INJURY SEVERITY FACTORS - TRAFFIC PEDESTRIAN COLLISIONS

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INTRODUCTION

Motor vehicle accidents involving pedestrians comprise about 2 percent of the United States' traffic accidents, while pedestrians account for some 21 percent of the traffic accident fatalities (1). The combination of relatively low involvement and high fatality frequencies indicate that pedestrian collisions are severe and produce a higher fatality-collision ratio than any other type of highway accident.

The magnitude of the pedestrian injury severity problem has been recognized and several papers have been written on the subject. However, there have been comparatively few in-depth investigations of motor vehicle collisions involving pedestrians and as a result, the information available to determine pedestrian injury relationships and mechanisms is somewhat sparce. In an effort to improve the usefullness of the limited available data on pedestrian injuries, the National Highway Traffic Safety Administration, U.S. Department of Transportation undertook, in early 1976, the construction of a single computerized data file of available pedestrian accident data. These data had been collected and reported upon during the completion of contracts sponsored by the National Highway Traffic Safety Administration (NHTSA). There were three sources of data included in the file: A study (2) of 265 accidents involving 271 pedestrians conducted by Cornell Aeronautical Laboratory (now Calspan) in Toronto, Ontario, Canada during the years 1968-1971; a group of 175 accidents involving 196 pedestrians investigated and reported (3) by a multidisciplinary team of the University of Houston, Houston, Texas, U.S.A. during 1971-1973; and 47 accidents involving 57 pedestrians, investigated by various multidisciplinary accident investigation teams scattered throughout the United States.

The resulting data file completed in May 1976, contains general information on items such as location, time, weather, lighting condition, roadway type and configuration, speed limit, vehicle description, driver and pedestrian description and so forth. Of greater interest for immediate analyses were the specific items of vehicle impact speed, vehicle contact areas, and the resulting injuries.

These items reflect the investigation team's best effort to interpret scene data, participant and witness statements, traffic conditions, marks and damage on the vehicle, etc. The resulting file is the best data available from "real-world" collisions between motor vehicles and pedestrians.

Analysis of the composite data file will provide the best available guidelines for countermeasures directed towards mitigating the severity of injuries inflicted upon pedestrians involved in collisions with motor vehicles. This paper represents some of the findings of the initial analysis of the data contained in the file.

Impact Speeds

Impact speeds were calculated from such evidence as skid marks, location of actual contact, and final resting positions, and then reviewed for collaboration with traffic conditions, participant and witness statements.

The impact speed ranges for the 460 accidents for which impact speeds were estimated are shown in Table 1. The vast majority (81 percent) of the pedestrians collided with vehicles traveling at speeds less than 40 kph (approximately 25 mph). The low impact speeds reflect the speed limits of the areas in which the accidents occurred - mainly on the streets where the speed limits were equal to or less than approximately 56 kph (35 mph); and also agrees with findings of an earlier study (3) that the majority of vehicles had been braked and slowed before the actual impact. Table 2 shows the frequency of pedestrian accidents within speed limit zones. Several speed limit data were unreported, and numerous accidents occurred in parking lots and other off street facilities. Although many of the high impact speed events occurred in high speed facilities -- freeways, open highways -- several others occurred while the involved drivers were exceeding the posted speed limits.

TABLE 1
FREQUENCY OF IMPACT SPEEDS

IMPACT SPEED KM/HR	FREQUENCY	PERCENT
less than 10	129	28
11-20	122	26
21-30	69	15
31-40	53	12
41-50	41	9
51-60	14	3
61-70	15	3
71-80	4	1
81-90	9	2
91-100	2	0.5
101-110	2	0.5
TOTAL	460	100.0

TABLE 2
SPEED LIMITS AT ACCIDENT SITES

SPEED LIMIT		
MPH	KM/HR	FREQUENCY
15	24.1	1
20	32.2	2
25	40.2	11
30	48.3	156
35	56.3	75
40	64.4	13
45	72.4	3
50	80.5	4
55	88.5	8
60 and over		6
TOTAL		279
N/A (Parking lots, etc.)		208

Injury Data

Pedestrian injury data were obtained from the medical treatment records and supported by interviews with the victim and medical personnel. A maximum of 12 injuries were coded for each pedestrian. The data in the file for each injury includes the vehicle contact area (bumper, grill, hood edge, windshield, etc., and the general location on vehicle-left, right, right-center, left-center, etc.), the area of the pedestrian body contacted (skull, right upper leg, left foot, etc.), type of injury (fracture, laceration, hematoma, etc.), and an estimated injury severity rating.

For a relative measure of injury severity, the data file utilizes the Abbreviated Injury Scale (AIS) as per the 1976 revision (4). The AIS rating has been developed by a joint committee of the American Medical Association, the Society of Automotive Engineers, and the American Association for Automotive Medicine. The injury severity code ranges from 0 through 6 degrees. Zero indicates no injury; 1 is a minor injury - superficial abrasions and lacerations, minor sprains, etc.; 2 is a moderate not life threatening injury-major abrasions and contusions, deep and extensive lacerations, etc; 3 is severe but not life threatening injury - abdominal organ contusions, displaced pelvic fracture, cerebral concussion with less than 15 minutes unconsciousness, etc.; 4 is life threatening with survival probable - limited amputation or crush, chest perforation or puncture, etc.; 5 is critical with survival uncertain - aorta laceration, cerebral injuries with more than 12 hours of unconciousness, etc.; 6 is those injuries that invariably result in death given our present emergency medical care capabilities - decapitation, massively crushed head, etc.

The overall AIS is an assessment of the total effect of multiple injuries on a crash victim measured in terms of severity. This is not a sum, or average of the codings of individual injuries. It is a clinical judgment or estimate made by the coder, and may be greater than the AIS coding of the most severe single injury, but it is never less.

In addition to the overall AIS for an individual, the Injury Severity Score (ISS) has been included to provide an additional rating of injury severity for pedestrians with multiple injuries. The ISS is the sum of the squares of the highest AIS code in each of the three most severely injured body areas, with all AIS ratings of 6 adjusted to ratings of 5 in accordance with reference (5).

Severity ratings were available for all 524 pedestrians. The frequency of overall accident injury severities is shown in Table 3. Note that some 84 percent of the pedestrians received injuries that produced an overall AIS of 3 or less while 16 percent were in the life threatening or fatal ranges.

TABLE 3
FREQUENCY OF LEVELS OF SEVERITY FOR 524 PEDESTRIANS

OVERALL INJURIES	PEDESTRIANS	PERCENT
0	1	--
1	244	46
2	123	23
3	77	15
4	22	5
5	10	2
6	47	9
TOTAL	524	100

DATA ANALYSIS*

One major item of interest in the data was to determine whether there was a relationship between impact speed and age and the pedestrian's resulting injuries. In order to approach this question the data were restricted to:

a) "frontal" collisions, i.e., the force applied to the vehicle from the pedestrian collision was within 45 degrees from straight ahead. This eliminated such collisions as when the vehicle was backing, the pedestrian ran into the side of the vehicle, or the pedestrian was struck by a protrusion,

b) collisions in which the involved vehicles were passenger vehicles. Trucks, vans, etc., were excluded thus allowing the analysis to concentrate on the predominate type of motor vehicle,

c) collisions in which impact speed had been estimated.

When these restrictions were applied to the data, a total of 349 involved pedestrian records were available for analysis.

In order to control the number of cells which had a zero frequency, the data were grouped according to arbitrary classifications:

a) Overall injury severity was limited to 2 classes - minor which includes all overall AIS ratings of 3 and less, and critical consisting of all severities of AIS 4 and greater.

*The authors wish to express their appreciation to Dr. James Hedlund and David Morganstein of the Office of Statistics and Analysis, NHTSA for their aid in the data analyses included in this paper.

b) Impact speeds of: 0-10 kph; over 10 to and including 20; over 20 to 40; and over 40.

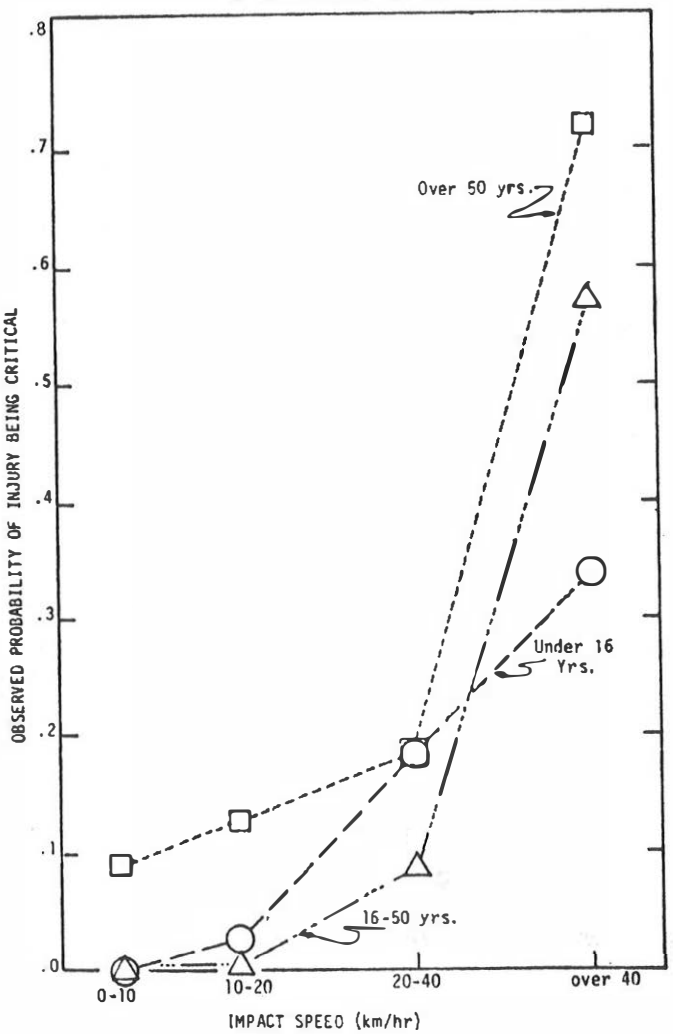
c) Age groups of 15 and younger; 16 through 50; and over 50 years of age.

Using these categories, Table 4 was constructed. Inspection of Table 4 and the presentation in Figure 1 justifies the intuitive concept that the injury severity experienced by a pedestrian struck by a passenger car increases with both the speed of the impacting vehicle and the pedestrian's age. An attempt was made to quantify and model this relationship. The approach used was to examine the odds of serious or fatal injury (number of individuals suffering AIS 4-6 injuries divided by a number of individuals experiencing AIS 1-3 injuries) for each of the 3-age and 4-speed categories to determine if a simple multiplicative model seemed appropriate. Clearly as shown in Figure 1, the odds are not independent of the speed or age category. This fact was demonstrated using a multiway contingency table analysis program, CONTAB, constructed by Solomon Kulback at George Washington University. The null hypothesis of no relation between the odds of serious or fatal injury and the independent factors was soundly rejected (statistical

TABLE 4. FREQUENCY OF OVERALL INJURY SEVERITY BY IMPACT SPEED AND PEDESTRIAN AGE

Impact Speed KM/HR	Overall Injury Severity	PEDESTRIAN AGE GROUP			TOTAL
		15 and younger	16-50	Over 50	
10 and less	Minor	41	26	20	87
	Critical	0	0	2	2
	Total	41	26	22	89
Over 10 thru 20	Minor	47	35	14	96
	Critical	1	0	2	3
	Total	48	35	16	99
Over 20 thru 40	Minor	49	22	9	80
	Critical	11	2	2	15
	Total	60	24	11	95
Over 40	Minor	11	14	5	30
	Critical	5	18	13	36
	Total	16	32	18	66
TOTAL		165	117	67	349

FIGURE 1. PROBABILITY OF INJURIES BEING CIRITICAL BY IMPACT SPEED AND PEDESTRIAN AGE



significance of less than 10^{-4}). Additional hypotheses of dependence on speed but independence on age and vice versa were similarly rejected.

The resulting conclusion suggests a strong interaction between the factors, as seen in Figure 1, as the odds for an injury to be more severe increase with increases in impact speeds and also increase with speed at a much faster rate for older pedestrians than for younger pedestrians.

There were 1,801 reported body injuries inflicted upon the 349 pedestrians struck by the front of a moving vehicle with a known impact speed. Of the 1,801 injuries, 87 could not be identified with a contacting surface thus 1,714 injuries were suitable for analysis. The data elements of these injuries were categorized as follows:

a) Three major body areas: head including neck and face; trunk - chest, thoracic spine, abdomen, pelvis, and the internal organs; extremities - legs, feet, shoulders, arms and hands.

b) Five major contact surfaces including four areas of the impacting vehicle: bumper; grill area; leading hood edge; and top of hood. Other vehicle areas such as windshield, wheels, undercarriage, side panels were grouped into a miscellaneous category and not used in this analysis. The fifth contacting surface was the roadway.

c) Two ranges of impact speed - below and including 40 kph and over 40 kph.

d) Two levels of injury severity, minor and critical, as previously described.

The data were analyzed for relationships between the documented injury severity and the variables of: a) vehicle contact area; b) pedestrian body contact area; and c) impact speed. The previously mentioned multiway contingency table analysis program, CONTAB, was used for this purpose.

The least complicated model which adequately estimated the frequencies shown in Table 5 was a multiplicative relationship consisting of a base, a variable for impact speed, and an interactive variable representing vehicle contact area and pedestrian body contact area. The numbers in parenthesis in Table 5 are estimated frequencies obtained from the model. The model may be used to estimate the ratio of the frequency of critical injuries to the frequency of minor injuries for a given impact speed, vehicle contact area, and pedestrian body contact area:

$$\text{Ratio}\ \frac{\text{critical injuries}}{\text{minor injuries}} = \text{Base Mean} \times \text{Speed Variable} \times \text{Vehicle-Body Interaction}$$

TABLE 5. INDIVIDUAL INJURY SEVERITY BY BODY AREA, IMPACT SPEED, CONTACT SURFACE

BODY AREA	IMPACT SPEED	CONTACT SURFACE									
		BUMPER		GRILL		HOOD/EDGE		HOOD/TOP		ROAD SURFACE	
		SEVERITY		SEVERITY		SEVERITY		SEVERITY		SEVERITY	
		MINOR	CRIT.	MINOR	CRIT.	MINOR	CRIT.	MINOR	CRIT.	MINOR	CRIT.
HEAD	Low	5 (5.0)	0 (0.0)	16 (14.9)	3 (4.1)	38 (38.6)	4 (3.4)	21 (22.8)	4 (2.2)	151 (155.3)	12 (7.7)
	High	1 (1.0)	0 (6.0)	0 (1.1)	4 (2.9)	5 (4.4)	3 (3.6)	28 (26.2)	22 (23.8)	32 (27.7)	9 (13.3)
TRUNK	Low	8 (8.1)	2 (1.9)	24 (24.1)	3 (2.9)	20 (20.1)	1 (0.9)	9 (6.8)	0 (2.2)	33 (31.8)	0 (1.2)
	High	1 (1.9)	2 (2.1)	2 (1.9)	2 (2.1)	10 (9.9)	4 (4.1)	3 (5.2)	18 (15.8)	18 (19.2)	8 (6.8)
EXTREMITIES	Low	200 (199.6)	4 (4.4)	102 (101.7)	1 (1.3)	90 (88.7)	1 (2.3)	23 (22.3)	0 (0.7)	295 (295.0)	0 (0.0)
	High	60 (60.4)	13 (12.6)	23 (23.3)	3 (2.7)	26 (27.3)	8 (6.7)	19 (19.7)	7 (6.3)	135 (135.0)	0 (0.0)

From this ratio, the probability (p) of a given contact resulting in an injury of critical severity is:

$$p = \frac{\text{ratio}}{1.0 + \text{ratio}} \times 100\%$$

Table 6 contains the values of the base mean, the speed variable, and the vehicle-body area variable estimated from the frequencies contained in Table 5.

The theoretical probabilities for the critical severity for each combination of pedestrian-vehicle contact areas were used to construct Figure 2. (The head-bumper contacts have not been shown since the probability of zero for this category is based upon a total of 6 minor injuries and therefore is suspect.)

Figure 2 reveals the following:

a) The separation by impact speed is clearly demonstrated.

b) The pedestrian's trunk and head are more vulnerable to critical injuries than the extremities. This reflects the low AIS rating assigned to most injuries of the body's extremities.

c) The injuries resulting from contact with the road surface have a lower probability of being critical than injuries from contact with the vehicle.

d) Probabilities of critical injuries from contact with the hood edge are lower than for other vehicle contacts. This factor requires additional examination before any decisive conclusion is made.

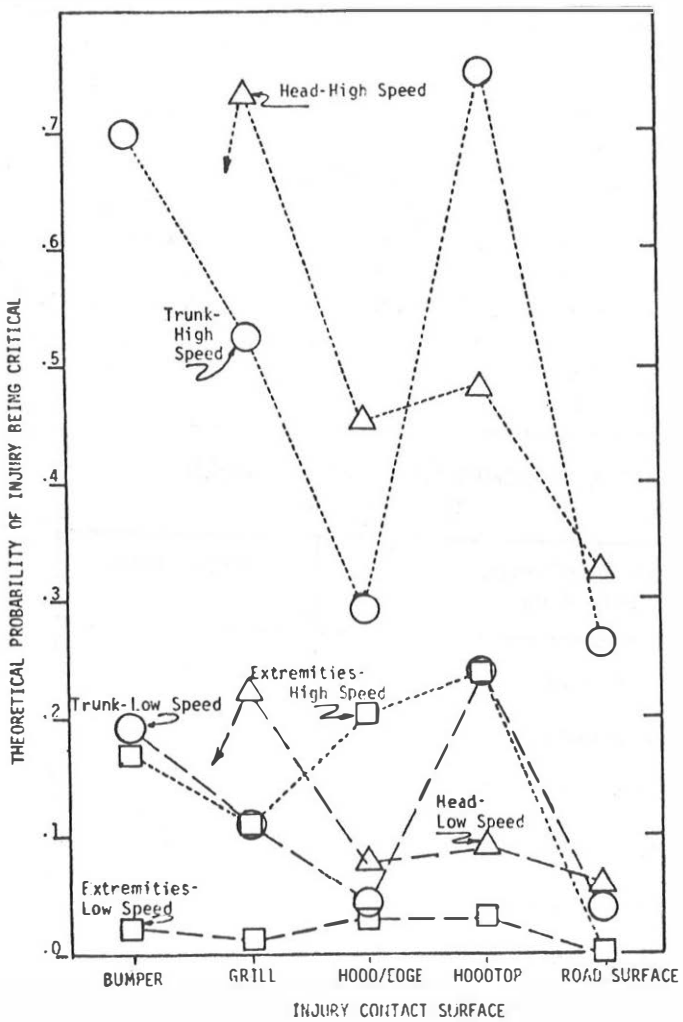
TABLE 6
VALUES OF MODEL VARIABLES

BASE MEAN		0.026
SPEED	LOW	0.32
	HIGH	3.10

CONTACT SURFACE - BODY AREA INTERACTION

CONTACT SURFACE	BODY AREA		
	HEAD	TRUNK	EXTREMITIES
BUMPER	0.00	28.45	2.62
GRILL	33.02	14.27	1.48
HOOD EDGE	10.44	5.23	3.08
TOP OF HOOD	11.40	38.26	3.97
ROAD SURFACE	5.98	4.45	0.00

FIGURE 2. PROBABILITY OF INJURIES BEING CRITICAL FOR CONTACT SURFACE, BODY AREA AND IMPACT SPEED



Among the 524 injured pedestrians there were 47 fatalities with 105 injuries of AIS 6 and 28 injuries of AIS 5 identified. One of the fatalities had four AIS 5 injuries and no AIS 6 severities.

Several of the fatalities occurred under unusual conditions, i.e., a small girl under the wheels of a semi-trailer, a male worker caught between a vehicle's door and a rigid shelf on a concession stand. These events occurred at low speeds and the velocity associated with the impact seldom inflicted the fatal injury; that is, injury severity was independent of impact speed. Although of great concern, these events were not of primary interest in deciphering the mechanisms involved in injury generation from the more routine type of event in which the motor vehicle impacts a pedestrian.

Thirty-nine of the fatalities were coded as being impacted by the front of a vehicle while moving forward and thus would be more representative of the type of collisions under consideration.

The general body areas which received fatal injuries are the head, neck, and trunk including the pelvis. Table 7 lists the frequency of injuries to these body areas. Approximately one-half of the fatalities had suffered more than one injury of AIS 6. Again, the head appears to be the most vulnerable part of the body receiving fatal injuries in a total of 31 cases. The neck and trunk were involved in 17 fatalities each.

The neck injuries require special consideration because they often occur without contact to an impacting surface. This was true in both of the neck only injuries and in seven additional combination injury groups of Table 7. The proposed theory is that the injury is a whiplash type of event in which: a) the pedestrian's body is contacted at high speed, b) the body is accelerated rapidly to the vehicle's speed, and c) the forces required to accelerate the head must be exerted through the neck and these exceed the strength tolerance of the neck.

TABLE 7. FREQUENCY OF FATAL INJURIES BY BODY AREAS

AIS 6 Injuries Body Area	Fatalities
Head Only	15
Neck Only	2
Trunk Only	2
Head and Neck	6
Head and Trunk	4
Head, Neck, and Trunk	6
Neck and Trunk	3(1)*
TOTAL	38

*One additional fatality had AIS 5 injuries, no AIS 6 injuries.

REFERENCES

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(5) S.P. Baker, et. al "Injury Severity Score" Journal of Trauma, 1974