PEDESTRIAN INJURY—ANALYSIS OF THE PCDS FIELD COLLISION DATA

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ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) has initiated the Pedestrian Crash Data Study (PCDS) to provide detailed information regarding vehicle/pedestrian crashes. The PCDS was implemented to focus on pedestrian crashes occurring after 1994, involving vehicle model years 1990 and later. NHTSA had previously conducted the Pedestrian Injury Causation Study (PICS) which focused on crashes that occurred between 1977 and 1980. However, vehicle designs have changed dramatically since that time, necessitating a new evaluation of pedestrian collisions with current vehicle models.

The PCDS study concentrates on several aspects of the pedestrian crash data including those proposed by the ESV/IHRA Project Pedestrian Safety Accident Survey Procedure (May, 1997) and several areas of the PICS study. The data used in the study was taken from pedestrians involved in frontal vehicle crashes in six major United States cities. The cases may involve more than one pedestrian but excludes persons operating motor-driven cycles or bicycles. Correlation and evaluation of the data will be based on age, impact speed, injured body regions and parts, and injuring vehicle regions and parts. A thorough comparison will be made between the PICS and PCDS results to evaluate the correlation between changes in vehicle geometry and the severity and location of injuries.

INTRODUCTION:

In 1994, there were approximately 40,700 traffic fatalities in the United States with a societal cost of over 150.5 billion dollars. In 1995, the number of fatalities increased by 2.7 percent to 41,798. For children between the ages of five and nine, more than one third of child traffic fatalities are pedestrians. According to the U.S. Department of Transportation's Traffic Safety Facts for 1996, 82,000 pedestrians were injured and 5,412 fatally injured in traffic crashes. Although this represents a 20% decline in pedestrian fatalities since 1984, the financial and emotional burdens associated with pedestrian crashes are substantial and cannot be overlooked.

NHTSA's implementation of the Pedestrian Injury Causation Study (PICS) program in the late 1970's was aimed at enhancing pedestrian safety and alleviating economic burdens as well as suffering and disabilities imposed on individuals as a result of pedestrian crashes. The study was conducted by evaluating almost 2,000 cases that were collected and reviewed by investigators in five U.S. cities. Trends and averages were used to evaluate areas of concern and initiate change in order to alleviate the number and severity of pedestrian crashes. One area of interest that resulted from the PICS study was the investigation into vehicle pedestrian interaction. Vehicle geometries were studied to identify pedestrian contact sources as well as injury severity caused by the contact.

Since the late 1970's, cars have "downsized" to accommodate demands for fuel economy, for instance hoods tend to be shorter and more sloped. There is also an increasing number of light truck and vans along with the introduction of front wheel drive on most types of vehicles. In addition, the vehicle materials have changed to make them lighter and safer. These changes prompted a new study, the Pedestrian Crash Data Study (PCDS) to evaluate vehicles manufactured in the 1990's and to assess the impact of geometrical changes and their relationship to the injuries inflicted onto the pedestrian. The following paper contains several areas in pedestrian research including a comparative analysis of the PICS study and the PCDS study, results from the PCDS study, and conclusions. (Isenberg et. al.)

METHODS

PICS/PCDS Program Comparison

The objectives set forth in the PICS and the PCDS programs are very similar. Both studies examine the factors that contribute to pedestrian injuries including their relationship to vehicle design. The PCDS study allows for an additional analysis of vehicle design changes over the past decade and its influence on injury profiles by focusing on changes in injury profiles. The study focuses on changes in injury severity and injury sources, with respect to vehicle changes since the collection of the PICS data.

The PCDS and PICS studies acquired the information through crash surveys by an investigation team, police reports, medical records and interviews with the pedestrian, driver and witnesses to the crash.

The data collection for the studies were very similar and only differed slightly in the criteria set forth for data collection. The PICS study included all fatalities in case collection but excluded pick-up trucks and vans greater than 6000 lbs. and sport utility vehicles (due to their non-existence at the time of the data collection) from the vehicle distribution. The PCDS study had a slightly different case collection profile. Fatalities were not a mandatory case collection and all vehicles were included in the study with a model year of 1990 or later. The pedestrian's first contact with the vehicle must have been forward of the top of the A-pillar and must have been the vehicle's only impact. Cyclists and pedestrians sitting or lying in the roadway were excluded from both studies.

The PICS data was collected over a 30 month period in five major United States cities: Buffalo, Palo Alto, Los Angeles, San Antonio and Washington D.C. Almost 2,000 cases were collected and the data was coded and recorded. Investigators for the PCDS study documented the information from six major U.S. cities: Fort Lauderdale FL., Dallas TX., Buffalo, NY, San Antonio, TX, Chicago IL., and Seattle WA. Almost 300 cases were available for this analysis although documentation will continue to achieve a goal of 900-1000 cases for evaluation.

Initial documentation for the PCDS crash data was required within 24 hours after the crash occurred. Some follow-up investigation was required to obtain additional information not available at the time of the collision (hospital stay, days of work missed, etc.). In addition to the coded information, the crash scene and the vehicle damage were recorded on videotape. After all of the necessary information was acquired, the final report was reviewed and recorded in the PCDS database.

The primary discrepancy in the PICS and PCDS data comparison exists in the methods used to assess injuries. The PICS study utilized two methods of injury assessment. The Occupant Injury Classification (OIC) System was used to describe injuries while the Association for the Advancement of Automotive Medicine (AAAM) Abbreviated Injury Scale (AIS) 1976 manual was used to assess the injury severity. The PCDS study used the AAAM AIS 1990 manual to indicate injury type and injury severity. The AIS 1990 introduced a more specific description of the injury and the possibility of different AIS values depending on the severity (for example, extreme blood loss is assigned a higher AIS value than the same injury with minimal blood loss).

The AIS values range from zero to six. Their description is as follows: AIS=0 "No Injury", AIS=1 "Minor Injury", AIS=2 "Moderate Injury", AIS=3 "Serious Injury", AIS=4 "Severe Injury", AIS=5 "Critical Injury", AIS=6 "Maximum Injury" and AIS=7,9 "Unknown."

The AIS codes will be used throughout the report along with the Maximum AIS (MAIS) to evaluate and summarize pedestrian injuries.

RESULTS

The following section contains several areas of pedestrian analysis. The first section discusses the differences between the PICS and PCDS data. The second section concentrates on the PCDS data only including a brief fatality analysis.

PICS/PCDS Data Comparison

Vehicle – Since the PICS study, improvements have been made to decrease the number of unknown variables through a more thorough data acquisition and coding system. The PCDS data coding resulted in less "unknown" or "other" classifications due to an increase of event selections in many categories. This incongruity will be reflected in some of the comparisons. For example, 22% of the PICS vehicle distribution were unidentified. In contrast, all vehicles were identified in the PCDS study. The changes that have occurred since the PICS study were in the redevelopment of the vehicle coding system. The NASS pedestrian coding manual for the PCDS study contains a code for every make and model vehicle manufactured for use in the United States. This helped eliminate the "other" and "unknown" category often needed in the PICS data.

Automobiles (passenger cars) were the most frequent vehicles in each study. The PCDS distribution included two additional categories that were not included in the PICS study. Since the 1970's, minivans and sport utilities have been introduced and made up approximately 20% of 1996's vehicle sales. The additional distribution may account for the decrease in the frequency of passenger cars since the PICS study. Eight-six percent of the PICS and 69% of the PCDS vehicles involved in the pedestrian studies were passenger cars.

The effect of vehicle geometry changes on injury patterns to the pedestrian has become a concern over the past decade. In addition to the introduction of mini-vans and sport utility vehicles to the types of vehicles driven, vehicle profiles have changed. Figure 1 is a schematic example that shows a comparison between a vehicle from

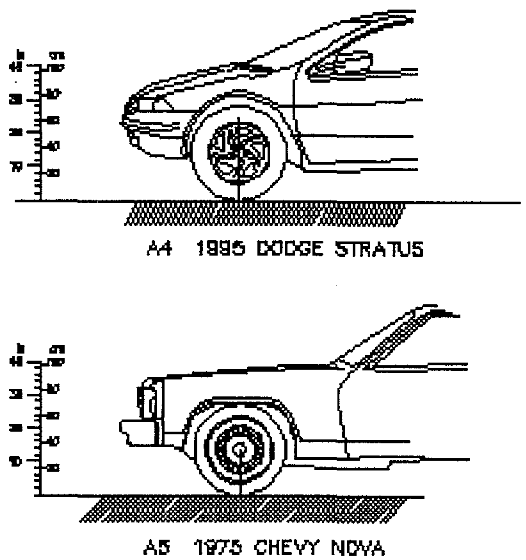

Figure 1. Vehicle profile changes.

1995 compared to a vehicle from 1975. Older vehicles tend to have a well-defined hood edge, vertical front end and horizontal hood as opposed to the sloped, curved features of newer vehicles.

Several aspects of the vehicle geometry have varied over the years. The vehicles in the PCDS study have changed significantly since the PICS study as follows: average curb weight (decreased 10.8%), the hood height (decreased 26.4%) and the hood length (decreased 26.3%). Another significant change in vehicle design is reflected in the bumper height, bumper lead and lead angles. The bumper heights have decreased approximately 16.5% as cars have taken on the lower profile designs decreasing bumper lead by 22%, hood length by 26% and lead angle by 8.7%. However, the PICS lead angle data had an exceptionally high number of unknowns (almost 50%) leaving the distribution notably subjective.

In conclusion, the types of vehicles involved in pedestrian crashes have not changed dramatically over the past decade, although vehicle designs have changed significantly. These changes have occurred to produce lighter, smaller cars to accommodate lower fuel consumption. In addition to the geometry changes, new materials have been utilized for weight, durability and occupant protection issues. This may also contribute to changes in pedestrian injuries caused by vehicle contact.

Pedestrian -- The following data represents profiles for the PICS and PCDS pedestrians including an injury assessment analysis.

The average pedestrian profile has changed since the PICS study. Average age (33 years old) has increased by 7 years while the height (161 cm) and weight (63 kg) have also increased by 16 cm and 15 kg. respectively. MAIS average values (approximately =2) have not changed significantly although ISS average value (14.6) has increased by approximately six points.

A more detailed look at the pedestrian age distribution can be seen in Figure 2. The PICS data has an evident peak at 6-10 years of age and tends to remain low for 40-75 years of age. The mean for the PICS age was 26 years old with a standard deviation of 23.3. The PCDS data has a minor peak at 6-10 years of age and again at 26-30 years of age. The mean PCDS age was 33 years old with a standard deviation of 21. The PCDS distribution remains higher than the PICS distribution between the ages of 20-55 years of age. It must be noted that the PCDS cases were collected during the case investigators' daytime working hours. Although the case can be recorded anytime within 24 hours of the crash, this may contribute to the lower frequency of child impacts because of their attendance at school during the majority of working business hours. It was found that among 184 PCDS cases involving children 18 years of age and under, 85% occurred between Monday and Friday, 16% occurred between six and nine AM and 50% occurred between three and ten PM.

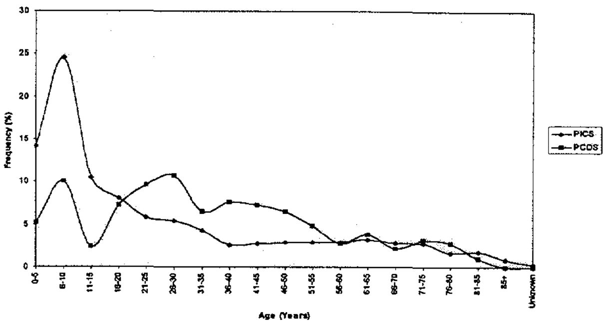

Figure 2. Age distribution.

According to the national statistics from 1996, over two thirds of the pedestrian fatalities were male. The PCDS data is not representative of this statistic or past historical data because it reflects an exact split between the number of males and females involved in pedestrian crashes as well as the number of male and female fatalities related to pedestrian crashes. The PICS study, on the other hand, indicates that males were more frequently involved in pedestrian crashes than females.

The pedestrian motion reflects the pedestrians actions prior to impact, such as running, jogging, stopped or other. The pedestrian motion distributions in the two studies were very similar. The majority of the pedestrians were either walking slowly across the road or running/jogging across the street before impact. As a result, both studies reflect a majority of all of the pedestrians standing (PICS-97.8%, PCDS-99.0%) as opposed to kneeling, bending, crouching, sitting etc.

An avoidance maneuver is defined as any action or reaction the pedestrian took to avoid contact with the vehicle before impact. The distributions between the studies were very similar with approximately 60% of the pedestrians with no avoidance maneuver. The remaining pedestrian avoidance maneuvers were distributed among a variety of remaining maneuvers such as "braced against" (second most predominant at 8%), "jumped", "accelerated", "turned toward", "turned away", "accelerated" or "stopped".

Pedestrian orientation is the pedestrian's body, or chest orientation prior to impact relative to the vehicle. The orientations were very similar between the two studies. The most predominant body orientations were the left and right sides toward the vehicle. Side impacts accounted for approximately 70% of the total pedestrian crashes.

Vehicle-pedestrian interaction, as seen in Figure 3, describes the pedestrian's body projection after impact. The chart reflects how pedestrians in the PCDS study were more frequently carried by the vehicle, while pedestrians in the PICS were more often thrown forward or knocked to the pavement. In the PCDS study, the vehicle carried over 40% of the pedestrians after impact and had a secondary interaction of being knocked to the pavement (25%). On the other hand, the PICS study reflects that approximately 45% of the pedestrians were knocked to the pavement with a secondary interaction of being thrown in front of the vehicle (23%). Pedestrians carried by the vehicle accounted for less than 10% of the pedestrian interaction.

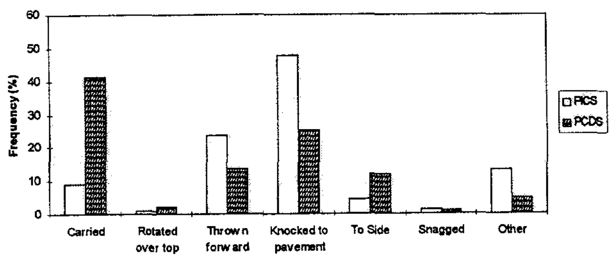

Figure 3. Vehicle pedestrian interaction.

This resultant interaction also relates to the injury source frequency distribution discussed in the injury section of this paper. Pedestrians in the PCDS study were more frequently carried by the vehicle and experienced injuries from the windshield, hood surface and the A-pillars. The pedestrians in the PICS were subject to injuries caused by the vehicle front end components (front fender, grille) and the environment corresponding to the interaction of being knocked to the pavement or thrown forward from the vehicle.

Injuries – Both studies reflected similar driver avoidance maneuvers with 40% of the drivers unable to perform any avoidance maneuver while 43% applied the brakes before contact with the pedestrian. Two peaks in the vehicle impact speed were prevalent in both the PICS and PCDS data. The first peak in the data occurred between 6-10 mph and 16-20 mph. In both studies, approximately 85% of the pedestrian impacts occurred at or below 35 mph and approximately 50% occurred below 15 mph.

Table 1 identifies sources that have caused AIS ≥ 2 injury. This was done in order to eliminate injuries that were very minor, such as small abrasions. The elimination of AIS 1 injuries resulted in a significant change in the distribution. The most evident change was the drastic decrease in the number of injuries caused by the

Table 1.
Injury Sources for AIS ≥ Injuries

Injury Sources: AIS=2+Injuries				
Source	PICS		PCDS	
	N	%	N	%
Front bumper/valance	350	15.2	173	25.5
Front fender	161	7.0	13	1.9
Front grille/headlight	196	8.5	21	3.1
Hoof surface	280	12.1	98	14.4
Hood edge/trim/face	198	8.6	76	11.2
Cowl/windshield wiper mounts	9	0.4	23	3.4
Windshield glazing/trim	88	3.8	114	16.8
A-pillar	11	0.5	54	8.0
Wheels/tires	104	4.5	20	2.9
Side components	25	1.1	1	0.1
Rear components	12	0.5		
Non-contact	133	5.8	8	1.2
Environment	363	15.7	58	8.5
Unknown/other	375	16.3	20	2.9
Total	2305		679	

environment. With the inclusion of AIS 1 injuries the environment was responsible for 37.6% and 24.7% (PICS, and PCDS respectively) while the elimination of the AIS 1 injuries decreased the environmental incidence by 21.9 and 16.2 percentage points, respectively. The remaining injury sources were distributed in a similar manor to the inclusion to AIS 1 injuries with the exception of the front bumper/valance in the PCDS study, which increased by 10.4%.

When focusing on injuries with an AIS 2 or greater, there is a significant difference in the injury trends between the two studies. There tends to be an increase in frequency of injuries caused by the front-end top components since the PICS study. The increase in frequency occurs with the bumper/valance, windshield glazing and trim, A-pillar and the hood and its components. There was a decrease in injuries caused by the environment, front fender, front grille/headlight, side components and non-contact sources.

The injury sources tend to correlate with the pedestrian and vehicle interaction where the pedestrian tended to be knocked to the pavement in the PICS data, correlating with a higher number of environment, non-contact and front end components. Similarly, the PCDS pedestrians were more often carried by the vehicle corresponding to the increase in bumper, windshield and hood components as predominant injury sources.

The body region injury distribution is given in Figure 4 and shows that the lower extremity represents the most frequently injured region. Approximately one third of all injuries were inflicted on the lower extremities followed by a high occurrence to the head, neck, face and upper extremities. The PCDS data showed considerable reductions in thoracic, abdominal, and pelvic injuries compared to the PICS study.

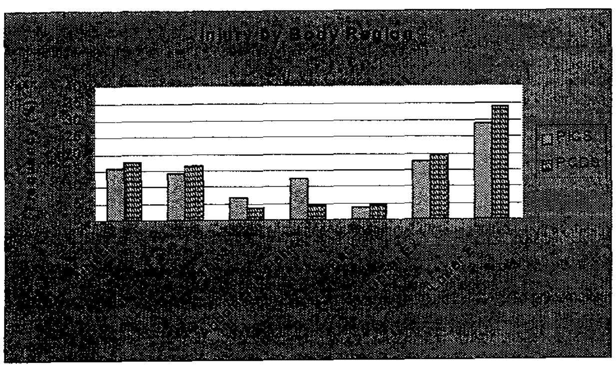

Figure 4. Injury by body region.

PICS/PCDS CONCLUSIONS

The analysis of pedestrian collisions has been performed over the years to identify areas of concern in pedestrian safety and determine changes in trends and patterns from previous studies. This section concentrated on trends from current vehicles sampled in the current PCDS study in comparison with the PICS study from the late 1970's and early 1980's. While there are many similarities, there have also been several significant changes among vehicle and pedestrians since the PICS study.

From the pedestrians sampled in both studies, the motions and maneuvers of both the vehicle and pedestrians were very similar. The most predominant pedestrian motion was either walking or jogging with their left or right side oriented toward the vehicle. The majority of the pedestrians did not attempt any avoidance maneuver (such as bracing against the vehicle, turning toward the vehicle, etc.). There is also a similarity in the driver's reactions. The majority of the drivers were not able to perform an avoidance maneuver to avoid hitting the pedestrian. The impact speed distributions were also very similar between the two studies with 85% of the impacts occurring below 35 miles per hour and approximately 50% occurring below 15 miles per hour.

In addition to the PICS and PCDS similarities, considerable changes have occurred in vehicle geometry and pedestrian profiles since the PICS study. Both studies were predominantly comprised of automobiles, but the average measurements indicate that the vehicles have changed in both size and shape. Current vehicle geometry has changed as much as 26% since the PICS study, including a decrease in bumper height, hood height, bumper lead, hood length and lead angle. In addition to the change in vehicle geometry, the average pedestrian in the PCDS study tended to be approximately 8 years older, taller and heavier.

Both of these influences (vehicle and pedestrian changes) have contributed to the changes in the pedestrian interaction with the vehicle and resultant injury patterns. The most evident difference between the two studies is the vehicle pedestrian interaction. In the PICS study, approximately 50% of the pedestrians were knocked to the pavement, while the vehicle carried 40% of the PCDS pedestrians.

The injury sources and resultant bodily injuries inflicted on the pedestrian seem to have a direct correlation with the vehicle interaction profile. In the PICS study the environment, front fender, front grille/headlight, side components and non-contact sources were more frequent than in the PCDS study. Also more prevalent in the PICS study were injuries to the thorax, abdomen and pelvis. In the PCDS study where pedestrians were often carried by the

the PCDS study where pedestrians were often carried by the vehicle, there was an increase in injuries caused by the bumper/valance, windshield, hood and A-pillars. Injuries to the head, neck, back, upper extremities and lower extremities were more frequent than in the PICS study.

PCDS Data

The following section will reveal information exclusively from the PCDS study that has not been discussed in the previous section. This section will include information on the vehicle, pedestrian and injuries from the cases sampled in addition to a fatality analysis.

Vehicle – Vehicles involved in the PCDS data included any vehicle equipped with original manufacturers' equipment only. Some vehicles involved were 1988, 1989 and 1997 model years, although the predominant model years were 1990-1996. There are currently 292 cases collected in the PCDS database, but collection is expected to continue until 900-1000 cases have been compiled.

The vehicles in the PCDS data were categorized in several different classes as shown in Figure 5. Utility vehicles make up almost ten percent of the total vehicles while vans and pick-ups make up about 10%-15%. The remaining 65% were passenger cars categorized by sub-compact, compact, intermediate, full size and largest according to wheel base width.

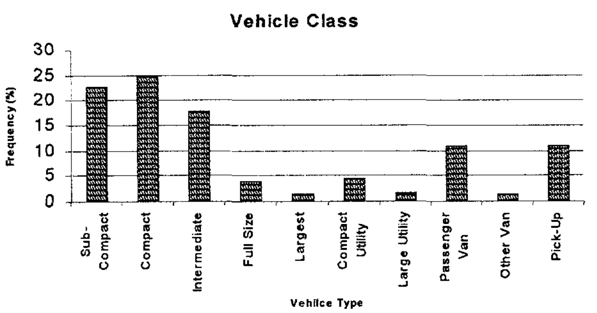

Figure 5. Vehicle Class

Injuries – The most predominant pedestrian body orientation before impact was with the left side (40%) and right side (32%) of the body toward the vehicle. Although turning accounts for 30% of the vehicle movement before hitting a pedestrian, almost half of the side impacts were while the vehicle was in a straight path of motion. Over 50% of the vehicles were traveling at speeds less than 30 miles an hour before the impact occurred. At impact, over 50% of the vehicles were traveling at speeds less than 20 miles per hour.

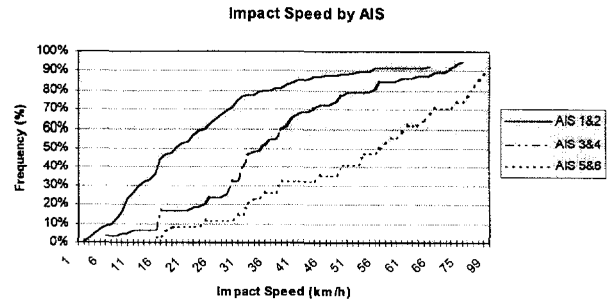

Figure 6. Impact speed by AIS.

One area of concern is how speed effects the severity of injury inflicted on the pedestrian. Figure 6 shows the relationship between vehicle velocity and AIS. The line representing AIS 1 and 2 rises sharply in the beginning because of the high frequency of injuries at lower speed, and begins to taper off at speeds above 35 km/h (22 mph). The AIS 3 and 4 injury frequency is below 30% until 30 km/h (19 mph), but rises to 70% by 45 km/h (28 mph). The AIS $\geq$ 5 injuries have few occurrances below 30 km/h (19 mph), with 30% being above 65 km/h.

A new area of pedestrian safety concern has been introduced with the recent popularity of vans, trucks and sport utility vehicles. As presented in the PICS/PCDS comparison section, approximately 70% of all vehicles involved in pedestrian crashes were automobiles. Figure 7 indicates the type of vehicle involved in the pedestrian crashes according to MAIS. The distribution indicates that automobiles are the most frequently involved vehicles among MAIS values equal to one through five. On the other hand, an MAIS equal to six is the most severe injury, most often resulting in a fatality. This MAIS=6 category was dominated by vans and pick-up trucks.

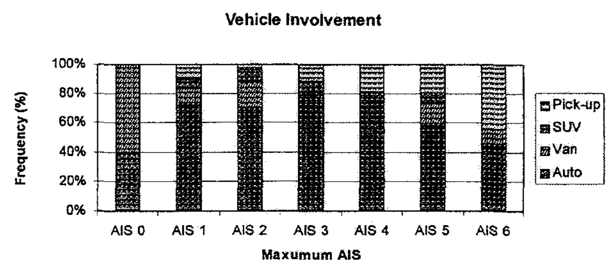

Figure 7. Vehicle involvement.

Figure 8 summarizes injuries by body area and AIS severity. The most often injured body regions were the upper and lower extremities, followed by the head and face. The neck, thorax, abdomen and spine had a lower incident of common injury, but were often the most serious. The injury regions are also categorized by AIS. The lower extremities are most often an AIS=1 injury followed by an

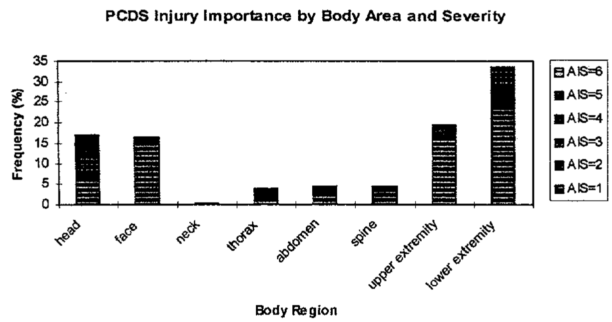

Figure 8. PCDS injury importance by body area and severity.

injuries. Most of the injuries are AIS=1 followed by AIS=2 and AIS=3. The head and the face also had very predominant injuries with an overall involvement of 17% and 16% respectively. Of those injuries, the face was comprised of mostly AIS=1 injuries. The head incurred more severe injuries with a significant involvement of all AIS values.

Fatalities – In 1996, traffic crashes were the cause of 41,907 fatalities in the United States. Approximately 13% (5,412) of all traffic fatalities were pedestrians, and over one fifth of all traffic fatalities under the age of 16 were pedestrians. This section contains results and information involving pedestrian fatalities only. Of the 292 PCDS cases, 28 resulted in a pedestrian fatality. NHTSA's Traffic Safety Facts for 1996 show that seven percent of police reported pedestrian crashes resulted in a fatality. According to the PCDS data, the fatalities are slightly over represented with an approximate fatality rate of ten percent.

Fatal age distribution differs slightly from the non-fatal distribution as shown in Table 2. The 1-12 year old age group represents children, 13-59 years old represents adults and 60 and above represents the elderly. In the fatality distribution the elderly are over represented by about 10%. The adult distribution is very similar and the child involvement is lower by approximately 8%.

Table 2.
Non-fatal/fatal Age Distribution

AGE GROUP	NON-FATAL % (N=263)	FATAL % (N=28)
1-12	19.0	10.7
13-59	69.2	67.9
60 +	11.8	21.4

The PCDS impact speed distribution for non-fatal and fatal crashes is represented in Figure 9. The majority of vehicles involved in non-fatal pedestrian crashes were at the lower end of the distribution, which tapered off at higher speeds. The frequency of pedestrian fatalities, according to the impact speed distribution, is more predominant at higher speeds where the two most predominant peaks are shifted by approximately 15-20 miles per hour. Over 40% of the fatalities occurred above 36-40 miles per hour, whereas only 7% of the total number of PCDS crashes occur within this range.

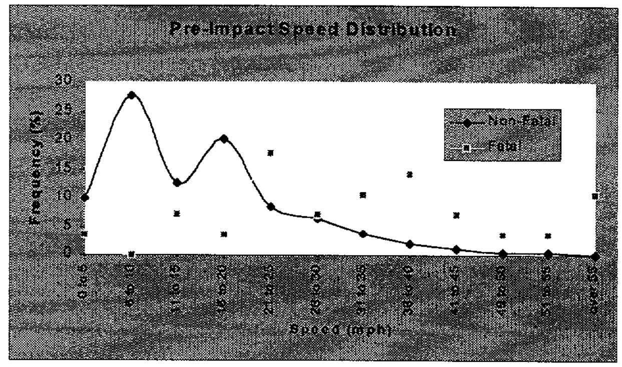

Figure 9. Impact speed distribution.

Pedestrians involved in fatal crashes had very similar body orientation as those involved in non-fatal accidents. Fatal and non-fatal had 70% pedestrians with left or right side toward the vehicle at impact; 65% had non-avoidance action. The main motion was walking or running with 80% fatal and 87% non-fatal crossing the road straight or in a diagonal manor.

The additional cases are needed prior to an assessment of how well the PCDS data represents the U.S. pedestrian collisions.

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