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KEY PEDESTRIAN COLLISION SCENARIOS IN THE U.S. FOR EFFECTIVE COLLISION AVOIDANCE TECHNOLOGIES

DANIEL BLOWER

UMTRI
UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE

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Daniel Blower

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

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16. Abstract

Pedestrians account for more than half of traffic fatalities and injuries in some countries, and a substantial and increasing share in the United States. This report develops pedestrian crash scenarios to identify the primary modes and circumstances in which pedestrians are killed and injured in traffic crashes to support the development of collision avoidance technologies to reduce pedestrian fatality and injury. Crash scenarios are developed separately for light vehicles (LVs) and trucks, because significant differences in operations and vehicle design result in different scenario distributions. National crash data from the Fatality Analysis Reporting System and the General Estimates System from 2010 through 2012 are used. Scenarios are ranked by frequency (number of involvements) and total societal burden as estimated by comprehensive crash costs.

Priority pedestrian crash scenarios for the development of pedestrian collision avoidance technologies for LVs include non-intersection, vehicle going straight; night time crashes, particularly in dark/lighted conditions; left turns, both in daylight and nighttime; pedestrians crossing in daylight; younger pedestrians darting out in non-intersections; and, pedestrians walking along or in the road at night. For trucks, priority scenarios include non-intersection, vehicle going straight; night time, particularly dark/not lighted conditions; pedestrians walking along or in the road at night; left turns, especially in daylight or dark/lighted conditions; higher-speed roads (45+ mph); older pedestrians at intersections; and, younger pedestrians darting out at non-intersections.

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1. Introduction

Traffic crashes result in approximately 1.2 million deaths worldwide each year. Vulnerable road users such as pedestrians, bicyclists, and motorcyclists account for about half of these fatalities. In many low-income countries, pedestrians alone account for over half of all traffic deaths (Zegeer and Bushell 2012). In the United States, the pedestrian share of the toll from traffic crashes is significantly less, though still substantial. Annually, about 4,500 pedestrians die in traffic accidents each year in the United States, which is 13% of all traffic fatalities. About 74,000 are injured, accounting for 3% of all traffic related injuries (Tefft 2011). Both older and younger pedestrians are more at risk of death and injury. Children (15 and younger) account for about 4% of all traffic deaths, but 7% of pedestrian fatalities. They also account for 9% of injuries in traffic crashes, but 23% of pedestrian injuries. The over-involvement of pedestrian injuries is not as marked for older persons, but still significant. People 65 and older make up about 8% of all injuries in traffic crashes, but 11% of all injured pedestrians (Griswold, Fishbain et al. 2011).

Advanced collision-avoidance technologies (ACATs) are being developed and deployed to reduce the overall incidence of crashes. These devices work by sensing a vehicle's stability or its position relative to the roadway and other vehicles on the road. The devices either warn of an unsafe situation so the driver can take action or intervene autonomously by applying the brakes or in some cases steering (Tefft 2011). To date, the technologies are primarily aimed at avoiding or mitigating collisions with other vehicles or at helping the driver maintain control of the vehicle and keeping it in lane. However, because pedestrians account for such a significant share of the fatality and injury burden of traffic crashes, technologies are increasingly being aimed at what are called vulnerable road users, especially pedestrians.

The purpose of this report is to describe the characteristics of pedestrian crashes to support the development of ACATs to reduce pedestrian fatality and injury. The devices work by using sensors, such as radar, Lidar (analogous to radar but using laser light instead of radio frequency waves), or cameras, to detect the presence of pedestrians. Depending on the relative position and motion of vehicles and pedestrians, algorithms evaluate the threat and intervene by warning the driver or applying the brakes or both. Certain features of pedestrian crashes are fundamental to the design of ACATs aimed at pedestrians. These factors include the motion and speed of vehicles, the position and motion of pedestrians, and the presence of obstacles, atmospheric conditions, or other factors that may degrade the functioning of the sensors. This report presents a set of pedestrian crash scenarios that describe the primary crash types involving pedestrians. These crash scenarios are ranked by frequency and by a measure of total harm.

The analysis does not consider vehicle designs or structures that absorb some of the impact energy in order to reduce injury. Instead, the report focuses on developing crash scenarios to identify and prioritize interventions to reduce the frequency of pedestrian crashes.

2. Background

In the most recent three calendar years for which national crash data are available (2010-2012), there has been an average of 75,201 pedestrian crashes annually, involving an average of 78,815 pedestrians (Table 2-1). Both pedestrian crashes and involvements increased substantially from 2011 to 2012, increasing by about 10%. The number of other types of crashes also rose from 2011 to 2012, though by a lower percentage than pedestrian crashes. Passenger-vehicle crash involvements rose by 6.3%, truck involvements by 8.7%, and bicycle involvements by 2.1%. Only motorcycle involvements rose by more, by 15% (National Highway Traffic Safety Administration 2013b). In addition, pedestrians account for a growing share of traffic fatalities. From 2002 to 2007, pedestrians were about 11% of total traffic fatalities, but that has risen to around 14% in 2011 and 2012 (National Highway Traffic Safety Administration 2014).

Table 2-1
Pedestrians and Crashes Involving Pedestrians, by Year.

Unit of analysis	Year			Annual average
	2010	2011	2012	
Pedestrians	76,311	76,783	83,350	78,815
Crashes	73,510	72,403	79,689	75,201

Source: FARS, GES 2010-2012

Table 2-2 shows annual frequencies of pedestrian injuries by severity from 2010 to 2012. The number of fatal injuries has increased significantly, from 4,280 in 2010 to 4,743 in 2012, an increase of over 10%. The number of serious injuries to pedestrians has also increased substantially. A-injuries (defined as incapacitating but not fatal) rose by 22.6% and B-injuries (non-incapacitating but evident) increased by 9.7%. At least in recent years, there is evidence that the pedestrian traffic injury problem is not only significant but also growing.

Table 2-2
Pedestrian Injury Severity, by Year.

Pedestrian injury severity	Year			Annual average
	2010	2011	2012	
Fatal	4,280	4,432	4,743	4,485
A-injury	12,017	12,122	14,736	12,958
B-injury	25,102	23,776	27,543	25,474
C-injury	28,755	29,544	29,898	29,399
None	1,165	1,868	1,969	1,667
Injured, unknown severity	3,777	3,334	2,581	3,231
Unknown	1,216	1,707	1,880	1,601
Total	76,311	76,783	83,350	78,815

Source: FARS, GES 2010-2012

Pedestrians are deemed "vulnerable road users," meaning that they are essentially unprotected in crashes. Clearly, pedestrians are injured at much higher rates in crashes than other road users. An average of 5.7% of pedestrians in crashes were fatally injured, compared with 2.8% for motorcycle riders and about 0.1% for the occupants of other motor vehicle types. (See Table 2-3.) Almost 55% of pedestrians received serious injuries (combining fatal, A-, and B-injuries), compared with 5.4% for occupants of LVs, 3.0% for truck occupants and 2.9% for bus occupants. Only motorcycle riders in crashes were injured at a higher rate, with 63.2%. Only 2.1% of pedestrians in crashes were coded as uninjured. Clearly, reducing pedestrian crash involvements will significantly reduce injuries, compared with other traffic crashes.

Table 2-3
Distribution of Injury Severity of Pedestrians
and Occupants of Selected Vehicle Types.

Injury severity	Pedestrian	LV	Truck	Bus	Motorcycle
Fatal	5.7%	0.1%	0.1%	0.0%	2.8%
A-injury	16.4%	1.0%	0.6%	0.4%	21.2%
B-injury	32.3%	4.3%	2.3%	2.5%	39.2%
C-injury	37.3%	9.8%	2.8%	10.5%	17.4%
None	2.1%	81.1%	89.2%	84.1%	16.6%
Injured, unknown Severity	4.1%	0.4%	0.2%	0.6%	1.1%
Unknown	2.0%	3.2%	4.8%	1.9%	1.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: GES 2010-2012

The purpose of this report is to analyze pedestrian crashes to support the development of ACATs that can reduce the number and severity of pedestrian crashes. In doing this, the report focuses on crashes in which the striking vehicles were passenger cars and other light passenger vehicles such as minivans, sport utility vehicles, and light-duty pickups, as well as medium and heavy trucks. Passenger cars and other light passenger vehicles, collectively referred to as light vehicles (LVs) herein, were the striking vehicles in 92.0% of pedestrian crash involvements (Table 2-4) and are the primary candidate for interventions to reduce pedestrian crashes. Trucks are included also, as a separate vehicle type, even though they were involved in only 1.6% of pedestrian crashes over the period. Trucks have different physical characteristics (longer stopping distances, sweeping out a greater area in turns, higher eye position for the driver, restrictions on driver visibility around the vehicle because of design reasons) and operating environments (more travel on highways, more travel at night) than LVs, resulting in a significantly different challenge in reducing truck pedestrian collisions. Pedestrian crashes for LVs and trucks are analyzed separately.

Table 2-4
Striking Vehicle Type in Pedestrian Crashes
Annual Average 2010-2012.

Striking vehicle type	N	Percent
Passenger car	43,319	55.0
Minivan, sport utility vehicle, pickup truck	29,146	37.0
Truck	1,280	1.6
Motorcycle	634	0.8
Bus	894	1.1
Other type	66	0.1
Unknown	3,475	4.4
Total	78,815	100.0

Source: FARS, GES 2010-2012

3. Relevant recent research

Zegeer and Bushell (2012) reviewed pedestrian crash trends from around the world to identify the primary factors associated with pedestrian crashes and identify potential countermeasures. While most pedestrian crashes occur in urban areas (73% in the U.S.), rural pedestrian crashes are more likely to be fatal because vehicle speeds tend to be higher and because rural areas have fewer walkways than urban areas for pedestrians that are separated from traffic streams. Roadway characteristics associated with pedestrian crashes include higher traffic volumes; higher volumes of crossing pedestrians; the ratio at intersections of traffic volume on the major road to that on minor road; the number of travel lanes to cross; and nearby bus stops, schools, and retail establishments serving alcohol. Raised medians or median islands, fewer lanes, pedestrian crossing signals, and better nighttime lighting were identified as appropriate countermeasures. Other infrastructure related countermeasures include changes in signal timing to give pedestrians a head start before through traffic is allowed to go, and removing left-turn only signals. Improved lighting, restricting street parking near intersections (to improve pedestrian visibility), and prohibiting right-turn-on red were also proposed (Zegeer and Bushell 2012).

A number of different crash typologies have been developed to partition crashes by causal factors and identify opportunities for interventions. Early work included a NHTSA project to classify pedestrian and bicyclist crashes based on an analysis of crash reports from six states. The typologies were designed to assist in developing improvements in infrastructure and road-user education to reduce pedestrian and bicycle crashes. About a third of pedestrian crashes occurred at or near intersections, with a quarter occurring mid-block. Two-thirds occurred in urban areas and they were most frequent in the late afternoon or early evening. The study found that younger and older populations were overrepresented in pedestrian crashes (Hunter, Stutts et al. 1996).

DaSilva and others (2003) analyzed crash data from 1995-1998 Fatality Analysis Reporting System (FARS) and National Automotive Sampling Systems General Estimates System (NASS GES) to support pedestrian crash avoidance systems as part of the U.S. Department of Transportation's Intelligent Vehicle Initiative (IVI). This typology was primarily oriented toward vehicle-based interventions. The authors identified as a high priority ten specific scenarios that accounted for 86% of all pedestrian crashes. The top scenario was a vehicle traveling straight with the pedestrian crossing at a non-junction, accounting for 25.9% of all pedestrian crashes. Younger pedestrians were overinvolved, and pedestrian injuries were more severe in crashes at non-intersection locations (daSilva, Smith et al. 2003).

Jermakian and Zuby (2011) also analyzed FARS and GES data to support vehicle-based interventions. They used FARS and GES data from 2005-2009 to identify three crash scenarios that they said accounted for 65% of pedestrian involvements in traffic crashes, and 58% of deaths. Their analysis focused on single-vehicle crashes in which a pedestrian was struck by the front of a passenger vehicle. The three crash scenarios were as follows: Pedestrian crossing a road with a striking vehicle going straight; pedestrian traveling along a road with the striking vehicle going straight; and, pedestrian crossing a road with the striking vehicle turning. They also identified non-daylight conditions and roads with speed limits over 40 mph as particularly associated with fatal pedestrian crashes (Jermakian and Zuby 2011).

In European work, Ebner et al., (2010) used the German In-Depth Accident Study (GIDAS), as well as FARS and GES data, to identify crash scenarios where pedestrian safety systems could be effective, as well as to develop representative test scenarios. This study weighted crashes by an estimate of total harm in order to prioritize the most serious crash types. The top scenario, both in terms of frequency and harm, was vehicle going straight and the pedestrian crossing in front on low-speed roads. In the U.S. GES data, this scenario accounted for 46% of pedestrian crashes and 47% of total harm. The scenario was even more important in the German data, accounting for 72% of target pedestrian crashes and 71% of harm (Ebner, Samaha et al. 2010).

Huang, et al., (2006) applied the NHTSA crash typology to a Swedish crash data set (STRADA, for Swedish Traffic Accident Data Acquisition) as part of a project to understand the geometry of car-pedestrian collision, including relative motion and angles. The purpose was to determine the appropriate sensor angular field of view to detect pedestrians in the most common scenarios, taking into account vehicle and pedestrian motions. The crash scenario analyzed was pedestrian crossing with the vehicle going straight. The crash data did not include actual travel speed for either cars or pedestrians. Pedestrian speeds were taken from measurements of various populations of pedestrians walking and running, broken down by age bands. Car speeds were taken from posted speed limits. The authors concluded that the detector angle must be at least 60°. If the angle was only 30°, 99.1% of walkers and 73.4% of running pedestrians could be detected (Huang, Yang et al. 2006).

In contrast, a German study using the GIDAS data found that a view angle of 40° was optimal, and that wider fields of view did not offer significant improvements in effectiveness. The target crash type was pedestrians struck by the fronts of light vehicles. Using estimates of pedestrian speeds, vehicle speed and avoidance maneuvers, and the pre-crash trajectory of the pedestrians and vehicles, the location of pedestrians relative to the vehicles was estimated for one second prior to impact. The study estimated that reductions of 40% of fatalities and 27% of severe injuries could be achieved by implementing a system coupling pedestrian detection with autonomous braking (Rosen, Kallhammer et al. 2010).

Lenard, et al., (2011) took a different approach in developing crash scenarios. They used cluster analysis to define six clusters that captured 75% to 80% of pedestrian crashes. The researchers used the STATS19 crash data in Great Britain, which is a comprehensive traffic accident database. The clustering method was repeated in an in-depth crash database (OTS, or On-The-Spot study, based on data from two counties in Great Britain) with comparable results, demonstrating the robustness of the findings, at least in the conditions of Great Britain. The primary cluster in the STATS19 data, accounting for almost 40% of pedestrian crashes, occurred in daylight, in good weather, with the vehicle going straight, pedestrian crossing, and no driver-vision obstruction. The next most common cluster, with 14% of crashes, was similar, except that the driver's vision was blocked by an obstruction until just prior to the collision. In both clusters, younger pedestrians were overrepresented (Lenard, Danton et al. 2011).

Pedestrian crash scenarios have been developed to better understand how they occur and to identify countermeasures. It should be understood that the specific design of scenarios is guided by the range of interventions considered—e.g., vehicle-based, infrastructure, vehicle design, and driver and pedestrian education—and constrained by the types of information in available crash data. The approach taken by Lenard et al. (2011) using a statistical cluster analysis is notable in that it seemingly presumes there is a clustering in nature that is meaningful in terms of interventions. Most classifications were more deliberately constructed to identify sets of crashes that could be mitigated by particular countermeasures. However, it is also notable that the scenarios that have been developed are reasonably similar, depending on how detailed they are and the data that were used. In the present case, the most recent available data were used, and the scenarios were tailored to vehicle-based interventions. In addition, while previous work has focused on light-vehicle scenarios, the present work developed separate scenarios for light vehicles and for trucks.

4. Methods

4.1. Crash data sets used

The analysis here used the two primary national crash data files in the United States, FARS and GES, to develop pedestrian crash scenarios. Both are compiled by the National Highway Traffic Safety Administration (NHTSA). The analysis used the most recent years available at the time of the work, 2010-2012.

The FARS and GES files are the standard national files for the analysis of traffic crashes in the United States. FARS is a census file of all traffic crashes in which a person was killed. As a "census" file, it contains records for every fatal crash and every vehicle and person involved in the crashes. FARS analysts in each state code a standard set of data, relying primarily on police reports, but also using other sources to complete the records, including supplementary investigation, coroner and medical reports, driver records, and vehicle registration files. FARS is the standard file for data on fatal traffic crashes in the U.S.

GES is a nationally representative sample of the estimated 6.4 million police-reported crashes that occur annually. GES covers traffic accidents of all severities, not just fatal crashes. GES is the product of a sample survey with clustering, stratification, and weighting that allows calculation of national estimates. GES researchers sample crash reports from a set of police jurisdictions, and code the needed data from those reports. Unlike FARS, all data for GES records are coded from crash reports only.

Developing ACATs for pedestrians requires an understanding of pre-crash circumstances. Both FARS and GES incorporate a substantial amount of information about pre-crash states and actions of motor vehicles and pedestrians. This makes them well suited to the task. In contrast, state files typically do not have the same amount of information in their coded data. To get to more detail from state-level files would entail sampling police reports and coding additional information about the geometry of the crashes from narratives and diagrams on the police reports. It is also worth mentioning that in 2010 FARS added pre-crash information that GES has long had. These additional variables make FARS and GES pre-crash detail similar to that in comprehensive in-depth crash files such as the NASS Crashworthiness Data System (CDS).

This analysis used FARS data for fatal crashes and GES for nonfatal crashes. A hybrid crash file was developed by combining fatal crash records from FARS with nonfatal crash records from GES. This combination of data sets provided the most accurate representation of traffic crashes in the U.S. Beginning in 2010, the structure and data in the FARS and GES files were harmonized substantially, so that variables common to the two files are identically structured. The convergence of FARS and GES facilitated combining data, because there was no need to re-code variables to make them consistent. Three years of data are used in the analysis, 2010 to 2012. Using multiple years of data makes the resulting estimates more stable and robust.

4.2. Prioritization of crash scenarios

Crash scenarios are ranked by frequency of involvement and by a measure of harm. Frequency of involvement is just the number of pedestrians involved in crashes. Ranking and identifying pedestrian scenarios by how often different crash scenarios occur is a common means. However, it is useful to take into consideration the amount of harm in terms of fatalities and injuries caused by pedestrian crashes. By considering costs in terms of deaths and injuries in pedestrian crashes, crash scenarios that cause the most harm can be prioritized in developing technologies and interventions to reduce the total societal burden.

The measure of harm used was an estimate of the comprehensive societal costs related to the crashes. These costs include medical costs, lost productivity, and quality-adjusted life years lost per injury (Miller, Zaloshnja et al. 2004). Quality-adjusted life years lost vary by age, so injury costs are estimated for six age groups: 0 to 4, 5 to 9, 10 to 14, 15 to 19, 20 to 64, and 65 years and older. For each level of injury severity, Miller, Zaloshnja, et al. (2004) provide an estimate of the total associated societal harm. Comprehensive crash scenario costs are computed by counting the number of injured pedestrians by age group and injury severity for each crash scenario, and then multiplying by the associated costs for each age group and injury level.

Injury costs in Miller, Zaloshnja, et al. (2004) are provided using the Maximum Abbreviated Injury Score (AIS). However, injuries in the crash data were coded using the so-called KABCO scale of injury severity. This scale is common to crash files based on police reports. In the KABCO scale, K corresponds to a fatal injury, A to an incapacitating injury, B means a non-incapacitating but evident injury, C is used for complaint of pain, and O means no injury. The KABCO injury levels were translated to the MAIS scale using a method described in Ebner, Samaha et al. (2010) and then costs applied to the resulting injury scores. Estimates given by Miller, Zaloshnja, et al. (2004) were expressed in 2000-year dollars. In the present report, year 2000 dollars were adjusted to 2013 dollars using the Bureau of Labor Statistics consumer price index (CPI) inflation calculator (Bureau of Labor Statistics 2013).

In the analysis here, crash scenarios are ranked both by the frequency of occurrence and by the total associated societal costs.

4.3. Problem definition and limitations

Pedestrian crash scenarios were developed primarily to define the circumstances in which vehicle-based ACATs must perform to avoid or mitigate pedestrian crashes. ACATs function by detecting and evaluating an impending collision and then warning drivers of the threats or intervening autonomously by braking or steering to avoid or mitigate impacts with pedestrians.

This formulation of the problem helps to define constraints on the set of crashes included in the analysis. The analysis includes only crashes in which a pedestrian was struck as the first event in the crash. Pedestrian impacts that occurred after the striking vehicle hit other vehicles or objects are not included, because a pedestrian-focused ACAT is not relevant to such crashes. Crashes initiated by vehicle loss of control are also not included, because the functioning of the technologies presupposes vehicle control. Crashes in which the driver was impaired are included, however, because some technologies autonomously apply the brakes. Likewise, crashes in which the pedestrian was impaired are included as well because vehicle-based collision avoidance technologies do not require any cooperation from pedestrians.

Only pedestrian collisions with motor vehicles are included here. Bicyclists and other non-motorists are excluded.

Two vehicle types are included in the analysis, light vehicles and trucks. Light vehicles (LVs) include passenger cars, sport utility vehicles (SUVs), minivans, and pickup trucks. Trucks include all medium- and heavy-duty trucks with a gross vehicle weight rating (GVWR) over 10,000 lbs. This truck definition covers basically all trucks with at least two axles and six tires, and bigger.

Trucks are differentiated from LVs because of the significant differences in vehicle design and operations. The driver eye position for trucks is significantly higher than in LVs, the driver's field of view is significantly restricted by the hood and cargo body, and there are significant differences in the operating environment. Trucks, particularly tractor-semitrailers, tend to operate more at night, compared with LVs, and more on higher speed roads, particularly in rural areas.

In addition, the broad vehicle types differ in performance characteristics, which may affect the collision-mitigation interventions. Trucks tend to have longer stopping distances than LVs; in addition, air-braked trucks have a lag time between the time when the brake treadle is depressed and the braking system develops maximum braking power. This lag can be as much as a second or more. The design and performance characteristics of trucks may call for implementations of pedestrian ACATs that differ from those for LVs.

Buses, motorcycles, and other motor vehicle types are not included as the striking vehicle type.

4.4. Developing pedestrian crash scenarios

The development of the specific pedestrian crash scenarios was primarily designed around the geometry of the crashes, to establish the relative motion of the striking vehicle and pedestrian, within the constraints of the information coded in crash databases. The goal was to establish the relationship between the vehicle and pedestrian in physical space.

Variables for pre-crash maneuver were used to determine the initial motion of the striking vehicle. Pre-crash maneuver (P_CRASH1 in both FARS and GES) establishes the vehicle's activity immediate prior to its driver becoming aware of an impending collision, or at impact if the driver took no evasive maneuver. In pedestrian crashes, the primary pre-crash maneuvers were going straight (including negotiating a curve), turning left, turning right, starting in lane, and backing. The pedestrian's pre-crash motion is captured in the MPR_ACT variable, common to both GES and FARS. This is a multiple response variable, meaning more than one action can be coded. The most common code levels were crossing, waiting to cross, walking along the roadside with or against traffic, and working or playing in the road. Some of the code levels, such as going to or from school, were not informative about actions or the relation to the road so when more than one code was selected for a pedestrian, the action that most clearly captured movement or position relative to the road was used to define scenarios. In addition, the MTM_CRSH variable was used to identify pedestrians who had "darted" into the road. This captures situations in which the pedestrian suddenly moved into the roadway. In the scenarios, "crossing" and "darting" are mutually exclusive, so that crossing implies the pedestrian did not dart. The location of the pedestrian in relation to the roadway at the time of the crash was captured in the LOCATION variable in both FARS and GES. This variable was used to classify the pedestrian as being at an intersection, non-intersection, or along the roadside (National Highway Traffic Safety Administration 2013c; National Highway Traffic Safety Administration 2013a; National Highway Traffic Safety Administration n.d.).

These variables were used to create a set of crash scenarios that capture the main combinations of vehicle movement, pedestrian movement, pedestrian location with respect to the roadway, and whether the crash location was at an intersection or non-intersection roadway segment.

In the next step, the effect of environmental conditions that may degrade the effectiveness of pedestrian detection and intervention systems was examined. Environmental conditions include light condition, weather condition, and road condition. Light condition sets the circumstances under which sensors must operate. Similarly, adverse weather, particularly snow, rain, fog, and smoke, may reduce how well the sensors can detect pedestrians. Road condition can also be important. Some pedestrian-ACATs autonomously brake the vehicle or increase braking power. Wet, snow-covered, or icy roads can reduce the effectiveness of braking.

Other factors also considered include pedestrian age, which is used as a surrogate for size and may affect pedestrian detection, and whether there were any driver vision obstructions. Any such obstructions may also obstruct pedestrian detection sensors.

5. Results

5.1. Vehicle maneuver, pedestrian action, and roadway location

The distribution of the striking vehicles' pre-crash maneuver is tabulated in Table 5-1. Separate distributions are shown for LVs and trucks. The table is based on the P_CRASH1 variable that captures the movement of the vehicle prior to the driver's realization of an imminent crash or just prior to impact if the driver took no action. The table shows an aggregation of the primary actions. "Straight" combines going straight with negotiating a curve, essentially driving in lane with no active control maneuvers such as changing lanes, stopping, or making a U-turn. The "other" category combines a large number of maneuvers with relatively few cases each. It includes maneuvers such as entering a parked position, leaving a parked position, decelerating in lane, merging, and others.

Overall, the distributions of pre-crash maneuver for LVs and trucks in pedestrian crashes are reasonably similar. Trucks were more likely to be going straight at the time of the crash than LVs, possibly because they travel more on higher-speed roads. They are somewhat less likely to be involved in backing crashes (surprisingly). One might have expected trucks to have a higher proportion of backing crashes than LVs because a truck driver's vision to the rear is typically obstructed by the cargo body or cargo. However, that proves not to be the case.

Table 5-1
Distribution of Pre-crash Vehicle Maneuver by Striking Vehicle Type.

Pre-crash vehicle action	Light vehicle	Truck	Total
Straight	52.9%	60.4%	53.0%
Turning left	24.6%	23.9%	24.6%
Turning right	9.1%	7.3%	9.1%
Backing	4.4%	2.5%	4.4%
Starting	2.9%	2.5%	2.9%
Other	6.0%	3.5%	6.0%
Total	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

Substantially more pedestrian crashes occurred during vehicle left turns than right turns. The over-involvement of left turns was observed for both LVs and trucks. Almost a third of pedestrian crashes occurred during a turning maneuver, and in almost 75% of these cases, the turn was to the left.

The actions and states of pedestrians prior to the crashes were captured in multiple response variables, meaning that more than one action could be recorded. In cases where more than one action was coded, the one that most clearly represented a movement or position in relation to the roadway was chosen. For example, if a pedestrian was coded both as going to or from school and crossing the road, the pedestrian was classified as crossing.

The most common pedestrian action was crossing the roadway, though there are significant differences between the striking vehicle types (Table 5-2). For LVs, almost three-quarters of pedestrians were crossing the road at the time of impact; about 6% were working or playing in the road; and an additional 6% were moving along the roadway, either with the direction of traffic or against it. In truck pedestrian crashes, pedestrians were crossing the road in 56.9% of crashes, substantially less than for LVs. The difference is made up by higher proportions of pedestrians who were moving along the road (11.6%), working or playing in the road (15.1%), and entering/exiting a vehicle (6.4%). This latter category includes pedestrians working on, pushing, or leaving/approaching a disabled vehicle. Differences between common pedestrian actions in LV and truck crashes are likely explained by differences in operations and exposure to pedestrians. Trucks operate more in rural areas with no sidewalks for pedestrians and on higher-speed roads. LVs operate more in urban areas with a heavier concentration of pedestrians, resulting in a different distributions of pedestrian actions prior to the crashes.

Table 5-2
Distribution of Pedestrian Action Prior to Crash by Striking Vehicle Type.

Pedestrian action	Light vehicle	Truck	Total
Crossing	73.6%	56.9%	73.3%
Waiting to cross	1.3%	1.4%	1.3%
Moving along roadway with traffic	4.5%	10.1%	4.6%
Moving along roadway against traffic	1.4%	1.4%	1.4%
Moving along roadway, unk. direction	0.0%	0.1%	0.0%
Moving on sidewalk	1.8%	0.7%	1.7%
Working/playing on road	5.9%	15.1%	6.1%
Adjacent to road	1.4%	0.5%	1.4%
Entering/exiting vehicle	1.3%	6.4%	1.3%
Unspecified	8.8%	7.4%	8.8%
Total	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

About half of pedestrian crashes occurred at intersections, and about half occurred along non-intersection road segments, but almost 95% occurred on roadways themselves. (See Table 5-3.) Only 1 in 20 pedestrian victims were coded as being on the roadside, e.g., in parking lanes, driveway access, or on the shoulder. Only a tiny percentage (less than 0.1%) was located on sidewalks or on a median or crossing island. In the vast majority of pedestrian crashes, pedestrians were located within the boundaries of travel lanes at the point of impact. The distribution of pedestrian location was reasonably similar for LVs and trucks. LVs had a somewhat higher proportion of intersection crashes (48.8% to 44.3%), while trucks had a somewhat higher proportion of crashes on non-intersection segments (50.2% to 45.7%). This difference is consistent with the operational and exposure differences identified earlier.

Table 5-3
Distribution of Pedestrian Location by Striking Vehicle Type.

Road location	Light vehicle	Truck	Total
Intersection	48.8%	44.3%	48.7%
Non-intersection	45.7%	50.2%	45.8%
Roadside	4.5%	5.3%	4.6%
Unknown	1.0%	0.1%	0.9%
Total	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

5.2. Crash scenarios

Using the basic elements of crash geometry, a set of pedestrian crash scenarios was developed. These crash scenarios exhaustively classify all pedestrian crashes by location, vehicle maneuver, and pedestrian action. “Exhaustively” here means that each pedestrian crash was classified into one and only one scenario.

It should be noted that the scenarios here are in no real sense a “natural” classification. Many different classification schemes could have been developed, depending on the goal of the classification. The system here was developed to be useful in the development of vehicle-based pedestrian-detection and collision-avoidance technologies. Accordingly, it is oriented around the motion of the vehicles and pedestrian motions relative to the vehicles. Different classification methods would be used for infrastructure-based countermeasures or countermeasures based on changing the behavior of the pedestrians.

Classification methods also differ in the amount of detail included, and whether to lump or split detailed categories. For example, in this report, all types of intersections were combined and classified as an intersection, with no detail on crosswalks. Pedestrians in crosswalks at intersections could be broken out separately, but that detail was judged to be not as important to vehicle-based systems as the fact that the location was an intersection, which implies certain things about vehicle speed and the concentration of pedestrians and other vehicles. Adding detail adds to the number of possible crash scenarios; it was decided not to allow scenarios smaller than about 0.3%. In the end, 23 pedestrian crash scenarios were developed.

5.3. Pedestrian crash scenarios ranked by frequency

Table 5-4 shows the pedestrian crash scenarios developed from the combination of roadway location, vehicle maneuver, and pedestrian action. The scenarios are displayed in order of frequency of involvement, along with the percentage of all pedestrian involvements for each scenario. This list combines both LV and truck pedestrian crashes.

In this method of classification, the most common scenario occurred at an intersection, with the striking vehicle making a left turn, and the pedestrian crossing the roadway. This scenario accounted for almost 20% of all pedestrian involvements. The next most common scenarios occurred away from intersections, with striking vehicles going straight, and pedestrians either crossing the roadway or darting unexpectedly in front of vehicles. These two scenarios accounted for an additional 22.4% of the pedestrian involvements. Along with the next scenario, *at intersection, vehicle going straight, pedestrian crossing*, the top four scenarios account for over half of all relevant pedestrian involvements. In each scenario, pedestrians crossed in front of striking vehicles. In most of these scenarios, striking vehicles were going straight, though in a significant percentage among the top four scenarios, they were turning left. Overall, most of the top scenarios in terms of involvements occurred at intersections. Backing crashes accounted for only 4.6% of all pedestrian involvements. Even fewer occurred while the striking vehicle was starting up, with only 2.9% of all.

Table 5-4
Pedestrian Crash Scenarios.

Location, vehicle maneuver, pedestrian action	Percent
At intersection, vehicle turning left, pedestrian crossing	19.5
Non-intersection, vehicle going straight, pedestrian darting across	12.0
Non-intersection, vehicle going straight, pedestrian crossing	10.4
At intersection, vehicle going straight, pedestrian crossing	9.6
At intersection, vehicle turning right, pedestrian crossing	6.5
At intersection, vehicle going straight, pedestrian darting across	4.7
Non-intersection, vehicle going straight, pedestrian other	4.6
Vehicle backing	4.4
Non-intersection, vehicle going straight, pedestrian moving with traffic	3.4
Non-intersection, vehicle going straight, pedestrian work/play in road	3.2
Vehicle starting	2.9
Non-intersection, vehicle turning left, pedestrian crossing	2.3
At intersection, vehicle going straight, pedestrian other	2.0
At intersection, vehicle turning left, pedestrian other	1.6
Non-intersection, vehicle turning right	1.0
Non-intersection, vehicle going straight, pedestrian moving against traffic	1.0
Vehicle turning right, pedestrian on roadside	0.8
Non-intersection, vehicle turning left, pedestrian other	0.8
Vehicle going straight, pedestrian on roadside	0.8
At intersection, vehicle turning right, pedestrian other	0.7
At intersection, vehicle going straight, pedestrian work/play in road	0.6
Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	0.5
Vehicle turning left, pedestrian on roadside	0.3
Other crash type	5.2
Unknown crash type	1.3
Total	100.0

Source: FARS, GES 2010-2012

Table 5-5 shows the top 12 crash scenarios for LVs. The scenarios are shown ranked by frequency (in the left column), along with the percentage of all LV pedestrian involvements and the rank for trucks. Overall, the top 12 LV pedestrian crash scenarios accounted for 83.5% of all LV pedestrian involvements. (The percentages in Table 5-5 are very similar to those in Table 5-4 because LVs account for 98.6% of combined truck and LV pedestrian involvements.) In most of these scenarios, pedestrians were crossing the roadway in front of the LV, primarily at intersections. In the top scenario, LVs were turning to the left, accounting for almost one out of five LV pedestrian involvements. Backing was relatively rare, as was starting in traffic. In addition, crashes in which pedestrians were moving along the side of the road were uncommon, as were crashes in which pedestrians were essentially stationary in the roadway, either working or playing.

Table 5-5
Top 12 Pedestrian Crash Scenarios for Light Vehicles, Ranked by Frequency.

Rank	Location, vehicle maneuver, pedestrian action	Percent	Rank for trucks
1	At intersection, vehicle turning left, pedestrian crossing	19.5	1
2	Non-intersection, vehicle going straight, pedestrian darting across	12.0	3
3	Non-intersection, vehicle going straight, pedestrian crossing	10.4	4
4	At intersection, vehicle going straight, pedestrian crossing	9.6	6
5	At intersection, vehicle turning right, pedestrian crossing	6.6	9
6	At intersection, vehicle going straight, pedestrian darting across	4.7	8
7	Non-intersection, vehicle going straight, pedestrian other	4.6	10
8	Vehicle backing	4.4	13
9	Non-intersection, vehicle going straight, pedestrian moving with traffic	3.3	5
10	Non-intersection, vehicle going straight, pedestrian work/play in road	3.1	2
11	Vehicle starting	2.9	12
12	Non-intersection, vehicle turning left, pedestrian crossing	2.3	23
	Total percent accounted for by top 12 LV scenarios	83.5	

Source: FARS, GES 2010-2012

Many of the top 12 truck scenarios were also among the top 12 for LVs, but the relative ranking was different. (See Table 5-6.) *At intersection, vehicle turning left, pedestrian crossing* ranked first for both trucks and LVs. But the second ranking truck scenario, *non-intersection, vehicle going straight, pedestrian work/play in road*, with 9.9% of all truck pedestrian involvements, was ranked only tenth on the LV list with 3.1%. *Non-intersection, vehicle going straight, pedestrian enter/exit vehicle* was twenty-second for LVs, with only 0.4% of all, but seventh for trucks with 5.6% of truck pedestrian involvements. Pedestrians essentially stopped in the road were a bigger problem for trucks than LVs. *Vehicle backing*, which ranked number 8 on the LV, list did not appear among the truck top 12, though it was thirteenth for trucks. These differences likely reflect exposure to pedestrians related to operational differences.

Table 5-6
Top 12 Pedestrian Crash Scenarios for Trucks, Ranked by Frequency.

Rank	Location, vehicle maneuver, pedestrian action	Percent	Rank for LVs
1	At intersection, vehicle turning left, pedestrian crossing	20.1	1
2	Non-intersection, vehicle going straight, pedestrian work/play in road	9.9	10
3	Non-intersection, vehicle going straight, pedestrian darting across	9.7	2
4	Non-intersection, vehicle going straight, pedestrian crossing	8.2	3
5	Non-intersection, vehicle going straight, pedestrian moving with traffic	7.8	9
6	At intersection, vehicle going straight, pedestrian crossing	5.9	4
7	Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	5.6	22
8	At intersection, vehicle going straight, pedestrian darting across	5.5	6
9	At intersection, vehicle turning right, pedestrian crossing	4.8	5
10	Non-intersection, vehicle going straight, pedestrian other	3.6	7
11	At intersection, vehicle turning left, pedestrian other	2.9	14
12	Vehicle starting	2.5	11
	Total percent accounted for by top 12 truck scenarios	86.5	

Source: FARS, GES 2010-2012

5.4. Pedestrian crash scenarios ranked by costs

Ranking scenarios in terms of societal costs resulted in a significantly different order from involvements. Table 5-7 shows the top 12 LV pedestrian crash scenarios ranked by societal costs. The table also shows estimated costs, distribution of costs, and rankings in terms of involvements. Note that the number 1 scenario in terms of involvements, *at intersection, vehicle turning left, pedestrian crossing*, with 19.5% of involvements (Table 5-5), ranked seventh in terms of costs, with only 4.2%. Higher priority scenarios tended to occur at non-intersections and with striking vehicles going straight. Travel speeds typically are higher on non-intersection stretches of road and when vehicles are going straight rather than turning. Higher speeds result in more severe injuries. The top LV pedestrian scenarios was *non-intersection, vehicle going straight, pedestrian crossing*, accounting for 27.6% of all crash cases. This scenario ranked third by involvements with 10.4%. The next two scenarios also were non-intersection with the striking vehicles going straight. Together these three scenarios accounted for 53.3% of LV pedestrian crash costs, though only 25.5% of involvements. This implies that effectiveness in higher speed environments should be a priority in developing pedestrian collision-avoidance technologies.

Table 5-7
Top 12 LV Pedestrian Crash Scenarios, Ranked by Societal Costs.

Rank	Location, vehicle maneuver, pedestrian action	Costs (millions $)	% of costs	Ranked by frequency
1	Non-intersection, vehicle going straight, pedestrian crossing	3,046.41	27.6	3
2	Non-intersection, vehicle going straight, pedestrian darting across	1,501.96	13.6	2
3	Non-intersection, vehicle going straight, pedestrian work/play in road	1,331.02	12.1	10
4	At intersection, vehicle going straight, pedestrian crossing	1,303.81	11.8	4
5	Non-intersection, vehicle going straight, pedestrian moving with traffic	816.48	7.4	9
6	Non-intersection, vehicle going straight, pedestrian other	564.08	5.1	7
7	At intersection, vehicle turning left, pedestrian crossing	464.80	4.2	1
8	At intersection, vehicle going straight, pedestrian darting across	399.06	3.6	6
9	Non-intersection, vehicle going straight, pedestrian moving against traffic	177.97	1.6	16
10	Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	157.77	1.4	22
11	At intersection, vehicle turning right, pedestrian crossing	155.08	1.4	5
12	Vehicle backing	142.90	1.3	8
	Total of these 12	10,061.35	91.2	

Source: FARS, GES, Miller et al. 2004

A similar pattern was observed for truck pedestrian crashes. However, because truck pedestrian crashes tended to occur somewhat more often away from intersections, there was more agreement at the top for truck pedestrian scenarios when ranked by costs and by frequency. Moreover, the top three truck pedestrian scenarios in terms of costs were the same (though in a different order) as the top three LV scenarios. For trucks, the top three scenarios accounted for 53.1% of crash costs (Table 5-8), though only 27.8% of crash involvements (Table 5-6). The top four scenarios accounted for almost 60% of the total societal burden of truck pedestrian crashes, though only 31.4% of involvements.

Table 5-8
Top 12 Truck Pedestrian Crash Scenarios, by Ranked Societal Costs.

Rank	Location, vehicle maneuver, pedestrian action	Costs (millions $)	% of costs	Ranked by frequency
1	Non-intersection, vehicle going straight, pedestrian crossing	127.01	19.5	4
2	Non-intersection, vehicle going straight, pedestrian work/play in road	112.70	17.3	2
3	Non-intersection, vehicle going straight, pedestrian darting across	106.25	16.3	3
4	Non-intersection, vehicle going straight, pedestrian other	38.18	5.9	10
5	At intersection, vehicle going straight, pedestrian crossing	35.64	5.5	6
6	At intersection, vehicle turning right, pedestrian crossing	31.40	4.8	9
7	Non-intersection, vehicle going straight, pedestrian moving with traffic	31.35	4.8	5
8	Vehicle backing	28.73	4.4	13
9	At intersection, vehicle turning left, pedestrian crossing	27.51	4.2	1
10	Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	20.53	3.2	7
11	At intersection, vehicle going straight, pedestrian darting across	14.37	2.2	8
12	Non-intersection, vehicle turning right	11.96	1.8	17
	Total of these 12	585.63	90.0	

Source: FARS, GES, Miller et al. 2004

Pedestrian crashes in which trucks were turning clearly produced significantly less harm than when they were going straight. The most common truck scenario by frequency, *at intersection, vehicle turning left, pedestrian crossing*, with 20.1% of involvements, accounted for only 4.2% of associated costs, and ranked well down the cost list at ninth. Right turns for trucks tended to be more harmful than left turns.

5.5. Driver visual obstruction, distraction, and impairment

Some obstructions to a driver's vision in crashes may also occlude pedestrian detection sensors. The crash data captured several types of obstruction, including environmental factors such as rain or snow, glare and bright sunlight; physical obstructions such as curves or parked vehicles; and vehicle conditions that could obscure a driver's vision such as dirty windshields, splash/spray from passing vehicles, and inadequate defrost/defogging systems.

In Table 5-9, conditions that would block a driver's view outside of the vehicle, and that may also degrade the function of pedestrian sensors, were combined as external obstructions, while those on the interior of the vehicle or the vehicle itself were combined as internal. Some cases had both external and internal obstructions. External obstructions included buildings, trees, in-transport vehicles, hills, as well as rain, snow, and fog. These are all factors that may reduce the effectiveness of pedestrian sensors. Internal obstructions include inadequate defrost or defogging systems, inadequate vehicle lighting systems, and other interior obstructions. Also included as an interior obstruction are vehicle designs that may block a driver's vision in some areas around the vehicle, such as cargo bodies blocking a truck driver's direct view toward the rear. These are all conditions that, while they may impair a driver's view, would not degrade the effectiveness of pedestrian sensors. In fact, the sensors would be useful in these conditions.

Impediments to a driver's visual field were noted in 13.3% of LV pedestrian crashes, but only 4.4% of truck pedestrian crashes (Table 5-9). For both vehicle types, external obstructions were identified more often than internal. An external obstruction was coded for 9.4% of LV pedestrian crash involvements but only 3.0% of truck pedestrian crashes. Internal obstructions were noted in 4.0% of LV pedestrian crashes and 1.4% of truck pedestrian crashes. Pedestrian detection systems may be particularly effective in these circumstances.

Table 5-9
Distribution of Driver Vision Obstructed
by Striking Vehicle Type.

Driver vision obstructed	LV	Truck
None	86.7%	95.6%
External	9.3%	3.0%
External & internal	0.1%	0.0%
Internal	3.9%	1.4%
Total	100.0%	100.0%

Source: FARS, GES 2010-2012

Table 5-10 shows the distribution of vision obstruction by roadway location. External vision obstruction is primarily an issue at non-intersection locations. In most of these cases, the driver's view of the pedestrians was blocked by parked or (stopped) working vehicles. In some cases, the view was blocked by another in-transport vehicle. At intersections also, LV drivers' view of pedestrians was blocked primarily by other vehicles, most often in-transport rather than parked vehicles. Obstruction by curves, hills, buildings, billboards, trees, and so on was relatively rare. It appears that other vehicles are the chief obstacle to be overcome in pedestrian detection systems. Rain or snow was identified as an obstruction in only about 1% of LV pedestrian crashes. The most common "internal" factors were reflected glare, bright sunlight, and headlights of other vehicles.

Table 5-10
Distribution of Driver Vision Obstructed in LV Pedestrian Crashes
by Road Location.

Road location	None	External	External & internal	Internal	Total
Intersection	89.7%	4.9%	0.0%	5.3%	100.0%
Non-intersection	82.2%	14.9%	0.2%	2.7%	100.0%
Roadside	96.6%	2.6%	0.0%	0.7%	100.0%
Unknown	98.9%	0.1%	0.0%	1.0%	100.0%
Total	86.7%	9.3%	0.1%	3.9%	100.0%

Source: FARS, GES 2010-2012

Driver distraction was noted much more commonly than vision obstruction, particularly in LV crashes. Distraction was recorded in 21.8% of LV pedestrian crashes, but only 5.4% of truck pedestrian crashes.[1]

Table 5-11
Distribution of Driver Distracted
in LV and Truck Pedestrian Crashes.

Driver distracted?	LV	Truck
No	78.2%	94.6%
Yes	21.8%	5.4%
Total	100.0%	100.0%

Source: FARS, GES 2010-2012

Neither road location, the movements of pedestrians, or light condition were associated with significant differences in the incidence of LV driver distraction. Driver distraction did not vary significantly with respect to road location, pedestrian action, or light condition, though distraction may contribute less to pedestrian crashes in dark conditions. However, that might be related to the fact that LVs were primarily going straight in dark conditions, and there was an association between distraction and turning and other low-speed maneuvers. Coded distraction was significantly higher for LV pedestrian crashes that occurred during turns, backing, or starting up from a stopped position (Table 5-12). All of these maneuvers are more likely in urban areas, where the visual environment may be more complex, with more vehicles and a greater density of pedestrians. In turning maneuvers, drivers may be focusing to the left in right turns and to the right in left turns, to look for crossing traffic, and not notice pedestrians. The most common distraction in turning maneuvers was "looked but did not see," which is used for drivers who were paying attention to the driving task, not otherwise distracted, but who failed to perceive the relevant crash threat. Pedestrian detection systems may be especially effective in such cases because the driver is already focused on driving and would not need to switch attention away from some other focus.

[1] Distraction was coded as unknown in 18.0% of pedestrian crashes; unknown records are excluded from the calculation of percent distracted. This approach assumes that the distraction in the unknown cases is distributed the same as in the cases where distraction is coded as either present or not present.

(Table 5-12
Distribution of Driver Distraction
by Vehicle Maneuver, LV Pedestrian Crashes.

Vehicle maneuver	Driver distracted?		Total
	No	Yes	
Straight	84.1%	15.9%	100.0%
Turning left	74.5%	25.5%	100.0%
Turning right	63.0%	37.0%	100.0%
Backing	64.9%	35.1%	100.0%
Starting	68.6%	31.4%	100.0%
Other	78.2%	21.8%	100.0%
Total	78.2%	21.8%	100.0%

Source: FARS, GES 2010-2012

Driver impairment from alcohol use was relatively uncommon in pedestrian crashes. Driver drinking was recorded for only 2.6% of LV drivers and 1.1% of truck drivers. There was some overrepresentation of LV alcohol use in dark or dark/lighted conditions, which is probably a function of the fact that drinking tends to occur in the evening. In LV pedestrian crashes, the LV driver was coded as drinking in 6.1% of dark cases, and 5.3% of dark/lighted cases. The driver was coded as drinking in only 1.0% of daylight LV pedestrian crashes.

Table 5-13
Distribution of Driver Alcohol Use
in LV and Truck Pedestrian Crashes.

Driver alcohol use	LV	Truck
None indicated	97.4%	98.9%
Alcohol use	2.6%	1.1%
Total	100.0%	100.0%

Source: FARS, GES 2010-2012

Drink driving cases were not excluded from the analysis because impaired drivers may also benefit from pedestrian detection and warning systems. Moreover, some systems may also autonomously brake or steer, reducing the driver’s influence.

5.6. Crash circumstances for light-vehicle pedestrian crashes

In this section, crash circumstances are broadly considered. These crash conditions can potentially affect the operations of vehicle-based pedestrian crash avoidance and mitigation systems, by reducing the ability of the systems to detect pedestrians and respond in time to mitigate a crash. The conditions include ambient light, weather, pedestrian age (used as a surrogate for size), and road speed limit.

The patterns discussed do not necessarily reflect crash *risk*, that is, factors that increase the probability of a crash (though they may). Pedestrian crash occurrence is the product of exposure to pedestrians and factors that increase the risk of a crash for a given level of exposure. Without exposure data, it is not possible to identify factors that increase the risk of crashes. Instead, the patterns discussed here describe the main features that pedestrian ACATs will have to contend with, and the conditions within which pedestrian ACATs need to operate to reduce the number and severity of pedestrian crashes.

First, factors important in light-vehicle crashes will be discussed, followed by a discussion of the circumstances of truck pedestrian crashes. The factors operate in different ways between the two vehicle types so it is useful to separate them in the discussion.

The Appendix in Section 9 includes tables with the distributions of LV pedestrian scenarios by light condition, weather, and pedestrian age.

5.6.1. Light condition

Ambient lighting is critical in pedestrian crashes. Night has been shown to increase the risk of pedestrian crashes by three to seven times (Sullivan and Flannagan 2002). Pedestrians are more vulnerable in dark conditions because they are less visible to drivers. Headlamps are the primary current technology used to help drivers detect pedestrians in dark conditions. However, at night, drivers who use the low-beam setting to reduce glare for oncoming traffic can over-drive their headlights, reducing the time available to avoid collisions with pedestrians, particularly on high-speed roads. When vehicles are turning, pedestrians crossing roads may be out of the field of illumination until it is too late for the driver to react effectively.

Overall, in the crash data examined, 58.4% of LV pedestrian crash involvements occurred in daylight conditions, 29.3% in dark/lighted, and 7.3% in dark/not lighted. (Please see

Figure 1.) For LVs, dawn and dusk together accounted for only 4.5% of pedestrian crashes, with about twice as many crashes at dusk as dawn.

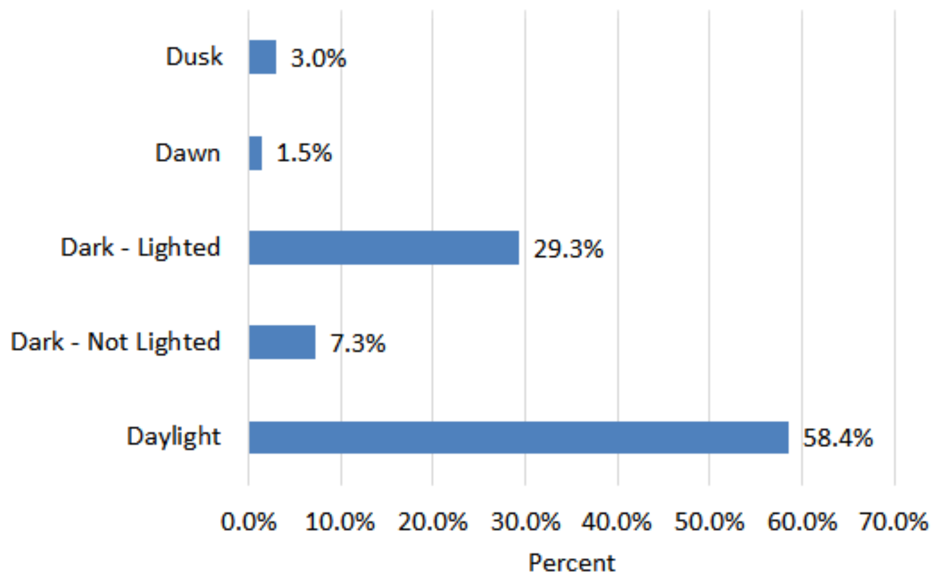

Figure 1. Distribution of Light Condition in LV Pedestrian Involvements (FARS, GES 2010-2012).

In dark conditions, the predominant striking-vehicle maneuver was going straight, with about 80.3% striking vehicles going straight and only 9.1% turning (7.1% left and 2.0% right). (Please see Table 5-14.) Turning movements were more frequent in daylight (38.1%; 27.6% left and 10.5% right) and in dark/lighted conditions (32.2%; 24.8% left and 7.4% right). In each light condition, however, there were significantly more left turns than right.

Table 5-14
Distribution of Vehicle Maneuver
by Light Condition, LV Pedestrian Crashes.

Vehicle maneuver	Daylight	Dark/Not Lighted	Dark - Lighted	Dawn/ Dusk	Total
Straight	45.8%	80.3%	58.1%	63.5%	52.9%
Turning left	27.6%	7.1%	24.8%	14.1%	24.6%
Turning right	10.5%	2.0%	7.4%	15.6%	9.1%
Backing	5.6%	4.1%	2.2%	4.6%	4.4%
Starting	3.2%	1.1%	2.9%	1.1%	2.9%
Other	7.2%	5.5%	4.6%	1.1%	6.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

Also in darkness, pedestrians were much more likely to have been walking/moving along the roadway or working/playing in the roadway than in other light conditions. Over a third (34.0%) were moving along the road or working/playing in the road in dark conditions, compared with 10.2% in daylight and 9.6% in dark/lighted conditions. Geometrically, pedestrians moving along the road were most likely to the right of the LVs, rather than directly out in front. Crossing pedestrians were more likely to be out in front of the LVs, although the coded crash data do not capture the precise location relative to the LVs. In daylight and dark/lighted conditions, about three-quarters of pedestrians were crossing the road at the time of impact, compared with only 53.3% for the dark condition.

Table 5-15
Distribution of Pedestrian Movement
by Light Condition, LV Pedestrian Crashes.

Pedestrian action	Daylight	Dark/Not Lighted	Dark - Lighted	Dawn/ Dusk	Total
Crossing	74.7%	53.3%	76.5%	73.6%	73.6%
Waiting to cross	1.5%	0.2%	1.2%	0.7%	1.3%
Moving along roadway with traffic	2.7%	20.8%	4.5%	1.4%	4.5%
Moving along roadway against traffic	1.2%	5.2%	1.1%	0.2%	1.4%
Moving along roadway, unk. direction	0.0%	0.2%	0.1%	0.0%	0.0%
Moving on sidewalk	2.3%	0.2%	0.5%	5.0%	1.8%
Working/playing on road	6.3%	8.0%	3.9%	9.4%	5.9%
Adjacent to road	1.6%	1.9%	1.2%	0.6%	1.4%
Entering/exiting vehicle	1.1%	3.0%	1.3%	0.2%	1.3%
Unspecified	8.6%	7.1%	9.7%	9.0%	8.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

Given this pattern of pedestrian actions and vehicle maneuvers in LV pedestrian crashes, it is not surprising that a disproportionate percentage (78.5%) of pedestrian crashes in darkness took place at non-intersection locations. This compares with 42.3% of daylight pedestrian crashes and 45.1% of dark/lighted (Table 5-16). Crashes in which the pedestrian was coded as crossing at a non-intersection occurred more often in dark/lighted and dark/not lighted conditions. The direction of pedestrian crossing is not reported in FARS or GES, but a study based on reviewing police crash reports of pedestrian crashes demonstrated a significant overinvolvement of pedestrians crossing from the left compared to the right in non-intersection pedestrian crashes at night. The difference was not statistically significant but consistent with the hypothesis that the pattern of illumination from headlamps makes detecting pedestrians on the left more challenging in dark conditions (Sullivan and Flannagan 2011). Crashes in which the pedestrian was coded as moving along the road, either with or against the direction of travel, occurred more in dark conditions, particularly dark/not lighted, which are more often in rural areas.

Table 5-16
Distribution of Roadway Location
by Light Condition, LV Pedestrian Crashes.

Roadway location	Daylight	Dark - Not Lighted	Dark - Lighted	Dawn/ Dusk	Total
Intersection	51.3%	17.1%	51.0%	54.8%	48.8%
Non-intersection	42.3%	78.5%	45.1%	41.5%	45.7%
Roadside	5.3%	3.4%	3.5%	3.7%	4.5%
Unknown	1.0%	1.1%	0.4%	0.0%	1.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

With respect to pedestrian crashes at intersection, there is also likely an overinvolvement of pedestrians crossing from left to right across the driver's field of view in dark or dark/lighted conditions. The Sullivan and Flannagan study cited above showed a statistically significant overinvolvement at night of pedestrians crossing from the driver's left in left-turning crashes at intersections. There may be an interaction with the pattern of light from headlamps that makes pedestrians crossing from the left especially vulnerable. Headlamps, particularly in the low-beam setting, are typically directed down and to the right in order to minimize glare to on-coming traffic. Consequently, they direct less light to the driver's left in left turn situations, while the headlights would sweep across pedestrians crossing from the right in left turns (Sullivan and Flannagan 2011).

Crashes in darkness also tend to occur on higher speed roads than in either daylight or dark/lighted. About 44.1% of pedestrian crashes in darkness occurred on roads with speed limits of 45 mph or higher, compared with 7.1% of daylight pedestrian crashes and 13.5% of dark/lighted crashes.

Distributions of pedestrian ages varied depending on light condition. Younger pedestrians were overrepresented in daylight and significantly underrepresented in dark or dark/lighted conditions. In the crash data examined, 12.1% of pedestrians struck in daylight were 9 or younger, compared with 0.7% in dark and 4.1% in dark/lighted (Table 5-17). Insofar as pedestrian age correlates with size, smaller statured pedestrians were more of a problem during the daytime. At night, 87.2% of pedestrians were 15 to 64; in dark/lighted conditions, that group accounted for 81.3%. Older and therefore likely slower pedestrians were also overrepresented in daylight hours: 13.1% were 65 or older, compared with 8.5% in dark and 7.4% in dark/lighted.

Table 5-17
Distribution of Pedestrian Age
by Light Condition, LV Pedestrian Crashes.

Pedestrian age	Daylight	Dark/Not Lighted	Dark - Lighted	Dawn/ Dusk	Total
0 to 4	3.5%	0.2%	1.4%	2.7%	2.6%
5 to 9	8.5%	0.5%	2.8%	4.1%	6.0%
10 to 14	10.9%	3.5%	7.2%	13.6%	9.3%
15 to 19	10.8%	12.9%	10.8%	10.4%	11.0%
20 to 64	53.2%	74.3%	70.5%	62.1%	60.3%
65+	13.1%	8.5%	7.4%	7.1%	10.8%
Unknown	0.0%	0.1%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

Light condition is important in pedestrian crashes because of the dominant role of visibility. Scenarios differed significantly based on the light condition of the crashes. Daylight pedestrian crashes included more younger and likely smaller-statured pedestrians, on lower-speed roads, with the striking vehicles more likely turning (particularly to the left), and pedestrians crossing the road. This means that pedestrian detection systems must be able to detect smaller targets in the day, and to be able to detect pedestrians while turning and not only in the direct line of travel. Pedestrian crashes in dark/lighted conditions had similar factors to those in daylight, probably because they occurred in urban areas. In darkness, pedestrians were mostly adults or of adult stature, more likely to be moving along the road (typically with the flow of traffic) or working/playing in the road, and the collisions were much more likely on higher-speed roads. In darkness, the problem is primarily in the straight line of travel with pedestrians more often moving along the road or in it, and the striking vehicle traveling on higher-speed roads. In dark, sight distance is diminished; the challenge is to detect pedestrians in low-light conditions, and to respond faster because of higher vehicle speeds.

5.6.2. Weather

Weather can affect the incidence of pedestrian crashes through two primary means. Precipitation may reduce a driver's ability to see pedestrians on the road, as well as interfere with detection technologies. On the other hand, adverse weather may reduce pedestrian exposure if walkers delay trips for better weather or choose alternative modes of transportation.

Weather conditions in 86.3% of LV pedestrian crashes were categorized as clear or cloudy, i.e., with no adverse conditions (Figure 2). Rain was coded in only 10.4% and snow, sleet, or hail in only 1.3%. In the analysis of the effect of adverse weather on pedestrian crashes, crashes in clear or cloudy weather were combined as no adverse conditions, and conditions coded rain, snow, sleet, fog, smoke, and blowing snow were aggregated into a single category. Overall, most pedestrian crashes occurred with no adverse weather conditions. The weather included precipitation, fog, or smoke in only 12.2% of LV pedestrian crashes.

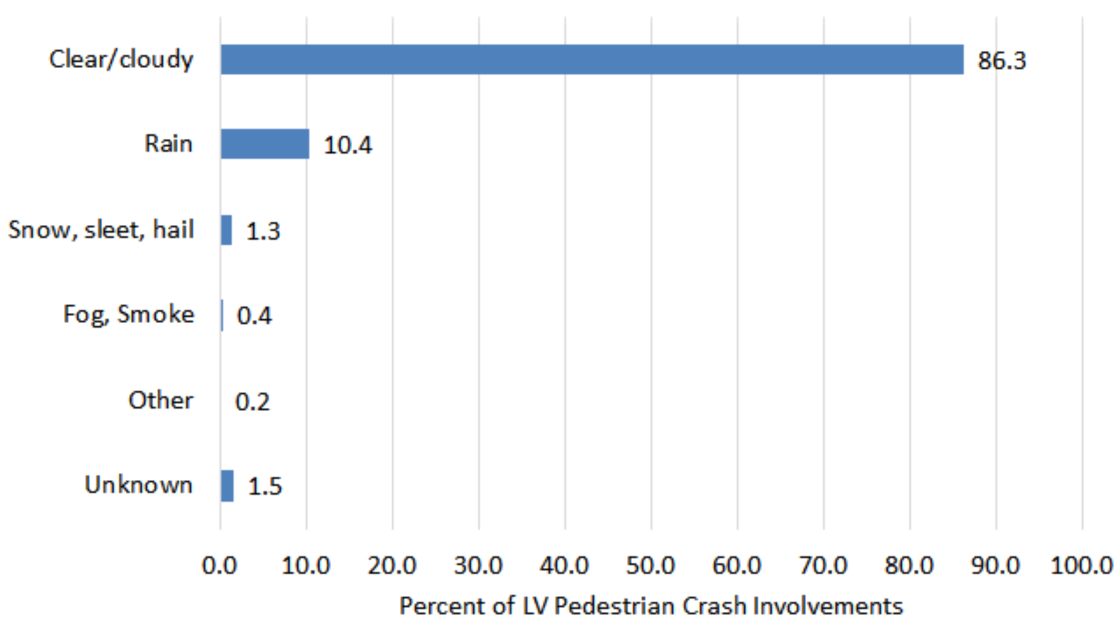

Figure 2. Weather Condition in LV Pedestrian Crashes.

Pedestrian crashes in which the striking vehicles were turning were significantly overrepresented in poor weather conditions (Table 5-18). In 44.0% of adverse weather crashes, vehicles were turning left, and turning right in 6.9%. This compares with 21.9% left and 9.6% right in good weather. Turns to the left were significantly more of a problem in bad weather, indicating a challenge in detecting pedestrians. The direction of crossing was not identified in the data, but there may be a similar mechanism to that described above for low-light conditions, in which there was a large overrepresentation of pedestrians crossing from the driver's left in left-turning crashes at night (Sullivan and Flannagan 2011). Diminished visibility due to adverse weather may function in a way similar to darkness.

Table 5-18
Percent Distribution of Striking Vehicle Maneuver
by Weather Condition, LV Pedestrian Crashes.

Vehicle maneuver	Clear/ cloudy	Precip/ fog/smoke	Unknown	Total
Straight	54.7%	40.4%	49.1%	52.9%
Turning left	21.9%	44.0%	25.2%	24.6%
Turning right	9.6%	6.9%	3.1%	9.1%
Backing	4.6%	2.6%	12.1%	4.4%
Starting	3.2%	0.6%	1.1%	2.9%
Other	6.0%	5.5%	9.5%	6.0%
Total	100.0%	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

There were no significant differences by weather condition in pedestrian action. Roughly, 75% of pedestrians were crossing the road at the time of the crashes, about 7% were moving along the road, and 4-6% were working/playing in the road. However, bad weather crashes were more likely to occur at intersections than those in good weather. Almost 64% of adverse weather pedestrian crashes occurred at intersections, compared with 46.8% at intersections in clear or cloudy weather. The effect of rain, snow, and fog may be similar to darkness in reducing driver visibility. Pedestrian detection systems must be able to function accurately in poor weather. It appears that the ability to detect pedestrians not in the direct line of travel but to the left, especially, or right during turns is particularly important.

Younger pedestrians (0 to 9 years) tended to be underrepresented in adverse conditions, accounting for only 2.3% of victims, compared with 9.7% in clear/cloudy weather. It is possible their exposure in adverse weather is more limited than other age groups. In contrast, pedestrians of adult size, age 15 to 64, made up 84.1% of pedestrians struck in bad weather, compared with 69.4% in good weather. Adults may limit their exposure to bad weather less than children.

5.6.3. Pedestrian age

Pedestrian age is of interest because it is associated with size and therefore the size of the object to be detected. In addition, age is likely associated with speed of mobility, such that younger pedestrians average faster travel speeds (Huang, Yang et al. 2006). Overall, most pedestrians struck by LVs are 20 to 64 years of age, 60.3% of the total. These individuals were presumably of typical adult stature. However, almost 18% percent were younger than 15, likely smaller than the average adult. Of these, about half were younger than 10 (Figure 3).

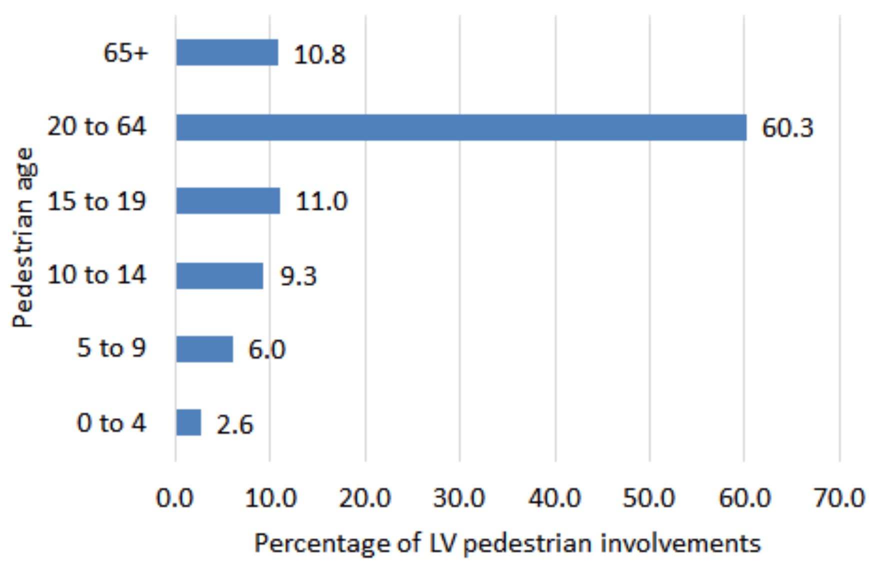

Figure 3. Distribution of Pedestrian Age in LV Crashes (FARS, GES 2010-2012).

Pedestrians tended to be involved in different types of crash situations, depending on their age. In terms of the striking-vehicle maneuver prior to the crashes, older pedestrians (65 and older) were more likely to be involved when the striking vehicle was turning, while pedestrians up to age 9 were overinvolved when the vehicles were going straight or starting up from a stopped position. Pedestrians up to 9 years of age were significantly underrepresented in backing crashes. Children accounted for only 1.2% of the pedestrians struck in backing crashes, though they were 8.6% of all pedestrians struck. Older pedestrians were overrepresented in turning crashes, possibly because they may have less ability to evade; they were also overrepresented in backing crashes, as were pedestrians in the 20 to 64 age group.

Table 5-19
Percent Distribution of Pedestrian Age
by Vehicle Maneuver, LV Pedestrian Crashes.

Vehicle maneuver	Pedestrian age				Total
	0 to 9	10 to 19	20 to 64	65+	
Straight	12.6%	23.8%	55.8%	7.8%	100.0%
Turning left	3.0%	13.0%	67.5%	16.5%	100.0%
Turning right	4.2%	25.4%	56.3%	14.1%	100.0%
Backing	1.5%	14.2%	69.4%	15.0%	100.0%
Starting	10.9%	17.7%	67.8%	3.6%	100.0%
Other	7.2%	17.8%	66.1%	8.9%	100.0%
Total	8.6%	20.3%	60.3%	10.8%	100.0%

Source: FARS, GES 2010-2012

In terms of pedestrian movement, most pedestrians of all ages were crossing the road at the time of the crashes. However, there were significant differences between age groups in the distributions of activity (Table 5-20). Children (0 to 9) were overrepresented in the road (coded working/playing or adjacent to the road), though most pedestrians in the road were in the 20 to 64 age group. Adult-sized pedestrians accounted for over 70% of the pedestrians coded working/playing in the road and about 75% of the pedestrians coded as walking/moving along the roads. Children were the least likely to be struck while moving along the roads, but that crash type tends to be in dark conditions, when they are less likely to be out. Older pedestrians were more likely to be crossing and less likely to be walking along the road or working/playing in the road.

Table 5-20
Percent Distribution of Pedestrian Age
by Action, LV Pedestrian Crashes.

Pedestrian action	Pedestrian age				Total
	0 to 9	10 to 19	20 to 64	65+	
Crossing	7.9%	20.9%	58.8%	12.3%	100.0%
Waiting to cross	11.6%	10.6%	54.0%	23.7%	100.0%
Moving along roadway with traffic	0.9%	21.7%	71.0%	6.3%	100.0%
Moving along roadway against traffic	1.6%	31.5%	56.8%	10.0%	100.0%
Moving along roadway, unk. direction	0.0%	8.8%	86.8%	4.4%	100.0%
Moving on sidewalk	13.0%	32.3%	46.4%	8.3%	100.0%
Working/playing on road	12.7%	13.9%	71.4%	1.9%	100.0%
Adjacent to road	17.7%	10.3%	69.3%	2.7%	100.0%
Entering/exiting vehicle	3.5%	18.8%	74.8%	2.9%	100.0%
Unspecified	14.8%	17.5%	60.1%	7.5%	100.0%
Total	8.6%	20.3%	60.3%	10.8%	100.0%

Source: FARS, GES 2010-2012

Children were more likely to be struck in non-intersection locations. About 13.4% of pedestrians struck at non-intersections were 0 to 9, compared with 8.6% overall (Table 5-21). This points to a heightened need to detect smaller pedestrians at non-intersection locations, where travel speeds are greater. In contrast, older pedestrians were overrepresented in collisions at intersections. An estimated 13.9% of the pedestrians struck at intersections were older than 64 years, though that age group made up 10.8% of pedestrian victims overall. Children under the age of 10 made up only 4.9% of the population of pedestrian crash victims at intersections.

Table 5-21
Percent Distribution of Pedestrian Age
by Road Location, LV Pedestrian Crashes.

Road location	Pedestrian age				Total
	0 to 9	10 to 19	20 to 64	65+	
Intersection	4.9%	19.8%	61.3%	13.9%	100.0%
Non-intersection	13.4%	20.6%	58.2%	7.7%	100.0%
Roadside	2.4%	19.2%	70.0%	8.4%	100.0%
Unknown	1.2%	32.7%	58.6%	7.4%	100.0%
Total	8.6%	20.3%	60.3%	10.8%	100.0%

Source: FARS, GES 2010-2012

Some of the pedestrian crash scenarios include “darting” as part of the definition. Darting identifies situations where the pedestrians appeared suddenly and unpredictably in front of the vehicles. According to coding instructions, the code is used for pedestrians who ran in front of the vehicle or pedestrians who walked in front of the vehicle whose view was blocked until an instant before the collision (National Highway Traffic Safety Administration 2013a). The salient point here is that pedestrian detection systems will have to deal with rapid movement of pedestrians or pedestrians that only become visible in the instant before impact.

Overall, 23.1% of the pedestrians were coded as having darted in front of the striking vehicles. The probability of being coded as darting was associated with pedestrian age, and therefore, up to a point, with pedestrian size. Younger pedestrians tended to be overinvolved as darting up to age 19, with 61.0% of pedestrians 0 to 4, 63.0% of 5 to 9, and 47.2% of pedestrians age 10 to 14 coded as darting. Table 5-22 shows the distribution of pedestrian age for those coded darting or not darting. Overall, 42.2% of pedestrians who were coded as darting out in front of the striking vehicles were 14 years of age or younger, and therefore likely of small stature, presenting a smaller target for pedestrian detection systems.

Table 5-22
Distribution of Pedestrian Age
by "Darting," LV Pedestrian Crashes.

Pedestrian age	Darted out?		Total
	No	Yes	
0 to 4	1.3%	6.8%	2.6%
5 to 9	2.9%	16.4%	6.0%
10 to 14	6.4%	19.0%	9.3%
15 to 19	10.5%	12.6%	11.0%
20 to 64	65.8%	41.9%	60.3%
65+	13.0%	3.3%	10.8%
Unknown	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

Most of the cases where pedestrians were recorded as having darting out in front of the vehicles occurred when the vehicles were going straight (87%) and on non-intersection segments of the roads (71.7%). Darting was actually somewhat less likely in dark/not lighted conditions or in adverse weather conditions. Only 13.4% of pedestrians struck in dark/not lighted conditions darted, compared with 24.3% in daylight; and only 16.1% in rain, snow, or sleet, compared with 24.2% in clear or cloudy weather. Visibility impairment from the weather or lower light levels did not seem to play a significant role in the frequency of pedestrians as having darted out in front. Road speed limit did not seem to make any difference, with about the same proportion coded as darting on lower- and higher-speed roads. On roads with speed limits of 40 mph or less, 26.9% of the pedestrians were coded as darting; and on roads with speed limits over 40 mph, 25.2% darted. Overall, 85.9% of the pedestrians coded as darting occurred on lower-speed roads, so this is a problem primarily to be addressed there.

5.7. Crash circumstances for truck pedestrian crashes

The circumstances of truck pedestrian crashes differed in significant respects from LV pedestrian crashes. These differences are likely related to the operating environment of trucks (and consequent exposure to pedestrians) and differences in the design and performance of trucks. Trucks operate more on high-speed roads, and more of their travel is at night. As working vehicles, they may be exposed to less pedestrian traffic than LVs, which are used to transport people. Truck-driver vision around the vehicle is much more attenuated than in LVs. In addition, trucks tend to have longer stopping distances, take longer to accelerate to speed, and sweep out a larger area in turns, particularly tractor-semitrailers in low-speed maneuvers. Accordingly, the challenge to detect and avoid collisions with pedestrians differs from LVs in important respects. This section provides a discussion of some of the primary environmental and other factors and discusses important differences with LVs.

The Appendix in Section 9 includes tables with the distributions of truck pedestrian scenarios by light condition, weather, and pedestrian age.

5.7.1. Light condition

The distribution of light condition in truck pedestrian crashes was somewhat different from LVs. Truck pedestrian crashes were more likely than LV crashes to occur in full dark. Almost 14% of truck pedestrian crashes occurred in dark/not lighted conditions, which is about twice the proportion for LVs. (Compare Figure 1 on page 32 with Figure 4.) This difference is likely accounted for by the different travel patterns of trucks and LVs. Trucks are more likely than LVs to operate at night in rural areas, where roadway lighting is less common. Different travel patterns may also account for the lower proportion of dawn/dusk crashes, because trucks may be less likely than LVs to operate in urban areas during those hours.

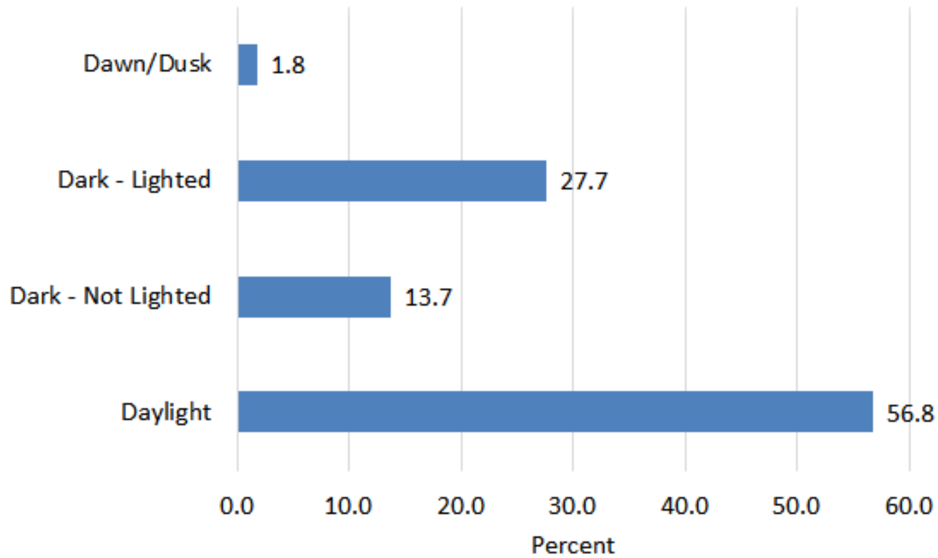

Figure 4. Distribution of Light Condition in LV Pedestrian Involvements (FARS, GES 2010-2012).

In dark conditions, trucks were going straight in 86.7% of truck pedestrian crashes and were turning in only 12.0% (Table 5-23). At night and in dark conditions, then, the predominant pedestrian crash problem was ahead of the trucks. In contrast, in dark/lighted conditions, which are consistent with travel in urban areas, almost half of the crashes occurred in turning maneuvers, with turns to the left over 15 times more prevalent than turns to the right. The sample of such crashes is relatively small, but it is clear that left turns were a substantially greater problem than right turns in dark/lighted conditions.

Table 5-23
Distribution of Light Condition by Vehicle Maneuver, Truck Pedestrian Crashes.

Vehicle maneuver	Daylight	Dark	Dark - Lighted	Dawn/ dusk	Other/ Unknown	Total
Straight	61.0%	86.7%	46.9%	58.3%	33.2%	60.4%
Turning left	17.0%	4.2%	46.2%	31.6%	62.0%	23.9%
Turning right	9.3%	7.8%	3.0%	6.1%	0.0%	7.3%
Backing	4.0%	0.3%	0.5%	2.0%	4.7%	2.5%
Starting	4.3%	0.0%	0.3%	0.0%	0.0%	2.5%
Other	4.3%	1.1%	3.1%	2.0%	0.0%	3.5%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

Truck pedestrian crash scenarios were quite different at night, depending on whether the conditions were dark or dark/lighted, corresponding to rural and urban conditions, respectively. In dark conditions, 87.6% of truck pedestrian crashes occurred at non-intersections. In almost half of these crashes, pedestrians were moving along the roadside or working/playing on the road, and in 52.6% of crashes the pedestrians were crossing the road. In dark/lighted conditions (largely urban), over 80% of crashes occurred at intersections and almost 90% of the pedestrians were crossing the road, i.e., moving laterally across the field of view of the truck driver.

In daylight truck pedestrian crashes, 57.4% occurred at non-intersections, compared with 34.1% at intersections; only 41% of the pedestrians were crossing the road, while 15.3% were moving along the road, and 18.6% were working/playing in the road. In addition, 10.3% of the pedestrians were entering or exiting a vehicle. The circumstances of LV pedestrian crashes were significantly different. A much higher percentage of daytime pedestrian crashes occurred with crossing pedestrians (74.7%), with only 4.9% moving along the road, and 6.3% working/playing in the road.

Compared with LVs, truck pedestrian crashes were shifted significantly toward higher-speed roads, regardless of light condition. In dark conditions, 93.1% of truck pedestrian crashes occurred on roads with speed limits of 45 or greater. In dark/lighted conditions, the percentage of high-speed roads was 61.9%, and in daylight it was 25.4%. The comparable percentages for LVs were 44.1%, 13.5%, and 7.1%, respectively. Trucks have significantly longer stopping distances than light vehicles, so they are more likely to overdrive their headlights at night. Pedestrian detection systems for trucks will have to look farther in order to warn and brake earlier than LVs, and function more in full dark conditions than LVs.

In contrast with LV pedestrian crashes, the percentage of younger pedestrians (14 years and younger) in truck pedestrian crashes in dark or dark/lighted conditions was very small. Only 0.3% of pedestrians struck by trucks in dark conditions were under 15 years of age; and only 0.9% of those struck in dark/lighted conditions were under 15. The respective percentages were higher for LVs, at 4.2% and 11.3%. Detecting smaller pedestrians in low light conditions is not a substantial issue for trucks.

5.7.2. Weather

Weather may also interfere with truck pedestrian detection systems, but 90.3% of truck pedestrian crashes occurred in clear or cloudy weather. The percentage of good-weather pedestrian crashes is even higher for trucks than for LVs (86.3%, see Figure 2). Rain was coded in only 8.0%, and snow, fog, or smoke in only 1.0%.

There was little difference between adverse and good conditions in terms of vehicle maneuver. About the same percentage were turning and going straight in adverse weather as in good weather. As with low light conditions, the percentage of younger (and therefore smaller) pedestrians was very low, so any interference from the weather in detecting small pedestrians is not an issue.

Pedestrians were coded as crossing, i.e., moving laterally across the direction of travel of the truck, more often in adverse weather than in clear conditions. In poor weather, 73.2% of pedestrians were crossing in front of the truck, compared with 55.0% in clear/cloudy weather. Consistent with that finding, a higher percentage of crashes occurred at intersections compared with crashes in clear/cloudy weather (67.5% to 41.8%). In addition, a slightly lower percentage of adverse weather truck pedestrian crashes occurred on high-speed roads (41.4%) than in good weather (47.1%).

5.7.3. Pedestrian age

Pedestrians in truck pedestrian crashes tended to skew older, compared with pedestrians struck by LVs. Only about 20.2% of truck pedestrian victims were under 20 years of age, compared with almost 29% for LVs. (Compare Figure 5 below with Figure 3 on page 39.) The differences are not enormous, but a higher percentage of pedestrians in truck crashes tended to be of working age, 20 to 64, than in LV crashes. The proportions of young or old pedestrians were correspondingly lower. This distribution may be related to the fact that trucks are working vehicles and may be exposed to more pedestrians of working age.

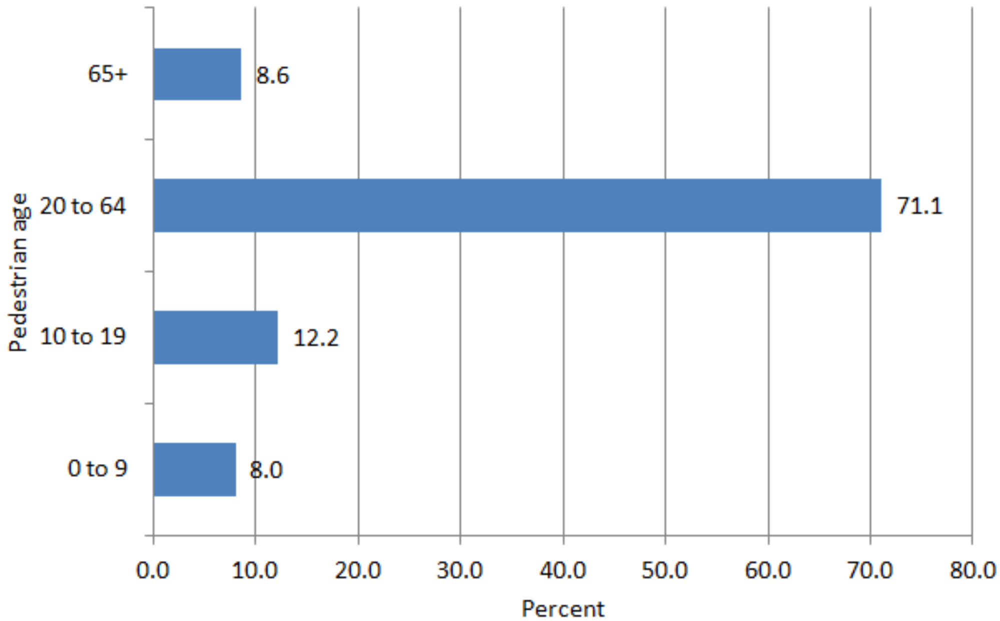

Figure 5. Distribution of Pedestrian Age in Truck Crashes (FARS, GES 2010-2012).

Table 5-24 shows the distribution of pedestrian age by road location in truck crashes. Almost 14% of the pedestrians struck by trucks on non-intersection road segments were children younger than 10, and therefore smaller. Pedestrians age 10 to 19 tended to be overrepresented at intersections, as did pedestrians older than 64. Older pedestrians may move more slowly than younger, likely take longer to cross, and may be physically less able to evade.

Table 5-24
Distribution of Pedestrian Age by Road Location, Truck Pedestrian Crashes.

Road location	Pedestrian age				Total
	0 to 9	10 to 19	20 to 64	65+	
Intersection	3.2%	19.8%	64.6%	12.4%	100.0%
Non-intersection	13.1%	6.8%	74.4%	5.6%	100.0%
Roadside	0.7%	0.0%	94.3%	5.0%	100.0%
Unknown	0.0%	0.0%	66.7%	33.3%	100.0%
Total	8.0%	12.2%	71.1%	8.6%	100.0%

Source: FARS, GES 2010-2012

Pedestrians were more likely to be recorded as having “darted” out in front of trucks than LVs. Over 30% of pedestrians in truck pedestrian crashes darted out in front, compared with

23.1% in LV crashes. There was no association of darting with light condition (about the same percentage were coded as darting, regardless of light condition), but darting was much more likely at non-intersections and when the truck was going straight. In other words, pedestrians were perceived as having darted out in front most often during normal driving, and not around intersections when drivers may have some more awareness of pedestrians. Moreover, as with LVs, darting was strongly associated with pedestrian age, so the problem was greater for smaller stature pedestrians. Over 70% of pedestrians younger than 10 were recorded as having darted in front of the trucks; 49.4% of pedestrians 10 to 19; 25.1% of those 20 to 64; and only 11.1% for pedestrians older than 64. A substantial fraction of those coded as darting were younger pedestrians (Table 5-25). About 18.5% were younger than 10 and an additional 19.7% were 10 to 19. Many of these were also not yet adults and so of smaller stature, which may affect the ability of pedestrian sensors to detect them.

Table 5-25
Distribution of Pedestrian Age by "Darting,"
Truck Pedestrian Crashes.

Pedestrian age	Darted out?		Total
	No	Yes	
0 to 9	3.5%	18.5%	8.0%
10 to 19	8.9%	19.7%	12.2%
20 to 64	76.5%	58.5%	71.0%
65+	11.0%	3.1%	8.6%
Unknown	0.2%	0.1%	0.1%
Total	100.0%	100.0%	100.0%

Source: FARS, GES 2010-2012

6. Conclusions: Primary factors and pedestrian crash avoidance technologies

There is a growing awareness of the magnitude of the pedestrian crash problem worldwide. In many low-income nations, pedestrian crash deaths account for half or more of total traffic deaths. In the U.S., the latest available information (2012, at the present writing) indicates that the frequency of pedestrian crashes and fatalities may be increasing, though the trend is short. Whether the increase in 2012 was the beginning of a trend or just a random fluctuation, it is clear that the pedestrian share of traffic fatalities and injuries is increasing.

Clearly, advances in restraints (seat belts and air bags), increasing restraint use, and improved crashworthiness to protect occupants in collisions have contributed to the reduction in fatalities and injuries to motor vehicle occupants. However, the increase in technologies aimed at avoiding or reducing the severity of collisions between vehicles may also have contributed. More LVs are equipped with ACATs to reduce the incidence and severity of motor vehicle crashes, including electronic stability control (ESC), forward collision warning and autonomous emergency braking (FCW and AEB), and lane/road departure warning and prevention. These technologies function by sensing the stability of the vehicle and attempting to help the driver regain control or by sensing imminent collisions with other vehicles and either warning or autonomously intervening or both (Blower 2014).

Similar collision-avoidance technologies are also being developed to reduce the number and severity of pedestrian collisions, particularly in Europe. They work by sensing the presence of pedestrians and warning or braking when collisions are imminent (Rosen, Kallhammer et al. 2010; Keller, Dang et al. 2011). It is also noteworthy that, somewhat analogous to improving crashworthiness of motor vehicles to protect car occupants, efforts are under way to change the design of light vehicles to reduce the severity of collisions with pedestrians (Hu and Klinich 2012).

The purpose of the current report is to describe the primary conditions and circumstances of pedestrian crashes in the United States to support the development of vehicle-based interventions. Scenarios were developed for crashes in which the first event was a collision between a motor vehicle and a pedestrian. This is the set of pedestrian crashes that are most amenable to crash avoidance. The most current available crash data (2010-2012) were used in the analysis, and unlike previous work, pedestrian crashes for LVs were evaluated separately from those of trucks. Treating the two vehicle types separately is appropriate because there were significant differences between the two in terms of the types and locations of crashes.

For LVs, the top crash scenarios were *At intersection, vehicle turning left, pedestrian crossing*; *Non-intersection, vehicle going straight, pedestrian darting across*; and *Non-intersection, vehicle going straight, pedestrian crossing*. Together, these three scenarios accounted for almost 42% of all LV pedestrian crashes. For trucks, the top three scenarios were *At intersection, vehicle turning left, pedestrian crossing*; *Non-intersection, vehicle going straight, pedestrian work/play in road*; and, *Non-intersection, vehicle going straight, pedestrian darting across*. These three scenarios accounted for 39.7% of truck pedestrian crashes.

Pedestrian crash scenarios were also ranked in terms of crash costs. Crash costs include the sum of estimated societal costs from the crashes, accounting for immediate medical and other costs, as well as long-term costs associated with loss of life or quality of life. These crash costs are an estimate of the total societal burden from pedestrian crashes. Ranking by crash costs identifies scenarios and situations where the most benefit can be realized from crash avoidance. In terms of costs, the top three LV scenarios were *Non-intersection, vehicle going straight, pedestrian crossing*; *Non-intersection, vehicle going straight, pedestrian darting across*; and *Non-intersection, vehicle going straight, pedestrian work/play in road*. Combined, these three accounted for 53.3% of all associated crash costs. The top three were all scenarios that occurred away from intersections where the striking vehicles were going straight. For trucks, the top three were *Non-intersection, vehicle going straight, pedestrian crossing*; *Non-intersection, vehicle going straight, pedestrian work/play in road*; and, *Non-intersection, vehicle going straight, pedestrian darting across*. These accounted for 53.1% of truck pedestrian crash costs but only slightly over a quarter of involvements. Again, the top three scenarios were on non-intersection stretches of road with the striking vehicle going straight.

The cost analysis showed that effectiveness of detection and avoidance in high-speed environments should be a priority. The top scenarios there were all non-intersection crashes, with vehicles going straight. These crashes were typically on higher-speed roads, where detection systems must be able to detect pedestrians farther down the road and issue warnings or brake earlier than in lower-speed, more urban scenarios.

Driver vision was clearly a critical factor in pedestrian collisions, as indicated by the fact that night has been shown to increase the risk of pedestrian crashes by up to seven times. This is an important factor in evaluating pedestrian crashes for detection and avoidance, because conditions that reduce a driver's ability to see may also affect pedestrian detection sensors, such as light condition, weather, and vision obstructions.

Almost 42% of LV pedestrian crashes occurred in conditions of diminished visibility. LV pedestrian crashes in low light (dark, dark/lighted, dawn or dusk) tended to occur more often with the vehicles going straight (80.3%), with pedestrians out in front, either stationary in the road or walking along the road side. In these crashes, the main challenge is to detect pedestrians out in front of the vehicle, with little ambient light. These crashes also tended to occur more often on higher-speed roads. Relatively few nighttime crashes involved turning maneuvers, though one study found a significant nighttime overinvolvement of pedestrians crossing from left to right when LVs were turning left (Sullivan and Flannagan 2011). Pedestrian crashes in turning maneuvers were more of a problem in the day. During daylight hours, most pedestrian crashes occurred at intersections, and almost 40% when the striking vehicle was turning. Pedestrian crashes occurred in left turns much more often than right. In the study just mentioned, the authors suggested that nighttime crashes involving pedestrians moving from left to right across the driver's path in left turns occurred much more often than right to left because the headlights would move across the location of pedestrians crossing from right to left, but not left to right. The overinvolvement of left turns in the day may be similarly explained with reference to the driver's field of view in the day. With respect to pedestrian detection systems, the challenge in turning maneuvers will be to detect pedestrians off to the side of the vehicle's path as it turns, and the area to the left of the driver appears to be particularly important.

Pedestrians were frequently coded as "darting" out in front of the vehicles. In darting crashes, pedestrian collision avoidance devices will have little time to detect and react. Darting was coded in 23.1% of LV pedestrian crashes overall. Whether a pedestrian was recorded as darting is based on the judgment of FARS analysts who rely on crash reports, witness statements, and any other evidence. It is inevitably a subjective judgment; nevertheless, the pedestrians were perceived to have suddenly appeared in front of the vehicles. In addition, darting was often associated with external obstructions. The pedestrians appeared from behind obstacles, often parked cars, that obscured drivers' view. In 70% of crashes where an external obstacle was coded, the pedestrians were coded as darting out into the vehicles' path. This set of pedestrian crashes is particularly challenging because avoidance systems will have to respond very quickly. The presence of obstacles to driver vision would be expected to interfere with or degrade the ability of sensors to detect pedestrians.

Younger pedestrians were much more likely to be coded as darting out. Younger pedestrians were most likely to dart out on non-intersection stretches of road. Overall, almost 18% of pedestrians struck by LVs were 14 years old or younger. Taking age as a surrogate for size, the detection target in these cases would be smaller, presenting an additional challenge.

An obstruction in the driver's line of sight to the pedestrian was identified more frequently for LVs than trucks. In most pedestrian crashes, no obstruction was claimed, but obstruction was coded in over 9.4% of LV pedestrian crashes, though only 3% in truck pedestrian crash involvements. The reason for the difference is not known, though it could stem from differences in operation environments. LVs operate more in urban environments, where obstacles such as parked vehicles are more likely. In addition, truck drivers sit up higher in their vehicles, which may allow them to see over other vehicles, including parked vehicles, and be able to see pedestrians more readily. This difference could have implications for where to locate pedestrian sensors. On trucks, sensors located high up could "see over" other smaller vehicles.

Driver distraction was a more significant issue, and again, identified substantially more frequently for LV drivers than for truck drivers. Excluding cases where distraction was unknown, almost 22% of LV drivers were coded as distracted, compared with only 5.4% of truck drivers. This difference may be related to the fact that most truck drivers are professional drivers and are driving as part of their job. LV drivers primarily drive for personal reasons and few are professional drivers. There was no particular pattern to the cases in which the driver was identified as distracted. There were no significant differences in light condition, road location, or pedestrian activity, suggesting that distraction may be an independent, random factor. However, distraction was more likely in low-speed maneuvers, such as turning, backing, and starting. Most such distraction-related pedestrian crashes are likely preventable with pedestrian detection devices. In particular, pedestrian detection in low-speed maneuvers may be especially useful and effective.

Compared with LVs, truck pedestrian crashes occurred more often on higher speed roads, more often away from intersections, and more often at night. At night, almost 90% of truck pedestrian crashes occurred with the truck going straight. In half of these crashes, the pedestrians were moving along the road or stopped in the road, i.e., in front of the truck. In the other half, the pedestrians were crossing the road in front of the truck, so in these cases, effective detection would include the areas along the sides of the roads. Because trucks take longer to brake (there can be a lag of up to a second for air brakes to develop full stopping power) and to stop, truck drivers are more likely to over-drive their headlights at night. Consequently, truck pedestrian detection systems will have to look farther down the road, cope with full darkness more, and intervene earlier.

Weather was typically not a significant contributor to pedestrian crashes for either trucks or LVs, since 85% to 90% of pedestrian crashes were in clear or cloudy weather. But it appears that adverse weather functioned somewhat like low-light conditions. Crash scenarios were similar between adverse weather and nighttime. Rain, snow, and fog may present challenges to detection systems.

Based on the analysis, Table 6-1 identifies the primary situations and scenario characteristics of LV and truck pedestrian crashes. These are the priority situations and circumstances for pedestrian ACATs to have the greatest effect in reducing the societal burden of pedestrian crashes.

Table 6-1
Priority Scenario Characteristics in LV and Truck Pedestrian Crashes

Priority characteristics of LV pedestrian crashes
• Non-intersection, vehicle going straight. • Night time, particularly dark/lighted. • Non-intersections, particularly at night. • Left turns, both day and night. • External obstructions to driver vision, particularly at non-intersections. The obstructions are mostly parked vehicles or other motor vehicles. • Driver distraction, particularly in low-speed maneuvers such as turning and backing (distraction is an opportunity for ACATs to be effective). • Pedestrians walking along or in the road at night. • Pedestrians crossing in daylight. • Younger pedestrians during daylight hours. • Younger pedestrians darting out in non-intersections. • Older pedestrians in dark or dark/lighted conditions. • Left turns in adverse weather.
Priority characteristics of truck pedestrian crashes
• Non-intersection, vehicle going straight. • Night time, particularly dark/not lighted. • Left turns, in daylight and dark/lighted conditions. • Pedestrians walking along or in the road at night. • Pedestrians crossing in daylight or dark/lighted. • Higher-speed (speed limit 45+ mph) roads. • Pedestrians crossing at intersections in adverse weather. • Older pedestrians at intersections. • Younger pedestrians darting out at non-intersection road segments.

7. Limitations and further work

Crash scenarios and factors in this report were developed for generic pedestrian detection systems. ACATs designed for pedestrian crashes will have operational characteristics that affect whether they will be effective in different circumstances. For example, differences in the range and detection systems may limit their effectiveness in darkness, rain, or on high-speed roads. Crash scenarios should be tailored to the specific operating domain and characteristics of specific devices.

The crash analysis presented here relied on coded crash data. In recent years, crash data systems have increased information on pre-crash conditions and circumstances, which provides good information for understanding the scenarios in which crash avoidance technologies must operate. However, while the data provide relatively good detail on the immediate pre-crash position and movement of vehicles and pedestrians, general purpose crash data sets can only go so far. Important details are not captured, such as impact speeds, how fast the pedestrians were moving, the direction from which they were coming, and when they came into view.

Detailed evaluation and testing of specific technologies would require a more detailed understanding of how pedestrian crashes occur than can be obtained from existing crash data files. Crash files do not have detailed information about pedestrian activities, even something as basic as whether pedestrians were crossing right to left or left to right in intersection crossing crashes. However, detailed analysis of careful samples of police crash reports can be fruitful in obtaining critical details about pedestrian crashes (Sullivan and Flannagan 2011). The present analysis has described the primary modes in which LV and truck pedestrian crashes occurred. Future research to obtain more detailed crash analysis or to develop test scenarios can be performed using samples of crash reports. Crash report analysis is a feasible methodology to go beyond the limitations of general purpose public crash data files.

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9. Appendix: Detailed crash scenarios

Table 9-1
Distribution of LV Pedestrian Crash Scenarios by Light Condition.

Location, vehicle maneuver, pedestrian action	Daylight	Dark	Dark/ lighted	Dawn/ Dusk	Total
At intersection, vehicle going straight, pedestrian crossing	8.7%	7.4%	11.4%	13.3%	9.6%
At intersection, vehicle going straight, pedestrian darting across	4.3%	2.0%	5.7%	7.0%	4.7%
At intersection, vehicle going straight, pedestrian work/play in road	0.6%	0.6%	0.2%	3.2%	0.6%
At intersection, vehicle going straight, pedestrian other	1.9%	1.0%	2.5%	1.6%	2.0%
Non-intersection, vehicle going straight, pedestrian crossing	6.9%	22.8%	14.5%	9.7%	10.4%
Non-intersection, vehicle going straight, pedestrian darting across	12.2%	9.7%	11.1%	21.4%	12.0%
Non-intersection, vehicle going straight, pedestrian moving with traffic	1.7%	18.9%	3.1%	0.5%	3.3%
Non-intersection, vehicle going straight, pedestrian moving against traffic	0.7%	4.5%	0.9%	0.2%	1.0%
Non-intersection, vehicle going straight, pedestrian work/play in road	3.2%	6.2%	1.9%	3.6%	3.1%
Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	0.5%	0.6%	0.3%	0.2%	0.4%
Non-intersection, vehicle going straight, pedestrian other	4.2%	4.1%	5.9%	2.6%	4.6%
Vehicle going straight, pedestrian on roadside	1.0%	1.3%	0.2%	0.2%	0.7%
At intersection, vehicle turning left, pedestrian crossing	21.4%	3.8%	21.6%	7.7%	19.5%
At intersection, vehicle turning left, pedestrian other	1.7%	0.2%	0.9%	5.4%	1.5%
Non-intersection, vehicle turning left, pedestrian crossing	2.9%	2.5%	1.5%	0.6%	2.3%
Non-intersection, vehicle turning left, pedestrian other	0.9%	0.3%	0.6%	0.3%	0.8%
Vehicle turning left, pedestrian on roadside	0.5%	0.3%	0.1%	0.0%	0.3%
At intersection, vehicle turning right, pedestrian crossing	7.6%	1.0%	5.1%	11.8%	6.6%
At intersection, vehicle turning right, pedestrian other	0.6%	0.3%	0.8%	2.9%	0.7%
Non-intersection, vehicle turning right	1.4%	0.4%	0.5%	0.7%	1.0%
Vehicle turning right, pedestrian on roadside	0.9%	0.3%	1.0%	0.3%	0.8%
Vehicle backing	5.6%	4.1%	2.2%	4.6%	4.4%
Vehicle starting	3.2%	1.1%	2.9%	1.1%	2.9%
Other crash type	6.1%	5.3%	4.2%	1.1%	5.2%
Unknown crash type	1.4%	1.2%	0.7%	0.0%	1.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table 9-2
Distribution of Truck Pedestrian Scenarios by Light Condition.

Location, vehicle maneuver, pedestrian action	Daylight	Dark	Dark/ Lighted	Dawn	Dusk	Total
At intersection, vehicle going straight, pedestrian crossing	2.8%	1.1%	14.4%	21.4%	13.5%	5.9%
At intersection, vehicle going straight, pedestrian darting across	1.6%	0.3%	16.5%	0.0%	0.0%	5.5%
At intersection, vehicle going straight, pedestrian work/play in road	0.3%	0.0%	0.1%	0.0%	0.0%	0.2%
At intersection, vehicle going straight, pedestrian other	3.1%	0.3%	0.1%	0.0%	0.0%	1.8%
Non-intersection, vehicle going straight, pedestrian crossing	7.2%	16.2%	6.6%	7.1%	5.7%	8.2%
Non-intersection, vehicle going straight, pedestrian darting across	6.9%	31.3%	4.6%	7.1%	22.6%	9.7%
Non-intersection, vehicle going straight, pedestrian moving with traffic	11.2%	8.6%	1.2%	0.0%	0.0%	7.8%
Non-intersection, vehicle going straight, pedestrian moving against traffic	0.1%	1.6%	0.1%	0.0%	0.0%	0.3%
Non-intersection, vehicle going straight, pedestrian work/play in road	11.2%	19.8%	2.1%	21.4%	8.5%	9.9%
Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	9.1%	2.9%	0.3%	7.1%	0.0%	5.6%
Non-intersection, vehicle going straight, pedestrian other	4.7%	4.3%	0.9%	0.0%	0.0%	3.6%
Vehicle going straight, pedestrian on roadside	2.9%	0.3%	0.0%	14.3%	0.0%	1.7%
At intersection, vehicle turning left, pedestrian crossing	11.5%	2.4%	44.7%	7.1%	41.2%	20.1%
At intersection, vehicle turning left, pedestrian other	4.4%	0.0%	1.5%	0.0%	0.0%	2.9%
Non-intersection, vehicle turning left, pedestrian crossing	0.3%	0.3%	0.0%	0.0%	0.0%	0.2%
Non-intersection, vehicle turning left, pedestrian other	0.1%	1.5%	0.0%	0.0%	0.0%	0.3%
Vehicle turning left, pedestrian on roadside	0.8%	0.0%	0.0%	0.0%	0.0%	0.4%
At intersection, vehicle turning right, pedestrian crossing	7.1%	0.3%	2.3%	14.3%	2.8%	4.8%
At intersection, vehicle turning right, pedestrian other	0.8%	7.5%	0.4%	0.0%	0.0%	1.6%
Non-intersection, vehicle turning right	0.7%	0.0%	0.3%	0.0%	0.0%	0.5%
Vehicle turning right, pedestrian on roadside	0.8%	0.0%	0.0%	0.0%	0.0%	0.4%
Vehicle backing	4.0%	0.3%	0.5%	0.0%	2.8%	2.5%
Vehicle starting	4.3%	0.0%	0.3%	0.0%	0.0%	2.5%
Other crash type	4.1%	1.1%	3.1%	0.0%	2.8%	3.3%
Unknown crash type	0.3%	0.0%	0.0%	0.0%	0.0%	0.2%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 9-3
Distribution of LV Pedestrian Crash Scenarios by Pedestrian Age.

Location, vehicle maneuver, pedestrian action	0 to 9	10 to 19	20 to 64	65+	Total
At intersection, vehicle going straight, pedestrian crossing	5.6%	10.4%	9.6%	1 1.5%	9.6%
At intersection, vehicle going straight, pedestrian darting across	6.9%	8.1%	3.7%	1.9%	4.7%
At intersection, vehicle going straight, pedestrian work/play in road	0.2%	0.8%	0.7%	0.1%	0.6%
At intersection, vehicle going straight, pedestrian other	1.4%	2.4%	2.2%	0.8%	2.0%
Non-intersection, vehicle going straight, pedestrian crossing	7.1%	7.7%	11.3%	13.0%	10.4%
Non-intersection, vehicle going straight, pedestrian darting across	30.4%	20.0%	8.2%	3.9%	12.0%
Non-intersection, vehicle going straight, pedestrian moving with traffic	0.3%	4.0%	3.6%	2.3%	3.3%
Non-intersection, vehicle going straight, pedestrian moving against traffic	0.2%	1.3%	1.1%	0.8%	1.0%
Non-intersection, vehicle going straight, pedestrian work/play in road	7.8%	2.5%	3.0%	0.8%	3.1%
Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	0.4%	0.1%	0.6%	0.1%	0.4%
Non-intersection, vehicle going straight, pedestrian other	16.6%	3.7%	3.7%	2.1%	4.6%
Vehicle going straight, pedestrian on roadside	0.3%	0.6%	0.9%	0.3%	0.7%
At intersection, vehicle turning left, pedestrian crossing	7.2%	12.5%	21.7%	30.4%	19.5%
At intersection, vehicle turning left, pedestrian other	0.1%	1.9%	1.5%	2.3%	1.5%
Non-intersection, vehicle turning left, pedestrian crossing	0.5%	0.7%	2.9%	3.5%	2.3%
Non-intersection, vehicle turning left, pedestrian other	0.7%	0.2%	1.0%	0.3%	0.8%
Vehicle turning left, pedestrian on roadside	0.2%	0.3%	0.2%	1.2%	0.3%
At intersection, vehicle turning right, pedestrian crossing	3.1%	7.2%	6.3%	9.3%	6.6%
At intersection, vehicle turning right, pedestrian other	0.1%	1.0%	0.6%	1.4%	0.7%
Non-intersection, vehicle turning right	1.1%	2.1%	0.8%	0.6%	1.0%
Vehicle turning right, pedestrian on roadside	0.2%	1.1%	0.9%	0.6%	0.8%
Vehicle backing	0.8%	3.1%	5.1%	6.2%	4.4%
Vehicle starting	3.6%	2.5%	3.2%	0.9%	2.9%
Other crash type	4.8%	4.5%	5.7%	4.4%	5.2%
Unknown crash type	0.3%	1.0%	1.5%	1.3%	1.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table 9-4
Distribution of Truck Pedestrian Scenarios by Pedestrian Age.

Location, vehicle maneuver, pedestrian action	0 to 9	10 to 19	20 to 64	65+	Total
At intersection, vehicle going straight, pedestrian crossing	0.5%	4.4%	6.6%	7.6%	5.9%
At intersection, vehicle going straight, pedestrian darting across	0.0%	39.3%	0.8%	0.8%	5.5%
At intersection, vehicle going straight, pedestrian work/play in road	0.0%	1.5%	0.0%	0.4%	0.2%
At intersection, vehicle going straight, pedestrian other	0.0%	10.7%	0.7%	0.0%	1.8%
Non-intersection, vehicle going straight, pedestrian crossing	0.9%	6.0%	9.3%	9.3%	8.2%
Non-intersection, vehicle going straight, pedestrian darting across	1.8%	9.5%	11.4%	3.0%	9.7%
Non-intersection, vehicle going straight, pedestrian moving with traffic	0.0%	1.6%	10.6%	0.8%	7.8%
Non-intersection, vehicle going straight, pedestrian moving against traffic	0.0%	0.6%	0.3%	0.4%	0.3%
Non-intersection, vehicle going straight, pedestrian work/play in road	20.8%	3.8%	10.1%	5.9%	9.9%
Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	48.6%	0.3%	2.2%	1.3%	5.6%
Non-intersection, vehicle going straight, pedestrian other	5.5%	1.8%	4.0%	1.3%	3.6%
Vehicle going straight, pedestrian on roadside	0.5%	0.0%	2.3%	0.4%	1.7%
At intersection, vehicle turning left, pedestrian crossing	2.8%	9.1%	23.4%	25.4%	20.1%
At intersection, vehicle turning left, pedestrian other	9.2%	0.0%	0.9%	17.2%	2.9%
Non-intersection, vehicle turning left, pedestrian crossing	0.0%	0.0%	0.1%	1.3%	0.2%
Non-intersection, vehicle turning left, pedestrian other	0.0%	0.0%	0.3%	0.4%	0.3%
Vehicle turning left, pedestrian on roadside	0.0%	0.0%	0.5%	1.0%	0.4%
At intersection, vehicle turning right, pedestrian crossing	5.0%	4.5%	4.3%	9.3%	4.8%
At intersection, vehicle turning right, pedestrian other	0.0%	0.3%	2.0%	0.8%	1.6%
Non-intersection, vehicle turning right	1.8%	0.3%	0.4%	0.4%	0.5%
Vehicle turning right, pedestrian on roadside	0.0%	0.0%	0.5%	0.4%	0.4%
Vehicle backing	0.0%	0.3%	2.9%	5.1%	2.5%
Vehicle starting	0.5%	5.5%	1.8%	6.5%	2.5%
Other crash type	2.3%	0.3%	4.3%	0.8%	3.3%
Unknown crash type	0.0%	0.3%	0.2%	0.0%	0.2%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table 9-5
Distribution of LV Pedestrian Scenarios by Weather Condition.

Location, vehicle maneuver, pedestrian action	Clear/ Cloudy	Rain, snow, hail, fog, etc.	Total
At intersection, vehicle going straight, pedestrian crossing	10.0%	8.0%	9.6%
At intersection, vehicle going straight, pedestrian darting across	4.6%	5.6%	4.7%
At intersection, vehicle going straight, pedestrian work/play in road	0.6%	1.2%	0.6%
At intersection, vehicle going straight, pedestrian other	1.9%	2.7%	2.0%
Non-intersection, vehicle going straight, pedestrian crossing	10.7%	7.8%	10.4%
Non-intersection, vehicle going straight, pedestrian darting across	13.1%	5.3%	12.0%
Non-intersection, vehicle going straight, pedestrian moving with traffic	3.2%	4.0%	3.3%
Non-intersection, vehicle going straight, pedestrian moving against traffic	1.0%	0.9%	1.0%
Non-intersection, vehicle going straight, pedestrian work/play in road	3.4%	1.4%	3.1%
Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	0.4%	0.2%	0.4%
Non-intersection, vehicle going straight, pedestrian other	4.8%	1.6%	4.6%
Vehicle going straight, pedestrian on roadside	0.8%	0.2%	0.7%
At intersection, vehicle turning left, pedestrian crossing	17.3%	35.0%	19.5%
At intersection, vehicle turning left, pedestrian other	1.2%	3.8%	1.5%
Non-intersection, vehicle turning left, pedestrian crossing	2.1%	3.7%	2.3%
Non-intersection, vehicle turning left, pedestrian other	0.9%	0.1%	0.8%
Vehicle turning left, pedestrian on roadside	0.4%	0.3%	0.3%
At intersection, vehicle turning right, pedestrian crossing	6.9%	5.0%	6.6%
At intersection, vehicle turning right, pedestrian other	0.6%	1.4%	0.7%
Non-intersection, vehicle turning right	1.1%	0.3%	1.0%
Vehicle turning right, pedestrian on roadside	0.9%	0.2%	0.8%
Vehicle backing	4.6%	2.6%	4.4%
Vehicle starting	3.2%	0.6%	2.9%
Other crash type	5.3%	4.1%	5.2%
Unknown crash type	0.9%	3.8%	1.3%
Total	100.0%	100.0%	100.0%

Table 9-6
Distribution of Truck Pedestrian Scenarios by Weather Condition.

Location, vehicle maneuver, pedestrian action	Clear/ Cloudy	Rain, snow, hail, fog, etc.	Total
At intersection, vehicle going straight, pedestrian crossing	2.8%	37.8%	5.9%
At intersection, vehicle going straight, pedestrian darting across	5.9%	1.2%	5.5%
At intersection, vehicle going straight, pedestrian work/play in road	0.2%	0.0%	0.2%
At intersection, vehicle going straight, pedestrian other	2.0%	0.0%	1.8%
Non-intersection, vehicle going straight, pedestrian crossing	8.5%	5.2%	8.2%
Non-intersection, vehicle going straight, pedestrian darting across	9.9%	7.7%	9.7%
Non-intersection, vehicle going straight, pedestrian moving with traffic	8.5%	2.0%	7.8%
Non-intersection, vehicle going straight, pedestrian moving against traffic	0.2%	0.8%	0.3%
Non-intersection, vehicle going straight, pedestrian work/play in road	10.7%	2.4%	9.9%
Non-intersection, vehicle going straight, pedestrian enter/exit vehicle	5.8%	4.6%	5.6%
Non-intersection, vehicle going straight, pedestrian other	3.9%	1.2%	3.6%
Vehicle going straight, pedestrian on roadside	1.9%	0.4%	1.7%
At intersection, vehicle turning left, pedestrian crossing	20.6%	12.0%	20.1%
At intersection, vehicle turning left, pedestrian other	2.6%	5.8%	2.9%
Non-intersection, vehicle turning left, pedestrian crossing	0.2%	0.0%	0.2%
Non-intersection, vehicle turning left, pedestrian other	0.0%	2.2%	0.3%
Vehicle turning left, pedestrian on roadside	0.5%	0.0%	0.4%
At intersection, vehicle turning right, pedestrian crossing	4.4%	9.2%	4.8%
At intersection, vehicle turning right, pedestrian other	1.6%	1.1%	1.6%
Non-intersection, vehicle turning right	0.5%	0.0%	0.5%
Vehicle turning right, pedestrian on roadside	0.2%	3.1%	0.4%
Vehicle backing	2.6%	2.0%	2.5%
Vehicle starting	2.8%	0.4%	2.5%
Other crash type	3.6%	0.8%	3.3%
Unknown crash type	0.2%	0.0%	0.2%
Total	100.0%	100.0%	100.0%