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Crash Avoidance Needs and Countermeasure Profiles for Safety Applications Based on Light-Vehicle-to-Pedestrian Communications

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16. Abstract

This research supports establishing an updated understanding of the pedestrian crash problem and defining a way to connect the crash problem with vehicle-to-pedestrian (V2P) communication crash avoidance technology. It describes 5 priority pre-crash scenarios that might be addressed by V2P communications. Priority scenarios are:

1. Vehicle going straight and pedestrian crossing the road
2. Vehicle going straight and pedestrian in the road
3. Vehicle going straight and the pedestrian adjacent to the road
4. Vehicle turning left and the pedestrian crossing the road
5. Vehicle turning right and the pedestrian crossing the road

The focus is on vehicle-pedestrian crashes involving light vehicles (passenger car, van, minivan, sport utility vehicle, or light pickup truck) with a gross vehicle weight rating of 10,000 pounds or less. The 2011-2012 General Estimates System (GES) and Fatality Analysis Reporting System (FARS) crash databases were used to quantify the societal cost and describe the driving environment, driver- and pedestrian- characteristics, and crash contributing factors. These priority scenarios account for 79 percent of all target pedestrian crashes and 91 percent of the fatal target pedestrian crashes. Target pedestrian crashes include a light vehicle striking a pedestrian in the first event of the crash. The highest frequencies of pedestrian crashes (GES) occur in scenarios where the pedestrian is crossing the road. The majority of fatalities (FARS) involved vehicles that were going straight (i.e., not turning or making a maneuver). Kinematic depictions for the time-to-collision and avoidance maneuvers are presented to identify information needs for the crash countermeasures based on V2P technology. This information serves the development of functional requirements, performance specifications, test procedures, and benefits estimation for potential V2P-based safety applications. The document is intended for the use of various groups currently researching and prototyping different V2P-based safety systems to help determine which ones are most useful in preventing or mitigating pedestrian-vehicle crashes.

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List of Acronyms

AIS	Abbreviated Injury Scale
DSRC	Dedicated Short Range Communication
FARS	Fatality Analysis Reporting System
GES	General Estimates System
GPS	Global Positioning System
LV	light vehicle
MAIS	Maximum Abbreviated Injury Scale
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
PCAM	Pedestrian Crash Avoidance/Mitigation System
TTC	time-to-collision
V2P	vehicle-to-pedestrian
V2V	vehicle-to-vehicle

List of Kinematic Parameters

a_p	pedestrian acceleration
a_v	vehicle acceleration
D_0	initial distance from front of vehicle to pedestrian
D_{pi}	initial distance from front of pedestrian to collision zone
D_{vi}	initial distance from front of vehicle to collision zone
D_{vti}	initial distance from front of vehicle to end of turn
l_p	length of pedestrian
l_v	length of vehicle
S_d	stopping distance
t_{pr}	time for pedestrian to reach collision zone
t_{pc}	time for pedestrian to clear collision zone
TTC	time-to-collision
t_{vr}	time for vehicle to reach collision zone
t_{vc}	time for vehicle to clear collision zone
v_{pi}	initial pedestrian velocity
v_{vi}	initial vehicle velocity
w_p	width of pedestrian
w_v	width of vehicle
δ	gap between vehicle and pedestrian when vehicle stops
λ	lateral distance from edge of pedestrian to curb

Executive Summary

This report defines the vehicle-pedestrian crash problem and describes potential pre-crash scenarios that represent crash avoidance opportunities for vehicle-to-pedestrian (V2P) communication technology. In addition, this report delineates a comprehensive crash scenario framework that consists of the ranking and depiction of priority pedestrian pre-crash scenarios addressable by V2P-based crash avoidance technology, and profiles of crash countermeasure concepts. The National Automotive Sampling System (NASS) General Estimates System (GES) and Fatality Analysis Reporting System (FARS) crash databases were queried to identify and statistically describe target pedestrian pre-crash scenarios for V2P-based safety applications. Target pedestrian crashes include a light vehicle striking a pedestrian in the first event of the crash. Light vehicles include any passenger car, van, minivan, sport utility vehicle, or light pickup truck with a gross vehicle weight rating up to 10,000 pounds. A pedestrian, as defined in this report, includes any person on foot, walking, running, jogging, hiking, sitting, or lying down.[1] This report presents results based on an average annual estimate from yearly light vehicle crashes for a 2-year period including 2011 and 2012 datasets. Results are presented in terms of annual police-reported pedestrian crashes, fatal pedestrian crashes, and comprehensive costs.

From a list of 21 pre-crash scenarios based on vehicle and pedestrian maneuvers (See Table 6), 5 priority pre-crash scenarios were selected based on the associated costs. The cost includes lost productivity, medical costs, legal and court costs, emergency service costs, insurance administration costs, travel delay, property damage, and workplace losses. The 5 priority scenarios comprise a total of 88 percent of total target pedestrian crash costs, 79 percent of all target pedestrian crashes, and 91 percent of all fatal target pedestrian crashes. The 5 vehicle-pedestrian maneuvers ranked by associated cost are as follows.

1. Vehicle going straight and the pedestrian crossing the road
2. Vehicle going straight and the pedestrian in the road
3. Vehicle going straight and the pedestrian adjacent to the road
4. Vehicle turning left and the pedestrian crossing the road
5. Vehicle turning right and the pedestrian crossing the road

The top 3 scenarios represent the vehicle traveling straight and the pedestrian either crossing, in, or adjacent to the road. These 3 scenarios account for 78 percent of the V2P-addressable pedestrian crash costs. Scenario 1 is the most frequent pre-crash scenario and has the highest value of all pedestrian costs at 56 percent. Scenarios 4 and 5 account for 10 percent of the cost and address the higher frequency vehicle-turning scenarios observed in the crash data. V2P systems are potentially more capable of dealing with these two scenarios than the vehicle-based pedestrian crash avoidance and mitigation systems that use forward-looking detection sensors such as radar and/or cameras.

Crash contributing factors were examined to identify physical settings, environmental conditions, driver and pedestrian characteristics, and other circumstances. These results will help to enable the identification of V2P-based crash avoidance application's potential functional requirements, minimum performance specifications, and initial safety effectiveness benchmarks. The analysis of physical settings and environmental factors such as vehicle location, pedestrian location, roadway alignment, roadway profile, atmospheric and light conditions, and surface conditions was performed to support the optimization of V2P technology by addressing the most common situations. Characteristics relating to the pedestrian, driver, or both, such as age and other contributing factors (impairment, obstructions, pedestrian direction,

[1] While a pedestrian may include a person in a stroller, in a wheelchair, on a skateboard, etc., this report does not focus on pedestrians with those characteristics due to the complications involved with movements, kinematics, geometry, etc.

and physiological conditions) were examined to aid in the development of algorithms to accurately detect pedestrians.

Based on this analysis, the highest frequencies of pedestrian crashes occur in scenarios where the pedestrian is crossing the road. The majority of fatalities involved vehicles that were going in a straight line at higher travel speeds as compared to those required during more complex maneuvers (e.g., turning left, turning right). The majority of fatal crashes:

- occurred at higher impact speeds,
- involved pedestrians on the roadway outside of the crosswalk,
- occurred at non-junctions,
- were associated with darkness,
- had pedestrian alcohol involvement, and
- involved pedestrians 30 and older.

Finally, kinematic representations (equations) of the pedestrian and the vehicle were derived to define crash avoidance needs (how much time/distance is needed to avoid the crash, braking level, etc.) for the V2P-based countermeasures for each of the 5 priority pre-crash scenarios. These equations incorporate key parameters that the countermeasures must measure in order to decide on whether a crash is imminent in a specific scenario and to determine when to assist the driver. The list of parameters consists of, but is not limited to, the relative position of the pedestrian, vehicle and pedestrian velocities and accelerations, vehicle yaw rate, vehicle and pedestrian sizes, and the lane position of the vehicle. Countermeasures need also to recognize driver intent to change lanes, merge, pass, turn left, turn right, or cross a junction. The equations were exercised to obtain estimates of the minimum stopping distances for the various vehicle velocities and braking levels. This information can help to establish minimum performance requirements for the various V2P-based safety applications. It can also aid groups currently researching and prototyping different V2P-based safety systems by helping to determine which ones are most useful in preventing or mitigating pedestrian-vehicle crashes.

1 Introduction

This report includes a detailed definition of the pedestrian crash problem based on national crash statistics. This information is used to identify intervention opportunities for crash avoidance systems based on vehicle-to-pedestrian (V2P) communications in terms of vehicle and pedestrian pre-crash scenarios. Pre-crash scenarios depict vehicle and pedestrian movements and dynamics that occur immediately prior to a crash. V2P-based crash avoidance systems use wireless communication to transfer information between vehicles and pedestrians using Dedicated Short-Range Communications, Wi-Fi, Global Positioning System (GPS), tracking via cellular networks, or others. The information transfer is conducted either directly between the driver and pedestrian or indirectly through infrastructure. Its purpose is to prevent or mitigate a potential collision by making the driver and pedestrian aware of the presence of each other. It is envisioned that communication between vehicles and pedestrians will support a new generation of active safety applications and systems.

This report documents the results of a crash analysis that focuses on police-reported crashes involving a pedestrian who is struck by a light vehicle (i.e., passenger car, van, minivan, sport utility vehicle, or pickup truck with a gross vehicle weight rating of 10,000 pounds or less) in the first event of the crash. Such results provide a basis for the selection and development of V2P safety applications that address the most critical pedestrian pre-crash scenarios. An enhanced knowledge database is needed to identify new intervention opportunities, set research priorities and direction in technology development, and evaluate the effectiveness of potential crash countermeasures. Statistical descriptions of pedestrian pre-crash scenarios provide that knowledge to better define the functions, develop performance guidelines, set up test procedures, and estimate the benefits for active safety technologies such as crash avoidance and crash severity reduction systems based on V2P communications.

1.1 Background

NHTSA sets vehicle safety standards, conducts research, develops programs, trainings, campaigns, and provides funding to States and local communities to address and promote pedestrian safety. NHTSA has available resources and tools to help officials, educators, and others address pedestrian safety issues. NHTSA also collects, maintains, and analyzes data. Data from NHTSA's Traffic Safety Facts [1], [2] illustrate that the number of pedestrian fatalities in the United States from 2002 to 2013 has fluctuated throughout the years as shown in Figure 1. Although the total number of pedestrian fatalities fluctuates, the proportion of pedestrian fatalities to all fatalities shows an increasing trend.

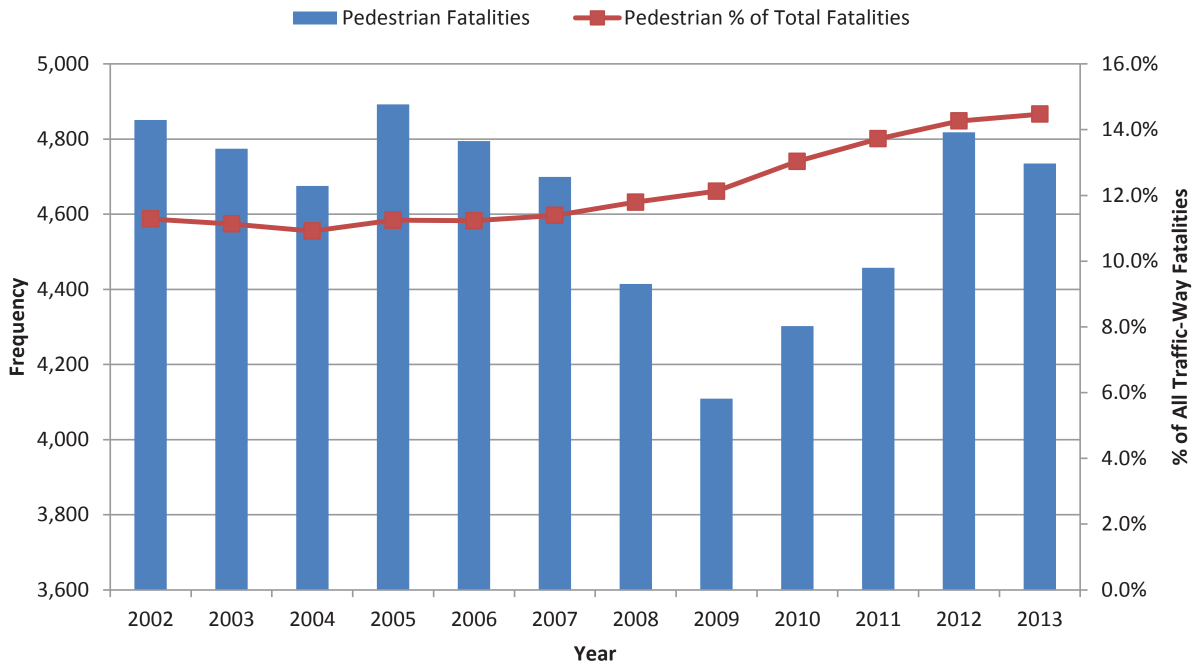
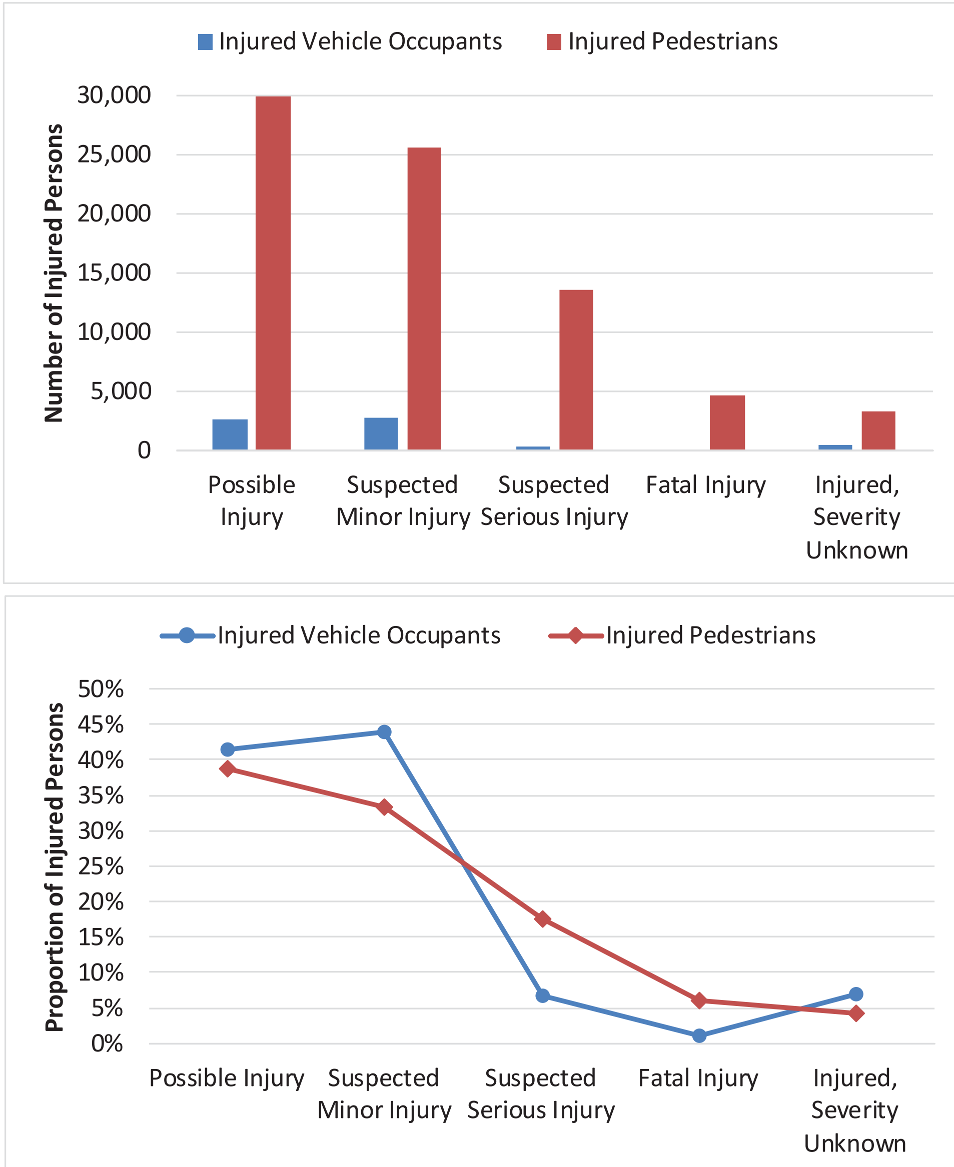


Figure 1. U.S. Pedestrian Fatalities

Pedestrian crashes from the 2011 and 2012 National Automotive Sampling System (NASS) General Estimates System (GES) and the Fatality Analysis Reporting System (FARS) databases [3], [4], [5] were examined to compare the injury levels of pedestrians versus occupants of all vehicles involved in the pedestrian crash. The total number of injured pedestrians and injured vehicle occupants is shown for each injury severity level in the top graph in Figure 2. The bottom graph shows the probability density function of each distribution (injured pedestrians and injured vehicle occupants). The probability of suffering a possible or minor injury is higher for vehicle occupants than for pedestrians, and the probability of serious or fatal injury is higher for pedestrians. Higher or more severe injury levels translate to higher costs. The data represent an annual average of approximately 74,500 crashes, and involves about 78,400 pedestrians, who are defined as any person on foot, walking, running, jogging, hiking, sitting, or lying down. Note that the pedestrian injury data represented in Figure 2 show higher counts for pedestrians than those presented subsequently in this report in Section 2.1 since it represents all pedestrian crashes, and not only those involving a light vehicle striking a pedestrian in the first event of a crash.



Notes:

1. Average of all 2011 and 2012 GES crashes involving pedestrians
2. Actual fatalties from FARS
3. Injury level based on KABCO scale

Figure 2. Injury Severity Levels of Pedestrians Versus All Vehicle Occupants in Crashes Involving Pedestrians

Pedestrian crash analysis can help to establish a framework by which the crash problem can be further defined and new crash avoidance opportunities identified and described to address the problem of pedestrian crashes. Defining the pedestrian crash problem and translating the crash perspective into information that developers can use to develop safety applications based on V2P communications can contribute to the goal of reducing pedestrian deaths. Various groups are currently researching and prototyping different V2P-based safety systems to help determine which ones are most useful in preventing or mitigating pedestrian-vehicle crashes.

1.2 Prior Research

The Volpe National Transportation Systems Center (Volpe) has been supporting NHTSA with crash avoidance safety research of connected vehicle crash warning and avoidance applications based on cooperative vehicle-to-vehicle (V2V) communications. Three relevant reports that identified and described target pre-crash scenarios addressable by V2V-based safety applications were recently written related to light vehicles:

1. *Description of Light-Vehicle Pre-Crash Scenarios for Safety Applications Based on Vehicle-to-Vehicle Communication* [6]
2. *Depiction of Priority Light-Vehicle Pre-Crash Scenarios for Safety Applications Based on Vehicle-to-Vehicle Communications* [7]
3. *Light Vehicle Crash Avoidance Needs and Countermeasure Profiles for Safety Applications Based on Vehicle-to-Vehicle Communications* [8]

The reports present a template of light vehicle pre-crash scenarios to depict national crash statistics and crash countermeasure profiles and functions for 5 target pre-crash scenario groups based on V2V communications. The research conducted in these three reports is very similar to the current research, with the exception being that the current report's focus is on V2P versus V2V collisions and avoidance systems.

An additional pedestrian research report focused on crash analysis and development of a method to estimate potential safety benefits for pedestrian crash avoidance and mitigation (PCAM) systems [9]. PCAM systems use vehicle-based forward-looking detection sensors, typically radar and/or cameras, to detect pedestrians in front of a forward-moving vehicle. These systems can reduce the speed of the vehicle prior to impact with a pedestrian through the use of driver warning, brake assist, or automatic braking. A potential safety benefit is realized from the avoidance or mitigation of the injury severity of an imminent crash with a pedestrian. The PCAM report recommended the following 4 pedestrian pre-crash scenarios to maximize potential safety benefits for PCAM systems, and presented a simple estimation of system effectiveness and safety benefits in terms of the methodology, equations, assumptions, and key parameters:

- S1 - Vehicle going straight and pedestrian crossing the road
- S2 - Vehicle turning right and pedestrian crossing the road
- S3 - Vehicle turning left and pedestrian crossing the road
- S4 - Vehicle going straight and pedestrian walking along/against traffic

Pedestrian safety is also a priority for the Federal Highway Administration's Office of Safety. A sponsored report details a literature review and technology scan of current V2P technologies with a focus on wireless communication technologies [10]. The report assesses and provides details on the methodologies for the detection of pedestrians in imminent crash situations. These systems are further described in Section 6.3. The report includes bicyclists who are not addressed in this report.

NHTSA has conducted research in order to address the 210 fatalities and 15,000 injuries (yearly average) associated with pedestrian backover crashes. Backover crashes typically happen in driveways or parking lots[2]. Young children are most likely to be killed in such crashes. To address this problem, the agency announced in March, 2014 that it will require all vehicles under 10,000 pounds to incorporate rear visibility technology beginning in 2018 [14]. V2P technology, in addition to the new technology

[2] Backover crashes occurring "off-road" are not included in this report since the databases used do not contain information for these types of crashes.

requirement, could help to mitigate or avoid crashes that occur on these off-road locations. Note that the statistics contained in this report describe crashes that only occur on public roadways.

1.3 Approach

This project updates the pedestrian pre-crash scenarios and related crash statistics, which will form the framework for subsequent tasks to identify and assess the effectiveness of V2P communication-based crash avoidance technology. The objective of this framework is to correlate the most common pedestrian pre-crash scenarios to V2P-based crash avoidance applications and provide information that will enable the identification of their functional requirements, minimum performance specifications, test procedures, and initial safety effectiveness benchmarks. This framework will feed the research and development of new crash avoidance technology and applications that will address the most pressing aspects of the pedestrian crash problem. Moreover, the framework will contribute to classifying and grouping pedestrian crash avoidance technology so that deployed systems can be rated for their ability to reduce the likelihood and severity of pedestrian crashes.

The outcome of this work is a comprehensive crash scenario framework that consists of the ranking and depiction of priority pedestrian pre-crash scenarios addressable by V2P-based crash avoidance technology, and profiles of crash countermeasure concepts. The goal of each scenario depiction is to gain a better understanding of the dynamics of each pre-crash scenario, and to provide a basis to estimate the potential safety benefits and assess the capabilities required to develop V2P-based crash avoidance systems to address these scenarios. The emphasis of the analysis is on crashes involving a light vehicle (LV) striking a pedestrian in the first event of a crash. Pedestrians include any person on foot, walking, running, jogging, hiking, sitting, or lying down. Vehicle and pedestrian movements prior to the crash are ranked according to frequency and comprehensive cost to identify high-priority crash scenarios. Two national crash databases are used including the GES and FARS to query key characteristics of the priority pedestrian pre-crash scenarios, including driver and pedestrian actions/circumstances, crash location, and environmental conditions. Kinematic equations that represent the time-to-collision (TTC) and avoidance maneuvers for each priority pre-crash scenario are developed and used to define crash avoidance needs for the V2P-based countermeasures. These equations incorporate key parameters that the countermeasures must measure in order to decide on whether a crash is imminent in a specific scenario and to determine when to assist the driver. The equations are exercised to obtain estimates of the minimum stopping distances for the various vehicle velocities and braking levels. This information could be used to establish minimum performance requirements for various V2P-based safety applications.

1.4 Data Sources

The 2011 and 2012 GES and FARS crash databases were used to identify and statistically describe target pedestrian pre-crash scenarios for V2P-based safety applications. The GES is a nationally representative sampling of police-reported crashes involving any injury or least major property damage. The FARS is a complete census of all fatal crashes. Both databases contain information on physical settings, environmental conditions, and other pedestrian and vehicle contributing factors and circumstances. In addition, both databases contain information on injuries, but the FARS data set is recommended for examining fatalities since it is a more accurate representation as it is not an estimated count. Each individual database is described below in more detail.

This report presents results based on an average annual estimate from yearly crashes for a 2-year period from the 2011 and 2012 datasets. These years were chosen because FARS and GES have a consistent set of data elements post-2011.

General Estimates System
The GES crash database estimates the national crash population each year based on a probability sample of about 50,000 police-reported crash cases that include all vehicle types and injury levels. These crash estimates do not account for non-reported crashes. Thus, the national estimates produced from the GES data may differ from the true population values because they are based on a probability sample of police-reported crashes rather than a census of all crashes. The GES data contain information on fatalities, but since this information is collected from police reports and weighted based on a probability sample, the results may differ from those contained in FARS.

Fatality Analysis Reporting System
FARS data are a complete nationwide census of all police-reported crashes involving a vehicle in traffic that resulted in a fatal injury suffered by an occupants and/or a non-occupants. The deaths reported in the FARS crashes must have happened as a result of the crash and occurred within thirty days. FARS data contain in-depth analysis of contributing factors of fatalities, including any violations, travel speed, environmental factors, obstructions, and pedestrian characteristics. A preliminary version of the FARS database is released when the data are available. Any additions and changes to the data, particularly regarding alcohol test results and deaths are added and released in a final version. The data in this report represent the final FARS datasets.

1.5 Scope and Limitations

Analysis of the data *includes* the following:

- Only crashes involving a pedestrian struck by a light vehicle
- Pedestrians struck in the first event of the crash only
- 2011 and 2012 GES and FARS crashes
- Police-reported pedestrian crashes only

The following crashes are *not included* in the data:

- Crashes occurring entirely on private property such as private ways, parking lots, driveways, etc.
- Crashes where a person on a personal mobility device (bicycles, wheelchairs, carriages, scooters, etc.) is the first pedestrian struck.
- Crashes where the pedestrian is not struck in the initial event of the crash; i.e., the pedestrian is struck after harmful or non-harmful events occurred. Harmful events include collisions with other vehicles, objects, structures, etc. Non-harmful events include vehicle situations like: ran off roadway, cross median or centerline, downhill runaway, vehicle went airborne, etc.

The following assumptions apply to the data and/or analysis:

- The data include sampling errors since the GES is a nationally-representative data set estimated from samples of crashes.
- There exist gaps in the data where no information exists that is coded as unknown or not on the police report.
- The data include limitations of police-reported data: Police reports may contain limited data, may have under-reporting of important facts, and are subject to the interpretation of the police officer or coders. In addition, many non-severe crashes are unreported.
- Only the first pedestrian struck is considered assuming that there would not be injury to any subsequent pedestrians if the injury to the first pedestrian was avoided. There exists the

possibility that a maneuver to avoid hitting the pedestrian would cause a strike to a different pedestrian, but those situations are not addressed in this report.

- There is an inability to determine pedestrian speed, which direction the pedestrian was crossing, or distinguish whether the pedestrian was sitting, lying down, etc. because of lack of detail in the data.
- The analysis does not distinguish or specifically focus on children and unique characteristics related to them such as size, erratic behavior, etc.
- Pedestrians on personal mobility devices such as people in strollers, on wheelchairs, on skateboards, etc., are not included in the data.
- Both GES and FARS contain values for fatalities. GES is an estimated value and FARS represents an actual count. When determining costs, the actual fatality values from FARS are used to replace the estimated values in GES. There is no double-counting of fatalities.

Note that about 1.6 percent of the target crash population include impaired pedestrians who are blind, deaf, physically challenged, or walking with a cane or crutches. Although they are all categorized together as impaired, people with disabilities should not be considered on the same level as those who are impaired by alcohol.

1.6 Report Organization

In addition to Chapter 1, this report consists of the following chapters:

- Chapter 2 - describes the methods used to identify and prioritize the pedestrian pre-crash scenarios.
- Chapter 3 - presents key crash statistics for the priority scenarios. Since the interests of the reader may vary, the relationship of the key crash parameters to the priority pre-crash scenarios are presented in two different formats. In Sections 3.1 through 3.8, which contain crash parameter descriptions, the priority scenarios are compared for each individual parameter.
- Chapter 4 – contains all the characteristics as defined for each of the 5 scenarios in Sections 4.1 through 4.5.
- Chapter 5 - presents kinematic depictions in terms of time-to-collision and avoidance action equations for each priority scenario in Sections 5.1 through 5.4.
- Chapter 6 - includes the critical kinematic parameters and V2P crash avoidance requirements. It also contains descriptions of the countermeasure technology and needs.
- Chapter 7 – presents the conclusions.

When references to data frequencies or percentages from the databases are made throughout the report, the terms, GES and FARS, can be used synonymously for “all crashes” and “fatal crashes,” respectively.

2 Pedestrian Pre-Crash Scenarios

An analysis was conducted to identify and prioritize pedestrian pre-crash scenarios from vehicle-pedestrian maneuvers in the GES and FARS data sets. Both GES and FARS contain useful information to determine the most frequent and most fatal vehicle-pedestrian crashes. A pedestrian pre-crash scenario is defined for each crash based on the vehicle movement and pedestrian action prior to the crash. Prioritization of these pre-crash scenarios can aid the development of test procedures for V2P systems. The results of the crash analysis support the derivation of performance measures and identify the estimation of the potential safety benefits as well as provide intervention opportunities for V2P systems.

2.1 Target Crash Population

The 2011 and 2012 GES and FARS databases were queried to obtain all crashes that involve a light vehicle striking a pedestrian in the first event of a crash. The definition of a pedestrian is any person on foot, walking, running, jogging, hiking, standing still, sitting, or lying down. Other non-motorists, such as those involving a wheelchair, baby carriage, scooter, or cycle, are beyond the scope of this study, although V2P systems might address these types of pedestrian crashes, too. There are an estimated 68,000 overall crashes and 3,799 fatal crashes involving a light vehicle hitting a pedestrian. The databases are designed so that each crash is represented by a series of chronological events, non-harmful or harmful, resulting from a hazardous situation or critical pre-crash event (e.g., ran off road-right, crossed center line, hit guardrail, hit parked motor vehicle, etc.). A pedestrian can be hit in any event related to the crash (e.g., a vehicle could hit another vehicle or object and then hit a pedestrian). Since it is complex to accurately define the vehicle and pedestrian interactions that occur in later events, these cases are out of scope for this analysis. However, a potential does exist for V2P to avoid pedestrians that are struck in later events. Table 1 shows that in 92 percent of the GES crashes and 88 percent of the FARS crashes the pedestrian is struck in the first event. This translates to a target pedestrian crash population of 63,000 crashes in the GES and 3,337 in FARS that will be used throughout the analysis.

Table 1. Pedestrian Target Crash Population

Target Population

Pedestrian Struck by Light Vehicle Crashes	Yearly Average 2011 & 2012			
	GES		FARS	
Pedestrian Struck in First Event of Crash	63,000	92%	3,337	88%
Pedestrian Struck in a Later Event	5,000	8%	462	12%
Total Crashes	68,000	100%	3,799	100%

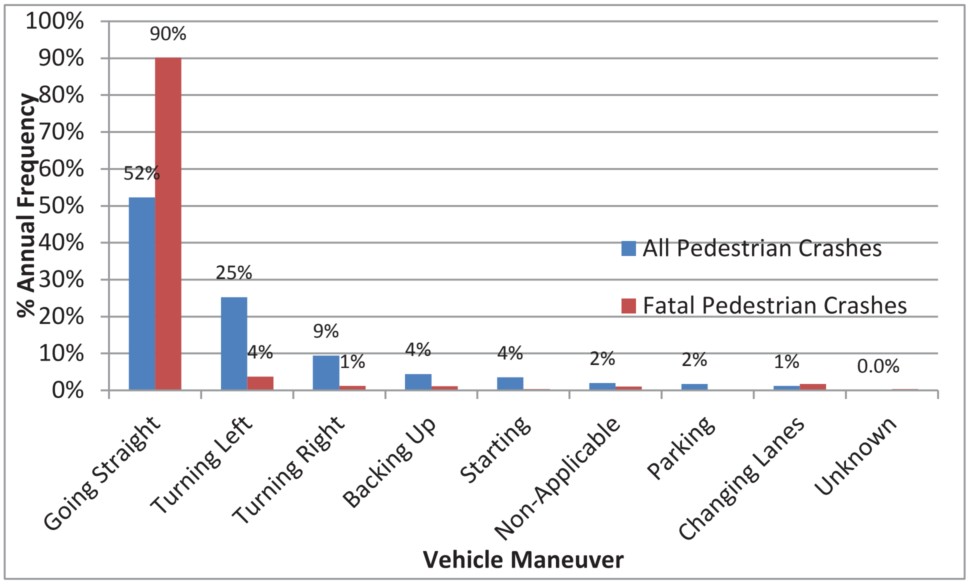
2.2 Vehicle Movement

Categories to describe the vehicle maneuver just prior to the critical pre-crash event are shown in Table 2 along with a description of each movement. To assess how countermeasures can address pedestrian crashes, it is critical to describe the vehicle and pedestrian relationship based on kinematics. Table 2 shows similar vehicle movements grouped together. Non-applicable cases reflect those in which it is very difficult to predict how a V2P system would mitigate an associated pedestrian crash due to either the instance of unknowns or the ambiguity associated with the vehicle movement or circumstance. The frequency of these non-applicable and unknown vehicle movement crashes is under two percent for both GES and FARS.

Table 2. Vehicle Movement Prior to Impact

Category	Vehicle Movement	Description
Straight	Straight	Traveling straight ahead on the road without any attempted or intended changes
	Curve	Traveling straight ahead along a road that curved to the right or left
	Decelerating	Traveling straight ahead along a road while decelerating
Starting	Accelerating	Traveling straight ahead along a road while accelerating
	Starting	Starting forward from a stopped position (e.g., start up from traffic signal)
Turning Left	Turning Left	Moving forward and turned left: changing lanes from one roadway to a different roadway (e.g., from or to a driveway, parking lot or intersection)
Turning Right	Turning Right	Moving forward and turned right: changing lanes from one roadway to a different roadway (e.g., from or to a driveway, parking lot or intersection)
Backing	Backing	Traveling backwards within the trafficway. Does not include backing into a parking space
Parking	Parking	Leaving/entering a parking area adjacent to the traffic lanes
Changing Lanes	Changing Lanes	Changing travel lanes to the right or left while on the same roadway
	Merging	Merging from the left or right into a traffic lane (e.g., roadway narrows, exit/entrance ramps)
	Passing	Passing or overtaking another vehicle on the left or right
Non-Applicable	No Driver	No driver present in vehicle
	Other	Movement is known but does not reflect other attributes, ex. vehicles traveling on off-roadway locations or movement is unknown
	Stopped	Stopped momentarily, with the motor running within the roadway portion of the trafficway (e.g., stopped for traffic signal)
	U-Turn	Making a U-turn
	Successful Avoidance Maneuver to a Previous Critical Event	Responded to a previous critical event and successfully avoided an impact. However, this maneuver precipitated a subsequent critical crash envelope, which resulted in this vehicle's first impact
Unknown	Unknown	Movement is unknown

The percentages of the vehicle movement categories are shown in Figure 3[3]. These represent the pedestrian target crash population from the 2011 and 2012 GES and FARS databases. Based on GES statistics, 87 percent of vehicles were traveling straight, turning left, or turning right. The remaining 13 percent encompass backing, starting, parking, changing lanes, and the non-applicable categories. There were no unknown cases since the imputed values were used. From the FARS data, a vehicle traveling straight involved a fatality for 90 percent of the crashes. The crashes involving a fatality and a vehicle turning left or right contributed to an additional 5 percent of the crashes.



2011 and 2012 average: GES = 62,900 total crashes; FARS = 3,337 fatal crashes

Figure 3. Vehicle Maneuver in Pedestrian Crashes

2.3 Pedestrian Action

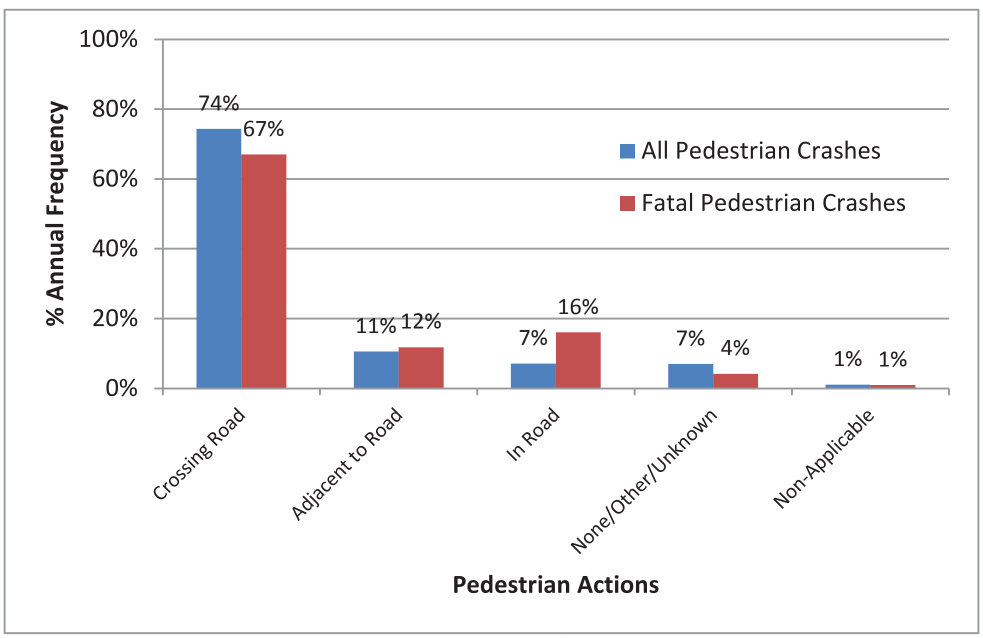
The pedestrian "actions/circumstance prior to the crash" variable is coded in GES and FARS as a "select all that apply" data element. Only about 5 percent of the FARS and GES cases had more than one action defined for the pedestrian. For these cases, a priority scheme was used to identify a single pedestrian action in each crash. Attributes that defined a pedestrian's motion and location such as "crossing the road" took priority over those that were not as definitive, such as "jogging/running" or "going to and from school." The pedestrian actions were analyzed and grouped according to the categories in Table 3. Similarly, as in the vehicle movement category, the pedestrian movement categories contain non-applicable or unknown motions that did not contribute any information to definitively predict a scenario to be addressed by V2P. Note that the category "working in traffic way (incident response)" describes cases where the pedestrian was in the road as part of an official response to an incident and it accounts for only 0.3 percent of GES and 0.1 percent of FARS crashes. This category was specified as "non-applicable" because of the unique situations associated with this type of crash such as a firefighter moving between a fire truck and a crashed vehicle.

[3] Backover crashes that occur on off-road locations (i.e., driveways, parking lots) are not included.

Table 3. Priority Pedestrian Actions Prior to the Crash

Pedestrian Category	Description
Crossing	Moving across the travel lanes to cross roadway
Adjacent to Road	Adjacent to road (shoulder, median); movement along roadway with/against traffic (in or adjacent to travel lane); movement on sidewalk, waiting to cross roadway
In Road	Disabled vehicle related (working on, pushing, leaving/approaching); entering /exiting a vehicle; in roadway - other (working, playing, etc.)
Non-Applicable	Going to or from school; jogging/running; movement along roadway - direction unknown; working in trafficway (incident response)
Other/Unknown	Actions/circumstances do not reflect other attributes; case report specifies actions/circumstances were unknown; no actions/circumstances prior to the crash specificately stated in report

For GES pedestrian maneuvers, 74 percent of pedestrians were crossing the road as seen in Figure 4. In FARS crashes, 67 percent of pedestrians were crossing the road. Although the frequencies are low for the pedestrian action, "adjacent to road" and "in road" categories, the fatalities are higher in these crashes. In about 8 percent of the total crashes, the pedestrian action could not be determined or was not-applicable. These same categories translated to 5 percent of the fatal crashes. In some of these cases, it is probably due to the fact that the police report had no record of the pedestrian making an action and does not necessarily mean that the pedestrian did nothing.



2011-2012 average: GES = 62,900 total crashes; FARS = 3,337 fatal crashes

Figure 4. Pedestrian Maneuver in Pedestrian Crashes

2.4 Identification of Pre-Crash Scenarios

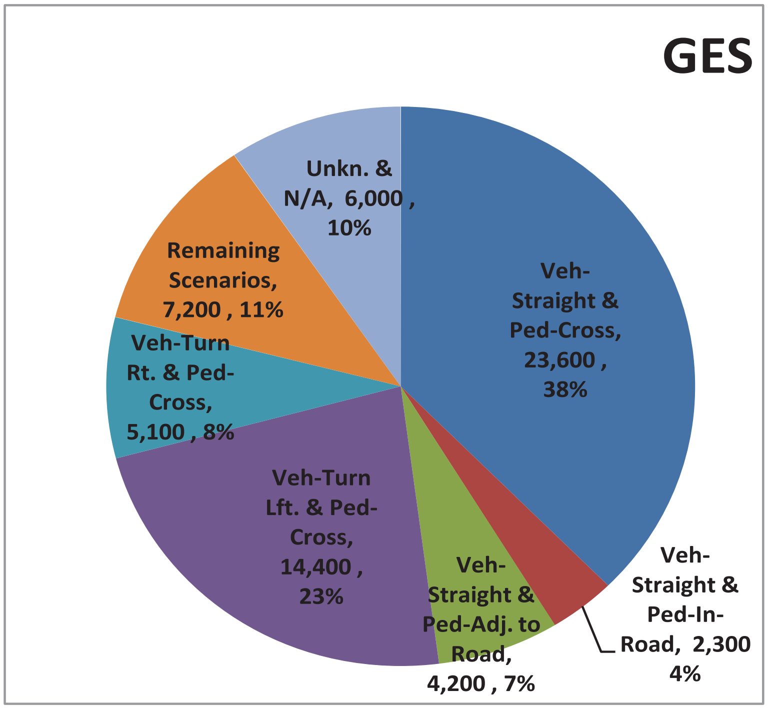
The combination of 9 “vehicle-motion” categories and 5 “pedestrian-maneuver” categories for each crash yielded a total of 45 pre-crash scenarios. After eliminating all maneuvers with “unknown” or “non-applicable,” 21 combinations remained, which together comprised a total of 90 percent of target pedestrian crashes and 94 percent of fatal crashes. These combinations were ranked by GES frequency and the associated FARS values are shown in Table 4. The rows highlighted in gray represent the crashes with unknowns or non-applicable vehicle maneuvers or pedestrian actions.

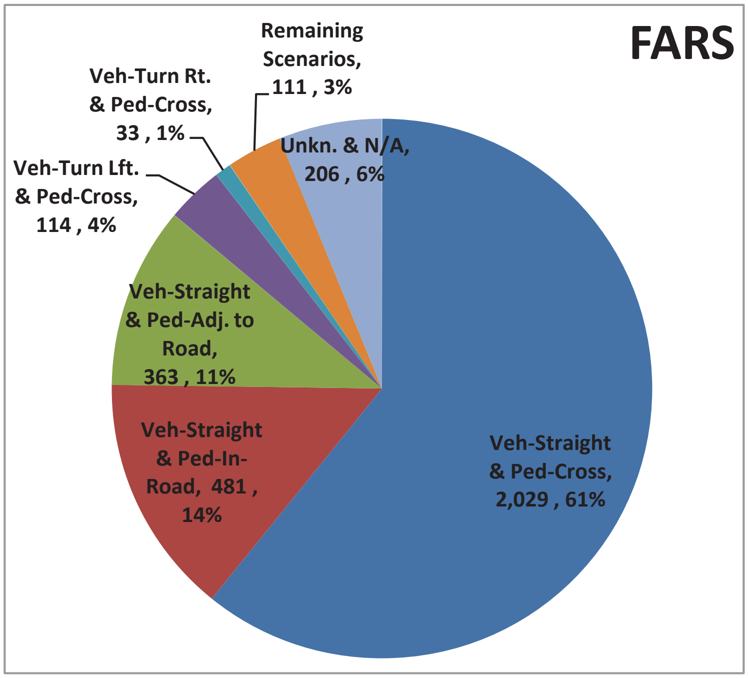
Table 4. Pre-Crash Scenarios Ranked by Crash Frequency

GES Rank	Vehicle Maneuver	Pedestrian Action	GES Fequency of Crashes	%	FARS Fequency of Crashes	%
1	Going Straight	Crossing Road	23,558	37.4%	2,029	60.8%
2	Turning Left	Crossing Road	14,427	22.9%	114	3.4%
3	Turning Right	Crossing Road	5,123	8.1%	33	1.0%
4	Going Straight	Adjacent to Road	4,243	6.7%	363	10.9%
5	Going Straight	In-Road	2,326	3.7%	481	14.4%
6	Going Straight	None/Other/Unknown	2,276	3.6%	106	3.2%
7	Starting	Crossing Road	1,285	2.0%	9	0.3%
8	Backing Up	Crossing Road	1,090	1.7%	5	0.1%
9	Backing Up	None/Other/Unknown	824	1.3%	9	0.3%
10	Backing Up	Adjacent to Road	653	1.0%	12	0.3%
11	Starting	In-Road	518	0.8%	2	0.1%
12	Changing Lanes	Crossing Road	510	0.8%	31	0.9%
13	Going Straight	Non-Applicable	495	0.8%	28	0.8%
14	Turning Left	Adjacent to Road	492	0.8%	3	0.1%
15	Turning Right	Adjacent to Road	478	0.8%	4	0.1%
16	Turning Left	In-Road	464	0.7%	3	0.1%
17	Turning Left	None/Other/Unknown	462	0.7%	4	0.1%
18	Non-Applicable	In-Road	436	0.7%	19	0.6%
19	Parking	Crossing Road	405	0.6%	2	0.1%
20	Non-Applicable	Crossing Road	361	0.6%	5	0.1%
21	Parking	In-Road	283	0.5%	3	0.1%
22	Starting	Adjacent to Road	257	0.4%	1	0.0%
23	Non-Applicable	None/Other/Unknown	255	0.4%	11	0.3%
24	Backing Up	In-Road	239	0.4%	12	0.4%
25	Parking	Adjacent to Road	216	0.3%	2	0.0%
26	Parking	None/Other/Unknown	199	0.3%	2	0.0%
27	Non-Applicable	Adjacent to Road	194	0.3%	2	0.0%
28	Turning Right	None/Other/Unknown	180	0.3%	1	0.0%
29	Starting	None/Other/Unknown	172	0.3%	3	0.1%
30	Changing Lanes	In-Road	134	0.2%	14	0.4%
31	Changing Lanes	Adjacent to Road	127	0.2%	9	0.3%
32	Turning Right	Non-Applicable	119	0.2%	-	0.0%
33	Turning Left	Non-Applicable	43	0.1%	1	0.0%
34	Turning Right	In-Road	38	0.1%	3	0.1%
35	Starting	Non-Applicable	15	0.0%	-	0.0%
36	Changing Lanes	None/Other/Unknown	13	0.0%	3	0.1%
37	Non-Applicable	Non-Applicable	5	0.0%	-	0.0%
38	Backing Up	Non-Applicable	-	0.0%	1	0.0%
39	Changing Lanes	Non-Applicable	-	0.0%	2	0.0%
40	Parking	Non-Applicable	-	0.0%	-	0.0%
41	Unknown	Adjacent to Road	-	0.0%	-	0.0%
42	Unknown	Crossing Road	-	0.0%	9	0.3%
43	Unknown	In-Road	-	0.0%	1	0.0%
44	Unknown	Non-Applicable	-	0.0%	-	0.0%
45	Unknown	None/Other/Unknown	-	0.0%	4	0.1%
		Total	62,917	100%	3,337	100%

Average of 2011 and 2012

The top 5 scenarios representing 79 percent of pedestrian crashes and 91 percent of fatal crashes involve three vehicle maneuvers: going straight, turning left, or turning right. Also for these top scenarios, there are three pedestrian maneuvers, including crossing the road, in-road, and adjacent to the road. These top 5 scenarios are shown in Figure 5 for both GES and FARS. The other 16 of 21 scenarios are shown in either the “remaining scenarios” or “unknown and not applicable” categories. Although the vehicle-turning scenarios are part of the most frequent crash scenarios, they typically result in less harm to pedestrians, vehicles, and the surrounding area. This may be due to the fact that lower impact speeds are typically associated with vehicles making turns at intersections.





Note that the GES percentages in this figure may vary slightly from the percentages shown in Table 4 due to rounding of the values.

Figure 5. Vehicle - Pedestrian Crash Scenarios

The frequency of these pedestrian crashes gives an indication to the rate at which these pre-crash scenarios occur; however, they give little information about the outcome or resulting injury to the pedestrian and associated costs. Comprehensive costs are calculated based on injury in each crash to assess this value. Comprehensive costs account for goods and services that must be purchased or productivity that is lost as a result of motor vehicle crashes [11]. They include costs associated with lost productivity, medical costs, legal and court costs, emergency service costs, insurance administration costs, travel delay, property damage, and workplace losses. Intangible consequences of these events, such as pain and suffering or loss of life, are also included. In addition, comprehensive costs include the value of quality-adjusted life-years.

The comprehensive costs are based on injuries using the Maximum Abbreviated Injury Scale (MAIS) and the GES and FARS databases report injuries using the KABCO scale. Therefore, the KABCO non-fatal injuries reported in the GES need to be translated into MAIS values. Appendix A contains details on how this conversion is done. To get accurate values for cost for the GES target crashes, the fatalities from FARS are used to replace those in GES, since GES is a weighted sample and FARS are actual counts[4].

The comprehensive cost as reported for the GES target crashes is based on the maximum injury of the first pedestrian struck. Although other pedestrians may be struck in some of these crashes, the assumption is that if the driver can avoid injury to the first pedestrian, then subsequent pedestrians would not be struck. There exists the possibility that a maneuver to avoid hitting the pedestrian would cause a strike to a different pedestrian, but those situations are not addressed in this report.

Categories for vehicle maneuver and pedestrian action are prioritized according to the highest rank of cost in Table 5 for the top 20 scenarios (which represent 98 percent of the crashes.) However, approximately 6 percent of these top scenarios include an unknown value for either the vehicle maneuver or pedestrian action. The positional ranking is different for the cases based on GES frequency versus cost. This is because some scenarios (high-speed crashes) have a low frequency of crashes but a high count of fatalities, which translates to a higher cost to society. The reverse is also true where some scenarios have a high frequency of crashes but the costs associated with these crashes may be lower (such as in the vehicle-turning scenarios.)

[4] Note that in 1 percent of the FARS crashes, the fatality does not equate to the first pedestrian hit and may result from an additional pedestrian or occupant struck in a subsequent event.

Table 5. Pre-Crash Scenarios Ranked by Cost

Cost Rank	Vehicle	Pedestrian	Cost	% Cost
1	**Going Straight**	**Crossing Road**	**$ 45,582,062,129**	**56.1%**
2	**Going Straight**	**In Road**	**$ 9,450,945,953**	**11.6%**
3	**Going Straight**	**Adjacent to Road**	**$ 8,391,303,767**	**10.3%**
4	**Turning Left**	**Crossing Road**	**$ 6,048,459,422**	**7.4%**
5	Going Straight	None/Other/Unknown	$ 2,800,222,249	3.4%
6	**Turning Right**	**Crossing Road**	**$ 2,048,500,397**	**2.5%**
7	**Changing Lanes**	**Crossing Road**	**$ 793,622,679**	**1.0%**
8	Going Straight	Non-Applicable	$ 661,283,838	0.8%
9	**Starting**	**Crossing Road**	**$ 476,915,685**	**0.6%**
10	Non-Applicable	In Road	$ 458,796,788	0.6%
11	**Backing**	**Adjacent to Road**	**$ 372,667,524**	**0.5%**
12	**Backing**	**Crossing Road**	**$ 369,745,125**	**0.5%**
13	Backing	Other/Unknown	$ 327,721,747	0.4%
14	**Backing**	**In Road**	**$ 312,082,666**	**0.4%**
15	**Changing Lanes**	**In Road**	**$ 283,309,976**	**0.3%**
16	Non-Applicable	Other/Unknown	$ 272,278,304	0.3%
17	Turning Left	Other/Unknown	$ 250,509,196	0.3%
18	**Turning Right**	**Adjacent to Road**	**$ 227,854,386**	**0.3%**
19	**Parking**	**Crossing Road**	**$ 204,328,834**	**0.3%**
20	**Turning Left**	**Adjacent to Road**	**$ 201,621,863**	**0.2%**
All other remaining scenarios (25)			**$ 1,663,049,631**	**2.0%**
		Total	**$ 81,197,282,158**	

2.5 Priority Pre-Crash Scenarios

To determine the priority pre-crash scenarios, the top scenarios based on cost and frequencies are examined. Table 6 includes the cost ranking and the frequency ranking for each scenario. The scenarios with unknowns or non-applicable crashes are grouped together and these represent 7 percent of the cost and 10 percent of the frequency. The remaining scenarios (without unknowns) represent 21 scenarios, accounting for 93 percent of the cost and 90 percent of the total crashes.

Table 6. Vehicle-Pedestrian Scenarios Ranked Cost and Frequency Comparison

Vehicle Maneuver	Pedestrian Action	Cost Rank	Cost	% Cost	GES Rank	GES Fequency of Crashes	% GES	FARS Rank	FARS Fequency of Crashes	% FARS
Going Straight	Crossing Road	1	$ 45,582,062,129	56.1%	1	23,558	37.4%	1	2,029	60.8%
Going Straight	In-Road	2	$ 9,450,945,953	11.6%	5	2,326	3.7%	2	481	14.4%
Going Straight	Adjacent to Road	3	$ 8,391,303,767	10.3%	4	4,243	6.7%	3	363	10.9%
Turning Left	Crossing Road	4	$ 6,048,459,422	7.4%	2	14,427	22.9%	4	114	3.4%
Turning Right	Crossing Road	6	$ 2,048,500,397	2.5%	3	5,123	8.1%	6	33	1.0%
Changing Lanes	Crossing Road	7	$ 793,622,679	1.0%	12	510	0.8%	7	31	0.9%
Starting	Crossing Road	9	$ 476,915,685	0.6%	7	1,285	2.0%	17	8.5	0.3%
Backing Up	Adjacent to Road	11	$ 372,667,524	0.5%	10	653	1.0%	12	11.5	0.3%
Backing Up	Crossing Road	12	$ 369,745,125	0.5%	8	1,090	1.7%	18	5.0	0.1%
Backing Up	In-Road	14	$ 312,082,666	0.4%	24	239	0.4%	11	12.0	0.4%
Changing Lanes	In-Road	15	$ 283,309,976	0.3%	30	134	0.2%	10	14.0	0.4%
Turning Right	Adjacent to Road	18	$ 227,854,386	0.3%	15	478	0.8%	21	3.5	0.1%
Parking	Crossing Road	19	$ 204,328,834	0.3%	19	405	0.6%	29	2.0	0.1%
Turning Left	Adjacent to Road	20	$ 201,621,863	0.2%	14	492	0.8%	23	3.0	0.1%
Changing Lanes	Adjacent to Road	21	$ 185,405,304	0.2%	31	127	0.2%	14	9.0	0.3%
Turning Left	In-Road	24	$ 147,900,834	0.2%	16	464	0.7%	23	3.0	0.1%
Starting	In-Road	25	$ 137,174,283	0.2%	11	518	0.8%	29	2.0	0.1%
Parking	In-Road	26	$ 125,703,151	0.2%	21	283	0.5%	25	2.5	0.1%
Parking	Adjacent to Road	27	$ 93,633,915	0.1%	25	216	0.3%	31	1.5	0.0%
Turning Right	In-Road	31	$ 66,812,673	0.1%	34	38	0.1%	25	2.5	0.1%
Starting	Adjacent to Road	32	$ 60,896,853	0.1%	22	257	0.4%	38	0.5	0.0%
		Subtotal	$ 75,580,947,418	93.1%		56,868	90.4%		3,130.5	93.8%
Scenarios with Unknowns			$ 5,616,334,740	6.9%		6,050	9.6%		206.0	6.2%
		Total	$ 81,197,282,158	100.0%		62,917	100.0%		3,336.5	100.0%

Eight scenarios were selected[5] for review and represented cases where the crash frequencies were all above 1,000 (excluding vehicle-changing lanes and pedestrian-crossing). Each of the top ranked scenarios for cost and frequencies was represented in these 8 scenarios excluding the scenarios with unknowns. Figure 6 shows a comparison of these 8 scenarios in terms of cost, frequency of all crashes, and frequency of fatal crashes. The vehicle going straight and pedestrian crossing scenario represents the largest percentages at 56 percent for cost, 37 percent of total crashes, and 61 percent of all fatalities. Since the last 3 scenarios, "vehicle changing lanes and pedestrian crossing," "vehicle starting and pedestrian crossing," and "vehicle backing up and pedestrian crossing," contribute to very small percentages (each has a percentage of either cost or frequency under 1 percent), the top 5 scenarios were chosen as the priority pre-crash scenarios. The 5 priority pre-crash scenarios are illustrated in Figure 7. All 4 recommended pre-crash scenarios that were presented in the PCAM report (see Section 1.2) are included in this current research as priority scenarios. Note that the two pedestrian actions, "in-road" and "walking with/against the traffic," are combined into one scenario (S4) in the PCAM report but they are reported as separate scenarios in this report.

5 These were the top 8 scenarios based on cost (after removing unknowns).

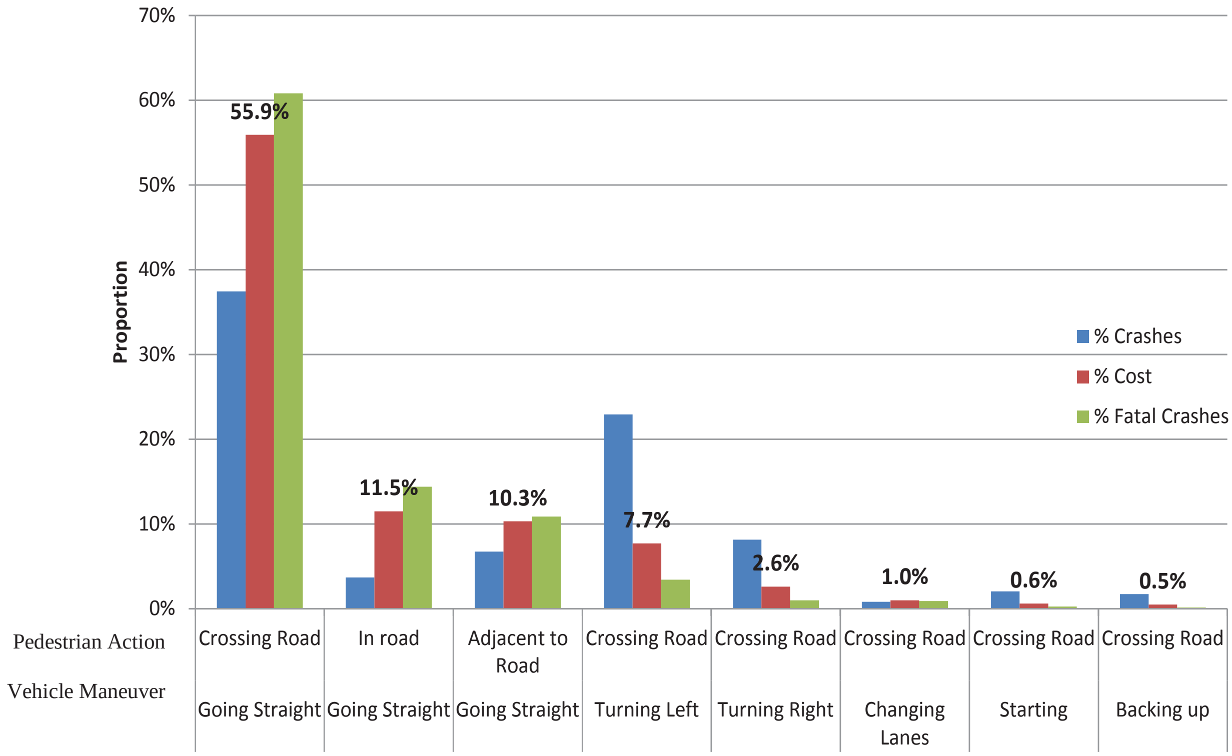


Figure 6. Comparison of Cost, Frequency, and Fatal Crashes in Top 8 Scenarios

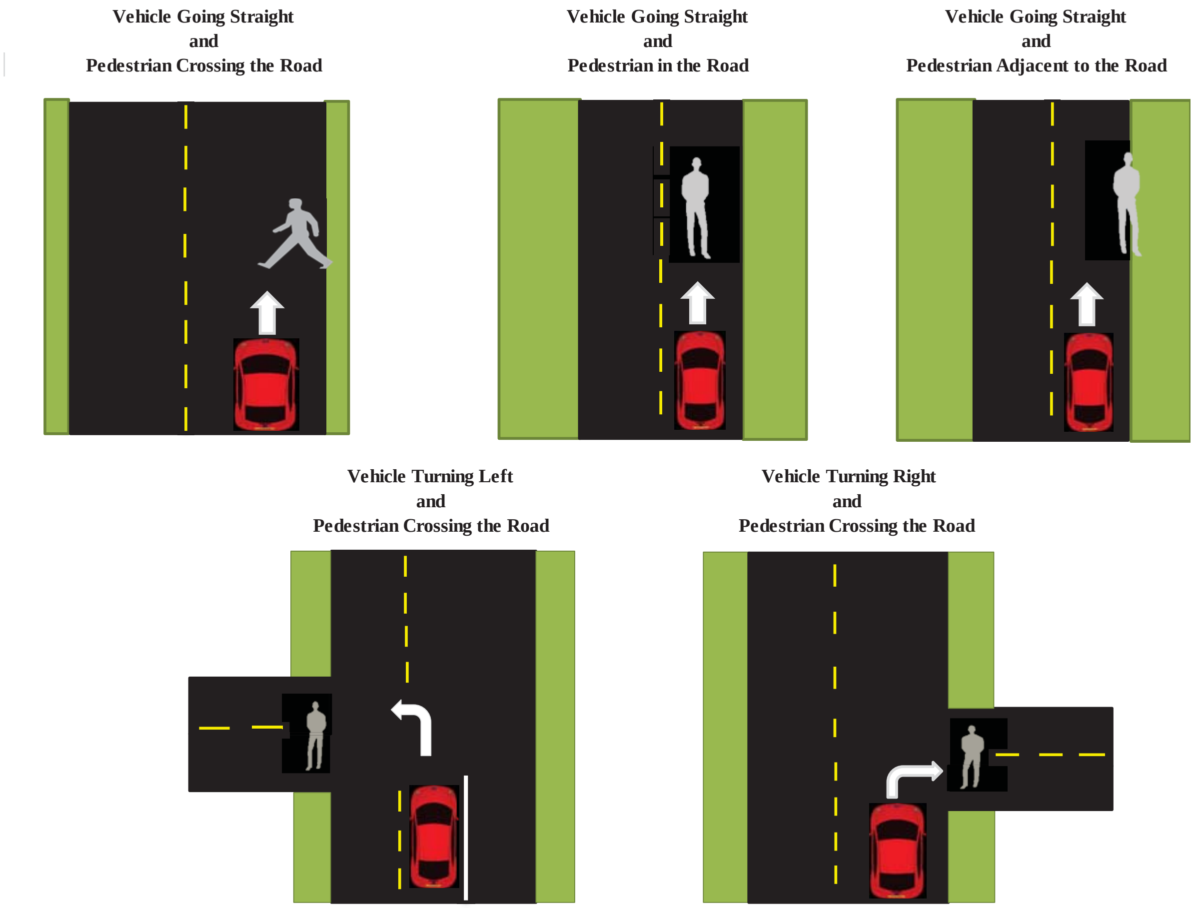


Figure 7. Five Priority Pre-Crash Scenarios

Three distinct vehicle maneuvers and three distinct pedestrian maneuvers were identified in the priority scenarios; these maneuvers were vehicle going straight, vehicle turning right, vehicle turning left, pedestrian crossing, pedestrian in the road, and pedestrian walking adjacent to the road. The top 5 priority pre-crash scenarios encompass the most frequent and injury-prone vehicle-pedestrian maneuvers and result in a total of 88 percent of all costs, 79 percent of the frequency of all vehicle-pedestrian crashes, and 91 percent of the fatalities. The vehicle going straight and the pedestrian crossing scenario is the most frequent pre-crash scenario and has the highest cost. This scenario also has the highest fatalities and indicates that V2P systems should likely have high-accuracy pedestrian detection that operates at high travel speeds in order to address the safety need. The vehicle turning (right or left) scenarios represent 31 percent of the total crashes but contribute to only 10 percent of the cost. Although these scenarios result in less severe injuries, V2P systems functioning correctly within these scenarios would help maximize crash avoidance and would potentially perform better than PCAM systems. Generally, V2P systems would help to overcome the line-of-sight limitations of PCAM systems. The vehicle going straight and pedestrian either in road or adjacent to the road each contributes to over 10 percent of the cost but under that amount in frequency of crashes. It is important to note that these crashes tend to result in fatalities. V2P systems performing correctly in a variety of vehicle and pedestrian maneuvers would help to maximize the potential reduction of crashes and fatalities.

3 Characteristics of Pedestrian Crashes

Crash characteristics were examined to identify physical settings, environmental conditions, driver and pedestrian characteristics, and other circumstances to define the pedestrian crash problem. Physical settings and environmental conditions include crash location, obstructions, roadway alignment, roadway profile, atmospheric and light conditions, and road surface conditions. Driver characteristics include driver physiological conditions, vision obstructions, and distractions. Pedestrian factors include pedestrian location, visibility, physiological conditions, dash/dart, and age. These elements were examined to aid in the development of algorithms to accurately detect pedestrians. Addressing the most common situations helps to support the efficiency and development of optimization methodologies for V2P technology. Each of the crash characteristics in Figure 8 is defined further in Sections 3.1 through 3.8. In some instances, it is also beneficial to collect additional information by correlating multiple variables. These results are also presented.

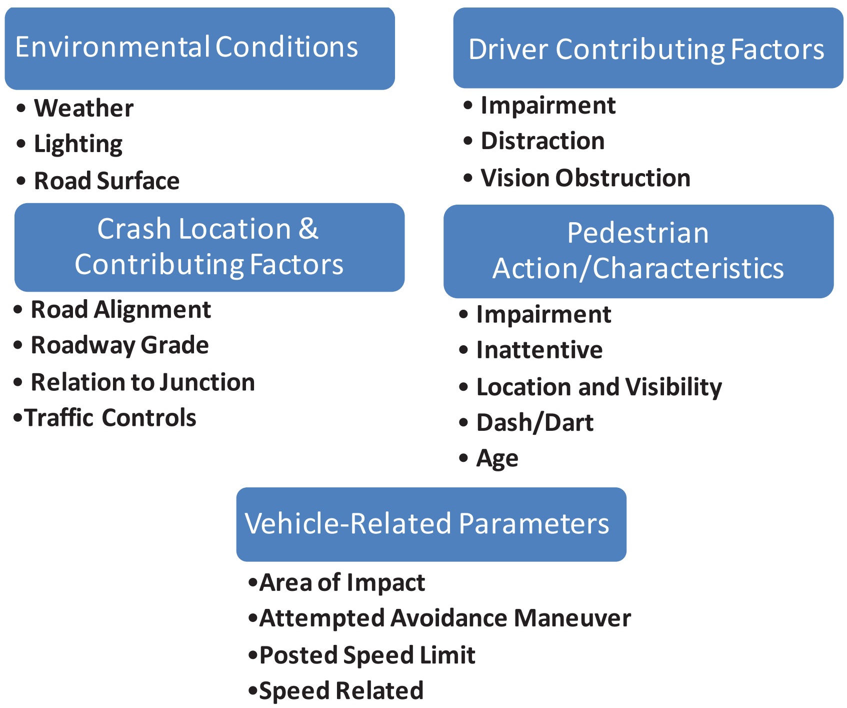


Figure 8. Pedestrian Crash Characteristic Categories

3.1 Crash Location

Crash location identifies the type of roadway where the crash occurred in terms of intersection, junction, driveway, and other/unknown. It is described using two variables related to the vehicle and pedestrian. The variables that describe the vehicle's relation to junction and the pedestrian's location differ slightly. The vehicle's relation to junction includes categories such as intersection, intersection-related, and non-junction. The pedestrian's location includes intersection and non-intersection categories and also includes references to the crosswalk. A separate variable to determine if any traffic control devices are present at the site of the crash is also included. The three variables (vehicle relation to junction, pedestrian location, and traffic control) are presented individually and correlated in Sections 3.1.1 to 3.1.4.

3.1.1 Vehicle Relation to Junction

Definition: This variable describes the location of the crash related to junctions or interchange areas.

Categories:

- Non-Junction
- Intersection and Intersection-Related
- Driveway Access and Driveway Access-Related
- Other/unknown (<1 percent) - Ramps, Railway Crossing, Crossover - Related, Paths/Trails, Acceleration/Deceleration Lanes, Through Roadways, etc.

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 56 percent of all pedestrian crashes and 28 percent of fatal crashes happen at intersections and intersection-related areas.
- 37 percent of all pedestrian crashes and 67 percent of fatal crashes happen at non-junctions.

Scenarios:

- Vehicle - going straight and pedestrian in the road or adjacent to the road - the majority of cases do not happen at intersections.
- Vehicle - going straight and pedestrian crossing - the majority of fatal cases happen at non-junctions.

Influence on V2P Systems: In order to address these findings, V2P systems would need to activate accurately regardless of location (intersection or non-junction). Intersections have a high crash frequency but lower fatalities, while the opposite is true for non-junctions. If and when it becomes available, infrastructure communication could provide additional input to the safety systems to aid in accurate activation.

Comparison of Vehicle Relation to Junction in Priority Scenarios

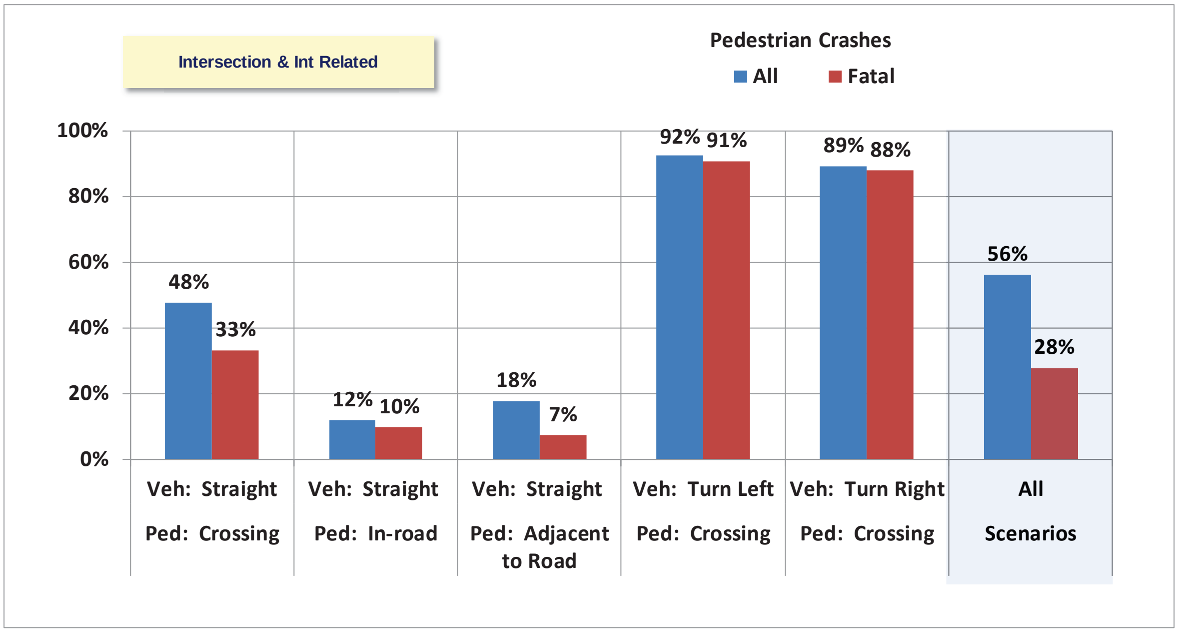


Figure 9. Percentage of Intersection and Intersection-Related Crashes per Total Crashes in Each Priority Scenario

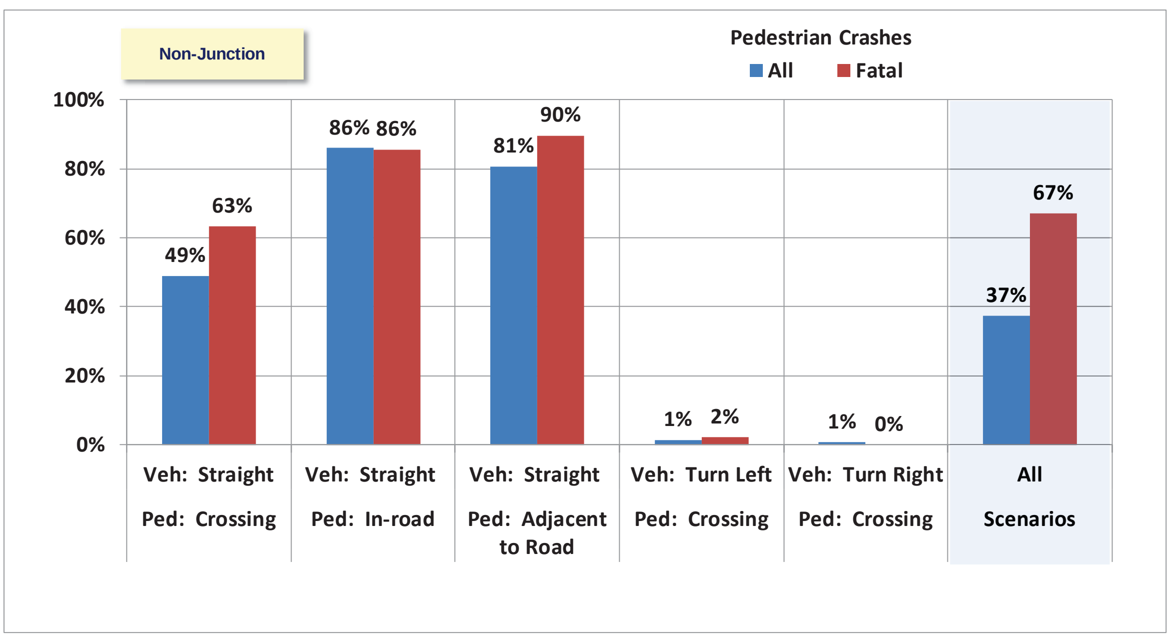


Figure 10. Percentage of Non-Junction Crashes per Total Crashes in Each Priority Scenario

3.1.2 Pedestrian Location at the Time of the Crash

Definition: This variable defines the location of the pedestrian in relation to the roadway at the time of the crash.

Categories:

- Intersection-In Marked Crosswalk
- Intersection-Unmarked Crosswalk
- Intersection-Not in Crosswalk
- Intersection-Unknown Location
- Non-Intersection-In Marked Crosswalk
- Non-Intersection-On Roadway, Not in Marked Crosswalk
- Non-Intersection-On Roadway, Crosswalk Availibility Unkn.
- Bicycle Lane
- Shoulder/Roadside
- Sidewalk
- Median/Crossing Island
- Driveway Access
- Non-Trafficway Area
- Parking Lane/Zone
- Not Reported/Other/Unknown

Note that an available category, "Shared-Use Path/Trail," was not represented in the target population.

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 41 percent of all pedestrian crashes and 69 percent of fatal crashes happen at non-intersections with a pedestrian not in a marked crosswalk.
- 25 percent of all pedestrian crashes and 10 percent of fatal crashes happen at intersections with a pedestrian in the crosswalk.

Scenarios:

- Vehicle - turning left or right and pedestrian crossing - more than half of all crashes were at intersections and in crosswalks; about 58 percent of the fatal crashes were also at intersections and in crosswalks.
- Vehicle - straight and pedestrian in the road or adjacent to the road - the majority of cases do not happen at intersections.

Influence on V2P Systems: In order to address these findings, V2P systems would need to activate regardless of pedestrian location (e.g., crosswalk, not in crosswalk, intersection, non-intersection). Infrastructure data could only support locations where pedestrians are expected (i.e., crosswalks). To address the safety needs as assessed here, V2P systems would need to have the ability to activate when pedestrians are not expected (i.e., non-intersection, non-crosswalk.) In these situations, the pedestrians would need something that would allow them to transmit a message to surrounding vehicles.

Comparison of Pedestrian Location at the Time of Crash in Priority Scenarios

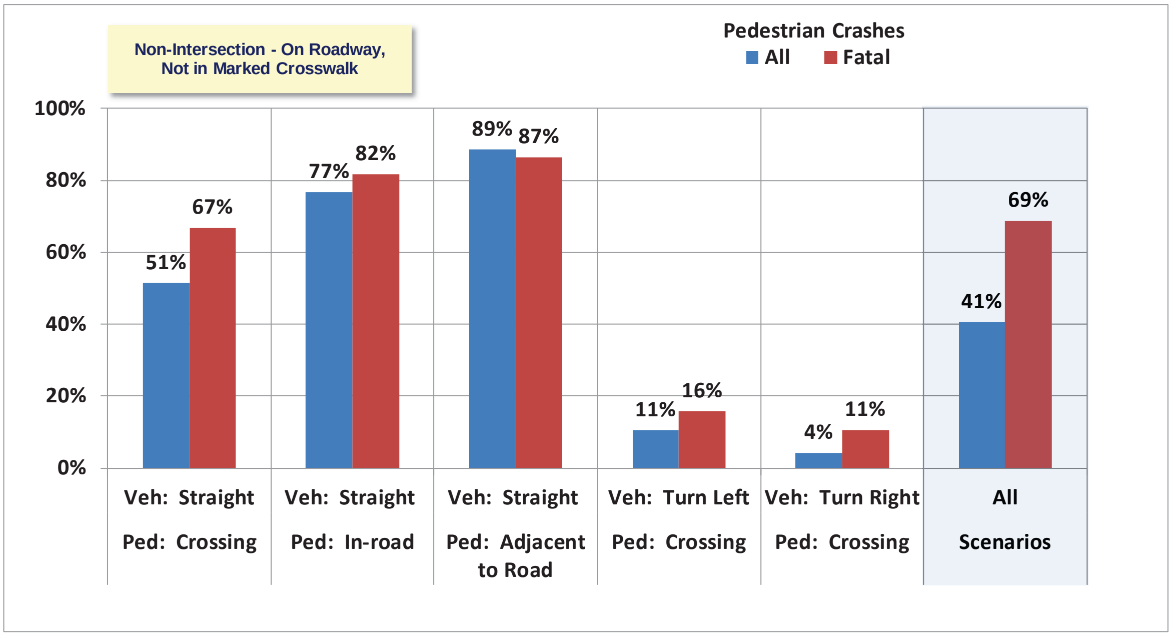


Figure 11. Percentage of "Non-Intersection - On Roadway Not in Marked Crosswalk" Crashes per Total Crashes in Each Priority Scenario

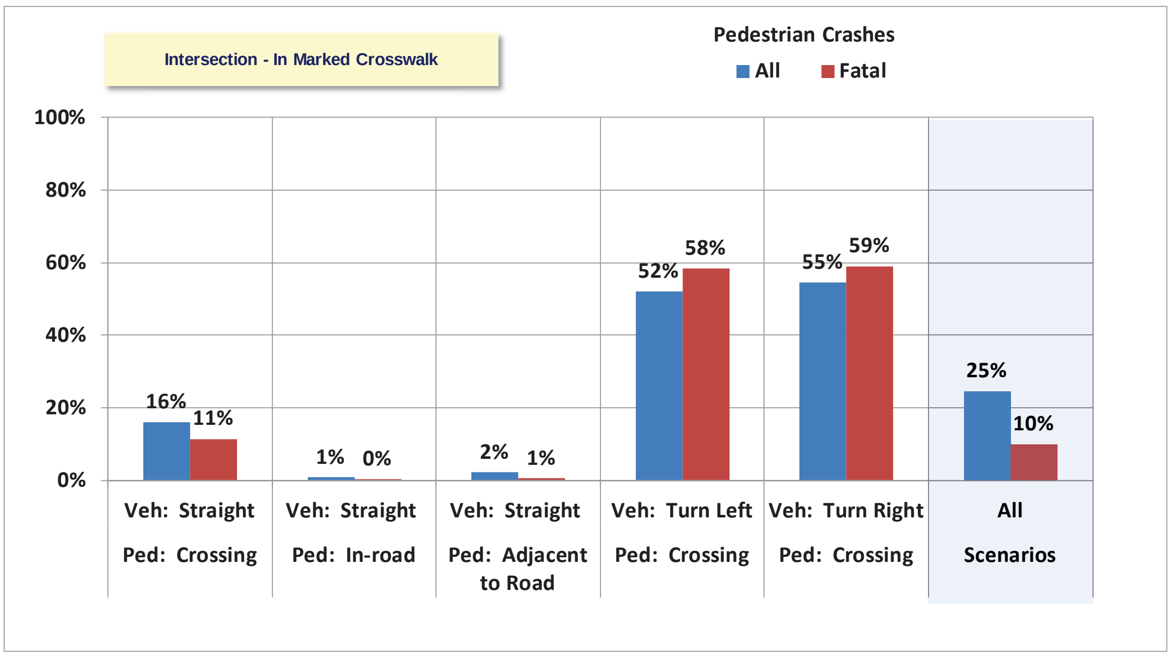


Figure 12. Percentage of "Intersection - In Marked Crosswalk" Crashes per Total Crashes in Each Priority Scenario

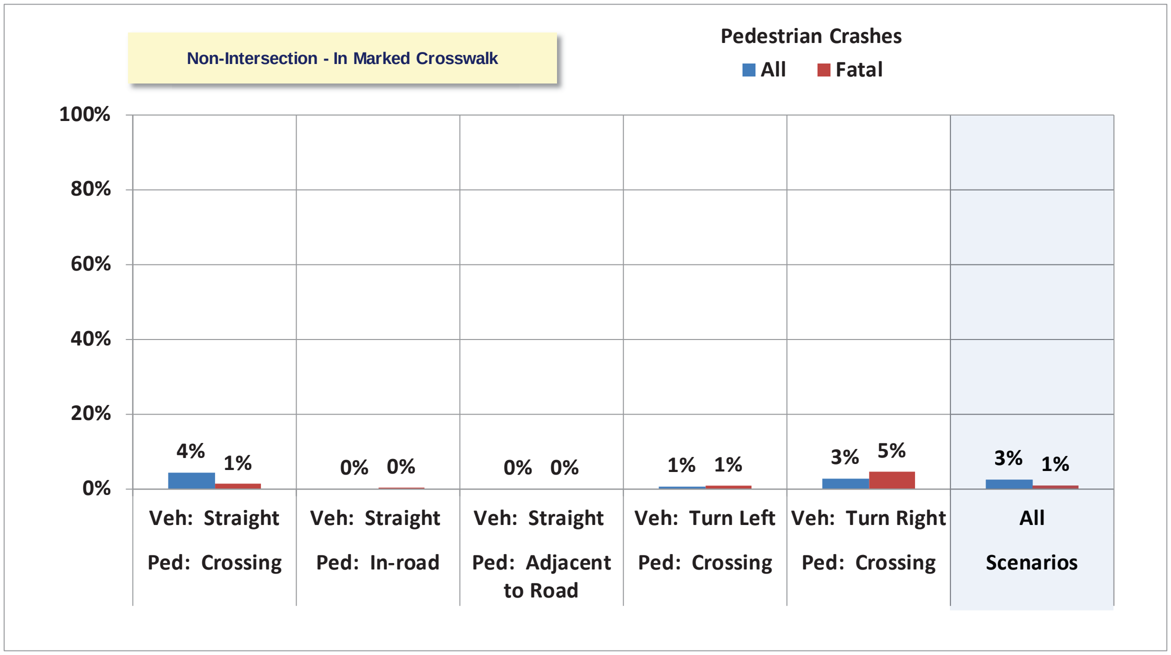


Figure 13. Percentage of "Non-Intersection - In Marked Crosswalk" Crashes per Total Crashes in Each Priority Scenario

3.1.3 Traffic Controls

Definition: This variable describes the traffic controls in the vehicle's environment just prior to the crash.

Categories:

- No Controls
- Not Reported/Other/Unknown

Traffic Control Signal:

- Traffic Control Signal (Tri-Color) Without Pedestrian Signal
- Traffic Control Signal (Tri-Color) With Pedestrian Signal
- Traffic Control Signal (Tri-Color) Not Known if Pedestrian Signal
- Flashing Traffic Control Signal
- Other Highway Traffic Signal
- Unknown Highway Traffic Signal
- Lane Use Control Signal

Sign:

- Stop Sign
- Yield Sign
- School Zone Sign/Device
- Other Regulatory Sign
- Unknown Regulatory Sign
- Warning Sign

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 54 percent of all pedestrian crashes and 82 percent of fatal crashes happen with no traffic control device or signs present.
- 32 percent of all pedestrian crashes and 13 percent of fatal crashes happen with traffic control devices present (not including signs).

Scenarios:

- Vehicle - turning left or right and pedestrian crossing - more than half of the crashes involved had traffic controls present. Traffic signs were present in 18 percent of the vehicle turning left fatal crashes and 23 percent of the vehicle turning right fatal crashes.
- Vehicle - straight and pedestrian in the road or adjacent to the road - a very low percentage of these crashes had traffic controls present.

Influence on V2P Systems: V2P systems could rely on additional data from infrastructure systems that can detect a pedestrian in a crosswalk and notify a driver of the presence of a pedestrian and an impending collision to help avoid or mitigate vehicle-pedestrian collisions. However, in order to address the safety needs identified above, V2P systems would need to activate accurately without the presence of infrastructure data.

Comparison of Traffic Controls in Priority Scenarios

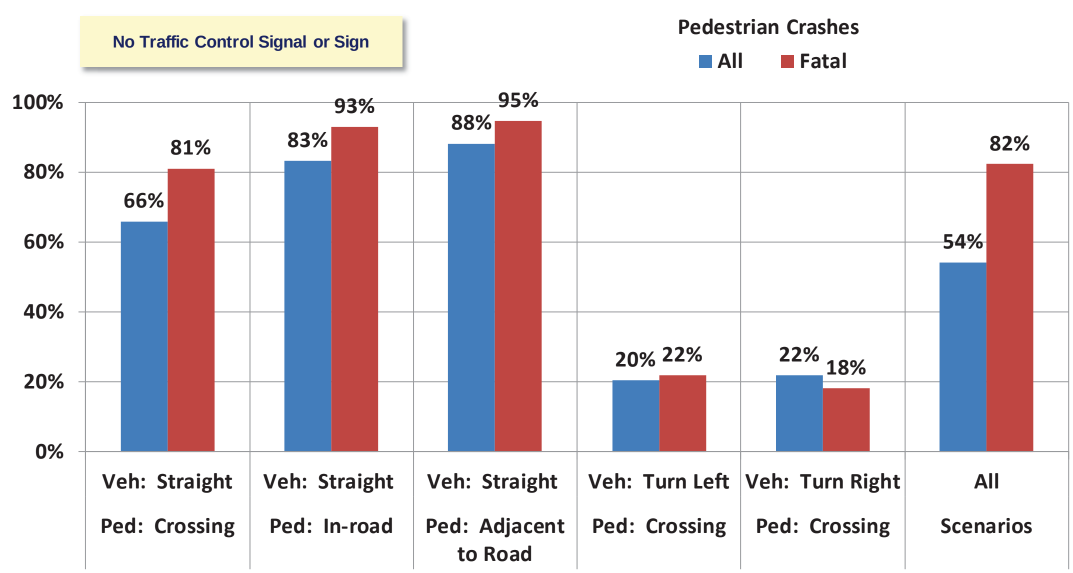


Figure 14. Percentage of "No Traffic Control Signal or Sign" Crashes per Total Crashes in Each Priority Scenario

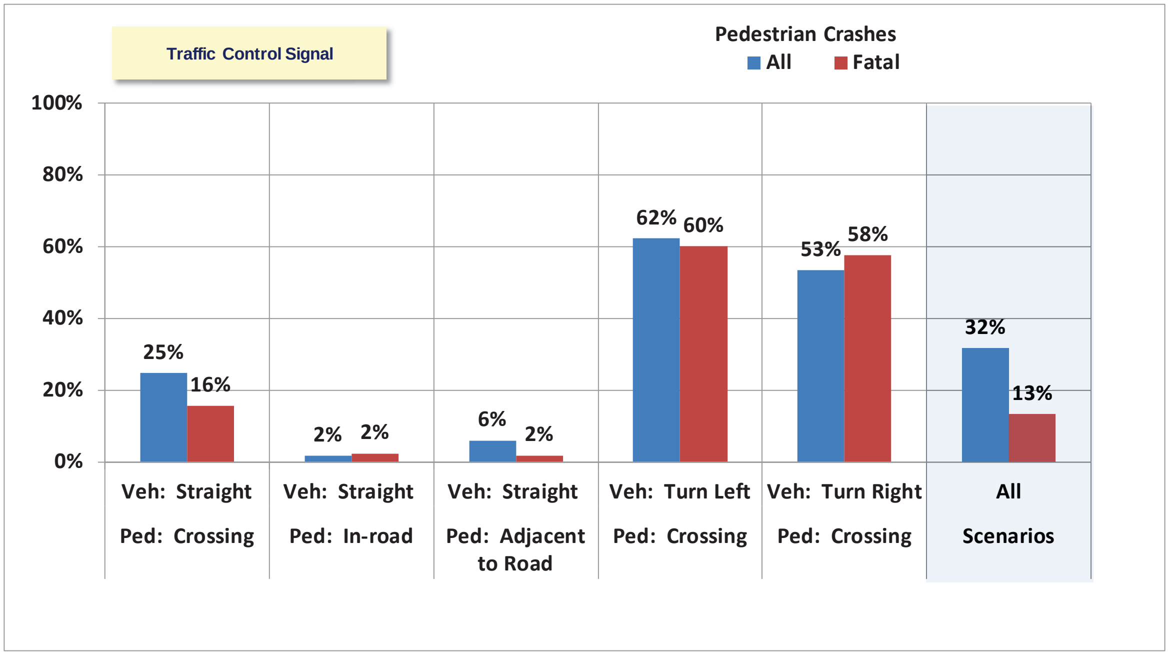


Figure 15. Percentage of Traffic Control Signal Crashes per Total Crashes in Each Priority Scenario

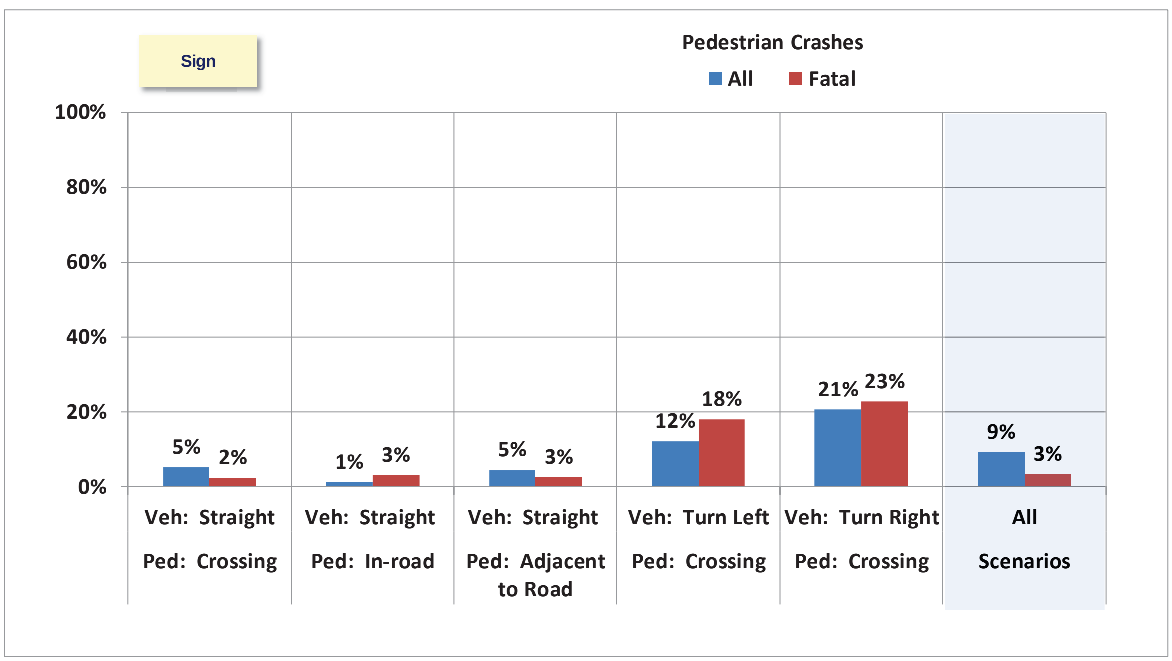


Figure 16. Percentage of Sign Crashes per Total Crashes in Each Priority Scenario

3.1.4 Correlation of Crash Location Variables

The three variables, vehicle relation to junction, pedestrian location, and traffic control, are correlated together and results are presented. The correlation allows for the identification of whether or not traffic controls, intersections, and crosswalks were present during the crash.

<u>Observations on Data (2011 and 2012 Annual Crash Average)</u>
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 30 percent of all pedestrian crashes and 58 percent of fatal crashes happen at non-intersections without crosswalks and without traffic control devices or signs present.
- 18 percent of all pedestrian crashes and 7 percent of fatal crashes happen at intersections with the pedestrian in a marked crosswalk and with traffic control signals present (not including signs).

Scenarios:

- <u>Vehicle - turning left or right and pedestrian crossing</u> - 45 percent of the fatalities happen even though a pedestrian is in a marked crosswalk at an intersection.
- <u>Vehicle - straight and pedestrian crossing, in, or adjacent to the road</u> - the majority of fatalities occur without traffic controls, intersections, and crosswalks present.

<u>Influence on V2P Systems</u>: V2P systems could help to increase the level of awareness for a driver or pedestrian during complex turning maneuvers at intersections or during unexpected encounters away from intersections and crosswalks.

<u>Comparison of Crash Location and Traffic Controls in Priority Scenarios</u>

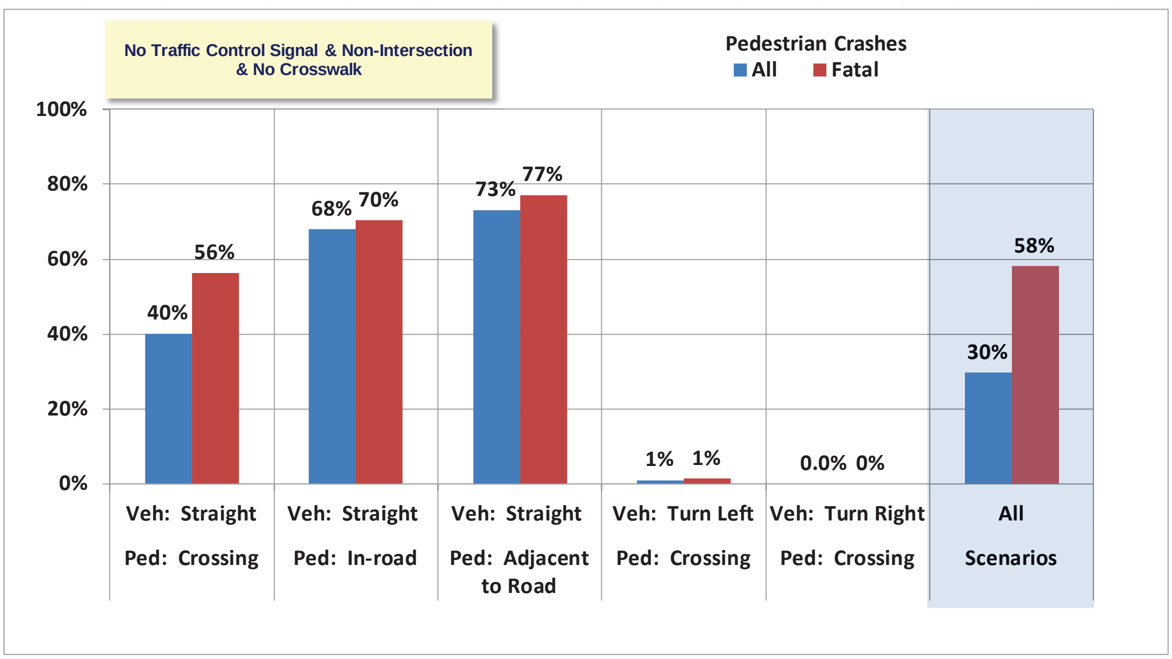


Figure 17. Percentage of "No Traffic Control Signal and Non-Intersection and No Crosswalk" Crashes per Total Crashes in Each Priority Scenario

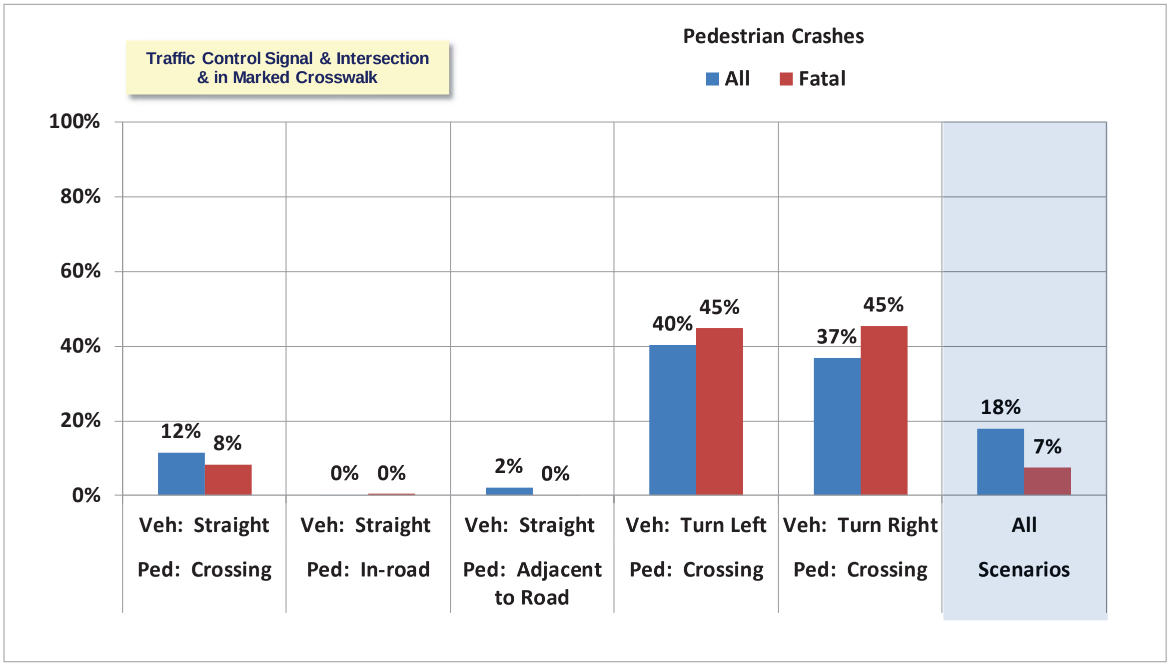


Figure 18. Percentage of "Traffic Control Signal and Intersection and in Marked Crosswalk" Crashes per Total Crashes in Each Priority Scenario

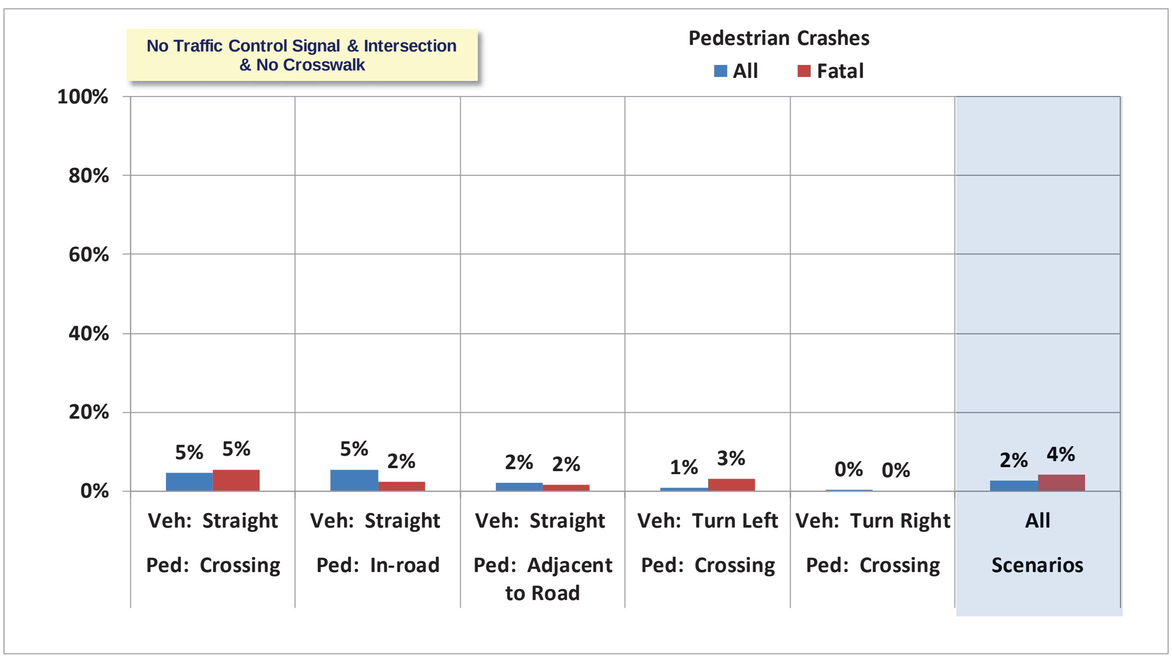


Figure 19. Percentage of "No Traffic Control Signal and Intersection and No Crosswalk" Crashes per Total Crashes in Each Priority Scenario

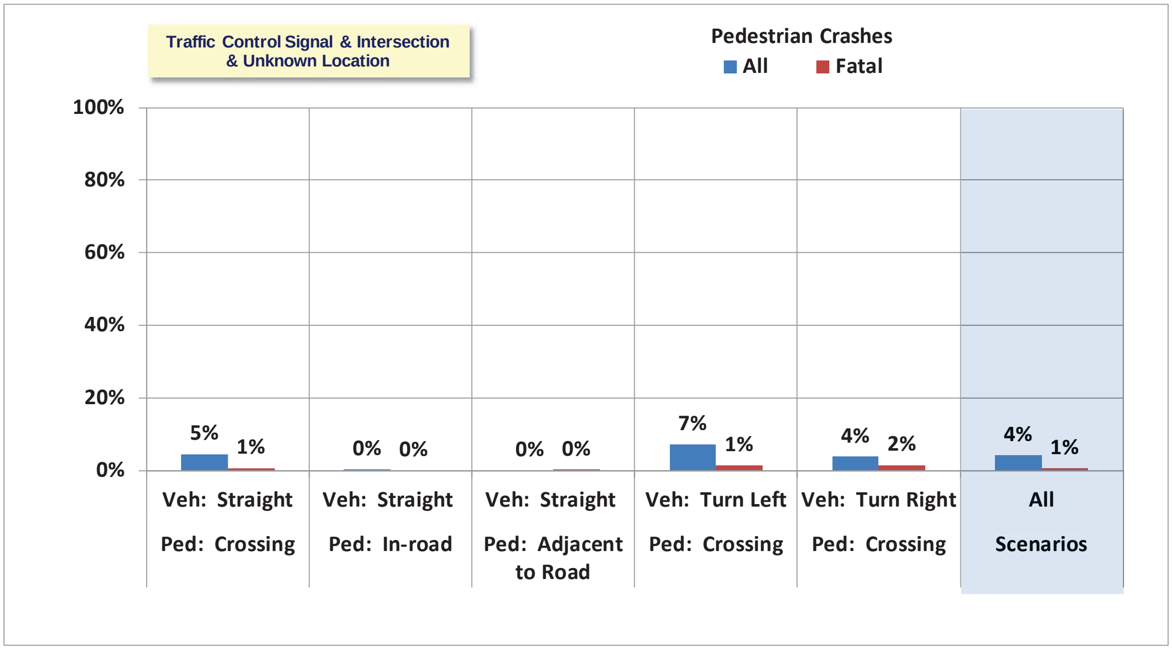


Figure 20. Percentage of "Traffic Control Signal and Intersection and Pedestrian in Unknown Location" Crashes per Total Crashes in Each Priority Scenario

3.2 Driving Environment

The driving environment describes the driving conditions at the time of the crash related to the weather, outdoor lighting, and road conditions. These three variables are presented individually and correlated together in Sections 3.2.1 through 3.2.4.

3.2.1 Weather

Definition: Weather describes the atmospheric conditions at the time of the crash.

Weather Categories:
- Clear - includes cloudy
- Adverse - rain, sleet, snow, fog, severe crosswinds, blowing sand, etc.
- Other/unknown (<1 percent GES and FARS)

Observations on Data (2011 and 2012 Annual Crash Average)
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):
- 88 percent of all pedestrian crashes and 89 percent of fatal crashes happen in clear weather.
- 12 percent of pedestrian crashes and 10 percent of fatal crashes happen in adverse weather.

Scenarios:
- Vehicle-turning left and pedestrian-crossing - 21 percent of these crashes occur in adverse weather, although these crashes may have infrequent fatalities.

<u>Influence on V2P Systems</u>: Pedestrians are more frequently out during normal weather conditions. Wet or slick roads can cause a decreased braking capability. Weather can also potentially affect the functionality of PCAM's pedestrian detection sensors (e.g., sun glare, reflections from wet roads) or V2P wireless signals (e.g., signal attenuation due to atmospheric conditions). V2P systems would need to function properly under adverse weather conditions.

<u>Comparison of Weather in Priority Scenarios</u>

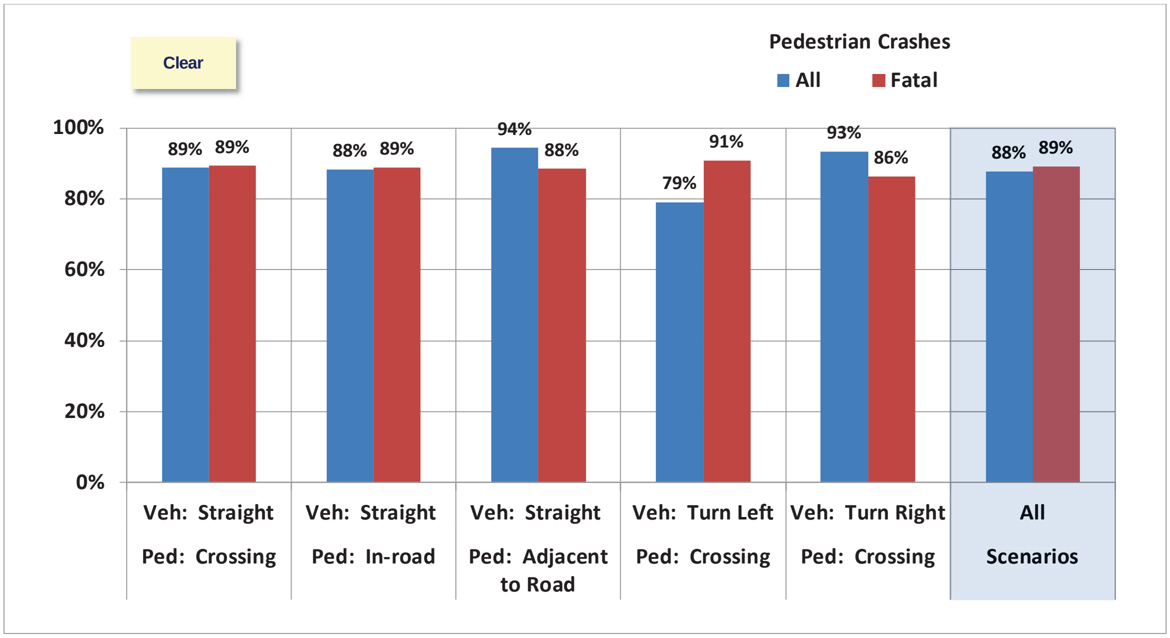


Figure 21. Percentage of Clear Weather Crashes per Total Crashes in Each Priority Scenario

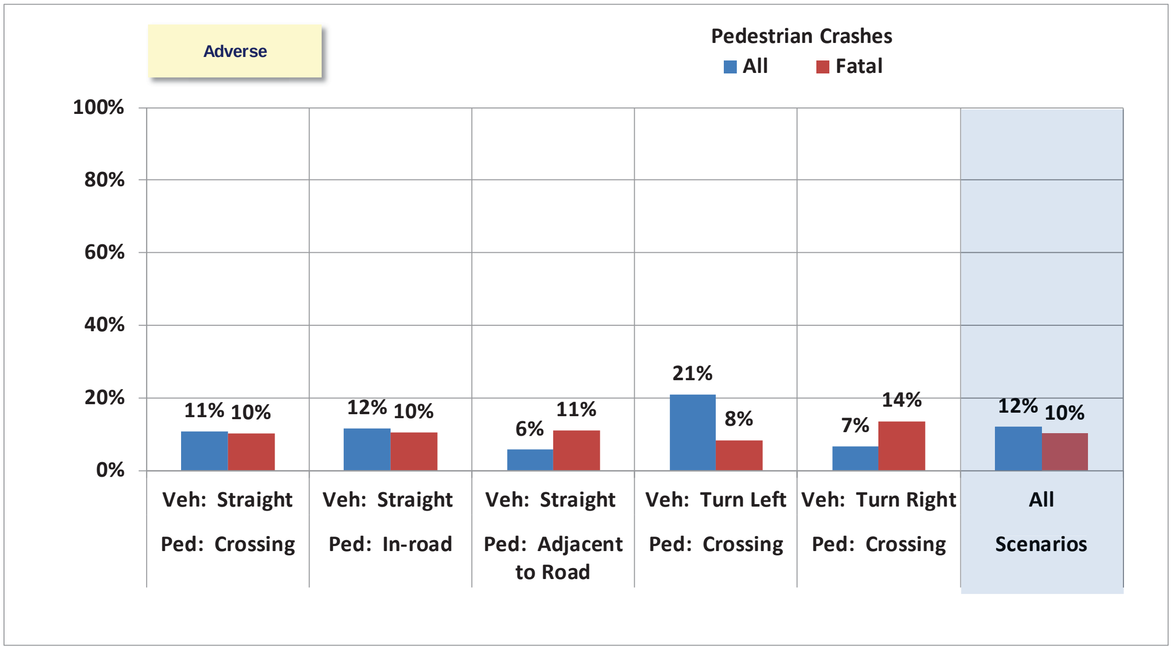


Figure 22. Percentage of Adverse Weather Crashes per Total Crashes in Each Priority Scenario

3.2.2 Lighting

<u>Definition</u>: Lighting encompasses both the natural light from the sun and light from overhead lighting fixtures.

<u>Lighting Categories</u>:

- Daylight
- Dark (no street lighting or unknown if street lighting present)
- Dark - with overhead street lighting
- Dawn/Dusk
- Other/unknown/not reported (not represented in the target population)

<u>Observations on Data (2011 and 2012 Annual Crash Average)</u>
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 58 percent of all pedestrian crashes and 20 percent of fatal crashes happen in daylight.
- 8 percent of all pedestrian crashes and 36 percent of fatal crashes happen in the dark.
- 30 percent of all pedestrian crashes and 40 percent of fatal crashes happen in the dark but with overhead lighting.

Scenarios:

- <u>Vehicle - turning left or right and pedestrian crossing</u> - high percentage of these crashes and fatal crashes occur in the daylight.
- <u>Vehicle - straight and pedestrian crossing, in, or adjacent to the road</u> - high percentage of these crashes occur in the daylight, however they are not frequently fatal.

Influence on V2P Systems: Lighting might have an influence on whether the driver is able to see the pedestrian and/or a crosswalk, even when reflective clothing on the pedestrian might increase the pedestrian's visibility in darkness. V2P systems will have the potential to detect pedestrians under various lighting conditions, and possibly offer better detection performance than camera-based PCAM systems.

Comparison of Lighting in Priority Scenarios

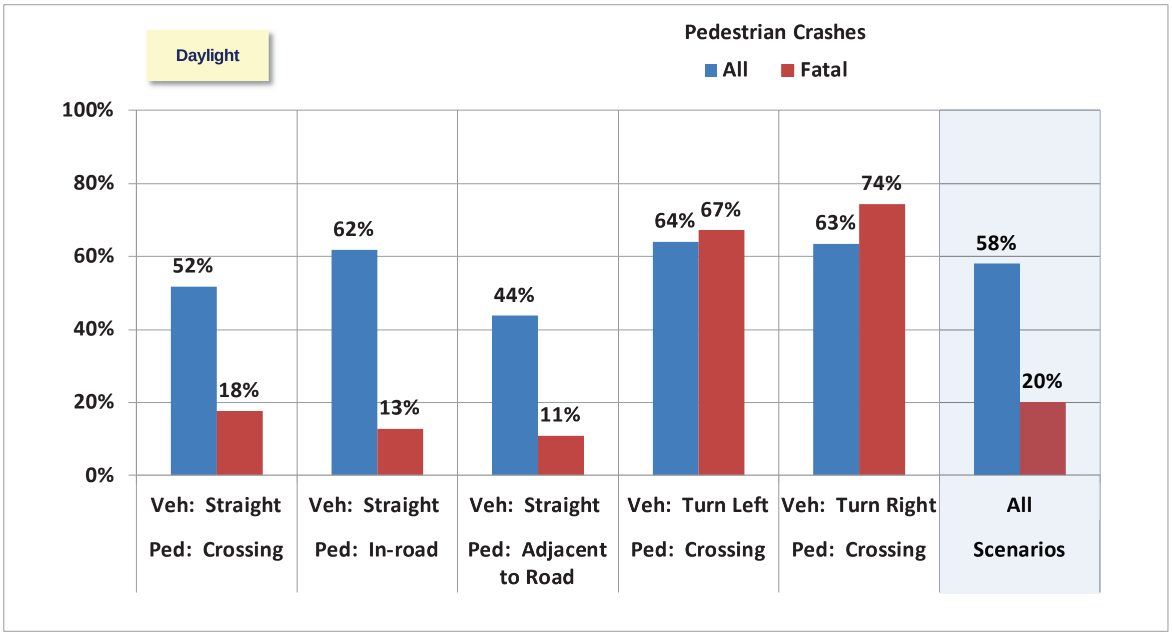


Figure 23. Percentage of Daylight Crashes per Total Crashes in Each Priority Scenario

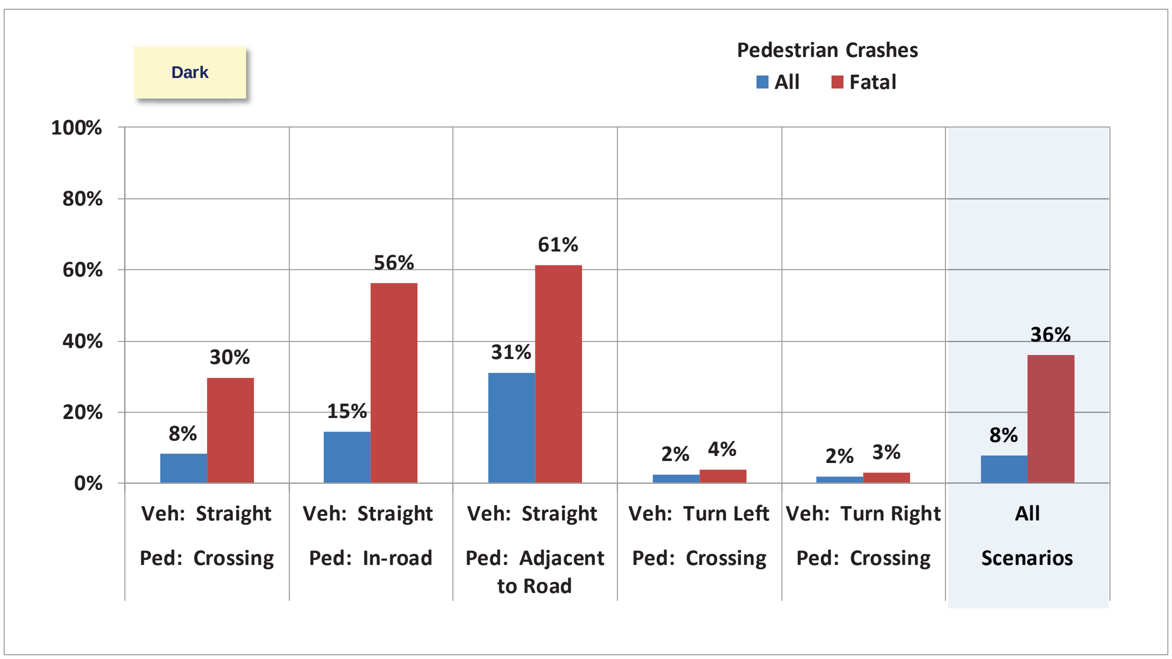


Figure 24. Percentage of Dark Crashes per Total Crashes in Each Priority Scenario

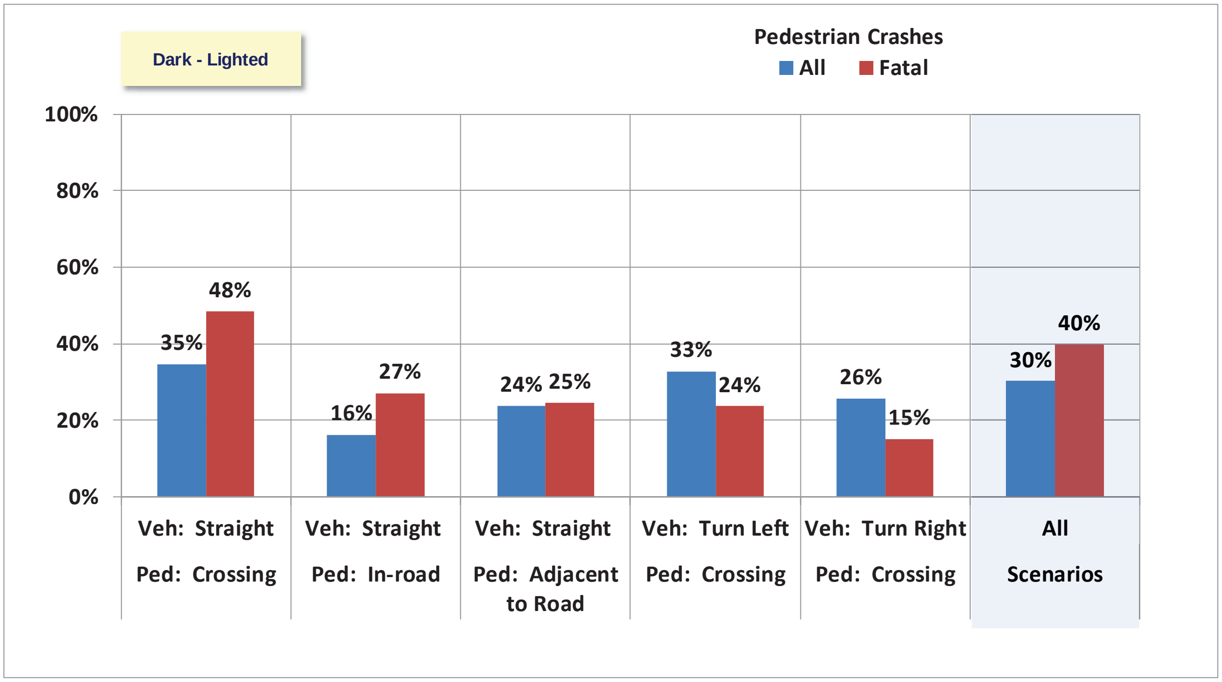


Figure 25. Percentage of "Dark but Lighted" Crashes per Total Crashes in Each Priority Scenario

3.2.3 Road Surface Condition

Definition: This variable describes the road surface condition that would have most affected the vehicle's traction at the time of the crash.

Road Surface Condition Categories:

- Dry
- Wet/Slippery - Wet, Snow, Ice, Water, Slush, Mud, Sand, etc.
- Other/Unknown (<2 percent)

Note – there is a category for "non-traffic way area" (4 percent - GES, 0.7 percent FARS)

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 77 percent of all pedestrian crashes and 86 percent of fatal crashes happen on dry roads.
- 17 percent of all pedestrian crashes and 13 percent of fatal crashes happen on wet/slippery roads.

Scenarios:

- Vehicle - turning left and pedestrian crossing - high percentage of these crashes occur on a wet/slippery road.

Influence on V2P Systems: Ice, snow, or slippery road conditions may degrade the vehicle's braking capabilities. Surface conditions can also affect the functionality of PCAM detection sensors (e.g., sun glare, reflections from wet roads, etc.) If V2P systems included the use of automatic control or pre-fill braking, information on the road surface condition could be beneficial to improve system performance.

<u>Comparison of Road Surface Conditions in Priority Scenarios</u>

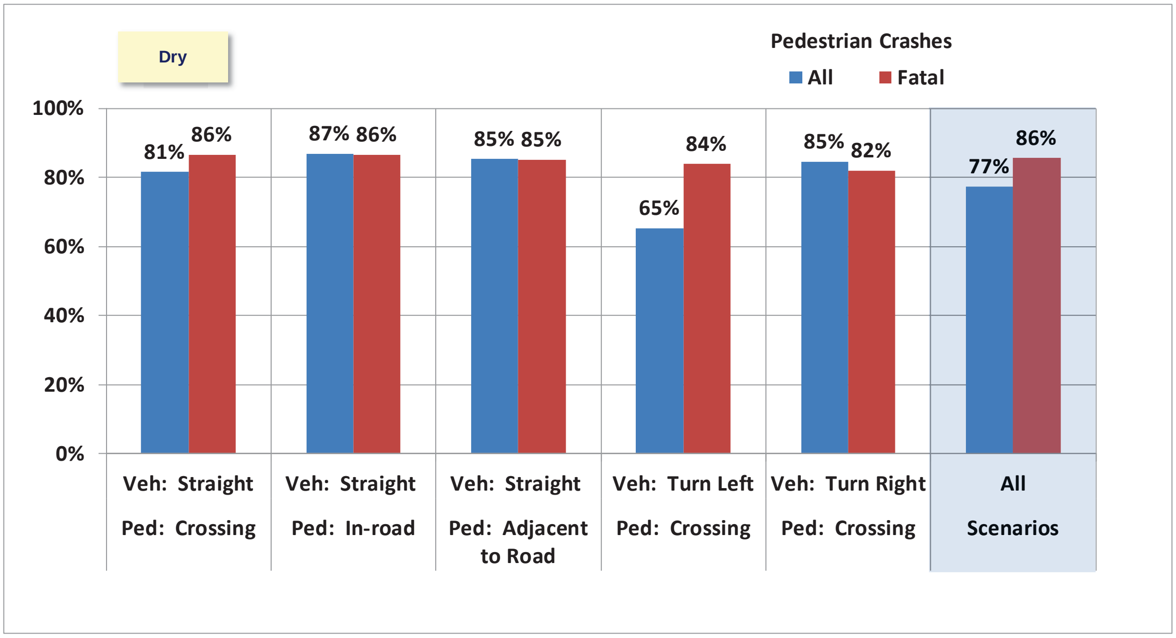


Figure 26. Percentage of Dry Road Crashes per Total Crashes in Each Priority Scenario

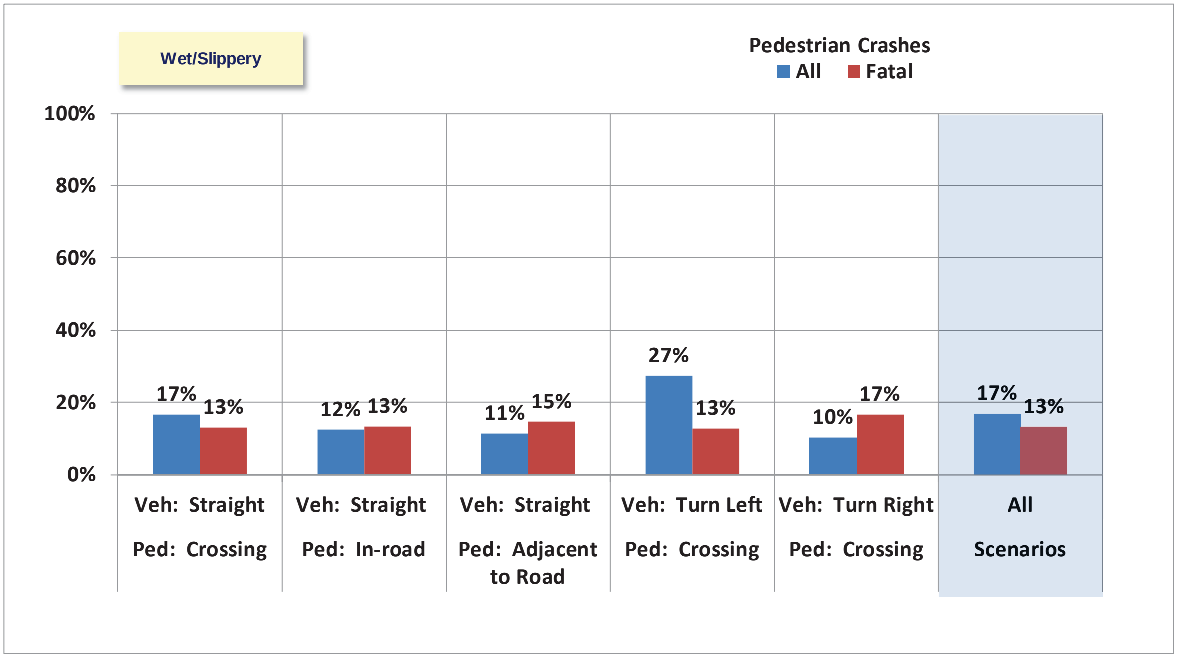


Figure 27. Percentage of Wet/Slippery Road Crashes per Total Crashes in Each Priority Scenario

3.2.4 *Correlation of Environmental Variables*

The weather, outdoor lighting, and road condition variables are correlated together to identify situations where there is a potential for degraded visibility.

Observations on Data (2011 and 2012 Annual Crash Average)
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 47 percent of all pedestrian crashes and 18 percent of fatal crashes happen in clear weather, on dry roads and in daylight.
- 21 percent of all pedestrian crashes and 33 percent of fatal crashes happen in clear weather, on dry roads and in the dark with overhead lighting.
- 7 percent of all pedestrian crashes and 30 percent of fatal crashes happen in clear weather, on dry roads, and in the dark without overhead lighting.

Scenarios:

- Vehicle - turning left or right and pedestrian crossing - high percentage of these fatal crashes occur on a clear day, dry road, and in daylight.
- Vehicle - straight and pedestrian crossing - high percentage of these fatal crashes occur on a clear day, dry road, and in the dark with overhead lighting.

Influence on V2P Systems: In order to address the issues identified above, V2P systems would need to help identify conflicts under various environmental conditions, including when a driver is in situations of degraded visibility due to combinations of environmental variables, such as glare from the sun or light reflecting on a wet road. V2P systems should function correctly when adverse environmental conditions could cause issues (e.g., signal interference, weakened signals).

Comparison of Environmental Variables in Priority Scenarios

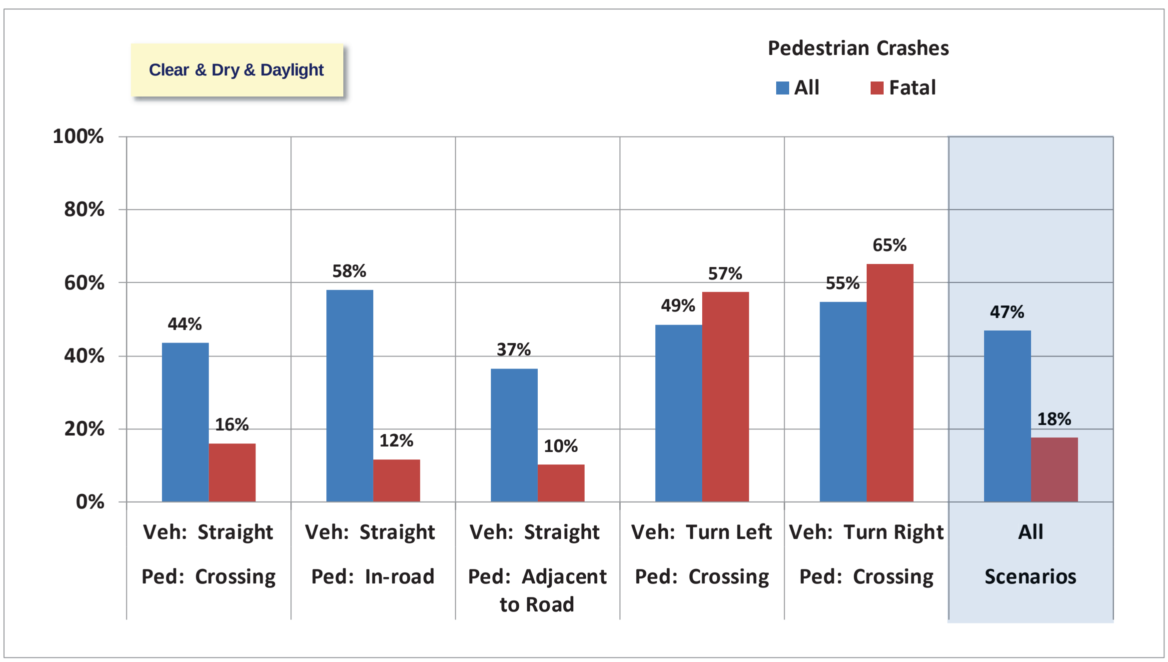


Figure 28. Percentage of "Clear Weather, Dry Road, and Daylight" Crashes per Total Crashes in Each Priority Scenario

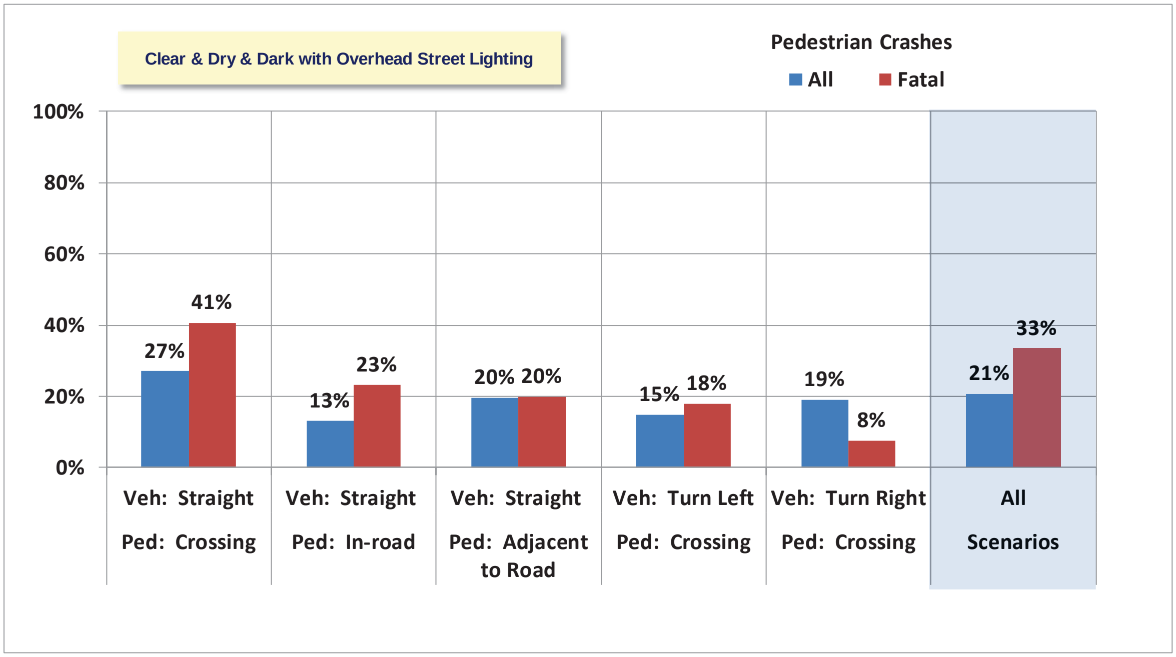


Figure 29. Percentage of "Clear Weather, Dry Road, and Dark With Overhead Street Lighting" Crashes per Total Crashes in Each Priority Scenario

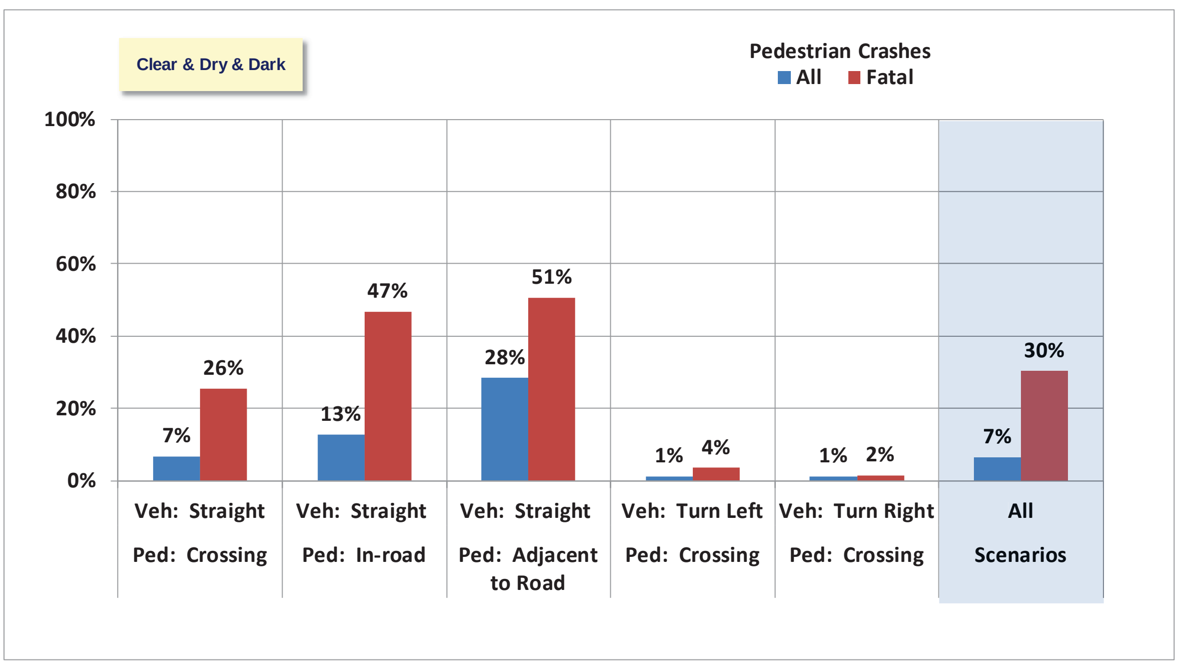


Figure 30. Percentage of "Clear Weather, Dry Road, and Dark" Crashes per Total Crashes in Each Priority Scenario

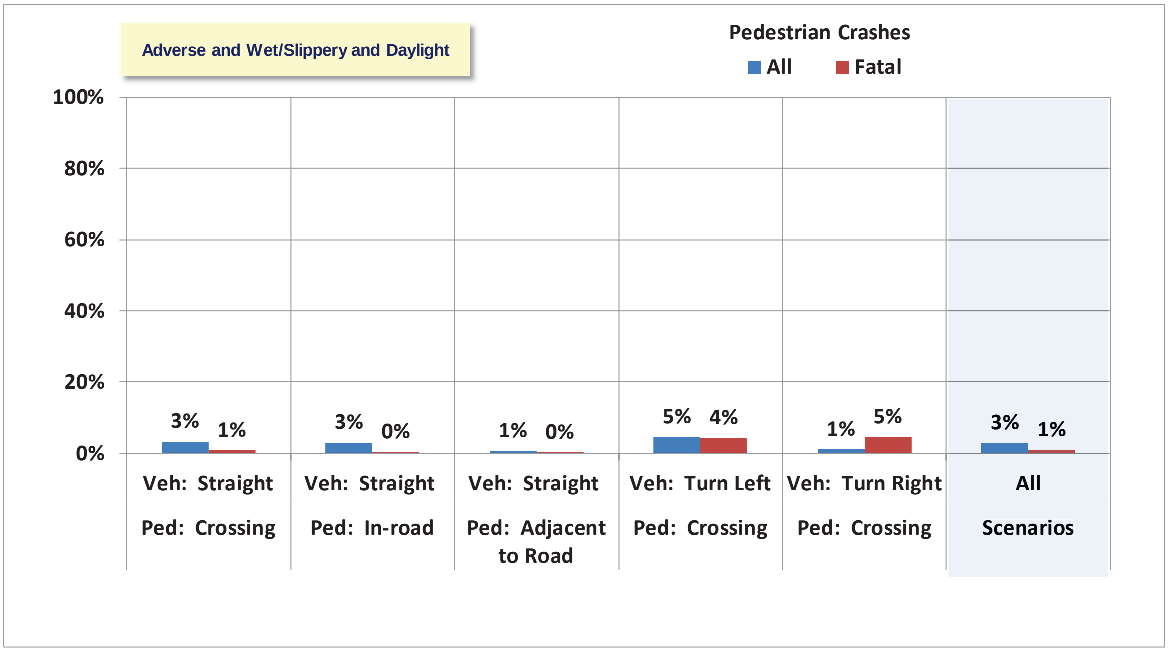


Figure 31. Percentage of "Adverse Weather, Wet/Slippery Road, and Daylight" Crashes per Total Crashes in Each Priority Scenario

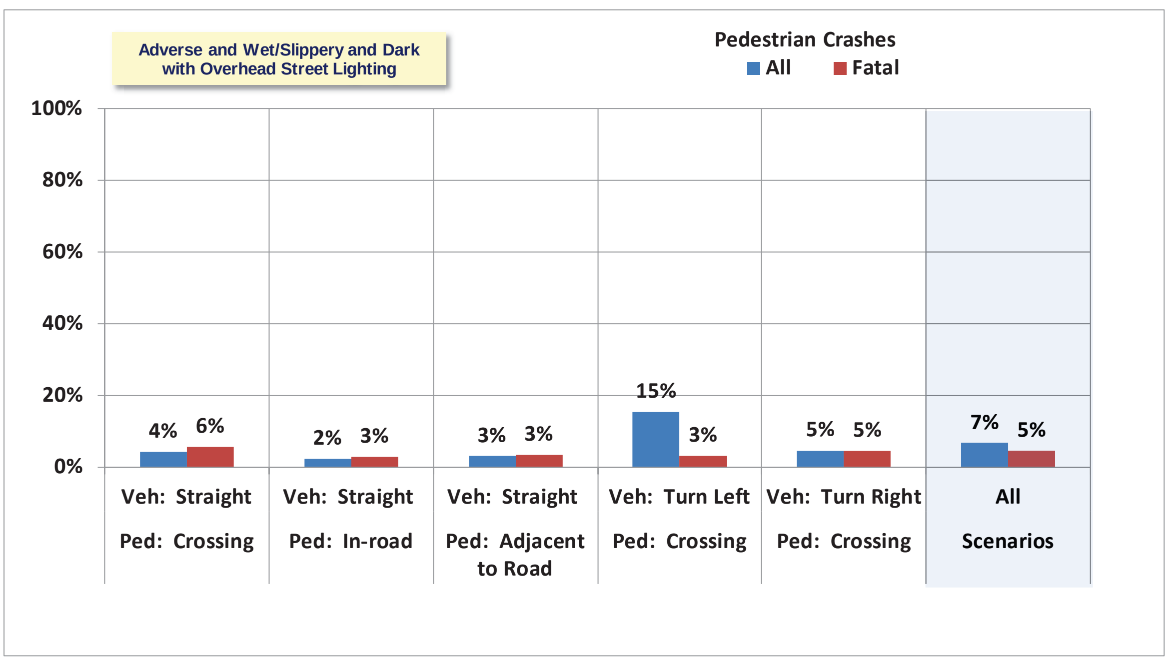


Figure 32. Percentage of "Adverse Weather, Wet/Slippery Road, and Dark With Overhead Street Lighting" Crashes per Total Crashes in Each Priority Scenario

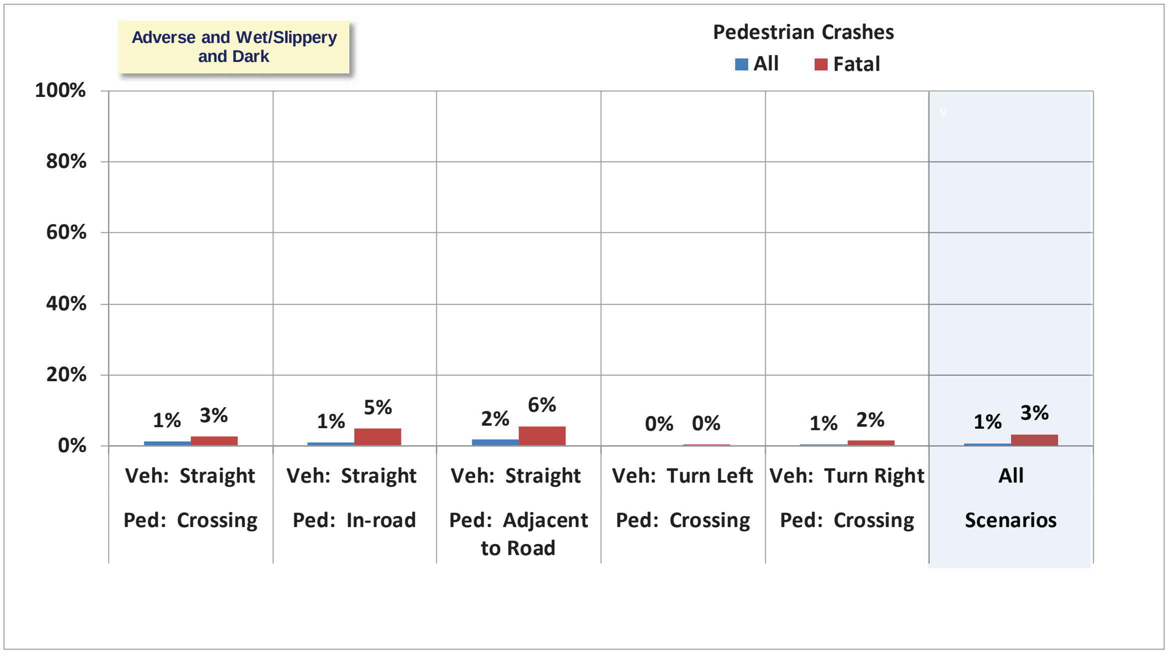


Figure 33. Percentage of "Adverse Weather, Wet/Slippery Road, and Dark" Crashes per Total Crashes in Each Priority Scenario

3.3 Road Geometry

The road geometry is described in terms of the road alignment and grade. These two variables are presented individually and correlated together in Sections 3.3.1 through 3.3.3.

3.3.1 Alignment

<u>Definition</u>: This variable describes whether the road the vehicle was traveling on prior to the crash was straight or curved.

<u>Categories</u>:
- Straight
- Curve (curved to the right or left, or curved in an unknown direction)
- Not reported/unknown (8 percent GES, 0 percent FARS)

<u>Observations on Data (2011 and 2012 Annual Crash Average)</u>
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):
- 85 percent of all pedestrian crashes and 94 percent of fatal crashes happen on straight roads.
- 2 percent of all pedestrian crashes and 5 percent of fatal crashes happen on curved roads.

Scenarios:
- <u>Vehicle going straight and pedestrian in road or adjacent to road</u> - 10 percent of these crashes occur on a curved road.

<u>Influence on V2P Systems</u>: It is often difficult for drivers to recognize pedestrians in or adjacent to the road around a curve. In order to address the safety needs described above, V2P systems would need to detect pedestrians on straight as well as curved roads. In this situation, V2P systems would potentially overcome the line-of-sight limitation of PCAM systems.

Comparison of Alignment in Priority Scenarios

Note that some vehicle maneuvers may sound contradictory when paired with straight or curved road alignments, but for the turning scenarios in Figure 34, the vehicle is traveling straight on a road and turns left at an intersection. Also, for the vehicle traveling straight scenarios in Figure 35, the vehicle is traveling straight ahead while on a curved road.

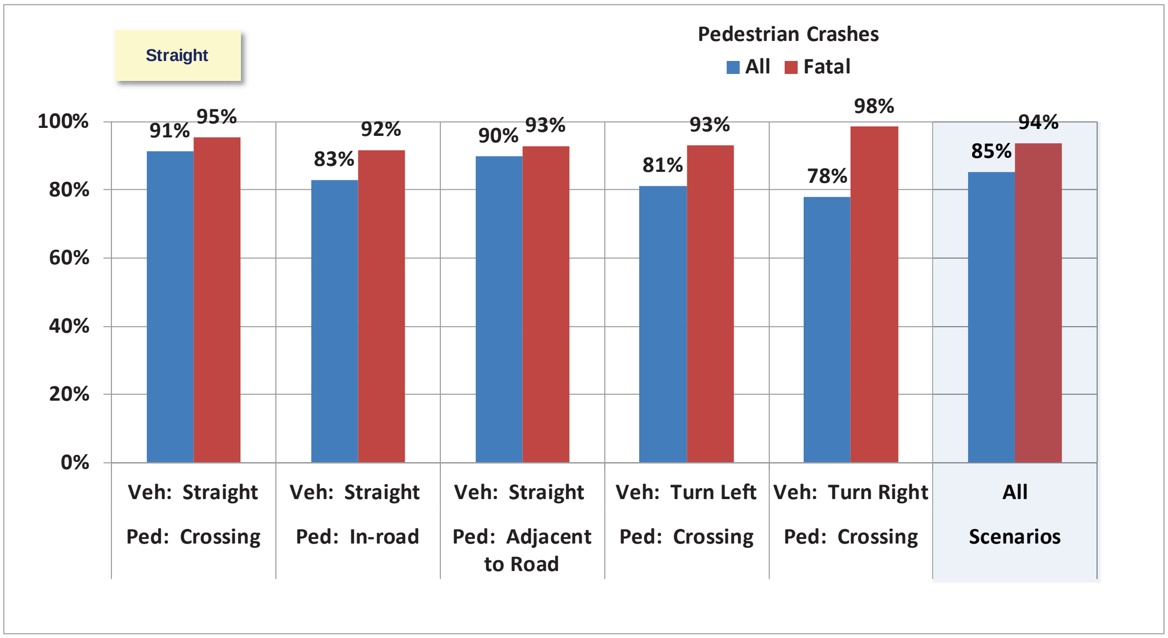


Figure 34. Percentage of Straight Road Crashes per Total Crashes in Each Priority Scenario

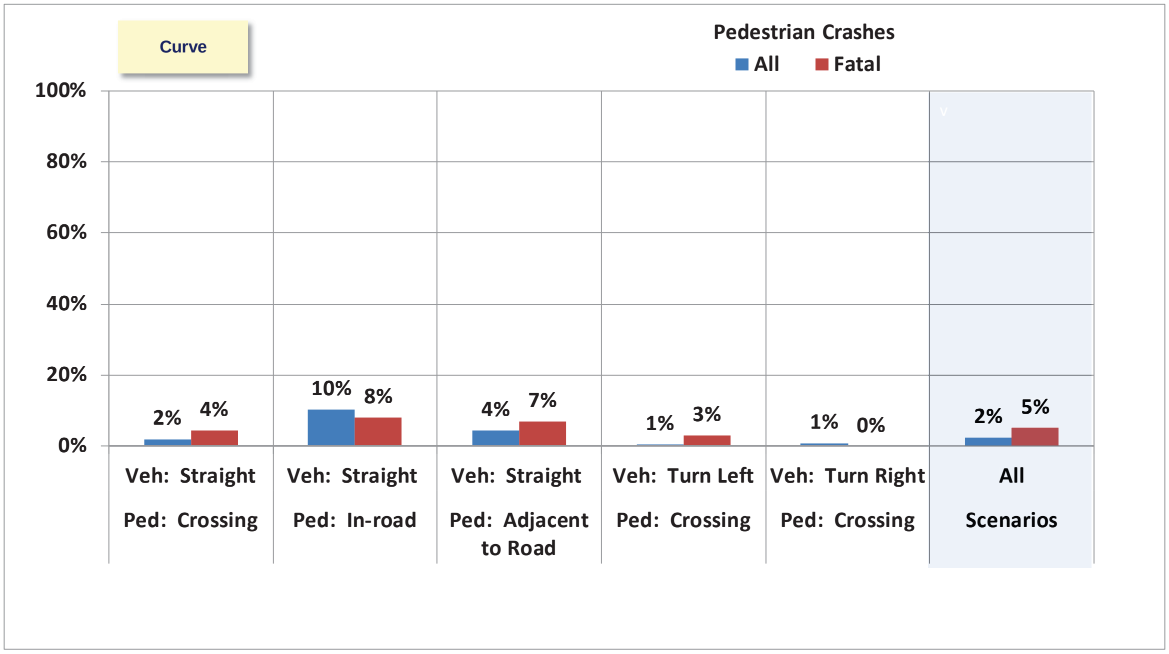


Figure 35. Percentage of Curved Road Crashes per Total Crashes in Each Priority Scenario

3.3.2 Road Grade

Definition: The vertical alignment of the road prior to the crash. "Non-traffic way area" is used when the vehicle was not on a traffic way but was entering one prior to its critical pre-crash event. See Figure 36 for an illustration of the road grade categories.

Categories:

- Non-Traffic way Area (Entering a Traffic way)
- Level
- Grade, Unknown Slope
- Hillcrest
- Sag (Bottom)
- Uphill
- Downhill
- Not Reported/Unknown (18 percent-GES, 3 percent-FARS)

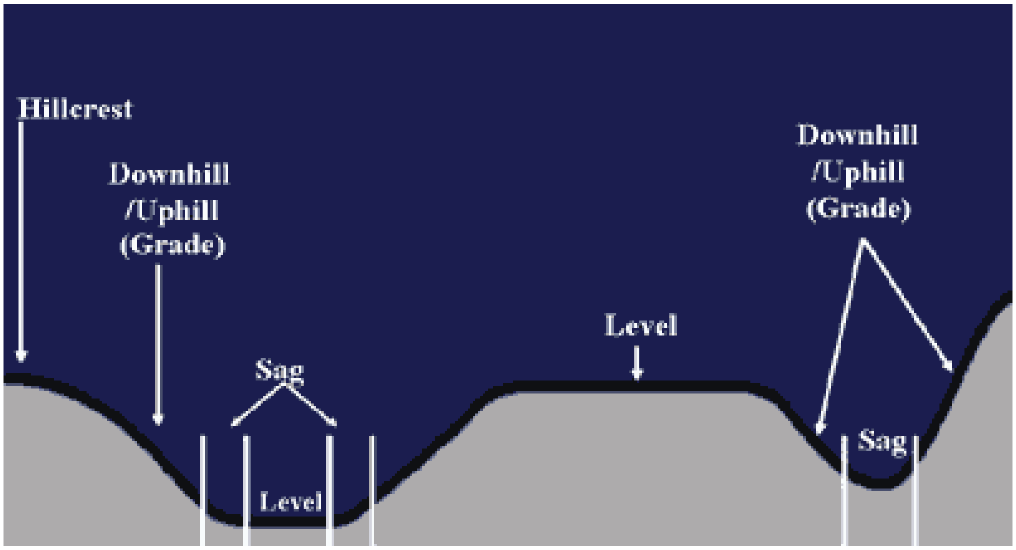


Figure 36. Road Grade Definition

<u>Observations on Data (2011 and 2012 Annual Crash Average)</u>
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 69 percent of all pedestrian crashes and 81 percent of fatal crashes happen on level roads.
- 7 percent of all pedestrian crashes and 13 percent of fatal crashes happen on graded roads (uphill, downhill, or unknown grade).

Scenarios:

- <u>Vehicle going straight and pedestrian in road</u> - 18 percent of these crashes happen on graded roads.

<u>Influence on V2P Systems</u>: In order to address the safety needs identified above, in addition to level roads, developers of V2P systems should consider focusing on graded roads since these types of roads may cause false or missed activations.

Comparison of Road Grade in Priority Scenarios

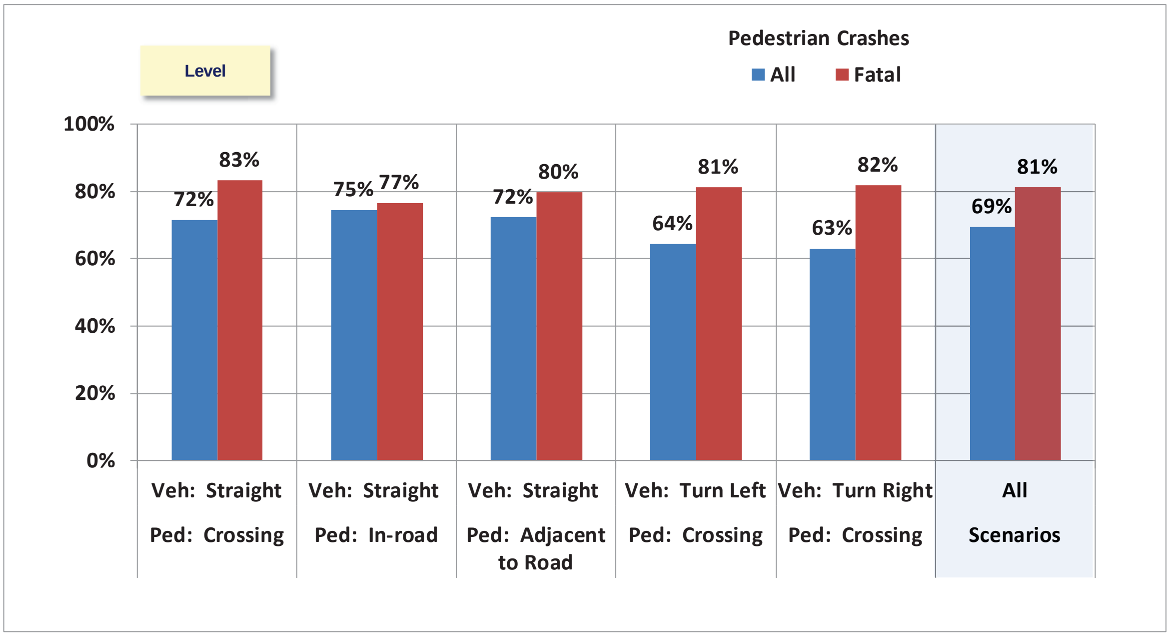


Figure 37. Percentage of Level Road Crashes per Total Crashes in Each Priority Scenario

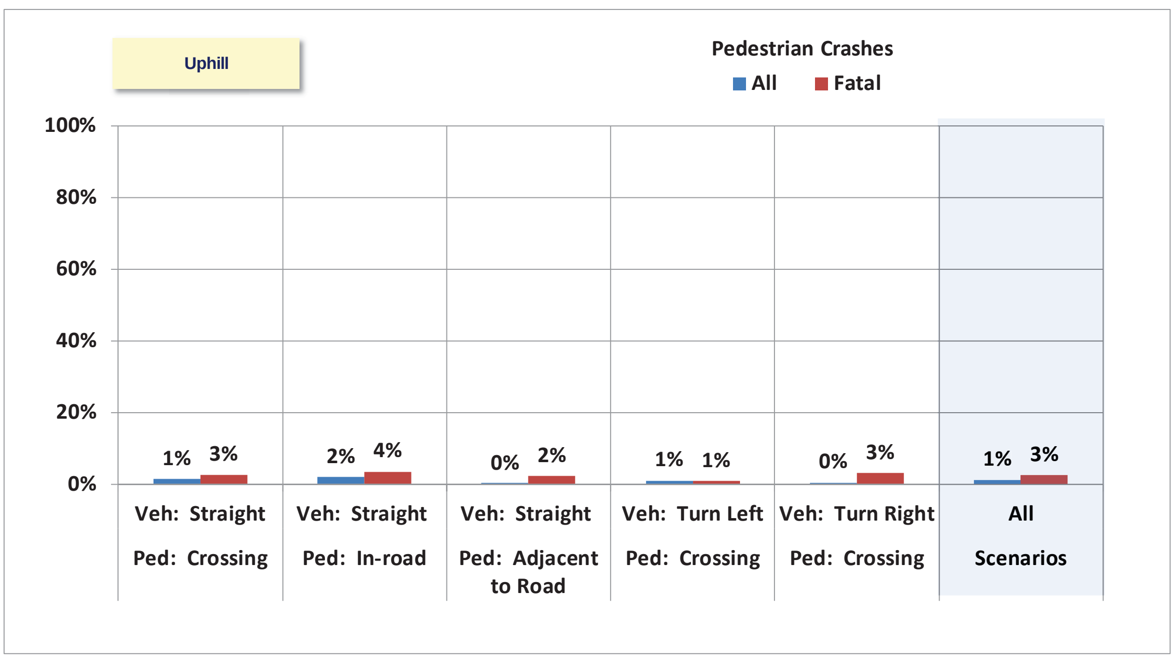


Figure 38. Percentage of Crashes on an Uphill Road per Total Crashes in Each Priority Scenario

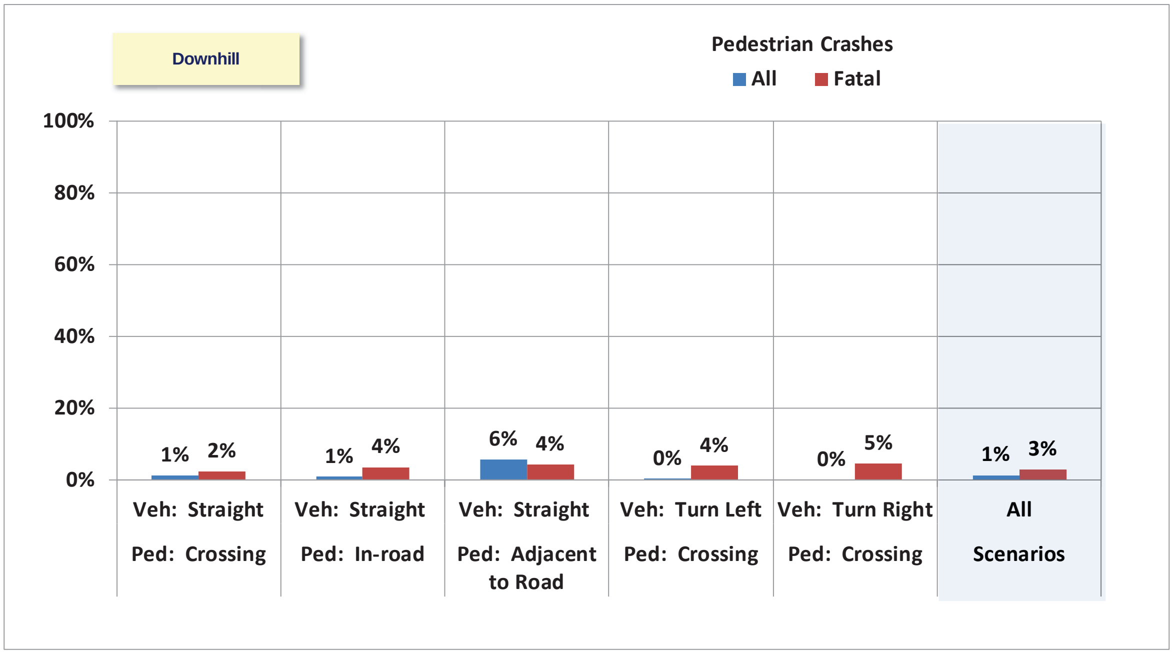


Figure 39. Percentage of Crashes on a Downhill Road per Total Crashes in Each Priority Scenario

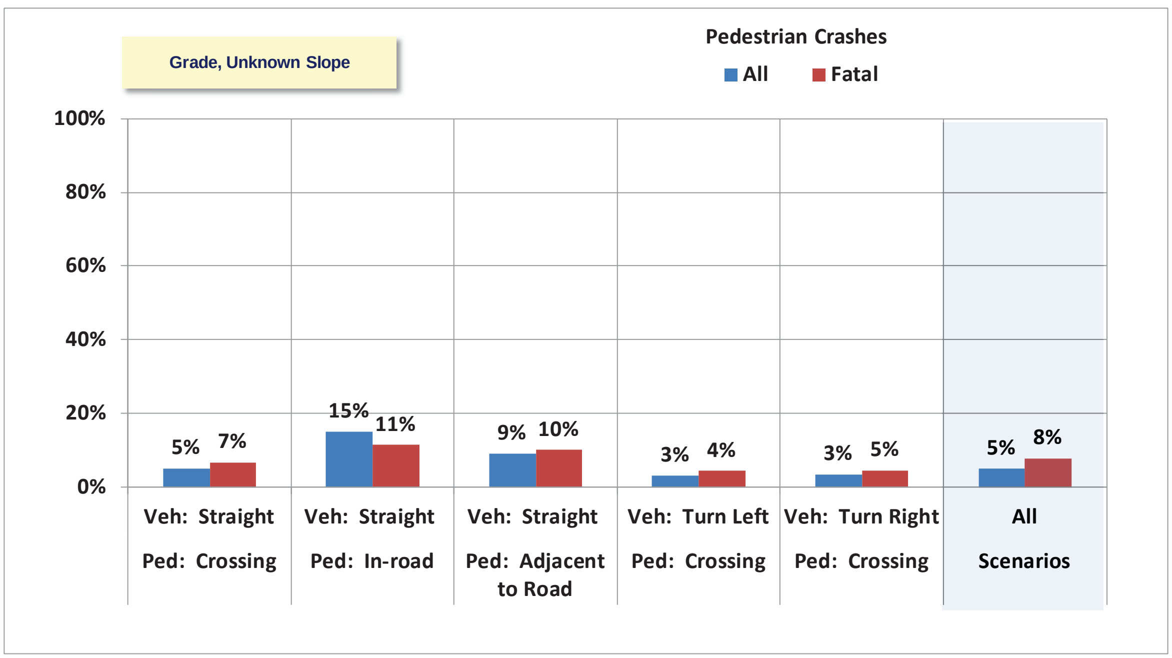


Figure 40. Percentage of Crashes on a Graded Road With an Unknown Slope per Total Crashes in Each Priority Scenario

3.3.3 Correlation of Road Geometry Variables

Road conditions are correlated together to identify situations where there is a potential for degraded visibility of the pedestrian due to a combination of curvature or elevation of the road.

<u>Observations on Data (2011 and 2012 Annual Crash Average)</u>
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 67 percent of all pedestrian crashes and 78 percent of fatal crashes happen on a straight and level road.
- 6 percent of all pedestrian crashes and 11 percent of fatal crashes happen on a straight and graded road.
- 1 percent of all pedestrian crashes and 3 percent of fatal crashes happen on a curved and level road.

<u>Influence on V2P Systems</u>: V2P systems can help aid in the detection of pedestrians who are out of the driver's line-of-sight on curved and/or graded roads.

<u>Comparison of Road Geometry in Priority Scenarios</u>

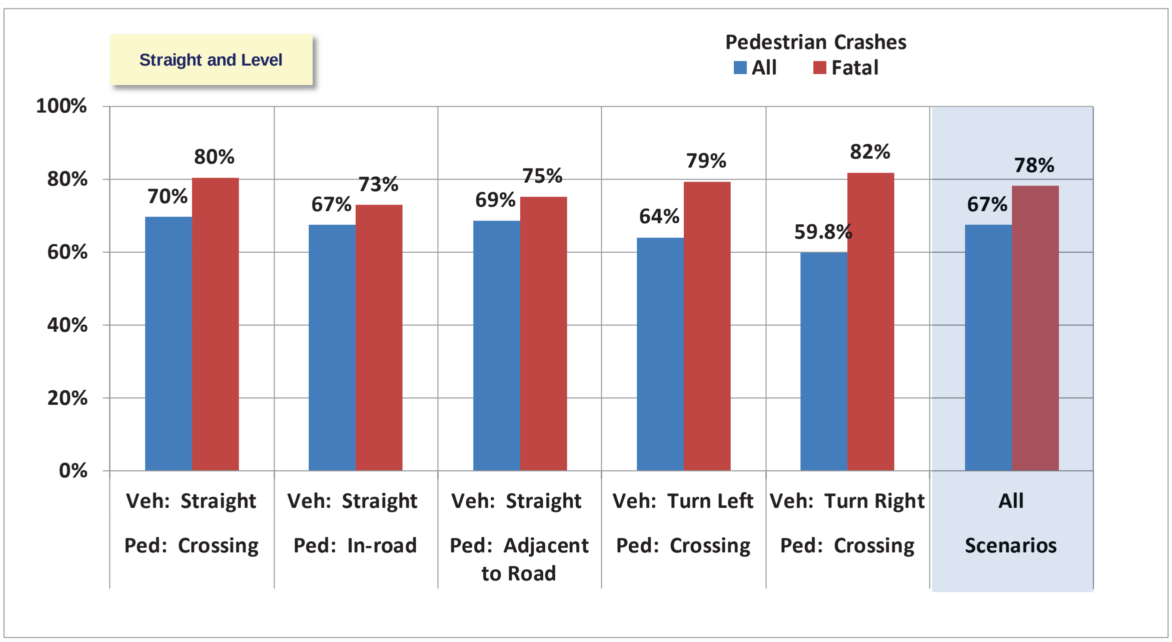


Figure 41. Percentage of Straight and Level Road Crashes per Total Crashes in Each Priority Scenario

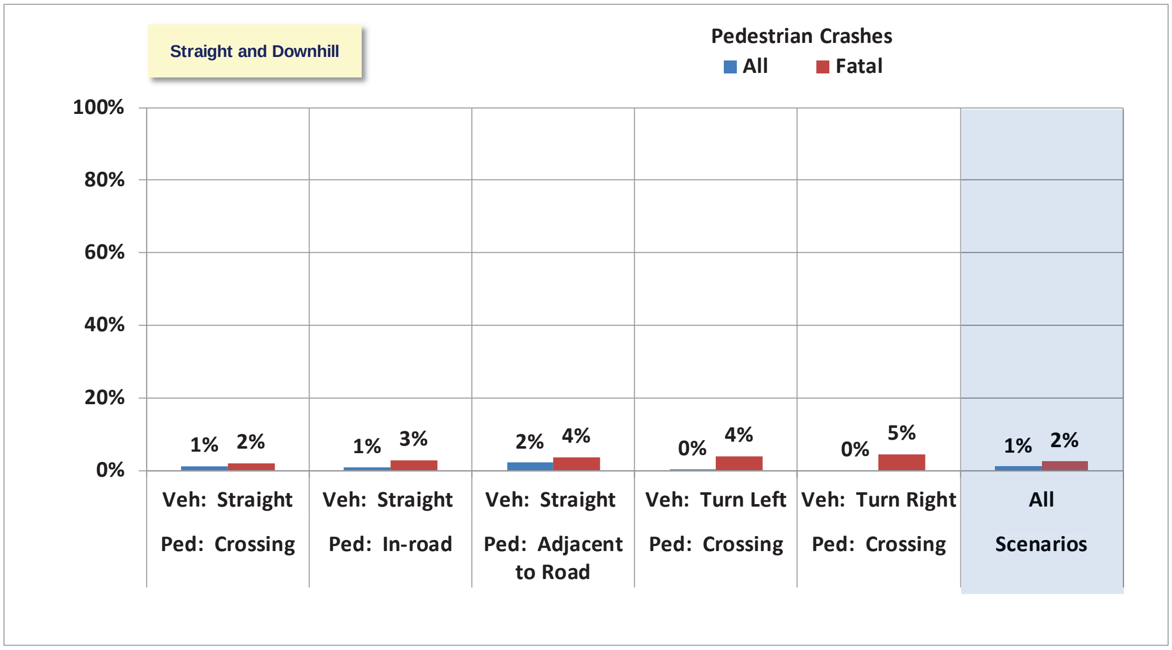


Figure 42. Percentage of "Straight and Downhill Road" Crashes per Total Crashes in Each Priority Scenario

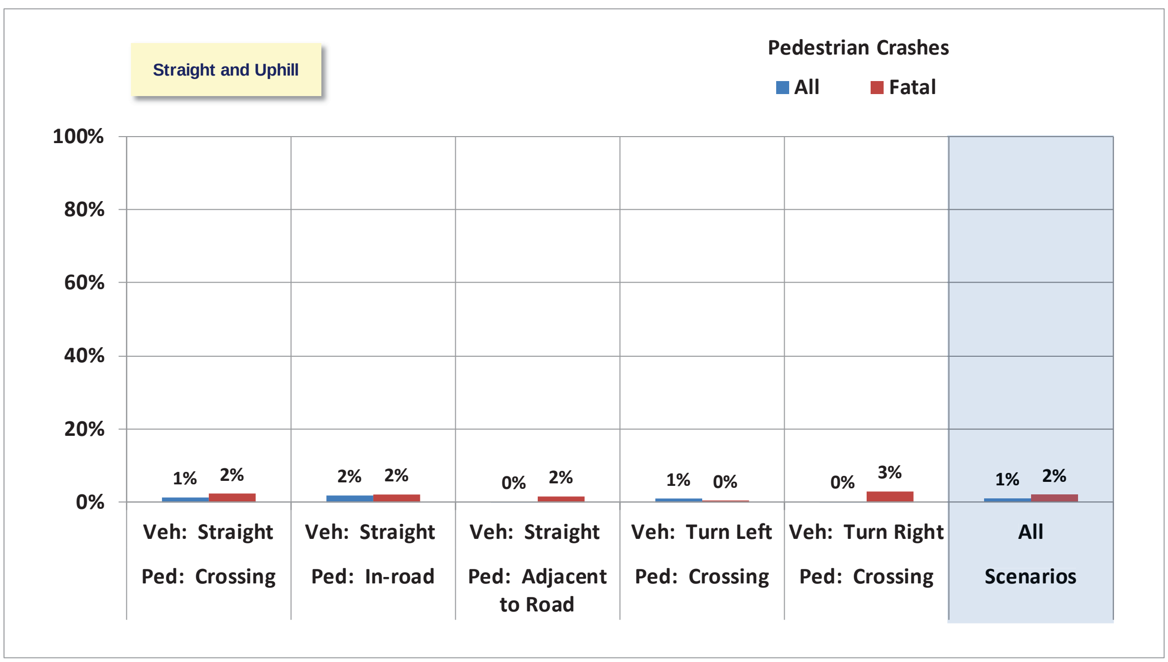


Figure 43. Percentage of "Straight and Uphill Road" Crashes per Total Crashes in Each Priority Scenario

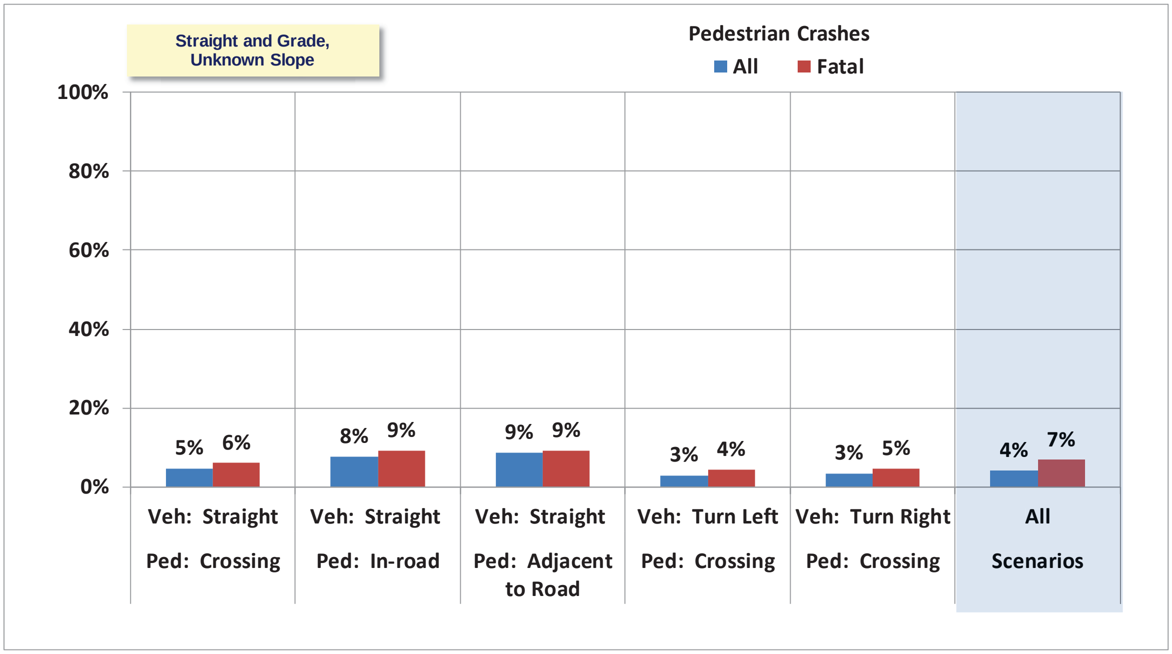


Figure 44. Percentage of "Straight and Graded With Unknown Slope Road" Crashes per Total Crashes in Each Priority Scenario

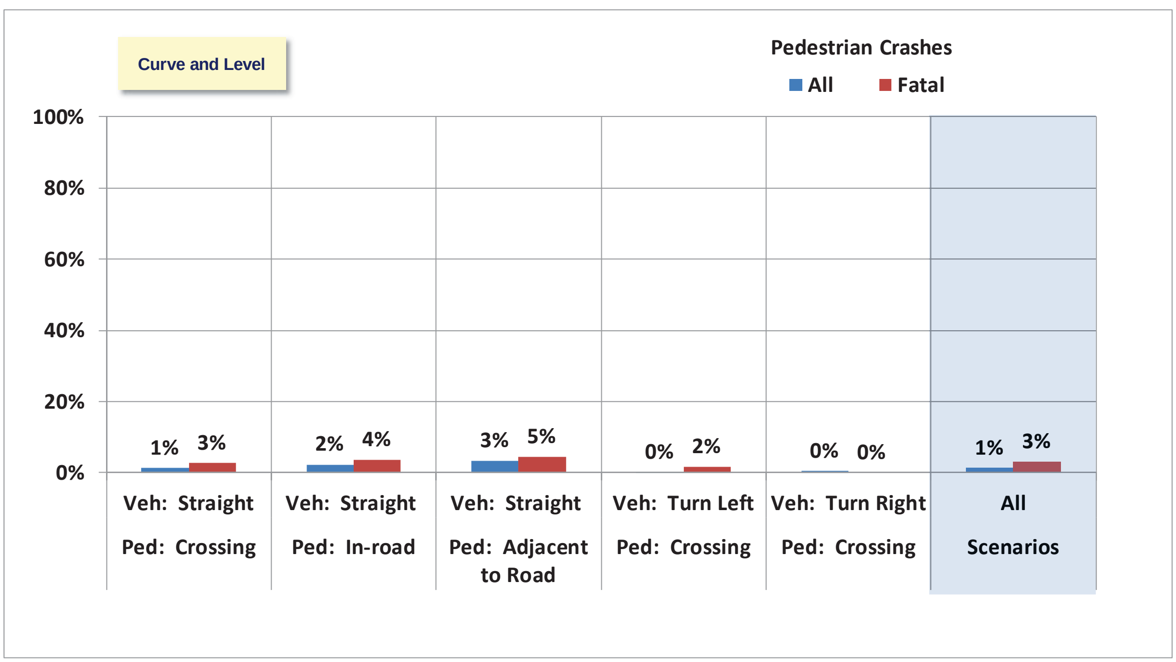


Figure 45. Percentage of "Curve and Level Road" Crashes per Total Crashes in Each Priority Scenario

3.4 Driver Contributing Factors

The driver contributing factors describe the key conditions that may have contributed to the crash related to the driver's impairment, visual obstruction, and distraction. Impairment and distraction are important to the description of the crash events but are not used to define the cause of the crash or to imply fault.

3.4.1 Driver Impairment

Definition: This variable describes any physical impairment of the driver that may have contributed to the crash. The majority of the cases where the driver was impaired is due to alcohol. Note that there can be more than one type of driver impairment defined, but each driver is only represented once as having an impairment.

Categories:

Driver Impaired:

- Ill, Blackout
- Asleep or Fatigued
- Impaired Due to Previous Injury
- Emotional (Depressed, Angry, Disturbed, etc.)
- Under the Influence of Alcohol, Drugs or Medication
- Physical Impairment - No Details
- Other Physical Impairment

Others:

- None/Apparently Normal
- No Driver/Unknown if Driver Present/Not Reported/Unknown if Impaired

Note that the impairment categories are the same for both the driver and pedestrian. The following categories were available but not represented in the target population for the driver because these categories typically apply to a pedestrian:

- Walking With a Cane or Crutches
- Paraplegic or Restricted to Wheelchair
- Deaf
- Blind

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 2 percent of all pedestrian crashes and 8 percent of fatal crashes occur with an impaired driver.

Scenarios:

- Vehicle - straight and pedestrian adjacent to the road - 13 percent of these fatal crashes occur with the driver impaired.

Influence on V2P Systems: Impairment (particularly alcohol) contributes to pedestrian fatalities. If an impaired driver may not react to warnings, a system capable of automatic braking/steering could help to avoid crashes. A pedestrian may potentially benefit from a warning, especially in instances where a driver may have a delayed or no response to a warning due to impairment.

__Comparison of Driver Impairment in Priority Scenarios__

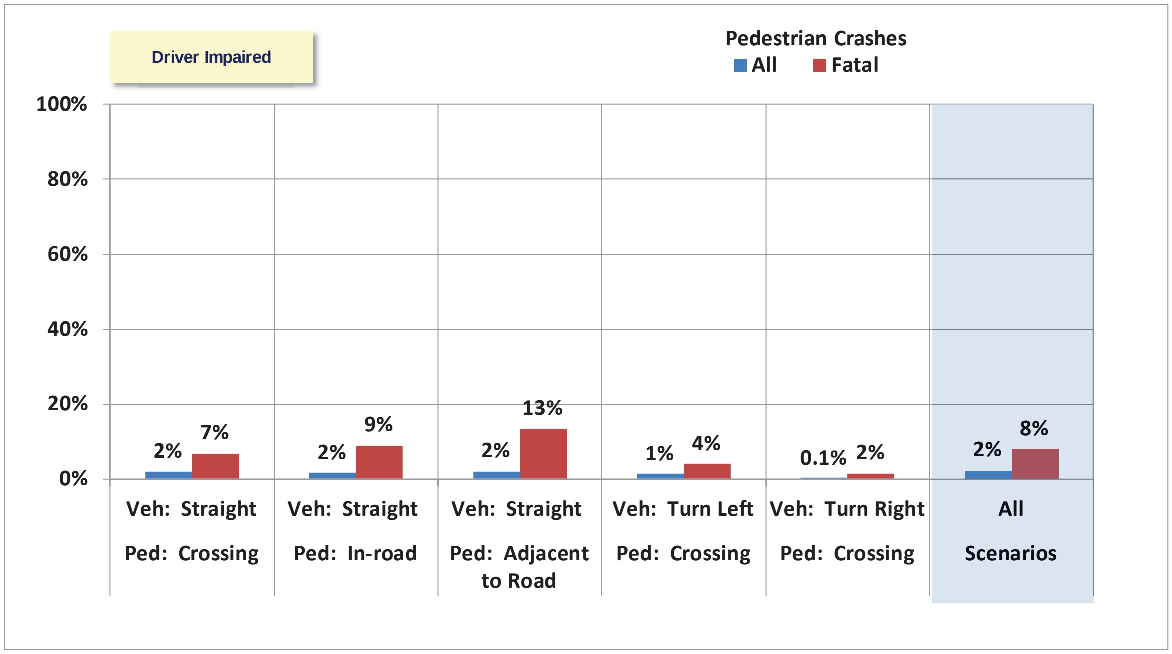


Figure 46. Percentage of Impaired-Driver Crashes per Total Crashes in Each Priority Scenario

3.4.2 Vision Obstruction

Obstructions can include external objects (vehicles, buildings, signs, etc.) or internal objects (blind spots, stickers, etc.). They can also be due to the weather (glare, snow, rain, etc.) or the environment (curves, hills, etc.).

__**Definition**__**:** This variable describes obstructions to the driver's field of vision. This variable is categorized as a "select all that apply" parameter. Note that there can be more than one type of obstruction defined in a crash. Each crash is only represented once as having an obstruction.

__**Categories**__**:**

Obstructions:

- Rain, Snow, Fog, Smoke, Sand, Dust
- Reflected Glare, Bright Sunlight, Headlights
- Curve, Hill, or Other Roadway Design Feature
- Building, Billboard, or Other Structure
- Trees, Crops, Vegetation
- In-Transport Motor Vehicle (Including Load)
- Not-in-Transport Motor Vehicle (Parked, Working)
- Inadequate Defrost or Defog System
- Inadequate Vehicle Lighting System
- Obstruction Interior to Vehicle
- Broken or Improperly Cleaned Windshield
- Obstructing Angles on Vehicle
- Vision Obscured-No Details
- Other Visual Obstruction

Other:

- No Obstruction
- No Driver/ Unknown

Note that two additional categories were not represented in the target population:
- Splash or Spray of Passing Vehicle
- External Mirrors

<u>Observations on Data (2011 and 2012 Annual Crash Average)</u>
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 13 percent of all pedestrian crashes and 8 percent of fatal crashes involve a visual obstruction for the driver.

Scenarios:

- <u>Vehicle going straight and the pedestrian in the road</u> - Almost a quarter of these crashes include an obstruction.

<u>Influence on V2P Systems</u>: V2P systems with a driver-warning component should generally have the capability to distinguish a pedestrian from other communication-equipped objects in order to minimize the occurrence of false positives. In order to address the safety issues identified above, it would also be helpful for systems to recognize pedestrians emerging from behind external obstructions such as another vehicle, structure, sign, etc. Additionally, it would be helpful if V2P systems were able to operate despite other obstructions or conditions such as hills, curves, etc.

<u>Comparison of Visual Obstruction in Priority Scenarios</u>

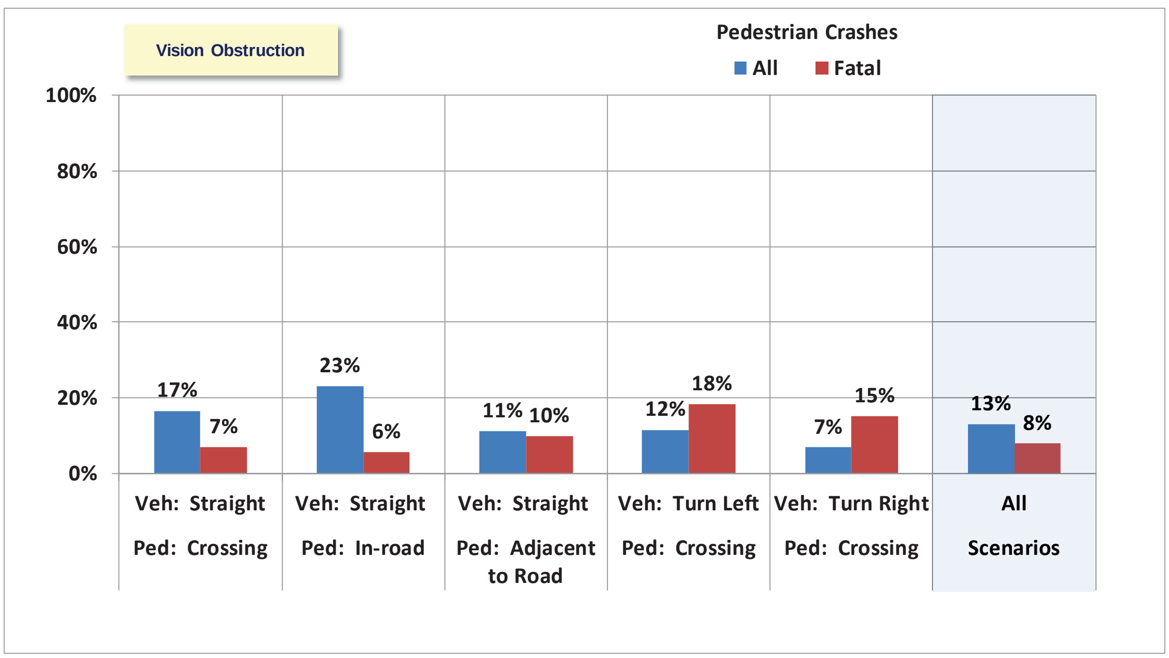


Figure 47. Percentage of "Driver Vision Obstructed" Crashes per Total Crashes in Each Priority Scenario

3.4.3 Distraction

Distraction includes typical distractions such as those from other passengers, eating, drinking, smoking, etc. Present day drivers also contend with a growing number of distractions due to increased usage and availability of cellular phones, navigation systems, crash avoidance technology, or video systems, etc. Driver distraction has become an important safety topic of discussion due to the number of crashes and injuries resulting from this factor. The number of distractions in the database may be underestimated because the police reports may inaccurately reflect the driver's status or appropriate known distractions. NHTSA includes driving while daydreaming or lost in thought as distracted driving but does not include physical conditions or impairments related to fatigue, alcohol, medical condition, etc. or psychological states related to anger, emotions, or depression, etc.

Definition: This variable describes the situations that cause the driver to lose attention to driving prior to the crash. Note that there can be more than one type of distraction defined in a crash but each crash is only represented once as having a distraction.

Categories:

Distracted:

- By Other Occupants
- By Moving Object In Vehicle
- While Talking or Listening To Cellular Phone
- While Manipulating Cellular Phone
- While Adjusting Audio or Climate Controls
- While Using Other Components/Controls Integral To Veh.
- While Using/Reaching For Device/Object Brought into Veh.
- Distracted By Outside Person, Object or Event
- Eating or Drinking
- Smoking Related
- Other Cellular Phone Related
- Distraction/Inattention (2012 only)
- Distraction/Careless (2012 only)
- Careless/Inattentive (2012 only)
- Distraction or Inattention, Details Unknown (2011)
- Distraction (Distracted), Details Unknown (2012)
- Inattention (Inattentive), Details Unknown (2012)
- Lost in Thought/Day Dreaming
- Other Distraction

Other:

- Not Distracted
- Looked But Did Not See
- No Driver/Not Reported/Unknown

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 12 percent of all pedestrian crashes and 8 percent of fatal crashes involve a distracted driver.
- 6 percent of all pedestrian crashes and 3 percent of fatal crashes involve a driver who looked but didn't see the pedestrian.

Scenario:

- Vehicle - turning right and pedestrian crossing - 22 percent of these crashes are due to a distracted driver.

Influence on V2P Systems: V2P systems could potentially mitigate or eliminate pedestrian injuries and reduce crash counts in cases where drivers are distracted or inattentive for a variety of reasons. A system that is capable of automatic braking/steering can potentially help to address the problem of a driver who fails to react to warnings. A pedestrian may potentially benefit from a warning, especially in instances where a driver may have a delayed or no response to a warning due to distraction.

Comparison of Driver Distraction in Priority Scenarios

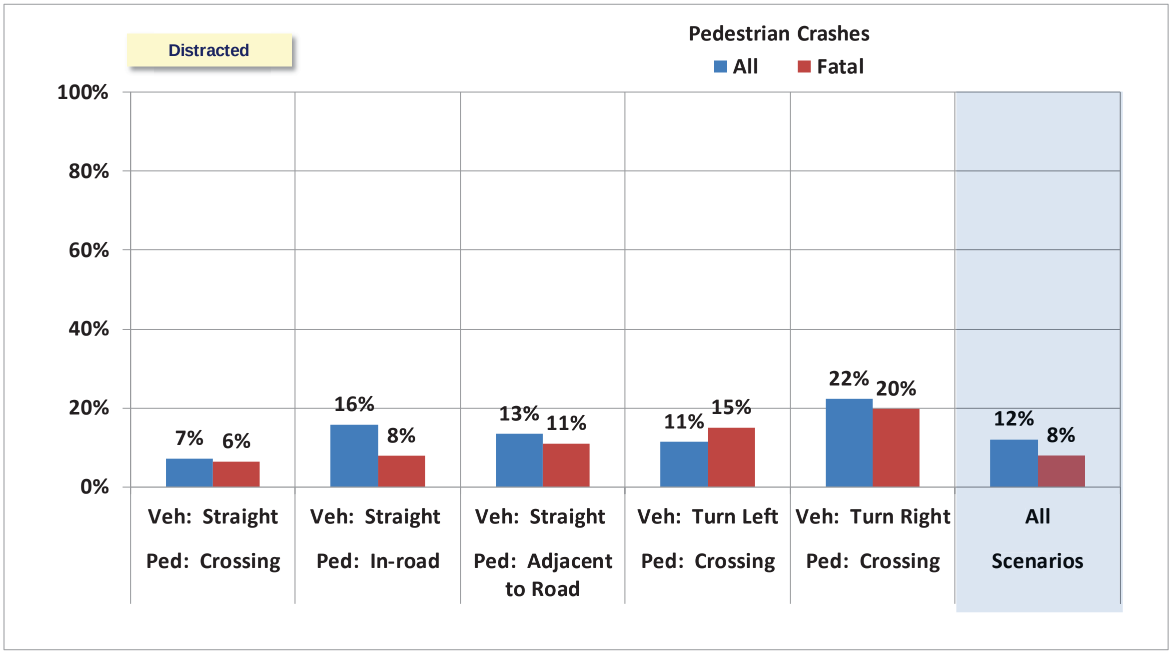


Figure 48. Percentage of Distracted Driver Crashes per Total Crashes in Each Priority Scenario

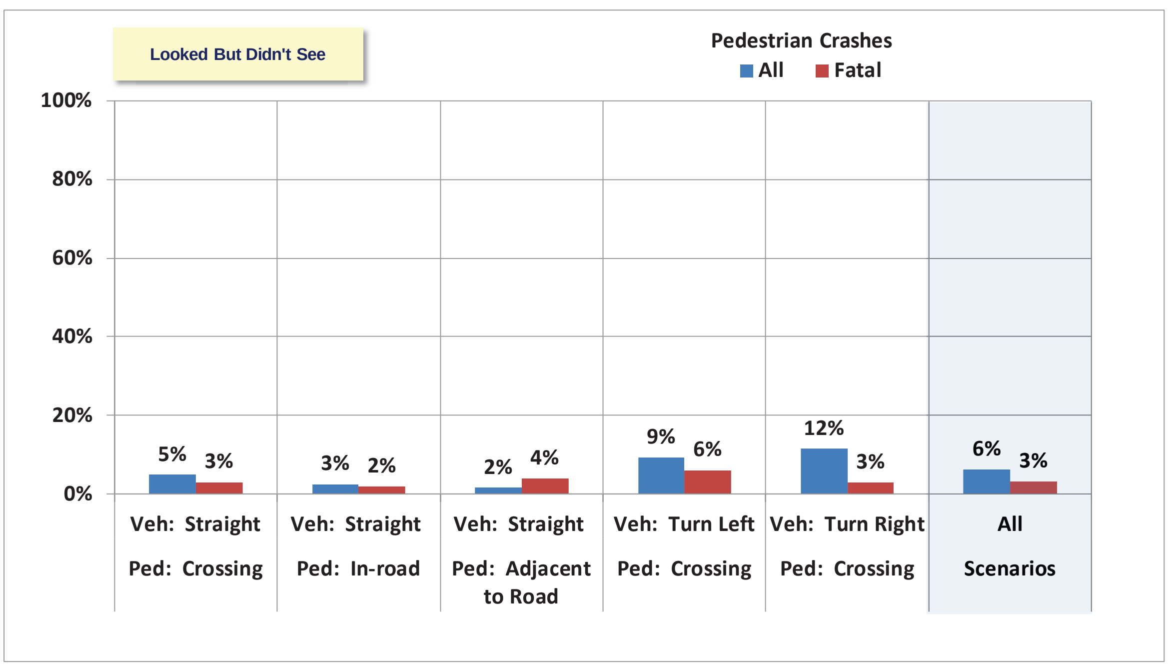


Figure 49. Percentage of “Driver - Looked But Didn’t See” Crashes per Total Crashes in Each Priority Scenario

3.5 Pedestrian Actions/Characteristics

The pedestrian actions and characteristics describe the key conditions that may have contributed to the crash related to the pedestrian's impairment, inattentiveness, visibility, or action of darting/dashing. These are important to the description of crash events but are not used as the cause of the crash or to imply fault. The pedestrian age is also included since age can be associated with factors such as the pedestrian's height or speed of the pedestrian (older pedestrians may not be as fast when crossing).

3.5.1 Pedestrian Impairment

The majority of pedestrian impairments is included in the category of "under the influence of alcohol, drugs, or medication" and is due to alcohol. Note that about 1.6 percent of the target crash population include people categorized as "impaired" who are blind, deaf, physically challenged, or walking with a cane or crutches. Although they are all categorized together as "impaired," people with disabilities should not be considered on the same level as those who are impaired by alcohol. This small group of pedestrians has unique needs and movements that are not specifically addressed in this report but may receive benefits from V2P-based safety systems.

The impairment data element is a "select all that apply" variable, so there can be more than one type of pedestrian impairment defined for each pedestrian. Each pedestrian is only represented once as having an impairment. Unknowns were reported in 23 percent of the crashes for GES and 19 percent for FARS.

Definition: This variable describes any physical impairment of the pedestrian that may have contributed to the crash.

Categories:

Pedestrian Impaired:

- Ill, Blackout
- Asleep or Fatigued
- Walking with a Cane or Crutches
- Impaired Due to Previous Injury
- Deaf
- Blind
- Emotional (Depressed, Angry, Disturbed, etc.)
- Under the Influence of Alcohol, Drugs or Medication
- Physical Impairment - No Details
- Other Physical Impairment

Others:

- None/Apparently Normal
- Not Reported/Unknown if Impaired

Note that the category, "Paraplegic or Restricted to Wheelchair," is not represented in the target pedestrian data since it does not include pedestrians in wheelchairs.

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 6 percent of pedestrians involved in light vehicle crashes and 19 percent of pedestrians involved in fatal light vehicle crashes are impaired.

Scenarios:

- Vehicle - straight and pedestrian in the road – 26 percent of fatalities from these crashes involved an impaired pedestrian.

Influence on V2P Systems: Impaired pedestrians can move unpredictably while on the roadway, such as the erratic behavior of an intoxicated pedestrian who may have wandered into the street unexpectedly. V2P systems could potentially be effective in these scenarios if they were able to identify a pedestrian with the unique characteristics associated with an impaired pedestrian (e.g., gait, appearance in unexpected locations, non-linear trajectories).

Comparison of Pedestrian Impairment in Priority Scenarios

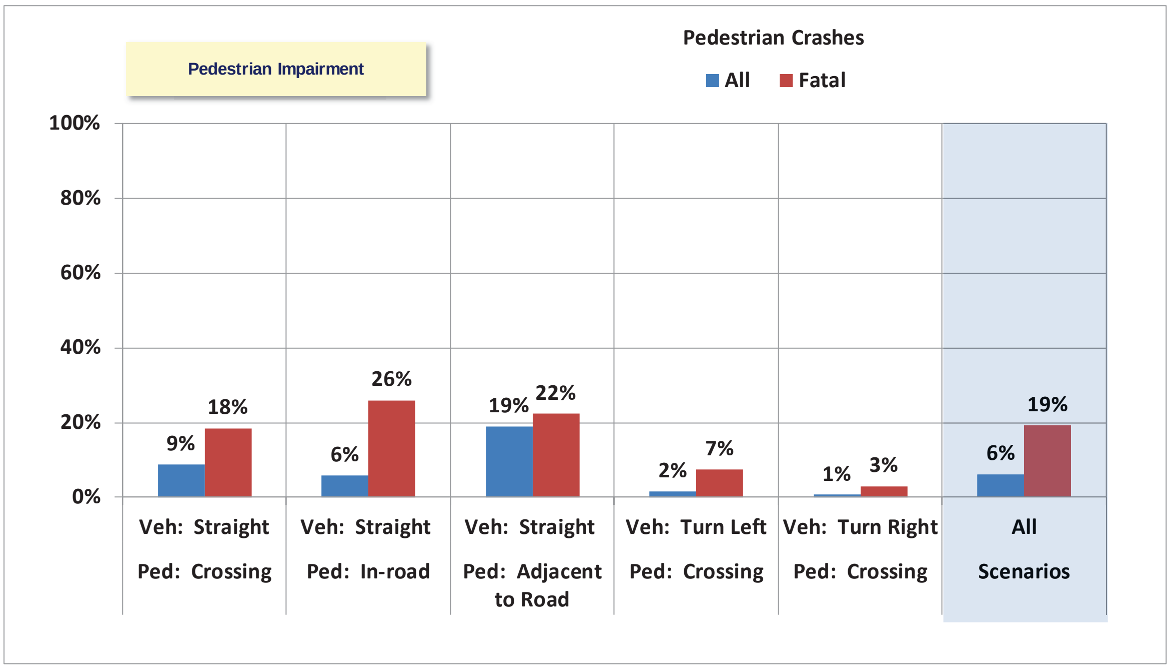


Figure 50. Percentage of Pedestrian-Impaired Crashes per Total Crashes in Each Priority Scenario

3.5.2 Inattentive

A variable for pedestrian distraction is not available in the databases, however, the "non-motorist action/circumstances at the time of the crash" data element has a variable coded as "inattentive" that is used. Since all distractions are categorized together, individual frequencies for distractions, such as a pedestrian talking on a cellphone, are not available.

Definition: The pedestrian inattentiveness as indicated by the police officer investigating the crash described as talking, eating, etc. Cellphone use is not specifically stated but it is included in this variable.

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 2 percent of all pedestrian crashes and 3 percent of fatal crashes involve an inattentive pedestrian.

Scenarios:

- Vehicle - going straight and pedestrian in-road - 9 percent of crashes involved an inattentive pedestrian.

Influence on V2P Systems: If possessed by the pedestrian, V2P systems can potentially help to refocus the pedestrian's attention to warn them of an impending impact with a vehicle if they are texting, talking, etc.

Comparison of Pedestrian Inattentiveness in Priority Scenarios

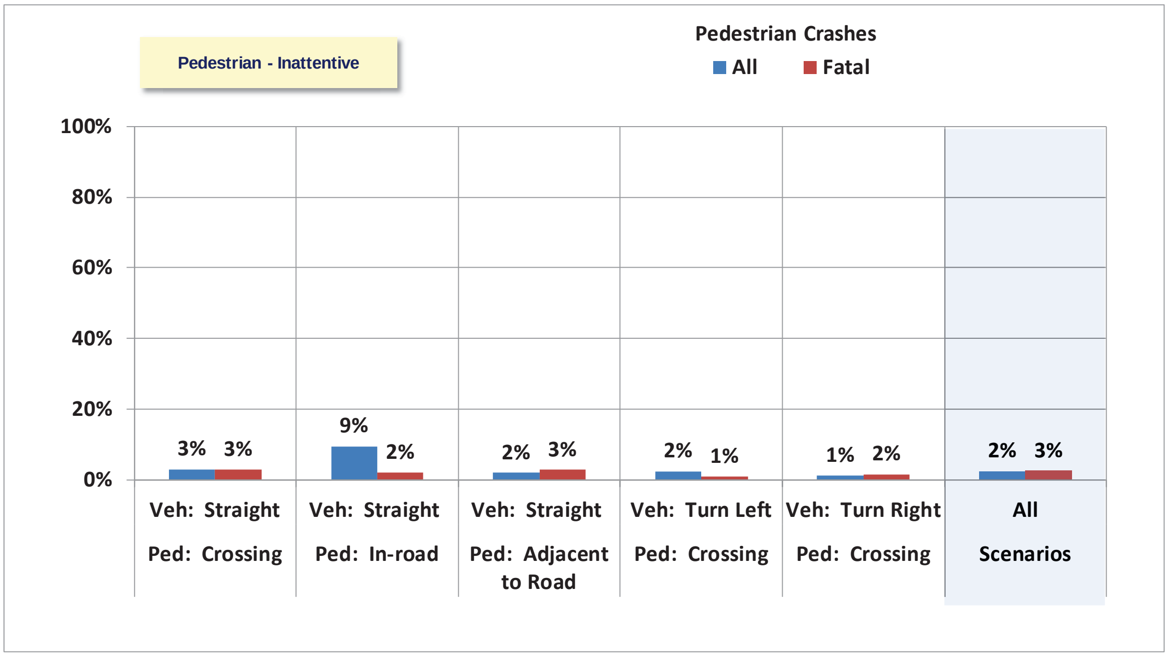


Figure 51. Percentage of Inattentive-Pedestrian Crashes per Total Crashes in Each Priority Scenario

3.5.3 Visibility

Pedestrian visibility is acquired from the "non-motorist action/circumstances at the time of the crash" data element through a variable coded as "not visible." It is not possible to determine the individual cause of why the pedestrian is not visible since all categories, such as clothing, lighting, blocked views, are classified together.

Definition: This variable specifies if the pedestrian was not visible to the driver due to blocked views, insufficient lighting, dark clothing, etc.

Observations on Data (2011 and 2012 Annual Crash Average):
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 4 percent of all pedestrian crashes and 19 percent of fatal crashes involve a pedestrian who is not visible.

Scenario:

- Vehicle - straight and pedestrian adjacent, in, or crossing the road – significant amount of fatal crashes involve limited visibility of the pedestrian (32 percent adjacent, 21 percent in-road, 18 percent crossing).

<u>Influence on V2P Systems</u>: In order to address the safety risks identified above, V2P systems would be able to identify pedestrians in limited visibility but would also need the ability to recognize pedestrians coming from behind external obstructions such as another vehicle, structure, sign, etc.

<u>Comparison of Pedestrian Visibility in Priority Scenarios</u>

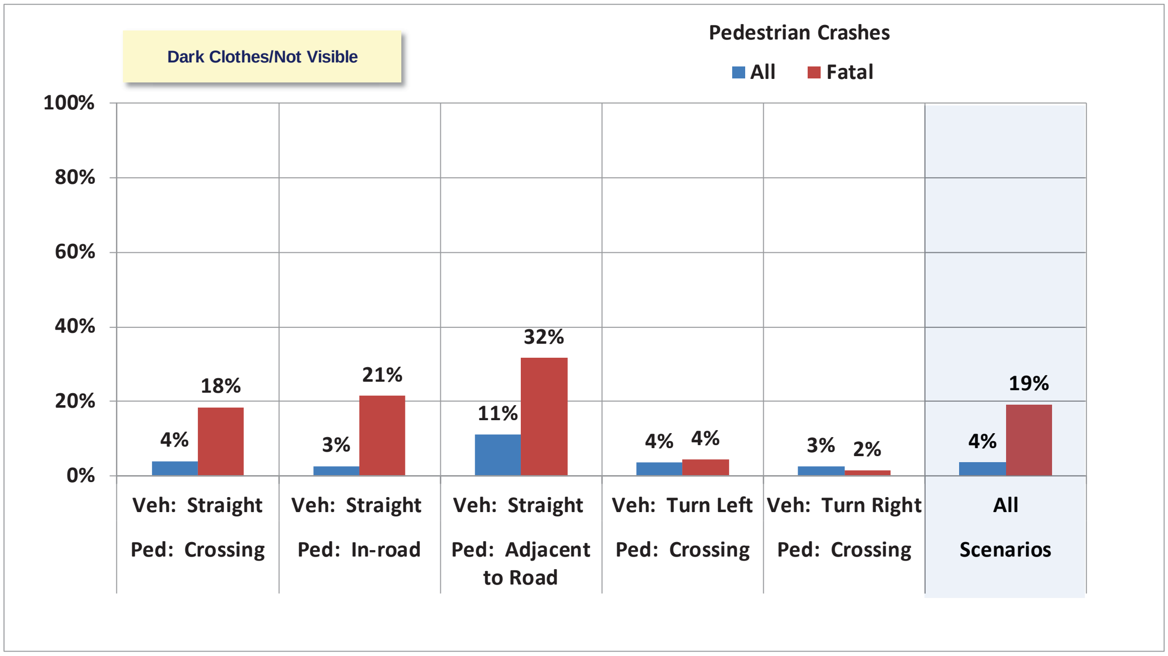


Figure 52. Percentage of "Not Visible Pedestrian" Crashes per Total Crashes in Each Priority Scenario

3.5.4 Dart/Dash

The dart/dash variable includes situations when a pedestrian, who is walking or running, suddenly appears and thus makes it difficult for the driver to react (e.g., a child running out into the street to get a ball). The dart/dash variable is coded in the FARS and GES database manuals [5] such that if the driver's view was obstructed until an instant before the crash, then the pedestrian walked, ran, etc. into the road. If there was no obstruction to the driver's view, then the pedestrian did not walk and most likely ran into the road. Since "dart/dash" is identified as one of the attributes from the "non-motorist action/circumstances at the time of the crash" data elements, there are no additional categories defined for this variable.

<u>Definition</u>: This variable defines the action of the pedestrian in terms of if they suddenly appear into the road.

<u>Observations on Data (2011 and 2012 Annual Crash Average)</u>:
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 23 percent of all pedestrian crashes and 17 percent of fatal crashes happen from a pedestrian darting or dashing into the road.

Scenarios:

- <u>Vehicle - straight and pedestrian crossing the road</u> - nearly half (45 percent) of all crashes in this scenario are related to the pedestrian darting or dashing into the road.

<u>Influence on V2P Systems</u>: Dart/dash typically involves situations where the driver had little time to react. As a consequence, more fatalities can occur if the driver does not apply the brakes and has a higher impact speed with the pedestrian. Pedestrian actions can be random and unpredictable. Pedestrians can dart or dash into the street or come from behind an obstruction. To address these issues, V2P systems would need a timely awareness of these erratic pedestrian movements to have the ability to accurately predict the most probable trajectory of the pedestrian and react accordingly.

<u>Comparison of Pedestrian Dart/Dash in Priority Scenarios</u>

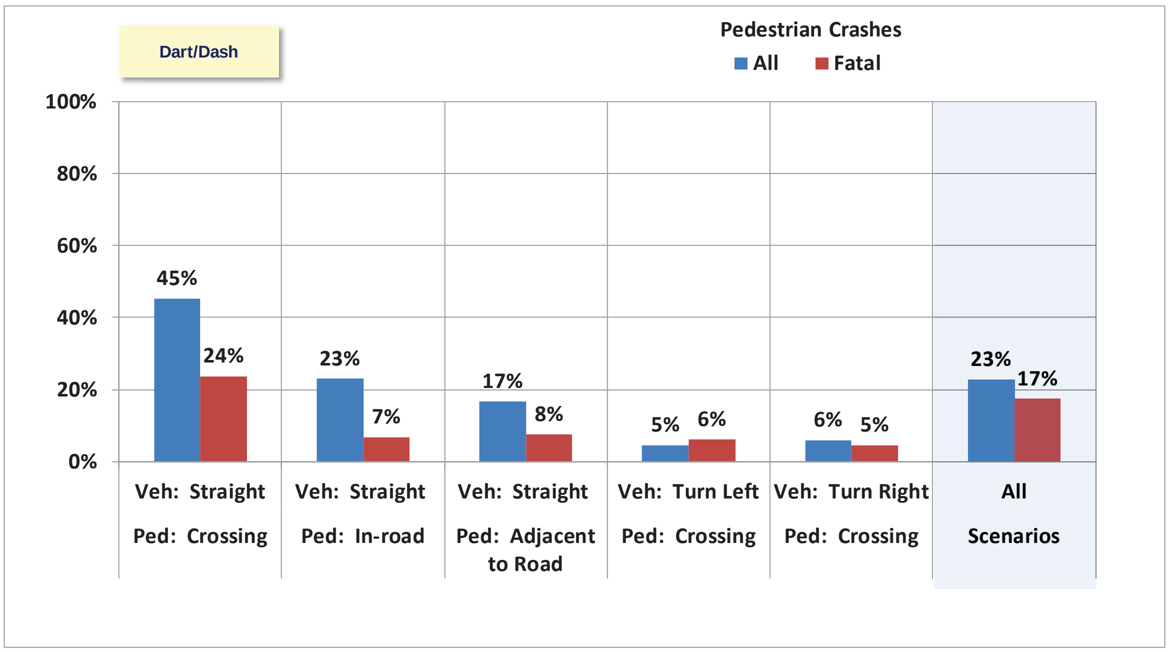


Figure 53. Percentage of "Pedestrian-Dart/Dash" Crashes per Total Crashes in Each Priority Scenario

3.5.5 Correlations of Dart/Dash Variables

Two different correlations of the pedestrian action related to darting or dashing into the road were made involving two individual variables: the driver's visual obstruction and the pedestrian's visibility. A correlation with the driver's visual obstruction is helpful to distinguish pedestrian movement since the data is coded such that if the driver's view was obstructed until an instant before the crash, then the pedestrian walked, ran, etc. into the road. If there wasn't an obstruction to the driver's view, then the pedestrian did not walk and most likely ran into the road. A correlation with visibility is useful to categorize situations where the pedestrian was darting or dashing into the road while not visible to the driver.

<u>Observations on Vision Obscured and Dart/Dash Data</u>
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 16 percent of all pedestrian crashes and 14 percent of fatal crashes happen with no vision obstruction for the driver and with the pedestrian performing a dart/dash maneuver by running only.

- 6 percent of all pedestrian crashes and 2 percent of fatal crashes happen with a vision obstruction for the driver and the pedestrian performing a dart/dash by either running or walking.

Scenarios:

- <u>Vehicle - turning left or right and pedestrian crossing</u> - High percentage of these fatal crashes occur with an obstruction and no darting or dashing involved (17 percent - left turn, 14 percent - right turn).

<u>Comparison of Vision Obscured and Dart/Dash in Priority Scenarios</u>

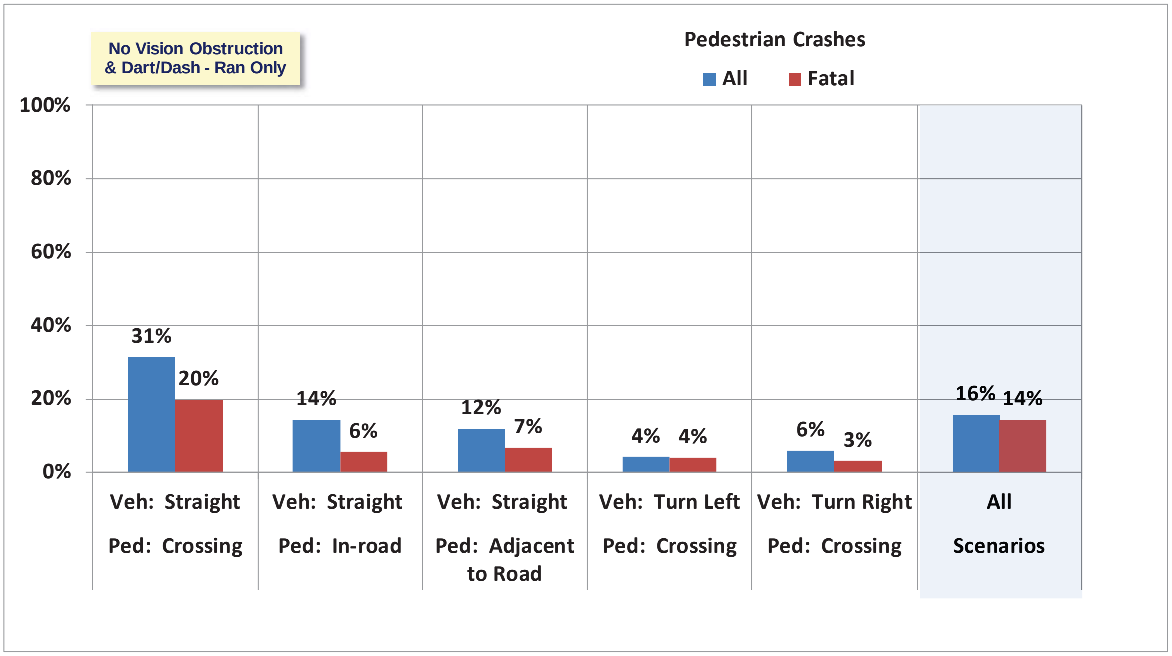


Figure 54. Percentage of "No Driver Vision Obstruction and Pedestrian Dart/Dash - Ran Only" Crashes per Total Crashes in Each Priority Scenario

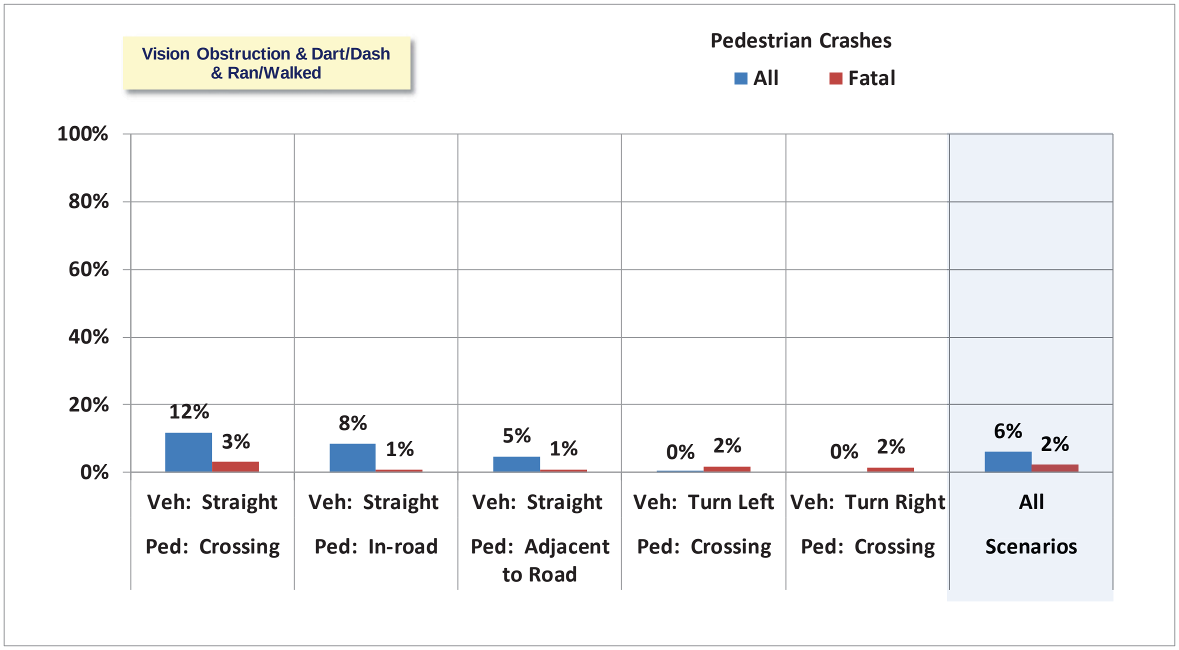


Figure 55. Percentage of "Driver Vision Obstruction and Pedestrian- Dart/Dash and Ran/Walked" Crashes per Total Crashes in Each Priority Scenario

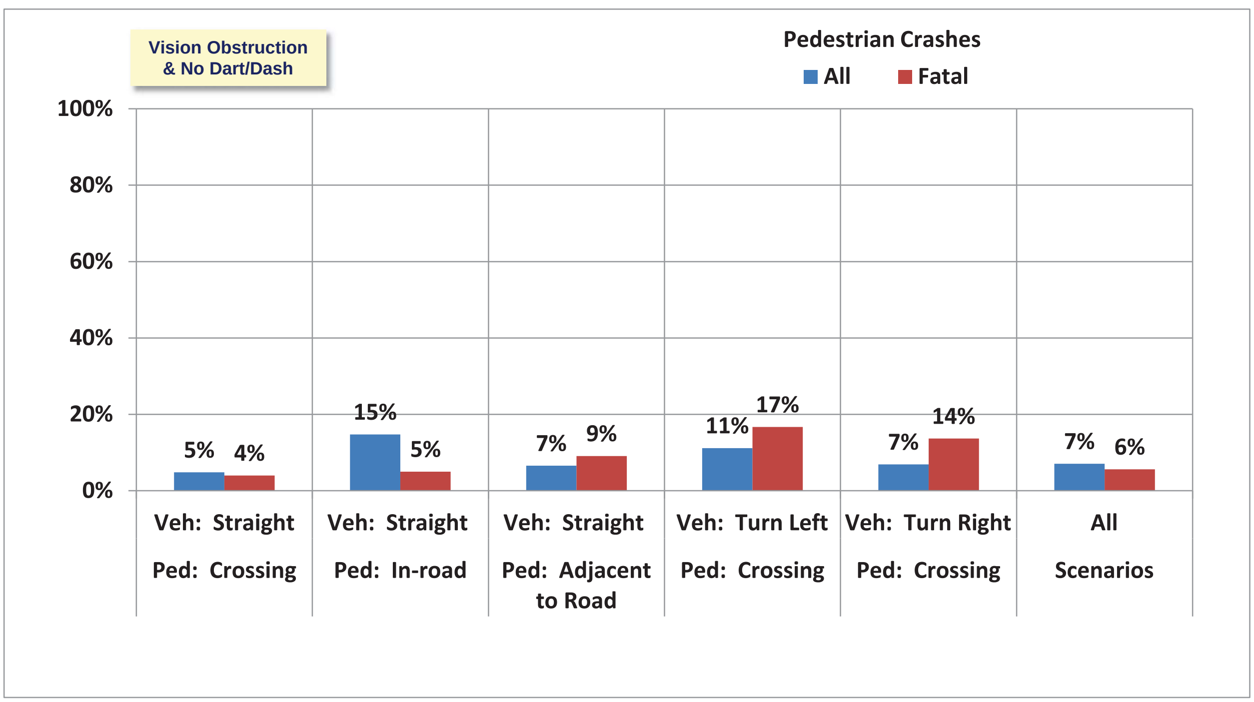


Figure 56. Percentage of "Driver Vision Obstruction and Pedestrian - No Dart/Dash" Crashes per Total Crashes in Each Priority Scenario

Observations on Pedestrian Visibility and Dart/Dash Data

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 3 percent of all pedestrian crashes and 16 percent of fatal crashes happen with a pedestrian who is not visible (clothing, lighting, blocked views) and not darting/dashing.
- 1 percent of all pedestrian crashes and 3 percent of fatal crashes happen with a pedestrian who is not visible (clothing, lighting, blocked views) and darting/dashing.

Scenarios

- Vehicle - straight and pedestrian crossing, in, or adjacent to the road - significant percentage of these fatal crashes occur with limited pedestrian visibility and no darting or dashing (30 percent adjacent, 21 percent in-road, 15 percent crossing).

Comparison of Pedestrian Visibility and Dart/Dash in Priority Scenarios

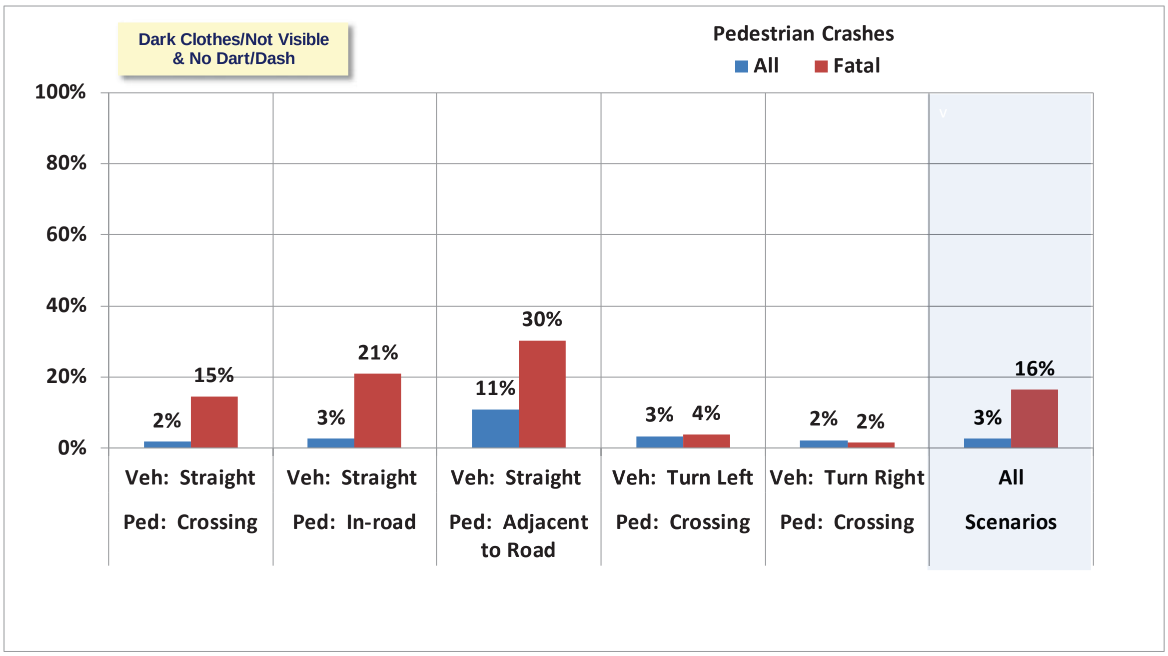


Figure 57. Percentage of "Pedestrian - Dark Clothes/Not Visible and No Dart/Dash" Crashes per Total Crashes in Each Priority Scenario

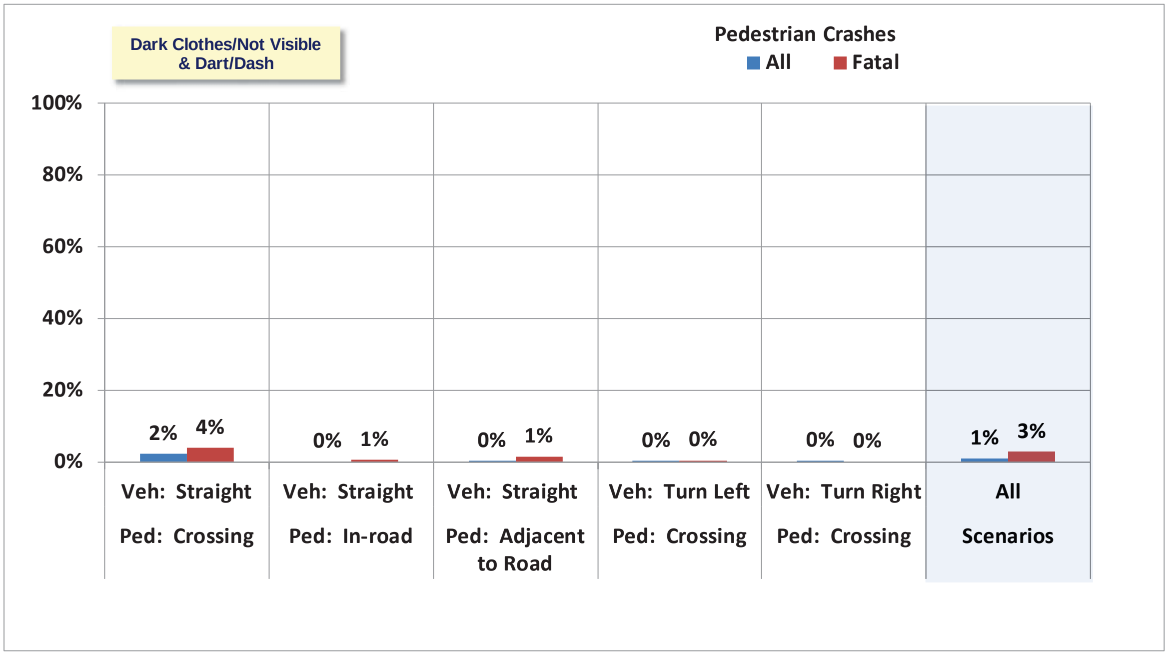


Figure 58. Percentage of "Pedestrian Dark Clothes/Not Visible and Dart/Dash" Crashes per Total Crashes in Each Priority Scenario

Influence on V2P Systems: To be most effective, V2P systems with a driver-warning component would require accuracy in distinguishing pedestrians from background communication-equipped objects. Systems could minimize false activations by focusing on targeting only pedestrians.[6] Movement assessment algorithms may help V2P systems identify pedestrians; however, pedestrian movement can be erratic at times.

3.5.6 Age

The pedestrian age is presented to gather insight on pedestrian size; generally, people grow bigger as they age and potentially get smaller in the elder years. From the previous Volpe PCAM research [9] it was shown that a pedestrian's height steadily increased for both genders until the age of 15, when the average height peaks and levels off at 70 inches for males and 65 inches for females. The weight showed a similar trend, however with a wider gap between genders. The weight steadily increases until age 15 and becomes level at around 200 pounds for males and 160 pounds for females. A slight loss of weight was observed as people get older.

Age can also affect the speed of the pedestrian to cross since older pedestrians may not be as fast when crossing. Other factors such as older pedestrians tending to use crosswalks more frequently or teenagers having a tendency to be distracted can be associated with age but were not specifically addressed in this report.

Definition: The pedestrian's age with respect to their last birthday.

[6] The detection of objects, other than pedestrians, could possibly also aid in the prevention of crashes.

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- The highest frequency of all crashes happen with 11- to 20-year-old pedestrians. The highest frequency of fatal crashes happen with 51- to 60-year-old pedestrians as shown in Figure 59 for all scenarios. The percentage of fatal crashes is lowest for 6- to 10-year-olds and those over 90.

Scenarios:

- Vehicle - turning left or right and pedestrian crossing - These fatal crashes tend to involve older pedestrians. However, when all crashes in this scenario were considered, younger pedestrians tended to be more involved.

Influence on V2P Systems: V2P systems may be able to prevent these types of crashes if they can distinguish pedestrians of varying heights and sizes. Note that children can have unpredictable movements (darting into a road to chase a ball, playing around or pushing another child into the street, running into a street behind parked vehicles, etc.). In addition, children may not have an awareness of vehicles in the road, may have difficulty judging distances and speeds of vehicles, or may not fully understand traffic rules.

Comparison of Pedestrian Age in Priority Scenarios

Figure 59. Comparison of Pedestrian Age in Priority Scenarios

3.6 Vehicle Speed

The actual vehicle speed at the time of impact with the pedestrian is not always accurately reflected in the data because either the driver was not able to provide precise information or it is unknown in the police report. About 75 percent of the GES and 55 percent of the FARS crashes record an unknown or unreported travel speed. The posted speed limit and a variable to specify whether the driver’s speed was related to the crash are used as substitutes to estimate the vehicle speed. The crash is determined to be speed-related if the police report states that the vehicle was traveling too fast for conditions, the driver was issued a speeding citation, or the speed used was higher than a reasonable or prudent speed. If the driver was traveling “too slow” it would not be considered as “speed-related.” The majority of cases does not have speeding as a factor; and in these cases, an assumption is made that the vehicle is traveling close to the range of the posted speed limit.

3.6.1 Posted Speed Limit

Description: This variable represents the posted speed limit prior to the vehicle’s critical pre-crash event and it is given in miles per hour.

Categories:
- 5 MPH
- 10 MPH and 15 MPH
- 20 MPH and 25 MPH
- 30 MPH and 35 MPH
- 40 MPH and 45 MPH
- 50 MPH and 55 MPH
- 60 MPH, 65MPH, 70 MPH, and 75 MPH
- Not Reported/Unknown (32 percent-GES, 4 percent-FARS)
- No Speed Limit/Non-Traffic Way Area (5 percent-GES,<1 percent-FARS)

Observations on Data (2011 and 2012 Annual Crash Average)
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):
- 25 percent of all pedestrian crashes and 28 percent of fatal crashes happen at a posted speed limit of 30-35 mph (highest frequency for all crashes)
- 11 percent of all pedestrian crashes and 32 percent of fatal crashes happen at a posted speed limit of 40-45 mph (highest frequency for fatal crashes)

Influence on V2P Systems: Systems would need to be accurate and provide quick-notification timing at various speeds. High impact speeds are typically correlated with high injuries to pedestrians (refer to the pedestrian harm functions [9] for speed/injury values).

Comparison of Speed in Priority Scenarios

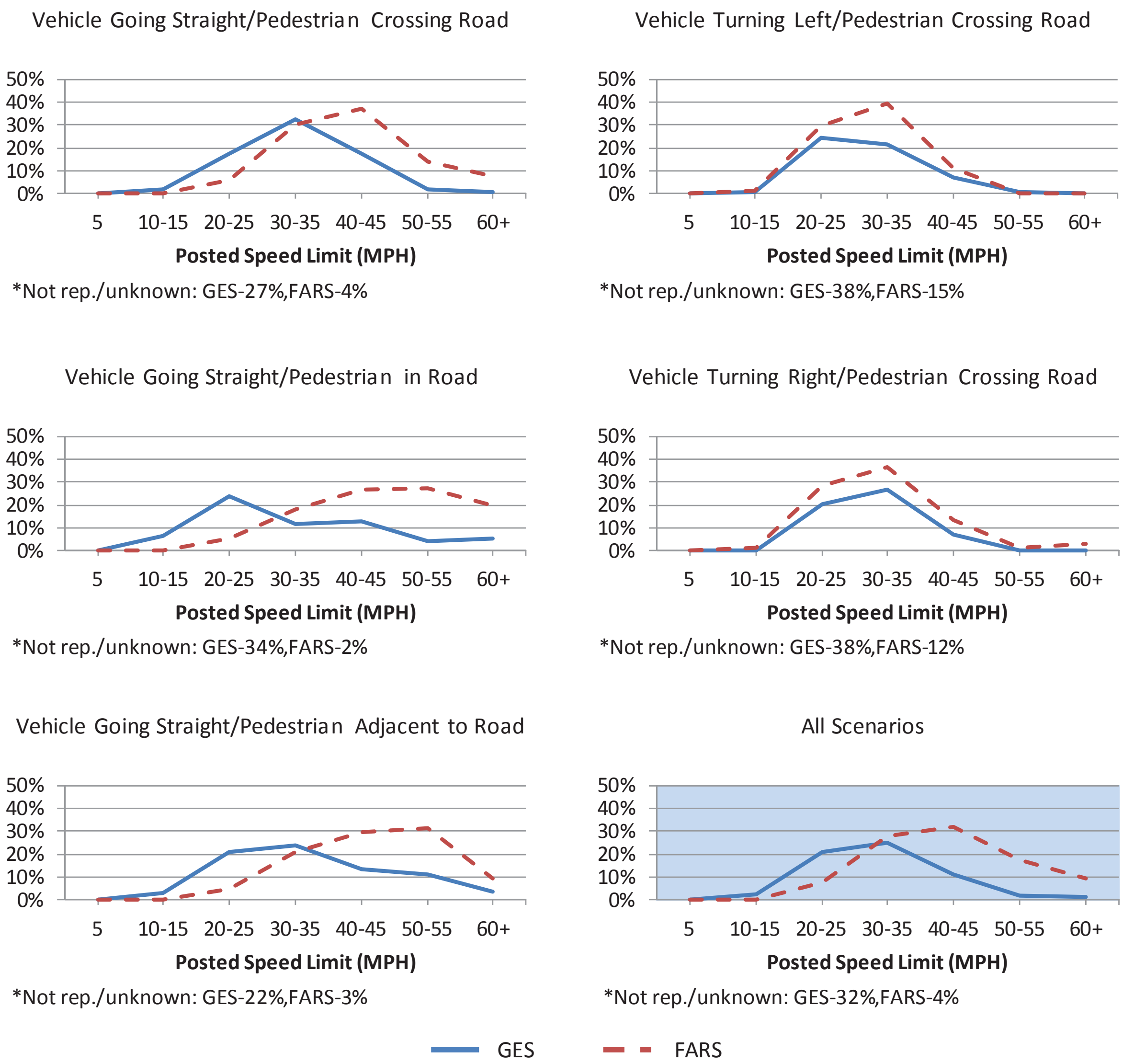


Figure 60. Percentage of Posted Speed Limit in Each of the 5 Priority Scenarios for GES and FARS

3.6.2 Speeding

Definition: This variable describes whether the driver's speed was related to the crash as determined by the police report.

Categories:
- Yes
- No
- No Driver/Unknown if Driver Present
- Unknown

Observations on Data (2011 and 2012 Annual Crash Average)
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 2 percent of all pedestrian crashes and 6 percent of fatal crashes are speeding-related.

Influence on V2P Systems: Same as those associated with posted speed limit.

Comparison of Speed -Related in Priority Scenarios

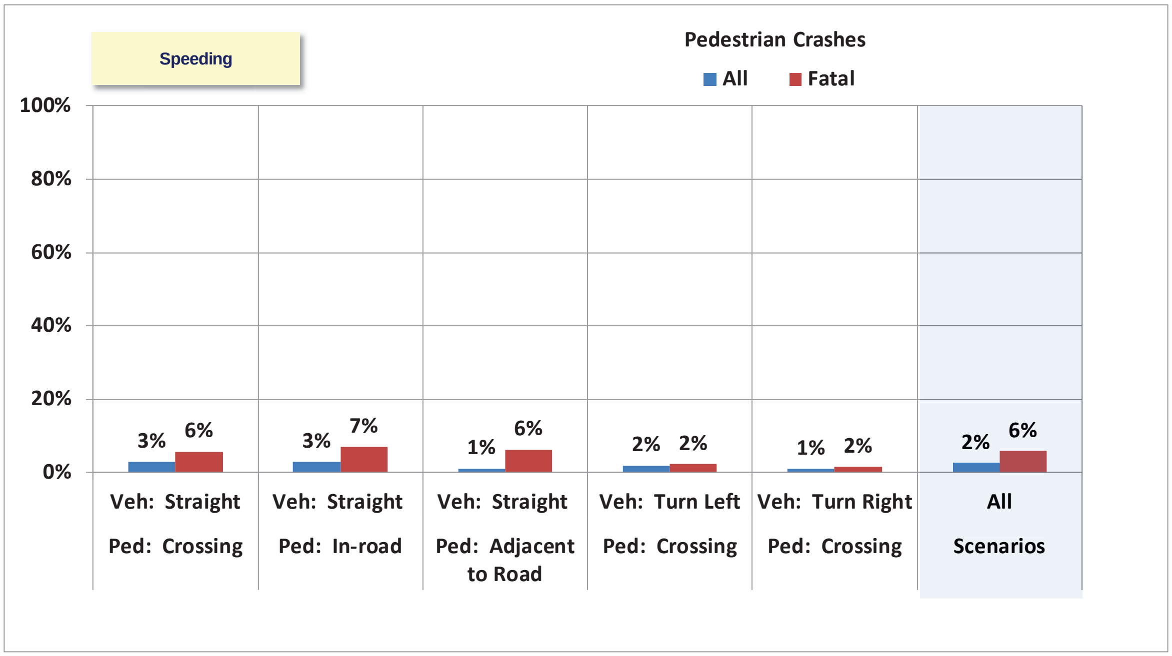


Figure 61. Percentage of Speeding Crashes per Total Crashes in Each Priority Scenario

3.6.3 Correlation of Speed Variables

Posted speed limit and speeding are used to get an estimate of vehicle speed as mentioned in Section 3.6.

Observations on Data (2011 and 2012 Annual Crash Average)
All Crashes:

- 0.9 percent of all pedestrian crashes and 0.8 percent of fatal crashes occur when the vehicle is speeding and the speed limit is 20 or 25 MPH.
- 0.6 percent of all pedestrian crashes and 2.4 percent of fatal crashes occur when the vehicle is speeding and the speed limit is 30 or 35 MPH.
- 0.1 percent of all pedestrian crashes and 1.3 percent of fatal crashes occur when the vehicle is speeding and the speed limit is 40 or 45 MPH.

Speed Limit and Speeding in All Crashes

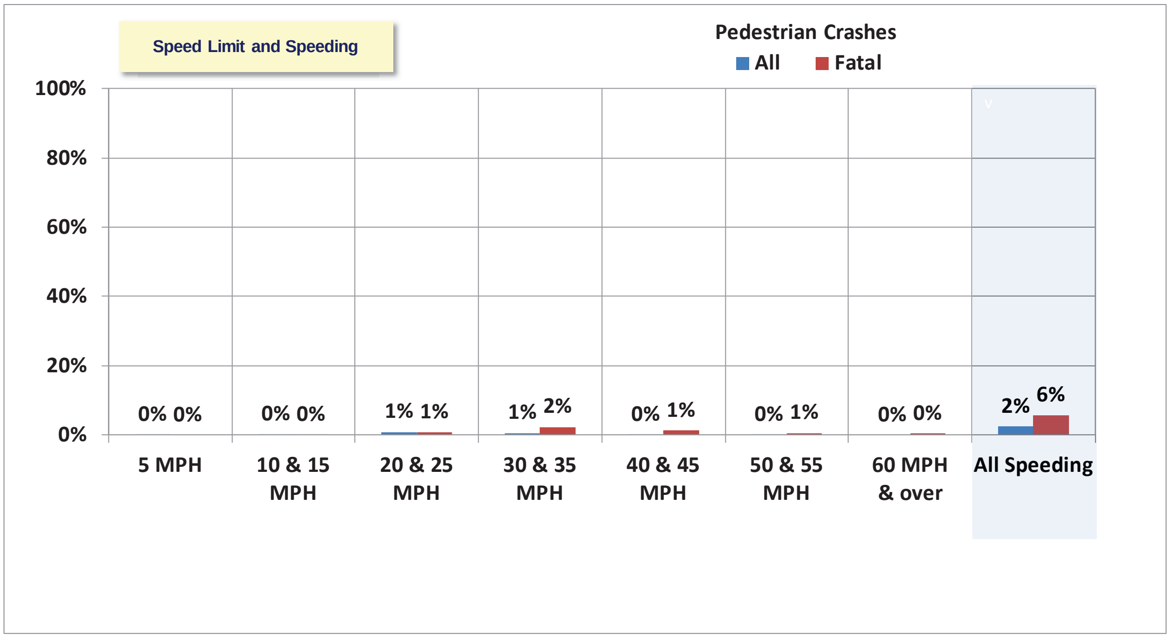


Figure 62. Percentage of Speeding Crashes per Total Crashes by Speed Limit

Comparison of Speed Limit and Speed in Priority Scenarios
Appendix B contains charts of the speed correlations (posted speed limits of 20-25 MPH, 30-35 MPH, and 40-45 MPH for speeding and not speeding.)

Influence on V2P Systems: The combination of posted speed limit and speed-related variables suggests that to address the safety issues identified above, V2P systems would need to potentially function at all speeds.

3.7 Driver Attempted Avoidance Maneuver

A driver may attempt to prevent a crash with a pedestrian by braking, steering, accelerating, or a combination of these actions. It may also be the case that a driver will not perform one of these maneuvers if, for example, the pedestrian was not visible until right before the crash or if the driver was distracted.

Definition: This variable describes the driver's action in response to the pedestrian.

Categories:

- No Avoidance Maneuver
- Braking (No Lockup)
- Braking (Lockup)
- Braking (Lockup Unknown)
- Steering Left
- Steering Right
- Braking and Steering Right
- Braking and Steering Left
- Accelerating and Steering Left
- Accelerating Only
- Other, No Driver, Unknown

Note that other categories are available but are not present in the target population. These are:

- Releasing Brakes
- Accelerating and Steering Right

Observations on Data (2011 and 2012 Annual Crash Average)

All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- In 52 percent of all pedestrian crashes and 72 percent of fatal crashes, the drivers did not perform an avoidance maneuver.
- The driver attempted to brake in 6 percent, steer in 3 percent, and brake and steer in only 1 percent of pedestrian crashes.

Scenarios:

- Vehicle - turning left or right and pedestrian crossing - over 80 percent of the time in these fatal crashes, the driver does not attempt an avoidance maneuver.

Influence on V2P Systems: Crash countermeasures that notify the driver of an impending collision with a pedestrian, and automatically apply the brakes, steer, etc., if the driver does not take the proper action to avoid the collision, may help to address the safety issues identified above.

Comparison of Attempted Avoidance Maneuver in Priority Scenarios

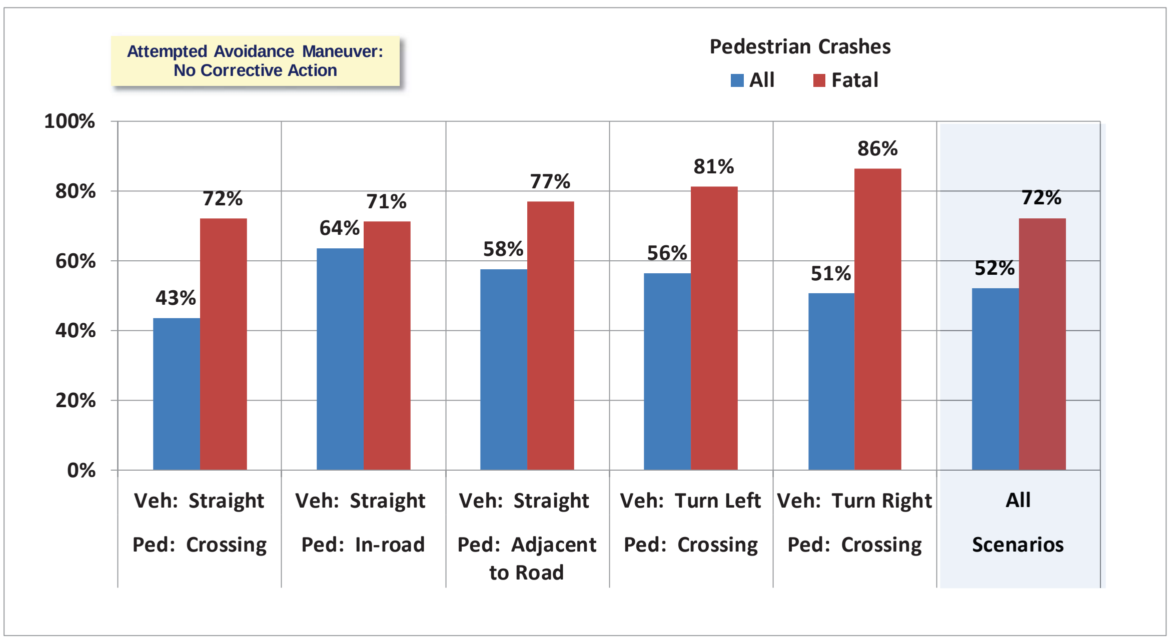


Figure 63. Percentage of "No Corrective Action" Crashes per Total Crashes in Each Priority Scenario

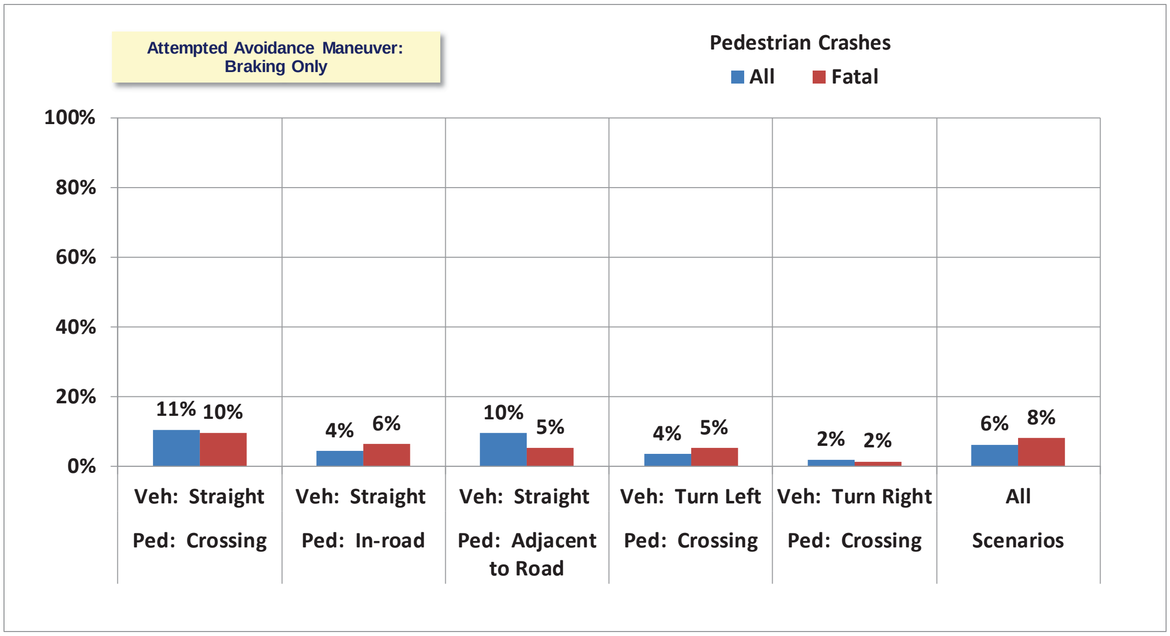


Figure 64. Percentage of "Vehicle-Braking Only" Crashes per Total Crashes in Each Priority Scenario

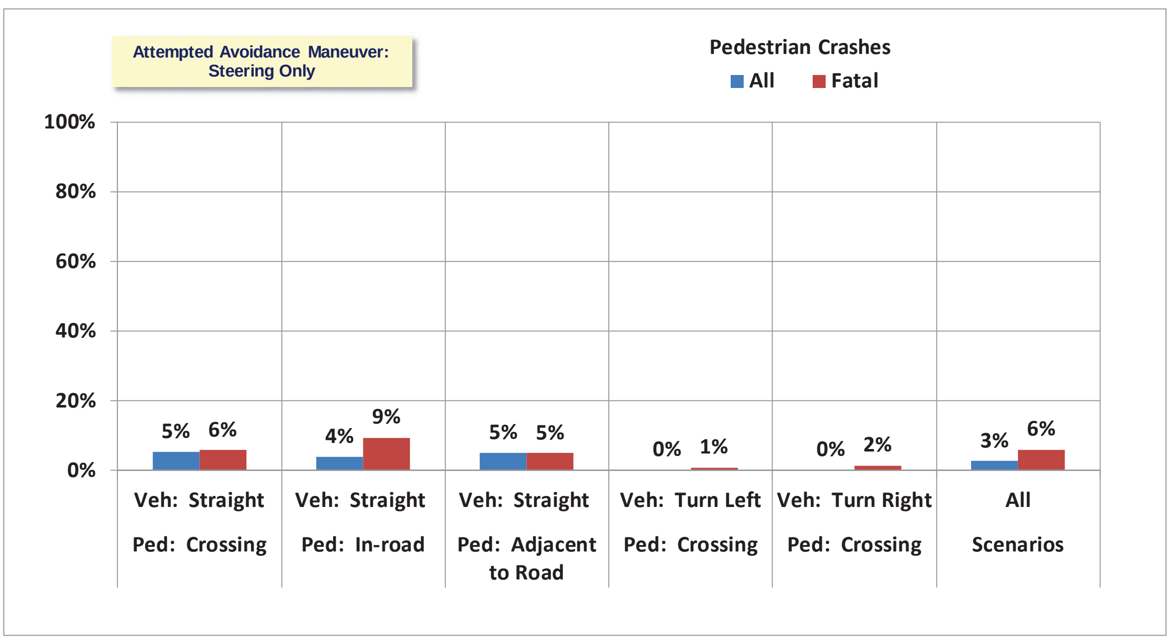


Figure 65. Percentage of "Vehicle-Steering Only" Crashes per Total Crashes in Each Priority Scenario

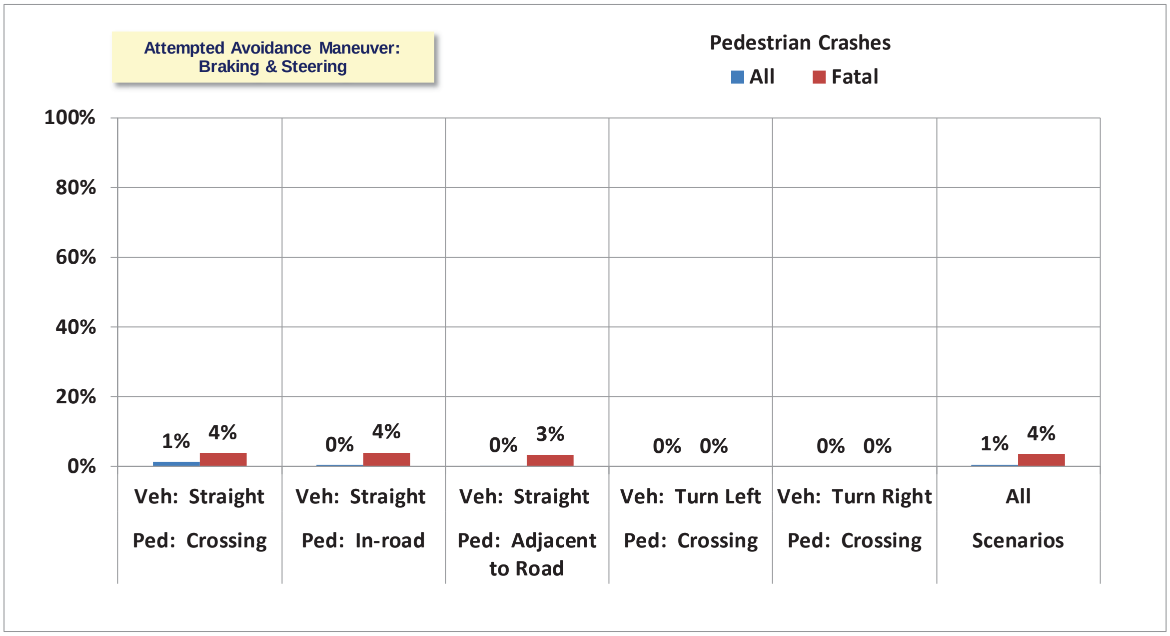


Figure 66. Percentage of "Vehicle-Braking and Steering" Crashes per Total Crashes in Each Priority Scenario

3.8 Vehicle Area of Impact

The vehicle area of impact is helpful in determining the position of the pedestrian with respect to the vehicle. When combined with the kinematics of the vehicle and pedestrian, determination can be made about the pedestrian's relative position.

Definition: This variable defines the impact point on the vehicle that caused personal injury.

Categories:

	Code*
• 1-12 Clock Points	1-12
• Left	61
• Left - Front Side	62
• Left - Back Side	63
• Right	81
• Right - Front Side	82
• Right - Back Side	83
• Top	
• Set-in-Motion	
• Undercarriage – impacts to tires/wheels, axles, exhaust system, etc.	
• Not Reported	
• Unknown	

*Refer to Figure 67 for coding

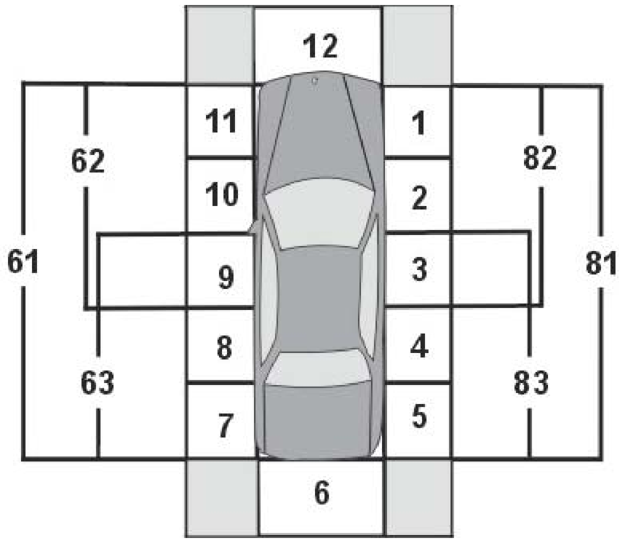


Figure 67. Area of Impact Vehicle Codes

Note that for the target pedestrian crashes, if the area of impact is not the top, undercarriage, set-in-motion, or one of the clock points, then one of the four vehicle quadrants would be coded followed by either side of the vehicle.

<u>**Observations on Data (2011 and 2012 Annual Crash Average)**</u>
All Crashes (GES - 62,900 crashes; FARS - 3,337 crashes):

- 60 percent of all pedestrian crashes and 80 percent of fatal crashes have an impact point directly on the front of the vehicle (12 o'clock)

<u>**Influence on V2P Systems**</u>**:** Knowledge of the pedestrian impact point on the vehicle could aid in the development of objective test procedures for V2P systems.

Comparison of Vehicle Area of Impact in Priority Scenarios

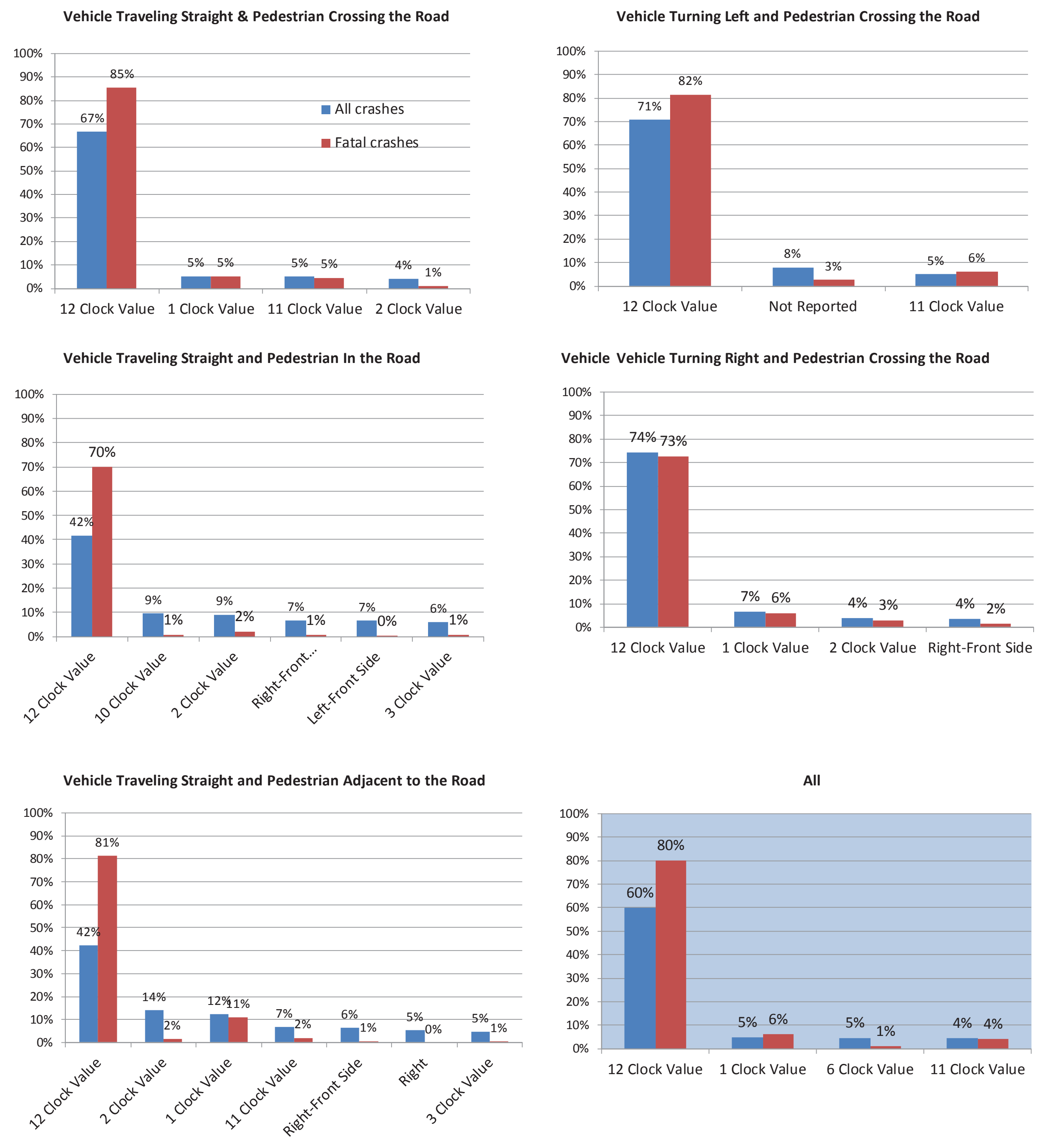


Figure 68. Percentage of Vehicle Area of Impact in Each of the 5 Priority Scenarios for GES and FARS

4 Characteristics of Priority Pedestrian Pre-Crash Scenarios

While the generic scenario descriptions capture the essence of the events, there can be many complex and confounding factors that need to be considered for a more complete pre-crash scenario depiction. Many of these factors are common to all crash modes. A multitude of crash characteristics may influence the time-to-collision value other than simple range between the pedestrian and the vehicle. Where possible, all relevant crash characteristics should be considered in the calculation of the TTC variable. The alert logic of V2P-based safety applications depends on accurate detection and measurements of these crash characteristics.

The depictions of the pre-crash scenarios become more complex as real-world considerations are taken into account. In particular, detection of pedestrians beyond topographical features such as hills or sloped terrain can be improved by V2P-based safety systems. Pedestrian path determination can also be enhanced by measuring GPS data if available. Consideration should be given to obstructions to the driver's line of sight such as other vehicles, hills, buildings, and vegetation, etc.

There are several environmental factors that may contribute to pedestrian crashes. These include reduced visibility due to darkness at night or sun glare during the day. Precipitation and window condensation can negatively impact the driver's ability to recognize and react to crash circumstances. Further, precipitation and icing can contribute to reduced traction between the vehicle and the road surface.

Environmental factors can often be inferred through the use of equipment such as headlights and fog lights, windshield wipers, window defrosters, turn signals, and hazard lights. Their use can indicate reduced visibility, for example. Similarly, the activation of traction control systems or anti-lock brake systems may indicate poor braking performance and thus may serve as measures of the road surface condition.

A template containing related crash characteristics from the GES and FARS databases is presented for each of the 5 priority scenarios as shown in in Sections 4.1 through 4.5. Appendix C contains crash characteristics for 3 additional scenarios that did not qualify as priority scenarios, but were the next highest in rank by cost. These scenarios were the "vehicle changing lanes and pedestrian crossing," "vehicle starting and pedestrian crossing," and "vehicle backing up and pedestrian crossing."

4.1 Vehicle Going Straight and Pedestrian Crossing

Vehicle Going Straight/Pedestrian Crossing Road			
Total Crashes - 23,558 / Total Fatal Crashes - 2,029 (2011 & 2012 Annual Crash Average)			
	GES (%)	**FARS (%)**	**Crash Location Parameters**
Relation to Junction	49.0	63.4	Non-Junction
	47.7	33.2	Intersection and Intersection Related
Pedestrian Location			**Non-Intersection and:**
	51.5	66.8	On Road, Not in Marked Crosswalk
	4.4	1.3	In Marked Crosswalk
	4.1	5.1	On Road, Crosswalk Availability Unknown
			Intersection and:
	16.1	11.5	In Marked Crosswalk
	9.4	8.9	Not in Crosswalk
	7.5	4.5	Unmarked Crosswalk
	6.3	1.7	Unknown Location
Traffic Control Device	65.9	81.1	No Traffic Control Signal or Sign
	24.7	15.7	Traffic Control Signal (Color, Flashing, Lane-Use, Highway)
	5.3	2.4	Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning)
Traffic Control Device × Relation to Junction × Pedestrian Location			**No Traffic Control Signal and:**
	40.1	56.3	Non-Intersection and on Road, Not in Marked Crosswalk
	4.6	5.4	Intersection and not in Crosswalk
			Traffic Control Signal and:
	11.6	8.4	Intersection and in Marked Crosswalk
	4.5	0.6	Intersection and Unknown Location

	GES (%)	FARS (%)	Driving Environment Parameters
Weather	88.8	89.3	Clear
	10.8	10.2	Adverse
Lighting Condition	51.7	17.6	Daylight
	34.7	48.5	Dark with Overhead Street Lighting
	8.3	29.8	Dark
Road Surface Condition	81.5	86.4	Dry
	16.6	13.1	Wet/Slippery
Weather × Road Surface Condition × Lighting			**Clear and Dry and:**
	43.5	16.0	Daylight
	27.0	40.7	Dark with Overhead Street Lighting
	6.8	25.6	Dark
	4.0	3.3	Dawn, Dusk
			Adverse and Wet/Slippery and:
	1.3	0.3	Dawn, Dusk
	3.3	0.8	Daylight
	4.2	5.6	Dark with Overhead Street Lighting
	1.3	2.8	Dark

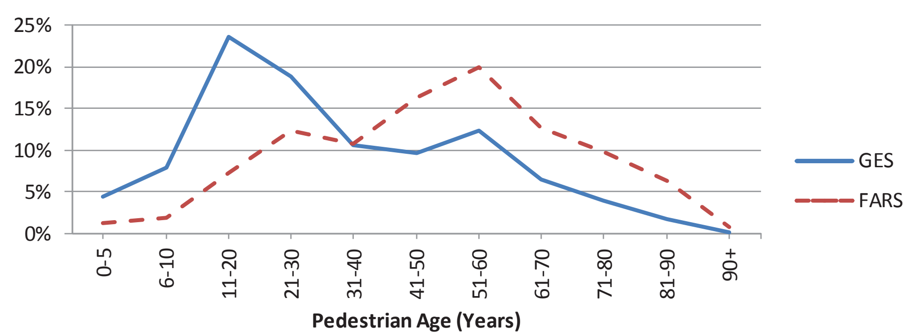
Vehicle Going Straight/Pedestrian Crossing Road

	GES (%)	FARS (%)	Road Geometry Parameters
Roadway Alignment	91.2	95.3	Straight
	2.1	4.5	Curve
Roadway Grade	71.6	83.2	Level
	5.1	6.8	Grade, Unknown Slope
	1.4	2.6	Uphill
	1.3	2.4	Downhill
Roadway Alignment × Roadway Grade			**Straight and:**
	69.6	80.4	Level
	4.6	6.0	Grade, Unknown Slope
	0.6	1.3	Hillcrest
	1.2	2.0	Downhill
	1.4	2.3	Uphill
			Curve and:
	1.4	2.8	Level

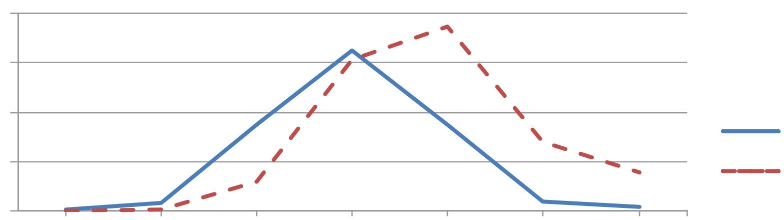
	GES (%)	FARS (%)	Driver Contributing Factors
Driver Impairment	1.9	6.9	Impairment
Vision Obscured	16.6	7.0	Obstruction
Distraction	7.1	6.3	Distracted
	5.0	3.1	Looked but Didn't See

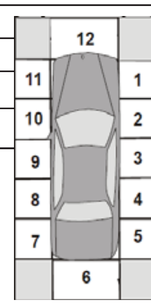
	GES (%)	FARS (%)	Pedestrian Actions/Characteristics
Pedestrian Impairment	8.7	18.5	Impairment
Inattentive	3.0	2.9	Inattentive
Visibility	4.0	18.5	Dark Clothes/Not Visible
Dart/Dash	45.3	23.8	Dart/Dash
Vision Obscured × Dart/Dash			**No Vision Obstruction and:**
	40.7	71.0	No Dart/Dash
	31.4	19.7	Dart/Dash - Ran Only
			Vision Obstruction and:
	11.8	3.0	Dart/Dash & Ran/Walked
	4.8	4.0	No Dart/Dash
Pedestrian Visibility × Dart/Dash			**Dark Clothes/Not Visible and:**
	2.2	3.9	Dart/Dash
	1.8	14.6	No Dart/Dash

Age



Vehicle Going Straight/Pedestrian Crossing Road

	GES (%)	FARS (%)	Vehicle Related Parameters
Posted Speed Limit			
Speed Related	2.9	5.7	Speed Related
Speed Related × Posted Speed Limit			**Not Speeding and:**
	15.5	5.3	20-25 MPH
	28.0	26.9	30-35 MPH
	16.6	35.0	40-45 MPH
	1.8	13.6	50-55 MPH
	0.9	7.8	60 MPH and over
			Speeding and:
	0.7	0.8	20-25 MPH
	1.1	2.8	30-35 MPH
	0.1	1.3	40-45 MPH
Attempted Avoidance Maneuver	43.5	72.0	No Corrective Action
			Braking Only:
	5.8	3.5	No Lockup
	2.7	3.9	Lockup
	2.1	2.4	Lockup Unknown
			Steering Only:
	4.1	3.7	Steering Left
	1.3	2.1	Steering Right
			Braking and Steering:
	0.5	2.4	Braking and Steering Left
	0.9	1.5	Braking and Steering Right
Area of Impact	66.7	85.4	12 O'clock Value
	5.1	5.1	1 O'clock Value
	5.0	4.5	11 O'clock Value
	4.0	1.0	2 O'clock Value



* Note that some categories are not shown because they represent smaller percentages and/or unknowns, other, or not-reported variables.

4.2 Vehicle Going Straight and Pedestrian in Road

Vehicle Going Straight/Pedestrian In Road			
Total Crashes - 2,326 / Total Fatal Crashes - 481 (2011 & 2012 Annual Crash Average)			
	GES (%)	**FARS (%)**	**Crash Location Parameters**
Relation to Junction	86.0	85.6	Non-Junction
	11.9	9.8	Intersection and Intersection Related
Pedestrian Location			**Non-Intersection and:**
	76.8	81.8	On Road, Not in Marked Crosswalk
	0.0	0.3	In Marked Crosswalk
	9.0	11.8	On Road, Crosswalk Availability Unknown
			Intersection and:
	0.8	0.4	In Marked Crosswalk
	6.9	3.3	Not in Crosswalk
	5.6	0.7	Unmarked Crosswalk
	0.8	1.0	Unknown Location
Traffic Control Device	83.3	92.9	No Traffic Control Signal or Sign
	1.7	2.4	Traffic Control Signal (Color, Flashing, Lane-Use, Highway)
	1.2	3.1	Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning)
Traffic Control Device × Relation to Junction × Pedestrian Location			**No Traffic Control Signal and:**
	68.0	70.3	Non-Intersection and on Road, Not in Marked Crosswalk
	5.4	2.3	Intersection and not in Crosswalk
			Traffic Control Signal and:
	0.3	0.4	Intersection and in Marked Crosswalk
	0.3	0.0	Intersection and Unknown Location

	GES (%)	**FARS (%)**	**Driving Environment Parameters**
Weather	88.3	88.9	Clear
	11.5	10.4	Adverse
Lighting Condition	61.7	12.9	Daylight
	16.3	27.2	Dark with Overhead Street Lighting
	14.6	56.3	Dark
Road Surface Condition	86.8	86.5	Dry
	12.3	13.3	Wet/Slippery
Weather × Road Surface Condition × Lighting			**Clear and Dry and:**
	58.1	11.7	Daylight
	13.1	23.2	Dark with Overhead Street Lighting
	12.7	46.8	Dark
	2.6	2.5	Dawn, Dusk
			Adverse and Wet/Slippery and:
	4.8	0.3	Dawn, Dusk
	3.0	0.4	Daylight
	2.3	2.8	Dark with Overhead Street Lighting
	1.1	5.0	Dark

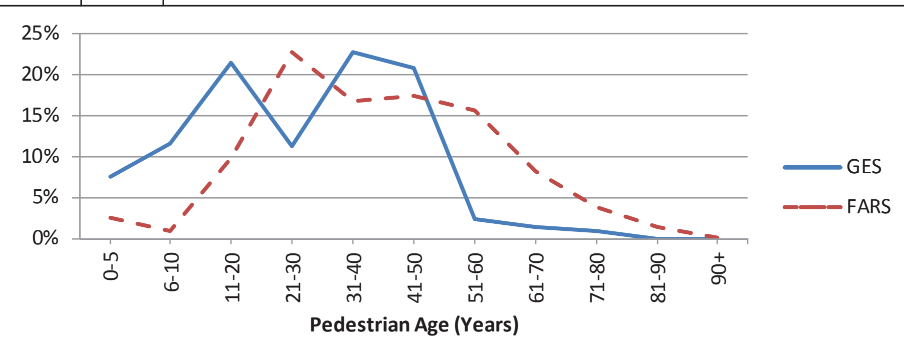
Vehicle Going Straight/Pedestrian In Road

	GES (%)	FARS (%)	Road Geometry Parameters
Roadway Alignment	82.9	91.7	Straight
	10.3	8.1	Curve
Roadway Grade	74.5	76.6	Level
	15.0	11.4	Grade, Unknown Slope
	1.9	3.5	Uphill
	0.8	3.5	Downhill
Roadway Alignment × Roadway Grade			**Straight and:**
	67.4	72.8	Level
	7.7	9.2	Grade, Unknown Slope
	0.2	2.4	Hillcrest
	0.8	2.9	Downhill
	1.9	2.2	Uphill
			Curve and:
	2.4	3.7	Level
	7.3	2.3	Grade, Unknown Slope

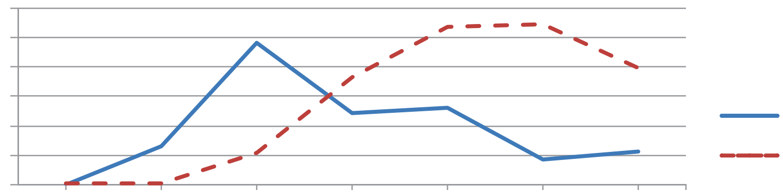
	GES (%)	FARS (%)	Driver Contributing Factors
Driver Impairment	1.6	8.9	Impairment
Vision Obscured	23.1	5.7	Obstruction
Distraction	15.7	7.8	Distracted
	2.6	2.0	Looked but Didn't See

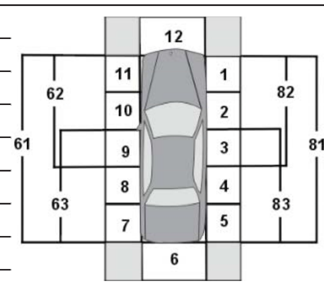
	GES (%)	FARS (%)	Pedestrian Actions/Characteristics
Pedestrian Impairment	5.8	26.0	Impairment
Inattentive	9.5	2.0	Inattentive
Visibility	2.7	21.4	Dark Clothes/Not Visible
Dart/Dash	23.0	6.8	Dart/Dash
Vision Obscured × Dart/Dash			**No Vision Obstruction and:**
	45.7	86.5	No Dart/Dash
	14.4	5.5	Dart/Dash - Ran Only
			Vision Obstruction and:
	8.4	0.7	Dart/Dash & Ran/Walked
	14.7	5.0	No Dart/Dash
Pedestrian Visibility × Dart/Dash			**Dark Clothes/Not Visible and:**
	0.0	0.5	Dart/Dash
	2.7	20.9	No Dart/Dash

Age



Vehicle Going Straight/Pedestrian In Road

	Vehicle Related Parameters		
Posted Speed Limit			
	GES (%)	**FARS (%)**	
Speed Related	2.9	7.0	Speed Related
Speed Related × Posted Speed Limit			**Not Speeding and:**
	23.5	4.8	20-25 MPH
	10.0	16.4	30-35 MPH
	11.9	24.8	40-45 MPH
	3.1	25.8	50-55 MPH
	0.8	17.9	60 MPH and over
			Speeding and:
	0.5	0.6	20-25 MPH
	0.3	1.2	30-35 MPH
	0.2	1.6	40-45 MPH
Attempted Avoidance Maneuver	63.5	71.2	No Corrective Action
			Braking Only:
	3.1	2.8	No Lockup
	0.2	2.4	Lockup
	1.2	1.2	Lockup Unknown
			Steering Only:
	3.2	6.6	Steering Left
	0.8	2.9	Steering Right
			Braking and Steering:
	0.4	2.5	Braking and Steering Left
	0.0	1.6	Braking and Steering Right
Area of Impact	41.7	70.0	12 O'clock Value
	3.2	7.4	1 O'clock Value
	3.0	3.7	11 O'clock Value
	9.1	2.1	2 O'clock Value
	9.4	0.7	10 Clock Value
	6.1	0.7	3 Clock Value
	6.5	0.2	Left-Front Side (62)
	6.6	0.5	Right-Front Side (82)
	2.8	10.6	Undercarriage



* Note that some categories are not shown because they represent smaller percentages and/or unknowns, other, or not-reported variables.

4.3 Vehicle Going Straight and Pedestrian Adjacent to Road

Vehicle Going Straight/Pedestrian Adjacent to Road			
Total Crashes - 4,243/ Total Fatal Crashes - 363 (2011 & 2012 Annual Crash Average)			
	GES (%)	**FARS (%)**	**Crash Location Parameters**
Relation to Junction	80.7	89.7	Non-Junction
	17.8	7.3	Intersection and Intersection Related
Pedestrian Location			**Non-Intersection and:**
	88.6	86.5	On Road, Not in Marked Crosswalk
	0.0	0.0	In Marked Crosswalk
	2.4	6.5	On Road, Crosswalk Availability Unknown
			Intersection and:
	2.2	0.6	In Marked Crosswalk
	2.7	1.9	Not in Crosswalk
	0.3	0.3	Unmarked Crosswalk
	0.7	0.6	Unknown Location
Traffic Control Device	88.2	94.6	No Traffic Control Signal or Sign
	6.0	1.8	Traffic Control Signal (Color, Flashing, Lane-Use, Highway)
	4.6	2.6	Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning)
Traffic Control Device × Relation to Junction × Pedestrian Location			**No Traffic Control Signal and:**
	73.1	77.1	Non-Intersection and on Road, Not in Marked Crosswalk
	2.0	1.5	Intersection and not in Crosswalk
			Traffic Control Signal and:
	2.2	0.3	Intersection and in Marked Crosswalk
	0.0	0.1	Intersection and Unknown Location

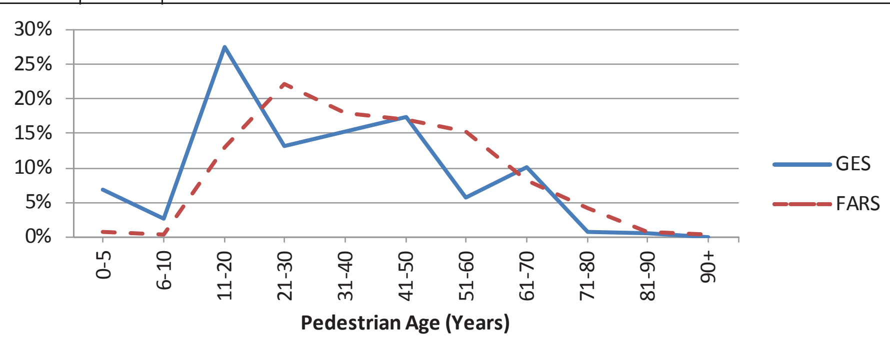
	GES (%)	**FARS (%)**	**Driving Environment Parameters**
Weather	94.3	88.4	Clear
	5.7	11.0	Adverse
Lighting Condition	43.7	10.9	Daylight
	23.7	24.5	Dark with Overhead Street Lighting
	31.1	61.3	Dark
Road Surface Condition	85.2	85.1	Dry
	11.4	14.6	Wet/Slippery
Weather × Road Surface Condition × Lighting			**Clear and Dry and:**
	36.6	10.2	Daylight
	19.7	20.0	Dark with Overhead Street Lighting
	28.4	50.7	Dark
	0.6	2.5	Dawn, Dusk
			Adverse and Wet/Slippery and:
	0.2	0.1	Dawn, Dusk
	0.7	0.3	Daylight
	3.0	3.4	Dark with Overhead Street Lighting
	1.8	5.6	Dark

Vehicle Going Straight/Pedestrian Adjacent to Road

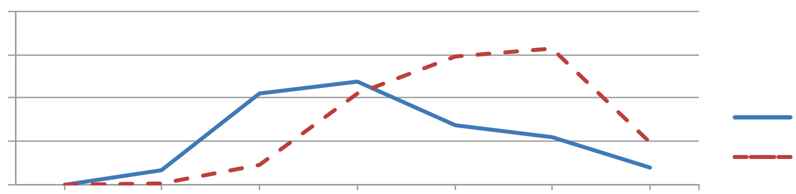
	GES (%)	FARS (%)	Road Geometry Parameters
Roadway Alignment	89.8	92.8	Straight
	4.5	7.0	Curve
Roadway Grade	72.3	79.8	Level
	9.1	10.1	Grade, Unknown Slope
	0.1	2.2	Uphill
	5.7	4.3	Downhill
Roadway Alignment × Roadway Grade			**Straight and:**
	68.6	75.2	Level
	8.7	9.1	Grade, Unknown Slope
	2.3	1.9	Hillcrest
	2.1	3.7	Downhill
	0.1	1.7	Uphill
			Curve and:
	3.4	4.5	Level

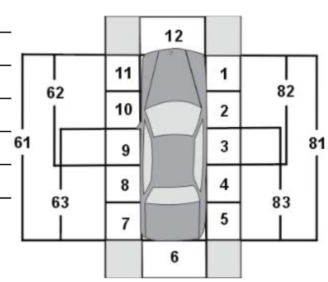
	GES (%)	FARS (%)	Driver Contributing Factors
Driver Impairment	2.0	13.4	Impairment
Vision Obscured	11.3	9.9	Obstruction
Distraction	13.3	10.9	Distracted
	1.7	4.0	Looked but Didn't See

	GES (%)	FARS (%)	Pedestrian Actions/Characteristics
Pedestrian Impairment	18.9	22.3	Impairment
Inattentive	1.9	2.8	Inattentive
Visibility	11.1	31.7	Dark Clothes/Not Visible
Dart/Dash	16.7	7.6	Dart/Dash
Vision Obscured × Dart/Dash			**No Vision Obstruction and:**
	61.4	81.3	No Dart/Dash
	11.8	6.7	Dart/Dash - Ran Only
			Vision Obstruction and:
	4.8	0.8	Dart/Dash & Ran/Walked
	6.5	9.1	No Dart/Dash
Pedestrian Visibility × Dart/Dash			**Dark Clothes/Not Visible and:**
	0.1	1.4	Dart/Dash
	11.0	30.3	No Dart/Dash
Age			



Vehicle Going Straight/Pedestrian Adjacent to Road

	Vehicle Related Parameters		
Posted Speed Limit			
	GES (%)	FARS (%)	
Speed Related	1.0	6.2	Speed Related
Speed Related × Posted Speed Limit			**Not Speeding and:**
	19.8	3.6	20-25 MPH
	21.3	18.2	30-35 MPH
	12.1	27.5	40-45 MPH
	10.4	29.6	50-55 MPH
	4.0	9.6	60 MPH and over
			Speeding and:
	0.2	1.0	20-25 MPH
	0.3	2.2	30-35 MPH
	0.3	1.5	40-45 MPH
Attempted Avoidance Maneuver	57.6	76.9	No Corrective Action
			Braking Only:
	7.1	2.3	No Lockup
	1.6	1.5	Lockup
	0.8	1.5	Lockup Unknown
			Steering Only:
	4.7	3.0	Steering Left
	0.3	1.9	Steering Right
			Braking and Steering:
	0.3	2.8	Braking and Steering Left
	0.0	0.7	Braking and Steering Right
Area of Impact	42.4	81.3	12 O'clock Value
	12.3	11.0	1 O'clock Value
	6.8	2.1	11 O'clock Value
	13.9	1.7	2 O'clock Value
	5.3	0.0	Right (81)
	6.4	0.7	Right-Front Side (82)



* Note that some categories are not shown because they represent smaller percentages and/or unknowns, other, or not-reported variables.

4.4 Vehicle Turning Left and Pedestrian Crossing the Road

Vehicle Turning Left/Pedestrian Crossing Road			
Total Crashes - 14,427 / Total Fatal Crashes - 114 (2011 & 2012 Annual Crash Average)			
	GES (%)	FARS (%)	Crash Location Parameters
Relation to Junction	1.5	2.2	Non-Junction
	92.5	90.8	Intersection and Intersection Related
Pedestrian Location			**Non-Intersection and:**
	10.5	15.8	On Road, Not in Marked Crosswalk
	0.7	0.9	In Marked Crosswalk
	0.2	0.0	On Road, Crosswalk Availability Unknown
			Intersection and:
	52.0	58.3	In Marked Crosswalk
	6.0	12.7	Not in Crosswalk
	16.5	9.2	Unmarked Crosswalk
	13.0	2.2	Unknown Location
Traffic Control Device	20.5	21.9	No Traffic Control Signal or Sign
	62.2	60.1	Traffic Control Signal (Color, Flashing, Lane-Use, Highway)
	12.1	18.0	Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning)
Traffic Control Device × Relation to Junction × Pedestrian Location			**No Traffic Control Signal and:**
	1.0	1.3	Non-Intersection and on Road, Not in Marked Crosswalk
	0.8	3.1	Intersection and not in Crosswalk
	5.4	3.1	Intersection and in Unmarked Crosswalk
			Traffic Control Signal and:
	40.3	44.7	Intersection and in Marked Crosswalk
	7.1	1.3	Intersection and Unknown Location
	7.3	3.5	Intersection and in Unmarked Crosswalk
	4.9	9.2	Intersection and not in Crosswalk
			Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning) and:
	4.9	9.2	Intersection and in Marked Crosswalk

	GES (%)	FARS (%)	Driving Environment Parameters
Weather	79.1	90.8	Clear
	20.9	8.3	Adverse
Lighting Condition	64.0	67.1	Daylight
	32.9	23.7	Dark with Overhead Street Lighting
	2.5	3.9	Dark
Road Surface Condition	65.2	83.8	Dry
	27.3	12.7	Wet/Slippery
Weather × Road Surface Condition × Lighting			**Clear and Dry and:**
	48.6	57.5	Daylight
	14.9	18.0	Dark with Overhead Street Lighting
	1.2	3.5	Dark
	0.4	4.4	Dawn, Dusk
			Adverse and Wet/Slippery and:
	0.3	0.4	Dawn, dusk
	4.5	4.4	Daylight
	15.4	3.1	Dark with Overhead Street Lighting
	0.4	0.4	Dark

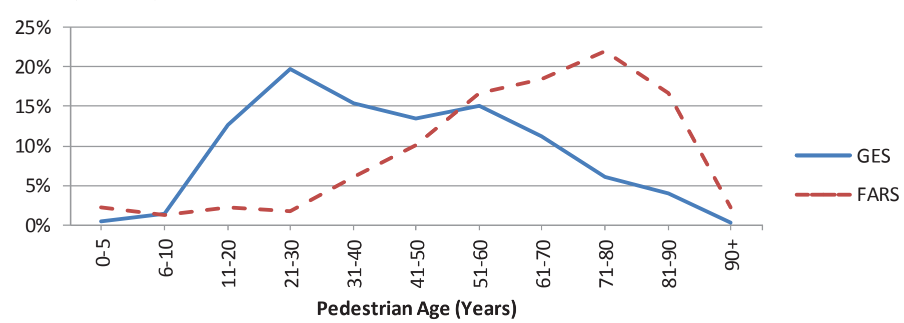
Vehicle Turning Left/Pedestrian Crossing Road

	GES (%)	FARS (%)	Road Geometry Parameters
Roadway Alignment	81.2	93.0	Straight
	0.5	3.1	Curve
Roadway Grade	64.4	81.1	Level
	3.1	4.4	Grade, Unknown Slope
	1.0	0.9	Uphill
	0.3	3.9	Downhill
	6.3	2.6	Non-Trafficway Area
Roadway Alignment × Roadway Grade			**Straight and:**
	64.0	79.4	Level
	2.9	4.4	Grade, Unknown Slope
	0.2	0.0	Hillcrest
	0.3	3.9	Downhill
	1.0	0.4	Uphill
			Curve and:
	0.2	1.8	Level

	GES (%)	FARS (%)	Driver Contributing Factors
Driver Impairment	1.3	3.9	Impairment
Vision Obscured	11.6	18.4	Obstruction
Distraction	11.4	14.9	Distracted
	9.3	6.1	Looked but Didn't See

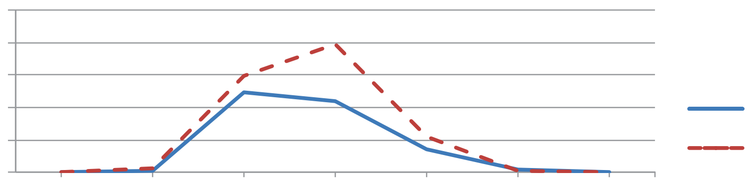
	GES (%)	FARS (%)	Pedestrian Actions/Characteristics
Pedestrian Impairment	1.5	7.5	Impairment
Inattentive	2.4	0.9	Inattentive
Visibility	3.6	4.4	Dark Clothes/Not Visible
Dart/Dash	4.7	6.1	Dart/Dash
Vision Obscured × Dart/Dash			**No Vision Obstruction and:**
	75.3	75.4	No Dart/Dash
	4.1	3.9	Dart/Dash - Ran Only
			Vision Obstruction and:
	0.4	1.8	Dart/Dash & Ran/Walked
	11.2	16.7	No Dart/Dash
Pedestrian Visibility × Dart/Dash			**Dark Clothes/Not Visible and:**
	0.1	0.4	Dart/Dash
	3.5	3.9	No Dart/Dash

Age

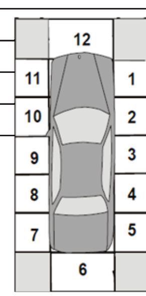


Vehicle Turning Left/Pedestrian Crossing Road

Vehicle Related Parameters



	GES (%)	FARS (%)	
Posted Speed Limit	6.4	2.6	No Speed Limit
Speed Related	1.9	2.2	Speed Related
Speed Related × Posted Speed Limit			**Not Speeding and:**
	21.5	28.9	20-25 MPH
	20.4	38.6	30-35 MPH
	7.0	10.1	40-45 MPH
	0.8	0.4	50-55 MPH
	0.1	0.0	60 MPH and over
			Speeding and:
	1.3	0.9	20-25 MPH
	0.2	0.4	30-35 MPH
	0.1	0.9	40-45 MPH
Attempted Avoidance Maneuver	56.4	81.1	No Corrective Action
			Braking Only:
	3.3	2.2	No Lockup
	0.0	1.3	Lockup
	0.2	1.8	Lockup Unknown
			Steering Only:
	0.1	0.4	Steering Left
	0.1	0.4	Steering Right
			Braking and Steering:
	0.0	0.0	Braking and Steering Left
	0.0	0.0	Braking and Steering Right
Area of Impact	70.7	81.6	12 O'clock Value
	2.0	3.9	1 O'clock Value
	5.0	6.1	11 O'clock Value
	0.6	0.9	2 O'clock Value



* Note that some categories are not shown because they represent smaller percentages and/or unknowns, other, or not-reported variables.

4.5 Vehicle Turning Right and Pedestrian Crossing the Road

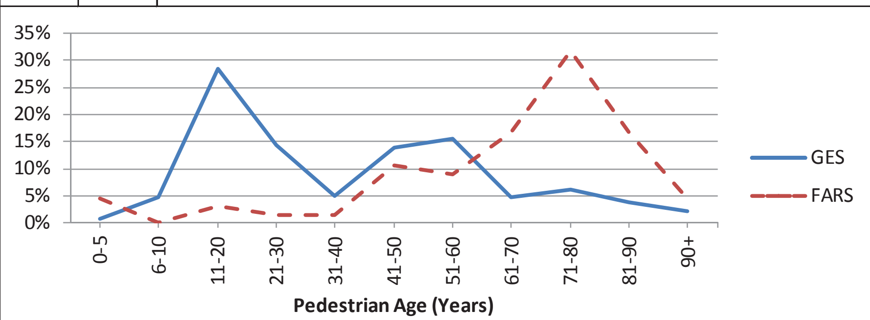
Vehicle Turning Right/Pedestrian Crossing Road

	GES (%)	FARS (%)	Road Geometry Parameters
Roadway Alignment	78.0	98.5	Straight
	0.9	0.0	Curve
Roadway Grade	63.0	81.8	Level
	3.5	4.5	Grade, Unknown Slope
	0.5	3.0	Uphill
	0.0	4.5	Downhill
	5.0	1.5	Non-Trafficway Area
Roadway Alignment × Roadway Grade			**Straight and:**
	59.8	81.8	Level
	3.4	4.5	Grade, Unknown Slope
	0.1	0.0	Hillcrest
	0.0	4.5	Downhill
	0.2	3.0	Uphill
			Curve and:
	0.4	0.0	Level

	GES (%)	FARS (%)	Driver Contributing Factors
Driver Impairment	0.1	1.5	Impairment
Vision Obscured	6.9	15.2	Obstruction
Distraction	22.2	19.7	Distracted
	11.6	3.0	Looked but Didn't See

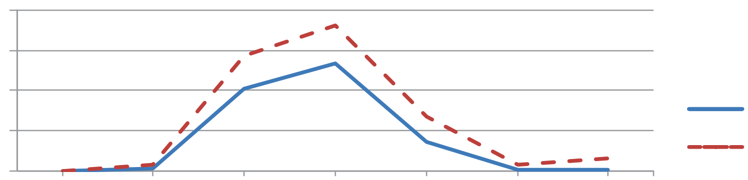
	GES (%)	FARS (%)	Pedestrian Actions/Characteristics
Pedestrian Impairment	0.7	3.0	Impairment
Inattentive	1.1	1.5	Inattentive
Visibility	2.6	1.5	Dark Clothes/Not Visible
Dart/Dash	6.0	4.5	Dart/Dash
Vision Obscured × Dart/Dash			**No Vision Obstruction and:**
	72.5	80.3	No Dart/Dash
	5.9	3.0	Dart/Dash - Ran Only
			Vision Obstruction and:
	0.0	1.5	Dart/Dash & Ran/Walked
	6.9	13.6	No Dart/Dash
Pedestrian Visibility × Dart/Dash			**Dark Clothes/Not Visible and:**
	0.3	0.0	Dart/Dash
	2.3	1.5	No Dart/Dash

Age

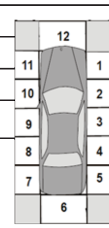


Vehicle Turning Right/Pedestrian Crossing Road

Vehicle Related Parameters



	GES (%)	FARS (%)	
Posted Speed Limit	7.3	3.0	No Speed Limit
Speed Related	1.0	1.5	Speed Related
Speed Related × Posted Speed Limit			**Not Speeding and:**
	19.5	27.3	20-25 MPH
	19.9	36.4	30-35 MPH
	6.6	13.6	40-45 MPH
	0.1	1.5	50-55 MPH
	0.4	3.0	60 MPH and over
			Speeding and:
	0.0	1.5	20-25 MPH
	0.4	0.0	30-35 MPH
	0.0	0.0	40-45 MPH
Attempted Avoidance Maneuver	50.6	86.4	No Corrective Action
			Braking Only:
	1.9	1.5	No Lockup
	0.0	0.0	Lockup
	0.0	0.0	Lockup Unknown
			Steering Only:
	0.2	1.5	Steering Left
	0.0	0.0	Steering Right
			Braking and Steering:
	0.0	0.0	Braking and Steering Left
	0.0	0.0	Braking and Steering Right
Area of Impact	74.3	72.7	12 O'clock Value
	6.7	6.1	1 O'clock Value
	3.1	4.5	11 O'clock Value
	4.0	3.0	2 O'clock Value



* Note that some categories are not shown because they represent smaller percentages and/or unknowns, other, or not-reported variables.

5 Depiction of Priority Pedestrian Pre-Crash Scenarios

Pre-crash scenarios are depicted to convey information that will be helpful in the development of functional requirements, performance specifications, test procedures, and estimation of safety benefits for V2P-based safety applications. For each priority pre-crash scenario, the pre-crash kinematics leading to the moment of impact are illustrated graphically and plotted to illustrate the relationship between the vehicle and pedestrian velocities and the closing gap between them. Plots show the crash timeline that occurs in the absence of a crash countermeasure.[7] Each depiction includes the TTC equation if no crash countermeasure is applied. Although the overall stopping distance incorporates driver reaction time, system delays, and vehicle delays, the analysis accounts for only the actual stopping distance of the vehicle.

While the pre-crash scenario depictions are designed to encompass a wide range of possible scenarios, they must rely on a set of assumptions in order to be analyzed and accurately modeled**.** These assumptions help to simplify the vehicle dynamics and generalize the driving conditions to allow for the development of fundamental kinematic equations. The assumptions are categorized in Table 7 by priority pre-crash scenarios.

[7] Crash countermeasure refers to any avoidance maneuver (initiated by driver, system, or pedestrian) after a crash conflict has been recognized. Pedestrians have the ability to avoid the crash through their actions. However, pedestrians can immediately change directions and speeds and may have erratic behaviors in these situations (freeze, jump out of the way, etc.), therefore the focus of this report will be on vehicle-based countermeasures (using a recommended avoidance maneuver of braking).

Table 7. Priority Pre-Crash Scenario Analysis Assumptions

Assumption	Description	Priority Scenario				
		Vehicle-Going-Straight/ Pedestrian-In-Road	Vehicle-Going-Straight/ Pedestrian-Adjacent- to-Road	Vehicle-Going-Straight/ Pedestrian-Crossing-Road	Vehicle-Turning-Left/ Pedestrian-Crossing-Road	Vehicle-Turning-Right/ Pedestrian-Crossing-Road
1. Constant Vehicle Acceleration	The acceleration level while the vehicle is braking is instantaneously achieved and is constant through the entire braking period.	✓	✓	✓	✓	✓
2. No Delay	There is no delay between the detection of the critical event and the initiation of the avoidance maneuver by the vehicle.	✓	✓	✓	✓	✓
3. Constant Radius	The vehicle is able to initiate and maintain a turn along an arc of constant radius without loss of traction.	✗	✗	✗	✓	✓
4. Turn and Brake without Traction Loss	The vehicle is able to turn and brake at the same time without loss of traction.	✗	✗	✗	✓	✓
5. Constant Pedestrian Acceleration	The acceleration level while the pedestrian is avoiding the vehicle is instantaneously achieved, is constant, and is independent of pedestrian dimensions.	✗	✓	✓	✓	✓
6. Constant Pedestrian Size	The pedestrian's size is constant and the stride length does not affect the distance between the vehicle and the pedestrian.	✗	✓	✓	✓	✓

Assumptions 1, 2, 3, and 4 in Table 7 are necessary to account for variability in driver behavior (e.g., response time or braking level) and vehicle performance capabilities (e.g., coefficient of friction between the tires and the road, maximum braking level, or turning radius), which will all affect the vehicle dynamics. Assumptions 5 and 6 are necessary to simplify unpredictable pedestrian movement patterns.

Additionally, not all assumptions are applicable to every scenario. Assumptions 5 and 6 do not apply to the vehicle-going-straight/pedestrian-in-road scenario since it does not feature pedestrian movement. Also, assumptions 3 and 4 do not apply to the 3 vehicle-going-straight scenarios since these scenarios do not feature vehicle turning maneuvers.

Several constant values are used in the examples provided in Sections 5.2 through 5.4 since they represent common values. These values are shown below in Table 8 and are referred to in this report as "standard pedestrian speed," "standard vehicle length," and "standard pedestrian width" in these sections. The pedestrian walking speed is based on an average adult walking speed [12]. The vehicle length is the approximate length of common 2016 model-year full-sized sedans as determined from a literature review. The pedestrian width is based on the forearm breath of a 95th percentile male [13].

Table 8. Constants Used in Pre-Crash Scenario Examples

Variable	Value	Description
Pedestrian Walking Speed	3.1 mph	Average adult walking speed
Vehicle Length	17 feet	Approximate length of average full-sized car
Pedestrian Width	19.9 inches	Forearm breadth of 95th percentile male

5.1 Vehicle Going Straight and Pedestrian in Road

The scenario configuration for a vehicle going straight and approaching a pedestrian who is stopped in the road is shown in Figure 69.

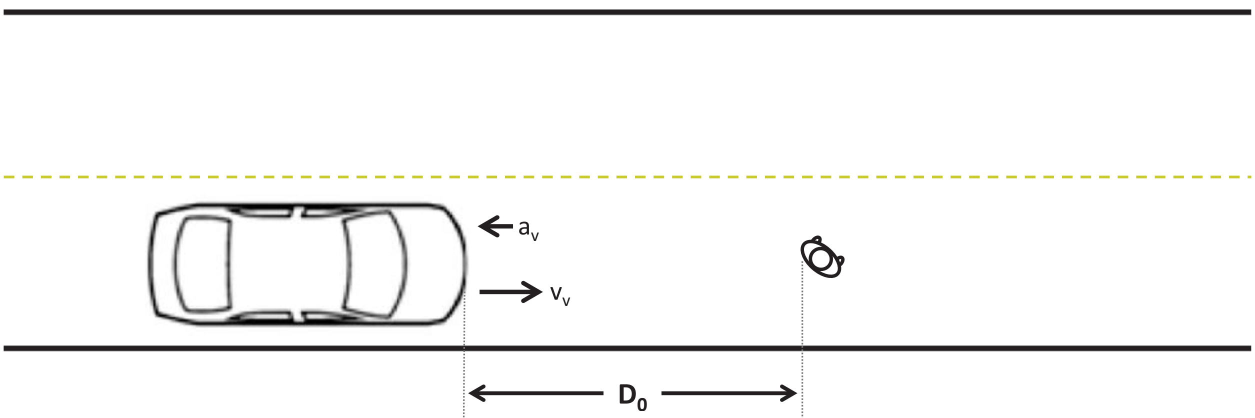


Figure 69. Vehicle-Going-Straight/Pedestrian in Road Pre-Crash Scenario Configuration

If the vehicle does not react to the pedestrian's presence in the road, then a collision is guaranteed and the time-to-collision may be calculated from the initial gap and the velocity of the vehicle:

$$ttc = \frac{D_0}{v_{vi}} \tag{1}$$

Figure 70 traces the time history of this pre-crash scenario.

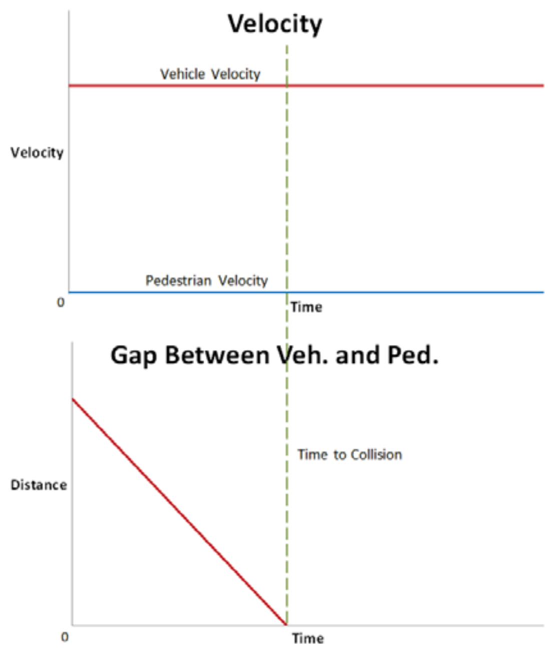


Figure 70. Timeline of Vehicle-Going-Straight/Pedestrian-in-Road Pre-Crash Scenario

The critical event that determines if a vehicle-going-straight/pedestrian-in-road crash will be imminent is the presence of a pedestrian who is stopped in the same lane as a moving vehicle, and in front of the vehicle. To be effective, crash countermeasures must account for the distance between the vehicle and pedestrian as well as the velocity and acceleration of the vehicle. A system that continuously calculated the time-to-collision, as seen in Equation (2), would be able to alert the driver of an impending collision as soon as possible. The recommended avoidance maneuver for the vehicle in this scenario is to brake.

If the critical event has occurred and the vehicle executes the recommended avoidance maneuver, the time to collision becomes:

$$ttc = \frac{-v_{vi} + \sqrt{{v_{vi}}^2 + 2a_v D_0}}{a_v} \qquad (2)$$

Where:

TTC	=	time-to-collision
D_0	=	initial gap between the front of the vehicle and the pedestrian
v_{vi}	=	initial velocity of the vehicle
a_v	=	acceleration of the vehicle

Figure 71 traces the time history of the scenario with vehicle braking. The gap between the vehicle and the pedestrian decreases with time until the vehicle stops or a collision occurs.

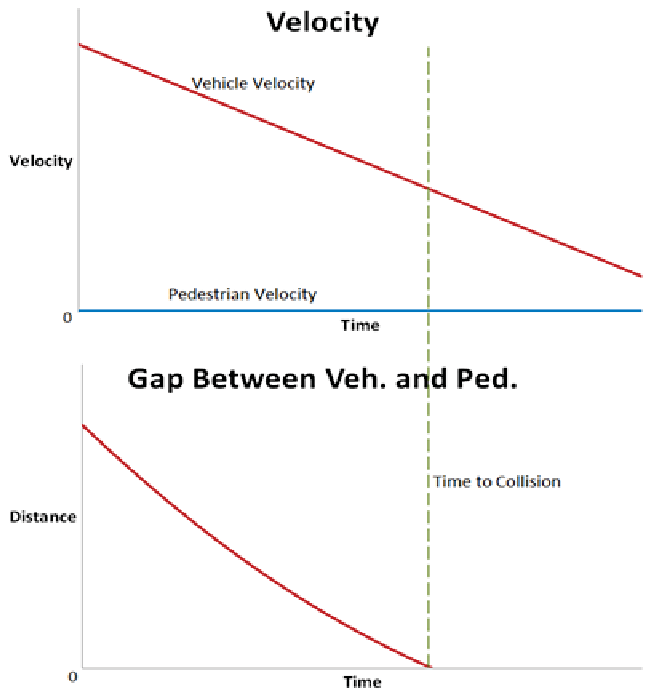


Figure 71. Vehicle-Going-Straight/Pedestrian-in-Road Timeline With Avoidance Maneuver

Vehicle-going-straight/pedestrian-in-road crashes occur if the initial gap between the front of the vehicle and the pedestrian is less than the stopping distance of the vehicle. The stopping distance, as seen in Equation (3), is calculated from the initial velocity and the acceleration of the vehicle.

$$S_d = \frac{-{v_{vi}}^2}{2a_v} \tag{3}$$

A collision will be avoided in this scenario if the initial gap is greater than the stopping distance of the vehicle. This relationship is expressed as:

$$D_0 > \frac{-{v_{vi}}^2}{2a_v} \tag{4}$$

If a collision is avoided, it may be important to know the final gap between the vehicle and the pedestrian when the vehicle stops. This gap is found to be:

$$\delta = D_0 + \frac{{v_{vi}}^2}{2a_v} \tag{5}$$

A table of the required minimum stopping distances, given an initial vehicle velocity and braking level, is seen below in Table 9. A color gradient is used to illustrate the effect harder braking and lower speeds have on the time needed to come to a full stop. The coloring represents the minimum allowable TTC at which braking should occur to stop the vehicle and avoid a collision. The minimum TTC is based on the distance that it takes for a vehicle to stop given the specified speed and braking level. It is the last moment that a warning can be issued with instantaneous reaction and/or automatic control in order to avoid a crash. Green-colored values in Table 9 represent a lower minimum TTC (closer to 0 sec) while red-colored values represent a higher minimum TTC (closer to 5 sec).

Table 9. Minimum Stopping Distance (ft.) by Initial Velocity and Braking Level

Vehicle Initial Velocity (mph)	Brake Level (g)								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
75	1879	939	626	470	376	313	268	235	209
70	1637	818	546	409	327	273	234	205	182
65	1411	706	470	353	282	235	202	176	157
60	1202	601	401	301	240	200	172	150	134
55	1010	505	337	253	202	168	144	126	112
50	835	418	278	209	167	139	119	104	93
45	676	338	225	169	135	113	97	85	75
40	534	267	178	134	107	89	76	67	59
35	409	205	136	102	82	68	58	51	45
30	301	150	100	75	60	50	43	38	33
25	209	104	70	52	42	35	30	26	23
20	134	67	45	33	27	22	19	17	15
15	75	38	25	19	15	13	11	9	8
10	33	17	11	8	7	6	5	4	4
5	8	4	3	2	2	1	1	1	1

A legend for the color gradients used in Table 9 to identify the minimum allowable TTC's for brake onset is shown in Figure 72.

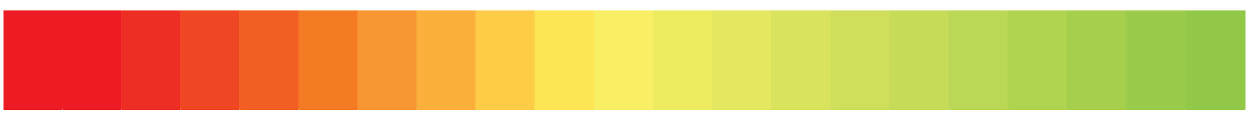


Figure 72. Color Palette of Minimum Allowable TTC's for Brake Onset Used in Table 9

5.2 Vehicle Going Straight and Pedestrian Adjacent to Road

This scenario is depicted for two configurations in which the vehicle is going straight and the pedestrian is adjacent to the road and moving either towards the vehicle or away from the vehicle. The primary difference between the two configurations is the use of a negative pedestrian velocity when the pedestrian is approaching the vehicle.

The scenario configuration for the vehicle going straight and approaching a pedestrian who is adjacent to the road and moving towards the vehicle is shown in Figure 73.

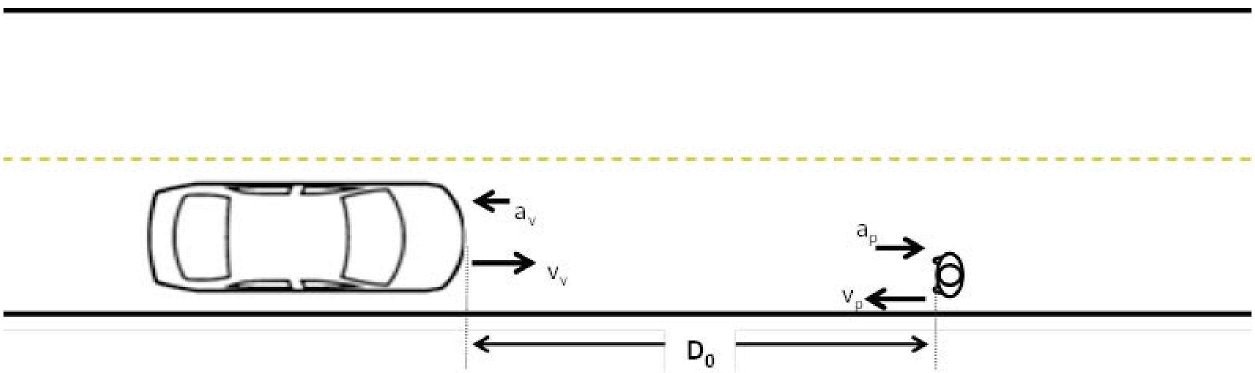


Figure 73. Vehicle-Going-Straight/Pedestrian-Adjacent-and-Approaching Pre-Crash Scenario Configuration

Similarly, the scenario configuration for the vehicle going straight and approaching a pedestrian who is adjacent to the road and moving away from the vehicle is shown in Figure 74.

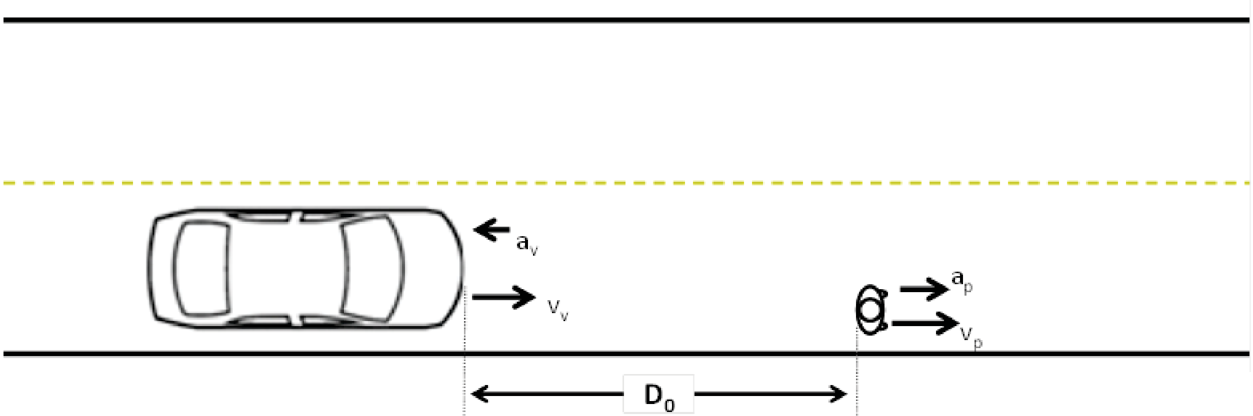


Figure 74. Vehicle-Going-Straight/Pedestrian-Adjacent-and-Moving-Away Pre-Crash Scenario Configuration

Under the initial conditions of the pre-crash scenario, and assuming the vehicle makes no avoidance maneuver, a collision is guaranteed. The TTC is then calculated from only the initial gap and the vehicle and pedestrian velocities:

$$ttc = \frac{D_0}{v_{vi} - v_{pi}} \tag{6}$$

Figure 75 traces the time history of this pre-crash scenario.

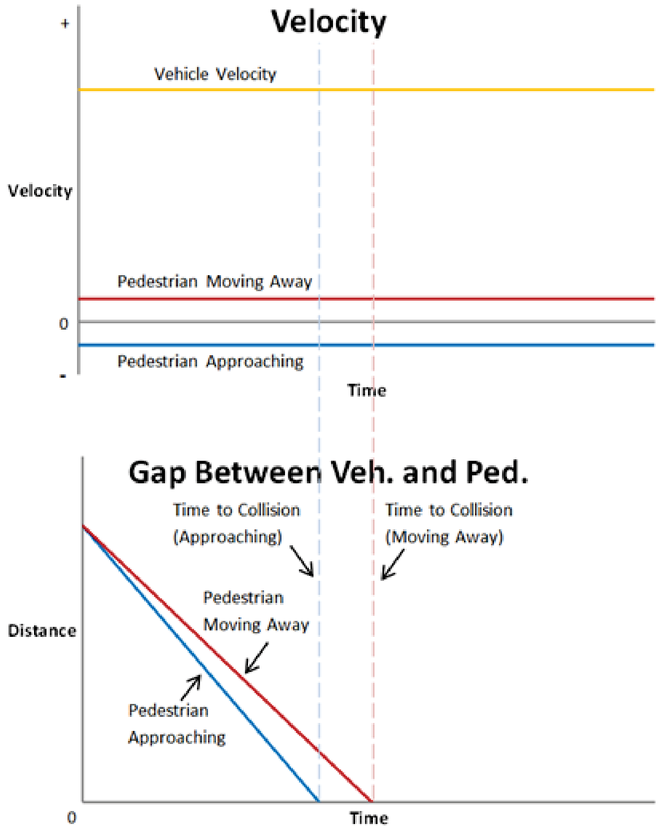


Figure 75. Timeline of Vehicle-Going-Straight/Pedestrian-Adjacent Pre-Crash Scenario

The critical event that determines if a vehicle-going-straight/pedestrian-adjacent crash will be imminent is the presence of a pedestrian who is in front of a moving vehicle and moving in the same lane as the vehicle. Crash countermeasures must account for the gap between the pedestrian and the vehicle, and the velocities and accelerations of both the pedestrian and the vehicle. A system that continuously calculated the time-to-collision would be able to alert the driver of an impending collision as early as possible. The recommended avoidance maneuver for the vehicle in this scenario is to brake.

If the critical event has occurred and the vehicle executes the recommended avoidance maneuver then the time-to-collision becomes:

$$ttc = \frac{(v_{pi} - v_{vi}) + \sqrt{(v_{vi} - v_{pi})^2 + 2D_0(a_v - a_p)}}{a_v - a_p} \tag{7}$$

Where:
TTC = Time-to-collision

D_0 = Initial gap between the front of the vehicle and the pedestrian
v_{vi} = Initial velocity of the vehicle
v_{pi} = Initial velocity of the pedestrian
a_v = Acceleration of the vehicle
a_p = Acceleration of the pedestrian

Figure 76 traces the time history of this pre-crash scenario with vehicle braking. The gap between the vehicle and the pedestrian decreases with time until both the vehicle and pedestrian have stopped or a collision occurs. The vehicle is braking while the pedestrian maintains a constant speed.

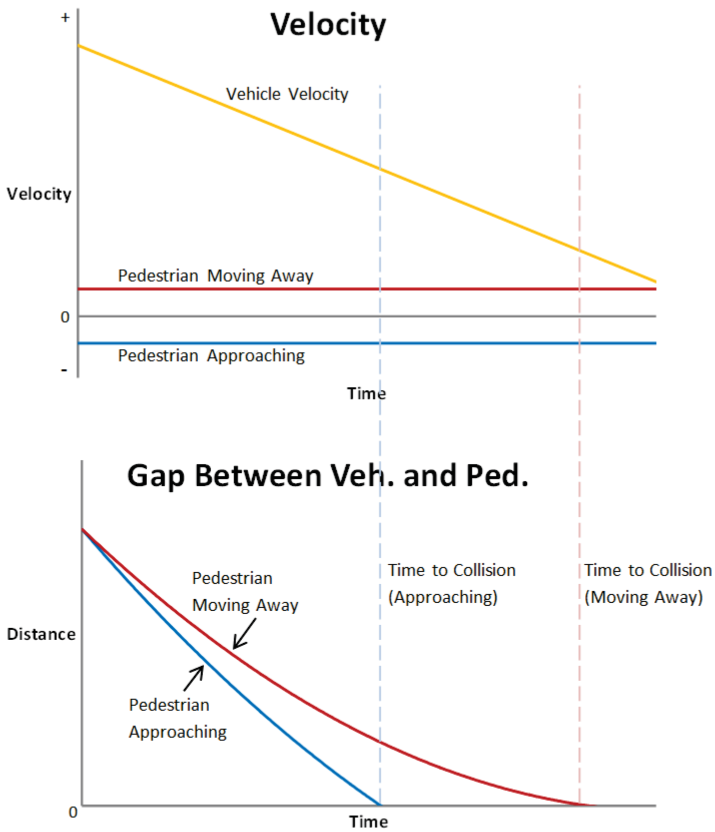


Figure 76. Timeline of Vehicle-Going-Straight/Pedestrian-Adjacent Pre-Crash Scenario With Vehicle Avoidance Maneuver

Vehicle-going-straight/pedestrian-adjacent crashes occur if the sum of the initial gap and the distance traveled by the pedestrian is less than or equal to the stopping distance of the vehicle. This relationship is expressed as:

$$D_0 + d_p \leq S_d \tag{8}$$

Where d_p is the distance traveled by the pedestrian.

If a collision is avoided, it may be important to know the final gap between the vehicle and the pedestrian when the vehicle stops. This gap is found to be:

$$\delta = D_0 + \frac{(a_v + a_p){v_{vi}}^2 - 2a_v v_{vi} v_{pi}}{2{a_v}^2} \tag{9}$$

Table 10 and Table 11 show the final gaps between the vehicle and the pedestrian when the vehicle has stopped. The values are created using the standard pedestrian speed as shown in Table 8. To provide an example, a time of 3 seconds was selected to define the initial gap, which is the distance to collision at the initial vehicle speed. A negative value represents the distance traveled by the vehicle after a collision occurs. A positive value represents the gap remaining when the vehicle stops without a collision. These tables are useful for identifying the limits at which a crash may be avoided when the pedestrian is moving towards or away from the approaching vehicle. Given the initial conditions, a red (negative) value denotes a crash and a green (positive) value denotes an avoided collision.

Table 10. Final Gap (ft.) by Initial Velocity, Initial Distance, and Braking Level (Moving Away)

Vehicle Initial Velocity (mph)	Brake Level (g)								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
75	-1394	-532	-245	-101	-15	43	84	115	138
70	-1184	-438	-189	-65	10	59	95	122	142
65	-991	-352	-140	-33	31	73	104	126	144
60	-814	-275	-95	-6	48	84	110	129	144
55	-655	-206	-57	18	63	93	114	130	142
50	-512	-146	-24	37	74	98	115	129	139
45	-385	-94	4	52	81	101	115	125	133
40	-276	-50	25	63	86	101	111	120	126
35	-183	-14	42	70	87	98	106	112	117
30	-106	13	53	72	84	92	98	102	106
25	-47	32	58	71	79	84	88	90	93
20	-4	42	57	65	70	73	75	76	78
15	22	44	51	55	57	59	60	60	61
10	31	38	40	41	41	42	42	42	43
5	24	23	23	23	22	22	22	22	22

Table 11. Final Gap (ft.) by Initial Velocity, Initial Distance, and Braking Level (Approaching)

Vehicle Initial Velocity (mph)	Brake Level (g)								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
75	-1704	-687	-348	-179	-77	-9	39	76	104
70	-1474	-583	-286	-137	-48	11	53	85	110
65	-1260	-487	-229	-100	-23	28	65	93	114
60	-1063	-399	-178	-68	-1	43	74	98	117
55	-882	-320	-133	-39	17	55	81	101	117
50	-719	-249	-93	-15	32	64	86	103	116
45	-572	-187	-59	6	44	70	88	102	112
40	-441	-133	-30	22	53	73	88	99	107
35	-328	-87	-7	34	58	74	85	94	100
30	-231	-49	11	41	59	72	80	87	92
25	-151	-20	23	45	58	67	73	77	81
20	-87	0	30	44	53	59	63	66	69
15	-40	13	31	39	45	48	51	53	54
10	-10	17	26	30	33	35	36	37	38
5	3	13	16	17	18	19	19	20	20

If the vehicle does not brake and the pedestrian accelerates, then the time-to-collision becomes:

$$ttc = \frac{v_{vi} - v_{pi} + \sqrt{(v_{vi} - v_{pi})^2 - 2D_0 a_p}}{a_p} \quad (10)$$

In this scenario, the collision may be avoided if:

$$(v_{vi} - v_p)^2 - 2a_p D_0 \leq 0 \quad (11)$$

5.3 Vehicle Going Straight and Pedestrian Crossing the Road

The scenario configuration for the vehicle going straight and approaching the path of a pedestrian who is crossing the road is shown in Figure 77.

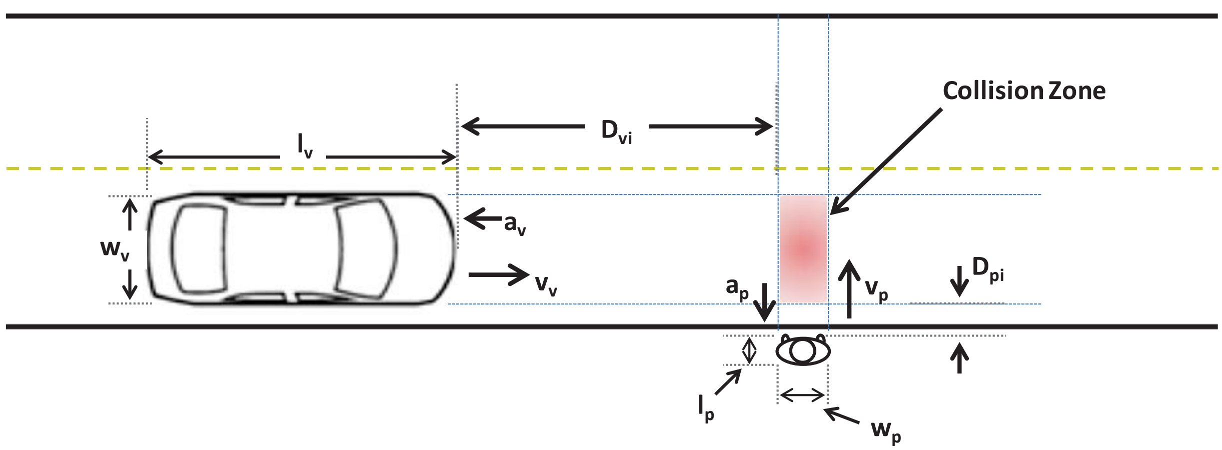


Figure 77. Vehicle-Going-Straight/Pedestrian-Crossing-Road Pre-Crash Scenario Configuration

A collision will occur in this scenario if the vehicle and the pedestrian occupy the collision zone at the same time. This relationship can be expressed as:

$$t_{pr} \leq t_{vc} \leq t_{pc}$$

OR

$$t_{vr} \leq t_{pc} \leq t_{vc} \quad (12)$$

Under the initial conditions of the pre-crash scenario, and assuming that the vehicle does not make an avoidance maneuver, the times for the vehicle to reach and clear the collision zone are:

$$t_{vr} = \frac{D_{vi}}{v_{vi}} \tag{13}$$

$$t_{vc} = \frac{D_{vi} + l_v + w_p}{v_{vi}} \tag{14}$$

Similarly, if the pedestrian does not make an avoidance maneuver, the times for the pedestrian to reach and clear the collision zone are:

$$t_{pr} = \frac{D_{pi}}{v_{pi}} \tag{15}$$

$$t_{pc} = \frac{D_{pi} + w_v + l_p}{v_{pi}} \tag{16}$$

Where:

v_{pi}	=	initial velocity of pedestrian
v_{vi}	=	initial velocity of vehicle
l_p	=	length of pedestrian
l_v	=	length of vehicle
w_p	=	width of pedestrian
w_v	=	width of vehicle
D_{pi}	=	initial distance from front of pedestrian to collision zone
D_{vi}	=	initial distance from front of vehicle to collision zone
t_{pr}	=	time for pedestrian to reach collision zone
t_{pc}	=	time for pedestrian to clear collision zone
t_{vr}	=	time for vehicle to reach collision zone
t_{vc}	=	time for vehicle to clear collision zone

Figure 78 shows the time history of this pre-crash scenario.

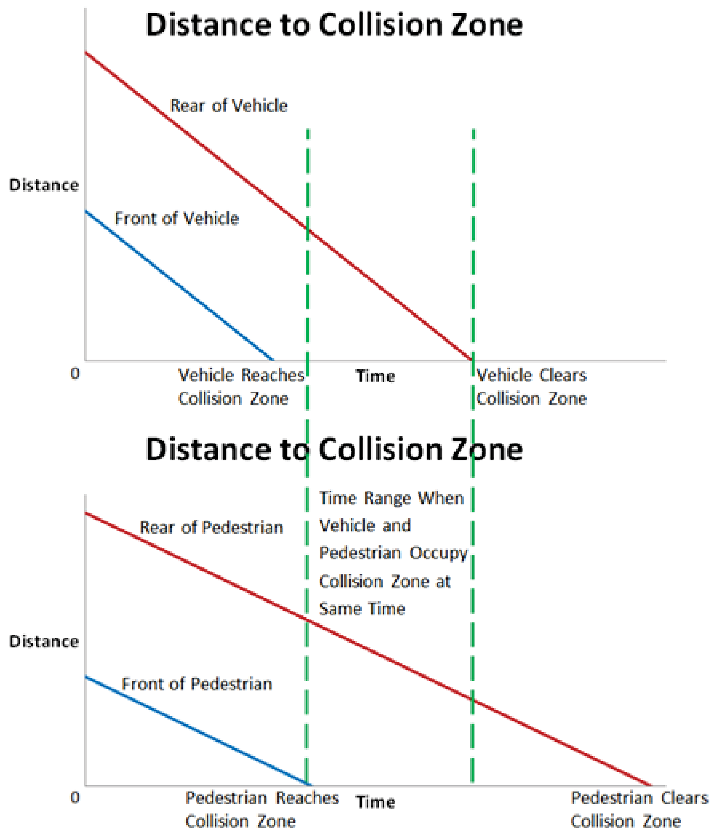


Figure 78. Timeline of Vehicle-Going-Straight/Pedestrian-Crossing-Road Pre-Crash Scenario

The critical event that determines if a vehicle-going-straight/pedestrian-crossing-road crash is imminent is when a pedestrian's intended path intersects with the intended path of a vehicle that is driving in a straight line. Crash countermeasures must account for the positions, velocities, and accelerations of both the pedestrian and the vehicle. A system that continuously calculated the times for the pedestrian and vehicle to reach and clear the collision zone, as expressed in Equations (13), (14), (15), and (16), would be able to alert the driver of impending collisions as early as possible. The recommended avoidance maneuver for the vehicle in this scenario is to brake.

If the critical event has occurred and the vehicle executes the recommended avoidance maneuver, then the times for the vehicle to reach and clear the collision zone become:

$$t_{vr} = \frac{-v_{vi} + \sqrt{{v_{vi}}^2 + 2a_v D_{vi}}}{a_v} \tag{17}$$

$$t_{vc} = \frac{-v_{vi} + \sqrt{{v_{vi}}^2 + 2a_v(D_{vi} + l_v + w_p)}}{a_v} \tag{18}$$

Where a_v is the acceleration of the vehicle.

Figure 79 shows the time history of the scenario in which the vehicle and the pedestrian are traveling perpendicular to each other while the vehicle is braking and the pedestrian maintains a constant speed.

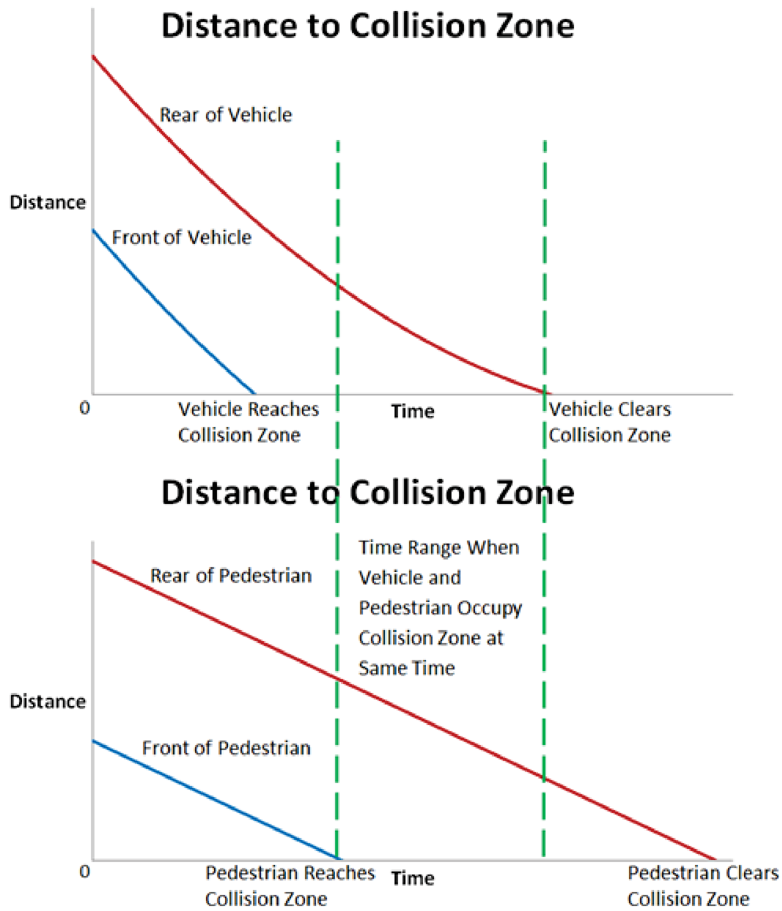


Figure 79. Timeline of Vehicle-Going-Straight/Pedestrian-Crossing-Road Pre-Crash Scenario With Vehicle Avoidance Maneuver

If the pedestrian accelerates and attempts to avoid the collision, the times for the pedestrian to reach and clear the collision zone are:

$$t_{pr} = \frac{-v_{pi} + \sqrt{{v_{pi}}^2 + 2a_p D_{pi}}}{a_p} \tag{19}$$

$$t_{pc} = \frac{-v_{pi} + \sqrt{{v_{pi}}^2 + 2a_p (D_{pi} + w_v + l_p)}}{a_p} \tag{20}$$

Where a_p is the acceleration of the pedestrian.

To avoid a vehicle-going-straight/pedestrian-crossing-road collision, the vehicle should reach the collision zone after the pedestrian clears it or the vehicle should clear the collision zone before the pedestrian reaches it. This relationship is expressed below:

$$t_{vr} > t_{pc}$$

OR

$$t_{vc} < t_{pr}$$

(21)

It may be possible to prevent an impending crash by braking if the vehicle is far enough away from the collision zone. The minimum allowable distance to avoid a crash by braking is:

$$D_{vi} > \frac{1}{2} {t_{pc}}^2 a_v + t_{pc} v_{vi}$$

(22)

If the vehicle is able to stop before reaching the collision zone, it may then be important to know the final gap between the vehicle and the collision zone. This gap is found to be:

$$\delta = D_{vi} + \frac{{v_{vi}}^2}{2a_v}$$

(23)

If the vehicle is within a certain distance of the collision zone, braking can result in a crash. However, it may be possible to avoid a crash if the vehicle maintains a constant speed at this distance. The maximum distance at which a vehicle can avoid a crash by maintaining a constant speed is:

$$D_{vi} < \frac{1}{2} {t_{pr}}^2 a_v + t_{pr} v_{vi} - l_v - w_p$$

(24)

The maximum distances between the vehicle and the collision zone where the vehicle can maintain a constant speed and not crash is shown in Table 12. The values are created using the standard pedestrian speed, standard vehicle length, and standard pedestrian width as shown in Table 8. A negative value indicates that it is not possible for a vehicle to avoid a crash by maintaining a constant velocity at that given speed and pedestrian distance from the collision zone. Table 12 is useful for identifying the limits at which a crash will occur.

Table 12. Maximum Distances Where Vehicle Can Maintain Speed

Vehicle Initial Velocity (mph)	D_{pi} (feet)								
	2	4	6	8	10	12	14	16	18
75	14	47	80	113	146	179	212	245	278
70	12	43	73	104	135	166	197	227	258
65	10	38	67	95	124	153	181	210	238
60	7	34	60	87	113	139	166	192	219
55	5	29	54	78	102	126	150	175	199
50	3	25	47	69	91	113	135	157	179
45	1	21	40	60	80	100	120	139	159
40	-1	16	34	51	69	87	104	122	139
35	-4	12	27	43	58	73	89	104	120
30	-6	7	21	34	47	60	73	87	100
25	-8	3	14	25	36	47	58	69	80
20	-10	-1	7	16	25	34	43	51	60
15	-12	-6	1	7	14	21	27	34	40
10	-15	-10	-6	-1	3	7	12	16	21
5	-17	-15	-12	-10	-8	-6	-4	-1	1

Figure 80 shows the distances at which a vehicle can brake and the distances at which it can maintain its speed in order to avoid a crash. The figure is created to provide an example using a braking level of 0.6 g with the standard pedestrian speed from Table 8 and a pedestrian distance from the collision zone of 10 feet. The pink region represents the combinations of speeds and distances where the vehicle should brake. The blue region represents the combinations of speeds and distances where the vehicle can maintain its speed. The purple region represents the combinations of speeds and distances where the vehicle can either brake or maintain its speed. Finally, the gray region represents the combinations of speeds and distances where a crash is guaranteed.

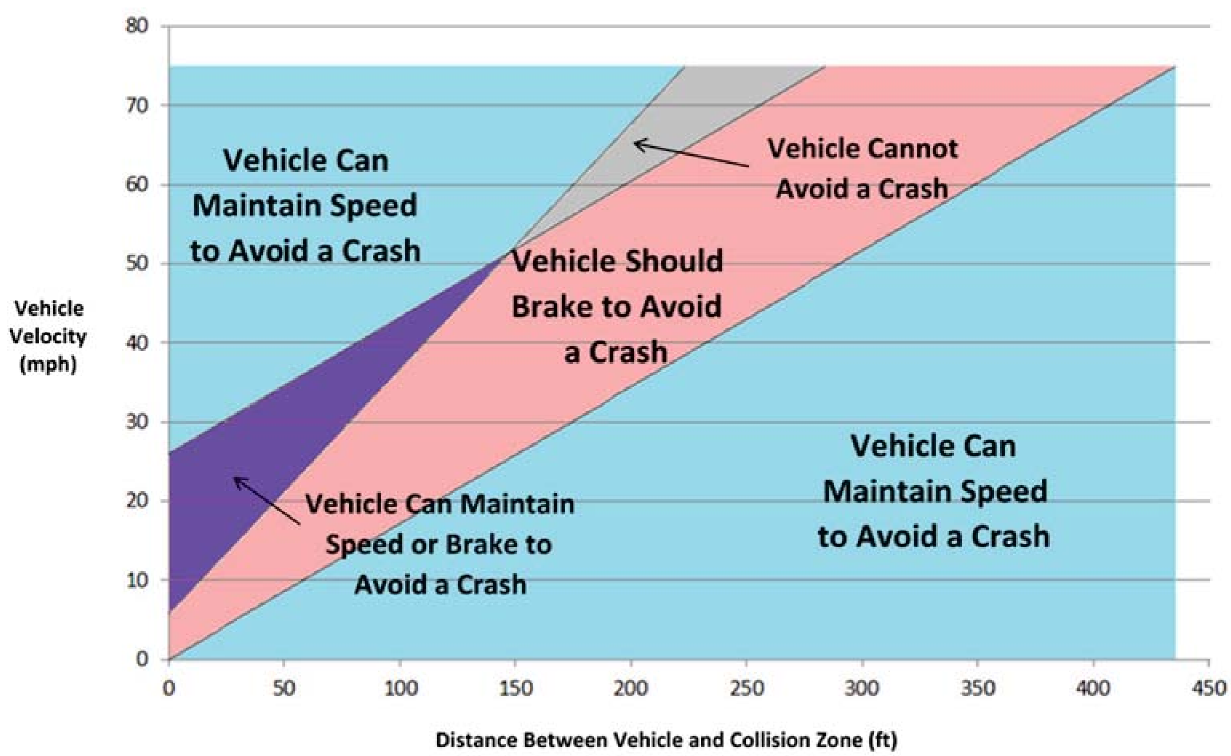


Figure 80. Distances to Avoid a Crash by Maintaining Speed or Braking (Vehicle Going Straight)

While there are some situations where the vehicle cannot brake or maintain a constant speed to avoid an impending crash, a crash can be avoided if the vehicle accelerates. And, while this is a possible solution, it is not a recommended one. The maximum distances between the vehicle and the collision zone where the vehicle can accelerate to avoid a crash is shown in Table 13. The values are created using a standard pedestrian speed, standard vehicle length, and standard pedestrian width as shown in Table 8. The example values shown in Table 13 assume a vehicle acceleration rate of 0.25 g. This table is useful for identifying the limits at which a crash may be avoided through vehicle acceleration.

Table 13. Maximum Distances Where Vehicle Can Accelerate at 0.25 g

Vehicle Initial Velocity (mph)	D_{pi} (feet)								
	2	4	6	8	10	12	14	16	18
75	15	50	87	125	165	207	250	295	341
70	13	46	80	117	154	194	235	277	321
65	10	41	74	108	143	181	219	260	301
60	8	37	67	99	132	167	204	242	282
55	6	33	61	90	121	154	189	224	262
50	4	28	54	81	110	141	173	207	242
45	2	24	47	73	99	128	158	189	222
40	-1	19	41	64	88	115	142	172	202
35	-3	15	34	55	77	101	127	154	183
30	-5	11	28	46	66	88	112	136	163
25	-7	6	21	37	55	75	96	119	143
20	-9	2	14	29	44	62	81	101	123
15	-12	-3	8	20	33	49	65	84	103
10	-14	-7	1	11	22	35	50	66	84
5	-16	-11	-5	2	11	22	35	48	64

5.4 Vehicle Turning Left or Right and Pedestrian Crossing the Road

This scenario is depicted for two configurations in which the pedestrian is crossing the road and the vehicle is either turning left or turning right at an intersection. The primary difference between the two configurations is the turning radii in each of the two situations.

The scenario configuration for the vehicle turning left and approaching the path of a pedestrian who is crossing the road is shown in Figure 81.

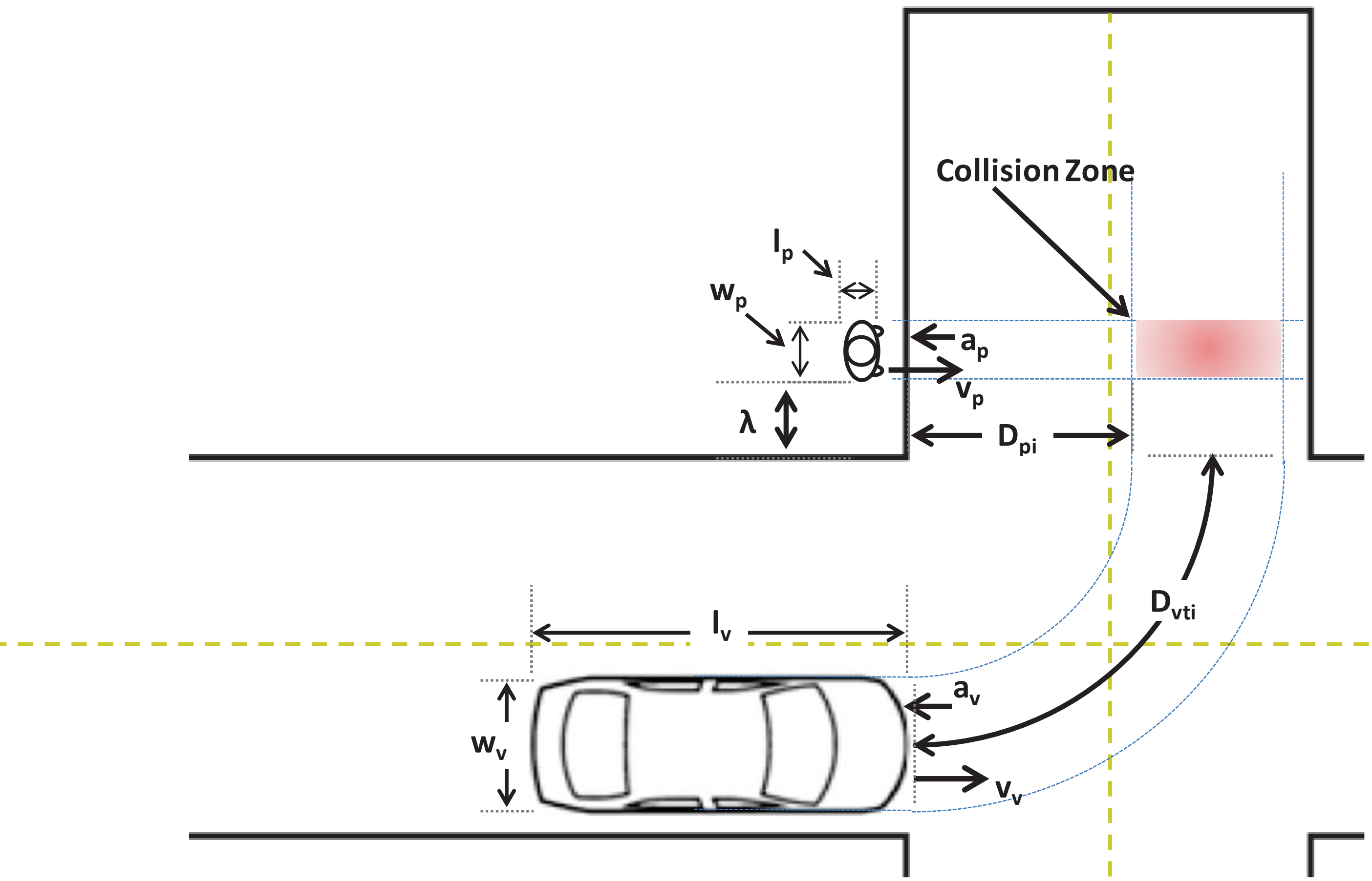


Figure 81. Vehicle-Turning-Left/Pedestrian-Crossing-Road Pre-Crash Scenario Configuration

Similarly, the configuration for the vehicle turning right and approaching the path of a pedestrian who is crossing the road is shown in Figure 82.

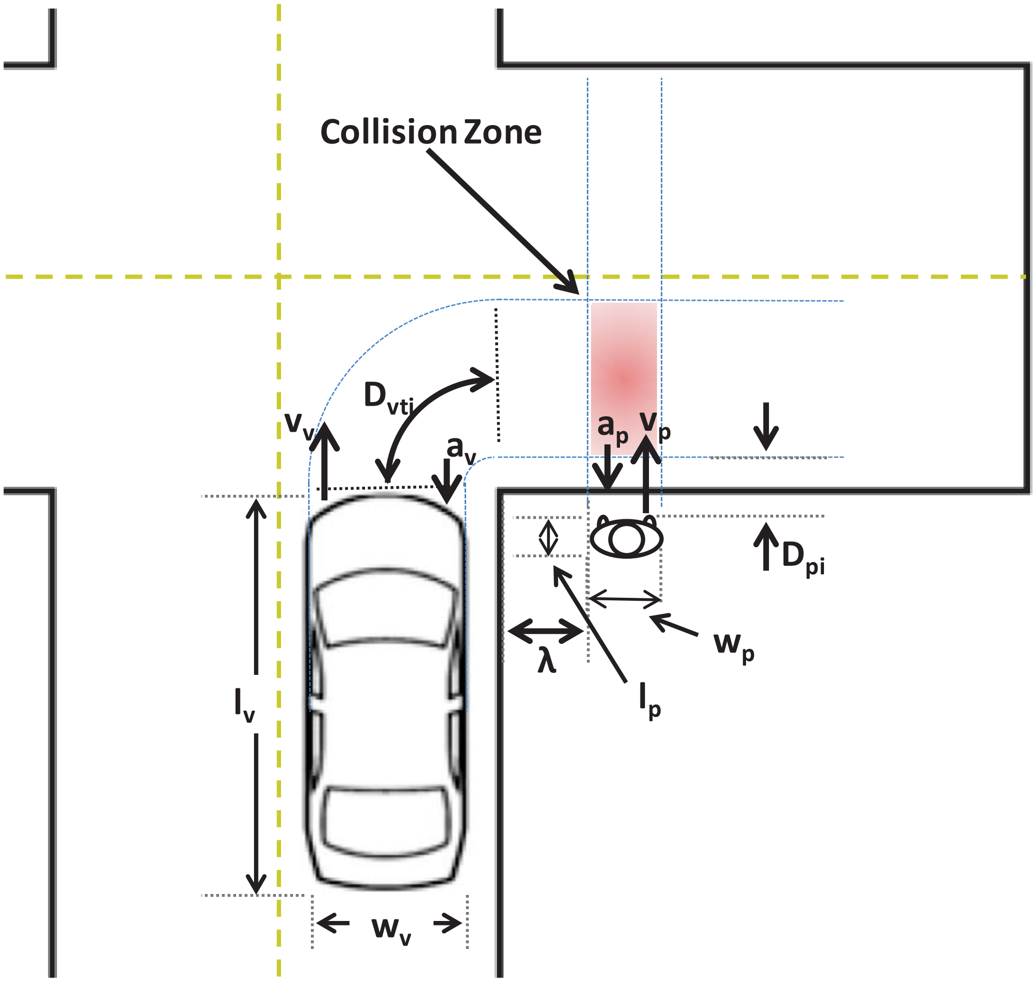


Figure 82. Vehicle-Turning-Right/Pedestrian-Crossing-Road Pre-Crash Scenario Configuration

A collision will occur in this scenario if the vehicle and the pedestrian occupy the collision zone at the same time. This relationship is expressed as:

$$t_{pr} \leq t_{vc} \leq t_{pc}$$

OR

$$t_{vr} \leq t_{pc} \leq t_{vc} \tag{25}$$

Under the initial conditions of the pre-crash scenario, and assuming that the vehicle does not make an avoidance maneuver, the times for the vehicle to reach and clear the collision zone are:

$$t_{vr} = \frac{D_{vti} + \lambda}{v_{vi}} \tag{26}$$

$$t_{vc} = \frac{D_{vti} + \lambda + l_v + w_p}{v_{vi}} \tag{27}$$

If the pedestrian maintains a constant speed, and does not attempt to avoid a crash, then the times for the pedestrian to reach and clear the collision zone are:

$$t_{pr} = \frac{D_{pi}}{v_{pi}} \tag{28}$$

$$t_{pc} = \frac{D_{pi} + w_v + l_p}{v_{pi}} \tag{29}$$

Where:

v_{pi}	=	initial velocity of pedestrian
v_{vi}	=	initial velocity of vehicle
l_p	=	length of pedestrian
l_v	=	length of vehicle
w_p	=	width of pedestrian
w_v	=	width of vehicle
D_{pi}	=	initial distance from front of pedestrian to collision zone
D_{vti}	=	initial distance from front of vehicle to end of curve
λ	=	lateral distance from edge of pedestrian to curb
t_{pr}	=	time for pedestrian to reach collision zone
t_{pc}	=	time for pedestrian to clear collision zone
t_{vr}	=	time for vehicle to reach collision zone
t_{vc}	=	time for vehicle to clear collision zone

Figure 83 shows the time history of this pre-crash scenario.

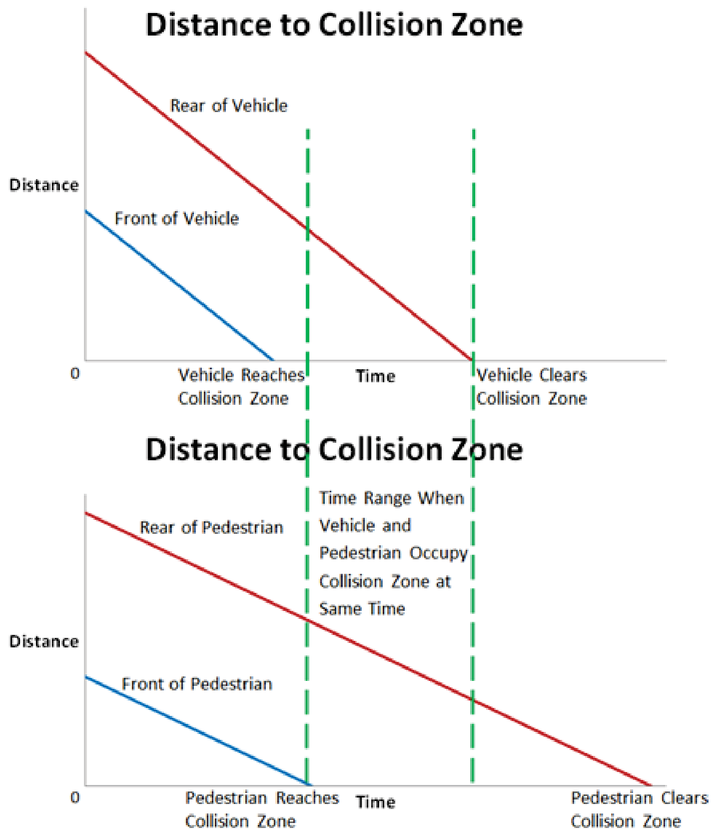


Figure 83. Timeline of Vehicle-Turning/Pedestrian-Crossing-Road Pre-Crash Scenario

The critical event that determines if a vehicle-turning/pedestrian-crossing-road crash is imminent is when a pedestrian's intended path intersects with the intended path of a vehicle that is turning. Crash countermeasures must account for the positions, velocities, and accelerations of both the pedestrian and the vehicle. A system that continuously calculated the times for the pedestrian and vehicle to reach and clear the collision zone, as expressed in Equations (26), (27), (28), and (29), would be able to alert the driver of impending collisions as early as possible. The recommended avoidance maneuver for the vehicle in this scenario is to brake.

Assuming the critical event has occurred and the vehicle executes the recommended avoidance maneuver, the times for the vehicle to reach and clear the collision zone become:

$$t_{vr} = \frac{-v_{vi} + \sqrt{{v_{vi}}^2 + 2a_v(D_{vti} + \lambda)}}{a_v} \tag{30}$$

$$t_{vc} = \frac{-v_{vi} + \sqrt{{v_{vi}}^2 + 2a_v(D_{vti} + \lambda + l_v + w_p)}}{a_v} \tag{31}$$

Where a_v is the acceleration of the vehicle.

Figure 84 shows the time history of the pre-crash scenario in which the vehicle and the pedestrian are traveling perpendicular to each other at the time of collision. The vehicle is braking while the pedestrian maintains a constant speed.

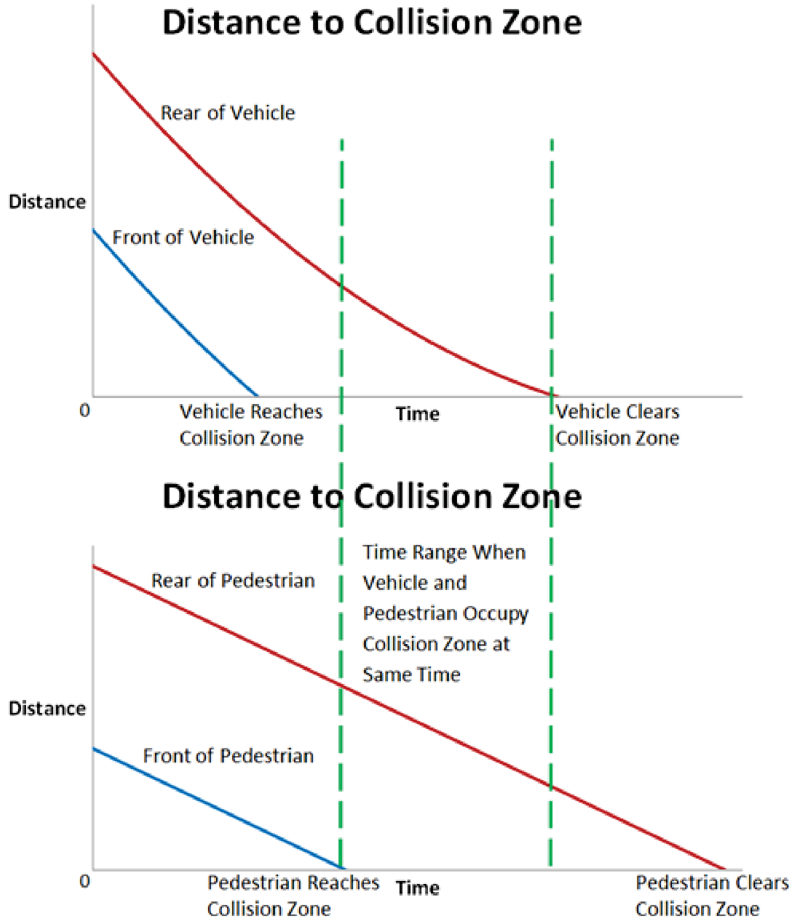


Figure 84. Timeline of Vehicle-Turning/Pedestrian-Crossing-Road Pre-Crash Scenario With Vehicle Avoidance Maneuver

If the pedestrian accelerates, the times for the pedestrian to reach and clear the collision zone are:

$$t_{pr} = \frac{-v_{pi} + \sqrt{{v_{pi}}^2 + 2a_p D_{pi}}}{a_p} \tag{32}$$

$$t_{pc} = \frac{-v_{pi} + \sqrt{{v_{pi}}^2 + 2a_p (D_{pi} + w_v + l_p)}}{a_p} \tag{33}$$

Where a_p is the acceleration of the pedestrian.

To avoid a vehicle-turning/pedestrian-crossing-road collision, the vehicle should reach the collision zone after the pedestrian clears it or the vehicle should clear the collision zone before the pedestrian reaches it. This relationship is expressed in Equation (21).

If the vehicle is far enough from the collision zone, it may be possible to prevent an impending crash by braking. The minimum allowable distance to avoid a crash by braking is:

$$D_{vti} + \lambda > \frac{1}{2} {t_{pc}}^2 a_v + t_{pc} v_{vi} \tag{34}$$

And, if the vehicle is able to stop before reaching the collision zone, it may be important to know the final gap between the vehicle and the collision zone. This gap is found to be:

$$\delta = D_{vti} + \lambda + \frac{{v_{vi}}^2}{2a_v} \tag{35}$$

If the vehicle is within a certain distance of the collision zone, braking can result in a crash. However, it may be possible to avoid a crash if the vehicle maintains a constant velocity at this distance. The maximum distance at which a vehicle can avoid a crash by maintaining a constant speed is:

$$D_{vti} + \lambda < \frac{1}{2} {t_{pr}}^2 a_v + t_{pr} v_{vi} - l_v - w_p \tag{36}$$

A table of the maximum distances between the vehicle and the collision zone where the vehicle can maintain a constant speed and not crash is shown below in Table 14. The example values are created using the standard pedestrian speed, standard vehicle length, and standard pedestrian width as shown in Table 8. A negative value shows that it is not possible for a vehicle to avoid a crash by maintaining a constant velocity at that given speed and pedestrian distance from the collision zone. Table 14 is useful for identifying the limits at which a crash will occur.

Table 14. Maximum Distances Where Vehicle Can Maintain Speed (Turning)

Vehicle Initial Velocity (mph)	D_{pi} (feet)								
	2	4	6	8	10	12	14	16	18
35	-4	12	27	43	58	73	89	104	120
30	-6	7	21	34	47	60	73	87	100
25	-8	3	14	25	36	47	58	69	80
20	-10	-1	7	16	25	34	43	51	60
15	-12	-6	1	7	14	21	27	34	40
10	-15	-10	-6	-1	3	7	12	16	21
5	-17	-15	-12	-10	-8	-6	-4	-1	1

Figure 85 shows an example of the distances at which a vehicle can brake and the distances at which it can maintain its speed in order to avoid a crash. The figure is created to provide an example using a braking level of 0.6 g with a standard pedestrian speed from Table 8 and a pedestrian distance from collision zone of 3 feet. The pedestrian distance from collision zone was selected to represent the lack of visibility that exists while going around a turn. The pink region represents the combinations of speeds and distances where the vehicle should brake. The blue region represents the combinations of speeds and distances where the vehicle can maintain its speed. Finally, the gray region represents the combinations of speeds and distances where a crash is guaranteed.

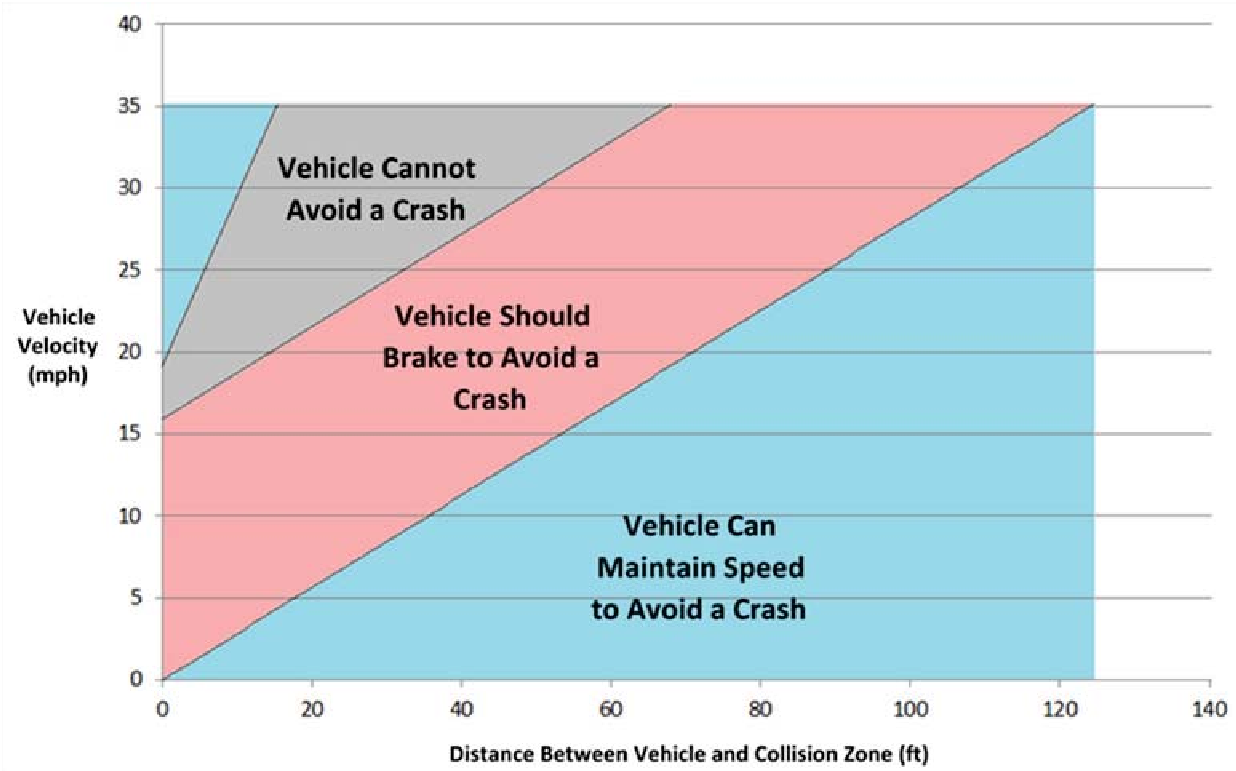


Figure 85. Distances to Avoid a Crash by Maintaining Speed or Braking (Vehicle Turning)

6 Crash Avoidance Needs and Countermeasure Profiles

This chapter presents the crash avoidance needs and countermeasure profiles for the 5 priority pre-crash scenarios. The critical kinematic parameters are shown in Section 6.1. The crash avoidance requirements are described in Section 6.2. A description of the V2P countermeasure technology and the countermeasure needs are presented respectively in Sections 6.3 and 6.4.

6.1 Critical Kinematic Parameters

The relative position between the vehicle and the pedestrian is the primary positioning element. Crash countermeasures must record multiple kinematic parameters for the calculation of TTC, the gap between the vehicle and pedestrian, and the stopping distance, as well as to determine if a critical event has occurred. The following variables that were illustrated in Chapter 5 are applicable to all pre-crash scenarios:

a_p	pedestrian acceleration
a_v	vehicle acceleration
D_0	initial distance from front of vehicle to pedestrian
D_{pi}	initial distance from front of pedestrian to collision zone
D_{vi}	initial distance from front of vehicle to collision zone
D_{vti}	initial distance from front of vehicle to end of turn
l_p	length of pedestrian
l_v	length of vehicle
v_{pi}	initial pedestrian velocity
v_{vi}	initial vehicle velocity
w_p	width of pedestrian
w_v	width of vehicle
λ	lateral distance from edge of pedestrian to curb

The following are derived parameters using the variables listed above:

S_d	stopping distance
t_{pr}	time for pedestrian to reach collision zone
t_{pc}	time for pedestrian to clear collision zone
TTC	time-to-collision
t_{vr}	time for vehicle to reach collision zone
t_{vc}	time for vehicle to clear collision zone
δ	gap between vehicle and pedestrian when vehicle stops

Many of the parameters are variables that are used to define the initial positional, directional, and dimensional conditions. Some of these variables are relevant to only one specific scenario while many are relevant to multiple scenarios. Table 15 shows the variables used and their relationship to the scenarios.

Table 15. Variables Used in Time-to-Collision and Avoidance Equations

Description	Variable	Vehicle-Going-Straight/Pedestrian-Crossing-Road	Vehicle-Going-Straight/Pedestrian-in-Road	Vehicle-Going-Straight/Pedestrian-Adjacent	Vehicle-Turning/Pedestrian-Crossing-Road
Pedestrian Acceleration	a_p	✓		✓	✓
Vehicle Acceleration	a_v	✓	✓	✓	✓
Initial Distance from Front of Vehicle to Pedestrian	D_0		✓	✓	
Initial Distance from Front of Pedestrian to Collision Zone	D_{pi}	✓			✓
Initial Distance from Front of Vehicle to Collision Zone	D_{vi}	✓			
Initial Distance from Front of Pedestrian to End of Curve	D_{vti}				✓
Length of Pedestrian	l_p	✓			✓
Length of Vehicle	l_v	✓			✓
Initial Pedestrian Velocity	v_{pi}	✓		✓	✓
Initial Vehicle Velocity	v_{vi}	✓	✓	✓	✓
Width of Pedestrian	w_p	✓			✓
Width of Vehicle	w_v	✓			✓
Lateral Distance from Edge of Pedestrian to Curb	λ				✓

The position and path of the vehicle and the pedestrian are the basis for TTC and avoidance equations. The initial state of the vehicle must be known and the potential influence of other driving factors must be estimated in order to accurately predict critical events. In addition, other vehicles, pedestrians, and infrastructure may be located in front of, behind, to either side of, above, or below the vehicle. To address these issues, V2P-based safety applications would need to determine the pedestrian's relative position to the vehicle (including elevation), velocity, acceleration, and size. Elevation may be important at overpasses or underpasses where two-dimensional representations of the trajectories could generate false alerts.

6.2 V2P Crash Avoidance Requirements

In order to avoid vehicle/pedestrian crashes, countermeasures must alert the driver or affect control over the vehicle before an imminent crash is realized.[8] Countermeasures would need to do the following to prevent these types of crashes:

- Vehicle-going-straight/pedestrian-in-road crash - countermeasures must be enacted when the gap between the vehicle and the pedestrian is larger than the predicted stopping distance. The conditions necessary to avoid a pedestrian-in-road crash are depicted in Equation (4).

- Vehicle-going-straight/pedestrian-adjacent crash - countermeasures must take effect when the sum of the initial gap and the estimated pedestrian travel distance is greater than the predicted stopping distance. The conditions necessary to avoid a pedestrian-adjacent crash are depicted in Equation (8).

- Pedestrian-crossing-road crash - countermeasures must be enacted if the vehicle is projected to occupy the collision zone at the same time as the pedestrian. The conditions necessary to avoid a pedestrian-crossing-road crash are depicted in Equation (21).

The recommended avoidance actions for each scenario are seen below in Table 16. If the countermeasures do not alert the driver, do not alert the pedestrian, or affect control over the vehicle in a timely manner, the avoidance actions taken may not be able to prevent or mitigate a crash. Note that these are ideal avoidance pedestrian actions, since it is difficult to regulate or modify pedestrian behavior.

Table 16. Recommended Avoidance Actions by Scenario[9]

Pre-Crash Scenario		Avoidance Action	
Vehicle Maneuver	**Pedestrian Action**	**Vehicle**	**Pedestrian**
Going Straight	Crossing Roadway	Brake	Abort
Going Straight	In Road	Brake	N/A
Going Straight	Adjacent to Road	Brake/Steer	Retreat
Turning Left	Crossing Roadway	Abort*/Brake	Abort
Turning Right	Crossing Roadway	Abort/Brake	Abort

*Abort - Inhibit or do not initiate maneuver (decision phase)

If a crash cannot be avoided, it may still be beneficial to brake and reduce the speed of the vehicle in order to mitigate the severity of the crash and injury to the pedestrian.

6.3 Countermeasure Technology

V2P system algorithms are designed to correctly identify pedestrians, continuously estimate TTC, and assess the need for activation of warning systems, brake pre-fill, or automatic braking in order to avoid or reduce the severity of the crash.

[8] Pedestrian actions may avoid a crash as well. However, pedestrian actions can change immediately and may be erratic.
[9] A pedestrian has the ability to stop much quicker than a vehicle. If a pedestrian can aid in crash avoidance by not crossing the road through a warning, the best option for a pedestrian countermeasure may be to abort their crossing attempt.

There are three types of systems available for the detection and notification of road users: bilateral detection and warning systems (bilateral warning systems), unilateral pedestrian detection and driver warning systems (driver warning systems), and unilateral vehicle detection and pedestrian warning systems (pedestrian warning systems).

6.3.1 Bilateral Warning Systems

Bilateral systems utilize point-to-multipoint communication between relevant road users and infrastructure in order to create a local wireless network of road-user locations and movement patterns. With V2P communications, the pedestrians and driver both detect and alert each other of their presence and of potential impending collisions. Bilateral systems may communicate using DSRC, Wi-Fi, GPS tracking via cellular networks, or any combination of the three. These systems will typically use technology that is unaffected by the light conditions, environmental and weather factors, road condition, or vehicle speed. They also have the ability to detect pedestrians or vehicles that are not visible due to obstructions or due to the geometry of the roadway and to map the locations of all road users. Bilateral systems may use audio and/or visual cues in order to notify and alert the driver and pedestrian of an impending collision [10].

A major benefit of bilateral systems is that all potential participants in a collision would be alerted simultaneously. If the pedestrian misses the alert, the driver may still be able to react in order to avoid or mitigate the crash, and vice versa. In order for bilateral countermeasure technology to be efficient, there must be a high usage rate among both pedestrians and drivers. It would be ineffective if only a small minority of pedestrians and vehicles were communicating together. Another limitation of bilateral systems is the latency of communication of data. If the latency is high, a warning may not be issued to the pedestrian or driver in time to avoid a crash. Improvements to electronic communications and data compression limits may help to lower the latency of V2P communications.

6.3.2 Driver Warning Systems

Driver warning systems alert drivers of potential vehicle/pedestrian collisions. These systems commonly utilize vehicle-based sensors or infrastructure sensors in order to detect pedestrians. A camera mounted to the vehicle may be used to detect pedestrians using image processing. During low-light or night conditions, vehicles may use infrared cameras in order to detect pedestrians. Another vehicle-based detection solution is a laser-scanner used to identify pedestrians in the visible area. Infrastructure-based sensors (e.g., crosswalk pushbuttons or weight-sensors) identify any pedestrians entering the roadway and notify drivers accordingly. Similar to bilateral systems, drivers may be alerted via auditory and/or visual notifications [10].

Many newer vehicles are already pre-equipped with detection and warning systems for collisions between vehicles, and could potentially be modified to include pedestrian detection capabilities. As such, there may be a relatively low cost-to-entry and fewer barriers-to-entry for driver warning systems, and they may be closer to the market introduction than bilateral systems. Nevertheless, driver warning systems still face some disadvantages. Many current collision-avoidance systems face issues with false positives and false negatives due to imperfections in detection algorithms. An excess of false warnings might cause a driver to ignore or, if possible, disable the system in the car. Additionally, the time it takes for image-processing algorithms to run through their many calculations can result in a noticeable (and potentially fatal) delay between an event and a notification. Finally, camera-based systems rely on visibility to be effective, and may have difficulty detecting pedestrians if it is not a clear day, well-lighted conditions, or if there is an obstruction between the vehicle and the pedestrian.

6.3.3 Pedestrian Warning Systems

Pedestrian warning systems alert pedestrians of potential vehicle/pedestrian collisions. These systems commonly use wearable technology, camera-based systems, or infrastructure-based systems in order to detect vehicles and notify the pedestrian. Pedestrian warning systems may use auditory, visual, and/or vibratory alerts in order to notify a pedestrian of an impending collision [10].

Due to the prevalence of smartphones, the majority of pedestrian warning systems is accessible through mobile application software (mobile apps) and thus is available for a large percentage of pedestrians. The ability to download a system and integrate it into a pre-owned device may encourage more pedestrians to use this type of system. However, pedestrians who do not own smartphones will not benefit from this type of system. Also, an ideal app-based pedestrian warning system would need to be available across all smartphone platforms and for all cellular providers. Another disadvantage is that if pedestrians are walking in a noisy location and they are not holding their phone, they may neither see, hear, nor feel the vibration from the alert on their phone.

Table 17 shows the summary of the communication abilities for vehicle-based, pedestrian-based, and infrastructure-based technologies.

Table 17. Summary of V2P Detection and Notification Technology

Technology		Vehicle	Pedestrian	Infrastructure
Communication Method	DSRC	DSRC Radio	DSRC-Capable Phone	
	GPS via Cell	Smart Phone	Smart Phone	X
	Wi-Fi Direct	Wi-Fi Direct Equipped	Wi-Fi Direct Capable Phone	X
	Infrastructure Sensors	DSRC Radio		X
Notification Method		Display	Phone Screen + Audio	
		Vehicle Speakers	Wearable Technology	

Additionally, if a crash is imminent, the vehicle's countermeasures could potentially be designed to affect control over the vehicle horn and high-beam headlights in order to further warn the pedestrian and driver of the danger.

6.3.4 Benefits and Disadvantages of Systems

The benefits and disadvantages of each detection/warning system are summarized in Table 18.

Table 18. Benefits and Disadvantages of Each Detection and Warning System Type

	Detection and Warning System		
	Bilateral	Driver Notification	Pedestrian Notification
Benefits	Simultaneous Alerts	Low Cost-to-Entry	Easily Downloadable
	Works in Low/No Visibility Situations		
Disadvantages	Latency	False Warnings	Not Every Pedestrian has a Smartphone
	Requires High Number of Users	Latency	Alert may go Unnoticed in Chaotic Environment
		Requires Near-Perfect Visibility	Requires Near-Perfect Visibility

While, in the short term, the driver-warning and pedestrian-warning systems may potentially be more easily implemented, bilateral warning systems may be more efficient and offer a greater range of data in the long term. Ideally, a combination of both unilateral and bilateral warning systems could be used to prevent collisions.

6.4 Countermeasure Needs

Countermeasures need to detect a pedestrian, assess the threat of a collision using the collected data, and take action to warn the driver/pedestrian and/or affect automatic control over the vehicle. Effectively reducing the occurrence of vehicle/pedestrian crashes through the use of V2P-based countermeasures requires gathering information from the vehicle, the environment, the pedestrian, and the driver. The identified informational needs will allow the countermeasures to recognize that a crash is imminent, account for environmental and driver factors, and identify the instance when an avoidance maneuver or decision must be initiated to avoid the crash. Crash countermeasures must measure the relative position of the pedestrian, the vehicle and pedestrian velocities and accelerations, the vehicle yaw rate, and the position of the vehicle in the lane. The kinematic data serve to calculate the relative distance between the vehicle and the pedestrian, the rate at which that distance changes, and the time to collision in order to identify if a crash is impending and if it can be avoided. Additionally, since the effective braking level depends upon the road surface condition (i.e., dry, wet, icy) and the tire type (i.e., summer, winter, all-season), the system can be more effective by collecting data from the vehicle to determine these factors. To do so, vehicle information including the use of windshield wipers/defrosters, usage of traction control and anti-lock braking systems within the current trip, and the outside temperature could be monitored and tire type (if known) could be taken into account in order to consider the optimal braking level. In the event of a vehicle-turning/pedestrian-crossing-the-road scenario, the effective braking level also depends on the turning radius of the vehicle. For these scenarios, the system could collect and monitor steering-angle data when considering the optimal braking level.

The countermeasures must also have a high accuracy of detection and eliminate false alerts in order to help ensure safe driving. If a false positive signal alerts the driver that there is an impending crash, the driver may take an avoidance action. This could result in a loss of vehicle control, a vehicle/vehicle collision, and potential destruction of personal property inside of the vehicle due to sudden braking. In addition to property damage, the driver may no longer trust the system and could ignore alerts in the future. If the countermeasures affect control over the vehicle, the driver may be surprised by the sudden unnecessary change. If the countermeasures register a false negative reading and a collision is imminent, then a crash might occur if the driver was distracted. This could result in personal injury, vehicular damage, loss of functional years, and even death.

Driver conditions and errors are, to some degree, a contributing factor in almost every crash. These factors include misjudging the pedestrian behavior and false assumptions of the pedestrian's behavior, distraction, fatigue, aggressiveness, age, and impairment (e.g., alcohol or drug intoxication, physical handicap, etc.).[10] Potential measurements of driver factors could include eye and motion tracking cameras, blood alcohol content sensors, microphones, and temperature sensors. Vehicle drifting in and out of the lane may indicate driver fatigue or distraction. Additionally, use of the radio or a cell phone (either through a vehicle's Bluetooth® system or hand-held) may indicate driver distraction. Countermeasures that can compensate for the driver's limitations and respond accordingly would be ideal for safety, although they could face a variety of obstacles to implement.

Driver vision is also an important factor leading to a hazardous situation. Poor lighting, glare, or an obstruction between the driver and the pedestrian may prevent the driver from recognizing an impending crash. Countermeasures could perhaps account for these limiting visibility factors by either alerting the driver of the lack of visibility while also alerting of the crash, or by automatically affecting control over the vehicle.

If the driver and pedestrian do not respond in a timely manner to the warnings, then the countermeasures may automatically affect control over the vehicle's braking system in order to prevent a crash. The countermeasures may also have to affect control over the vehicle's steering abilities in order to maintain vehicle stability during braking and to prevent the vehicle from drifting out of the lane.

[10] Refer to the crash analysis done in Section 3 for statistics on the available factors.

Table 19 is a summary of V2P system needs/issues based on the crash characteristics that were presented in Section 3.1 through 3.8.

Table 19. Influence of Crash Characteristics on V2P Systems

Crash Characteristics		System Needs / Issues	Notes
Crash Location	Relation to Junction	Activate accurately regardless of location (intersection or non-junction)	If and when it becomes available, infrastructure communication could provide additional input to the safety systems to aid in accurate activation
			V2P systems could help to increase the level of awareness for a driver or pedestrian during complex turning maneuvers at intersections
	Pedestrian Location	Activate regardless of pedestrian location (i.e., crosswalk, not in crosswalk, intersection, non-intersection)	V2P systems could help to increase the level of awareness for a driver or pedestrian during unexpected encounters away from intersections and crosswalks (i.e., pedestrian equipped with device that would allow them to transmit a message to surrounding vehicles)
		Activate when pedestrians are not expected (i.e., non-intersection, non-crosswalk)	Infrastructure data could only support locations where pedestrians are expected (i.e., crosswalks)
	Traffic Controls	Activate accurately without the presence of infrastructure data	
Driving Environmental Variables	Weather	Wet or slick roads can cause a decreased braking capability	Pedestrians are more frequently out during normal weather conditions
		Weather can potentially affect the functionality of PCAM's pedestrian detection sensors (e.g., sun glare, reflections from wet roads) or V2P wireless signals (e.g., signal attenuation due to atmospheric conditions)	
	Lighting	Ability to detect pedestrian under various lighting conditions	Lighting might have an influence on whether the driver is able to see the pedestrian and/or a crosswalk, even when reflective clothing on the pedestrian might also increase the pedestrian's visibility in darkness

PCAM: Pedestrian crash avoidance/mitigation system

V2P: Vehicle-to-pedestrian

Crash Characteristics		System Needs / Issues (cont.)	Notes
Driving Environmental Variables (cont.)	Road Surface Condition	Ice, snow, or slippery road conditions may degrade the vehicle's braking capabilities	If V2P systems included the use of automatic control or pre-fill braking, information on the road surface condition could be beneficial to improve system performance
		Surface conditions can also affect the functionality of PCAM detection sensors (e.g., sun glare, reflections from wet roads, etc.)	
	Combination (Weather, Lighting, Road Surface Condition)	Identify conflicts in various environmental conditions, including when a driver is in situations of degraded visibility due to combinations of environmental variables, such as glare from the sun or light reflecting on a wet road, or when environmental conditions could cause issues such as, signal interference or weak signals.	
Road Geometry	Alignment	System could detect pedestrians on curved roads in addition to straight roads since it is difficult for drivers to recognize pedestrians in or adjacent to the road around a curve	V2P systems can help aid in the detection of pedestrians who are out of the driver's line-of-sight on curved and/or graded roads
	Grade	System should consider focusing on graded roads in addition to level roads since these types of roads may cause false or missed activations	
Driver Contributing Factors	Driver Impairment	If an impaired driver may not react to warnings, a system capable of automatic braking/steering could help to avoid crashes	Impairment (particularly alcohol) contributes to pedestrian fatalities
		A pedestrian may potentially benefit from a warning, especially in instances where a driver may have a delayed or no response to a warning due to impairment	
	Vision Obstruction	System should have the capability to distinguish a pedestrian from other communication-equipped objects as well as recognize pedestrians emerging from behind external obstructions such as another vehicle, structure, sign, etc.	
		System should operate accurately despite other obstructions or conditions such as hills, curves, etc.	
	Distraction	A system that is capable of automatic braking/steering can potentially help to address the problem of a driver who fails to react to warnings	V2P systems could potentially mitigate or eliminate pedestrian injuries and reduce crash counts in cases where drivers are distracted or inattentive for any reason
		A pedestrian may potentially benefit from a warning, especially in instances where a driver may have a delayed or no response to a warning due to distraction	

Crash Characteristics		System Needs / Issues (cont.)	Notes
Pedestrian Actions / Characteristics	Pedestrian Impairment	Systems could potentially be effective if they were able to identify a pedestrian with the unique characteristics associated with an impaired pedestrian (e.g., gait, appearance in unexpected locations, non-linear trajectories)	Impaired pedestrians can move unpredictably while on the roadway, such as the erratic behavior of an intoxicated pedestrian who may have wandered into the street unexpectedly
	Innattentive	V2P system can potentially help to refocus the pedestrian's attention to warn them of an impending impact with a vehicle if they are texting, talking, etc.	
	Visibility	Identify pedestrians in limited visibility; ability to recognize pedestrians coming from behind external obstructions such as another vehicle, structure, sign, etc.	
	Dart/Dash	V2P systems would a timely awareness of erratic pedestrian movements to have the ability to accurately predict the most probable trajectory of the pedestrian and react accordingly	Dart/dash typically involves situations where the driver had little time to react. More fatalities can occur if the driver does not apply the brakes and has a higher impact-speed with the pedestrian
		Pedestrian actions can be random and unpredictable. Pedestrians can dart or dash into the street or come from behind an obstruction	
	Pedestrian Age	Need ability to distinguish pedestrians of varying heights and sizes	Note that children often can have unpredictable movement (ex.darting into a road to chase a ball, playing around or pushing another child into the street, running into a street behind parked vehicles, etc.). In addition, children may not have an awareness of vehicles in the road, may have difficulty judging distances and speeds of vehicles, or may not fully understand traffic rules
	All	Accurately distinguish pedestrians from background communication-equipped objects	Movement assessment algorithms may help systems identify pedestrians; however, pedestrian movement can be erratic at times
		Focus on targeting only pedestrians so that false activations can be minimized. Note that the detection of objects, other than pedestrians, could possibly also aid in the prevention of crashes	

Crash Characteristics		System Needs / Issues (cont.)	Notes
Vehicle-Related	Vehicle Speed	Need to be accurate and provide quick-notification timing at various speeds	High impact speeds are typically correlated with high injuries to pedestrians
		Should potentially function at all speeds	
	Driver Attempted Avoidance Maneuver	Should notify the driver of an impending collision with a pedestrian, and automatically apply the brakes, steer, etc., if the driver does not take the proper action to avoid the collision	
	Vehicle Area of Impact		Knowledge of the pedestrian impact point on the vehicle could aid in the development of objective test procedures for V2P systems

7 Conclusion

A template was presented to completely depict pedestrian pre-crash scenarios deemed as priority for V2P-based safety applications. V2P-based safety systems utilize wireless communication to share information between a driver and a pedestrian about an impending vehicle-pedestrian conflict. Using this information, safety systems may alert the driver, the pedestrian, or activate automatic vehicle control to avoid the crash. The template consists of representative crash statistics from national crash databases as well as kinematic description of TTC equations. The pre-crash scenario template provides a basis for the development of functional requirements, performance specifications, test procedures, and safety benefits for V2P-based safety applications.

Crash data from the 2011 and 2012 NASS GES and FARS databases were queried to identify target crashes that may be addressable by V2P-based safety applications.[11] An annual average of 63,000 vehicle-pedestrian crashes and 3,337 fatal pedestrian crashes were analyzed for vehicle maneuvers and pedestrian maneuvers and to estimate comprehensive costs. From a list of 21 different pre-crash scenarios, 5 were selected as priority scenarios for consideration in V2P-based safety application systems. The selected 5 pre-crash scenarios are as follows.

- Vehicle going straight and pedestrian crossing the road
- Vehicle going straight and pedestrian in road
- Vehicle going straight and pedestrian adjacent to road
- Vehicle turning left and pedestrian crossing
- Vehicle turning right and pedestrian crossing

These 5 scenarios represent 88 percent of costs for V2P-addressable pedestrian crashes. These crashes also represent 79 percent of police-reported crashes and 91 percent of fatal crashes that may potentially be addressable by V2P-based pedestrian safety systems. Further, these 5 priority pre-crash scenarios were characterized by physical settings, environmental conditions, driver and pedestrian characteristics, and other circumstances that describe the crash.

Pre-crash scenarios were also described by kinematic equations. Additionally, the analysis identified potential intervention opportunities for V2P-based safety systems, building a crash countermeasure profile and needs for these systems. If V2P-based crash countermeasures were to prove effective in reducing the frequency and severity of light-vehicle pedestrian crashes, systems would need to be able to rapidly, accurately, and continually assess the likelihood of a crash with a pedestrian in each of the 5 priority pre-crash scenarios. Systems must determine whether a crash is imminent with sufficient lead time to allow the countermeasure to either prevent the crash or to reduce the harm to the pedestrian. A critical element of a pre-crash depiction is the determination of the range and range rate between the vehicle and the pedestrians in the vicinity. At all times, communications between the vehicle/pedestrian systems must determine the potential TTC that will, in turn, inform the determination of whether to deploy the countermeasures, and to what degree. To determine TTC, systems must be able to determine the relative pedestrian position, velocity, and acceleration. The systems must also determine the vehicle’s relation to other vehicles in close proximity. As a vehicle approaches a pedestrian, the TTC may approach zero. A series of thresholds may be crossed that could be used to trigger varying countermeasure interventions. Finally, V2P systems must be able to discriminate between crash-imminent driving situations and benign driving conditions so as to minimize the occurrence of false positive interventions.

[11] Pre-crash scenarios were created from combining vehicle and pedestrian maneuvers from historical crashes that involved a light vehicle colliding with a pedestrian in the first event of a crash.

8 References

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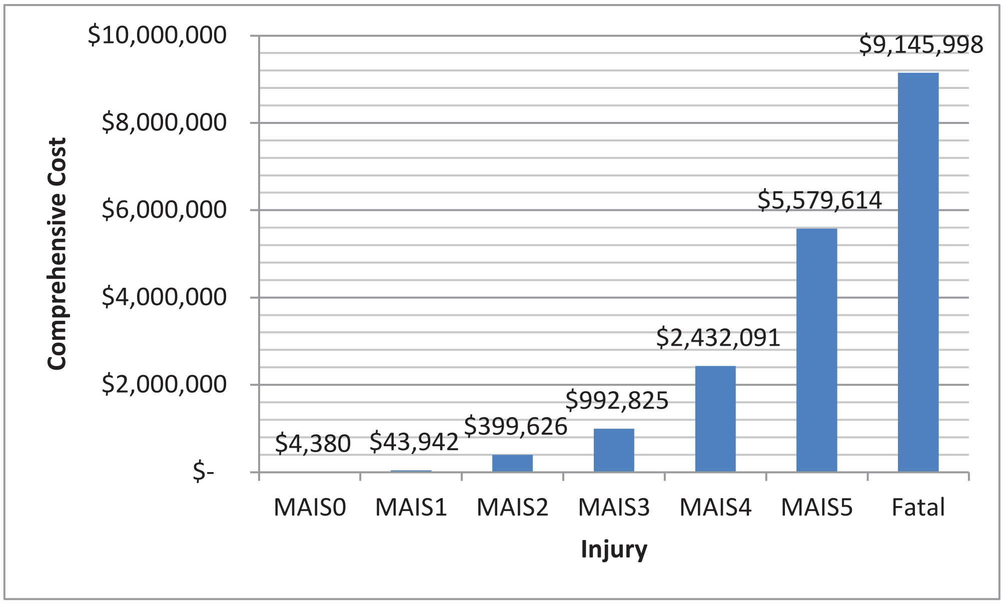
Appendix A: Injury Severity Scale Conversion

The comprehensive cost is computed from the maximum injury of all the injured people involved in a specific crash using the Abbreviated Injury Scale (AIS). The AIS is a classification system for assessing impact injury severity developed by the Association for the Advancement of Automotive Medicine. It provides the basis for stratifying the economic costs of crashes by injury severity. The Maximum AIS is a function of AIS on a single injured person, which measures overall maximum injury severity. Figure 86 illustrates the values of comprehensive cost associated with each MAIS level based on 2010 economics [11].



Note: Costs are per-person for all injury levels.

Figure 86. Comprehensive Cost by MAIS Level

Since detailed information regarding injury severity in GES and FARS is retrieved from police reports, the KABCO scale is used to classify injuries versus the AIS scale. The KABCO scale classifies crash victim injuries as: K - killed, A - incapacitating injury, B - non-incapacitating injury, C - possible injury, O - no apparent injury, or ISU - injury severity unknown. The KABCO coding scheme allows non-medically trained people to make on-scene injury assessments without a hands-on examination. The possibility exists that the KABCO ratings are imprecise and inconsistently coded between states and over different years. The matrix shown in Table 20 provides the KABCO to MAIS injury severity conversion [11].

Table 20. Injury Severity Scale Conversion Matrix

KABCO-to-MAIS Conversion Table							
MAIS	Police-Reported Injury Severity System						
	O	C	B	A	K	U	
	No Injury	Possible Injury	Non Incapacitating	Incapacitating	Fatality	Injured, Severity Unknown	Unknown
0	0.92535	0.23431	0.08336	0.03421	0.00000	0.21528	0.42930
1	0.07257	0.68929	0.76745	0.55195	0.00000	0.62699	0.41027
2	0.00198	0.06389	0.10884	0.20812	0.00000	0.10395	0.08721
3	0.00008	0.01071	0.03187	0.14371	0.00000	0.03856	0.04735
4	0.00000	0.00142	0.00619	0.03968	0.00000	0.00442	0.00606
5	0.00003	0.00013	0.00101	0.01775	0.00000	0.01034	0.00274
Fatal	0.00000	0.00025	0.00128	0.00458	1.00000	0.00046	0.01707
Total	1.00001	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

Appendix B: Speed Variable Comparison

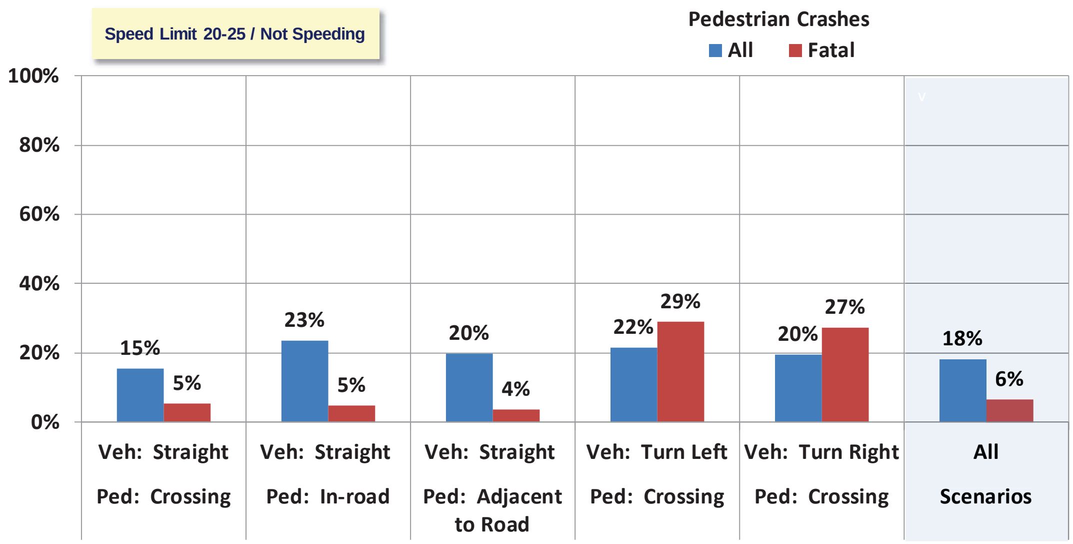


Figure 87. Percentage of "20-25 MPH Posted Speed Limit and Not Speeding" Crashes per Total Crashes in Each Priority Scenario

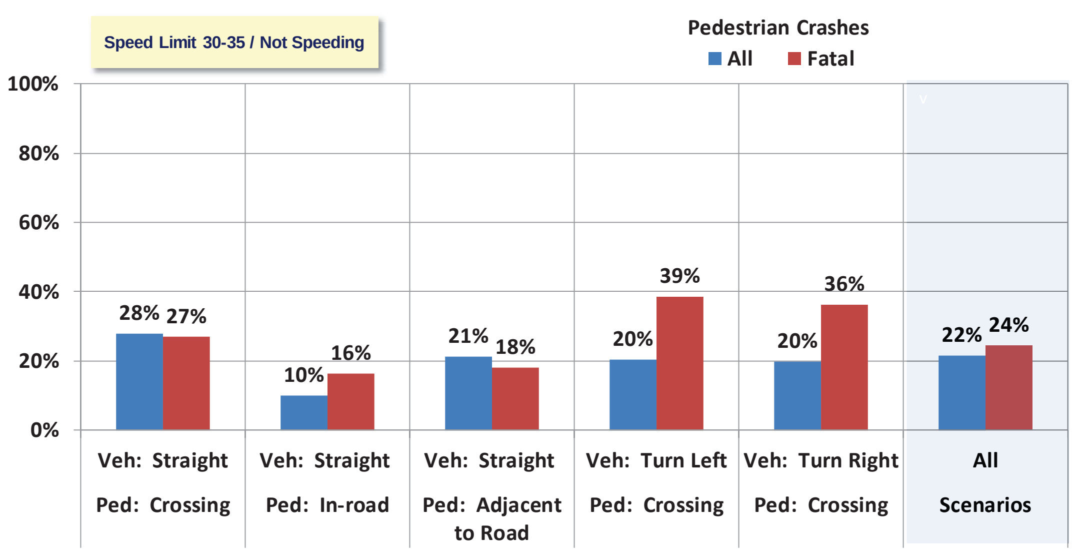


Figure 88. Percentage of "30-35 MPH Posted Speed Limit and Not Speeding" Crashes per Total Crashes in Each Priority Scenario

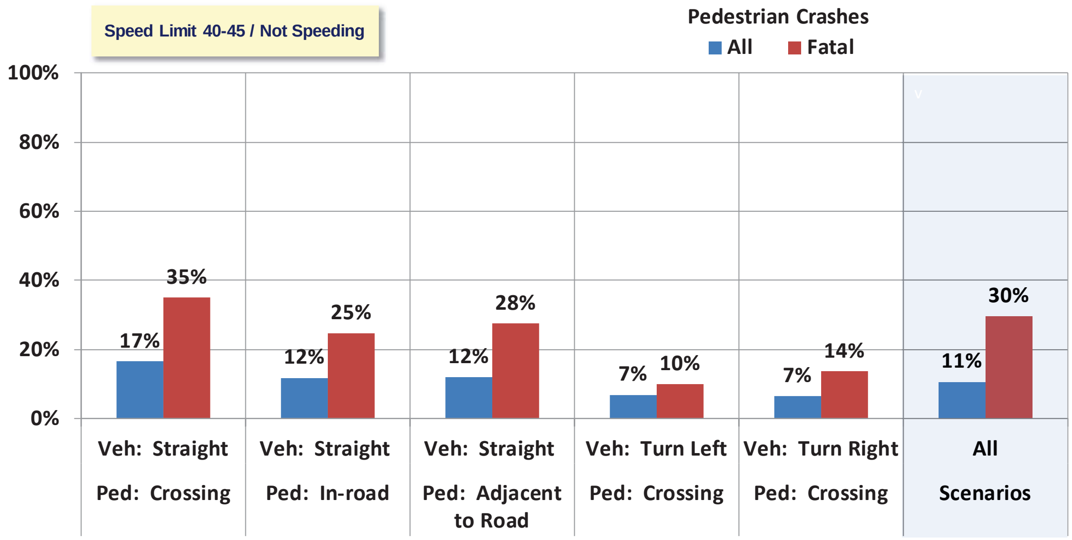


Figure 89. Percentage of "40-45 MPH Posted Speed Limit and Not Speeding" Crashes per Total Crashes in Each Priority Scenario

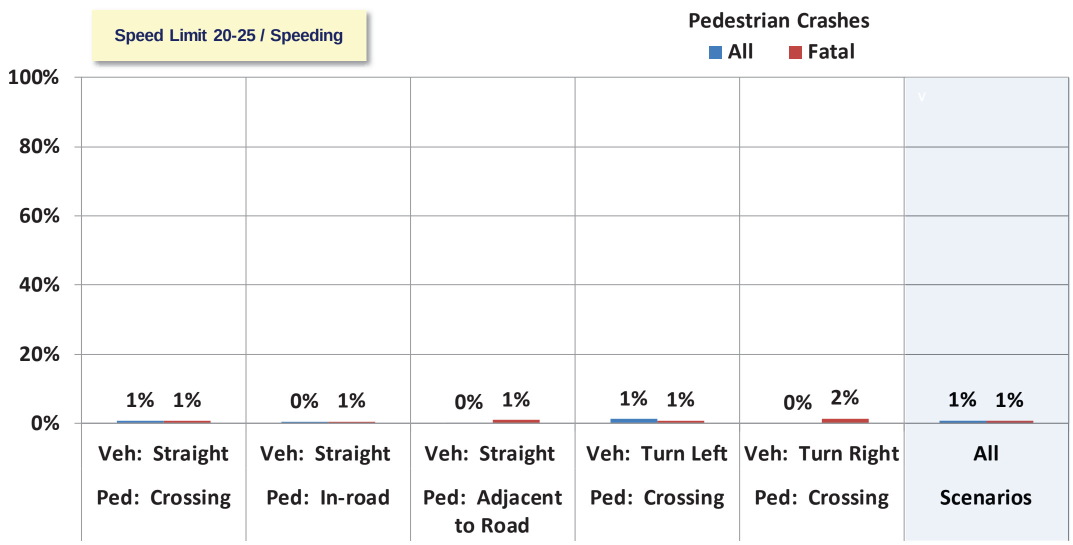


Figure 90. Percentage of "20-25 MPH Posted Speed Limit and Speeding" Crashes per Total Crashes in Each Priority Scenario

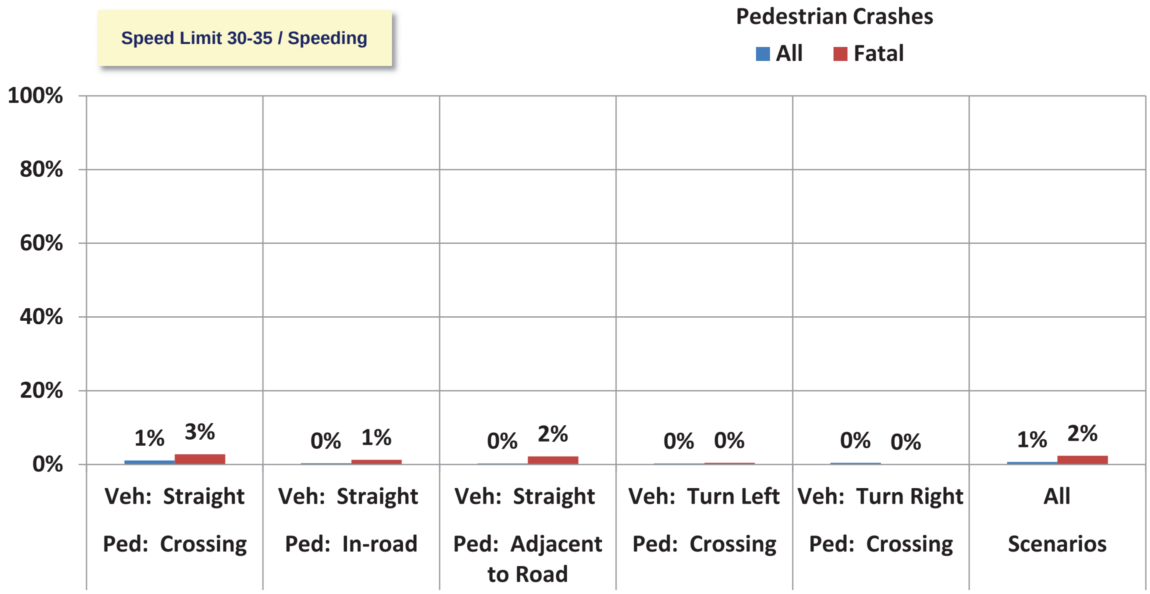


Figure 91. Percentage of "30-35 MPH Posted Speed Limit and Speeding" Crashes per Total Crashes in Each Priority Scenario

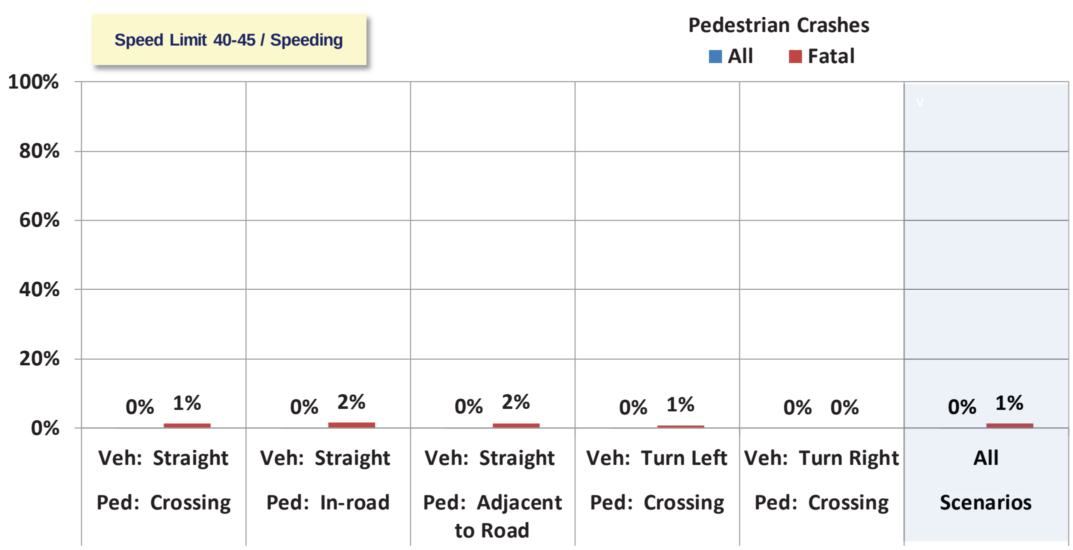


Figure 92. Percentage of "40-45 MPH Posted Speed Limit and Speeding" Crashes per Total Crashes in Each Priority Scenario

Appendix C: Pre-Crash Scenario Characteristics

Vehicle Changing Lanes/Pedestrian Crossing Road			
Total Crashes - 510 / Total Fatal Crashes - 31 (2011 & 2012 Annual Crash Average)			
	GES (%)	**FARS (%)**	**Crash Location Parameters**
Relation to Junction	63.3	77.0	Non-Junction
	34.7	16.4	Intersection and Intersection Related
Pedestrian Location			**Non-Intersection and:**
	43.6	82.0	On Road, Not in Marked Crosswalk
	22.4	1.6	In Marked Crosswalk
	6.3	3.3	On Road, Crosswalk Availability Unknown
			Intersection and:
	12.7	4.9	In Marked Crosswalk
	8.9	3.3	Not in Crosswalk
	4.9	4.9	Unmarked Crosswalk
	1.2	0.0	Unknown Location
Traffic Control Device	76.5	91.8	No Traffic Control Signal or Sign
	12.2	3.3	Traffic Control Signal (Color, Flashing, Lane-Use, Highway)
	7.5	1.6	Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning)
Traffic Control Device × Relation to Junction × Pedestrian Location			**No Traffic Control Signal and:**
	33.6	72.1	Non-Intersection and on Road, Not in Marked Crosswalk
	22.4	0.0	Non-Intersection and in Marked Crosswalk
	4.9	1.6	Non-Intersection and on Roadway, Crosswalk Availability Unknown
	1.1	4.9	Intersection and in Unmarked Crosswalk
	5.1	0.0	Intersection and not in Crosswalk
			Traffic Control Signal and:
	3.8	0.0	Intersection and in Unmarked Crosswalk
	1.7	1.6	Intersection and in Marked Crosswalk
	1.2	0.0	Intersection and Unknown Location
			Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning) and:
	7.5	1.6	Intersection and in Marked Crosswalk
	GES (%)	**FARS (%)**	**Driving Environment Parameters**
Weather	84.7	90.2	Clear
	15.3	8.2	Adverse
Lighting Condition	67.1	13.1	Daylight
	26.7	54.1	Dark with Overhead Street Lighting
	5.0	29.5	Dark
Road Surface Condition	78.4	88.5	Dry
	20.4	9.8	Wet/Slippery
Weather × Road Surface Condition × Lighting			**Clear and Dry and:**
	64.5	9.8	Daylight
	10.1	50.8	Dark with Overhead Street Lighting
	3.8	24.6	Dark
	0.0	3.3	Dawn, Dusk
			Clear and Wet/Slippery and:
	5.1	0.0	Dark with Overhead Street Lighting
			Adverse and Wet/Slippery and:
	0.0	0.0	Dawn, Dusk
	2.6	3.3	Daylight
	10.3	1.6	Dark with Overhead Street Lighting
	1.2	3.3	Dark

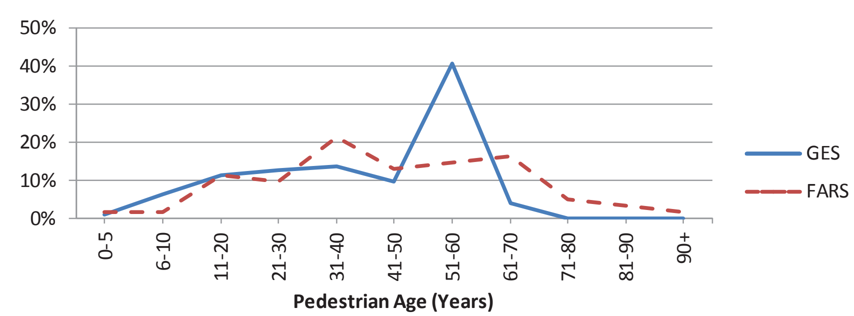
Vehicle Changing Lanes/Pedestrian Crossing Road

	GES (%)	FARS (%)	Road Geometry Parameters
Roadway Alignment	97.3	96.7	Straight
	1.4	3.3	Curve
Roadway Grade	57.7	82.0	Level
	1.2	13.1	Grade, Unknown Slope
	1.9	1.6	Uphill
	0.0	0.0	Downhill
Roadway Alignment × Roadway Grade			**Straight and:**
	56.2	82.0	Level
	1.2	9.8	Grade, Unknown Slope
	0.0	1.6	Hillcrest
	0.0	0.0	Downhill
	1.9	1.6	Uphill
			Curve and:
	1.4	0.0	Level

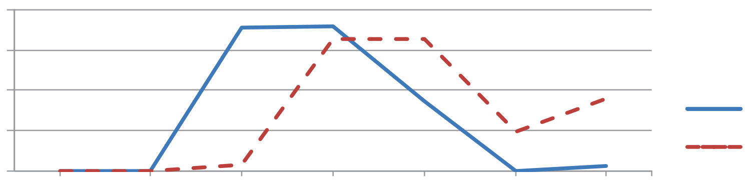
	GES (%)	FARS (%)	Driver Contributing Factors
Driver Impairment	0.0	6.6	Impairment
Vision Obscured	25.2	18.0	Obstruction
Distraction	25.8	6.6	Distracted
	28.9	3.3	Looked but Didn't See

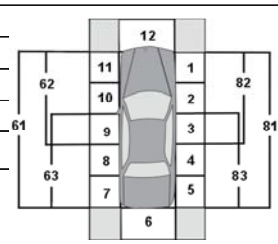
	GES (%)	FARS (%)	Pedestrian Actions/Characteristics
Pedestrian Impairment	14.5	18.0	Impairment
Inattentive	0.0	1.6	Inattentive
Visibility	10.3	14.8	Dark Clothes/Not Visible
Dart/Dash	32.0	14.8	Dart/Dash
Vision Obscured × Dart/Dash			**No Vision Obstruction and:**
	6.4	1.6	No Dart/Dash
	11.4	11.5	Dart/Dash - Ran Only
			Vision Obstruction and:
	13.7	21.3	Dart/Dash & Ran/Walked
	9.8	13.1	No Dart/Dash
Pedestrian Visibility × Dart/Dash			**Dark Clothes/Not Visible and:**
	4.0	16.4	Dart/Dash
	0.0	4.9	No Dart/Dash

Age



Vehicle Changing Lanes/Pedestrian Crossing Road

	Vehicle Related Parameters		
Posted Speed Limit			
	GES (%)	FARS (%)	
Speed Related	7.3	9.8	Speed Related
Speed Related × Posted Speed Limit			**Not Speeding and:**
	35.6	1.6	20-25 MPH
	31.6	29.5	30-35 MPH
	10.9	26.2	40-45 MPH
	0.0	9.8	50-55 MPH
	1.2	16.4	60 MPH and over
	0.0	0.0	Speeding and:
	0.0	0.0	20-25 MPH
	2.3	3.3	30-35 MPH
	3.8	4.9	40-45 MPH
Attempted Avoidance Maneuver	57.6	78.7	No Corrective Action
			Braking Only:
	2.2	4.9	No Lockup
	1.2	0.0	Lockup
	2.0	0.0	Lockup Unknown
			Steering Only:
	1.4	9.8	Steering Left
	2.6	1.6	Steering Right
			Braking and Steering:
	3.8	1.6	Braking and Steering Left
	0.0	1.6	Braking and Steering Right
Area of Impact	76.6	86.9	12 O'clock Value
	1.9	3.3	1 O'clock Value
	4.0	6.6	11 O'clock Value
	4.4	0.0	Right-front side (82)
	2.0	0.0	2 O'clock Value



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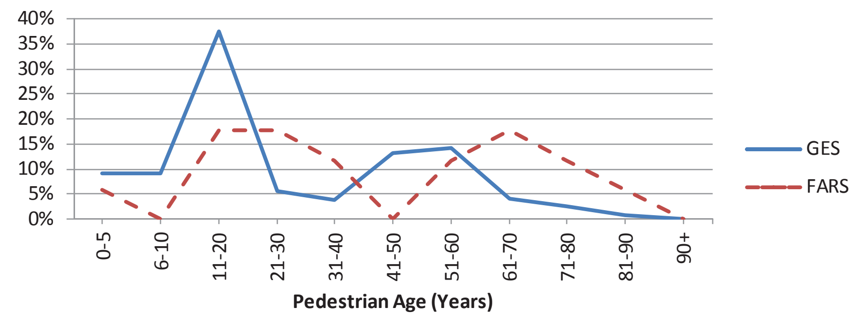
Vehicle Starting/Pedestrian Crossing Road			
Total Crashes - 1,285 / Total Fatal Crashes - 9 (2011 & 2012 Annual Crash Average)			
	GES (%)	FARS (%)	Crash Location Parameters
Relation to Junction	13.9	23.5	Non-Junction
	85.2	76.5	Intersection and Intersection Related
Pedestrian Location			**Non-Intersection and:**
	12.2	35.3	On Road, Not in Marked Crosswalk
	8.7	0.0	In Marked Crosswalk
	0.7	5.9	On Road, Crosswalk Availability Unknown
			Intersection and:
	35.3	41.2	In Marked Crosswalk
	11.7	5.9	Not in Crosswalk
	30.7	11.8	Unmarked Crosswalk
	0.7	0.0	Unknown Location
Traffic Control Device	7.4	35.3	No Traffic Control Signal or Sign
	25.9	52.9	Traffic Control Signal (Color, Flashing, Lane-Use, Highway)
	66.1	11.8	Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning)
Traffic Control Device × Relation to Junction × Pedestrian Location			**No Traffic Control Signal and:**
	5.2	17.6	Non-Intersection and on Road, Not in Marked Crosswalk
	0.0	5.9	Non-Intersection and on Roadway, Crosswalk Availability Unknown
	0.0	0.0	Intersection and not in Crosswalk
			Traffic Control Signal and:
	17.4	29.4	Intersection and in Marked Crosswalk
	0.9	5.9	Intersection and in Unmarked Crosswalk
	2.4	5.9	Intersection and not in Crosswalk
	0.4	0.0	Intersection and Unknown Location
			Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning) and:
	29.9	5.9	Intersection and in Unmarked Crosswalk
	17.5	5.9	Intersection and in Marked Crosswalk
	9.3	0.0	Intersection and not in Crosswalk
	8.1	0.0	Non-Intersection and in Marked Crosswalk
	GES (%)	FARS (%)	Driving Environment Parameters
Weather	94.6	76.5	Clear
	5.4	17.6	Adverse
Lighting Condition	64.1	52.9	Daylight
	31.8	35.3	Dark with Overhead Street Lighting
	0.4	11.8	Dark
Road Surface Condition	90.7	76.5	Dry
	7.4	17.6	Wet/Slippery
Weather × Road Surface Condition × Lighting			**Clear and Dry and:**
	62.7	41.2	Daylight
	24.8	29.4	Dark with Overhead Street Lighting
	0.4	5.9	Dark
	2.8	0.0	Dawn, Dusk
			Adverse and Wet/Slippery and:
	0.0	0.0	Dawn, Dusk
	0.7	5.9	Daylight
	4.6	5.9	Dark with Overhead Street Lighting
	0.0	5.9	Dark

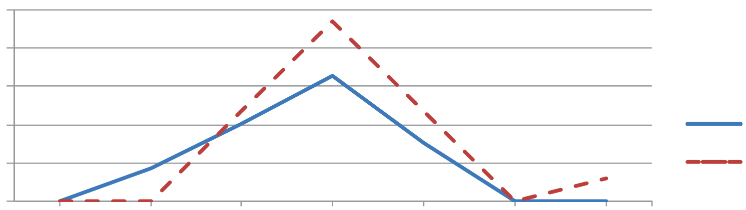
Vehicle Starting/Pedestrian Crossing Road

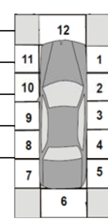
	GES (%)	FARS (%)	Road Geometry Parameters
Roadway Alignment	76.6	94.1	Straight
	9.3	5.9	Curve
Roadway Grade	77.5	94.1	Level
	4.4	5.9	Grade, Unknown Slope
	1.5	0.0	Uphill
	0.0	0.0	Downhill
Roadway Alignment × Roadway Grade			**Straight and:**
	68.2	88.2	Level
	3.8	5.9	Grade, Unknown Slope
	0.0	0.0	Hillcrest
	0.0	0.0	Downhill
	1.5	0.0	Uphill
			Curve and:
	8.7	5.9	Level

	GES (%)	FARS (%)	Driver Contributing Factors
Driver Impairment	0.0	11.8	Impairment
Vision Obscured	16.5	5.9	Obstruction
Distraction	21.5	11.8	Distracted
	13.2	11.8	Looked but Didn't See

	GES (%)	FARS (%)	Pedestrian Actions/Characteristics
Pedestrian Impairment	2.4	11.8	Impairment
Inattentive	2.0	0.0	Inattentive
Visibility	1.2	5.9	Dark Clothes/Not Visible
Dart/Dash	10.3	23.5	Dart/Dash
Vision Obscured × Dart/Dash	0.0	0.0	**No Vision Obstruction and:**
	70.6	76.5	No Dart/Dash
	10.3	11.8	Dart/Dash - Ran Only
	0.0	0.0	**Vision Obstruction and:**
	0.0	5.9	Dart/Dash & Ran/Walked
	16.5	0.0	No Dart/Dash
Pedestrian Visibility × Dart/Dash	0.0	0.0	**Dark Clothes/Not Visible and:**
	0.6	5.9	Dart/Dash
	0.6	0.0	No Dart/Dash
Age			

Vehicle Starting/Pedestrian Crossing Road

	Vehicle Related Parameters		
Posted Speed Limit			
	GES (%)	**FARS (%)**	
	1.4	0.0	No Speed Limit
Speed Related	0.9	11.8	Speed Related
Speed Related × Posted Speed Limit			**Not Speeding and:**
	8.1	0.0	10-15 MPH
	18.8	23.5	20-25 MPH
	31.8	35.3	30-35 MPH
	14.4	23.5	40-45 MPH
	0.0	0.0	50-55 MPH
	0.0	5.9	60 MPH and over
			Speeding and:
	0.4	0.0	20-25 MPH
	0.5	11.8	30-35 MPH
	0.0	0.0	40-45 MPH
Attempted Avoidance Maneuver	47.2	88.2	No Corrective Action
			Braking Only:
	13.6	5.9	No Lockup
	0.5	0.0	Lockup
	3.0	0.0	Lockup Unknown
			Steering Only:
	0.0	0.0	Steering Left
	0.0	0.0	Steering Right
			Braking and Steering:
	0.0	0.0	Braking and Steering Left
	0.0	0.0	Braking and Steering Right
Area of Impact	83.6	88.2	12 O'clock Value
	10.9	0.0	1 O'clock Value
	0.6	5.9	Undercarriage
	0.3	5.9	11 O'clock Value
	0.0	0.0	2 O'clock Value



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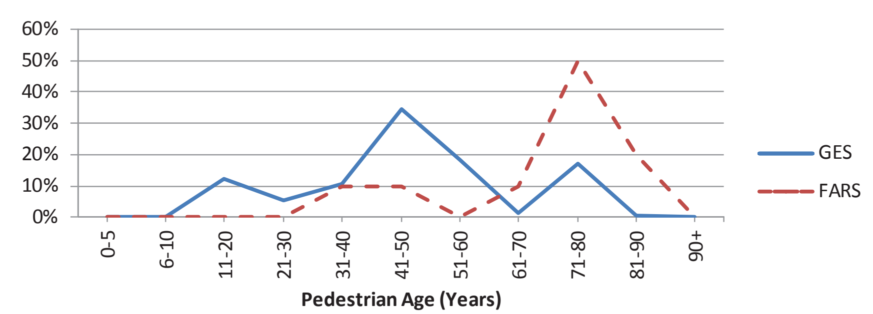
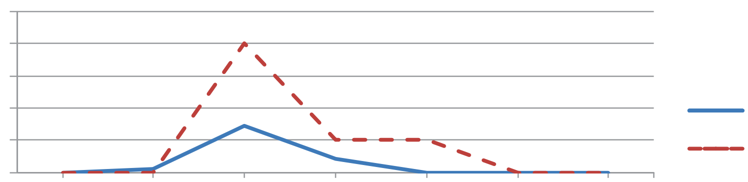
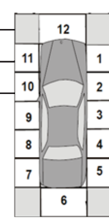
Vehicle Backing Up/Pedestrian Crossing Road			
Total Crashes - 1,090 / Total Fatal Crashes - 5 (2011 & 2012 Annual Crash Average)			
	GES (%)	**FARS (%)**	**Crash Location Parameters**
Relation to Junction	49.5	70.0	Non-Junction
	48.5	10.0	Intersection and Intersection Related
Pedestrian Location			**Non-Intersection and:**
	37.2	60.0	On Road, Not in Marked Crosswalk
	1.1	0.0	In Marked Crosswalk
	12.3	0.0	On Road, Crosswalk Availability Unknown
			Intersection and:
	15.0	0.0	In Marked Crosswalk
	0.5	0.0	Not in Crosswalk
	10.9	0.0	Unmarked Crosswalk
	10.4	0.0	Unknown Location
	0.0	20.0	**Non- Trafficway Area**
	11.7	10.0	**Parking Lane/Zone**
Traffic Control Device	63.5	80.0	No Traffic Control Signal or Sign
	24.1	10.0	Traffic Control Signal (Color, Flashing, Lane-Use, Highway)
	0.8	0.0	Sign (Stop, Yield, School Zone Sign/Device, Regulatory, Warning)
Traffic Control Device × Relation to Junction × Pedestrian Location			**No Traffic Control Signal and:**
	35.4	30.0	Non-Intersection and on Road, Not in Marked Crosswalk
	11.0	0.0	Non-Intersection - On Roadway, Crosswalk Availability Unknown
	0.0	20.0	Non-Junction and Non-Trafficway Area
	11.0	10.0	Non-Junction and Parking Lane/Zone
	0.5	0.0	Intersection and not in Crosswalk
			Traffic Control Signal and:
	13.5	0.0	Intersection and in Marked Crosswalk
	0.1	10.0	Non-Intersection and on Road, Not in Marked Crosswalk
	10.4	0.0	Intersection and Unknown Location
	GES (%)	**FARS (%)**	**Driving Environment Parameters**
Weather	96.5	90.0	Clear
	3.5	10.0	Adverse
Lighting Condition	97.3	90.0	Daylight
	2.7	10.0	Dark with Overhead Street Lighting
	0.0	0.0	Dark
Road Surface Condition	94.2	80.0	Dry
	3.3	10.0	Wet/Slippery
Weather × Road Surface Condition × Lighting			**Clear and Dry and:**
	92.3	70.0	Daylight
	1.8	10.0	Dark with Overhead Street Lighting
	0.0	0.0	Dark
	0.0	0.0	Dawn, Dusk
			Clear and Wet/Slippery and:
	0.7	10.0	Daylight
			Adverse and Wet/Slippery and:
	0.0	0.0	Dawn, Dusk
	2.6	0.0	Daylight
	0.0	0.0	Dark with Overhead Street Lighting
	0.0	0.0	Dark
			Adverse and Non-Trafficway and:
	0.0	10.0	Daylight

Vehicle Backing Up/Pedestrian Crossing Road			
	GES (%)	**FARS (%)**	**Road Geometry Parameters**
Roadway Alignment	86.8	90.0	Straight
	0.0	0.0	Curve
	1.9	10.0	Non-Trafficway
Roadway Grade	85.8	80.0	Level
	0.5	0.0	Grade, Unknown Slope
	0.0	0.0	Uphill
	0.0	10.0	Downhill
	1.9	10.0	Non-Trafficway Area
Roadway Alignment × Roadway Grade			**Straight and:**
	85.8	80.0	Level
	0.5	0.0	Grade, Unknown Slope
	0.0	0.0	Hillcrest
	0.0	10.0	Downhill
	0.0	0.0	Uphill
			Curve and:
	0.0	0.0	Level
	1.9	10.0	**Non-Trafficway Area**

	GES (%)	**FARS (%)**	**Driver Contributing Factors**
Driver Impairment	0.5	0.0	Impairment
Vision Obscured	0.8	20.0	Obstruction
Distraction	27.9	20.0	Distracted
	3.2	0.0	Looked but Didn't See

	GES (%)	**FARS (%)**	**Pedestrian Actions/Characteristics**
Pedestrian Impairment	0.1	0.0	Impairment
Inattentive	0.0	0.0	Inattentive
Visibility	0.0	0.0	Dark Clothes/Not Visible
Dart/Dash	1.5	10.0	Dart/Dash
Vision Obscured × Dart/Dash			**No Vision Obstruction and:**
	74.2	70.0	No Dart/Dash
	0.8	10.0	Dart/Dash - Ran Only
			Vision Obstruction and:
	0.0	0.0	Dart/Dash & Ran/Walked
	0.8	20.0	No Dart/Dash
Pedestrian Visibility × Dart/Dash			**Dark Clothes/Not Visible and:**
	0.0	0.0	Dart/Dash
	0.0	0.0	No Dart/Dash
Age			

Vehicle Backing Up/Pedestrian Crossing Road			
	Vehicle Related Parameters		
Posted Speed Limit			
	GES (%)	FARS (%)	
	2.6	10.0	No Speed Limit
Speed Related	1.1	0.0	Speed Related
Speed Related × Posted Speed Limit			**Not Speeding and:**
	12.3	40.0	20-25 MPH
	3.6	10.0	30-35 MPH
	0.0	10.0	40-45 MPH
	0.0	0.0	50-55 MPH
	0.0	0.0	60 MPH and over
			Speeding and:
	0.0	0.0	20-25 MPH
	0.5	0.0	30-35 MPH
	0.0	0.0	40-45 MPH
Attempted Avoidance Maneuver	83.3	70.0	No Corrective Action
			Braking Only:
	0.0	10.0	No Lockup
	0.0	0.0	Lockup
	0.0	0.0	Lockup Unknown
	0.0	0.0	**Steering Only:**
	0.0	0.0	Steering Left
	0.0	0.0	Steering Right
			Braking and Steering:
	0.0	0.0	Braking and Steering Left
	0.0	0.0	Braking and Steering Right
Area of Impact	86.1	90.0	6 O'clock Value
	0.1	0.0	5 O'clock Value
	0.0	0.0	7 O'clock Value
			

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