Primary Pedestrian Crash Scenarios: Factors Relevant to the Design of Pedestrian Detection Systems

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ABSTRACT

Objectives: Vehicle manufacturers are implementing advanced technologies aimed at reducing the severity of pedestrian crashes or avoiding them altogether. The objective of the current study was to determine the most common and injurious pedestrian crash scenarios in the United States to help set priorities for the design of pedestrian detection systems. The study focused on single-vehicle crashes in which pedestrians were struck by the fronts of passenger vehicles.

Methods: Crash records were extracted from the 2005-09 files of the National Automotive Sampling System General Estimates System (NASS GES) and the Fatality Analysis Reporting System (FARS). Crash descriptors such as vehicle movement, pedestrian movement, and driver view obstruction were reviewed to develop a typology of crash scenarios. Crashes then were classified into various scenarios, and the most common scenarios were identified.

Results: The largest number of pedestrian crash involvements and deaths involved a pedestrian crossing the roadway while the vehicle was traveling straight. This scenario accounted for 43 percent of pedestrian involvements and 46 percent of pedestrian deaths in single-vehicle crashes. The other main crash scenarios involved the pedestrian traveling in-line with traffic while the vehicle was traveling straight and the pedestrian crossing while the vehicle was turning. A larger proportion of fatal pedestrian crashes occurred in nondaylight conditions and on roadways with speed limits higher than 40 mi/h, when compared with pedestrian crash involvements of all severities.

Conclusions: Vehicle technologies that can quickly and accurately detect pedestrians in the three most common crash scenarios potentially can mitigate as many as 65 percent of pedestrian involvements and 58 percent of pedestrian deaths in single-vehicle crashes in the United States. There is great potential for pedestrian detection systems, but they must function in low-light conditions and at higher vehicle speeds to address a large proportion of pedestrian deaths.

Keywords: Pedestrian; Active safety; Crash avoidance technology; GES; FARS

INTRODUCTION

Pedestrian motor vehicle crash deaths have declined dramatically in the United States since 1975 but still account for 12 percent of all crash deaths. In 2009, 59,000 pedestrians were injured in motor vehicle crashes in the United States and 4,092 pedestrians were killed (National Highway Traffic Safety Administration (NHTSA), 2011). The downward trend is similar in Europe, where pedestrian deaths decreased 37 percent during 1997-2006 (European Road Safety Observatory, 2010) but still resulted in 3,547 deaths, more than 14 percent of all crash deaths, in 2006. Pedestrian protection becomes increasingly important as the world becomes more motorized and pedestrians increasingly cross paths with motor vehicles. The World Health Organization (2009) estimates that nearly half of the world's 1.2 million traffic-related deaths are vulnerable road users, a category that includes pedestrians.

Several highway engineering strategies have been effective in reducing pedestrian deaths including thoughtful roadway designs that minimize pedestrian exposure to motor vehicles, reduce vehicle speeds, and increase pedestrian conspicuity such as through improved lighting (Retting et al., 2003). More recent efforts to improve pedestrian protection have focused on the vehicle's role. In Europe, passenger vehicles must pass crash tests that assess injury risk to a pedestrian's head and legs from impacts with the vehicle's hood and bumper (European Commission, 2009). As a result, vehicle manufacturers are modifying hood and bumper designs to make pedestrian impacts with their vehicles less injurious.

In addition to vehicle design measures that seek to better manage crash energy, passenger vehicle manufacturers are implementing pedestrian detection systems aimed at reducing the severity of pedestrian collisions or avoiding them altogether. Pedestrian detection systems are a specialized subset of forward collision warning/mitigation systems. These systems use advanced algorithms coupled with some combination of cameras, radar, Light Detection And Ranging, or other sensors to monitor the area in front of a vehicle and alert the driver of a potential collision with a pedestrian. Some systems require the driver to take action, whereas other systems may autonomously brake or steer the vehicle to reduce crash severity or avoid a crash if driver action is not taken. It is estimated that as many as 3,279 fatal and 37,000 injury on-road crashes potentially could be prevented or mitigated each year if forward collision warning/mitigation systems were designed to detect vulnerable road users such as pedestrians and bicyclists (Jermakian, 2011).

Pedestrian crashes pose unique challenges to crash avoidance technologies. The technology must identify pedestrians accurately; determine the likelihood of impact; warn the driver; and, if driver action is not taken, initiate braking or steering to avoid the crash or mitigate its severity. Pedestrians are smaller than motor vehicles; they may be present around vehicles, on sidewalks, in crosswalks, and on roadsides; and, unlike vehicles, they often change trajectory quickly. They may blend into their surroundings, especially at night. An effective pedestrian detection system must constantly monitor a wide area in front of the vehicle and quickly and accurately predict an imminent collision across a wide range of circumstances. Given the wide diversity of potential crash scenarios, systems designed to address the most common and injurious scenarios would result in the largest effect. The objective of the current study was to determine these crash scenarios in the United States and assist in setting priorities for the design of pedestrian detection systems.

METHODS

Data from a census of fatal pedestrian crashes and a nationally representative sample of police-reported pedestrian crashes were reviewed to develop a typology of crash scenarios relevant to pedestrian detection systems. Crash scenarios were defined by seven main factors that describe the paths of the vehicle and pedestrian and other crash circumstances such as light conditions. These crash factors may have bearing on the selection of pedestrian detection sensors and the algorithms employed to decide when to issue a warning and/or autonomously apply braking on behalf of the driver.

- Vehicle and pedestrian motion define the path of a pedestrian relative to the vehicle that must be considered by algorithms estimating the risk of a crash.
- Obstruction of a pedestrian from the driver’s view is used as a proxy for the possibility that the pedestrian detection sensors’ view of the pedestrian also may be obscured.
- Light conditions at the time of a crash are important because some sensors depend on ambient light to distinguish pedestrians from the background environment.

- Speed limit is used as a proxy for the speed of a vehicle, which affects the distance ahead that sensors must scan as well as the timing of warnings and/or the initiation of autonomous braking.
- Pedestrian age is a surrogate for pedestrian size, which may affect the sensors' ability to determine that an object is a pedestrian.
- Precipitation may affect the sensors' ability to detect pedestrians and also may affect the friction on roadways and thereby a vehicle's ability to brake, which will have implications for the timing of warnings and the initiation of autonomous braking.
- Driver avoidance maneuvers, particularly braking, affect system designs, especially systems that autonomously initiate braking to support the driver's own control of the vehicle rather than interfere with it.

Data were extracted from two national crash databases maintained by NHTSA in the United States. The National Automotive Sampling System General Estimates System (NASS GES) contains information from annual national probability samples of police-reported crashes. Approximately 57,000 crashes are sampled each year. When each case is weighted by the inverse of its selection probability, the yearly sample is representative of about 6 million crashes nationwide (NHTSA, 2010). The Fatality Analysis Reporting System (FARS) is an annual census of crashes that occur on public roads and result in the death of a vehicle occupant or other involved party within 30 days of the crash.

All pedestrian person records in the 2005-09 NASS GES and FARS files (Per_type=5) were merged with the corresponding crash records. For single-vehicle crashes, pedestrian crash records then were merged with the associated driver and vehicle records. Records in GES were weighted by their case weights to produce national estimates. Crashes in GES with maximum injury severity coded as incapacitating (A) or nonincapacitating (B) were classified as severe or moderate injury crashes, respectively. To account for missing data in the crash files, imputed data were used whenever available in the GES files.

Pedestrian crashes were classified according to the seven crash factors. Crashes involving more than one vehicle were not considered because of an inability to clearly define the sequence of events and the likelihood that the pedestrian impact was incidental to the primary impact type. Pedestrian movement was classified as in-line with or crossing traffic and was determined using the nonmotorist's location (LOCATN), nonmotorist action (ACTION), and pedestrian crash type (PED_ACC) variables in GES and the nonmotorist location (LOCATION) and person-related factors (P_CF1-3) variables in FARS (Table 1). For FARS, the relevant variable code (P_CF1-3 = 4) also includes nonconstruction-related pedestrians who may be standing, sitting, or playing in the road. Vehicle movement was determined using the movement prior to critical event (P_CRASH1) variable in GES and the vehicle maneuver (VEH_MAN) variable in FARS. Crashes that involved a driver's vision being obscured were identified using the driver's vision obscured by (VIS_OBSC) variable in GES and the driver-related factors (DR_CF1-4), person-related factors (P_CF1-3), and driver's vision obscured by (D_VISION1-3) variables in FARS.

(Insert Table 1)

Crashes that occurred during inclement weather were identified using the atmospheric condition (WEATHER, WEATHER1-2) variables in GES and FARS. Crashes that occurred in nondaylight conditions were determined using the light condition (LGHT_CON, LGT_COND) variables in GES and FARS. Nondaylight conditions were defined to include dawn or dusk, dark, and dark but lighted conditions. Pedestrian age was determined using the age (AGE) variables in GES and FARS. Roadway speed limits were determined using the posted speed limit (SPD_LIM, SP_LIMIT) variables in GES and FARS. Crashes that involved preimpact braking were identified using the corrective action (P_CRASH3) variable in GES and the avoidance maneuver (AVOID) variable in FARS.

RESULTS

There were 10,079 pedestrian person records in the 2005-09 NASS GES files. When sampling weights were applied, these records represented approximately 346,000 pedestrians involved in crashes nationwide during the 5 years. There were 22,892 pedestrian deaths in the 2005-09 FARS files. Thus for the 5-year study period, there was an average of approximately 69,000 pedestrians involved in police-reported crashes per year, of which 4,578 pedestrians were killed. Ninety-six percent, or 333,000, of all crash-involved pedestrians and 91 percent, or 20,824, of fatally injured pedestrians were in single-vehicle crashes. Table 2 summarizes the distribution of pedestrians in single-vehicle crashes by vehicle, environmental, and pedestrian characteristics. Some of the characteristics of fatal pedestrian crashes differed from those of all pedestrian crashes.

(Insert Table 2)

Ninety-six percent of all pedestrians and 80 percent of fatally injured pedestrians in single-vehicle crashes were struck by passenger vehicles. More than two-thirds of pedestrians impacted the vehicle front, and three-quarters of the crashes occurred on roads with speed limits less than 40 mi/h. Thirty-seven percent of pedestrian deaths occurred on roads with speed limits less than 40 mi/h. The majority (59 percent) of all pedestrian crash involvements occurred during daylight, but nearly three-quarters (72 percent) of pedestrian deaths occurred in nondaylight conditions. Approximately 1 in 10 pedestrians were struck during inclement weather. A larger proportion (75 percent) of pedestrian deaths occurred outside of intersections compared with all pedestrian crash involvements (48 percent). Overall, 15 percent of all pedestrian involvements and 6 percent of pedestrian deaths were children 12 and younger.

During the 5-year study period, a total of 224,000 pedestrians and 13,193 fatally injured pedestrians in single-vehicle crashes were struck by the fronts of passenger vehicles, the study set of crash involvements. This represented 67 percent of pedestrian involvements and 63 percent of pedestrian deaths in single-vehicle crashes. Table 3 summarizes the distribution of pedestrians in single-vehicle crashes involving the fronts of passenger vehicles by vehicle, environmental, and pedestrian characteristics.

(Insert Table 3)

Table 4 summarizes pedestrian involvements and deaths in single-vehicle crashes involving the fronts of passenger vehicles by the various combinations of vehicle and pedestrian movements. Three combinations of vehicle/pedestrian movements — straight/crossing, straight/in-line, and turning/crossing — accounted for 96 percent, or 215,000, of pedestrian involvements and 92 percent, or 12,124, of pedestrian deaths in the study crash subset.

(Insert Table 4)

Tables 5-10 summarize the incidence of pedestrian involvements and deaths among the three main vehicle/pedestrian scenarios for the six crash factors: driver view obstruction, nondaylight condition, inclement weather, pedestrian 12 and younger, speed limit less than 40 mi/h, and vehicle braking. Pedestrians were obscured from drivers' views in 13 percent of all pedestrian involvements and 17 percent of pedestrian deaths (Table 5). A majority (57 percent) of pedestrian involvements occurred in daylight conditions (Table 6), but three-quarters of pedestrian deaths occurred in nondaylight conditions. Only about 1 in 10 pedestrian involvements and deaths occurred in inclement weather conditions (Table 7).

(Insert Tables 5 through 7)

Fifteen percent of pedestrian involvements but only 5 percent of pedestrian deaths were children 12 and younger (Table 8). Three-quarters of pedestrian involvements occurred on roads with speed limits less than 40 mi/h, but this proportion was much lower (37 percent) for pedestrian deaths (Table 9). Vehicle braking was reported in a minority of impacts — 10 percent of pedestrian involvements and 13 percent of pedestrian deaths (Table 10).

(Insert Tables 8 through 10)

There was some degree of overlap among the crash factors listed in Tables 5-10. For example, crashes that occurred in inclement weather also may have occurred in nondaylight conditions or with driver view obstruction. Table 11 shows a hierarchical tabulation of the number of pedestrian involvements for the three main crashes scenarios that may be addressed if pedestrian detection systems were able to function in nondaylight conditions, at speeds greater than 40 mi/h, in inclement weather, and with driver view obstruction.

(Insert Table 11)

During the 5-year study period, the three main crash scenarios accounted for 215,000, or 65 percent, of the 333,000 pedestrian involvements and 12,124, or 58 percent, of the 20,824 pedestrian deaths in single-vehicle crashes. The most common scenario, in which a pedestrian was crossing the roadway while the vehicle was traveling straight, accounted for 43 percent, or 142,000, of pedestrian involvements and 46 percent, or 9,495, of pedestrian deaths in single-vehicle crashes.

DISCUSSION

Pedestrians deaths have declined steadily during the past 35 years but still account for more than 1 in 10 motor vehicle crash deaths in the United States. Improved walkways, crossings, and other countermeasures have been effective in reducing pedestrian-vehicle conflicts (Eccles et al., 2004; Preusser et al., 2002; Retting et al., 2003; Van Houten et al., 2000), but crashes still resulted in 4,092 pedestrian deaths in 2009. A large proportion of pedestrian crashes involve errors made by the pedestrians (Preusser et al., 2002) such as running into the road or failing to the yield right-of-way; many fatally-injured pedestrians are impaired by alcohol. In a study of urban pedestrian crashes, pedestrians were determined to be at fault in 50 percent of the cases, compared with 39 percent for motor vehicle drivers (Preusser et al., 2002). In a crash, pedestrians are at a large disadvantage when compared with the size and weight of a vehicle. Modifying pedestrian and driver behavior can be difficult. Vehicle technologies that can reduce the likelihood or severity of a pedestrian impact have the potential to reduce pedestrian crashes, injuries, and deaths substantially. Modifying vehicle front-end structures may play some role in making pedestrian impacts less injurious, but crash avoidance technologies have great potential to further mitigate injuries or avoid these crashes altogether.

Systems that can quickly and accurately detect pedestrians in the three most common crash scenarios of vehicle/pedestrian movement potentially can mitigate as many as 65 percent of pedestrian involvements and 58 percent of pedestrian deaths in single-vehicle crashes in the United States. The scenario that resulted in the largest number of both pedestrian involvements and deaths involved the pedestrian crossing the roadway while the vehicle was traveling straight. This scenario accounted for 43 percent of pedestrian involvements and 46 percent of pedestrian deaths in single-vehicle crashes. Systems that address this scenario, therefore, will have by far the greatest effect on pedestrian safety.

Scenarios involving driver view obstruction are challenging for pedestrian detection systems but represent only a small proportion of the three most common crash scenarios — 13 percent of pedestrian involvements and 17 percent of pedestrian deaths. Pedestrians who are obscured from a driver's view until they step in front of the vehicle require the sensors and activation algorithms to respond much more quickly once the pedestrian comes into view. Systems that work in vehicle-turning scenarios would need a wider field of view and more complex algorithms to accurately identify the pedestrian and predict an impact. Rosén et al. (2010) used data from the German In-Depth Accident Study to model pedestrian crashes and found that pedestrian detection systems with field-of-view sensors wider than 40 degrees were only marginally more effective at reducing fatalities than systems with 40 degree field-of-view sensors. The study assumed that pedestrians were within a given field of view 1 second prior to the crash. This may be an appropriate assumption for crashes involving vehicles traveling straight prior to impact but may not be an appropriate assumption for crashes involving turning vehicles.

Less than half of pedestrian crash involvements but more than three-quarters of pedestrian deaths in the three most common crash scenarios occurred in nondaylight conditions. This suggests the importance of developing pedestrian detection systems that function in dark conditions, particularly when the goal is to prevent or mitigate fatal crashes. Some sensors depend on ambient light to differentiate pedestrians from the background environment and may not function well in low-light conditions. Other systems use infrared cameras to enhance driver vision at night and, in some cases, warn the driver through an audible or visual alert if pedestrians are present. Research has shown that infrared systems increase the distance at which pedestrians can be detected (Brown et al., 2010; Tsimhoni et al., 2005), which is critical to effectively mitigating or avoiding an impact. Darkness may be particularly dangerous when pedestrians are walking along the roadway, as 69 percent of pedestrian involvements and 86 percent of pedestrian deaths occurred in nondaylight conditions.

Pedestrian detection systems may be challenged by adverse weather conditions, which were present in 12 percent of pedestrian involvements and 10 percent of pedestrian deaths in the three most common crash scenarios. Some sensors may not be reliable in poor weather conditions because precipitation can either obscure objects from the view of cameras or interfere with reflected radar/Light Detection And Ranging signals. Inclement weather often affects roadway friction and thereby a vehicle's ability to brake effectively. This would have implications for the timing of driver warnings and potentially would affect autonomous brake initiation and effectiveness.

Fifteen percent of pedestrian crash involvements and 5 percent of pedestrian deaths in the three most common crash scenarios included children 12 and younger. Small-statured pedestrians such as children may affect a system's ability to correctly identify an object as a pedestrian.

Vehicle speed, approximated by speed limit, will affect the distance a system must scan and the timing of driver warnings and/or initiation of autonomous braking. As vehicle speed increases, it becomes more challenging for a pedestrian detection system to detect the pedestrian and intervene before a collision. Vehicle speed also has implications for system effectiveness in mitigating crash severity. Even a small reduction in vehicle speed prior to impact would reduce the likelihood of fatal injuries, as pedestrian fatality risk is highly dependent on vehicle speed (Rosén and Sander, 2009; Rosén et al., 2011). Using data from the German In-Depth Accident Study, Rosén and Sander (2009) estimated that a pedestrian's fatality risk in crashes involving vehicle speeds of 50 km/h (31 mi/h) was twice the risk in crashes involving vehicle speeds of 40 km/h (25 mi/h). Pedestrians struck at 75 km/h (47 mi/h) had a fatality risk of 50 percent. In the current study, the majority of pedestrian impacts but only one-third of pedestrian deaths in the three most common crash scenarios occurred on roads with speed limits below 40 mi/h.

Functionality of a pedestrian detection system may be different if a driver recognizes the threat of a collision and brakes. In particular, activation algorithms for systems that autonomously initiate braking should consider and balance the need to support a driver's own control of the vehicle without interfering with it.

The current study focuses on pedestrians involved in single-vehicle crashes with the fronts of passenger vehicles and factors that are relevant to the design of pedestrian detection systems. Although less common, several other crash scenarios also may benefit from pedestrian crash avoidance technologies including crashes involving pedestrian impacts with the sides of vehicles, crashes involving multiple vehicles, and crashes of vehicles other than passenger vehicles.

The current study has several limitations. The two national databases (NASS GES and FARS) rely on police-reported data, which may include some degree of misclassification of key variables that would affect the classification of crashes. Some variables may not map directly between GES and FARS. For example, the nonmotorist action (ACTION) and pedestrian crash type (PED_ACC) variables in GES include specific codes for walking with or against traffic, whereas the FARS variable used to determine whether a pedestrian was traveling in-line with traffic (P_CF1-3) also includes nonconstruction-related pedestrians who may be standing, sitting, or playing in the road. This means there is some degree of overcounting fatalities involving pedestrians walking in-line with traffic. Some variables such as those for attempted avoidance maneuvers often have missing or unknown values, which would result in underestimating crashes within that category. Other variables such as those for driver view obstruction may not be coded consistently or reliably and likely result in underestimating crashes meeting the condition. The timing and extent to which a driver's view was obstructed also is not characterized in GES or FARS, yet these measures would be critical to pedestrian detection system functionality. A driver's view may be obstructed by objects that may not be relevant to a pedestrian detection sensor such as objects located within the vehicle. Driver impairments such as distraction, alcohol use, medical issues, and drowsiness that would limit a driver's ability to react appropriately to a warning system were not considered and are beyond the scope of the study. Finally, capabilities of crash avoidance technologies vary among systems, and some systems may have capabilities or limitations beyond those described.

In summary, pedestrian detection systems that function under the condition/scenario of a vehicle travelling straight at a speed of less than 40 mi/h, a pedestrian crossing in daylight and clear weather, and the driver's view not obstructed have the potential to prevent or mitigate a large number of crashes, as many as 41,000 pedestrian involvements during the 5-year study period. However, this basic system would be less relevant for fatal crashes, preventing only up to 859 pedestrian deaths during the same period. It is important that systems aimed at reducing fatal crashes can function in low-light conditions and at higher vehicle speeds; such systems potentially could address an additional 6,519 pedestrian deaths during the study period. Systems that are able to detect pedestrians walking in-line with traffic are additionally relevant to 1,334 pedestrian deaths during the same period. Other factors such as inclement weather may reduce system effectiveness but to a lesser extent than factors such as speed and nondaylight conditions.

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Table 1
Classification of pedestrian and vehicle movement, driver view obstruction, light conditions, inclement weather, pedestrian age, speed limit, and vehicle braking using GES and FARS files, 2005-09

	GES	FARS
Pedestrian movement		
Pedestrian in-line with traffic	ACTION = 27 or 28 OR PED_ACC = 510, 531,532, or 539	P_CF1-3 = 4
Pedestrian crossing traffic	[LOCATN = 1,2,11,12, or 20 OR PED_ACC = 520,730,821,822,829, or 830] AND PED_ACC ≠ 430,510,531,532, 539,610,620, or 740	[LOCATION = 1,2,3,4,10,11,12, or 13 OR P_CF1-3 = 2 or 3] AND P_CF1-3 ≠ 4
Vehicle movement		
Vehicle traveling straight	P_CRASH1 = 1,2,3,4,6,14,15, or 16	VEH_MAN = 1,2,3,4,5,9,16, or 17
Vehicle turning	P_CRASH1 = 10,11, or 12	VEH_MAN = 10,11,12,13, or 14
Driver view obstruction reported	VIS_OBSC = 1-15 OR VIS_OBSC = 97	DR_CF1-4 = 61-76 OR P_CF1-3 = 1 OR D_VISION1-3 = 1-98
Nondaylight conditions	LGHT_CON = 2,3,4,5, or 6	LGT_COND = 2,3,4,5, or 6
Inclement weather	WEATHER = 2,3,4,5,6,7, or 8	WEATHER1-2 = 2,3,4,5,6, or 7
Pedestrian age 12 years or younger	AGE = 0-12	AGE = 0-12
Speed limit less than 40 mi/h	SPD_LIM = 1-39	SP_LIMIT = 1-39
Vehicle braking reported	IMPACT = 11,12, or 1 AND P_CRASH3 = 2,3,4,5,8, or 9	IMPACT1 = 11,12, or 1 AND AVOID = 1,2,3, or 5

Table 2
Percent distribution* of pedestrians in single-vehicle crashes by vehicle, environment, and pedestrian characteristics, 2005-09

	All pedestrians (N=333,000)	Pedestrians with nonfatal injuries (N=189,000)	Pedestrian with fatal injuries (N=20,824)
Vehicle type			
Passenger vehicle	96.2	95.6	80.0
Heavy truck or bus	2.3	2.8	5.5
Motorcycle	0.4	0.3	0.7
Other or unknown	1.1	1.4	13.7
Point of initial impact on vehicle			
Front	69.7	71.2	75.8
Right	15.8	15.4	10.4
Left	8.6	8.9	5.9
Rear	4.9	3.6	1.4
Other or unknown	0.9	0.9	6.5
Speed limit (mi/h)			
No limit	2.7	2.8	0.4
<30	30.2	31.6	10.0
30-39	43.2	42.5	27.4
40-49	17.0	16.6	26.8
49+	6.9	6.5	29.5
Unknown			5.9
Light condition			
Daylight/unknown	58.8	57.7	27.9
Dark	10.2	10.8	33.4
Dark but lighted	25.8	27.7	34.7
Dawn/dusk	5.2	3.9	4.0
Inclement weather	10.9	11.4	9.9
Pedestrian age (years)			
<6	4.4	4.9	2.8
6-12	10.9	10.5	2.7
13-17	13.8	12.6	4.2
18-64	61.2	61.9	69.4
64+	9.8	10.0	20.1
Unknown			0.8
Male pedestrians	55.7	59.3	69.3
Pedestrian location			
In crosswalk	21.6	21.9	10.1
Intersection/not in crosswalk	27.0	24.1	14.0
Nonintersection	47.8	50.7	75.1
Unknown	3.6	3.3	0.8

*Columns may not sum to total due to rounding

Table 3
Percent distribution* of pedestrians in single-vehicle crashes involving the fronts of passenger vehicles by vehicle, environment, and pedestrian characteristic, 2005-09

	All pedestrians (N=224,000)	Pedestrians with nonfatal injuries (N=129,000)	Pedestrians with fatal injuries (N=13,193)
Speed limit (mi/h)			
No limit	2.6	2.5	0.3
<30	28.9	30.7	8.5
30-39	45.4	44.2	28.3
40-49	17.4	17.4	30.2
49+	5.8	5.3	28.2
Unknown			4.7
Light condition			
Daylight/unknown	57.1	56.4	25.4
Dark	9.6	10.2	33.8
Dark but lighted	28.2	29.9	36.8
Dawn/dusk	5.1	3.5	4.0
Inclement weather	11.6	12.0	10.0
Pedestrian age (years)			
<6	4.2	5.1	2.5
6-12	10.9	10.6	2.7
13-17	14.6	12.6	4.2
18-64	60.1	62.3	69.0
64+	10.2	9.4	21.0
Unknown			0.7
Male pedestrians	55.5	58.7	68.9
Pedestrian location			
In crosswalk	25.9	25.7	10.7
Intersection/not in crosswalk	29.8	26.5	15.5
Nonintersection	41.6	45.3	73.4
Unknown	2.7	2.6	0.4
Vehicle movement			
Traveling straight	67.0	70.2	94.4
Turning	29.4	26.6	4.8
Other or unknown	3.6	3.2	0.9
Pedestrian movement			
Crossing traffic	95.5	96.0	76.6
Moving in-line with traffic	4.5	4.0	16.1
Other or unknown			7.3
Driver view obstruction reported	12.5	14.0	16.2
Vehicle braking reported	9.4	11.4	12.4

*Columns may not sum to total due to rounding

Table 4
Vehicle and pedestrian movement combinations* for pedestrian involvements and deaths in single-vehicle crashes involving the fronts of passenger vehicles, 2005-09

	Pedestrian movement							
Vehicle	Crossing		In-line		Other/unknown		Total	
movement	All	Fatal	All	Fatal	All	Fatal	All	Fatal
Straight	142,000	9,495	9,000	2,068	—	884	150,000	12,447
Turning	65,000	561	1,000	36	—	32	66,000	597
Other/unknown	7,000	48	1,000	18	—	51	8,000	117
Total	214,000	10,104	10,000	2,122	—	967	224,000	13,193

*Columns may not sum to total due to rounding

Table 5
Pedestrian involvements and deaths in single-vehicle crashes with reported driver view obstruction by three main crash scenarios, 2005-09

	Pedestrian involvements N (percent)	Pedestrian deaths N (percent)
Vehicle traveling straight, pedestrian crossing traffic	21,000 (14.8)	1,433 (15.1)
Vehicle traveling straight, pedestrian in-line with traffic	1,000 (8.9)	543 (26.3)
Vehicle turning, pedestrian crossing traffic	6,000 (9.1)	80 (14.3)
Total	28,000 (13.0)	2,056 (17.0)

Table 6
Pedestrian involvements and deaths in single-vehicle crashes in nondaylight conditions by three main crash scenarios, 2005-09

	Pedestrian involvements N (percent)	Pedestrian deaths N (percent)
Vehicle traveling straight, pedestrian crossing traffic	67,000 (46.9)	7,387 (77.8)
Vehicle traveling straight, pedestrian in-line with traffic	6,000 (68.7)	1,782 (86.2)
Vehicle turning, pedestrian crossing traffic	20,000 (31.3)	151 (26.9)
Total	93,000 (43.1)	9,320 (76.9)

Table 7
Pedestrian involvements and deaths in single-vehicle crashes in inclement weather by three main crash scenarios, 2005-09

	Pedestrian involvements N (percent)	Pedestrian deaths N (percent)
Vehicle traveling straight, pedestrian crossing traffic	14,000 (9.8)	916 (9.6)
Vehicle traveling straight, pedestrian in-line with traffic	1,000 (14.0)	280 (13.5)
Vehicle turning, pedestrian crossing traffic	10,000 (15.6)	43 (7.7)
Total	25,000 (11.7)	1,239 (10.2)

Table 8
Pedestrian involvements and deaths in single vehicle crashes involving children 12 and younger by three main crash scenarios, 2005-09

	Pedestrian involvements N (percent)	Pedestrian deaths N (percent)
Vehicle traveling straight, pedestrian crossing traffic	29,000 (20.3)	533 (5.6)
Vehicle traveling straight, pedestrian in-line with traffic	<1,000 (5.8)	79 (3.8)
Vehicle turning, pedestrian crossing traffic	4,000 (5.5)	21 (3.7)
Total	33,000 (15.2)	633 (5.2)

Table 9
Pedestrian involvements and deaths in single-vehicle crashes on roads with speed limit less than 40 mi/h by three main crash scenarios, 2005-09

	Pedestrian involvements N (percent)	Pedestrian deaths N (percent)
Vehicle traveling straight, pedestrian crossing traffic	103,000 (72.3)	3,444 (36.3)
Vehicle traveling straight, pedestrian in-line with traffic	6,000 (70.1)	606 (29.3)
Vehicle turning, pedestrian crossing traffic	52,000 (79.7)	396 (70.6)
Total	160,000 (74.5)	4,446 (36.7)

Table 10
Pedestrian involvements and deaths in single-vehicle crashes with reported vehicle braking by three main crash scenarios, 2005-09

	Pedestrian involvements N (percent)	Pedestrian deaths N (percent)
Vehicle traveling straight, pedestrian crossing traffic	18,000 (12.8)	1,286 (13.5)
Vehicle traveling straight, pedestrian in-line with traffic	1,000 (9.2)	253 (12.2)
Vehicle turning, pedestrian crossing traffic	2,000 (3.0)	24 (4.3)
Total	21,000 (9.7)	1,563 (12.9)

Table 11
Pedestrian involvements and deaths* in single-vehicle crashes by three main crash scenarios that may be addressed if pedestrian detection systems were able to function in nondaylight conditions, at speeds greater than 40 mi/h, in inclement weather, and with driver view obstruction, 2005-09

	Pedestrian involvements	Pedestrian deaths
Vehicle traveling straight, pedestrian crossing traffic		
Crashes addressed by base system		
Speed limit less than 40 mi/h, daylight, clear weather, no view obstruction	41,000	859
Potential crashes addressed		
Nondaylight conditions and speed limit 40 mi/h or greater	68,000	6,519
Inclement weather	12,000	684
Driver view obstruction	21,000	1,433
Subtotal for scenario	142,000	9,495
Vehicle traveling straight, pedestrian in-line with traffic		
Crashes addressed by base system:		
Speed limit less than 40 mi/h, daylight, clear weather, no view obstruction	2,000	112
Potential crashes addressed:		
Nondaylight conditions and speed limit 40 mi/h or greater	5,000	1,222
Inclement weather	1,000	191
Driver view obstruction	1,000	543
Subtotal for scenario	9,000	2,068
Vehicle turning, pedestrian crossing traffic		
Crashes addressed by base system:		
Speed limit less than 40 mi/h, daylight, clear weather, no view obstruction	31,000	240
Potential crashes addressed:		
Nondaylight conditions and speed limit 40 mi/h or greater	20,000	206
Inclement weather	9,000	35
Driver view obstruction	6,000	80
Subtotal for scenario	65,000	561
Total for three crash scenarios	215,000	12,124

*Columns may not sum to total due to rounding