned during Portland's first two years as a Vision Zero city and sets the stage for the next phase of work.
- **PedPDX: Portland's Citywide Pedestrian Plan** (Portland Bureau of Transportation, 2019)[13] – This document analyzed all reported pedestrian crashes in Portland since 2005 and identifies the key strategies and tools used to make Portland a great walking city.

3.2.1 Pedestrian Safety at Signalized Intersections (Alluri et al., 2014)

This paper analyzed crash data for 2,591 vehicle-pedestrian crashes at signalized intersections on state roads in Florida from 2008-2010. Researchers identified 7,054 intersections as signalized intersections of two state roads and using police reports, researchers determined which road user was at-fault user for each vehicle-pedestrian crash.

Key Findings:

- In Florida, one in every five traffic-related fatalities is a pedestrian.
- The most frequent contributing causes of vehicle-pedestrian crashes where the driver was at fault were careless driving, failure to yield the right-of-way, and disregard of traffic signal or other traffic control.
- The most frequent contributing causes of vehicle-pedestrian crashes where the pedestrian was at fault were failure to yield the right-of-way, under the influence of alcohol and/or drugs, and disregard of traffic signal or other traffic control.
- In over 50% of pedestrian crashes, pedestrians were at fault.

3.2.2 Analyzing pedestrian crash injury severity at signalized and non-signalized locations (Haleem et al., 2015)

Florida pedestrian crash data from 2008-2010 was used to identify and compare the significant risk factors affecting pedestrian crash injury severity at signalized and unsignalized intersections. Police reports provided a better understanding of how each pedestrian crash occurred, and information unavailable in the crash records (e.g., at-fault road user and pedestrian maneuver) was collected.

A total of 3,038 pedestrian crashes with complete information were identified and analyzed, including 2,360 pedestrian crashes at signalized intersections and 678 pedestrian crashes at unsignalized intersections. Separate analysis was performed for signalized and unsignalized intersections to identify and compare the significant factors affecting pedestrian injury severity including geometric predictors (e.g., presence and type of crosswalk and presence of pedestrian refuge area), traffic predictors (e.g., annual average daily traffic (AADT), speed limit, and percentage of trucks), road user variables (e.g., pedestrian age and pedestrian maneuver before crash), environmental predictors (e.g., weather and lighting conditions), and vehicle-related predictors (e.g., vehicle type).

Key findings:

- Conditions associated with higher pedestrian severity risk at signalized intersections included:
    - Traffic predictors: higher AADT, speed limit, and percentage of trucks
    - Road user variables: pedestrians age 80 or over and at-fault pedestrians
    - Environmental predictors: rainy weather and dark lighting conditions
- Conditions associated with higher pedestrian severity risk at unsignalized intersections included:
    - Geometric predictors: crosswalk type
    - Traffic predictors: higher speed limit
    - Road user variables: pedestrian walking along roadway, middle and very old pedestrians, and at-fault pedestrians
    - Environmental predictors: dark lighting conditions
    - Vehicle-related predictor: vans
- At-fault pedestrians are more vulnerable to severe injuries at unsignalized intersections.

3.2.3 Pedestrian safety at signalized intersections: Modelling spatial effects of exposure, geometry and signalization on a large urban network (Stipancic et al., 2020)

This article, published by *Accident Analysis & Prevention,* leverages a rich database of geometric and signalization variables for 1,864 intersections in Montreal, Quebec to model the effects of exposure, geometry, and signalization on pedestrian injuries at urban signalized intersections.

Key findings:

- The model confirmed the positive relationship between pedestrian and vehicle volumes and pedestrian injuries.
- Curb extensions, raised medians, exclusive left turn lanes, and pedestrian priority phases were all found to reduce pedestrian injuries.
- As the number of lanes or the number of commercial entrances increased, pedestrian injuries increased.
- Injuries to pedestrians also increased when drivers saw a green straight arrow.

3.2.4 A Bayesian spatial Poisson-lognormal model to examine pedestrian crash severity at signalized intersections (Munira et al., 2020)

This research models pedestrian crash severity by utilizing pedestrian exposure to examine the significant factors influencing the fatal, incapacitating injury (or suspected serious injury), and non-incapacitating injury pedestrian crashes at 409 signalized intersections in the Austin, Texas area. The study examined pedestrian crashes, including traffic characteristics, road geometry, built environment features, and pedestrian exposure volume at intersections.

Key findings:

- There is a significant positive influence of speed limit on fatal pedestrian crashes.
- Both incapacitating and non-incapacitating injury crashes increase with increasing motorized traffic volume.
- The pedestrian volume at intersections positively influences non-incapacitating injury crashes.

3.2.5 Influencing Factors on Conflicts of Turning Vehicles and Pedestrians at Intersections (Xu et al., 2015)

The Nevada Department of Transportation sponsored this study to analyze the influence of different factors on driver observation behavior and demonstrate the relationship between driver observation behavior and pedestrian crash type/frequency.

Key findings:

- Pedestrian movements often conflict with turning vehicles at intersections caused by either shared signal phases at signalized intersections or competitive right of way at unsignalized intersections.

- Pedestrian-turning-vehicle crashes account for a major part of intersection pedestrian crashes.
    - Nevada crash data from 2006-2012 shows that a third of pedestrian crashes at intersections involved turning traffic.
    - Half of intersection pedestrian crashes in Washington State involved turning vehicles, based on data from 2006-2013.

A literature review on the understanding of pedestrian crashes and studies the impact of intersection and roadway segment characteristics on pedestrian safety is also reported within this document. Conclusions of key findings from previous studies include:

- The pedestrian crash rate of left-turning vehicles is higher than the crash rate of the right-turning vehicles.
- Protected left-turn is safer than the permitted left-turn for pedestrians.
- Right-turn-on-red shows obvious relationship to the pedestrian-turning-traffic crash.
- T intersections have a higher traffic conflict rate than X-intersections.
- Pedestrian-turning-vehicle frequency is related to several contributing factors, such as pedestrian volume, traffic conditions, and intersection geometric features.

3.2.6 Saving Lives with Safe Streets (City of Portland, 2019)

The Vision Zero – 2 year update published by the City of Portland describes lessons learned during Portland's first two years as a Vision Zero city and sets the stage for the next phase of work.

Key findings:

- Between 2006-2015, 71% of all pedestrian crashes occurred at intersections, with 44% at signalized intersections.
- 20% of pedestrian crashes result from left-turning drivers failing to yield to pedestrians in the crosswalk at signalized intersections.

3.2.7 PedPDX: Portland's Citywide Pedestrian Plan (Portland Bureau of Transportation, 2019)

According to PedPDX, Portland's Citywide Pedestrian Plan, Portland experiences approximately five to nineteen pedestrian fatalities annually. PedPDX analyzed reported pedestrian crashes in Portland from 2006-2015 to identify potential patterns and trends in location.

Key findings:

- Nearly 20% of pedestrian crashes in Portland result in a pedestrian fatality or serious injury.
- 71% of all pedestrian collisions occurred at intersections.
- More than 40% of pedestrian crashes and 30% of severe/fatal crashes citywide occur at signalized intersections.
- Unsignalized and mid-block intersections have a higher probability of serious injury or fatality.

- The majority of intersection collisions occurred at locations with traffic signals and when the pedestrian had the “WALK” indication.

In a memorandum, included as Appendix F of the plan, the following observations are made:

- Intersections with more lanes have a significantly increased risk of both crash occurrence and a greater likelihood of a severe injury or fatality resulting from a crash.
- Over 25% of all crashes involve a turning driver failing to yield when the person walking has the right of way at the signal (20% left-turning drivers and 8% right turning drivers).
- Nearly half of crashes on Portland’s Vision Zero High Crash Network (HCN) occur at signalized intersections.
- Approximately 64% of crashes on the HCN involved pedestrians crossing the HCN, 30% of crashes involving pedestrians crossing at signalized intersections and 15% of crashes involving pedestrians crossing at unsignalized intersections.
- Pedestrian crashes where pedestrians cross against the signal account for 8% of pedestrian crashes and result in fatalities or serious injuries 25% of the time.
- The following crash types are more likely to result in a fatality or serious injury:
    - People walking across the street against the signal (8% of crashes; 25% are fatalities or serious injuries).
    - Driver going straight at unsignalized intersection fails to yield (4% of crashes; 22% are fatalities or serious injuries).
    - People walking across the street at unsignalized intersection and did not provide sufficient time for person driving to stop (6% of crashes; 25% fatalities or serious injuries).

3.3 Key Findings from Literature Search

Upon reviewing key findings from the literature search, the following observations were noted.

Pedestrian Fatalities

- Pedestrian fatalities in the United States increased by 53 percent from 2009 to 2018, while other traffic deaths increased by only 2 percent. (PBIC, 2020), (Retting, 2020)
- In 2019, the number of U.S. pedestrian deaths declined about 1% compared to 2018. (Retting, 2021)
- For the first six months of 2020, the Governors Highway Safety Association (GHSA) projects 2957 pedestrian fatalities, which closely mirrors the number of pedestrian fatalities reported in first six months of 2019 (2951 pedestrian fatalities). (Retting, 2021)

From 2009-2018, pedestrian fatalities in the United States increased by 53 percent, while other traffic deaths increased by only 2 percent.

State of Practice and Data Collection

- The state of practice and knowledge is evolving rapidly regarding identifying risk factors for pedestrian-related crashes. (Thomas et al., 2018)
- It is a challenge for agencies to collect pedestrian volume data using current methods, leading to a lack of data for measuring crash exposure. (PBIC, 2020), (Thomas et al., 2018)

Factors and Conditions Associated with Pedestrian Fatalities and Serious Injuries

The publications reviewed identified some common factors and conditions that appear to be associated with higher rates or increasing rates of pedestrian fatalities and serious injuries, at a national level:

- Urbanized locations (PBIC, 2020)
- Non-freeway arterials (Retting, 2020), (Retting, 2021); Principal and minor arterials (PBIC, 2020)
- Non-intersection locations (Retting, 2020), (Retting, 2021), (PBIC, 2020)
- Higher speeds / higher speed limits (Thomas et al., 2018), (PBIC, 2020)
- Dark lighting conditions (Thomas et al., 2018), (Retting, 2020), (Retting, 2021), (PBIC, 2020)
- Larger vehicle types (Thomas et al., 2018), (Retting, 2020), (Retting, 2021), (PBIC, 2020)
- Older age of pedestrian (65 and older) (Thomas et al., 2018), (PBIC, 2020)
- Older age of drivers (65 and older) (PBIC, 2020)
- Marginalized populations and historically underserved communities (PBIC, 2020)
- Race (black, indigenous, and people of color accounted for a larger proportion of pedestrian fatalities than expected based on their respective share of the population) (Retting, 2021)
- Alcohol impairment of the pedestrian (Thomas et al., 2018) (PBIC, 2020)
- Alcohol impairment for the pedestrian and/or the driver (Retting, 2020), (Retting, 2021)

Table 3 lists these factors and conditions that appear to be associated with higher rates or increasing rates of pedestrian fatalities and serious injuries, at a national level, assigned by general categories.

Table 3: Factors/conditions that research suggests are associated with higher or increasing rates of pedestrian fatalities and serious injuries

Category	Factors and Conditions
Roadway and Crash Environment	• Urbanized locations • Non-freeway arterials (principal and minor) • Non-intersection locations • Higher speeds / higher speed limits
Lighting	• Dark lighting conditions
Vehicle Type	• Larger vehicle types
Age and Demographics	• Older age of pedestrian (65 and older) • Older age of drivers (65 and older) • Marginalized populations and historically underserved communities • Race (black, indigenous, and people of color overrepresented compared to share of population)
Behavioral	• Alcohol impairment of pedestrian and/or driver

Studies that Investigate Crash Risk at Signalized Intersections

The body of literature on pedestrian crash risk at intersections (and specifically, signalized intersections) is limited. However, some locations have been studied more extensively than others. For example, the studies in the literature with analysis at signalized intersections were focused in the state of Florida; the city of Portland, Oregon; the city of Austin, Texas; and the city of Montreal, Quebec.

Presence of a Signal

Prior research suggests that the presence of a signal is consistent with reduced pedestrian crash severity but associated with increased crash frequencies.

- Prior research indicates moderate evidence that absence of a signal/stop sign or no traffic control is a potential roadway risk factor related to pedestrian crashes. (Thomas et al., 2018)
- Prior research has found that presence of a signal has a positive relationship with pedestrian crash frequency and a negative relationship with crash severity. (Thomas et al., 2018)

Presence of a Signal

Prior research suggests that the presence of a signal is consistent with reduced pedestrian crash severity but associated with increased pedestrian crash frequencies.

In Portland, Oregon, recent studies have shown that many pedestrian crashes and fatalities occur at signalized intersections.

- In the City of Portland between 2006-2015, 71% of all pedestrian crashes occurred at intersections, with 44% at signalized intersections. (City of Portland, 2019), (Portland Bureau of Transportation, 2019).

- Over 40% of pedestrian crashes and 30% of severe/fatal crashes citywide occur at signalized intersections. (Portland Bureau of Transportation, 2019)
- Unsignalized and mid-block intersections were found to have a higher probability of serious injury or fatality. (Portland Bureau of Transportation, 2019)

Pedestrian Crashes and Severity at Signalized Intersections

Keeping in mind the overall factors associated with pedestrian fatalities and serious injuries from previous research (see Table 3), some studies identified conditions or factors found to be associated with pedestrian crashes and/or crash severity at signalized intersections*:

- Lack of separate turning movements from walk phase and lack of leading pedestrian interval (LPI) have a positive correlation with risk of pedestrian crashes at signalized intersections. (Thomas, et. al, 2018)
- The total number of lanes and the number of commercial entrances were found to increase pedestrian injuries. (Stipancic et al., 2020)
- A positive relationship exists between pedestrian volumes and pedestrian injuries. (Stipancic et al., 2020), (Munira et al., 2020)
- Both incapacitating and non-incapacitating injury crashes increase with increasing motorized traffic volume. (Munira et al., 2020), (Stipancic et al., 2020)
- Conditions associated with higher pedestrian severity risk at signalized intersections included higher AADT, speed limit, percentage of trucks, pedestrians age 80 or over, at-fault pedestrians, rainy weather, and dark lighting conditions. (Haleem et al., 2015)
- Vehicle turning movements have been noted as a factor in pedestrian crashes at signalized intersections. (See "Vehicle Turning Movements at Signalized Intersections" below.)
- Road user actions (at-fault drivers, at-fault pedestrians) can be a contributing factor. (See "Driver Actions at Signalized Intersections" and "Pedestrian Actions at Intersections" below.)

Conditions and Factors Found to be Associated with Pedestrian Crashes and/or Crash Severity at Signalized Intersections*

- Lack of separate turning movements from walk phase
- Lack of leading pedestrian interval (LPI)
- Number of lanes/more lanes
- Number of commercial entrances
- Higher pedestrian volumes
- Higher traffic volumes
- Higher percentage of trucks
- Rainy weather
- Dark lighting conditions
- Pedestrians age 80 or over
- Turning vehicles
- At-fault drivers and at-fault pedestrians

**It is important to note that though some studies identified various conditions and factors associated with pedestrian crashes and/or severity at signalized intersections, the analysis and findings are often specific to selected geographic locations or sites and may not apply generally to all signalized intersections.*

Vehicle Turning Movements at Signalized Intersections

A summary of previous research suggests that high-turning volumes at intersections have an unknown threshold in terms of a roadway risk factor for pedestrian crashes at intersections. (Thomas et al., 2018) However, two studies noted a correlation with turning movements as a factor in pedestrian crashes at signalized intersections.

- Over a quarter of all crashes involve a turning driver failing to yield when the person walking has the right of way at the signal (20% left-turning drivers and 8% right turning drivers). (Portland Bureau of Transportation, 2019) (City of Portland, 2019)
- Pedestrian movements often conflict with turning vehicles at intersections caused by either shared signal phases at signalized intersections or competitive right of way at unsignalized intersections. (Xu et al., 2015)
- Protected left-turn is safer than the permitted left-turn for pedestrians. (Xu et al., 2015)
- Right-turn-on-red shows obvious relationship to the pedestrian-turning-traffic crash. (Xu et al., 2015)

Driver Actions at Signalized Intersections

In addition to turning movements noted in the previous section, the following driver actions were found to contribute to pedestrian crashes at signalized intersections:

- The most frequent contributing causes of vehicle-pedestrian crashes at signalized intersections where the driver was at fault were careless driving, failure to yield the right-of-way, and disregard of traffic signal or other traffic control. (Alluri et al., 2014)
- The majority of intersection collisions occurred at locations with traffic signals and when the pedestrian had the "WALK" indication. (Portland Bureau of Transportation 2019)

Pedestrian Actions at Signalized Intersections

Some studies have found at-fault pedestrians to be a factor in pedestrian-vehicle crashes and/or higher pedestrian severity risk at signalized intersections:

- In over 50% of pedestrian crashes at signalized intersections in Florida from 2008-2010, pedestrians were at fault. (Alluri et al., 2014)
- The most frequent contributing causes of vehicle-pedestrian crashes where the pedestrian was at fault were failure to yield the right-of-way, under the influence of alcohol and/or drugs, and disregard of traffic signal or other traffic control. (Alluri et al., 2014)
- One of the conditions associated with higher pedestrian severity risk at signalized intersections was at-fault pedestrians. (Haleem et al., 2015)
- Pedestrian crashes where pedestrians cross against the signal account for 8% of pedestrian crashes and result in fatalities or serious injuries 25% of the time. (Portland Bureau of Transportation, 2019)

4.0 Industry Scan

This section includes background information related to vehicle-equipped pedestrian detection systems and infrastructure-based pedestrian crossing safety countermeasures, followed by an industry scan of detection-based pedestrian safety technologies. The background information is intended to provide context leading into the industry scan, which focuses on technologies that can supplement infrastructure countermeasures and efforts by the automobile industry to standardize and improve vehicle-equipped pedestrian crash prevention systems.

4.1 Background

While an increasing number of new vehicles are being equipped with pedestrian detection as a standard feature, the performance of vehicle-equipped pedestrian crash prevention systems varies. In 2019, 38 percent of vehicle models sold in the U.S. had pedestrian detection as a standard feature, up from 19 percent in 2018 (Consumer Reports, 2019). In 2019, the Insurance Institute for Highway Safety (IIHS) rated pedestrian crash prevention systems of 16 midsize cars and found variable performance results, with six midsize cars earning a superior rating, six cars earning an advanced rating, and four cars earning a basic rating or no credit (IIHS, 2019).

In addition to advancements being made in the automobile industry, several infrastructure-based pedestrian safety countermeasures also exist. The USDOT Federal Highway Administration (FHWA) promotes the following seven countermeasures to improve pedestrian crossing locations as part of the Safe Transportation for Every Pedestrian (STEP) program (FHWA, n.d.):

- Road Diets
- Pedestrian Hybrid Beacons (PHBs)
- Pedestrian Refuge Islands
- Raised Crosswalks
- Crosswalk Visibility Enhancements
- Rectangular Rapid-Flashing Beacons (RRFBs)
- Leading Pedestrian Intervals (LPI)

According to the FHWA STEP Countermeasure Tech Sheet on RRFBs (FHWA, 2018), “RRFBs are pedestrian-actuated conspicuity enhancements used in combination with a pedestrian, school, or trail crossing warning sign to improve safety at uncontrolled, marked crosswalks. The device includes two rectangular shaped yellow indications, each with an LED-array-based light source, that flash with high frequency when activated.” This Tech Sheet indicates that RRFBs can reduce pedestrian crashes by 47% and are particularly effective at multilane crossings with speed limits less than 40 mph. The FHWA STEP website (FHWA, n.d.) notes that “RRFBs are active (user-actuated) or passive (automated detection) amber LEDs that use an irregular flash pattern at mid-block or uncontrolled crossing locations. They significantly increase driver yielding behavior.” Though RRFBs are often user-actuated, there may be growing interest in passive activation (automated detection) of RRFBs as detection technologies improve. The Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations (Blackburn et al., 2018) provides guidance for selecting safety countermeasures at uncontrolled crossing locations, including guidance for considering and deploying RRFBs.

Detection-based ITS technologies hold the potential to improve pedestrian safety, especially to supplement known infrastructure countermeasures and efforts by the automobile industry to standardize and improve pedestrian crash prevention systems. The following sections provide results from an online industry scan which identified several detection-based ITS technologies that aim to improve pedestrian safety. The detection-based safety system technologies presented in this section include mobile apps, video detection, and a variety of other approaches. Since this is a growing and active area within the field of ITS, the technologies presented in this section may not be the only technologies available. The approaches documented provide technologies that are commercially available or being researched and focus on preventing or minimizing pedestrian-vehicle crashes. Two categories of detection-based pedestrian safety technologies are summarized in the following sections:

- Detection-Based Technologies with Real-time Alerts
- Detection-Based Technologies with Data Collection and Analysis Platforms

4.2 Detection-Based Technologies with Real-time Alerts

Detection-based technologies with real-time alerts could include technologies that detect pedestrians, vehicles, or both. Detection sources vary and could utilize vehicle-based detection (built into the vehicle), infrastructure-based technology (cameras or lidar mounted at intersections) or connected and automated vehicle (CAV) technologies. Real-time alerts could be provided to the pedestrian, the driver, the automated driving system, or a combination of these, depending on the technology.

Table 4 provides an overview of the following detection-based pedestrian safety technologies with real-time alerts:

- !important
- TravelSafely™
- Applied Information and TravelSafely™
- Applied Information and Qualcomm and TravelSafely™
- Derq / FLIR
- MH Corbin / Bosch
- Draper (PathScout system)
- Reflective Surface for Intelligent Transportation Systems (REITS)
- Sensol
- TAPCO / FLIR
- Texas A&M Transportation Institute Transit, Bicycle and Pedestrian Safety Research
- University of Michigan Transportation Research Institute “Vehicle to Pedestrian Connections” project
- Viziblezone
- MultiNet
- VectorNet

Table 4: Detection-Based Pedestrian Safety Technologies with Real-time Alerts

Technology	Overview
!important *Smartphone app that alerts pedestrians, alerts drivers, and triggers brakes on connected vehicles automatically*	Sources: • !important website: https://www.important.com/ • !important app Download web page with videos: https://www.important.com/download • News Release: !important - The First App that Could Save Your Life (2020) • News Release: The Digital Seatbelt Is an App That Can Stop Cars from Hitting Pedestrians (2020) • App Review: Important App Review (2020) Functioning as a digital safety belt, the !important app **communicates the user's location to nearby connected vehicles**. The technology can immediately **alert drivers and soon will even trigger vehicles' brakes automatically** to prevent a collision with an approaching person, bicyclist, or motorcyclist. Users have the option of choosing their means of transportation including walking, bus, car, e-scooter, train/subway, motorbike, or wheelchair. Detection Method: • The smartphone application **uses location data and determines the distance** between a pedestrian or cyclist and an approaching self-driving car. • In addition to self-driving cars, the application can also be used for people-driven vehicles, requiring no hardware. The app just needs to be installed on a smartphone and on the head unit in the car. Real-time Alerts: • Sends an **alert to the self-driving car and the pedestrian**. Deployments/Testing: • The Digital Seatbelt Is an App That Can Stop Cars from Hitting Pedestrians (August 15, 2020): The University of California, Berkeley research team is currently in discussions with cellphone carriers and car manufacturers to launch an initial testing phase.
TravelSafely™ *Smartphone app that connects users with smart city infrastructure*	Sources: • TravelSafely™ website: https://travelsafelyapp.com/the-app/ • 2018 News Archive: Download Marietta's TravelSafely App Today at Google Play or iTunes Store! (2018) The TravelSafely™ app connects users with smart cities, other motorists, pedestrians, and cyclists to get where they're going quicker and stay safe. Detection Method: • User phone connects to a network of traffic intersections, school beacons, motorists, cyclists and pedestrians. • Connects users with city infrastructure to provide users information such as: get ready for green, red light warning, school zone warning, work zone warning, curve warning, low speed warning, cyclist ahead warning, **pedestrian ahead warning**, emergency vehicle warning, rear end collision warning, and vehicle approaching cyclist. See Figure 10.

<table>
<tr><th>Technology</th><th>Overview</th></tr>
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Real-time Alerts:

Provides real-time connected vehicle data through visual and audible notifications. See Figure 10.
Cyclists and pedestrians using the app are alerted of speeding vehicles and other dangerous conditions.

Figure 10: Vehicle (left) and Pedestrian (right) Views of TravelSafely App
(Source: Images from “TravelSafely Connected Traveler System explained” video on TravelSafely: How it Works web page 12/7/21)

Deployments/Testing:

Download Marietta’s TravelSafely App Today at Google Play or iTunes Store! (August 27, 2018): The Marietta TravelSafely app is designed to save lives by reducing first responder response time and making drivers, cyclists and pedestrians more visible to each other and improving traffic flow. Vehicles approaching intersections will communicate with traffic signals so drivers can adapt to traffic flow. Another feature of the app notifies drivers of cyclists and pedestrians ahead who in turn will be warned if a vehicle is approaching at an unsafe speed. Anyone driving, cycling or walking in the city can use the app which will automatically work in the city’s 23 square mile area.

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<tr><td>Applied Information and TravelSafely™

Pedestrian crossing safety system with roadside signs, audible alerts, and connection to smartphone app</td><td>
Sources:

Applied Information website: https://appinfoinc.com/
TravelSafely™ website: https://travelsafelyapp.com/the-app/
Applied Information Brochure: Pedestrian Crossing Safety System (n.d.)
News Release: Applied Information Introduces Next Generation Pedestrian Crossing Safety System Using Internet of Things Technology (2020, May 14)

Figure 11: PCSS Sign
(Source: Applied Information Pedestrian Crossing Safety System brochure)

Applied Information’s Pedestrian Crossing Safety System (PCSS) makes crosswalks safer for pedestrians with an innovative combination of flashing warnings, audible alerts, and connected technology that sends a text or email when there is a problem with the PCSS.

Detection Method:

Detects the speed of approaching vehicles using Internet of Things (IoT) technology.

Real-time Alerts:
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Technology	Overview
	• **Uses flashing patterns and**, in some cases, **a Digital Message Sign to warn motorists and pedestrians** of possible collisions. See Figure 11. • Automatically **connects to the TravelSafely™ app** and **provides an audible warning to pedestrians and motorists**.
Applied Information and Qualcomm and TravelSafely™ *System linking traffic signals and connected roadway users and devices*	Sources: • Applied Information website: https://appinfoinc.com/ • Qualcomm website: https://www.qualcomm.com/ • TravelSafely™ website: https://travelsafelyapp.com/the-app/ • News article: Applied Information Helps Bring C-V2X Connected Vehicle Technology to Improve Road Safety and Traffic Efficiency to Hawaii (2020) Applied Information roadside units (RSU) will provide connectivity between the traffic signals and roadway users and utilize the Qualcomm® 9150 C-V2X Platform. Detection and Real-Time Alerts: • The connectivity provided by the Applied Information solution enables the infrastructure to communicate with any cloud-connected or C-V2X enabled vehicle or device. The Applied Information TravelSafely smartphone app connects drivers to the infrastructure, providing the first application of connected vehicle technology using data from multiple infrastructure sources for day-to-day use by the general public. TravelSafely also connects drivers to other app users such as pedestrians, cyclists and scooter riders to provide alerts and warning of potential crashes. Deployments/Testing: • Applied Information Helps Bring C-V2X Connected Vehicle Technology to Improve Road Safety and Traffic Efficiency to Hawaii (August 5, 2020): C-V2X technology will be integrated into 34 traffic signals along the Nimitz Corridor in Honolulu. This project will test several connected vehicle applications using a V2X-enabled interconnected traffic control system program administered by the Hawaii DOT and the University of Hawaii College of Engineering. Among the applications to be deployed are Red Light Violation Warning, **Pedestrian and Cyclist Collision Warnings**, Emergency Vehicle Preemption, Transit Signal Priority, Traffic Queue Warning, the **TravelSafely™ smartphone app**, and Signal-Phase and Timing (SPaT). See Figure 12.  **Figure 12: Nimitz Corridor C-V2X Status (July 16, 2020)** *(Source: Applied Information Helps Bring C-V2X Connected Vehicle Technology to Improve Road Safety and Traffic Efficiency to Hawaii press release 8/5/2020)*

Technology	Overview
Derq / FLIR *Software application using artificial intelligence (AI) to run real-time edge analytics, enable V2X applications, and provide safety and traffic insights* *(See Table 5 for traffic insights)*	Sources: • Derq website: http://en.derq.com/ • Derq Sense website: https://en.derq.com/derq-sense • News Release: Derq and FLIR Systems Collaborate on MDOT V2X Safety Project in Detroit (2018) • News Release: Startups test safety systems in Michigan (2019) Derq's Platform **ingests and fuses data from IoT traffic cameras and sensors** then **runs real-time edge analytics** to enable infrastructure perception and V2X/5G applications as well as actionable safety and traffic insights. Derq Sense is an edge-based solution that **provides real-time infrastructure-based analytics** for off-board cooperative perception and traffic management applications, including **V2X applications for CAV, adaptive traffic management, and smart pedestrian crosswalks**. The Derq software **monitors vehicle-to-infrastructure and vehicle-to-pedestrian interactions** to predict and prevent collisions. Derq makes accurate inferences about vehicles that are going to run red lights before they do it, broadcasts immediate warnings to vehicles in the area, and **predicts the intentions of pedestrians and other vulnerable road users and alerts vehicles** if a conflict is anticipated. Detection Method: • Ingests and fuses data from IoT traffic cameras and sensors. Real-time Alerts: • Provides full situational awareness to connected and autonomous vehicles detecting and predicting conflicts with pedestrians, vehicles, or other vulnerable road users (VRU), to avoid collisions. See Figure 13. • Enables adaptive traffic signal actuation applications. • Provides pedestrian and other VRU detection and intent-to-cross prediction, to actuate flashing beacons and signs.  **Figure 13: Vehicle View of Derq Sense V2X Application** *(Source: Derq Sense website 12/7/2021)* Deployments/Testing: • Derq and FLIR Systems Collaborate on MDOT V2X Safety Project in Detroit (June 6, 2018) and Startups test safety systems in Michigan (April 30, 2019): Located at Jefferson Avenue and Randolph Street in Detroit, Michigan. Derq worked with Michigan DOT to select and install sensors on the intersection to provide data feeds for Derq to run its software applications, generate predictions, and communicate threats in real-time. Derq is collaborating with FLIR Systems for thermal imaging and combined visible/radar sensors.

Technology	Overview
MH Corbin / Bosch *Utilizes video images from cameras to detect and communicate the presence of a pedestrian*	Source: • MH Corbin website: https://mhcorbin.com/Solutions/Pedestrian-Detection MH Corbin utilizes video images from **Bosch cameras to detect the presence of a pedestrian**, whether the pedestrian is located inside or outside a designated crosswalk by mapping out detection zones. Detection Method: • **Applies video analytics to proactively warn motorists** of the presence of pedestrians in the roadway. • Connect:ITS receives and analyzes camera alert by running it through the onboard scripting engine. Real-time Alerts: • **Alert is sent from the camera to Connect:ITS** and Connect:ITS determines which outputs will be activated. • Connect:ITS **communicates the presence of a pedestrian to motorists** in the area using flashing warning signs, flashing beacons, and dedicated short-range communications (DSRC) messages to connected vehicles.
Draper (PathScout system) *Vehicle sensor using mobile phone GPS data and LiDAR to "see" pedestrians*	Sources: • Draper website: https://www.draper.com/ • Draper Detection web page: Object Detection for Obstacle Avoidance https://www.draper.com/business-areas/commercial/automotive/object-detection-obstacle-avoidance • News Release: Draper's New Driver Assist Tech Can 'See' Pedestrians (2020) Draper is developing sensor technologies to detect objects and predict their trajectories so that a self-driving car has more time to stop or maneuver. Draper's PathScout system aims to equip drivers with a system that alerts them to nearby pedestrians when it **detects GPS signals emitted by their mobile phones**. Detection Method: • The PathScout vehicle sensor **uses anonymized cell phone GPS data to detect unseen people and predict their immediate trajectories** to address the risk posed by pedestrians, bicyclists or other cars out of view emerging from behind an object suddenly into a car's path. • **Uses LiDAR technology to allow autonomous vehicles to "see" pedestrians** with higher resolution and further range. Real-time Alerts: • **Warns drivers of a potential collision** between their vehicle and vulnerable road users based on cell phone GPS data.
Reflective Surface for Intelligent Transportation Systems (REITS)	Sources: • News Release: Researchers suggest pedestrians should wear technology to communicate with driverless cars (March 2021) • Technical Report: REITS: Reflective Surface for Intelligent Transportation Systems (2021)

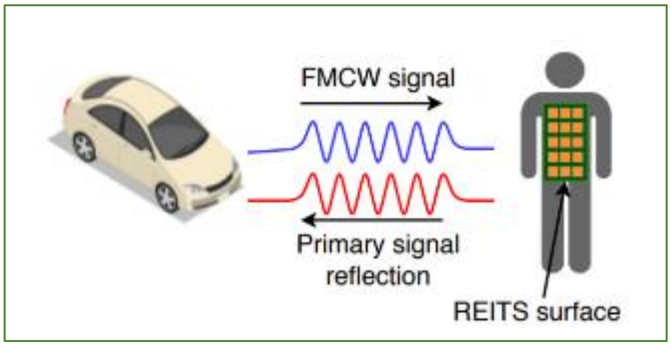
Technology	Overview
Wearable device to allow autonomous vehicles to detect pedestrians	• Video Presentation: HotMobile 2021 - REITS: Reflective Surface for Intelligent Transportation Systems (March 2021) Reflective Surface for Intelligent Transportation Systems (REITS), a system to improve the reliability of radio frequency (RF)-based sensing modules for autonomous vehicles, **allows pedestrians to wear radar reflectors in order to be "seen" by driverless cars.** REITS enables robust sensing for self-driving car radar by reflecting the radar signal to its incoming direction. See Figure 14. Created at Princeton University, the device makes people more visible to the vehicle's sensors. Cars that rely on visual sensors can have their awareness reduced by fog, rain, or snow while radar can struggle to pick out objects if they fail to reflect waves back to the car. Preliminary results show that REITS improves the detection distance of a self-driving car radar by a factor of 3.63.  **Figure 14: REITS Sensing for Self-driving Car Radar** *(Source: REITS: Reflective Surface for Intelligent Transportation Systems technical report 2021)* Detection Method: • Adopts a **multi-antenna design**, which **enables constructive blind beamforming to return an enhanced radar signal in the incident direction**. Real-time Alerts: • REITS allows the existing radar system to sense identification information from the REITS surface, to improve the detection distance of a self-driving car's radar system.
Sensol *High-tech illuminated crosswalk*	Sources: • Sensol website: https://www.sensolsystems.com/ • News Release: UW alum founded Sensol to develop smart crosswalks (2021) Sensol is a high-tech crosswalk that **illuminates a pedestrian's exact location from below** as they cross the road to increase visibility and save lives. As pedestrians step onto a sensor, the device illuminates the crosswalk for vehicles to see from farther away. See Figure 15. In April 2021, product testing will take place in three locations around the Pacific Northwest.

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Figure 15: Sensol Illuminated Crosswalk
(Source: Sensol website Product page 12/7/2021)

Detection Method:

- The crosswalk system is overlaid on top of the road with minimal change to the integrity of the asphalt or may be directly inset. The integrated detection system **detects and distinguishes pedestrians, vehicles, and bicycles**. **Chips inside the crosswalk use the detected traffic information** to **trigger the flashing beacons, directly illuminate pedestrians**, and send signals and data out for use in safety applications.

Real-time Alerts:

- As pedestrians step onto a sensor (in the crosswalk), the device illuminates the crosswalk.
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TAPCO / FLIR

Thermal detection-activated Rectangular Rapid-Flashing Beacon (RRFB) Pedestrian Crosswalk System
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Source:

- TAPCO case study web page: Small Town Overhauls Bike Trail Safety with Thermal-Activated RRFBs (Auburn, Iowa)

This technology consists of the solar-powered TAPCO Rectangular Rapid-Flashing Beacon (RRFB) Pedestrian Crosswalk System with FLIR thermal detection technology. TAPCO RRFBs are extra-large light bars that flash in the Interim Approval 21-approved wig-wag plus simultaneous (WW+S) flash pattern when activated. See Figure 16.

Figure 16: TAPCO Pedestrian Crosswalk System *(Source: TAPCO case study web page 1/21/2022)*

Detection Method and Real-time Alerts:

- With thermal activation, the RRFBs light up when pedestrians and bicyclists are present, rather than relying on people to push a button to activate the system.

Deployment/Testing:

- Small Town Overhauls Bike Trail Safety with Thermal-Activated RRFBs (Auburn, Iowa): This TAPCO thermal-activated RRFB Pedestrian Crosswalk System was deployed near Grant Park near Auburn, Iowa. Grant Park is an outdoor recreational space where vulnerable road users cross State Highway 71 – which averages about 7,500 cars per day – at the top of a hill where visibility was limited.
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Technology	Overview
Texas A&M Transportation Institute Transit, Bicycle and Pedestrian Safety Research *Research focusing on AV/CV technologies for transit vehicles and detection of pedestrians and bicyclists*	Sources: • Research Article: Transit, Bicycle and Pedestrian Safety Test Bed website • Research Article: Making Shared Space Safer: TTI Studies Automated, Connected Vehicle Technology to Improve Transit, Pedestrian and Bicyclist Safety (2018) • Research Article: Visualizing a Safer Transportation Community (2016) • Technical Report: Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety (2017) Texas A&M Transportation Institute (TTI) assisted the Texas Department of Transportation (TxDOT) in making shared spaces safer for all users as the focus of the research project, "Automated Vehicle/ Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety." The project focused on **identifying safety concerns** related to the **interaction of transit vehicles, bicyclists, and pedestrians**, and **targeting AV/CV technologies** to mitigate or eliminate those concerns. Detection Method: • A pilot of a **camera and sensor-based collision avoidance system** was conducted on one Texas A&M University (TAMU) bus. • The system has four different cameras that are aimed at the blind spots on the bus and where pedestrians and bicyclists are most likely to show up and be in harm's way. This technology is able to detect when there's an object that's moving that looks like a person or a cyclist. Real-time Alerts: • A visual display unit is **mounted inside the vehicle** and **sends a visual and audio alert** before an imminent collision with a pedestrian or cyclist, allowing the driver time to react. • The system provides **two types of warnings to the bus driver**. A yellow light goes off when a pedestrian or bicyclist is detected within range of the bus, alerting the driver to proceed with caution. A red light and a buzzer go off when a pedestrian or bicyclist is very close to the bus, alerting the driver to stop to avoid a possible collision. Deployments/Testing: • Transit, Bicycle and Pedestrian Safety Test Bed: Texas A&M Transportation Institute (TTI) developed a concept of operations plan for designing, testing, piloting, demonstrating, and deploying CAV technology hardware and applications to reduce and eliminate crashes involving transit, bicyclists, and pedestrians. A pilot test was also conducted of the Mobileye Shield + collision avoidance system on a Texas A&M University bus in Phase I of the project. See Figure 17.  **Figure 17: Mobileye Shield+ Collision Avoidance System** *(Source: TTI Transit, Bicycle and Pedestrian Safety Test Bed web page 12/7/2021)*

Technology	Overview
	• Making Shared Space Safer: TTI Studies Automated, Connected Vehicle Technology to Improve Transit, Pedestrian and Bicyclist Safety (December 2018): TTI researchers evaluated methods to warn pedestrians and bicyclists of turning buses at signalized intersections, and developed and pilot-tested a smart intersection **using visual and audible alerts and a beta smartphone app**. TTI installed a state-of-the-art smart intersection at Texas A&M University System's RELLIS Campus to pilot-test the system. See Figure 18.  **Figure 18: Illuminated Sign at Smart Intersection** *(Source: TTI Making Shared Space Safer web page* • Visualizing a Safer Transportation Community (March 2016): Concerns found in the research included buses making turns at intersections or traveling in a straight line and negatively interacting with bicyclists and pedestrians, as well as distracted bicyclists and pedestrians not being aware of a transit vehicle. The longer-term research focused on technologies associated with moving toward autonomous buses. The Mobileye/Rosco Shield+™ collision-avoidance system was installed on one Texas A&M University bus that traverses the heart of campus, passing thousands of students daily.
University of Michigan Transportation Research Institute "Vehicle to Pedestrian Connections" project *Research to detect pedestrians crossing the road using a cell phone application and an overhead camera*	Source: • University of Michigan Transportation Research Institute (UMTRI) "vehicle to Pedestrian Connections" project description web page: https://umtri.umich.edu/research/expertise/projects/vehicle-to-pedestrian-connections/ UMTRI researchers are examining two methods for detecting pedestrians crossing the road. By detecting pedestrians in the road, and by using technology deployed as part of the Ann Arbor Connected Environment, some drivers will be able to **receive warnings in their vehicle about pedestrians in the road ahead**. Detection Method: • Detection of pedestrians can happen in **two ways**: through a phone application, or through the use of an overhead camera. • A **cell phone application** uses the phone's GPS to determine when the phone is in or near one of the target crosswalks. When the application believes it is in a target area, it communicates with equipment installed on the side of the road, and the Pedestrian Safety Message is activated. • Above each of the four target crosswalks, a **camera is mounted looking down at the street**. When an object enters certain areas of the video and moves in a manner consistent with a crossing pedestrian, the Pedestrian Safety Message is activated. • A **connected vehicle system receives information** from GPS satellites, processes the information, and **transmits out its own GPS location** wirelessly. Real-time Alerts:

Technology	Overview
	• When the connected vehicle system determines that there may be the potential for a crash (another connected vehicle is stopped ahead, a pedestrian is in a crosswalk ahead) it can warn the driver by **flashing the LED lights** and playing **warning tones or messages from the speaker** ("Pedestrian Ahead"). • When a properly equipped vehicle approaches one of the equipped crosswalks, and the connected vehicle device on-board receives a Pedestrian Safety Message from the roadside equipment, **red LEDs on the dashboard light up and the speaker under the dashboard plays a voice** saying "pedestrian ahead." Deployments/Testing: • Vehicle to Pedestrian Connections (n.d.): About 800 vehicles currently driving around Ann Arbor are equipped with both a connected vehicle system, and a driver-vehicle interface, a row of LED lights mounted in-view of the drivers and a small speaker hidden under the dashboard. This study examines both the effectiveness of the two different detection systems as well as the safety benefit realized when drivers can receive the pedestrian safety message.
Viziblezone *A vehicle integrated "Pedestrian Detector" that pairs with a car infotainment system or smartphone*	Sources: • Viziblezone website: https://www.vizible.zone/ • News article: Viziblezone Wants Cars to Spot Pedestrians By Tracking Their Smartphones (2020) • News article: Israeli Startup Wants to Use Phone Tracing to Keep Pedestrians Safe (2020)  **Figure 19: Viziblezone Detecting Pedestrian** *(Source: Viziblezone website 12/7/2021)* Viziblezone identifies, tracks and protects pedestrians, even when they go undetected by a fast-approaching driver. The detector is **designed to operate in any adverse weather and visibility, whether day or night**. The technology aims to **turn smartphones into beacons**, transmitting the location of pedestrians directly to nearby vehicles and alerting their drivers. The system is **smart enough to know whether the pedestrian is on foot, using an electric scooter, or riding a bike**. Viziblezone is designed to pair with either a car infotainment system or smartphone. See Figure 19 and Figure 20.

Technology	Overview
	 **Figure 20: Viziblezone's Pedestrian Detection System** *(Source: [The Drive](#) website 12/7/2021)* Detection Method: • Can detect pedestrians behind obstacles when there is no line of sight. • Uses the **WiFi antenna on smartphones to transmit** a signal that can be picked up by other devices running Viziblezone's system as far as 590 feet away. • **Uses Radio Frequency (RF) technology** operating at a bandwidth that allows obstacles to be bypassed. Real-time Alerts: • Alerts provided to drivers using the vehicle's infotainment system or a smartphone app.
MultiNet *Uber's self-driving AI system that detects and predicts the motions of obstacles from autonomous vehicle lidar data*	Sources: • MultiNet website: https://multinetcom.ch/en/uber-uns/ • News Release: Uber's self-driving AI predicts the trajectories of pedestrians, vehicles, and cyclists (2020) • News Release: MultiNet: a system that detects and predicts obstacle movements (2020) • Paper: MultiXNet: Multiclass Multistage Multimodal Motion Prediction (2020) MultiNet reasons about the **uncertainty of the behavior and movement of cars, pedestrians, and cyclists** using a model that **infers detections and predictions** and then refines those to **generate potential trajectories**. Detection Method: • MultiNet **uses lidar sensor data and high-definition maps** of streets and jointly learns obstacle trajectories and trajectory uncertainties. Real-time Alerts: • Though alerts are not explicitly described in the source material, MultiNet is Uber's self-driving AI technology that predicts the future states of vehicles, pedestrians, and bicyclists. Deployments/Testing: • Uber's self-driving AI predicts the trajectories of pedestrians, vehicles, and cyclists (June 4, 2020): To test MultiNet's performance, researchers trained the system for a day on ATG4D, a data set containing sensor readings from 5,500 scenarios collected by Uber's autonomous vehicles across cities in North

Technology	Overview
	America using a roof-mounted lidar sensor. They report that MultiNet outperformed several baselines by a significant margin on all three obstacle types (vehicles, pedestrians, and cyclists) in terms of prediction accuracies. Modeling uncertainty led to improvements of 9% to 13%, and it allowed for reasoning about the inherent noise of future traffic movement.
VectorNet *Waymo's AI solution* that uses vectors to *predict pedestrian, cyclist, and driver behavior*	Sources: • Waymo website: https://waymo.com/company/ • Waymo Blog post: VectorNet: Predicting behavior to help the Waymo Driver make better decisions (May 14, 2020) • News Report: https://venturebeat.com/2020/05/14/waymos-ai-uses-vectors-to-predict-pedestrian-cyclist-and-driver-behavior/ Waymo's AI, VectorNet, uses vectors to **predict pedestrian, cyclist, and driver behavior** and provides more accurate projections. VectorNet helps predict the movements of road users by building representations to **encode information from maps**, including **real-time trajectories**, and collects high-definition, precise-to-the-centimeter **maps of regions where its autonomous vehicles drive**. **Paired with sensor data**, these representations **provide context to Waymo's driverless system**. The Waymo Driver's sensors and software **scan constantly for objects around the vehicle**—pedestrians, cyclists, vehicles, road work, obstructions—and **continuously read traffic controls**, from traffic light color and railroad crossing gates to temporary stop signs. See Figure 21.  **Figure 21: Waymo's autonomously driven electric Jaguar I-PACE electric SUV** *(Source: Waymo Media Resources web page 12/7/2021)* Detection Method: • Ingests each map and sensor input in the form of vectors. Waymo trained the system to **learn from context clues to make inferences about what could happen** near a vehicle. • **Computes future trajectories and captures relationships**, such as when a car enters an intersection or a pedestrian approaches a crosswalk, allowing better prediction of behaviors. Real-time Alerts: • Provides more accurate projections of pedestrian, cyclist, and driver behavior to Waymo drivers and in regions where autonomous vehicles drive.

4.3 Detection-Based Technologies with Data Collection and Analysis Platforms

Detection-based technologies with data collection and analysis platforms are systems that include sensors to detect and collect vehicle and/or pedestrian data over time, for analysis by agencies to identify problem locations. Systems like this are typically deployed at intersections but do not necessarily need to be at intersections. Analytics platforms could identify issues such as pedestrian crosswalk violations, vehicle violations that impact pedestrians (e.g., red light running), near misses, or other surrogate measures that could be associated with increased vehicle or pedestrian crash risk.

Table 5 provides an overview of the following detection-based pedestrian safety technologies with data collection and analysis platforms:

- Bluecity
- Boulder AI and MeterSYS
- GRIDSMART®
- Derq
- Iteris PedTrax
- MicroTraffic
- Miovision TrafficLink Safety Analytics
- Sensol
- Transoft Solutions' BriskLUMINA and BriskVantage
- Smart City PDX: Traffic Safety Sensor Project
- Currux Vision

Table 5: Detection-Based Technologies with Data Collection and Analysis Platforms

Technology	Overview
Bluecity *Technology that combines artificial intelligence and LiDAR to better understand and adjust smart city mobility*	Sources: • Bluecity website: https://bluecity.ai/ • Webinar: ITS America Webinar - A Lidar-Based Approach to Pedestrian Safety (November 12, 2020) Bluecity developed IndiGO, its computer vision and traffic data platform, to provide **real-time, traffic data and analytics** with pinpoint accuracy about the **speed and trajectory** of cars, pedestrians, and bicycles. with IndiGO, users access valuable information about which intersections are the most dangerous or where traffic light timing needs to be adjusted. IndiGO 3D uses AI and 3D LiDAR to provide information about the **type of road users, the count, speed, and trajectories** in real-time. IndiGO 1D uses AI and 1D LiDAR to provide **real-time data about pedestrians and cyclists** to provide information about how many people are on the streets at a chosen location with 95% accuracy. Detection Method: • **Combines artificial intelligence (AI) and LiDAR** to better understand and adjust smart city mobility. AI turns raw LiDAR data into actionable traffic information.

Technology	Overview
	• The IndiGO solution is a technology based on AI-powered sensors that provide reliable data in any extreme weather or poor lighting conditions. Deployments/Testing: • ITS America Webinar - A Lidar-Based Approach to Pedestrian Safety (November 12, 2020): Panelists discussed how lidar-based technologies are being implemented across industries, including for autonomous vehicles (AV), advanced driver assistance and intelligent infrastructure.
Boulder AI *Edge devices that perform real time sensing, inference, and actions to curate edge data, perform device and software orchestration, and support centralized learning and insights* **MeterSYS** *Platform that enables transportation planners and engineers to automatically access data and insights in real-time*	Sources: • Boulder AI website: https://boulderai.com/products/ • MeterSYS website: https://metersys.com/ • Deployment News: Boulder-based visual intelligence company lands contract with City of Denver, Colorado to improve pedestrian safety (2020) • Deployment News: Raleigh IoT startup lands 'smart cities' partnership to improve public safety in Denver (2020) The Boulder AI Edge Devices **perform real time sensing, inference, and actions** and **directly interface to the Cloud** to curate edge data, perform device and software orchestration, and support sophisticated centralized learning and insights. Detection Method: • Boulder AI integrates an optical sensor and in-camera computing architecture and leverages existing cameras to enable artificial intelligence (AI) at the Edge. Deployments/Testing: • Boulder-based visual intelligence company lands contract with City of Denver, Colorado to improve pedestrian safety (June 16, 2020): The project's specific **goal is automating pedestrian detection and notification**. This allows traffic signal operations to be modified if someone, such as a young child or a sight-impaired individual, needs a little more time to cross the street. • Raleigh IoT startup lands 'smart cities' partnership to improve public safety in Denver (August 13, 2020): MeterSYS' platform enables transportation planners and engineers in Denver to **automatically access data and insights in real-time**, rather than relying on snapshots of manually collected historical data to make decisions. Boulder AI's platform is then used to make decisions based on those traffic flow analytics and pedestrian behavior to inform real-time interventions and long-term projects.
GRIDSMART® *Gathers and interprets vital traffic data to improve safety and efficiency at intersections using a video*	Sources: • GRIDSMART website: https://gridsmart.com/ • News Release: GRIDSMART Version 19.10: Safety Shouldn't Come at a Premium (2020) GRIDSMART **gathers and interprets vital traffic data**, empowers traffic professionals to adjust signal timing and traffic flow strategies, and **enables real-time monitoring and visual assessment**. Deploys pedestrian and cyclist safety features as they travel through the intersection. **Tracks cyclists as they travel**

<table>
<tr><th>Technology</th><th>Overview</th></tr>
<tr><td>detection system</td><td>through the intersection, providing the correct amount of green time for individuals based on their chosen path and speed.

Detection Method:
Video detection system using a SMARTMOUNT Bell Camera, GS2 Processor with embedded proprietary algorithms, and GRIDSMART Client. Provides a full intersection view, including the center where cars, trucks, motorcycles, bicycles, and pedestrians actually cross paths.</td></tr>
<tr><td>Derq

Software application using AI to run real-time edge analytics, enable V2X applications, and provide safety and traffic insights

(See Table 4 for real-time alert capabilities)</td><td>Sources:
Derq website: http://en.derq.com/
Derq Insight website: https://en.derq.com/derq-insight
Derq’s Platform ingests and fuses data from IoT traffic cameras and sensors then runs real-time edge analytics to enable infrastructure perception and V2X/5G applications as well as actionable safety and traffic insights. Derq Insight generates an array of real-time safety and traffic insights, providing up-to-date, accurate and granular data enabling in-depth analysis of safety issues, countermeasure development and traffic performance assessment.
Safety Insights: Real-time identification and classification of safety events such as near-misses, collisions, violations, and pedestrian and cyclist compliance issues.
Traffic Insights: Counts by lane, turning movements, classifications, and other customized traffic reports.
Reporting Dashboard: User-friendly web-based dashboard using a wide variety of reporting toolkits for live or historical insights access.
Detection Method:
Ingests and fuses data from IoT traffic cameras and sensors.</td></tr>
<tr><td>Iteris PedTrax

Provides algorithm expertise that utilizes existing detection sensors to provide enhanced data output of bicycles and pedestrians</td><td>Sources:
Iteris website: https://www.iteris.com/products/pedestrian-and-cyclist
Iteris PedTrax website: https://www.iteris.com/products/pedestrian-and-cyclist/pedtrax
PedTrax provides bi-directional counting and speed tracking of pedestrians within the cross-walk, automatically collecting this information after normal vehicle detection has been implemented. The system also has the capability to provide detection outputs when pedestrians are in the crosswalk for enhanced safety applications.

Detection Method:
The PedTrax feature is embedded within the Iteris detection algorithms, and there is no need for any additional equipment for this feature to operate.</td></tr>
<tr><td>MicroTraffic

Software that measures near-misses from</td><td>Sources:
MicroTraffic website: https://www.microtraffic.com/
ITS Minnesota 2020 Fall Forum Presentation: Diagnosing Intersection Safety Risk (September 24, 2020)</td></tr>
</table>

<table>
<tr><th>Technology</th><th>Overview</th></tr>
<tr><td>video rather than looking at historical crash data</td><td>MicroTraffic diagnoses traffic safety risks at intersections to provide a picture of what’s going on at the intersection and uses AI-powered computer vision to measure near-misses and drive proactive road safety investments. See Figure 22. Forty (40) cities, counties, and State DOTs have programmed $225M worth of road safety investments using MicroTraffic diagnostic data.

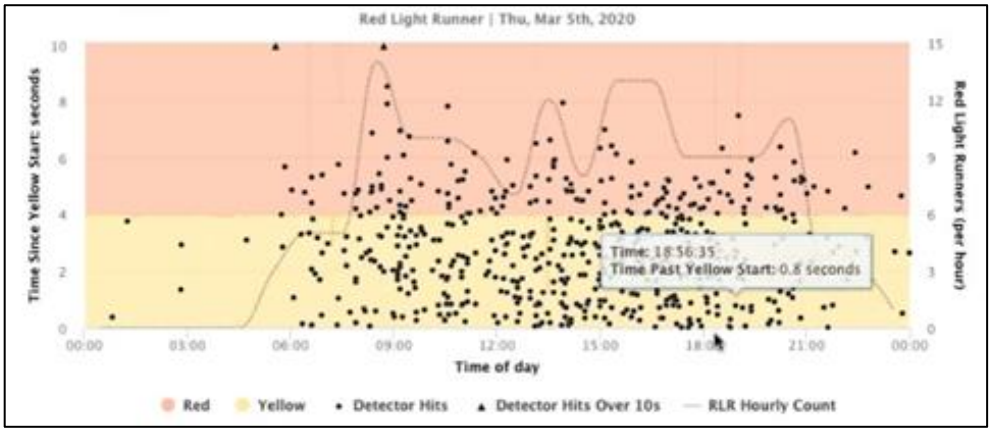

Figure 22: MicroTraffic Application
(Source: MicroTraffic website 12/7/2021)

Detection Method:
• Uses AI-powered computer vision to measure near-misses by collecting video from permanent or temporary cameras, then running the video through the MicroTraffic software. To estimate near misses, MicroTraffic artificial intelligence provides a parallel dataset to supplement historical data. This allows traffic engineers to pinpoint risk factors and problem intersections and provides an opportunity to review the video later to observe the near misses.

Deployments/Testing:
• Diagnosing Intersection Safety Risk (9/24/2020):
– MicroTraffic collected and analyzed data for MnDOT on an arterial road with a high-density of commercial and retail installments in Bemidji, MN. The study revealed 500 cross median risk events in 3 days. Using the diagnostic report, a corridor safety improvement plan that included geometric and operational measures was developed.
– MicroTraffic performed detailed video diagnostics at Beaver Ruin Road (Norcross, GA), using 10 mid-block cameras to identify high-speed, low-gap pedestrian crossing conflicts.</td></tr>
<tr><td>Miovision TrafficLink Safety Analytics

A smart traffic platform that helps cities modernize</td><td>Sources:
• Miovision TrafficLink Safety Analytics website: https://miovision.com/trafficlink/safety-analytics/
• Webinar: Making Every Road User Count - Safety Analytics

Miovision Red Light Runner and Pedestrian Compliance reports provide immediate insight into vehicle and pedestrian behavior to help identify safety risks at intersections. See Figure 23. Prioritizes intersections that could benefit the most from safety countermeasures and measures the impact of safety solutions in days</td></tr>
</table>

Technology	Overview
existing analog traffic signals by adding connectivity and video-based, multimodal traffic measurement and analysis	rather than waiting years for crash data. **Supplements quantitative data with observational video insights** to understand situational behaviors.  **Figure 23: Example Miovision Red Light Runner chart** *(Source: Image from "Making Every Road User Count - Safety Analytics" video on Miovision website 12/15/21)* Detection Method: • Uses **proactive assessment, prioritization, countermeasure evaluation, and video context** to identify safety risks associated with pedestrian and driver behavior patterns at intersections.
Sensol *Illuminated crosswalk system that collects traffic information, including pedestrians, for transportation planning and analysis* *(See Table 4 for real-time alert features)*	Sources: • Sensol website: https://www.sensolsystems.com/ • News Release: UW alum founded Sensol to develop smart crosswalks (2021) Sensol is a high-tech crosswalk that illuminates a pedestrian's exact location from below as they cross the road. As pedestrians step onto a sensor, the device illuminates the crosswalk for vehicles to see from farther away. The crosswalk system **sends signals and data out for use in safety applications**. The data in the Sensol cloud **can be used by traffic management centers** to better understand real time traffic patterns and design better roadways for all road users, not just cars. This data **can also be used by transportation applications** such as Google Maps to better predict travel times and route planning. Detection Method: • Sensol's crosswalks **detect every person, vehicle, and bicycle from their weight**. This makes the detection system independent of lighting and weather conditions. **Traffic information including pedestrian and vehicle speed and location is recorded and uploaded in real time** to the Sensol cloud.
Transoft Solutions' BriskLUMINA and BriskVantage	Sources: • Transoft Solutions website: https://safety.transoftsolutions.com/ • Case Study: Accelerating Vision Zero with Advanced Video Analytics: Video-based Network-wide Conflict and Speed Analysis: City of Bellevue, WA (2021) ○ Conflict Analysis Report: Video-based Network-wide Conflict Analysis to Support Vision Zero in Bellevue (WA), United States (July 2020)

<table>
<tr><th>Technology</th><th>Overview</th></tr>
<tr><td>Detects near-misses to help transportation authorities predict, diagnose and address road safety challenges before the next collision</td><td>

- Speed and Speeding Analysis Report: Video-based Network-wide Speed and Speeding Analysis to Support Vision Zero in Bellevue (WA) United States (July 2020)
- Conflict, Speeding, and Crash Correlation: Video-based Conflict, Speeding, and Crash Correlation in Bellevue (WA) United States (July 2020)

Transoft Solutions' BriskLUMINA and BriskVANTAGE **detect near-misses** to help predict, diagnose, and address road safety challenges and **applies AI and machine learning** to evaluate road user interactions. See Figure 24.

BriskLUMINA performs on-demand safety analysis to diagnose near-misses at the most dangerous intersections. Using video analysis, BriskLUMINA rapidly **tracks and classifies all individual road users** and automatically **detect near-misses** and other dangerous interactions indicative of potential collisions. It identifies traffic issues and assessing geometric improvements in a matter of days.

BriskVANTAGE conducts automated road safety and traffic analysis leveraging the current traffic CCTV camera infrastructure and **uses artificial intelligence and computer vision algorithms** to automatically **monitor and analyze real-time video data** to **track and classify all individual road users**, and automatically detect dangerous interactions between them that can lead to collisions. It provides transportation engineers and urban planners with continuous insight into traffic flow and near misses.

Figure 24: Transoft Solutions Classification of Road Users
(Source: Image from video on Transoft Solutions website 12/7/2021)

Detection Method:

- BriskLUMINA performs full automated near-miss and collision analysis on traffic **video from temporary cameras**.
- BriskVANTAGE monitors high-risk intersections by performing road safety analyses on **video streams from connected traffic cameras**.

Deployments/Testing:

- Accelerating Vision Zero with Advanced Video Analytics: Video-based Network-wide Conflict and Speed Analysis (February 12, 2021): The project began in August 2019 and used data supplied from the City of Bellevue, Washington's network of **360-degree, high-definition traffic cameras** at 40 selected intersections. BriskLUMINA and BriskVANTAGE collected traffic volumes, road

</td></tr>
</table>

Technology	Overview
	user speeds, and near-crash traffic conflict indicators from the **video feed**, then **used advanced artificial intelligence algorithms and video analytics** to process, analyze and identify safety issues at the intersections.
Smart City PDX: Traffic Safety Sensor Project *Sensor technology installed on streetlights that gathers data about potential danger spots*	Sources: • Smart City PDX Traffic Safety Sensor Project web page: https://www.smartcitypdx.com/traffic-safety-sensor-project • Portland Bureau of Transportation (PBOT) Traffic Safety Sensor Project web page: Traffic Safety Sensor Project • Smart City Traffic Safety Sensor PDX one-pager: High Tech for Safer Streets: The Traffic Safety Sensor Project The Traffic Safety Sensor Initiative will pilot new sensor technology deployed to streetlights to gather the data needed for full insights into how people are traveling and where potential danger spots may be. Detection Method/Approach: • **The sensors, which are manufactured by project partner, Current by GE, have hardware and software** that allow them to collect information about environmental conditions, parking and transportation activities. • The **sensors provide an accurate, around the clock count of vehicles, pedestrians and bicycles**, **analyze vehicle speeds** and **identify areas where excessive speeding is prevalent**, and identify demand and supply of parking spaces. Deployments/Testing: • Portland Bureau of Transportation Traffic Safety Sensor Project (n.d.): The Smart City PDX Traffic Safety Sensor Project will pilot the use of these new sensors on three of Portland's most dangerous streets: 122nd, Hawthorne and Division. CityIQ nodes will be installed and PBOT staff will use the sensor information to make recommendations about future changes to make it easier for people to travel safely along these and other Portland streets.
Currux Vision *Fully integrated autonomous AI systems for smart infrastructure using existing cameras, sensors, and traffic controllers for detection, analytics, and*	Sources: • Currux Vision website: https://currux.vision/ • Currux Vision SmartCity & Intelligent Transportation web page: https://currux.vision/smart-city • Press Release: Currux Vision LLC Announces Industry Leading Accuracy of Artificial Intelligence Smart City Traffic Platform Testing with the City of San José Currux Vision detects and classifies in real time cars, light and heavy trucks, buses, motorcyclists, bicyclists and pedestrians with over 95% accuracy and measures speed of every object with +/- 2 mph accuracy. Currux Vision extracts detailed traffic analytics and generates reports. Traffic safety analytics include: real time traffic safety analytics based on headway monitoring time, time to collision, and rates of acceleration and deceleration. Safety data is also displayed in analytic reports for each camera. Currux Vision predicts trajectories, speed and distance of cars, and pedestrians to inform customers about potential accidents and danger

Technology	Overview
incident detection	zones. Traffic safety data is presented in reports and real-time Near Miss notifications are issued. Detection Method: • Flexible system configurations work locally, at the edge and in the cloud and **utilize existing CCTV, traffic controller, and sensor infrastructure**. • Utilizes the **same technology stack and similar AI processors to those used in autonomous cars**, including automated object detection, classification and tracking; self-learning and advanced prediction algorithms, and automated lane detection. Deployments/Testing: • Currux Vision LLC Announces Industry Leading Accuracy of Artificial Intelligence Smart City Traffic Platform Testing with the City of San José (December 17, 2020): The San José Department of Transportation and Currux Vision are focused on creating a safer and smarter city. San José utilized the fully integrated, AI-based SmartCity ITS for city intersections and roadways. Testing included but was not limited to vehicle detection and classification, turning movement counts, pedestrian counts, bicycle discrimination, stopped vehicles, and speeding.

4.3 Industry Scan Summary

Detection-based ITS technologies hold the potential to improve pedestrian safety, especially to supplement known infrastructure countermeasures and efforts by the automobile industry to standardize and improve pedestrian crash prevention systems. A variety of detection-based pedestrian safety technologies were identified during the industry scan. Since this is a growing and active area within the field of ITS, the technologies presented in this document may not be the only technologies available. The industry scan presented a sampling of the many detection technologies and components that are commercially available or being researched.

Findings from the industry scan of detection-based pedestrian safety technologies were segmented into two categories:

- Detection-Based Technologies with Real-time Alerts
- Detection-Based Technologies with Data Collection and Analysis Platforms

Detection-Based Technologies with Real-time Alerts

Detection-based technologies with real-time alerts can include technologies that detect pedestrians, vehicles, or both. Detection sources vary and could utilize vehicle-based detection (built into the vehicle), infrastructure-based technology (cameras or lidar mounted at intersections), or connected and automated vehicle technologies. Real-time alerts are provided to the pedestrian, the driver, the automated driving system, the roadside infrastructure, or a combination of these depending on the technology.

Fifteen (15) detection-based pedestrian safety technologies with real-time alerts were summarized. Some individual products are featured in multiple technology applications, depending on their use and partnerships. Table 6 provides a brief overview of each technology, along with a designation for whether the technology communicates with roadside infrastructure such as roadside signs (e.g., with flashing beacons) or traffic signals, and could include data communicated from the roadside infrastructure to the technology, from the technology to the infrastructure, or both. The designation made for "communicates with roadside infrastructure" is based on review of the online resources located during the industry scan, as summarized in Table 4. See Table 4 in Section 4.1 for details about each technology.

Table 6: Overview of by Pedestrian Safety Technologies with Detection and Real-time Alerts

Technology	Brief Overview	Communicates with Roadside Infrastructure (e.g., signals, signs)
!important	Smartphone app that alerts pedestrians and drivers, and triggers brakes on connected vehicles automatically	
TravelSafely™	Smartphone app that connects users with smart city infrastructure	✓ Not specified
Applied Information and TravelSafely™	Pedestrian crossing safety system with roadside signs, audible alerts, and connection to smartphone app	✓ Roadside signs
Applied Information and Qualcomm and TravelSafely™	System linking traffic signals and connected roadway users and devices	✓ ▪ Traffic signals ▪ Roadside signs

Technology	Brief Overview	Communicates with Roadside Infrastructure (e.g., signals, signs)
Derq / FLIR	Software application using artificial intelligence (AI) to run real-time edge analytics, enable V2X applications, and provide safety and traffic insights	✓ ▪ Traffic signals ▪ Roadside signs
MH Corbin / Bosch	Utilizes video images from cameras to detect and communicate the presence of a pedestrian	✓ Roadside signs
Draper (PathScout system)	Vehicle sensor using mobile phone GPS data and LiDAR to "see" pedestrians	
Reflective Surface for Intelligent Transportation Systems (REITS)	Wearable device to allow autonomous vehicles to detect pedestrians	
Sensol	High-tech illuminated crosswalk	✓ Illuminated crosswalk
TAPCO / FLIR	Thermal detection-activated Rectangular Rapid-Flashing Beacon (RRFB) Pedestrian Crosswalk System	✓ Roadside signs
Texas A&M Transportation Institute Transit, Bicycle and Pedestrian Safety Research	Research focusing on AV/CV technologies for transit vehicles and detection of pedestrians and bicyclists	✓ Roadside signs
University of Michigan Transportation Research Institute "Vehicle to Pedestrian Connections" project	Research to detect pedestrians crossing the road using a cell phone application and an overhead camera	✓ Not specified
Viziblezone	A vehicle integrated "Pedestrian Detector" that pairs with a car infotainment system or smartphone	
MultiNet	Uber's self-driving AI system that detects and predicts the motions of obstacles from autonomous vehicle lidar data	
VectorNet	Waymo's AI solution that uses vectors to predict pedestrian, cyclist, and driver behavior	

Detection-Based Technologies with Data Collection and Analysis Platforms

Detection-based technologies with data collection and analysis platforms are systems that include sensors to detect and collect vehicle and/or pedestrian data over time, for analysis by agencies to identify problem locations. Systems like this are typically deployed at intersections but do not necessarily need to be at intersections. Analytics platforms could identify issues such as pedestrian crosswalk violations, vehicle violations that impact pedestrians (e.g., red light running), near misses, or other surrogate measures that could be associated with increased vehicle or pedestrian crash risk.

Eleven (11) detection-based pedestrian safety technologies with data collection and analysis platforms were summarized. Table 7 provides a brief overview of each technology, with a designation regarding whether the technology is typically deployed at intersections or connected to traffic signals. The designation made for "At Intersection or Connected to Traffic Signal" is based on review of the online resources located during the industry scan, as summarized in Table 5. See Table 5 in Section 4.2 for details about each technology.

Table 7: Overview of Detection-Based Pedestrian Safety Technologies with Data Collection and Analysis Platforms

Technology	Brief Overview	At Intersection or Connected to Traffic Signal
Bluecity	Technology that combines artificial intelligence and LiDAR to better understand and adjust smart city mobility	✓
Boulder AI and MeterSYS	Boulder AI: Edge devices that perform real time sensing, inference and actions to curate edge data, perform device and software orchestration, support centralized learning and insights MeterSYS: Platform that enables transportation planners and engineers to automatically access data and insights in real-time.	✓
GRIDSMART®	Gathers and interprets vital traffic data to improve safety and efficiency at intersections using a video detection system.	✓
Derq	Software application using AI to run real-time edge analytics, enable V2X applications, and provide safety and traffic insights	✓
Iteris PedTrax	Provides algorithm expertise that utilizes existing detection sensors to provide enhanced data output of bicycles and pedestrians	✓
MicroTraffic	Software that measures near-misses from video rather than looking at historical crash data	✓
Miovision TrafficLink Safety Analytics	A smart traffic platform that helps cities modernize existing analog traffic signals by adding connectivity and video-based, multimodal traffic measurement and analysis	✓
Sensol	Illuminated crosswalk system that collects traffic information, including pedestrians, for transportation planning and analysis	✓
Transoft Solutions' BriskLUMINA and BriskVantage	Detects near-misses to help transportation authorities predict, diagnose and address road safety challenges before the next collision	✓
Smart City PDX: Traffic Safety Sensor Project	Sensor technology installed on streetlights that gathers data about potential danger spots	✓
Currux Vision	Fully integrated autonomous AI systems for smart infrastructure using existing cameras, sensors, and traffic controllers for detection, analytics, and incident detection	✓

5.0 Project Interviews

This section summarizes information gathered from three state DOTs, one university, and one local government agency, regarding deployments or research on detection-based pedestrian safety technologies. The selected deployments and research projects were identified through the industry scan and as suggested by ENTERPRISE members. The information was gathered primarily through phone interviews along with other resources as provided by the contacts for each deployment or research effort. As available, information gathered included research approach, deployment conditions, technology type, evaluation approach, system performance, evaluation metrics and results, lessons learned, and suggestions for future research.

Information was gathered for the following deployments and research efforts:

- Automated and Connected Vehicle Test Bed to Improve Transit, Bicycle, and Pedestrian Safety – Texas Department of Transportation (TxDOT) and Texas A&M Transportation Institute (TTI)
- Experience with Detection-Based Technology for Safety Analysis – City of Bellevue, Washington
- Testing of Pedestrian Detection Systems for Activating the Pedestrian Crossing Phase – Minnesota Department of Transportation (MnDOT)
- Research on Utilizing Video Analytics with Connected Vehicles for Improved Safety – Michigan Department of Transportation (MDOT)

5.1 Automated and Connected Vehicle Test Bed to Improve Transit, Bicycle, and Pedestrian Safety (TxDOT and TTI)

The "Automated and Connected Vehicle Test Bed to Improve Transit, Bicycle, and Pedestrian Safety" project is a multi-phase research effort exploring the potential of automated and connected vehicle technology to reduce or eliminate crashes involving transit vehicles, bicyclists, and pedestrians. The research, sponsored by TxDOT and conducted at TTI, has deployed and tested detection-based technologies with real-time alerts in a testbed environment and at a fully operational signalized intersection. While the research is focusing on transit vehicles, some findings contribute to an increased understanding of pedestrians' awareness and preferences for detection-activated signage and other alert mechanisms. Table 8 provides a summary of information gathered for the "Automated and Connected Vehicle Test Bed to Improve Transit, Bicycle, and Pedestrian Safety" research effort.

Table 8: Automated and Connected Vehicle Test Bed to Improve Transit, Bicycle, and Pedestrian Safety (TxDOT and TTI)

Interview Date	August 9, 2021
Contacts	Wade Odell, Texas DOT and Katie Turnbull, Texas A&M Transportation Institute
Deployments	"Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety" research is exploring the potential of automated and connected vehicle (AV/CV) technology to reduce or eliminate crashes involving

	transit vehicles, bicyclists, and pedestrians. A multi-year innovative research project sponsored by TxDOT, with research and testing performed by the Texas A&M Transportation Institute (TTI). Other agencies, organizations, and private sector groups contributed equipment and time to assist in the project.

Overview	• Phase 1: Concept of Operations
	  ○ Included discussions with stakeholders to gain insight on safety issues involving pedestrian and bicycle conflicts with buses and a review of potential technologies.
	  ○ Piloted a Rosco Mobileye Sheild+™ collision-warning system on one Texas A&M University bus, which monitors movements of bicyclists and pedestrians in the path of a moving bus and provides in-vehicle alerts to the operator.
	  ○ Phase 1 Report: *Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety* (2017)
	• Phase 2: Testbed Deployment
	  ○ Deployed technology at a testbed smart intersection developed for the project at the Texas A&M University System RELLIS Campus. The smart intersection consisted of a customized system using mostly off the shelf products. Alerts were provided through supplemental bus signs at the intersection, an audio message "Caution Bus Turning" in English and Spanish, and a beta Android smart phone app to pedestrians or bicyclists. See Figure 25.
	
	Figure 25: Supplemental bus alert signs at the intersection (Source: TTI)
	  ○ Conducted surveys and held focus groups in Houston. The results indicated that the public wants alerts in a variety of methods, a simple message, and alerts provided in English and Spanish.
	  ○ Phase 2 Report: *Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety: Phase II Technical Report* (2020)
	• Phase 3: Field Testing Deployment
	  ○ Deployed the smart intersection at one intersection on the Texas A&M University Campus. The intersection was equipped with the same technology as the RELLIS Campus system, and 10 Texas A&M University buses were fitted with DSRC radio. Left turning buses at the intersection

	were automatically identified and a supplemental bus sign located above the pedestrian signal head was illuminated and the “Caution Bus Turning” announcement was made when pedestrians and bicyclists were detected at the crossing. The focus was to alert pedestrians and bicyclists. o Monitored two Rosco Mobileye Shield+ V4 ™ on two new Texas A&M University buses. o The Phase 3 report is pending publication.
System Performance	Field testing against system requirements in Phase 2 validated that the technology performed as intended, with detections and alerts as designed. Deployment in Phase 3 validated that the technology performed as intended.
Evaluation	• Phase 3 field deployment results showed no change in safety performance before and after the deployment; vehicle crashes remained similar before (3 crashes) and after (4 crashes) the deployment. None of the crashes in either period involved buses, bicycles, or pedestrians. All were angle crashes involving motor vehicles. The intersection where the technology was deployed did not have a major problem with crashes. Need to continue to test the technology in different situations such at intersections with more conflicts. • Results from a survey of pedestrians and bicyclists conducted for the Phase 3 deployment: 60% noticed the sign or heard the announcement, 60% found it helpful, 91% reported it would be helpful to others. • Results from a survey of bus operators indicated 93% were aware of the supplemental bus sign. Further, 63% felt it was helpful to alert bicyclists and pedestrians, while 21% were not sure, and 16% did not think it had an impact.
Future Research	• Deploy and evaluate this technology at other intersections that have more conflicts. • Analyze data gathered by the Mobileye Sheild+™ system to identify conflict hot spots. • Continue research on distraction with use of mobile apps. • Human factors research with bus operators, pedestrians and bicyclists. • Additional research on signage for pedestrians and bicyclists.

5.2 City of Bellevue Experience with Detection-Based Technology for Safety Analysis

In this deployment, the City of Bellevue, Washington utilized an off the shelf solution (Transoft Solutions’ BriskLUMINA and BriskVANTAGE products) that analyzes video feeds from in-place traffic cameras to identify safety issues at intersections. A benefit cited for use of this type of data collection and analysis product is that it provides unique insights at specific intersections to help identify countermeasures, compared to looking at several years’ worth of data. In addition, the technology can be deployed anywhere (e.g., rural areas) for a limited duration of time to perform temporary analysis. In this deployment, the City of Bellevue deployed the product to assess video feeds from in-place traffic cameras at 40 intersections for one week. Using results from the analysis platform, the city made traffic signal changes at one intersection and compared before-after video analytics data, confirming a 60% reduction in critical conflicts. A full summary of this deployment and findings can be found in Table 9.

Table 9: City of Bellevue Experience with Detection-Based Technology for Safety Analysis

Interview Date	August 6, 2021
Contact	Franz Loewenherz, City of Bellevue, Washington
Deployment	National Center of Excellence (NOCoE) Case Study: Accelerating Vision Zero with Advanced Video Analytics: Video-based Network-wide Conflict and Speed Analysis: City of Bellevue, WA (2021)
Overview	• The technology used for this effort was an off the shelf solution: Transoft Solutions (BriskLUMINA and BriskVANTAGE) which analyzes video feeds from in-place traffic cameras. The algorithms look at unique pixels, trains the software, and then distinguishes between a pedestrian, bicyclists, and a wheelchair. The variations are picked up through neural networks. • The system collected traffic volumes, road user speeds, and near-crash traffic conflict indicators from video feeds, then used advanced artificial intelligence algorithms and video analytics to process, analyze and identify safety issues at the intersections. • Assessed 40 intersections for one week in 2019. During the week there were approximately 8.2 million road users identified. Recorded imagery was analyzed for this project, not a real-time application. • The benefit of using this type of data collection and analysis product is that it provides unique insight at specific intersections to help the agency identify countermeasures (e.g., permissive to protective permissive) compared to looking at years' worth of data. • The City of Bellevue has existing cameras at all intersections with a 10-gigabyte network speed from fiber communication. Transoft Solutions used the video feeds from these cameras and processed it. The investment for Bellevue was modest since they could utilize existing cameras. However, not all communities have existing cameras and could use mobile cameras or drones for video. • Transoft Solutions was only deployed for the duration of this project. The technology could be used by taking the same platform anywhere (e.g., rural areas) for a limited duration of time to perform temporary analysis.
System Performance	• It is important to calibrate and have a good viewing angle for the camera's field of view. The data being collected needs to be tied to ground truth during the calibration phase. • There were no major issues with system performance. • Fixed cameras were used. PTZ cameras can be challenging if they are moved during data collection.
Evaluation	• A student worker looked at video for the same time period of the assessment to validate the data being collected. • Video clips stored by the system at the time of an identified conflict was reviewed to verify that a conflict had occurred. • The system's sensitivity was adjusted (2 seconds to 1.5 seconds) to optimize conflict identification. • Bellevue made traffic signal operations changes at 124th Avenue Northeast and Northeast Eighth Street, compared before-after video analytics data, and

	confirmed a 60% reduction in critical conflicts – a favorable return on investment for a $10,000 project. • Count, conflict, and speeding event data is generated by movement type (though, left, or right), by direction of approach (northbound, southbound, etc.), by time of day (AM, mid-day, PM), and day of the week (weekday versus weekend), and by mode (car, bus, motorcycle, truck, bicycle, pedestrian). In collaboration with Transoft Solutions and Together for Safer Roads, the City of Bellevue found – following a network-wide analysis using video analytics – that people who ride bicycles represent 0.1% of observed road users yet they are 8.7 times more likely to be involved in a conflict than a driver. As a result of these insights, the Bellevue City Council prioritized additional funding for new Vision Zero projects and improved bicycle infrastructure. • In collaboration with Transoft Solutions and Together for Safer Roads, the City of Bellevue found – following statistical analysis comparing crash/conflict data – that conflict indicators are an accurate predictor of where future crashes could occur.
Future Research	• Develop a centrally located (e.g., online, map-based) collaborative platform for safety practitioners to share safety data at specific locations. This would allow users to view specific attributes, before/after assessments, and surrounding land use conditions, to consider comparable situations that would help inform safety improvements at locations with similar attributes. • Pilot the additional types of camera systems such as those that integrate lidar.
Other Information	• The City of Bellevue has been working in the area of video analytics since 2016. • City of Bellevue, WA Progress Reporting – Tracks the eight elements of the Safe Systems approach. • Vision Zero Strategic Plan: One City Towards Safe Streets • Bellevue is starting a project on V2X. There are opportunities for ENTERPRISE to collaborate. • Vision Zero Rapid Build Data Driven Safety Program - Based on insights derived from these data, the signalization for left-turning drivers at the 124th Ave NE and NE 8th Street intersection changed from a permissive left-turn signal phase for northbound and southbound to a protected-permissive left-turn signal phase. After the changes were implemented, a seven day, before-after study was conducted to observe changes in safety. Using video analytics, this study was completed in two days. The frequency of critical conflicts decreased by 60% for conflicts between southbound through and northbound left-turning drivers, and by 65% for conflicts between northbound through and southbound left-turning drivers from before to after. This example demonstrates that video analytics provides fast and detailed analysis; it helps practitioners identify the least costly way to achieve a desired safety outcome and then quickly assess the effects of these changes in performance reports.

5.3 MnDOT Testing of Pedestrian Detection Systems for Activating the Pedestrian Crossing Phase at Signalized Intersections

The Minnesota Department of Transportation (MnDOT) is conducting a project to test capabilities of six commercially available pedestrian detection systems, focusing on the capability to detect pedestrians and communicate to the signal controller to activate the pedestrian crossing phase. Initial installations revealed that some systems have required a lot of time and effort to set up, with multiple trips to the signal cabinet. MnDOT plans to evaluate the systems based on performance and other factors, including whether the systems can determine directional factors for the pedestrians detected. A summary of MnDOT's testing of pedestrian detection systems is provided in Table 10.

Table 10: MnDOT Testing of Pedestrian Detection Systems

Interview Date	August 18, 2021
Contact	Mitch Deer, MnDOT
Overview	• MnDOT is conducting a project to test capabilities of six commercially available pedestrian detection systems across four different intersections. The purpose of the project is to test the capability of these systems to detect pedestrians and communicate to the signal controller to activate the pedestrian crossing phase (i.e., as a potential replacement for Accessible Pedestrian Signal (APS) push buttons). • At the time of the interview, MnDOT is nearing the end of the installation phase, beginning to collect data, and completing a ground truthing process to verify detection accuracy.
Planned Evaluation	• MnDOT plans to evaluate the systems based on their performance and against other criteria such as whether the systems can determine directional factors for the pedestrians detected. • Other potential factors to be evaluated include ease of installation, maintenance, and interoperability. Maintenance and interoperability considerations need to account for signalized corridors and networks that cross boundaries between state and county or city jurisdictions. • The evaluation results will be documented to show the different technologies with their respective pros and cons. Some initial guidance may be created but the project will not result in a full approved products list (APL), though this effort may inform a future effort to develop an APL.
Initial Observations and Lessons Learned	Initial installations revealed that some systems required a lot of time and effort to set up, with multiple trips to signal cabinet required. Vendors have been helpful with system set-up and the ground truthing process.
Timeline	An evaluation of the six commercially available pedestrian detection systems is expected to be completed and documented in a report by December 2023.

5.4 Michigan DOT Research on Utilizing Video Analytics with Connected Vehicles for Improved Safety

This Michigan Department of Transportation (MDOT) research project will install video analytics system(s) along a test corridor to evaluate, analyze and validate the effectiveness and improved traffic efficiencies in implementing solutions at MDOT's most challenging signalized intersections. The system(s) could provide a notification through connected vehicle technology to vehicles, pedestrians, and non-motorized users. The research will identify systems available on the market with their associated costs, install and test the systems, and evaluate performance. Table 11 provides a summary of this Michigan DOT research.

Table 11: Michigan DOT Research on Utilizing Video Analytics with Connected Vehicles for Improved Safety

Source	Michigan DOT Request for Proposals 500B-R (08/20) Scope of Service for Research Services[14] (Provided by Michele Mueller, MDOT, following a phone interview.)
Overview	This research plans to install video analytics system(s) along a test corridor to evaluate, analyze and validate the effectiveness and improved traffic efficiencies in implementing solutions at MDOT's most challenging signalized intersections. The system could provide a notification through connected vehicle technology to vehicles, pedestrians, and non-motorized users. Initially, under this project this notification capability would be set up in test vehicles. If proven effective, MDOT could expand installations to other vehicles at any time.
Project Objectives	Project objectives include: 1. Reduce the frequency and severity of intersection conflicts by utilizing the data to understand crashes and near misses and make necessary improvements; 2. Reduce the frequency and severity of intersection and mid-block conflicts through traffic control and operational improvements; and 3. Reduce crashes and fatalities by disseminating intersection and mid-block conflict alerts to motorists and non-motorized users.
Research Activities	The selected consultant will be responsible for various activities, such as: • Identify systems available on the market and associated cost (explore static/portable systems and various detection such as lidar, video, etc.); • System and software installation and integration; • Data collection and accuracy of data; • Identify accuracy of data including confidence level for each data type; • Identify system gaps and improvement; • Identify dashboard use cases, value and potential gaps; • Assign value (time, money, insurance, vehicle repair, etc.) to benefits of system at intersection level and corridor level (owner operator and user); • Conduct vehicle instrumentation equipment and integration; • Conduct testing with motorized and non-motorized including identification of use cases and testing scenarios; • Determine value and use case for various weather and time of day situations including evaluating performance.
Timeline	The RFP document lists an anticipated start date of 1/1/2020 and an anticipated end date of 12/31/2023 for the research project.

6.0 Potential Future Research

Based on findings from the literature search, industry scan, and project interviews, ideas for future research related to pedestrian safety were identified. This section provides a list of potential future research, with emphasis on ITS-based pedestrian safety systems. The research suggested often builds on current research activities identified through this project and could be pursued by agencies, universities, pooled fund studies, or other research entities.

Potential future research suggested during project interviews, along with the entity suggesting the research, include:

- Research on distraction with use of mobile apps. (TxDOT/TTI)
- Human factors research with bus operators, pedestrians, and bicyclists (TxDOT/TTI)
- Additional research on signage for pedestrians and bicyclists. (TxDOT/TTI)
- Develop a centrally located (e.g., online, map-based) collaborative platform for practitioners to share safety data at specific locations. Allow users to view specific attributes, before/after assessments, and surrounding land use conditions, to help inform safety improvements at locations with similar attributes. (City of Bellevue, WA)
- Pilot additional types of camera systems such as those that integrate lidar, for data collection and analytics. (City of Bellevue, WA)
- Field test and evaluate commercially available pedestrian detection systems (Michigan DOT and MnDOT)

Other suggestions for future research, developed by the research team and the project champion based on findings from this project, include:

Summarize Research and Evaluations of Pedestrian Safety Technologies

- *Background*: Many technology deployments and research efforts documented in this project are just getting underway. One to two years from now, it is anticipated that more information related to these deployments and evaluation results will be available.
- *Possible Tasks*: Conduct a literature search to compile research results and evaluation findings, gather insights and lessons learned through interviews with agencies that are deploying pedestrian safety technologies, and organize a webinar series for agencies to present deployments or research findings.

User Needs and Demonstration of Pedestrian Safety System Capabilities

- *Background*: The industry scan revealed there are several commercially available pedestrian safety systems that claim to achieve many different safety outcomes. It may be beneficial to narrow in on a specific use case, then utilize a systematic (i.e., systems engineering) approach to identify system needs and demonstrate corresponding system capabilities.

- *Possible Tasks:* Develop user needs for a specific use case (e.g., technologies at uncontrolled crossings). Engage DOT safety engineers or others involved in pedestrian safety to provide input during development of the user needs. Identify applicable products or deployments and organize presentations by vendors and/or agencies to demonstrate capabilities of commercially available products, per the user needs developed.

Proof-of-Concept Evaluation of Pedestrian Safety Technologies

- *Background:* Several commercially available pedestrian safety technologies are emerging with claims of various capabilities and safety improvement impacts. Often these technologies have not been rigorously field tested or evaluated to a level at which transportation practitioners are confident of their performance capabilities and effectiveness in improving safety. Field testing and evaluation of various technologies is needed to improve overall understanding of these technologies and their potential benefits.
- *Possible Tasks:* In Phase 1, select a specific use case for pedestrian safety technologies to address, create an evaluation plan, reach out to vendors who may wish to deploy in an ENTERPRISE state for demonstration and evaluation, and coordinate with ENTERPRISE agencies who may be willing to host a demonstration. In Phase 2, conduct a demonstration (multiple vendors), collect data, and evaluate the selected technologies.

Research to Correlate Crash or Conflict Causes with Appropriate Safety Technologies

- *Background*: Practitioners need resources to assist in decision-making for deploying safety solutions to address pedestrian/vehicle conflicts and crashes at specific problem locations.
- *Potential Tasks*: Perform research to identify causes (e.g., pedestrian non-compliance, at-fault driver) of pedestrian-involved conflicts and crashes. Per established research documenting effectiveness of technologies or other treatments, offer guidance on correlating an appropriate technology or safety solution with the issue that is occurring at a specific location (e.g., which treatment or technology is best suited to address the likely cause of the conflict?)

7.0 Summary

Pedestrian fatalities in the United States increased by 53 percent from 2009 to 2018, while other traffic deaths increased by only 2 percent. (PBIC, 2020), (Retting, 2020). ENTERPRISE members identified a need to improve their understanding of pedestrian traffic safety issues and explore recent advancements in detection-based pedestrian safety technologies. This project conducted a literature search to provide context for pedestrian safety issues and trends, completed an industry scan of detection-based pedestrian safety technologies, conducted interviews with selected agencies to document relevant deployments and research, and identified potential future research. Key findings are summarized in this section.

Pedestrian Safety Issues and Trends

The literature search (see Section 3.0) focused on data, trends, and contributing factors associated with pedestrian fatalities and serious injuries, and pedestrian-involved crashes. These insights are critical to improving agencies' understanding of contributing factors as they consider implementing appropriate safety treatments. These findings can also help agencies consider how technology-based solutions could help reduce pedestrian fatalities and serious injuries.

The state of practice and knowledge is evolving rapidly regarding identifying risk factors for pedestrian-related crashes. (Thomas et al., 2018). Table 12 shows factors and conditions that research suggests are associated with higher or increasing rates of pedestrian fatalities and serious injuries.

Table 12: Factors and conditions that research suggests are associated with higher or increasing rates of pedestrian fatalities and serious injuries

Category	Factors and Conditions
Roadway and Crash Environment	• Urbanized locations • Non-freeway arterials (principal and minor) • Non-intersection locations • Higher speeds / higher speed limits
Lighting	• Dark lighting conditions
Vehicle Type	• Larger vehicle types
Age and Demographics	• Older age of pedestrian (65 and older) • Older age of drivers (65 and older) • Marginalized populations and historically underserved communities • Race (black, indigenous, and people of color overrepresented compared to share of population)
Behavioral	• Alcohol impairment of pedestrian and/or driver

Selected findings from the literature provide insights for potential use of pedestrian safety technologies:

- In 2018 and 2019, 74% of pedestrian fatalities were at non-intersection locations (Retting, 2020), (Retting, 2021). In addition, prior research suggests that the presence of a signal is consistent with reduced pedestrian crash severity but associated with increased crash frequencies (Thomas et al., 2018). Therefore, agencies may consider deploying technologies that can be implemented at non-intersection locations in addition to those that can be instrumented at traffic signals.

- As agencies consider detection types, it is important to note that dark lighting conditions are a major factor. In 2018, 76% of pedestrian fatalities occurred after dark, and nighttime pedestrian fatalities were found to be increasing at a much higher rate than daytime fatalities (Retting, 2020). In 2019, 75% of pedestrian fatalities occurred after dark (Retting, 2021). Agencies may therefore consider deploying detection technologies that function in the dark, especially at locations where other contributing factors are present.
- Because increased rates of pedestrian fatalities and serious injuries are seen in older (65 and older) drivers and pedestrians (PBIC, 2020), it is important to understand the effectiveness of technology-based alerts on this at-risk age group.
- It is a challenge for agencies to collect pedestrian volume data using current methods, leading to a lack of data for measuring crash exposure. (PBIC, 2020), (Thomas et al., 2018). This suggests potential benefits of detection-based technologies that collect pedestrian volume data and provide analytics to help agencies assess crash risks at specific locations.

Industry Scan and Project Interviews

An industry scan (see Section 4.0) identified examples of detection-based technologies that aim to improve pedestrian safety, in two categories:

- Detection-Based Technologies with Real-time Alerts
    - These technologies detect pedestrians, vehicles, or both. Detection sources vary (e.g., video analytics, lidar, or other sensors) and can use detection built into the vehicle, infrastructure-based technology (e.g., cameras or lidar mounted at intersections or at crossing locations) or connected and automated vehicle technologies.
    - Real-time alerts can be provided to the pedestrian, the driver, the automated driving system, or a combination of these. Alerts varied and included visual messages, audible messages, or tactical alerts delivered through smartphone mobile apps, connected or automated vehicle technologies, an illuminated crosswalk, and a wearable technology.
    - Some technologies communicate with roadside infrastructure such as signs or traffic signals.
- Detection-Based Technologies with Data Collection and Analysis Platforms
    - These technologies detect the presence, speed, and trajectory of vehicles, pedestrians, bicycles, and other road users. They also often track “near-misses” and identify conflicts, which can be an indicator of where future crashes could occur.
    - These tools often provide real-time data, collect and store historical data, and perform analytics to help agencies assess crash risk and identify safety interventions.
    - Though these systems are often deployed at signalized intersections, some can also be deployed at other locations such as uncontrolled crossings, for temporary analysis.

In total, more than 25 examples of detection-based technologies (commercially available or being researched) were identified. While there is some evidence of deployments and testing, many appeared to be in early stages of planning or implementation. With so many emerging technologies on the market with various claims, field testing and evaluation is needed to improve overall understanding of capabilities and safety benefits.

Project Interviews

Phone interviews with selected agencies and entities (see Section 5.0) provided further insights on use of pedestrian safety technologies and related research:

- Researchers at TTI are testing automated and connected vehicle technologies with transit vehicles, bicyclists, and pedestrians. Field testing validated that a customized detection and alert system using mostly off the shelf products performed as intended. In an operational deployment, 60% of pedestrians and bicyclists surveyed found the detection-activated sign helpful.
- The City of Bellevue, WA utilized an off the shelf technology that analyzes video feeds from traffic cameras to identify safety issues at intersections. A benefit of this type of data collection and analysis product is that it provides unique insights at specific intersections to help identify countermeasures, compared to looking at several years' worth of data. The city found that it is important to calibrate and have a good viewing angle for the camera's field of view. Additionally, the data being collected needs to be tied to ground truth during the calibration phase.
- MnDOT is conducting a project to test the capability of six commercially available detection systems to detect pedestrians and communicate to the signal controller to activate the pedestrian crossing phase. Some systems have required a lot of time and effort to set up. However, vendors have been helpful with system set-up and the ground truthing process.
- Research at the Michigan DOT will install, evaluate, analyze, and validate the effectiveness of technology solutions at MDOT's most challenging signalized intersections. The research will identify systems available on the market, install and test the systems, and evaluate performance.

Future Research

Learnings from this project led to several ideas for potential future research (see Section 6.0 for details):

- Research on distraction with use of mobile apps.
- Research on effective signage (e.g., type, quantity, messages) for pedestrians and bicyclists.
- Develop a centrally located collaborative platform for practitioners to share and access safety data at specific locations, to help inform safety improvements at locations with similar attributes.
- Conduct pilot testing of camera systems that integrate lidar, for data collection and analytics.
- Continue to document evaluations of pedestrian safety technologies and research findings.
- Develop user needs and coordinate demonstrations of pedestrian safety technology capabilities.
- Deploy commercially available pedestrian safety technologies, with proof-of-concept evaluation.
- Research to correlate crash or conflict causes with appropriate safety technologies.

Use and Implementation

The results of this research can be used by agencies to improve their overall understanding of pedestrian safety issues and emerging technologies that could help improve safety. It also suggests ideas for follow-up research that could be conducted by ENTERPRISE or other research entities, to further expand the state of knowledge for the use of pedestrian safety technologies to improve safety.

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