

**REAL WORLD FRONTAL IMPACTS -
THE PROBLEM**

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Introduction

ECE Regulation 12 defines the minimum acceptable level of performance of cars in frontal collisions and is in general use throughout Europe. There has been little modification to the Regulation since its publication in the 1970's. There is now intense discussion concerning more stringent requirements that will result in cars offering improved levels of protection to their occupants. A revised test procedure need not reproduce the exact circumstances occurring most frequently amongst real-world crashes, rather it should reflect the essential characteristics of crashes which result in serious or fatal injury. Although a test procedure must examine the performance of structural components as well as interior fittings this need not be done in the same test.

The development of a new test procedure must be based on an understanding of the real-world crash event. It is essential to understand the nature of the problem that is to be addressed. The circumstances in which injuries occur as well as the nature of the injuries and their cause must be known. The crash configuration, impact severity and striking object are all key factors in determining the injury outcome.

This paper summarises the characteristics of frontal crashes which result in injured car occupants and describes the pattern of injuries sustained and their sources.

Data Analysis

This analysis is based on a set of real-world accident data describing a section of the UK accident population which has been examined within the UK Co-operative Crash Injury Study. In-depth investigations of crashes in the Midlands, the north-east and south-west areas of the UK have continued since 1983. Accidents were selected for investigation according to a strict sampling protocol which emphasised the number of the more severe and fatal crashes. All accidents involved cars aged less than 6 years old at the time of the accident which were towed away from the accident site. The sampling system allowed the links to be drawn between the sample of accidents upon which this analysis is based and the population of accidents in the study catchment areas by the use of weighting factors.

The analysis describes the crash conditions of 1382 cars involved in frontal collisions containing 2405 occupants. The initial bias of case selection in favour of the more severe injury outcomes has been removed by weighting the data in inverse proportion

to the likelihood of the accident being selected for examination. The sample of 1382 cars in frontal collisions represents a population of 6662 cars. The effect of weighting the accident sample is shown in Table 1 which gives the severity of the most severely injured occupants in each vehicle. It also shows the severity of each occupant. In Table 1 the terms "Slight", "Serious" and "Fatal" are the standard UK definitions as used in the UK.¹

Table 1: Accident sample and population sizes.

Severity	Vehicles				Occupants			
	Sample	%	Population	%	Sample	%	Population	%
Non-Injury	0	0%	0	0%	311	13%	1867	16%
Slight	450	33%	4840	73%	982	41%	7603	65%
Serious	797	58%	1638	25%	971	40%	1985	17%
Fatal	135	9%	185	3%	133	6%	179	2%
Not known	0	0%	0	0%	6	0.3%	30	0.2%
Total	1382	100%	6662	100%	2405	100%	11665	100%

The data presented in this paper is therefore representative of the population of tow-away injury accidents involving vehicles aged less than 6 years at the time of the crash.

Crashed vehicles were examined at recovery garages in considerable detail including the points of occupant contact and the quantity of crush and intrusion sustained. This data was supplemented by details of the injuries of both fatalities and survivors and has been coded using AIS-85². The data collection systems have been described in more detail elsewhere.^{3,4}

¹Road Accidents Great Britain, HMSO 1992

²Abbreviated Injury Scale (1985) Association for the Advancement of Automotive Medicine

³ The Causes of Injury in Car Accidents - an Overview of a Major Study Currently Underway in Britain. Margaret Galer, GM Mackay, Sue Clarke, SJ Ashton. 10th International Technical Conference on Experimental Safety Vehicles July 1985.

⁴Crashed Vehicle Examination Techniques. Yomi Otubushin, Margaret Galer. International Congress and Exposition SAE, Detroit, Michigan, USA February 1986.

Frontal Impact

All vehicles in this analysis were involved in a collision where the most severe impact involved loads applied to the front of the vehicle. The direction of the principle force was within 30° of the straight ahead direction.

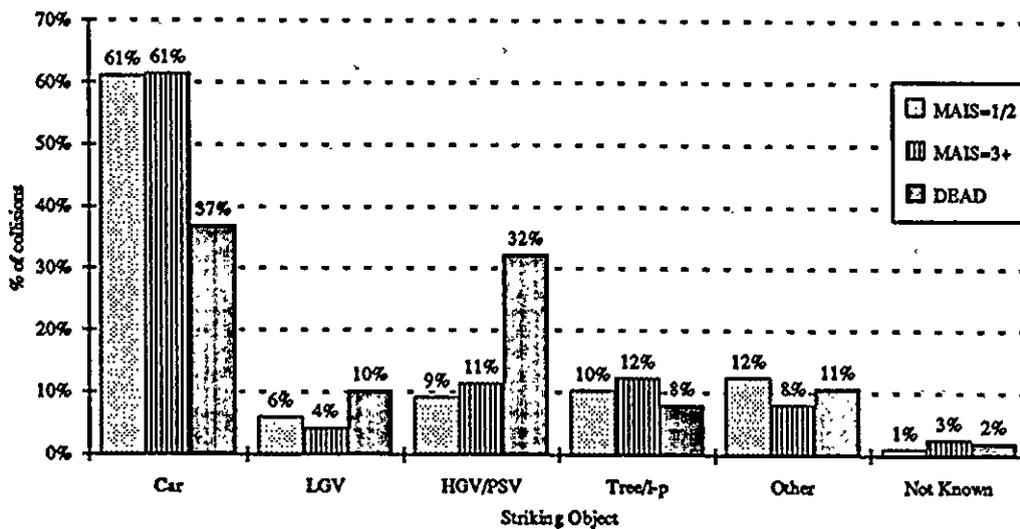
Crash Characteristics

The vehicles in the population were classified according to the most severe injury sustained by any of the occupants as measured by the maximum AIS. "MAIS 1-2" injuries have a maximum AIS of 2 while "MAIS 3+" injuries have an AIS of at least 3 although the casualty survived. "Fatal" casualties died within 30 days of the crash.

Striking Object

Figure 1 shows the distribution of the type of striking object. The term "small van" refers to EC classification N1 while HGV/PSV refers to trucks and buses of classification types N2, N3, M2 and M3.

Figure 1: Striking Objects



Collisions with cars are the most common at all severities of injury. 61% of the MAIS 1/2 and the MAIS 3+ occupants were involved in collisions with cars as were 37% of the fatalities. Collisions with trucks and buses and with narrow objects such as trees and lamp posts were also common where MAIS 3+ injuries were sustained forming 11% and 12% of the collisions respectively. Collisions involving trucks and buses were frequent in fatal collisions forming 32% of all fatal frontal crashes.

Overlap

The overlap between the case vehicle and striking object was measured and calculated as a proportion of the car width. Figure 2 shows the cumulative distribution of overlap for the whole accident population and the separate severity groups.

The cars in which occupants sustained fatal injuries tended to have larger percentages of overlap than cars where only minor injury was sustained. The 50th percentile values of overlap are shown in Table 2.

Figure 2: Cumulative Distribution Of Frontal Overlap

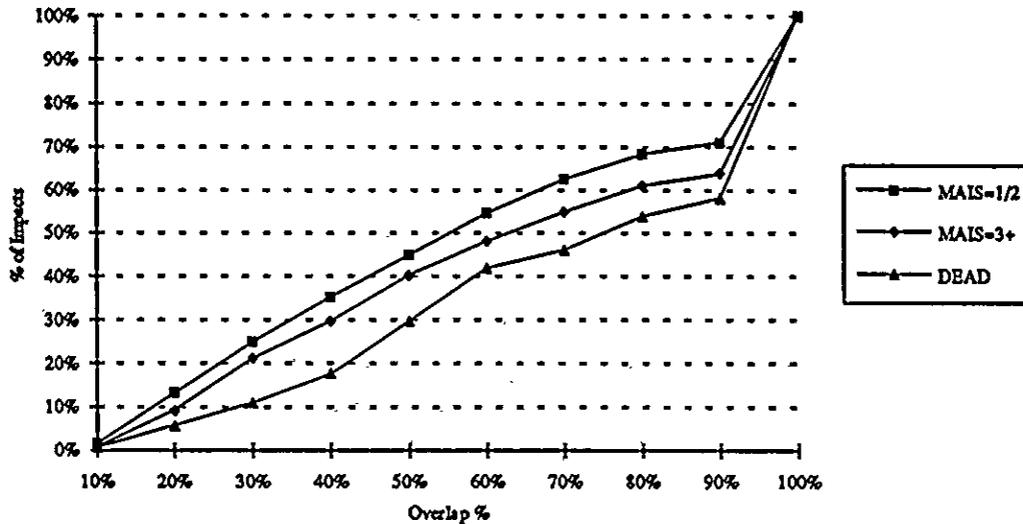


Table 2: 50th Percentile values of overlap

Maximum severity in car	50th Percentile Overlap Value
All Injuries	60% of car width
MAIS 1-2	55% of car width
MAIS 3+	63% of car width
Fatal	74% of car width

Half of the whole population of vehicles sustained a frontal overlap of 60% of the car width or less while 50% of the cars with fatalities sustained overlaps of 74% or less. 39% of cars where MAIS 3+ injury was sustained received a frontal overlap less than half the width of the car. Only 29% of fatal crashes involved less than half the car width and in 39% of fatal crashes the complete car front was loaded.

These fatal crashes with full overlap were predominantly impacts with trucks or with the front or sides of other cars. Although they did experience loading across the full

front of the vehicle a visual inspection identified that in many cases the loading was still concentrated onto less than half the width of the car. A more detailed examination of these cases is essential before the importance of full overlap in fatal crashes can be fully understood.

The loads applied to a car when it is in collision with another car can be very different to collisions with trucks or poles. Trucks and bus impacts frequently apply loads above the longitudinal members of the vehicle and often above the level of the engine. When the front of a moving truck is struck the energies are often large and there is considerable intrusion into the passenger compartment. The countermeasures include underrun guards fitted to the truck front and, in the future, collision avoidance systems. The fitting of front underrun guards to trucks has been estimated as having the potential of preventing 30% of fatal car crashes involving trucks.⁵ Collisions with lamp-posts and trees can apply concentrated loads to the complete height of the car in a uniform manner. The impact energies to be absorbed by the car can again be higher than in collisions with a deformable object. For these reasons it is considered that car to car collisions are of primary interest so the remainder of this section on crash characteristics concentrates on car to car collisions.

The summary values for the distribution of front overlap all car to car crashes are shown in Table 3.

Table 3: Summary values of overlap of car to car crashes.

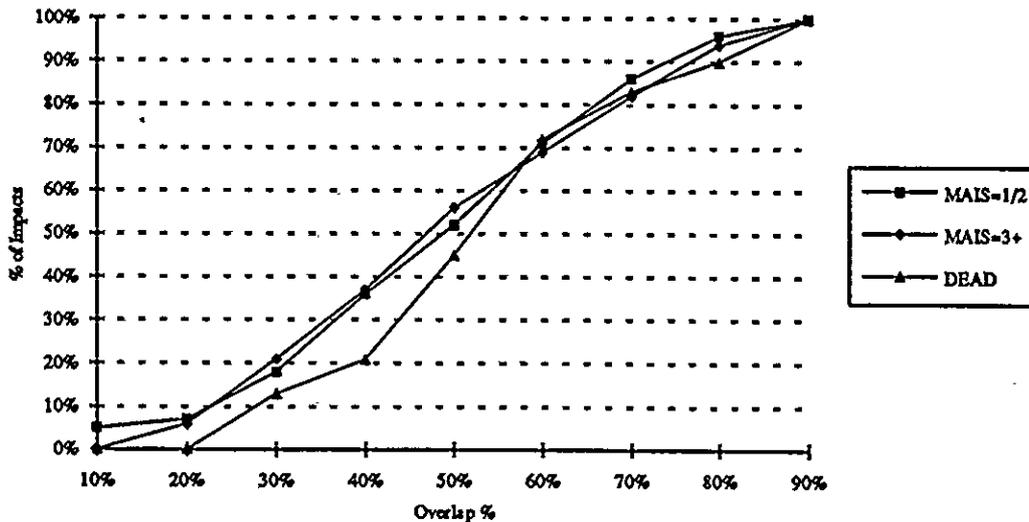
Overlap Values - Car to car Impacts - Weighted				
Variable	All Severities	MAIS 1-2	MAIS 3+	Fatal
% below 40% of car width	25%	25%	22%	11%
% below 50% of car width	35%	36%	34%	27%
50th % ile	62%	61%	70%	86%
% above 90%	31%	30%	38%	44%

When car to car crashes of all injury severities are examined the median value of frontal overlap was found to be 62% of the car width. Half of all MAIS 3+ crashes sustained a front overlap below 70% of the car width while 34% sustained an overlap below 50% of the car width. Fatal crashes frequently involved the complete width of the car. These impacts were with either the front of other cars or with a car side and 44% of all fatal crashes sustained a front overlap above 90% of the car width.

⁵Analysis of fatal accidents involving heavy goods vehicles - front underrun accidents in 1988. P Thomas and L Clift. TRL Contractor Report 289

The load paths of vehicles which are loaded across the complete car front can be different from a partial overlap condition. The full overlap crashes can be considered a special case. Figure 3 shows the distribution of overlap when the full overlap crashes are removed. The figure highlights the similar distribution in partial overlap across all injury severities. In these crashes between 45% and 55% of all crashes and all injury severities sustained an overlap of 50% of the car width or less.

Figure 3: Cumulative distribution of partial overlap - car to car crashes - excluding 100% overlap.

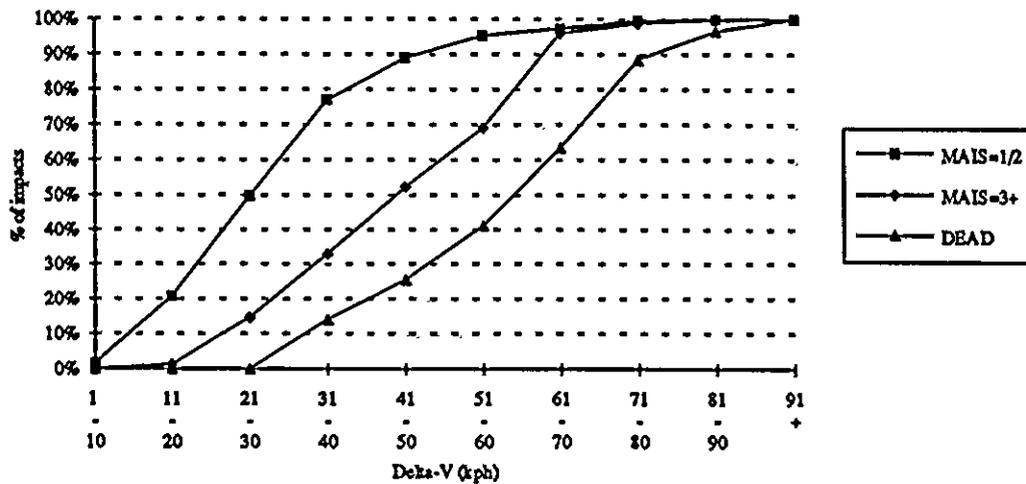


Impact Severity

The severity of the impact was estimated using the CRASH3 computer program. This program calculates the deformation energy from the residual crush and standard stiffness values, the energy is then converted to the velocity change during the impact. Due to the restrictions of the computer program it was only possible to calculate the delta-V in 35% of MAIS 1-2 cases, 61% of MAIS 3+ and 53% of fatal car to car crashes. Figure 4 shows the cumulative distribution of those car to car crashes where the delta-V was known.

The median delta-V for the complete population of car to car frontal collisions was 32 kph reflecting the large number of cars with occupants injured to MAIS 1-2 for which the median value was 31 kph. The MAIS 3+ and fatal injury groups were typically involved in more severe collisions with median delta-Vs of 49 kph and 64 kph respectively. 11% of MAIS 1-2 injury crashes, 48% of MAIS 3+ injury crashes and 74% of fatal crashes have delta-Vs above 50 kph.

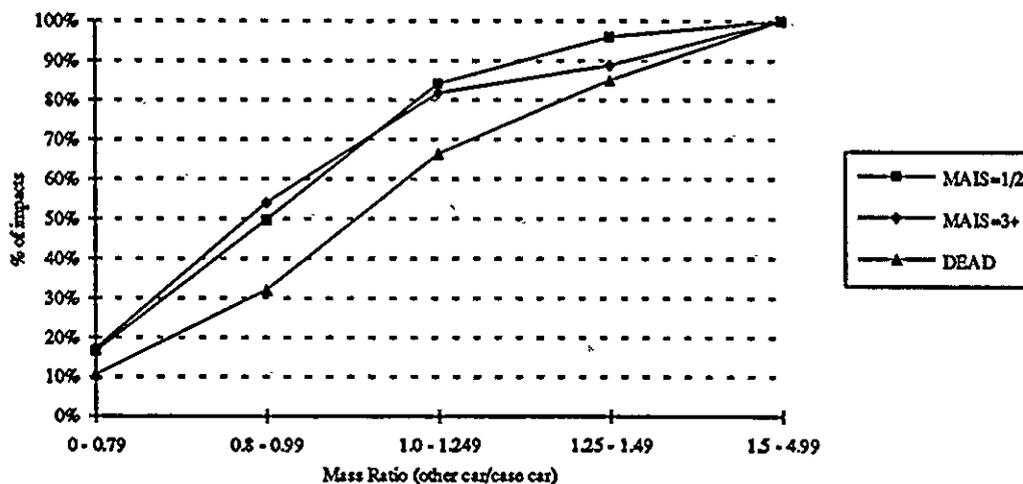
Figure 4: Cumulative delta-V distribution - car to car crashes



Mass Ratio

The inertial properties of a car influence the injury outcome and the ratio of the mass of the striking vehicle to the case vehicle can be used as a measure of the severity of the impact. The distribution of mass ratio is shown in Figure 5 for all car to car crashes.

Figure 5: Mass Ratio - car to car crashes



The median values of the mass ratio for the complete population of crashes was 1.00. MAIS 1-2 and MAIS 3+ collisions had values of 1.03 and 0.99 respectively. Fatal crashes tended to involve collisions with slightly heavier objects as the median mass ratio was 1.07. The small variation of mass ratio between injury severities indicates that other factors such as impact severity and intrusion may be of greater importance.

Occupant Details

There were 11665 occupants seated in the population of 6662 vehicles and Table 4 shows their seating position and restraint use. The final column shows the restraint use rates with the occupants with unknown use excluded.

Table 4: Restraint use and seat position

Seat Position	Restraint Use			Restraint use rate
	Restrained	Unrestrained	Not Known	
Front Right	4954	612	1094	89%
Front Left	2044	281	494	88%
Rear	264	1896	15	9%
Other	1	10	0	2%
Total	7263	2799	1603	-

The seat belt use rate for drivers and front seat passengers was 89% and 88% respectively and is compatible with that observed in the UK population.

Pattern of Injuries

The severity of each injury was measured using the Abbreviated Injury Scale. The scale assesses the threat to the life of the casualty and ranges from a value of 0 meaning "Uninjured" to 6 meaning "Currently unsurvivable". Table 4 shows that there were 6998 restrained front seat occupants and 6191 of these sustained an injury. Table 5 shows the pattern of injuries of these restrained occupants.

Injuries to the legs were the most common being sustained by 59% of all injured occupants. Chest injuries ranked second (55%) followed by arm injuries (47%). The head was least frequently injured.

The injuries to each body region are dominated by the large number of minor AIS 1 injuries representing cuts, bruises and abrasions. These injuries have a very low threat to life and are frequently considered to be unavoidable and of little importance despite their high frequency. A more important group of injuries are those of AIS 3 and above which have a significant threat to life and may also result in long-term impairment to survivors. The frequency with which each body region sustains AIS 3+ injuries is shown in Table 6 for the two groups of restrained front seat AIS 3+ survivors and AIS 3+ fatalities. The table also gives the total number of casualties in each group who sustained at least one AIS 3+ injury. Note that the total of injured body regions does not equal the total number of occupants as not every occupant has an AIS 3+ injury to every body region.

Table 5: Pattern of injuries - 6191 restrained front seat occupants with injuries.

AIS	No Injury	1	2	3	4	5	6	Total
Head	4945	648	471	50	23	36	18	6191
%	(80%)	(11%)	(8%)	(1%)	(0.4%)	(0.6%)	(0.3%)	(100%)
Face	3725	2192	239	26	8	0	0	6191
%	(60%)	(35%)	(4%)	(0.4%)	(0.1%)	(0%)	(0%)	(100%)
Spine	4769	1315	72	28	0	3	4	6191
%	(77%)	(21%)	(1%)	(0.5%)	(0%)	(0.0%)	(0.1%)	(100%)
Chest	2806	2776	444	68	53	31	13	6191
%	(45%)	(45%)	(7%)	(1%)	(0.8%)	(0.5%)	(0.2%)	(100%)
Abdomen	4539	1529	69	13	20	20	0	6191
%	(73%)	(25%)	(1%)	(0.2%)	(0.3%)	(0.3%)	(0%)	(100%)
Arms	3301	2296	493	100	0	0	0	6191
%	(53%)	(37%)	(8%)	(2%)	(%0)	(0%)	(0%)	(100%)
Legs	2558	3104	323	204	2	0	0	6191
%	(41%)	(50%)	(5%)	(3%)	(0.0%)	(0%)	(0%)	(100%)

Table 6: Pattern of AIS 3+ injuries - restrained front seat occupants.

Body Region	MAIS 3+	(%)	Fatal	(%)
Head	50	(15%)	77	(63%)
Face	20	(6%)	13	(11%)
Chest	69	(21%)	96	(78%)
Abdomen	16	(5%)	37	(30%)
Spine	22	(7%)	13	(10%)
Arms	85	(25%)	16	(13%)
Legs	158	(47%)	48	(39%)
Total casualties	339		122	

Amongst the survivors leg injuries (47%) were the most frequent followed by arm (25%) and chest (21%) injuries. The chest (78%), head (63%) and the legs (39%) were the most common sites of AIS 3+ injury amongst the fatalities and multiplicity of AIS 3+ injury was 1.24 and 2.45 for the two groups.

The considerable variation in injury patterns between survivors and fatalities has implications for the priorities that may be attached to countermeasures. The group of seriously injured survivors in the population is 2.8 times as large as the group of fatalities so the mitigation of their injuries can benefit greater numbers than the prevention of fatality. It is important that countermeasures are introduced that will reduce the number of their AIS 3+ leg and arm injuries. These injuries are very

common and can result in long-term mobility and manipulative difficulties. The countermeasures to reduce fatalities must address chest, head and abdomen injuries. Single countermeasures may have an effectiveness that is lower than expected since, for example, if only chest injuries are addressed there will still be many fatalities with a MAIS 3+ head injury. In the complete population of fatalities studied there were 75 (43%) of the fatalities with both an AIS 3+ chest and an AIS 3+ head injury.

Injury Sources

To target countermeasures to the most life threatening or impairing injuries it is useful to identify the key sources of injury. The 6191 restrained front seat occupants with injuries sustained a total of 27121 injuries and it was possible to identify the causes of 20793 of these. The distribution of these contacts is shown in Figure 6.

Figure 6 also uses the Harm scale to produce a single figure that measures the total economic cost of injuries from each contact zone. The Harm scale attaches a cost to each severity of injury. The full scale is shown in Table 7.

Table 7: Harm scale

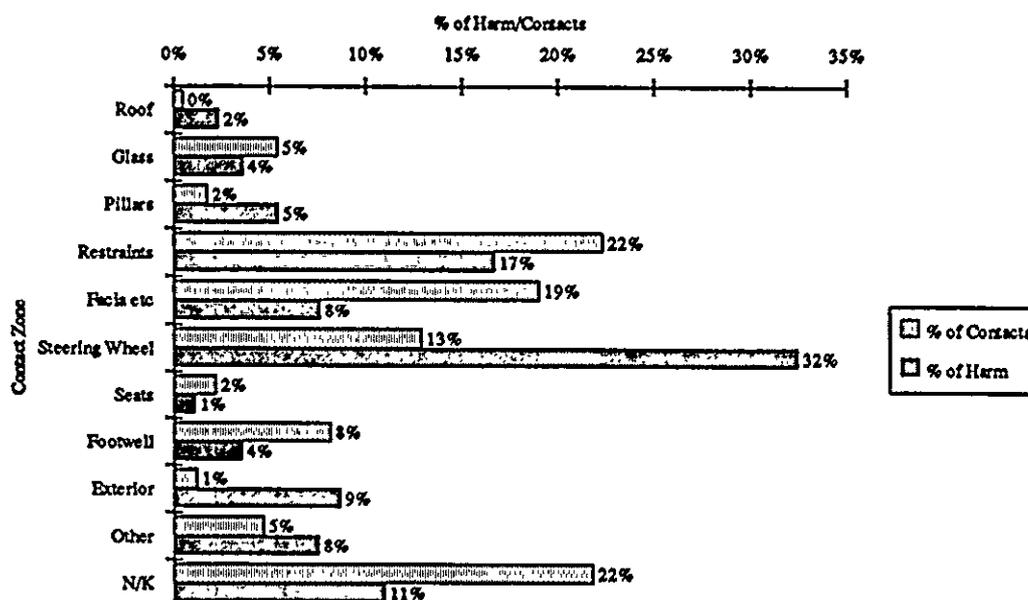
AIS Level	Harm (000s 1981 US \$)
1	0.7
2	3.9
3	10.2
4	107.1
5	264.5
6	307.8

The Harm scale has short-comings as it does not distinguish between the economic costs of injuries to different body regions but with the same AIS value. It is also based on the costs of injuries in the US in 1981. The scale is useful though as it allows the total cost of injuries from a single source to be combined in a single measure that also balances frequent minor injuries with relatively rare life-threatening injuries. Figure 5 also shows the percentage of the total harm attributable to each contact zone.

The parts of the car most frequently contacted by the 6191 restrained front seat occupants with injuries were the restraint (22%), facia (19%) and steering system (13%). Where there is a mismatch between the percentage of contacts and the percent of Harm attributed to a contact zone that zone can be interpreted as having a different risk of serious injury to the whole set of contacts. For example 19% of all contacts were with the facia and each one of these contacts was associated with an injury. The severity of these injuries was lower than average since the injuries only resulted in 8% of the total Harm. On the other hand the steering wheel represented only 13% of all contacts but was associated with 32% of all Harm indicating that either the steering system is a particularly hazardous contact zone or that the wheel is only contacted in high energy impacts where the chance of serious injury is greater. Other apparently

hazardous contact zones were exterior objects (1% contacts, 9% Harm) and the pillars (2% contacts, 5% Harm). Apparently benign zones were the facia (19% contacts, 8% Harm) and footwell (8% contacts, 4% Harm)

Figure 6 Contacts and Harm - 6191 Injured Front Seat Occupants



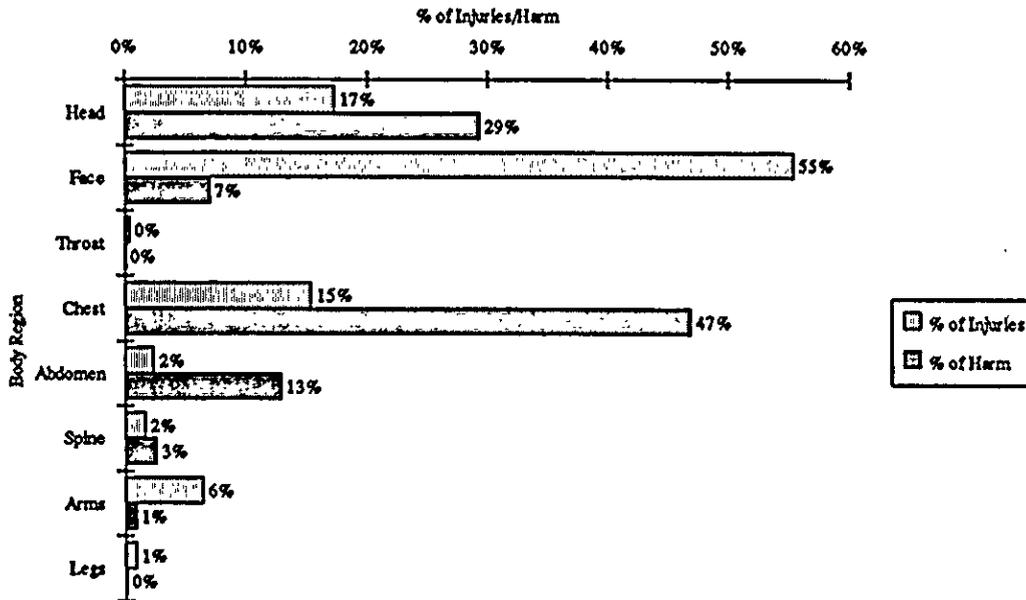
22% of the total contacts were with unidentified sources. When real-world crashes are investigated a frequent problem concerns identifying the causes of minor bruises and lacerations as low energy contacts may leave no evidence in the vehicle. Most of the unidentified contacts caused minor injuries and they represented only 11% of the total Harm.

Steering System Injuries

Contact with the steering wheel has been revealed as a major cause of head, face and torso injury and the use of airbags has been suggested as a supplementary restraint system to mitigate steering wheel contact. Smaller airbags called "Eurobags" or "Facebags" have been suggested as an economic way of reducing head and face injuries. The frequency with which the steering wheel caused injury to each body region of the restrained drivers and the distribution of the resulting Harm is shown in Figure 7.

Figure 11 shows that 72% of all steering wheel injuries were to the head or the face. The resulting injuries accounted for only 36% of the Harm. Contacts with the chest or abdomen were less frequent at 17% but the represented 60% of the Harm.

Figure 7: Injuries and Harm from Steering Wheel Contact - restrained drivers



A recent Australian study⁶ has compared the cost effectiveness of full-sized airbags and facebags and concluded that only full-sized airbags will be cost beneficial. Figure 11 suggests that whatever the size of airbag that is deployed the design that mitigates torso injuries has the biggest potential for injury reduction.

Summary of crash characteristics

MAIS 1-2 injury crashes typically involve another car with a median delta-V of 31 kph and a frontal overlap of 55% of the car width.

MAIS 3+ injury crashes typically involve another car although trucks and poles are also common striking objects. The median delta-V of car to car impacts is 49 kph and the frontal overlap 61%. 34% of cars sustained below 50% overlap while 38% sustained 100% overlap. Serious injuries to the legs are very frequent followed by arm and chest injuries. Each MAIS 3+ occupant sustained an average of 1.2 body regions injured to AIS 3+.

Fatal injuries are typically caused by high severity collisions with aggressive objects, collisions with trucks and buses are nearly as frequent as cars. The median overlap is 74% but only 27% sustain below 50% overlap while 44% sustain 100% overlap. The median delta-V is 64 kph while the striking object is most frequently a car but impacts

⁶Airbag and Facebag Benefits and Cost. BN Fildes, MH Cameron, AP Vulcan, KH Digges, D Taylor. 1992 IRCOB Conference

with trucks or buses are nearly as common. The mass ratio of car to car impacts is typically 1.07 but the frequent impacts with trucks and poles inherently imply the incidence of collisions with very stiff, high effective mass objects. AIS 3+ injuries to the chest and head are very common and the multiplicity of AIS 3+ injury is high at 2.5 AIS 3+ body regions per fatality..

Implications for a revised crash test procedure.

Before any new crash test procedure can be developed it has to be established what the objectives are to be. The objective might be to reduce fatal injuries, to reduce the serious injuries of the survivors or both. The difference in crash conditions is sufficiently substantial that a choice may have to be made otherwise several different tests must be employed.

This analysis has highlighted the substantial differences between the crash conditions leading to serious and to fatal injury.

There are three types of test procedure frequently discussed as methods of improving frontal crash protection. These are a 60 kph impact into a 40% deformable barrier, a 50 kph impact into a 50% rigid barrier and a 55 kph impact into a full overlap 30° barrier.

MAIS 3+ injury crashes frequently involve an overlap of less than 50% and most have a delta-V below 50 kph. The partial overlap test would seem to reproduce many of the circumstances where MAIS 3+ injury occurs. If this test reflects the deformable characteristics of car to car crashes then the realism is improved.

An improved test procedure that is intended to reduce MAIS 3+ injuries should encourage car designs that offer substantial improvements to occupant leg protection. The current understanding of the bio-mechanics of lower leg injuries is incomplete and the influence of the pedals and of intrusion has yet to be fully established. There is a need for further research into the mechanisms of lower leg injury to ensure that the test dummies can successfully discriminate between good and bad designs.

A 50% overlap test collision with a delta-V of 50 kph does not appear to reproduce the circumstances of fatal injury that most commonly occur. 74% of fatal collisions involve a higher impact velocity and 40% involve loads applied to the complete front of the car although these loads were not always evenly distributed. Collisions with trucks and buses are nearly as common as with other cars. A crash test with a full overlap barrier would reproduce the circumstances of fatal injury better if the delta-V were to be 64 kph or above. This analysis does not indicate whether such a barrier need be angled.

Car to car impacts were the most common type of frontal collision at all injury levels. Although many fatal crashes involve impacts with trucks or buses these often involve high impact severities and extensive underrun. As a result the most effective passive countermeasures might best be applied to the truck but it has to be accepted that many of these fatal crashes are unsurvivable with current technology. It would appear that a

test which simulates a car to car collision would reproduce the conditions where the majority of preventable serious and fatal injuries occur.

This paper has not analysed the incidence and consequences of intrusion in any detail. Other studies⁷⁸ have shown that intrusion can be a key factor in injury causation as it can increase the chance of contact with a zone and this contact area may still be intruding with a consequently greater contact velocity. Intrusion is also a measure of the response of the car structure to the input loads and is therefore a measure of impact severity. A detailed analysis is required to separate the effects of the two factors.

Conclusions

- The circumstances where AIS 3+ injuries alone occur are very different from the circumstances of fatal injury. There is a wide variation of crash conditions within both serious and fatal groups.
- AIS 3+ injuries typically occurred in car to car impacts with a median delta-V of 49 kph. 34% of cars sustain an overlap of less than 50% of the cars width. 47% of seriously injured casualties sustain AIS 3 leg fractures.
- A test involving an impact into a barrier simulating a 50% overlap car to car impact appears to reproduce the circumstances where many AIS 3+ injuries occur.
- Fatal collisions are often very severe with 50% involving a delta-V above 64 kph. Overlap of 50% or below only occurs in 27% of fatal collisions however many of the cars with loading across the complete front of the vehicle still have loads concentrated to one side. 37% of collisions are with cars while 32% involve collisions with trucks or buses.
- This paper demonstrates that a thorough understanding of the circumstances and nature of car occupant injuries can aid the development of test procedures considerably.

⁷The Nature and Cause of Leg Injuries in Car Crashes. Dan Pattimore, Edmund Ward, Pete Thomas, Mo Bradford. Stapp Conference San Diego, 1991

⁸Head and Torso Injuries to Restrained Drivers from the Steering System. Pete Thomas. IRCOBI Conference 1987

Further Analysis

This analysis has identified a number of areas where there is a need for a more detailed examination of the real-world crash data so that the requirements of a new frontal test procedure might be accurately identified and appropriate countermeasures be produced.

- The range of crash conditions where each of the proposed tests might reduce injuries needs to be compared with the spread of real-world crash types.
- The manner of crash loading to the car front structure needs to be evaluated in detail.
- There is a need for a thorough examination of the consequences of intrusion and to separate out impact severity effects.
- There is a need for an evaluation of the relative benefits of full-size and small airbags in European conditions.
- There is a need to understand the interaction between a restrained torso and the steering wheel at a variety of impact severities.
- There is a need to understand the biomechanics of injuries to all parts of the leg and the effect of intrusion.

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