The fatality and injury risk of light truck impacts with pedestrians in the United States

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Abstract

In the United States, passenger vehicles are shifting from a fleet populated primarily by cars to a fleet dominated by light trucks and vans (LTVs). Because light trucks are heavier, stiffer, and geometrically more blunt than passenger cars, they pose a dramatically different type of threat to pedestrians. This paper investigates the effect of striking vehicle type on pedestrian fatalities and injuries. The analysis incorporates three major sources of data, the Fatality Analysis Reporting System (FARS), the General Estimates System (GES), and the Pedestrian Crash Data Study (PCDS). The paper presents and compares pedestrian impact risk factors for sport utility vehicles, pickup trucks, vans, and cars as developed from analyses of US accident statistics. Pedestrians are found to have a two to three times greater likelihood of dying when struck by an LTV than when struck by a car. Examination of pedestrian injury distributions reveals that, given an impact speed, the probability of serious head and thoracic injury is substantially greater when the striking vehicle is an LTV rather than a car.
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1. Introduction

In 2000, 4739 pedestrians were killed in traffic accidents in the United States (NHTSA, 2001). As the number of light trucks and vans (LTVs) on US highways continues to increase, a new area of concern regarding pedestrian safety has emerged. With dramatically different size, shape, and stiffness than passenger cars, LTVs may pose a more serious risk of injury and fatality for vulnerable road users such as pedestrians.

As shown in Fig. 1, sales of LTVs between 1980 and 1999 have grown from 20% to almost 50% of all light passenger vehicles sold (Automotive News, 1980–1999). With such a profound change in the fleet of United States vehicles, it is important to investigate the safety repercussions on motorists and pedestrians. Several studies have shown that LTVs are incompatible with cars in LTV-to-car collisions (Summers et al., 2001; Gabler and Hollowell, 1998, 2000; Joksch, 2000; IIHS, 1998). In fatal LTV-to-car collisions, estimates are that 81% of the fatally injured occupants are in the car. Uninvestigated however is how the growing fleet of LTVs may affect the safety risk for pedestrians.

2. Objective

This study examines the effect of striking vehicle type on pedestrian fatalities and injuries in vehicle–pedestrian impacts. The study is based on an analysis of US traffic accident statistics from the Fatality Analysis Reporting System (FARS), the National Automotive Sampling System (NASS) General Sampling System (GES), and the NASS Pedestrian Crash Data Study (PCDS). By combining these three databases, this paper compares and contrasts the impact risk factor for pedestrians struck by light trucks, vans, and passenger cars. For this study, light trucks and vans (LTVs) include sport utility vehicles, pickup trucks, full-sized vans, and minivans. The paper analyzes pedestrian fatality trends and pedestrian injury response for passenger cars and LTVs. The results will be used to determine the threat of light truck and van impacts with pedestrians.

Numerous studies (Harris and Grew, 1985; Cesari et al., 1989; Lawrence, 1989; Higuchi and Akiyama, 1991) have shown the influence of frontal car design upon pedestrian accident severity, but have been primarily restricted to car–pedestrian impacts. Using Japanese traffic accident data, Mizuno and Kajzer (1999) compared the compatibility of cars and LTVs in impacts with pedestrians, and found that LTVs posed a significantly greater fatality risk than passenger cars. Jarrett and Saul (1998) presented data from
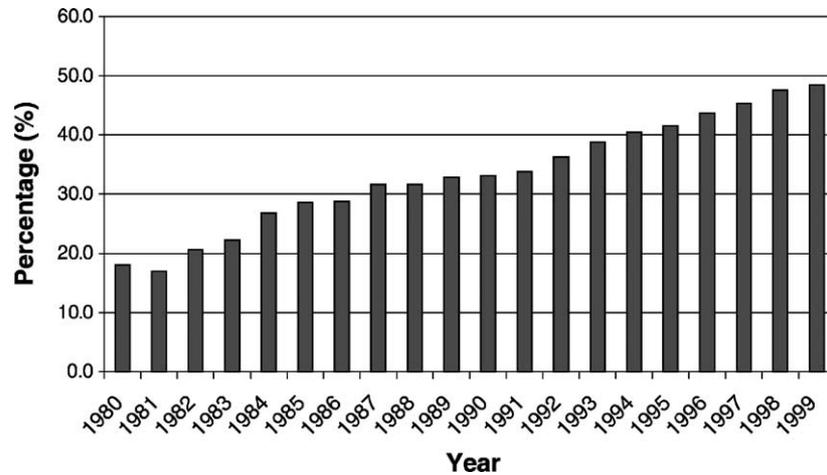

Fig. 1. US sales of light trucks and vans.

a US clinical study that suggested that LTVs might pose a more serious threat to pedestrian safety than cars. This study builds on this early work to provide the first comprehensive examination of pedestrian fatality risk and injury patterns as a function of body type for cars, light trucks and vans in the United States.

3. Approach

For the purposes of this study, only accidents involving single vehicle interaction with pedestrians were examined. Accidents in which multiple vehicles struck a pedestrian were excluded as in these cases it is unclear which vehicle to associate with the pedestrian's injury. Similarly, cases of multiple vehicles striking multiple pedestrians were excluded. When a single vehicle struck multiple pedestrians, each pedestrian was counted as a separate case. As shown in Table 1, this approach did not compromise the data analysis, as 91% of all cases involved single vehicle interaction with pedestrians, and a significant number of cases were still available to perform a detailed analysis. Cases of single vehicles striking multiple pedestrians accounted for less than 3% of pedestrian fatalities.

The analysis incorporated three major sources of data, the Fatality Analysis Reporting System (FARS), the General Estimates System (GES), and the Pedestrian Crash Data Study (PCDS). Pedestrian fatality numbers were obtained

from FARS. FARS is a comprehensive census of all traffic related fatalities in the US GES was analyzed to determine the number of pedestrians who were struck—both fatally and non-fatally—in traffic accidents. GES is a comprehensive database containing information on approximately 60,000 randomly sampled police reported accidents each year. Cases from GES are assigned weights that can be used to estimate the number of similar accidents that may have taken place that year that were not sampled. Because GES is a sample of police reported accidents, NHTSA (2000) notes that estimates from GES are subject to both sampling and non-sampling errors.

The later portion of this paper includes findings from the PCDS. This study is a 5-year compilation of pedestrian accident data collected from six major United States cities from 1994 to 1998 (Chidester and Isenberg, 2001). The database focused on late model year vehicles that strike pedestrians. The PCDS contained 543 cases with detailed information describing the collision including injury severity, vehicle characteristics, and accident configuration. The US National Highway Traffic Safety Administration conducted the study to better define the problem of pedestrian safety and to compare current data with previously conducted pedestrian reports to determine any modifications in trends over the years. The PCDS was invaluable for our analysis because the database focused exclusively on pedestrian accidents, both fatal and non-fatal. Each accident was investigated in detail, and provided information unavailable through either FARS or GES, including detailed descriptions of injuries.

4. Analysis

4.1. Pedestrian fatality trends

To determine pedestrian fatality trends, FARS 1991–2000 data were analyzed. In 2000, 4739 pedestrians were fatally injured—an 18% decrease from 1991. Fig. 2 shows the

Table 1
US pedestrian fatalities, 1995–2000

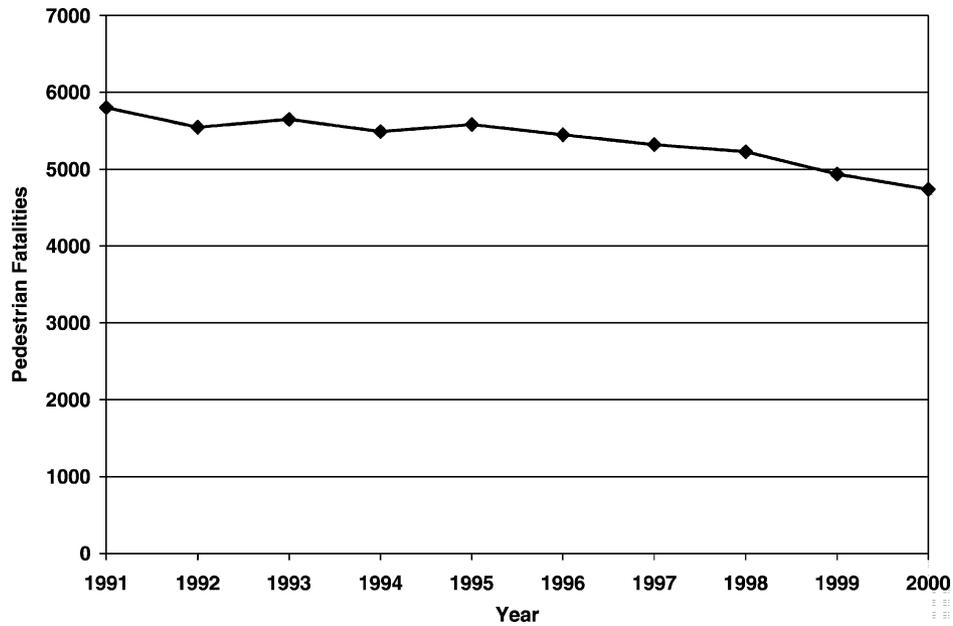| Collisions	Fatalities	Percent
Single vehicle–single pedestrian	27864	89.1
Single vehicle–multiple pedestrian	779	2.5
Single pedestrian–multiple vehicles	2428	7.8
Multiple vehicles–multiple pedestrians	189	0.6
Total	31260	100.0

Fig. 2. Pedestrian fatality trend, 1991–2000.

overall trend in pedestrian fatalities from 1991 to 2000. When separated by vehicle type and restricted to single vehicle collisions, Fig. 3 shows the decrease in fatalities occurs mainly in the passenger car category. Although pedestrian fatalities resulting from car impacts decreased by 32% from 1991 to 2000, the number of pedestrian fatalities resulting from LTV impacts actually increased by 10% from 1991 to 2000.

To take a closer look at the effect the striking vehicle has on pedestrian fatalities, fatality counts were extracted from

FARS 1995–2000 and the accident involvement counts were estimated from GES 1995–2000 for a variety of striking vehicle types. The analysis used the FARS body type categorization codes which included minivans, large vans, compact SUVs, large SUVs, compact pickups, and large pickups. The utility station wagon category was excluded from this analysis due to numerous FARS and GES coding errors for this body type. Vehicle body type was unknown for 8.5% of the LTV cases in GES and 1% of the LTV cases in FARS. To account for these cases, this study distributed the unknowns
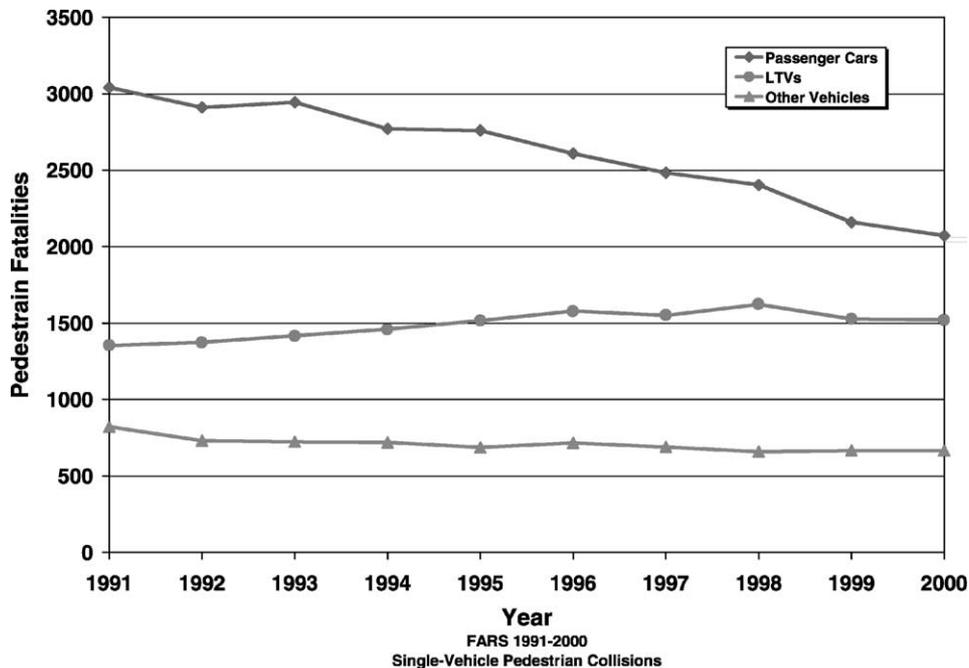

Fig. 3. Pedestrian fatality trend by vehicle type for single vehicle–pedestrian collisions.

based upon the known body type distributions to preserve the total number of cases. It should be noted that although this strategy has the advantage of maintaining the total number of single vehicle–pedestrian cases, this approach has the disadvantage of preserving any reporting biases. An improved approach would be to explore the missing data as a function of model year, and prorate unknown body types accordingly if biases exist.

To determine the risk of fatality by striking vehicle type, a Pedestrian Risk Metric (PRM) was computed for each vehicle category as shown below:

$$PRM = \frac{\text{total pedestrian fatalities by vehicle type}}{1000 \text{ pedestrian accidents involving vehicle type}}$$

The goal of this study was to determine how vehicle design differences between cars and LTVs affect the pedestrian impact risk. To focus the study on design, our Pedestrian Risk Metric normalized the number of pedestrian fatalities by pedestrian accident involvements—rather than normalizing by vehicle registrations. This approach helped to focus our analysis on vehicle design and away from driver behavior and vehicle use patterns, two potentially confounding factors. Vehicles that are driven more aggressively may tend to be involved in more collisions with pedestrians. Likewise, some categories of vehicles, e.g. large pickup trucks, may tend to be driven more frequently in rural areas with fewer pedestrians. By normalizing by number of pedestrian accident involvements, this approach focuses the analysis on outcome given that an accident has occurred, and explicitly avoids the question of what demographic or behavioral factors may have contributed to the accident occurring in the first place.

Fig. 4 shows that all categories of LTVs have a higher pedestrian risk than cars. Large vans have the highest risk, PRM = 133, while passenger cars have the smallest,

PRM = 45. When struck by a large van; 13.3% of pedestrians died as a result of the collision. In contrast, only 4.5% of pedestrian accidents involving a car resulted in a pedestrian death. For large SUVs, 11.5% of pedestrian accidents resulted in a pedestrian fatality. We conclude that, a pedestrian struck by a van is nearly three times more likely to suffer fatal injury than a pedestrian struck by a car. Pedestrians struck by large SUVs are twice as likely to die as pedestrians struck by cars.

Fig. 4 illustrates the influence of vehicle size upon pedestrian accident outcome. A cursory look at Fig. 4 suggests that larger striking vehicle mass leads to more severe accident outcomes. Impacts with large pickups, for example, have a greater risk than impacts with small pickups. Closer examination suggests however that striking vehicle mass may not be the controlling factor even though LTVs are much heavier than cars. As both cars and LTVs are an order of magnitude heavier than pedestrians, the pedestrian is at a severe disadvantage no matter what the mass of the striking vehicle. Fig. 4 indicates that design factors other than mass may have an important influence upon accident outcome. Mizuno and Kajzer (1999) showed that, in Japan, fatality risk was essentially independent of striking vehicle weight for vehicle weights up to 1400 kg (3000 lb). However, for vehicle weights above 1400 kg, fatality risk rises—presumably because these heavier vehicles are primarily SUVs.

Joksch (2000) has shown that vehicle mass is correlated with vehicle stiffness and frontal profile geometry—two other design parameters which may control accident outcome. Small pickups, for example, are of approximately the same mass as cars, but are much less aerodynamically streamlined than cars, and exhibit a dramatically higher pedestrian risk. Minivans, on the other hand, are significantly heavier than passenger cars, but share the sloping aerodynamic frontal profile observed in cars. As shown on Fig. 4,
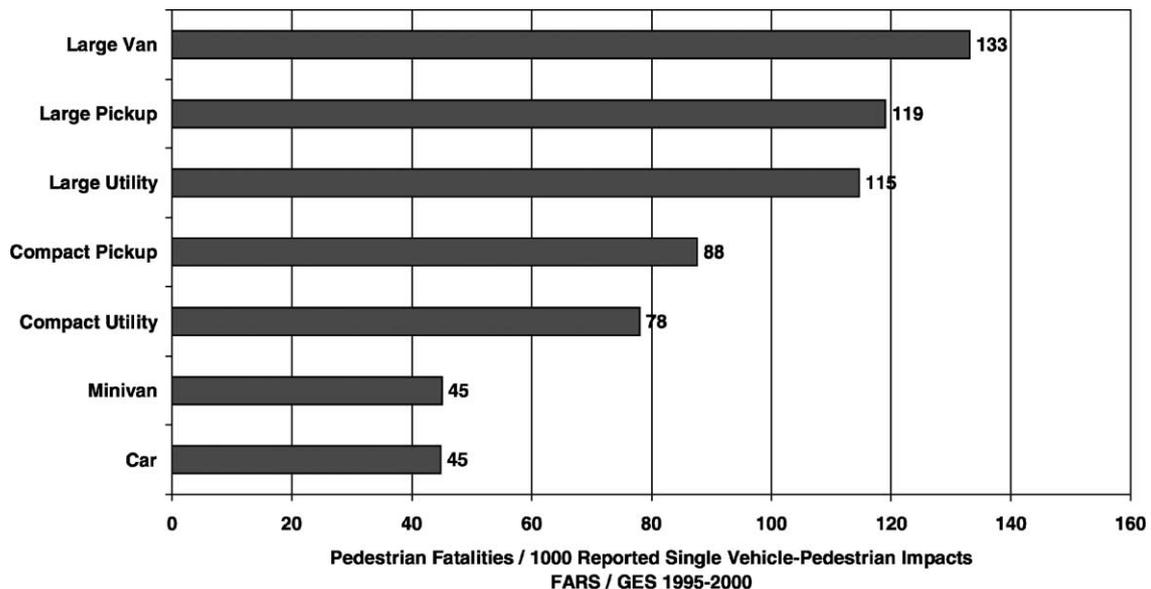

Fig. 4. Pedestrian risk by vehicle type (FARS and GES, 1995–2000).

the risk to pedestrians from impacts with minivans and cars are noted to be comparable. For these body types, frontal geometry, and not mass, would appear to be a better indicator of pedestrian risk.

The preceding discussion has focused on pedestrian impacts that lead to fatality. The analysis has shown that pedestrians struck by an LTV are much more likely to be fatally injured than are pedestrians struck by passenger cars. While invaluable to this study, the FARS database, on which these conclusions are based, has important limitations. FARS contains no information about striking vehicle speed in pedestrian impacts. Lacking this data element, the analysis cannot determine whether the higher fatality risk associated with a given body type is due to engineering design differences or simply the result of being driven faster on average. In addition, FARS is limited to studying fatalities—the least likely outcome of a pedestrian impact, and contains no information on non-fatally injured pedestrians. Likewise, FARS does not describe the distribution or severity of injury to either fatally or non-fatally injured pedestrians. When available, the distribution of injuries can provide important clues to the influence of frontal geometry on injury severity. For answers to these questions, the study next turned to the Pedestrian Crash Data Study database developed by NHTSA (Chidester and Isenberg, 2001).

4.2. Injury responses

The Pedestrian Crash Data Study (PCDS) database was analyzed to determine the distribution of injury responses for pedestrians struck by passenger cars and LTVs. The PCDS was a 5-year compilation of pedestrian accident data which was collected from six major United States cities from 1994 to 1998. Chidester and Isenberg (2001) note that the PCDS was designed to be a clinical study and was not intended to be a national sample of pedestrian crashes. The PCDS contained 543 cases with detailed information describing the collision including injury severity, vehicle characteristics, and accident configuration. For a crash to qualify for the PCDS:

(1) the vehicle had to be moving in a forward direction at time of impact;
(2) the vehicle had to be a late model car or LTV;
(3) the striking portion of the vehicle had to be unmodified and undamaged prior to impact;
(4) the first point of contact had to be forward of the top of the A-pillar, and the pedestrian impacts had to be the vehicle's only impacts.

NASS teams investigated each qualifying accident in detail, and provided information unavailable through either FARS or GES, including detailed descriptions of injuries.

Injury levels in the PCDS are characterized by the Abbreviated Injury Scale (AIS)—a measure of threat to life where AIS = 0 represents no injury and AIS = 6 represents a fatal injury (AAMA, 1990). The PCDS contains 371 (68.3%) cases involving passenger cars and 172 (31.6%) cases involving LTVs. This sampling reflects the US vehicle mix as currently LTVs comprise approximately one third of the entire United States passenger vehicle fleet.

Fig. 5 presents the distribution of the maximum AIS value by vehicle type for each pedestrian case in the PCDS. The figure demonstrates that most injuries are of minor severity (AIS 1), and that persons struck by passenger cars are more likely to incur an AIS 1 injury than are persons struck by an LTV. However, persons struck by LTVs are more likely to sustain a maximum injury level of AIS 4 or greater than are pedestrians struck by cars. Fig. 6 shows the distribution
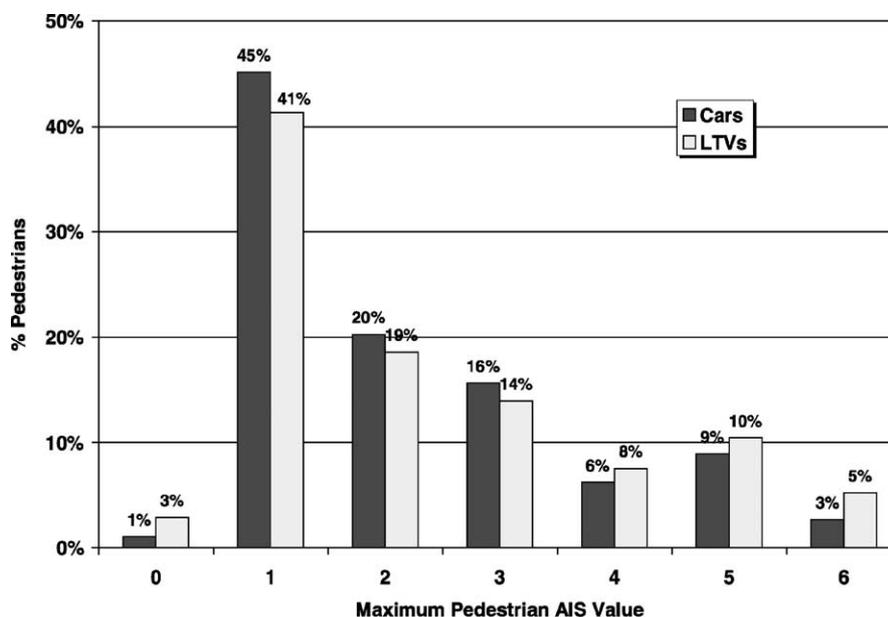

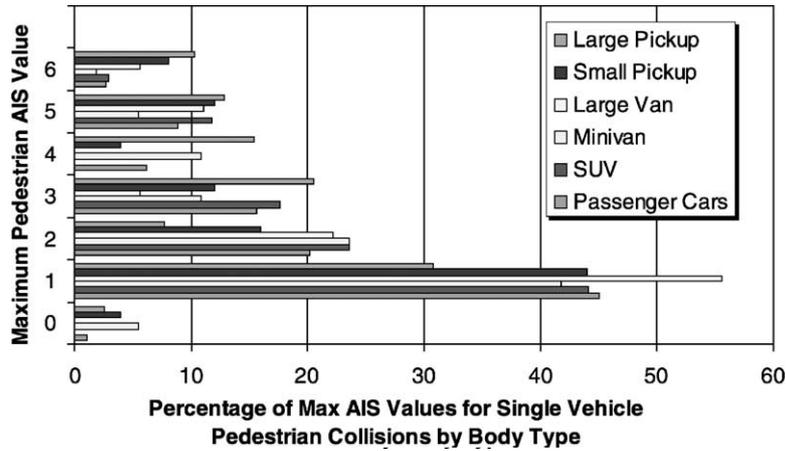Fig. 5. Frequency of maximum AIS value by vehicle type.

Fig. 6. Frequency of maximum AIS values by vehicle type.

of injury severity by vehicle type. In this figure the LTV category is broken down into its constituent types: large pickups, small pickups, large vans, minivans, and SUVs. Note that pedestrians struck by large pickups and SUVs are more likely to have AIS 3 and greater injuries than are persons struck by passenger cars.

Fig. 7 presents the distribution of known impact speeds by vehicle type for all struck pedestrians in PCDS. Impact speed estimates were available for 82% of the car impacts and 86% of the LTV impacts. Although the impact speed distribution for cars and LTVs is quite similar, the distribution of LTV cases is shifted towards slightly lower speeds. The median pedestrian impact speed is 32 km/h for LTVs and 36 km/h for cars.

4.3. Injury risk by body region

When struck by a vehicle, a pedestrian can suffer injuries to a wide range of body regions. Due to the different height and frontal geometry of cars and LTVs, pedestrians are impacted at different areas of the body and exhibit different kinematic responses after being struck. Both of these factors influence the injuries that a pedestrian sustains. The PCDS database was examined to determine the effect vehicle type has on the severity of injury level to each body region.

Injury severity was examined for AIS levels of 3 and greater because these injuries pose a serious threat to a pedestrian. Figs. 8–10 show the relationship between impact speed and AIS values of greater than or equal to 3 for the head, chest, and lower extremities. For each of these body regions, the median impact speed, which results in AIS 3 or greater severity injuries, is lower for LTVs than for cars. These figures suggest that at any given impact speed up to 60 km/h, the probability of serious head, chest, and lower extremity injury is higher for persons struck by LTVs than for persons struck by cars. No conclusion can be drawn for impact speeds that exceed 60 km/h, as the data in this speed
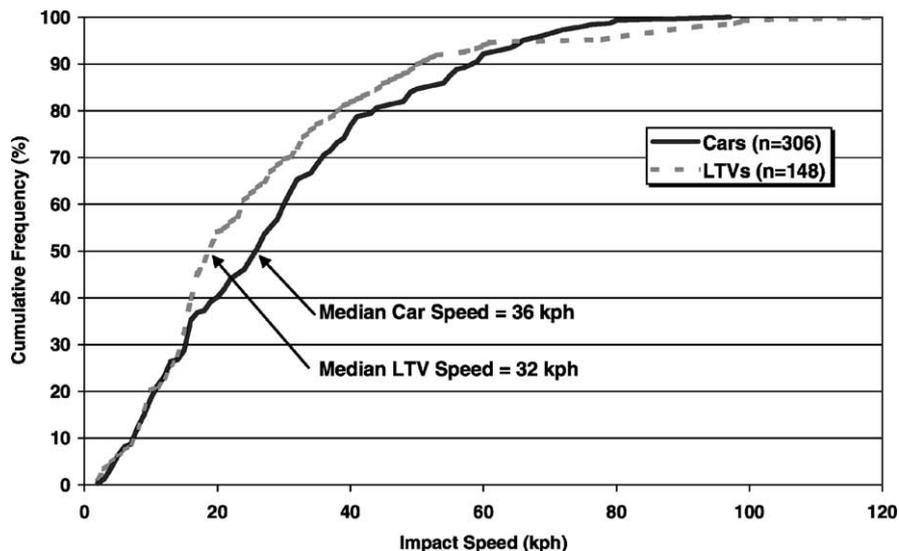

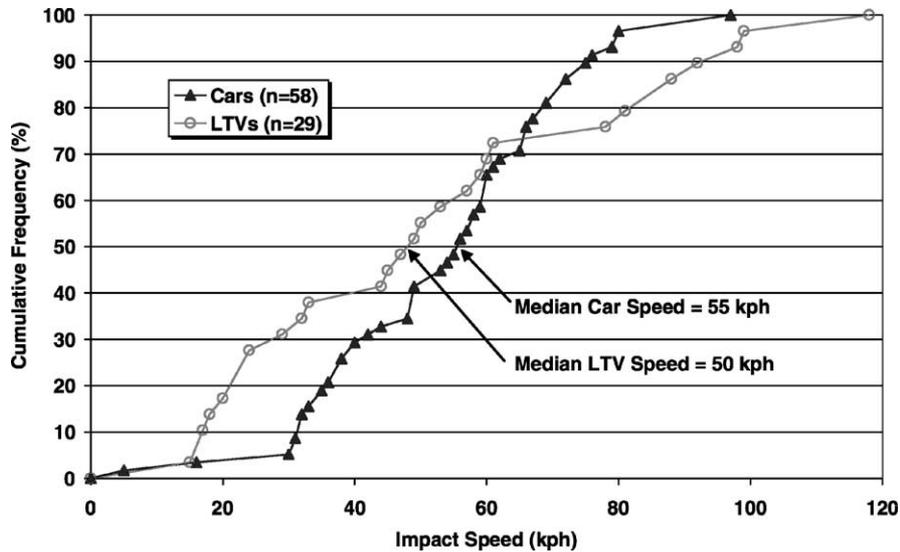Fig. 7. Distribution of impact speeds by vehicle type in PCDS database.

Fig. 8. Cumulative frequency of pedestrians with serious head injury AIS 3 or greater by vehicle type as a function of impact speed.

range is too sparse. As shown in Fig. 7, cases with impact speed exceeding 60 km/h account for less than 10% of the PCDS sample. As discussed earlier, the distribution of LTV impact speeds is less severe than the distribution of impact speeds for cars. Because the distribution of LTV impacts in PCDS are at lower speeds than car impacts, Figs. 8–10 may actually underestimate the severity of LTV impacts. To account for the differences in impact speed distributions, a second improved estimate of serious injury probability was calculated as described below.

Figs. 11–13 show the probability of sustaining an injury of AIS 3 or greater to different body regions by vehicle type. For these plots, the maximum head AIS level, maximum thoracic AIS level, and the maximum lower extremity AIS level were determined for each struck pedestrian. For each body region, the probability of serious injury for each of three speed ranges was estimated by dividing the number of persons incurring an AIS 3 or greater injury for that body region over each speed range by the number of pedestrian involvements over the same speed range. The data for impact speeds above 60 km/h were too sparse to support a calculation of probability of injury for this higher speed range.

Fig. 11 illustrates the probability of a head injury of AIS 3 or greater severity for three impact speed ranges. For the lower and higher impact speed ranges, there is a higher probability of serious head injury from LTVs than with passenger cars, while the moderate impact speed range shows a similar probability of injury level for both vehicle types. Fig. 12 presents the probability of sustaining a chest injury of AIS 3 or greater severity. The data shows that for all impact speed
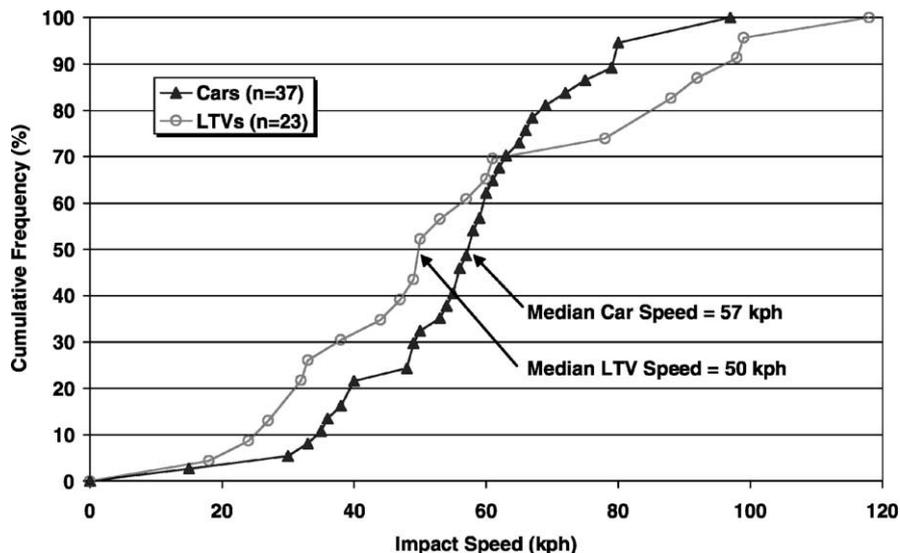

Fig. 9. Cumulative frequency of pedestrians with serious chest injury AIS 3 or greater by vehicle type as a function of impact speed.
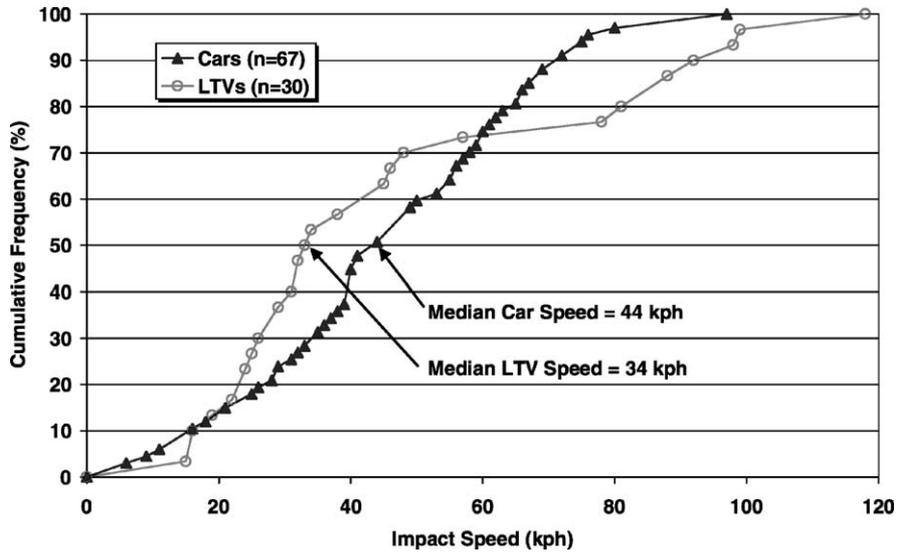
Fig. 10. Cumulative frequency of pedestrians with serious lower extremity injury AIS 3 or greater by vehicle type as a function of impact speed.
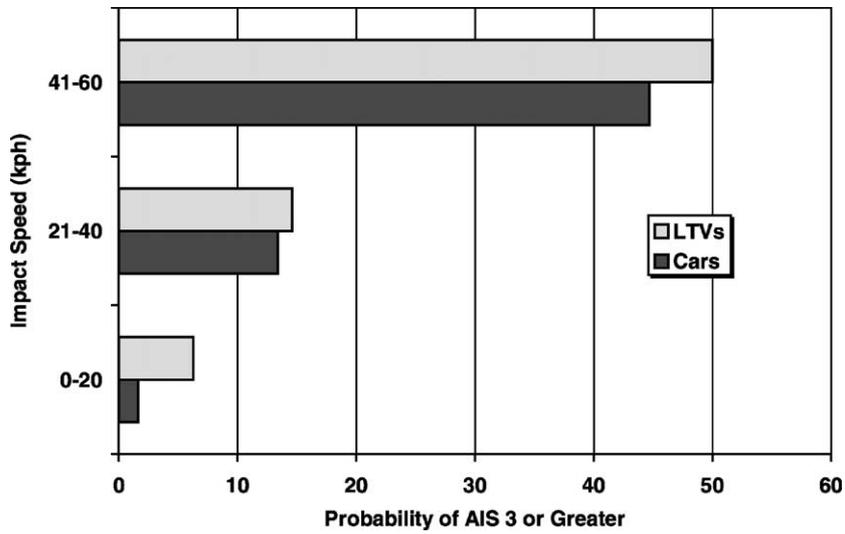

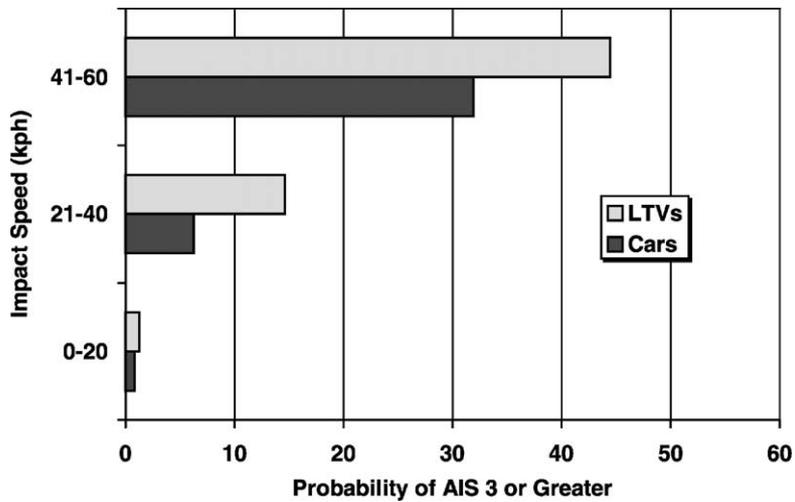Fig. 11. Probability of serious head injury AIS 3 or greater.

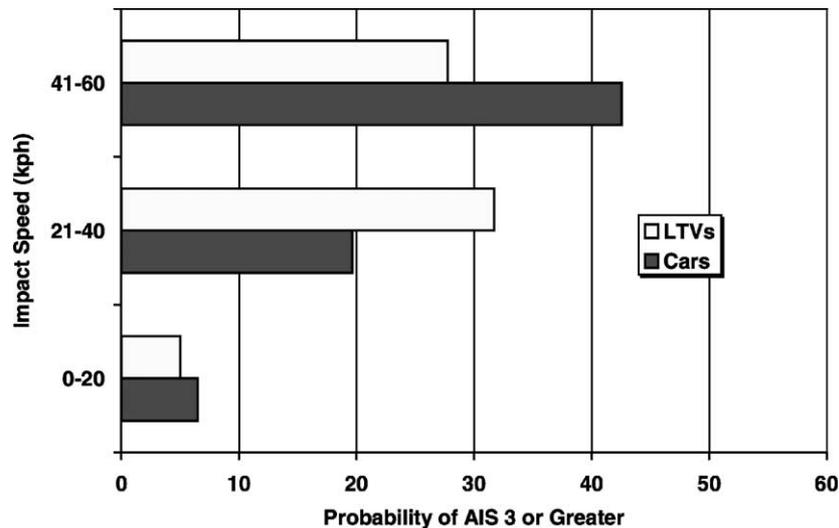Fig. 12. Probability of serious chest injury AIS 3 or greater.

Fig. 13. Probability of serious lower extremity injury AIS 3 or greater.

ranges, pedestrians struck by LTVs incurred a higher probability for serious chest injury than pedestrians struck by cars. Fig. 13 shows the probability of lower extremity injury AIS 3 or greater as a function of impact speed. For lower and higher impact speed ranges, there is a higher probability of serious lower extremity injuries from passenger cars, while at moderate impact speeds LTVs demonstrate a higher probability of causing serious injury.

This examination of injury patterns supports the hypothesis that impact speed and vehicle frontal geometry are dominant factors in predicting pedestrian injury. Clearly, the severity of pedestrian injury increases with higher speed. This supports numerous studies such as the investigation by Leaf and Preusser (1999). But even at a given impact speed, pedestrians struck by an LTV, with their higher bumpers and more blunt frontal profiles, are much more likely to incur a serious head injury than when struck by a car. Likewise, as cars are more aerodynamically streamlined and have lower bumpers than LTVs, pedestrians struck by a car are much more likely to incur a leg injury.

5. Conclusions

This paper has examined the effect of striking vehicle type on pedestrian fatalities and injuries in frontal impacts. The study was based on an analysis of US traffic accident statistics from the Fatality Analysis Reporting System (FARS), the General Sampling System (GES), and the NASS Pedestrian Crash Data Study (PCDS). Analysis of these three databases has clearly demonstrated that pedestrians have a substantially greater likelihood of dying when struck by an LTV than when struck by a car. For large vans, 13% of struck pedestrians are fatally injured. In contrast, when a car is the striking vehicle, fewer than 5% of pedestrian accidents result in a pedestrian death.

Examination of pedestrian injury distributions for impact speeds up to 60 km/h reveals similar results. At any given speed of impact, the likelihood of serious injury to the head and chest was shown to be greater in LTV impacts than in car impacts. Only for lower extremity impacts is the risk of serious injury greater for car impacts than for LTV impacts.

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