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TRAFFIC ACCIDENT RESEARCH UNIT

DEPARTMENT OF MOTOR TRANSPORT N.S.W.

A STUDY OF MEASURES TO REDUCE INJURIES TO PEDESTRIANS

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The Traffic Accident Research Unit was established within the Department of Motor Transport, New South Wales, in May 1969 to provide a scientific approach to the traffic accident problem.

This paper is one of a number which report the results of research work undertaken by the Unit's team of medical, statistical, engineering and other scientists and is published for the information of all those interested in the prevention of traffic accidents and the amelioration of their effects.

Commissioner.

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This paper was presented at the National Road Safety Symposium, Canberra, 14-16th March, 1972.

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DEPARTMENT OF MOTOR TRANSPORT,
NEW SOUTH WALES.

DECEMBER, 1972.

INTRODUCTION

Pedestrian-involved accidents constitute a significant proportion of all traffic accidents, and the number of injuries per accident in pedestrian accidents is approximately three times the number in other types of traffic accidents.

As with other types of traffic accidents, pedestrian accident countermeasures can be applied to the human being, the vehicle and the environment, during the pre-crash, crash and post-crash phases. This paper is primarily concerned with reducing injuries to pedestrians through a study of the vehicle during the crash phase of pedestrian accidents.

The effects of motor vehicle design on the severity of pedestrian injuries has received comparatively little scientific appraisal until recently. A basic section of data which has been lacking in this field is the distribution or pattern of contact points on the vehicle in pedestrian-involved accidents.

The actual point or area of contact on a vehicle by a pedestrian can influence the resulting injuries. This can be due to details of vehicle design in the area of initial impact with the pedestrian, and/or the overall vehicle structure and shape affecting the pedestrian's movement after the initial contact.

The major objectives of this paper are:

(1) to briefly summarise the motor vehicle design/pedestrian accident situation;
(2) to examine the distribution of pedestrian collision points on vehicles; and
(3) to examine the influence of the collision point distribution on the severity of pedestrian injuries.

THE PROBLEM: NEW SOUTH WALES PEDESTRIAN ACCIDENT STATISTICS

In New South Wales during 1970, 4373 pedestrian-involved traffic accidents occurred, resulting in 291 pedestrian fatalities and 4327 pedestrians being injured. Whilst the pedestrian-involved accidents represented only 4.7% of all traffic accidents, those killed totalled 22.2% of all traffic accident fatalities and the injured constituted 12.4% of all persons injured in traffic accidents.[1] Of all pedestrians struck, 6.3% died; in contrast, only 3.6% of injuries to other road users were fatal.

Pedestrian traffic accidents are largely an urban problem and, according to a recent O.E.C.D. report[2], Australia is the world's most urbanised society. During 1969, 46% (546) of all New South Wales' traffic accident fatalities occurred in the Sydney, Newcastle and Wollongong areas, while 76% (220) of pedestrian fatalities occurred in these cities during the same period. Putting these figures another way, pedestrians constituted 40% of the traffic accident fatalities in the above cities in 1969, while in the rest of the State, they constituted 11%[26].

As is the case for other increasingly motorised societies, pedestrian accidents in New South Wales have been steadily declining as a percentage of all traffic accidents over the past two decades[1,3,25]. At the same time, the proportion of pedestrians killed and injured in each pedestrian accident has remained substantially constant. Thus, although the proportion of pedestrian accidents has declined, the severity of these accidents has not declined.

It has been estimated that one motor car in every 25 in the United States will strike a pedestrian at some time[24,28]; equivalent figures are not readily available for New South Wales.

MOTOR VEHICLE BODY DESIGN TRENDS

Early motor cars had rudimentary bodies and provided many protrusions (chassis members, cranking handles, brackets) potentially hazardous to pedestrians. By World War I, mudguards had become standard equipment on motor vehicles and during the 1920's and 1930's bodies covered more and more of the vehicle.

During the 1940's headlamps, bonnets and bumper bars began to merge into a continuous body shape, a trend which became further developed in the 1950's. However, this period also saw the emergence of exaggerated styling features, with projections in the form of fins and mascots. By the early-to-mid 1960's, vehicle body projections had started to disappear, as had mud guards as a separate structural entity. It is possible that the general disappearance of more obvious projections in the mid 60's was associated with a general popular opinion swing to safer motor vehicle design, influenced by the United States lawyer Ralph Nader[18]. In the last few years, however, there does seem to have been a slight movement back towards more elaborate styling.

There have been a number of instances where public opinion has been voiced in opposition to apparently self evident pedestrian hazards in motor vehicle design. An example of this is the sheet metal projecting alongside the headlamps on the 1965 model Holden (HD) (see figure 2). It is generally acknowledged in the motor trade that sales resistance to this particular model Holden was quite high and this speeded the introduction of the replacement "face lifted" model HR in 1966 (Figure 3). Although there was much comment on the particular design feature around the headlamps as a pedestrian danger, its actual influence on the sales resistance of the public is impossible to assess. The injury potential of the HD design, however, has been demonstrated in a study by Fisher and Hall, who compared pedestrian injuries inflicted by HD and HR Holdens[7]. In the HD data, the injuries to the pelvis, spine and abdomen appeared to be over represented, but those to the legs under represented.

There have been a number of instances where motor vehicle designers have made conscious efforts to improve existing designs (from the pedestrian impact point of view). An example is the bonnet mascot of Mercedes Benz - for many years this item has been spring loaded so that very light contact bends it back flush with the bonnet (Figure 4). Once the load is released it springs upright again. A further example of the acceptance of the pedestrian problem and its adaption to an existing model is given by the detailed design of the Morris Mini Deluxe door handles (Figure 5). This model was released in 1965 to replace the existing Minis which had a pointed leading door handle. The replacement model had a pointed leading door handle. The replacement model had a small plastic guard at the front of the door handle, which effectively caused the door handle to be shaped as a closed loop (Figure 5), thus preventing clothing or any other objects being caught by it. There is at least one documented case in Australia of severe injuries being inflicted upon a pedestrian by an unguarded forward pointing door handle[12].

In both of the abovementioned examples, there was no obvious public pressure applied to cause these design changes - they were apparently conscious efforts by the manufacturers to reduce the injuries to pedestrians impacting vehicles of their manufacture. The effectiveness of such modifications is, however hard to assess.

PREVIOUS WORK IN VEHICLE DESIGN AND PEDESTRIAN INJURIES

Human Impact Tolerance

A factor basic to crash survival work is the tolerance of human beings to impact forces. Modern work in this field can be said to have commenced with De Haven's pioneering work in the post-World War I period[6]. His investigations of the impact tolerance of the human body led to the conclusions that quite large impact forces can be withstood without major injury, provided

(i) the total force is spread correctly over the body;

(ii) the impact time duration is short; and

(iii) the attitude of the body on impact is correct.

The above principles are the essential basis for investigation of, and design for, all aspects of human tolerance to impact forces. In recent years, they have been applied in the design of safer motor vehicle interiors, and can equally be applied to vehicle exterior design for pedestrian safety.

Theoretical Aspects of Pedestrian-Vehicle Collision Dynamics

The specific problem of pedestrian-motor vehicle collisions can be considered in terms of basic physics, particularly by utilising the laws governing conservation of momentus[14,28]. Since a pedestrian weight of 150 pounds is very small compared with a car's weight of, say, 3,000 pounds, the former can be assumed to be negligible for purposes of a simple collision analysis.

Another important parameter in collision dynamics is the coefficient of restitution, whose value lies between zero and one.

If the restitution coefficient is initially assumed to be unity, then a motor vehicle striking a stationary pedestrian will propel him forward with a velocity equal to twice that of the vehicle; that is, a vehicle impacting a stationary pedestrian at 20 m.p.h. will propel him forward with a speed of 40 m.p.h. These conditions may in fact be approximated in some accidents. In one accident investigated by the author, the coefficient of restitution was calculated from witness' information as approximately 0.9.

The other limiting value for the coefficient of restitution is zero, and in this case, the pedestrian would be carried forward after impact with the same velocity as the vehicle. Here, the energy of the collision is not translated into kinetic energy (as in the first case), but is dissipated in the form of work done in permanent deformation of the vehicle and the pedestrian; that is, by dents, tearing, collapsing and other damage to the vehicle, and by bruising and bone fracture in the pedestrian. It appears that bone breakage is the most important mechanism of energy dissipation in the body, while the amount of damage to the vehicle is a rough index of the amount of energy absorbed[28]. Accidents where the coefficient of restitution must have approached zero have been described in witness' statements of a pedestrian "carried along on the car's bonnet until they braked and he fell off".

In fact, a vehicle-pedestrian collision involves two semi-elastic objects. The vehicle structure has elastic properties within certain limits, beyond which plastic deformation occurs, whilst the human body has predominantly visco-elastic properties within its flesh and bone structure[14,28].

As a result of analysis along the above lines, a number of researchers have suggested [7,14,28] that vehicle designers should aim for a coefficient of restitution with as low a value as possible, by using a plastic material capable of absorbing the energy of impact slightly more easily than will the human body. This would cause an impacted pedestrian to be carried along with the vehicle and thus minimise the effects of any secondary impact, since the pedestrian would not be projected along a trajectory, but simply fall to the road as the vehicle stopped. This is undoubtedly desirable, since the secondary impact objects are usually hard and unyielding and are thus likely to result in a concentration of impact forces in a small area.

Probably the ultimate answer for an energy absorbing body structure is to use a putty-like material: polystyrene foam may well have suitable properties for development into vehicle body components in selected positions (e.g. mudguards, bonnet).

Simulation Experiments and Case History Studies of Motor Vehicle-Pedestrian Collisions

There have been a number of detailed studies of individual pedestrian accident case histories[7,9,11,12,14,15,16,19,20,28,29], and a number of simulation experiments have been carried out[13,21,22,23,24].

Some of the conclusions drawn from these various research projects are relevant to this paper, and they are as follows

(a) all other conditions being equal, the weight of the striking vehicle is not a significant factor in pedestrian accident injuries;

(b) motor vehicle-pedestrian accidents are multiple impact events and the initial impact is not necessarily the most severe, particularly where head injuries occur[24];

(c) where head injuries are absent from the secondary collision, the initial impact is the most injurious. Mackay and Fonseka[15] found that the initial impact causes more injuries in the severe and very severe categories;

(d) most head and upper limb injuries to pedestrians are produced by contact with the road, whilst most thoracic, abdominal, pelvic and lower limb injuries are caused by contact with the impacting vehicle[15,19,22,23,24];

(e) pedestrians suffer head, chest, abdominal and pelvic, major limb and spinal injuries[11,12,15,16];

(f) low, wedge shaped vehicle profiles increase upward projection of impacted pedestrians, but reduce initial impact injuries[7,14,19,24,28,13]. Blunt profiles decreases upward projection, but provide higher initial impact forces[19,22,23,24];

(g) resilient diaphragm-like sheetmetal surfaces (such as car bonnets) have excellent energy absorption properties in contrast with sheetmetal having longitudinal directional rigidity through folds in the metal (such as mudguards)[21,24];

(h) vehicle front-end design incorporating a guard is desirable to prevent over-running of pedestrians[23,24];

(i) a large number of fatal pedestrian accidents occur at low vehicle speeds (see Table 2)[14,26,28];

(j) a small reduction in vehicle travelling speeds could have a quite large effect on pedestrian injuries[29], and

(k) individual projections and ornaments on motor vehicles result in markedly increased (and in some cases, the only significant) pedestrian injuries[9,19,28], and there appears little reason not to abandon these features, particularly where they serve no useful technical purpose.

Attempts have been made to construct experimental motor vehicles which minimise pedestrian injury potential. A notable example is the New York State Safety Car, which had a design parameter of 15 m.p.h., at which speed direct impact injuries would be minor[4,5]. The vehicle is designed to deflect the pedestrian to either side rather than forward, while at the same time minimising upward deflection. The design specifically eliminates edges, points and projections which tend to be injurious to pedestrians. The tendency of the front bumper to produce leg fracture is minimised by design, as is the problem of head injury when the pedestrian strikes the vehicle's windscreen. The front of the vehicle is designed to be energy absorbent and to have a low coefficient of restitution in pedestrian collisions.

DISTRIBUTION OF PEDESTRIAN CONTACT POINTS ON MOTOR VEHICLES

Since motor vehicles have certain structural requirements which may conflict with vehicle design for pedestrian safety (including some requirements concerned with occupant safety), it is desirable for these structural requirements to be satisfied in such a manner as to minimise pedestrian injury potential. Before this becomes feasible, vehicle designers must be able to predict the most likely collision points on the vehicle.

Although this question has been considered in broad terms in other studies of pedestrian accidents, statistical details are lacking. Based on studies carried out at Cornell, Wakeland[28] has declared that pedestrians may be struck by an exterior portion of an automobile, including the rear-end and underside and excepting only the centre of the roof and rear window. Robertson, McLean and Ryan found in their Adelaide study[19] that pedestrians struck the bumper bar and leading edge of the bonnet, and adult pedestrians often continued to move, striking the top of the bonnet, the windscreen and/or windscreen surround and the rear of the car roof before falling to the ground.

In their study of accidents in the City of Birmingham, England, Mackay and Fonseks[15] listed the vehicle components causing pedestrian injuries (see Table 3). Bumper bars were by far the most common source of injury, followed by mudguards and headlamps. Wheel injuries occurred mainly to children. Windscreen and frames were also common sources of injury, due possibly to the fact that European cars tend to have shorter bonnets than many vehicles in Australia.

Jamieson et al[12] determined the distribution of contact points and the injury producing parts of the vehicles concerned in accidents studied in Brisbane, and the results are summarised in Tables 4 and 5.

The following sections concern studies carried out by the author to provide further statistical information in this field.

Data Sources

The necessary data for an analysis of the type envisaged are not available from normal N.S.W. traffic accident reports, so alternative sources had to be found. Two data sources were eventually used - one in New South Wales and one from the United States

The New South Wales data were obtained through the use of a special pedestrian accident report form in conjunction with the standard form. The new form was designed to provide accurate information on the location of the contact point or points on the vehicle, and dimensions and location of vehicle damage. The location of each contact point was referred to the vehicle's centreline. Basic vehicle and pedestrian data were provided by the standard accident form.

The special forms were issued to the ten Police Divisions in the Sydney area, within whose boundaries the highest number of pedestrian accidents had occurred during 1968, and were in use for the three month period May to June, 1969 inclusive.

The United States data were obtained from a study by Huelke and Davis of pedestrian fatalities in Michigan during 1965 and 1966[10].

The appendix to the paper contains a number of capsule case descriptions of fatal accidents in the study, selected on the sole basis of availability of Police photographs. It is the latter photographs and accompanying descriptions which formed the second data source.

ANALYSIS OF UNITED STATES DATA

The data consisted of 57 individual fatal pedestrian collision case descriptions accompanied by photographs of the vehicles involved, with indications of the collision points on the vehicles. In two cases, the sides only of the vehicle were struck, in three cases the front and sides of the vehicles were struck, and in 49 cases the vehicle front only was struck. There was insufficient evidence to locate the collision points in the remaining three cases.

The distribution of collision points was found by scaling of the photographic evidence. A histogram of the distribution of the collision points across the vehicles was drawn (Figures 7A) and since vehicle bodies have external symmetry of design about their longitudinal centrelines, a histogram in aggregate form was also drawn (Figure 7B). The collision frequency was reasonably even across the width of the vehicles, with a slight concentration at the drivers' side edge. The numbers involved, however, were relatively small. The impacts occurred at reported impact speeds having a mean value of 36.0 m.p.h., with a standard deviation of 12.5 m.p.h.

To determine whether there was any age bias in this study group, which could invluence the results, the distribution of the pedestrians' ages was examined. The ages of the pedestrians fatally injured ranged from three years to 82 years, with two peaks in the frequency distribution, a small peak in the under 20 years group, and a larger peak in the 70 to 80 age group (Figure 8).

Head injuries were incurred by 34 pedestrians, while 27 suffered thoracic injuries, 22 spinal injuries, 20 fractures of legs or ankles, 17 pelvic fractures, 13 abdominal injuries and two listed as having suffered "multiple fractures and injuries".

Analysis of the angle of the pedestrian relative to the vehicle at impact (based solely on the pedestrian's general movements prior to impact) indicated that 53 pedestrians were side-on to the vehicle when hit and five were facing away from the vehicle on impact.

The vehicle types involved in the cases studied can be divided into two basic structural groups. The first, and largest group consists of motor cars and motor car derivatives (station waggons, etc.), which present a relatively low bonnet line to adult pedestrians and allow them to pivot onto the mudguards or bonnet on impact. The second group consists of motor lorries, buses and vans which have either a very high bonnet line, or no bonnet at all, and thus these vehicles present an essentially vertical surface to impacting adult pedestrians. Small children impacting vehicles of either type are essentially presented with a vertical collision surface. There were 55 cases involving motor cars or derivatives, and two cases involving a van and a lorry, respectively.

ANALYSIS OF NEW SOUTH WALES DATA

The data consisted of 115 individual collisions with vehicle fronts, and four collisions with the sides of vehicles. There were 19 fatal collisions, all within the frontal collision classification.

The data were grouped in a number of different forms for analysis, as shown in the following sections. Since current vehicle bodies are essentially symmetrically designed about the longitudinal centreline, histograms in the following sections depicting collision point distributions across vehicle widths are repeated in aggregate form for one half of a vehicle body.

The mean width and standard deviation of the width of vehicles involved in this study were 67.3 inches and 6.6 inches respectively.

The ages of the pedestrians involved in this study ranged from two years to 83 years with two peaks in the frequency distribution: a sharp peak in the under 10 years old group and a more gradual peak around the 50 years old group (Figure 9). The collisions in the study were reported as having occurred at reported speeds having a mean value of 23.7 m.p.h. and a standard deviation of 8.9 m.p.h.

The attitude of the pedestrians to the vehicle at the time of impact could not be obtained from the data available. For purposes of analysis, it was assumed that this attitude was solely dictated by the relative pedestrian-vehicle movements prior to the accident. Based on this assumption, 110 pedestrians were side-on to the vehicle when struck, six were facing the vehicle and three had their backs to the vehicle on impact.

In a similar manner to the United States cases studied, the vehicles involved in the N.S.W. collisions can be classified into two structural groups: motor cars and motor car derivatives (station waggons, panel vans and utilities), and motor lorries, buses, and vans. There were 109 cases involving motor cars or derivatives, and 10 cases involving motor lorries, buses or vans.

Impact Distribution across the Vehicle as a Percentage of Vehicle Width

A histogram of the distribution of the collision points across the vehicle was drawn (Figure 10A) and since vehicle bodies are essentially symmetrical, an aggregate form of histogram was also drawn (Figure 10B).

The first point to be noted from the histograms is that they are the result of collision point counts only - no account has been taken of accident severity. Notwithstanding this limitation, a number of observations may be made. The first is that 75 collisions (including three of the non-frontal collisions) of the 119 examined (63%, or nearly 2/3) occurred at points on the kerb-side halves of the vehicles.

A second observation concerns the concentration of collision points near the kerb-side edge of the vehicle (there was insufficient data to indicate a reason for this phenomenom). The greatest concentration of collision points in aggregate form was found near the edge of the vehicles, 43% of all collision points being within 16.7% (1/6th) of vehicle width from the vehicles' extreme edges. A further examination of the latter group showed that of the 51 collision points in this category, 33 occurred when pedestrians were moving towards the vehicle (at right angles to the path of the vehicle), 12 when they were moving away from the vehicle (at right angles to its path), three when pedestrians were moving away from the vehicles, parallel to the vehicles' paths, two when pedestrians were stationary and one where the pedestrian's movements are unknown.

Distribution Grouped by Accident Severity

To take injury severity into account, the data were grouped into a moderate injury group, a severe injury group and a fatal injury group. Moderate injuries were defined as those not requiring hospitalisation and severe injuries as those requiring hospitalisation other than for observation. There were 48 cases of moderate injuries, 52 of severe injuries and 19 of fatal injuries. There were no reported pedestrian/vehicle collisions where the pedestrian was uninjured.

The distributions of contact points, impact speeds, pedestrian ages, injury types, attitude of the pedestrians to the vehicles, and vehicle types were compared.

Fatal injuries

A histogram of the distribution of the contact points across the vehicles in the 19 fatal cases was drawn (Figures 11A and 11B), and it was found that it has a dissimilar shape to the corresponding histogram of the distribution of all collision points studied (Figures 10A and 10B). The fatal impacts have a slight tendency to be concentrated near the vehicle centre; however, the numbers involved are very small. The fatal impacts occurred at reported speeds having a mean value of 28.0 m.p.h. with a standard deviation of 9.2 m.p.h.

The ages of the pedestrians fatally injured ranged from four years to 78 years old, with a tendency towards the older group. The distribution is not inconsistent with the bi-model distribution for all collision cases studied. The numbers involved, however, are very small and no firm conclusions could be made from this age distribution (see Figure 12).

Head injuries were definitely incurred by 16 of the pedestrians, while the remaining three possibly suffered head injuries - the injury descriptions for the latter cases were not explicit. In two cases, broken legs were specifically listed, in another two cases internal injuries were listed and a further four cases listed injuries as multiple body injuries and fractures.

Analysis of the attitude of the pedestrian to the vehicle at impact indicated that 17 pedestrians were side-on to the vehicle when hit, one was facing the vehicle and one had his back to the vehicle at impact.

Of the vehicles involved in these cases, 17 were motor cars or derivatives, and two were motor lorries or vans.

Severe Injuries

The distribution of the 52 impacts involving severe injuries to pedestrians was found (Figures 13A and 13B) to be similar to the corresponding histogram of the distribution of all collision points studied (Figures 10A and 10B), but with an even greater concentration of collisions near the kerb-side edge of the vehicle. Considering the aggregate histogram of distribution of collision points, more than half of them occurred within 1/6th of the vehicle's width from the vehicle edge. The severe injury collisions occurred at reported speeds having a mean value of 25.8 m.p.h. with a standard deviation of 7.1m.p.h.

The ages of the pedestrians severely injured ranged from three years to 81 years old, with two peaks similar to that shown for all collision cases studied, i.e. in the under 10 years old group and around the 50 year old group - see Figure 14.

The injuries suffered by the pedestrians in this group varied considerably. A total of 29 pedestrians suffered leg fractures, 18 suffered head injuries, 10 suffered a fracture of the pelvis, four suffered arm fractures, three suffered hip fractures, three suffered fractures of the collarbone, two suffered spinal injuries, and there was one case of each of the following; punctured lung, fractured ribs, kidney contusion, dislocated shoulder and "chest injuries".

Analysis of the attitude of the pedestrian to the vehicle at impact indicated that 49 pedestrians were side-on to the vehicle when hit, two had their backs to the vehicle and one was facing the vehicle.

Of the vehicles involved in these cases, 47 were motor cars or derivatives, and five were motor lorries, buses or vans.

<u>Moderate Injuries</u>

The distribution of the 48 impacts which resulted in moderate injuries to pedestrians was found (Figures 15A and 15B) to be similar to the distribution for all collisions (Figures 10A and 10B), but having the edge concentration spreading towards the central area of the vehicle. The moderate injury collisions occurred at reported speeds having a mean value of 19.7 m.p.h. with a standard deviation of 9.1 m.p.h.

The ages of the pedestrians moderately injured ranged from two years to 83 years old, with two peaks similar to that shown for all of the collision cases studied (Figure 9) and for the severe injury cases (Figure 14). The main variation in the moderate injuries case (Figure 16) is that the 50 to 60 years old peak has shifted slightly towards the younger age groups.

Of the pedestrians within the moderate injury group, fractures to the nose (two), wrist (one) and ankle (one) were suffered, as were abrasions and lacerations to the head (16), legs (14), arms (12), body (five) and hip (four). These pedestrians also suffered bruises to the legs (seven), head (three), hip (two), back (one), shoulder (one) and arms (one). One dislocated shoulder was also suffered.

Analysis of the attitude of the pedestrian to the vehicle at the point of impact indicated that 44 pedestrians were side-on to the vehicle, and four were facing the vehicle on impact.

Of the vehicles involved in these cases, 45 were motor cars or derivatives, and three were lorries, buses or vans.

Comparison between the Fatal, Severe and Moderate Injury Groups

Since the data are based upon those pedestrian accidents in which the location of the collision point on the vehicle could be determined and not upon all pedestrian accidents in the study area, it is suspected there is a bias towards the more serious accidents. This view is supported by the fact that 16% of all pedestrian injuries in New South Wales during 1969 were fatal[1].

Any age bias within a group could mean that injuries incurred or not incurred were a function of age distribution (and, by implication, general susceptibility to injury) rather than other factors in the accident situations. No statistically significant difference was found between any of the age distributions of the various groups ($\chi^2_{.05,6} = 5.52$). However, the numbers involved were small, particularly with the fatal injuries group.

The reported impact speed distributions of the groups were tested against each other to determine whether they could be considered to have come from the same speed population. It was found that there was no significant difference between the mean stated impact speeds in the fatal and severe injury groups ($t_{.05,69} = 1.065$). However, there was a significant difference between the mean impact speeds of each of these groups and the moderate injury group ($t_{.05,65} = 3.637$, $t_{.05,98} = 3.753$).

Subjectively, the distributions of collision points across the vehicles within the severe and moderate injury groups were basically the same, while the fatal group distribution appeared quite different. However, statistical tests did not indicate that there was any significant difference between any of the distributions ($\chi^2_{.05,4} = 7.34$), although the numbers in the fatal group were very small.

In all groups, the vast majority of pedestrians were side-on to the vehicle at impact, with only a few either facing or having their backs to the vehicle.

The fatal injured group of pedestrians predominantly suffered head injuries, with few other injuries reported: this is probably due to the tendency in New South Wales for the major injuries only to be reported, and it is highly likely that in fact many other injuries types were also sustained by this group. The severe injury group predominantly suffered bone fractures, including a large number of skull fractures. There were also a number of internal injury cases. The moderate injury cases were mainly abrasions and lacerations, followed by bruising and a small number of fracture cases.

The ratio of motor car structural types to motor lorry types was very similar in each injury group studied.

Accidents Involving Bone Fracture

Since bone fracture is a measure of collision energy absorbed by a pedestrian, those accidents in which the pedestrian suffered fractures most probably caused by contact with the vehicle itself (rather than, say the road surface) were separated for special examination. The bone fractures concerned were usually of limbs: since many fractured skulls in pedestrian accidents are known to result from secondary impacts they were not included in this group.

There were 45 pedestrians who suffered "vehicle-caused" bone fractures and another four pedestrians were suspected of suffering bone fractures inflicted by the vehicles. Information in the latter four cases was insufficient to be certain, and each of those cases was counted as half a fracture for statistical purposes. The bone fracture cases occurred at a mean speed of impact of 26.8 m.p.h., with a standard deviation of 7.5 m.p.h.

The distribution across the width of the vehicles of collision points of the bone fracture collisions is shown in Figures 17A and 17B. It is similar to the corresponding histogram of the distribution of all collision points studied ($\chi^2_{.05,1} = 1.44$), with a concentration of hits in edge area of the vehicles.

The ages of the pedestrians suffering vehicle inflicted bone fractures ranged from three years to 81 years old, with a peak in the 50 to 60 year old group and a tendency towards the older age groups generally (Figure 18). The tendency towards the older pedestrians seems reasonably explained by surmising that members of this group are more susceptable to injuries of this kind than younger members of the community. When the age distribution was compared with the equivalent distribution for all collisions studied, there was not found to be any statistically significant difference ($\chi^2_{.05,4} = 4.38$).

The characteristics of the bone fracture group are essentially the same as those in the severe injuries group. This is due to the fact that, of the 47 bone fracture cases, 39 are also severe injury cases, with five fatal injury cases and three moderate injury cases.

Of the vehicles involved in these cases, 44 were motor cars or derivatives and three were motor lorries, buses or vans.

DISCUSSION OF RESULTS

Since the New South Wales study covered the spectrum of severity of pedestrian accidents, the following discussion is based upon this study, with reference to the United States data where appropriate.

As previously discussed, the collision cases may be grouped by degree of injury to the pedestrian, i.e. into fatal, severe and moderate injury groups. The question then arises as to the fundamental differences in accident conditions which cause pedestrian age distributions, attitude of the pedestrian to the impacting vehicle, and vehicle types between the three groups.

There are no significant differences between the impact speed distributions of the fatal and severe injury groups: there is, however a significant difference between the speed distributions of these groups and the moderate injury group.

The distributions of collision points across the vehicle width are not significantly different between the moderate and severe injury groups, while these distributions are subjectively different to the fatal injury group distribution. Although the figures for the latter distribution were too small to show a statistically significant difference between it and the other two, it was subjectively different in that collision points were relatively evenly placed across the vehicle, in contrast to the concentration at the vehicle edge in the severe and moderate injury group distributions. It is contended that a real difference does exist and could be shown to be significantly different with a larger sample - this view is supported by the fact that the United States study gave a collision point distribution of the same type as the New South Wales fatal cases.

Hypothesis on Injury Severity

The differences given above between the three injury groups provide the basis for the following hypothesis.

In broad terms, pedestrian injury severity in a collision may be considered to be a function of two independent variables:

(1) impact speed

(2) point of collision across the width of the vehicle body, where colliding with the central area of the vehicle produces the most severe injuries and colliding with vehicle edge area produces the least severe injuries.

The hypothesis means that, in general, a pedestrian colliding with a vehicle at a point near the vehicle edge would suffer certain injuries, whereas if he collided with the vehicle centre (at the same impact speed) he would tend to suffer more severe injuries. The hypothesis also means that, for a given level of injury, the impact speeds would tend to be lowest in collisions at the vehicle centre, and highest at the vehicle edge.

To determine whether the hypothesis is reasonable, the impact speed distribution of the groups of collision points across the vehicle body were analysed, as shown in Table 6. In all but one of the various collision classifications (selected by injury level), the results support the hypothesis, in that in each classification, the impact speeds were highest at the vehicle edge and lowest at the vehicle centre. The single exception was the New South Wales fatal injuries group in which the reverse distribution occurred: however the figures for this group were extremely small. (It may also be noted that, due to the number of collisions which occurred on urban freeways, the United States impact speeds were generally much higher than the New South Wales speeds.)

The reason for the importance of the point of collision across the vehicle width is not as yet proven, but a possible explanation is as follows. When a person collides with a vehicle, he is projected along a trajectory with a velocity determined by a component of the vehicle's impact speed. The magnitude of the speed component depends upon variables such as the coefficient of restitution of the collision and the angle of the pedestrian's trajectory to the vehicle's initial movement. The higher the speed component given, the greater the chance of the pedestrian suffering serious injury on subsequent impact with, say, the road surface.

When a person collides with the centre of the front of a vehicle, it is probable he will be projected along a trajectory parallel with the vehicle longitudinal axis and this will tend to transmit a large component of the vehicle's velocity to the pedestrian. If, however, the pedestrian collides with a vehicle near its edge, he has a greater possibility of being deflected along a trajectory at an angle to the vehicle's longitudinal axis and this will result in a much smaller component of the vehicle's velocity being transmitted to the pedestrian.

Implications of the Hypothesis

If the hypothesis put forward is correct, then a number of observations may be made. The first is that the concentration of collisions with pedestrians near the vehicle edge is important, since this reduces accidents which might otherwise be fatal, to the severe injuries level.

The difference in collision mechanism of edge and centrally located collisions is not yet proved. However, if the mechanism is as described above, then it is better for a pedestrian to be deflected sideways rather than forward, and hence vehicle fronts should be designed with this in mind. A vehicle design feature having this characteristic would have great potential for overall pedestrian reduction, due to the large concentration of collisions around the edge of vehicle bodies. Some safety car designs produced in fact incorporate such features[10]. Vehicle designs incorporating protrusions near the body edges (e.g. HD Holden - Figure 2) which may snag or otherwise injury pedestrians are undesirable and should be abandoned.

Reduction of the forward velocity of pedestrians impacted by the central areas of vehicle fronts would seem to depend greatly upon a reduction in the coefficient of restitution of the collision. Since impacted adults tend to fall onto car bonnets, these, and the top leading edges of vehicles appear to be the logical areas to concentrate on. The problem of small children, and of adults striking lorries, vans etc., is more difficult to deal with. Possibly the answer is a central energy absorbent panel which could progressively deform under load.

The two variables nominated in the hypothesis are considered to be the most important parameters, in the overall vehicle-pedestrian collision situation. Other parameters, such as pedestrian age and vehicle detail design will of course effect the outcome of individual collisions, within the general framework of the two dominating variables.

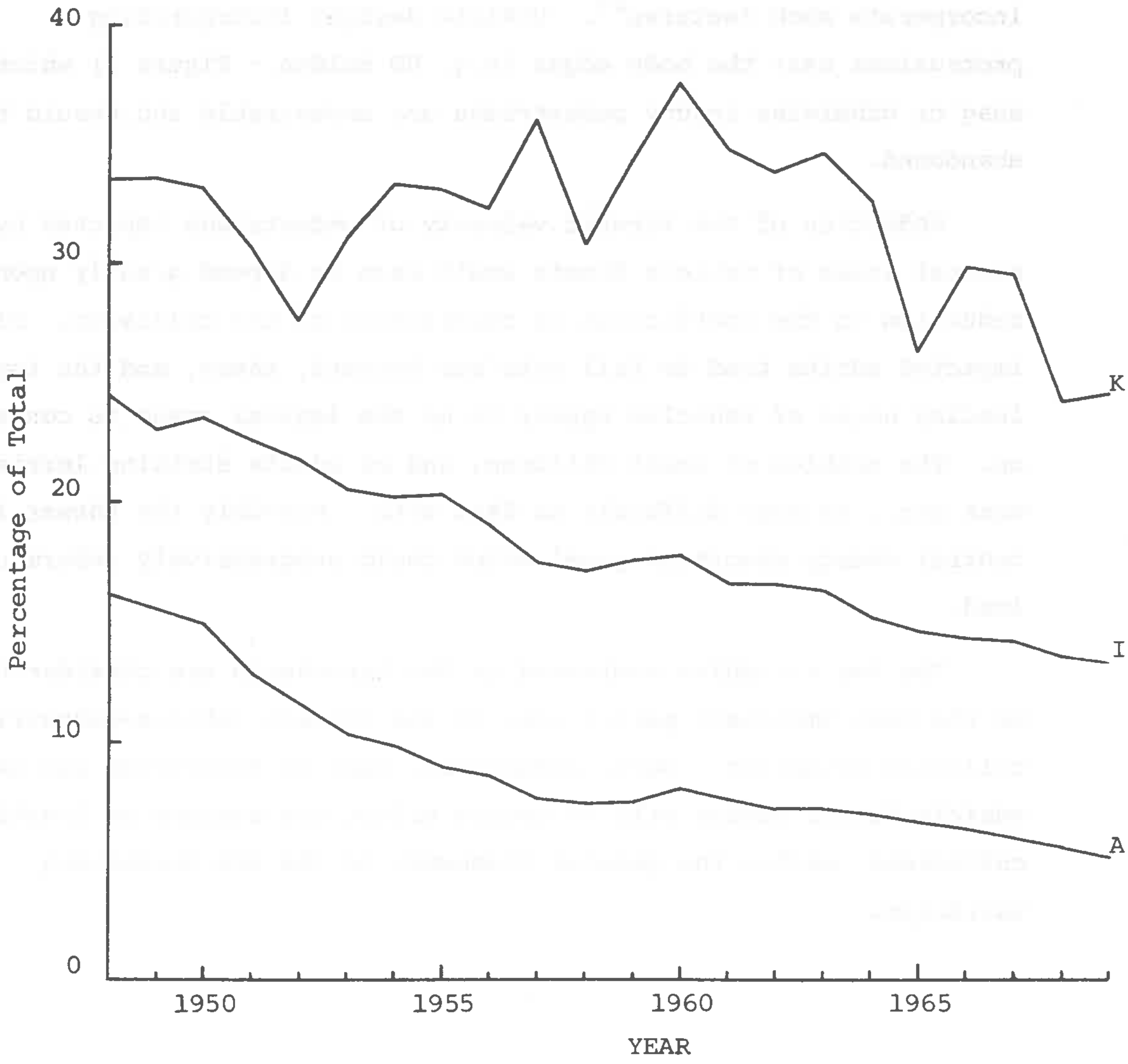


Figure 1 : Pedestrian Accidents as a Percentage of Total Road Accidents in New South Wales

A= Accidents
K= Killed
I= Injured

Figure 2 : Headlamp area of HD model Holden

Figure 3 : Headlamp area of HR model Holden

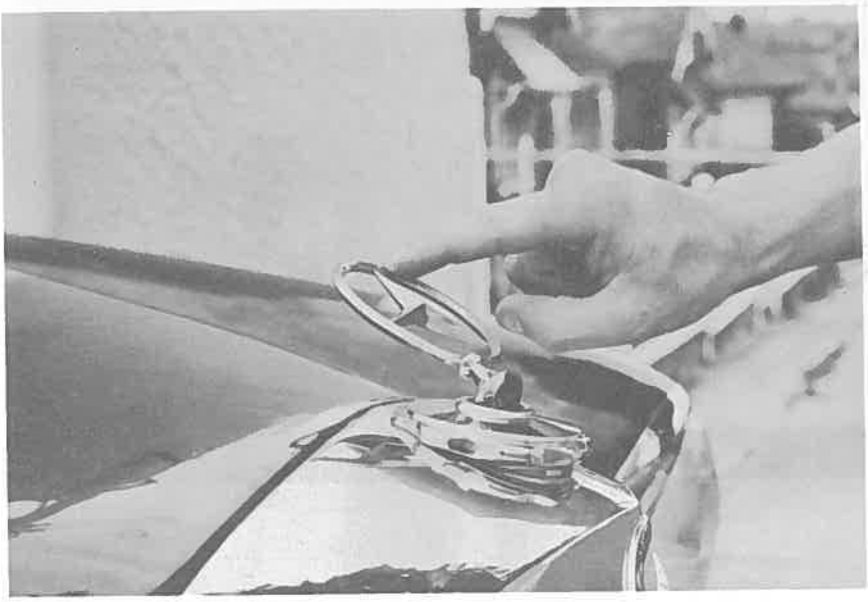


Figure 4 : Spring-loaded mascot of Mercedes Benz cars

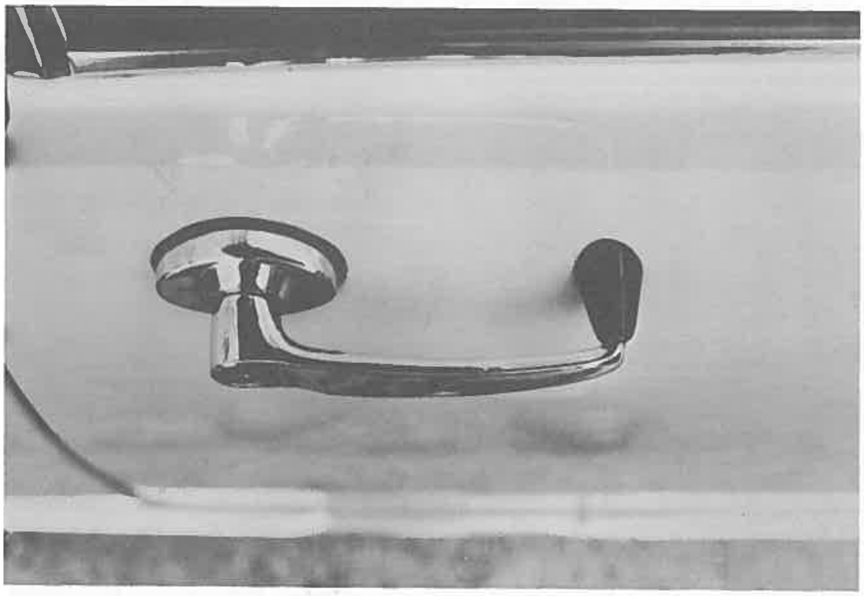


Figure 5 : Door handle of Morris Mini Deluxe

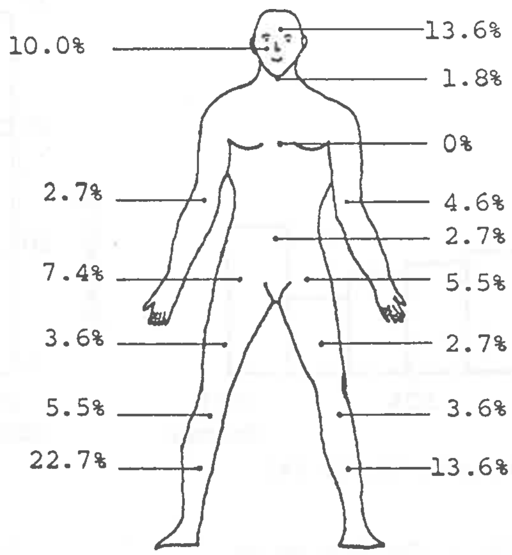


Figure 6A : Distribution of pedestrian injuries caused by vehicle impact (after Mackay and Fonseka[15])

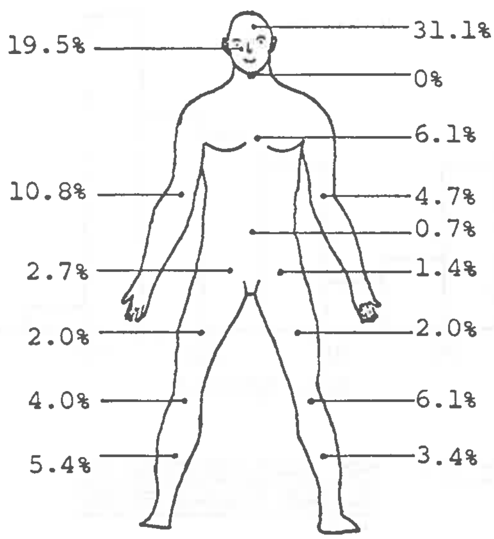


Figure 6B : Distribution of pedestrian injuries caused by road impact (after Mackay and Fonseka[15])

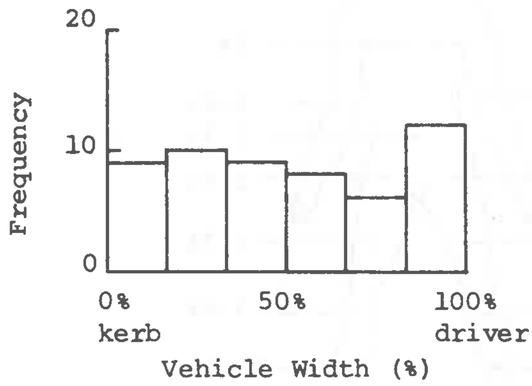


Fig. 7A : Collision Pt. Distribution

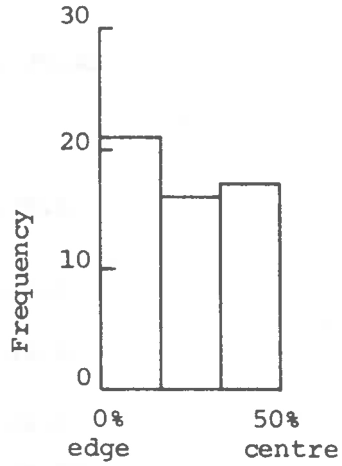


Fig. 7B : Aggregate Form

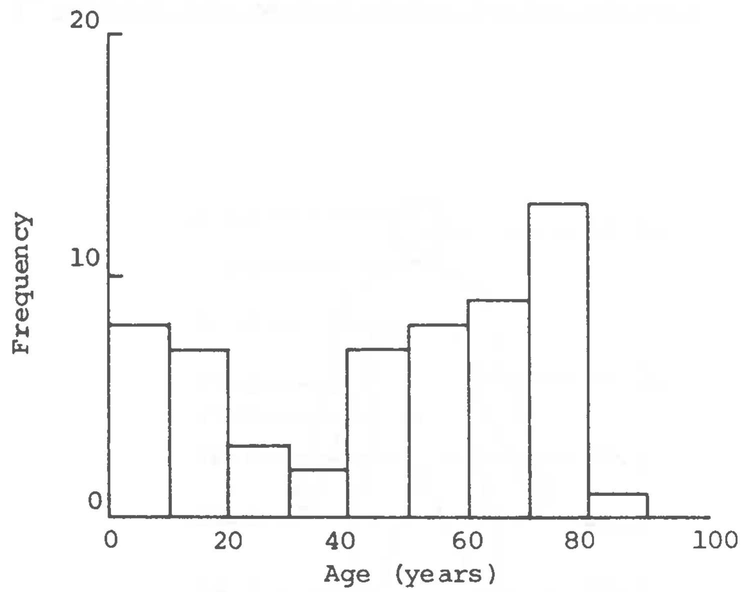


Figure 8 : Age distribution of United States Study

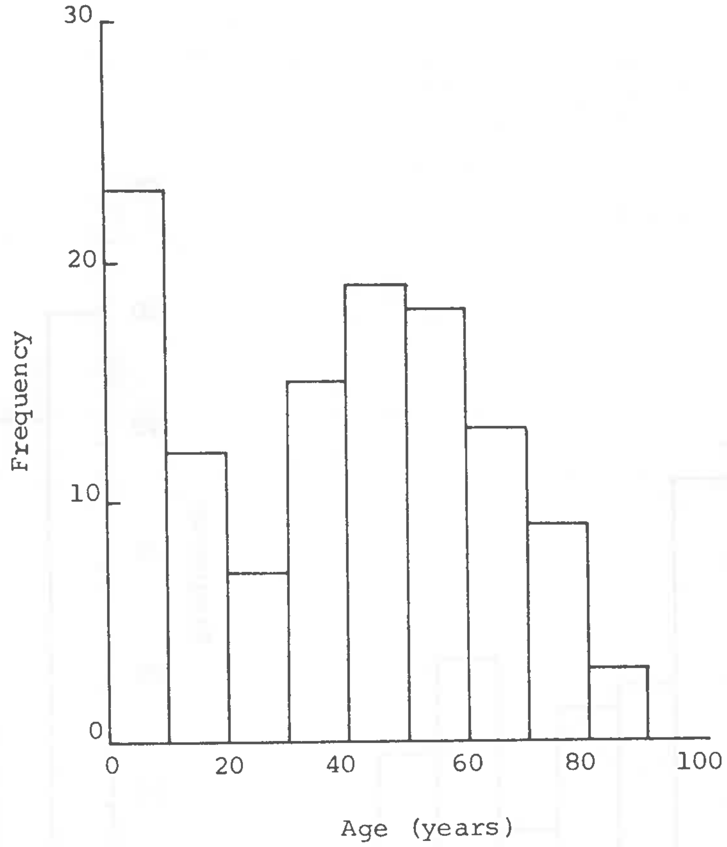
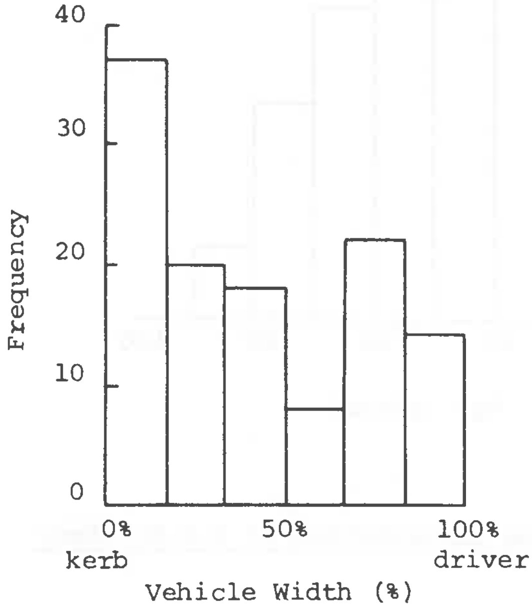


Figure 9 : Age Distribution of N.S.W. Study



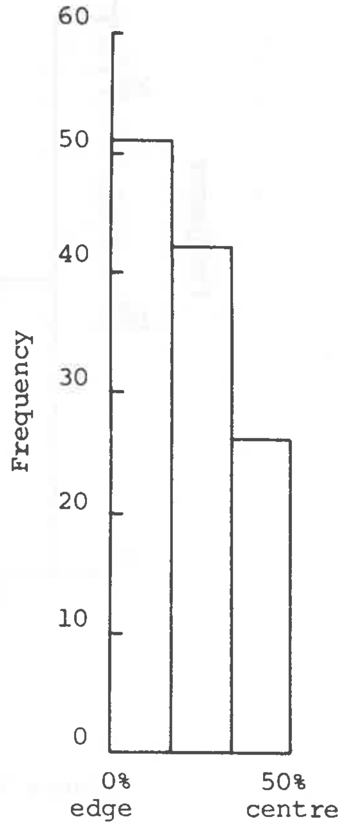


Fig. 10A : Collision Point Distribution

Fig. 10B : Aggregate Form

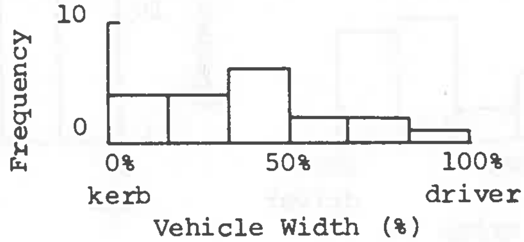


Fig 11A : Fatal Injury Collision Point Distribution

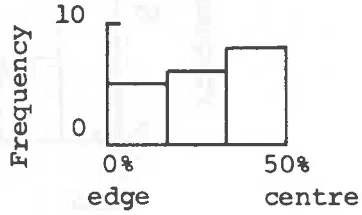


Fig 11B : Aggregate Form

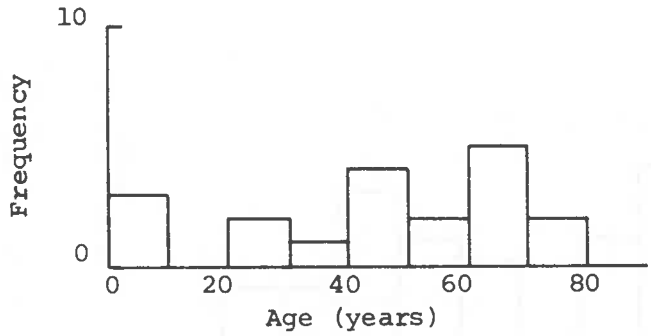


Fig. 12 : Age Distribution of Fatal Injury Collisions

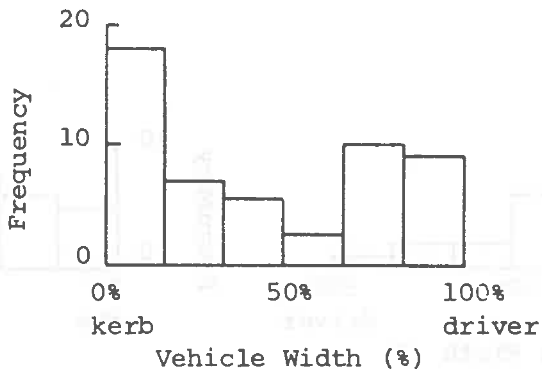


Fig. 13A : Severe Injury Collision Point Distribution

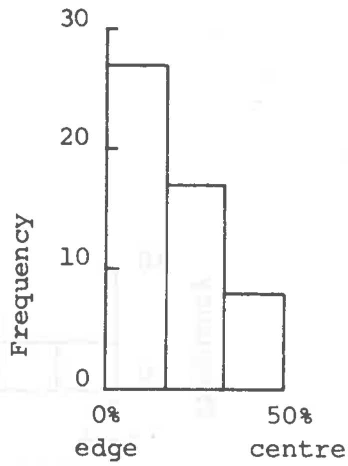


Fig 13B : Aggregate Form

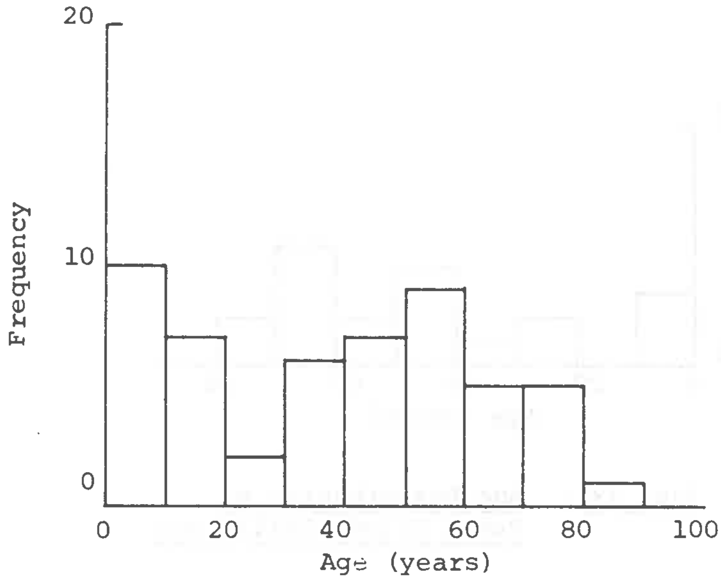
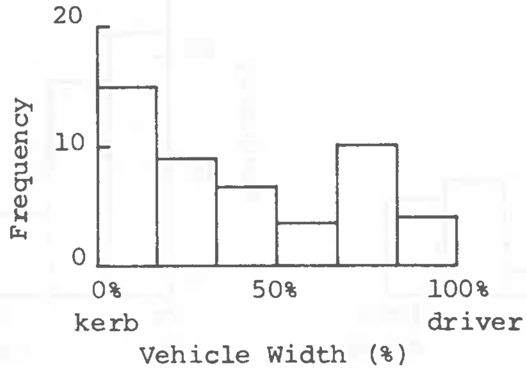


Fig. 14 : Age Distribution of Severe Injury Collisions



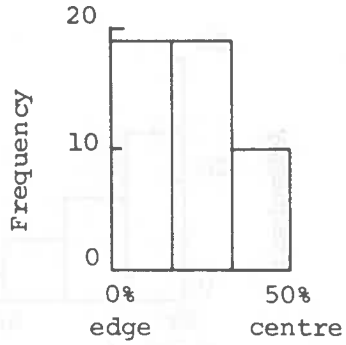


Fig. 15A : Moderate Injury Collision Point Distribution

Fig. 15B : Aggregate Form

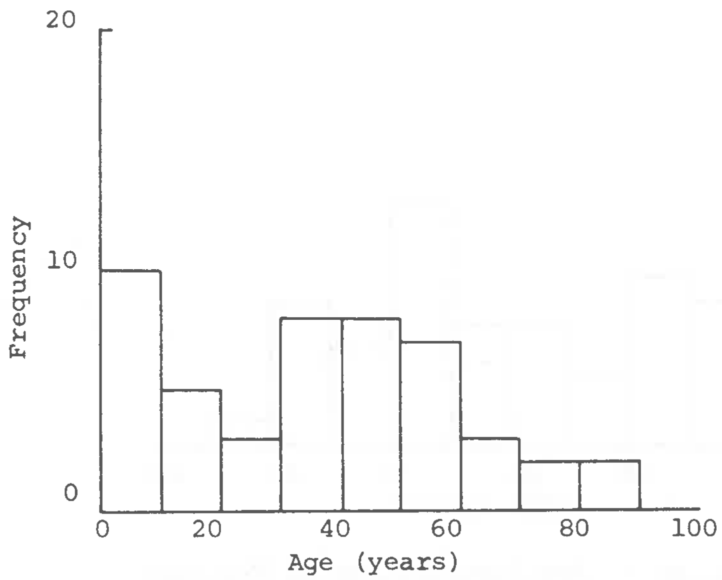


Fig. 16 : Age Distribution of Moderate Injury Collisions

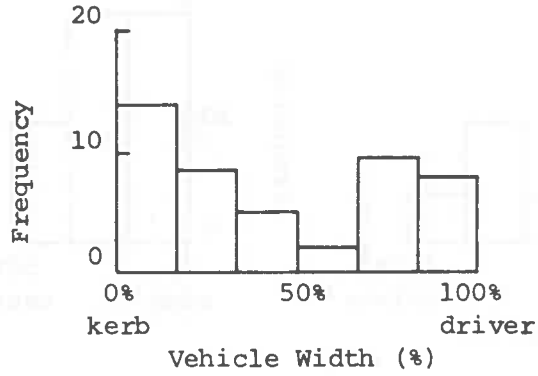


Fig. 71A : Fracture Injury Collision Point Distribution

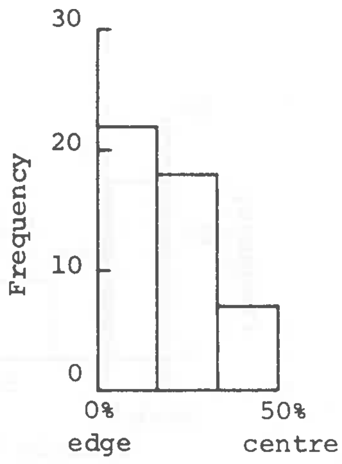


Fig. 17B : Aggregate Form

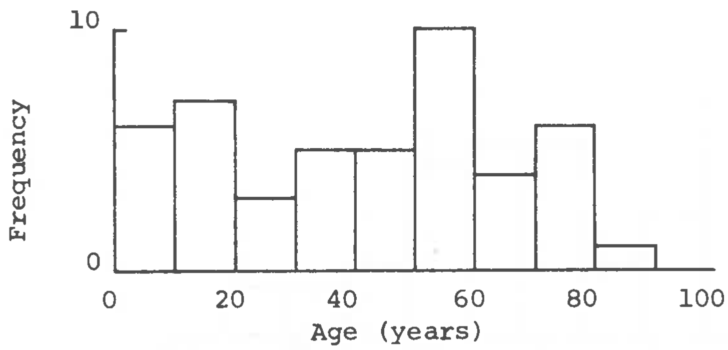


Fig. 18 : Age Distribution of Fracture Injury Collisions

	Nil	Minor	Moderate	Severe	Very Severe	Fatal	Total Injured
Head	18	8	14	1	0	10	33
Chest	44	1	1	0	1	4	7
Abdomen	37	4	0	4	3	3	14
Spine, pelvis	38	0	7	2	1	3	13
Right upper limb	29	18	3	1	0	0	22
Left upper limb	33	16	1	1	0	0	18
Right lower limb	15	21	5	9	1	0	36
Left lower limb	14	22	6	7	2	0	37

Table 1 : Injury Patterns for Pedestrians (after Jamieson, et al[12])

Impact Speed (m.p.h.)	Number of Fatalities	Cumulative Total (percent)
0 - 5	9	4.5%
6 - 10	3	6.1%
11 - 15	13	12.6%
16 - 20	15	20.2%
21 - 25	20	30.3%
26 - 30	65	63.0%
31 - 35	53	90.0%
36 - 40	9	94.5%
41 - 45	10	99.5%
46 - 50	1	100%

Total fatalities = 198

Mean impact speed = 26.5 m.p.h.

Standard deviation = 9.1 m.p.h.

Table 2 : Speed of impact in fatal pedestrian accidents in the Metropolitan Areas of Sydney, Newcastle and Wollongong during 1969[26].

Vehicle Component	% of Vehicle Contact Injuries
Bumper Bars	29.2
Mudguards	13.5
Headlights	9.4
Bonnet	8.3
Wheels	7.3
Windscreen	6.3
Windscreen frame	5.2
Grill	4.2
Rear Vision Mirrors on Mudguards	3.1
Doors and Door Handles	2.1
Vehicle Insignia	1.0
Unclassified Components	10.4
	100.0

Table 3 : Vehicle Components Causing Pedestrian Injury
(analysis of 94 cases by Mackay and Fonseka[15])

Part of Car which Struck Pedestrian					
	Front Nearside	Front Centre	Front Offside	Side	Unknown
Number	8	6	16	9	3

Table 4 : Distribution of Pedestrian Contact Points

(after Jamieson et al,[12])

Injury	Bumper Bar	Head Lamp Bonnet Line	Engine Bonnet	Bumper Bar and Head Lamps	Wind-Screen	Roof	Bumper Bar, Head Lamps, Bonnet	Bumper Bar, Head Lamps, Wind-screen	NR	Total
Nil	0	0	0	0	0	0	0	0	0	0
Minor	4	3	0	0	0	0	0	0	4	11
Moderate	1	0	0	0	0	0	0	1	1	3
Severe	3	3	0	1	0	0	1	1	1	10
Very Severe	0	0	0	1	0	0	2	0	0	3
Fatal	0	0	0	1	0	0	1	4	1	7
Totals	8	6	0	3	0	0	4	6	7	34

Table 5 : Injury Producing Parts of Vehicle Versus Injury - Frontal Impacts Only (after Jamieson et al,[12])

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