MULTIPLE IMPACT CRASHES – CONSEQUENCES FOR OCCUPANT PROTECTION MEASURES

Paul A. Fay and Raimondo Sferco, Ford Motor Company, UK and Germany.
Richard Frampton, Vehicle Safety Research Centre, Loughborough University, UK.

ABSTRACT

Much analysis of accident data and most crash tests focus on single impacts. However, in reality, multiple impacts account for a large proportion of serious injury accidents and are expected to become a larger proportion as countermeasures, developed primarily for single mode impacts, take effect. It is proposed that multiple impacts should be considered separately since consideration of their characteristics may have implications for occupant protection.

This study investigates multiple impacts in more detail and, in particular, explores their relative importance in the accident population, analyses their characteristics and discusses some possible consequences for occupant protection measures.

Key Words: Accident Analysis; Multiple Impacts; Rollovers; Restraint Systems

WHEN ANALYSING real world accident data, it is common to group accidents into to the 4 simple modes of frontal impacts, side impacts, rear impacts and rollovers. This approach has been adopted by numerous authors from accident research organisations around the world (for example, see Otte, 1988). Some authors have refined this approach slightly by separating side impacts into those where the impact occurred to the side of the vehicle on which the occupant was sitting and those where it occurred to the opposite side (Frampton, 2000; Stolinski, 1998), but the focus has still largely been on single impacts.

Similarly, most of the crash tests required by legislation (for example, see UN-ECE, 1998) and those carried out for consumer information programmes, such as Euro-NCAP (Hobbs, 1998), aim to replicate single impacts between two vehicles or between a vehicle and a fixed object. Furthermore, the vehicle safety ratings produced by retrospective analyses of real world accident or insurance claim data mainly focus on simple car-to-car accidents (Cameron, 1996).

In practice, the situation is more complicated than the simple 4 way distributions of accidents suggest because of the large number of vehicles which suffer multiple impacts. By dividing accidents into the 4 simple categories, a large number of multiple impacts are either uncategorised or incorrectly categorised.

Different organisations have chosen different methods for allocating multiple impacts to simple, single impact groups. Techniques include:

1. Considering the most severe impact only (eg by choosing the impact with the highest delta-V/EES or judging which impact was most likely to have the highest injury risk)
2. Considering the sequence of events and selecting the first impact only

3. Allowing one impact mode to take precedent over the others (eg it is common practice in the U.S. for any impact sequence in which a rollover occurs to be classed as a rollover accident).

It is the belief of the authors that all these techniques can be unreliable and potentially give misleading conclusions. It is proposed that a more reliable way of categorising accidents is to consider multiple impacts and single impacts as separate categories.

Some authors have separated multiple impacts from single impacts, usually to exclude them from more detailed analysis by impact mode rather than to investigate them in more detail (Hobbs, 1980; Fildes 1990; Jakobsson, 1994; Kullgren, 1996; Mackay, 1997; DeSantis Klinich, 2000).

Other studies have considered multiple impacts in some more detail. Neilson (1984) reported that head injuries in side impact can occur as a result of double or multiple impacts with almost anything within the car. Adams (1990) described how multiple impacts were considered during development of an airbag sensing system. He looked at a subset of cases where a frontal impact was the most severe impact suffered by a vehicle. In 68% of cases, the vehicles only sustained a single impact. For the remainder, the multiple impacts, the frontal impact was the first impact in approximately 2/3 of cases. In half the cases, the frontal impact was followed by a side impact. van Kampen (1993) looked at the increasing number of rear impacts in the Netherlands and reported an apparent large change from single rear-end collisions to multiple chain collisions. Otte (1997) described multiple impacts as "very frequent" in accidents involving cervical spine distortion and, in 1998, he also reported that 33% of people with arm injuries were injured in multiple impacts (Otte, 1998). Hell (1998) concluded that the severity of soft tissue neck injury was no greater in multiple collisions than in single car-to-car rear impacts. Temming (1998) identified multiple impacts as second only to frontal impacts with regard to the number of injuries sustained by belted occupants.

Multiple impacts have also been analysed in more detail for collisions involving pedestrians (e.g. Stcherbatcheff, 1977) and motor cyclists (e.g. Vallée, 1981) where there is a significant risk of multiple impacts to vulnerable body regions (for instance, a head impact against a vehicle may be followed by a head impact against the ground).

Multiple impacts are expected to become a larger proportion of the total accident population as the latest countermeasures, developed primarily for single mode impacts, take effect. It is felt that a deeper study of the current status of multiple impacts is required since consideration of the characteristics of multiple impacts may have implications for occupant protection.

This study investigates multiple impacts in more detail and, in particular, explores the relative importance of multiple impacts in the total accident population, analyses the characteristics of multiple impact events and discusses some possible consequences for occupant protection measures.

TERMINOLOGY – MULTI-VEHICLE IMPACTS VS. MULTIPLE IMPACTS

When moving away from considering accidents in the four simple impact modes described above, there are two additional categories of accidents which could potentially be considered: i) Multiple Vehicle Impacts (i.e. accident sequences involving more than two vehicles) and ii) Multiple Impacts (i.e. accident sequences in which any individual vehicle suffers more than one impact).

Multiple vehicle impacts are an important subset of accidents. For example, Table 1 shows the distribution of car occupant fatalities in Great Britain according to the number of vehicles involved in the accidents.

Single vehicle accidents	503
Accidents with two vehicle	841
Accidents with 3 or more vehicles	343
Total	**1687**

Table 1: Number of car occupant fatalities according to number of vehicles involved (DETR, 2000)

These figures indicate that approximately 20% of car occupant deaths occur in multiple vehicle accidents. Rosman (1998) gives a more detailed analysis of multi-vehicle accidents in Australia.

However in multi-vehicle impacts, some of the vehicles involved will only receive a single impact whilst others will receive 2 or more impacts. It is also the case that many of the vehicles experiencing multiple impacts are not actually involved in multi-vehicle impacts (e.g. a single vehicle crash may include multiple impacts). For these two reasons, it is suggested that using multi-vehicle impacts as an additional category for analysis is not advisable.

In this study therefore, the authors considered true multiple impacts only (i.e. accident sequences in which vehicles suffer more than one impact).

METHODOLOGY AND DATA SOURCES

In-depth accident data from the UK and Germany were used investigate the importance and characteristics of multiple impacts.

The UK data comes from the Co-operative Crash Injury Study (or "CCIS") (Mackay, 1985) and the German data from the Medical University of Hannover study (or "MHH") (Otte, 1994) and the German In-Depth Accident Study (or "GIDAS") (BASt/FAT, 2001). CCIS data was available from calendar years 1992-2000 and MHH/GIDAS data from 1996-2000.

Each study selects cases for investigation using a random sampling procedure based on injury severity. In the German study, that injury severity is based on any road user in an accident. In the UK study, injury severity is based on injury to car occupants only. In both studies there are many common variables but there are some differences in the manner in which multiple impacts are coded.

In the MHH/GIDAS database, provision is made to code up to six impacts. Each impact to a vehicle is coded separately. This means that all relevant crash reconstruction variables are available for each impact. The variables include impact severity, sequence, collision partner and other impact related information (e.g. CDC). It is rarely possible however to determine in which impact an occupant received a particular injury.

In CCIS, provision is made to describe up to three impacts plus rollover. The number of impacts greater than three is not recorded. Impacts are coded in sequence unless the sequence is not known. In that case, the order is based on an evaluation of which impact(s) held the highest risk of occupant injury.

Injury outcome is assessed in each study using the Abbreviated Injury Scale, although it is possible that different coding conventions are used in the different studies.

In this preliminary analysis, no account has been taken of crash severity. Previous analysis by the authors has shown that crash severity measures are difficult to compare between CCIS (which uses estimates based on vehicle deformation) and MHH/GIDAS (which uses estimates based on accident reconstructions). These differences become more difficult in the case of multiple impacts where the fundamental question, "What is meant by the severity of a multiple impact?" cannot yet be adequately answered. This aspect will be investigated further in future work.

RESULTS

THE IMPORTANCE OF MULTIPLE IMPACTS **–** In order to determine the overall significance of multiple impacts in the accident population, both databases were analysed and, where known, the vehicles were grouped according to impact configuration. This was carried out initially for all accidents, irrespective of injury severity. The analysis is summarised in Table 2. For both datasets, single frontal impacts were the most common impact configuration, followed by multiple impacts. Multiple impacts were more common than side impacts. Single rollover events were infrequent in both datasets.

Impact Type	**German Data**	**UK Data**
Single Front	43.6%	45.0%
Single Side	19.3%	17.0%
Single Rear	10.2%	4.0%
Single Rollover	0.4%	5.0%
Multiple Impact	26.5%	29.0%
Total %	100.0%	100.0%
Total N	5472	9288

Table 2: Distribution of Impact Configurations for German and UK data (all injury levels)

This analysis was then extended to look at the distribution of impact configuration as a function of the maximum injury severity sustained in the vehicle. The results are given in Table 3 for the German data and in Table 4 for the UK data.

	MAIS 0	**MAIS 1+**	**MAIS 2+**	**MAIS 3+**	**MAIS 4+**
Single Front	49%	33%	35%	33%	31%
Single Side	22%	15%	17%	21%	20%
Single Rear	11%	10%	2%	2%	2%
Single Rollover	0%	1%	1%	1%	1%
Multiple Impact	18%	41%	46%	43%	46%
Total %	**100%**	**100%**	**100%**	**100%**	**100%**
Total N	**4219**	**3427**	**808**	**290**	**156**

Table 3: Distribution of Impact Configuration by Injury Severity – MHH/GIDAS Data

	MAIS 0	**MAIS 1+**	**MAIS 2+**	**MAIS 3+**	**MAIS 4+**
Single Front	47%	45%	47%	41%	34%
Single Side	18%	16%	19%	25%	27%
Single Rear	4%	4%	1%	1%	1%
Single Rollover	4%	6%	4%	4%	5%
Multiple Impact	27%	29%	30%	30%	33%
Total %	**100%**	**100%**	**100%**	**100%**	**100%**
Total N	**1697**	**7591**	**2610**	**1157**	**578**

Table 4: Distribution of Impact Configuration by Injury Severity – CCIS Data

The data suggests that multiple impacts represent an increasing proportion of accidents as the level of injury severity increases. In contrast, frontal impacts and rear impacts become less significant as injury severity increases. Side impacts increase slightly in the UK data but they remain fairly steady in the German data. The proportion of single rollovers remains relatively low and steady in both datasets. In the German data, multiple impacts account for more injury accidents than frontal impacts at all injury levels.

Clearly there are some differences between the distributions from the two datasets. These could be due to the different sampling criteria used in the two studies but could also include differences in road infrastructure, traffic levels, vehicle population and provision and use of vehicle restraint systems. However, despite the different sampling criteria, it can be seen that multiple impacts are a substantial proportion of the total injury accident population in both Germany and the UK.

CHARACTERISTICS OF MULTIPLE IMPACT EVENTS - Having identified the importance of multiple impacts in the total accident population, the next step was to investigate the characteristics of the multiple impact events in more detail and, in particular, to consider the nature of the impact sequences (in an attempt to group and/or classify the sequences) and the patterns of the injuries sustained by the occupants. As a result of the differences in the manner in which the two datasets record and classify multiple impacts, the analysis of the impact sequences involved in multiple impacts will be carried out separately for each dataset. This allows the differences between the datasets to be used to explore different aspects of the impact sequences rather than restricting the analysis to cover common variables only.

<u>CCIS – Analysis of Impact Sequences</u> - In CCIS, the multiple impacts can be split into three groups as shown in Table 5.

	N	%
2 impacts only	1641	61%
3 or more impacts	311	12%
Sequences including rollovers and impacts	720	27%
Total	**2672**	**100%**

Table 5 - General grouping of multiple impact sequences (CCIS)

This breakdown shows that over 60% of the multiple impact sequences consist of only two impacts. The second largest group consists of impact sequences which involve both rollovers and impacts.

Of the cases involving 2 impacts only, the type of impacts and the impact sequence was known in 1396 cases. These are shown in Table 6. The largest groups (over 20% each) involve either a frontal impact followed by a side impact or a side impacts followed by another side impact. Rear impacts or side impacts followed by frontal impacts also occur relatively frequently. It was also found that in cases where 2 side impacts occurred, there was an almost equal split between cases where the two impacts were on the same side of the vehicle and those where they were on opposite sides.

		2nd Impact		
		Rear	**Front**	**Side**
1st Impact	**Rear**	0.1%	15.5%	3.3%
	Front	7.2%	8.0%	26.2%
	Side	2.9%	13.9%	22.8%

Table 6: Types and Sequence of impacts in 2 impact sequences (CCIS) (N=1396)

The impact sequences involving both rollover events and impacts are a little more difficult to group and categorise. At a first level, CCIS allows the sequences to be split into those where the rollover event occurred first (followed by the impact(s)) and those where an impact occurred first (followed by the rollover and, in some cases, further impact(s)). This split is shown in Table 7.

	N	%
Rollover followed by Impact(s)	102	14%
Impact followed by Rollover (and subsequent impacts)	618	86%
Total	**720**	**100%**

Table 7: Distribution of Accidents involving Rollovers and Impacts according to Impact Sequence (CCIS)

It can be seen that in the vast majority of these sequences, the rollover element occurs following an impact or series of impacts. In these sequences, most of the rollovers (79%) occur after only a single impact. In these cases, 42% of the impacts were frontal impacts and 50% were side impacts. Most of the remainder of these sequences (18%) involved 2 impacts followed by a rollover. Only 14% of cases involved an impact sequence which started with a rollover event.

<u>MHH/GIDAS – Analysis of Impact Sequences</u> - In MHH/GIDAS, the multiple impacts can be grouped according to the number of separate impacts that were coded as shown in Table 8. This shows that nearly 70% of the sequences involve only 2 impacts.

No of Impacts	N	%
2	1003	69.1%
3	328	22.6%
4	89	6.1%
5	21	1.4%
6 or more	10	0.7%
Total	**1451**	**100%**

Table 8: Number of Discrete Impacts in Multiple Impact Sequences (MHH/GIDAS)

This is apparently higher than the equivalent figure for CCIS (see Table 5) but it should be noted that there are differences in the way in which rollover events are coded between the two datasets and the MHH/GIDAS figure will also include some rollovers occurring in combination with another single impact. Impact sequences involving more than two impacts become less frequent as the number of impacts increases, but it is interesting to note that there were 10 cases involving 6 or more impacts.

Table 9 shows the distribution of impact modes according to the sequential order of the impacts.

Part of Vehicle Impacted	1st Impact	2nd Impact	3rd Impact	4th Impact
Front	53.8%	44.4%	32.1%	29.6%
Side	29.3%	38.0%	39.3%	41.7%
Rear	16.2%	13.0%	14.9%	13.0%
Roof	0.4%	4.0%	11.2%	12.2%
Underside	0.3%	0.6%	2.6%	3.5%
Total	**100%**	**100%**	**100%**	**100%**
N	**5452**	**1399**	**430**	**115**

Table 9: Distribution of Impact Modes According to Impact Sequence (MHH/GIDAS)

It can be seen that whilst frontal impacts are the most frequent mode for first impacts, they become less frequent in subsequent impacts. In contrast, side, roof and underside impacts become more frequent in subsequent impacts. This suggests that rollovers also occur more frequently after an initial impact than as the first event in a sequence.

Table 10 shows the combination of impacts which occur as the first two impacts in the multiple impact sequences.

		2nd Impact				
		Front	**Side**	**Rear**	**Roof**	**Underside**
1st Impact	**Front**	14.7%	14.7%	6.3%	2.5%	0.2%
	Side	11.0%	20.2%	4.5%	1.4%	0.1%
	Rear	18.3%	2.7%	2.0%	0.1%	0.1%
	Roof	-	0.2%	0.1%	-	-
	Underside	0.6%	0.1%	-	-	0.1%

Table 10: Combinations of Impacts in Multiple Impact Sequences (MHH/GIDAS) (N=1391)

The conclusions from this analysis are broadly similar to those calculated for the 2 impact CCIS cases (shown in Table 6), with front or side impacts followed by side impacts occurring relatively frequently. Rear impacts followed by frontal impacts are also common. The German data however shows a higher proportion of frontal impacts followed by frontal impacts. It can also be deduced from this table that the rollover events mainly follow frontal impacts and, to a lesser extent, side impacts. Again, as with the UK data, it was also found that in cases where 2 side impacts occurred, there was an approximately equal split between cases where the two impacts were on the same side of the vehicle and those where they were on opposite sides.

Injury Patterns in Multiple Impacts - For this limited initial review of multiple impacts, a comparison is made between injury severity levels in all multiple impacts grouped together and those in other impact modes. A preliminary analysis of the body regions injured in multiple impacts (again all grouped together) is then given. Clearly this overview analysis needs to be extended to give a more detailed breakdown according to the different categories of multiple impact if countermeasures are to be developed, but the overview does allow some general trends to be identified. It should also be mentioned that this initial analysis covers all occupants in the vehicles, irrespective of seating position and belt usage. Once again, a more detailed breakdown including these factors will be required. However, it should be noted that belt wearing status in many of the multiple impacts cannot be determined with high confidence.

Table 11 shows the distribution of occupant injury severity levels for the different types of impact in the German dataset. Table 12 gives the same data from the UK data. The German data shows, perhaps not surprisingly, that there is a higher risk of being seriously injured in a multiple impact than in a single impact. The risk of being uninjured is substantially lower than in either frontal or side impacts.

	MAIS 0	MAIS 1	MAIS 2	MAIS 3+	Total	N
Frontal Impacts	64.3%	26.9%	5.7%	3.0%	**100%**	**3193**
Side Impacts	63.8%	26.6%	5.5%	4.1%	**100%**	**1465**
Rear Impacts	58.1%	40.1%	1.0%	0.7%	**100%**	**805**
Single Rollovers	12.9%	67.7%	9.7%	9.7%	**100%**	**31**
Multiple Impacts	35.3%	47.6%	11.3%	5.8%	**100%**	**2152**

Table 11: Maximum Occupant Injury Severity Level by Impact Type (MHH/GIDAS)

The UK data shows that there is a higher risk of being injured, for all impact types, compared with the German data. This is likely to be due to the UK accident sampling procedure. However, the risk of sustaining moderate injury (MAIS 2) in a multiple impact is second to a single frontal crash and the risk of serious injury (MAIS 3+) is second to a single side impact.

	MAIS 0	MAIS 1	MAIS 2	MAIS 3+	Total	N
Frontal Impacts	19.0%	51.8%	17.9%	11.3%	**100%**	**4218**
Side Impacts	20.0%	49.1%	12.7%	18.2%	**100%**	**1559**
Rear Impacts	20.0%	72.2%	4.7%	3.1%	**100%**	**360**
Single Rollovers	12.4%	66.0%	12.9%	8.7%	**100%**	**482**
Multiple Impacts	16.9%	54.4%	15.8%	12.9%	**100%**	**2672**

Table 12: Maximum Occupant Injury Severity Level by Impact Type (CCIS)

Looking at multiple impacts in more detail, Table 13 shows which body regions are injured and at what severity for the German multiple impact cases. The corresponding UK data is shown in Table 14. The German data shows that the head is the body region most frequently injured with over 30% of occupants receiving a head injury. Over 20% of occupants received injuries to the neck, chest and upper extremities. The head and chest were the body regions most frequently sustaining serious injuries. It was also noted that there were a few AIS 5 and 6 level injuries to the head, neck, chest and abdomen.

	MAIS 0	MAIS 1	MAIS 2	MAIS 3+	Total (N=2211)
Head	68.7%	20.7%	7.4%	3.1%	**100%**
Neck	75.1%	23.7%	0.5%	0.7%	**100%**
Chest	78.7%	16.0%	3.2%	2.1%	**100%**
Upper Extremities	79.3%	17.1%	2.7%	0.9%	**100%**
Abdomen	95.6%	2.5%	0.9%	1.0%	**100%**
Pelvis	96.3%	2.2%	0.8%	0.7%	**100%**
Lower Extremities	83.2%	13.1%	1.8%	1.9%	**100%**

Table 13: Distribution of Injuries by Body Region for Multiple Impacts (MHH/GIDAS)

The UK data (Table 14) also shows that the head is the region most frequently injured, with over 40% of occupants receiving a head injury. The head and chest were again the two regions most frequently sustaining serious injury but the actual injury rates in the UK data were higher. A few AIS 5 and 6 level injuries were also noted to the head, neck, chest and abdomen.

	MAIS 0	MAIS 1	MAIS 2	MAIS 3+	Total

					(N=2672)
Head	57.3%	28.2%	8.1%	6.3%	**100%**
Neck	65.1%	33.1%	0.9%	0.9%	**100%**
Chest	69.4%	20.6%	2.9%	7.1%	**100%**
Upper Extremities	59.3%	32.0%	7.0%	1.7%	**100%**
Abdomen	82.1%	13.8%	2.7%	1.5%	**100%**
Pelvis	96.1%	0.5%	2.5%	0.8%	**100%**
Lower Extremities	63.0%	30.1%	3.3%	3.6%	**100%**

Table 14: Distribution of Injuries by Body Region for Multiple Impacts (CCIS)

CONSEQUENCES FOR OCCUPANT PROTECTION

This paper has provided an initial review of the importance and characteristics of multiple impact crashes. Despite sampling differences between German and UK accident data, multiple impacts are shown to be important both in terms of frequency and of injury risk in both countries. An overview of the body regions injured in multiple impacts identified the head and chest as the regions most frequently sustaining serious injury. A more detailed analysis, broken down according to the types of multiple impacts, is required before the implications can be fully understood, but it is possible to raise some general issues regarding the possible consequences of multiple impacts for occupant protection. At this stage, only consequences for occupant restraint systems have been considered (since the head and chest are the body regions most affected) although it is acknowledged that there may also be some issues for vehicle structures.

<u>Phased deployment of different protection systems</u> – There may be some value in being able to deploy different parts of the restraint systems at different times. For example, if a frontal impact is followed by a side impact, it may be desirable to deploy the frontal impact restraint systems (airbags, pretensioners, etc) during the first impact and the side impact restraint systems in the subsequent impact.

<u>Duration of Inflation</u> – In multiple impacts including two or more impacts requiring the same components of the restraint system, there may be some value in maintaining inflation of airbags and similar components for longer periods to give additional protection for the subsequent impacts. This could apply for example if a side impact is followed by another side impact or a rollover event. The value in having inflation for a longer duration will need to be balanced against any need to vent airbags during loading by the occupant.

<u>Multiple Inflation of Airbags</u> – As an alternative to extending the duration of inflation of airbag systems, the possibility of re-inflating an airbag for a subsequent impact may be worth investigating.

<u>Position of Occupants</u> – In multiple impacts, the position of the occupants in the second and subsequent impacts may differ from that of normal driving. For example, the position of an occupant in a side impact may be different depending on whether or not he has just experienced a frontal impact. One consequence of this is that consideration should be given to the range of positions over which protection is provided by each component of the restraint system.

<u>Time Period Covered by Sensors, Control Modules and Deployment Algorithms</u> – Since the time period between the individual impacts in a multiple impact sequence may reach a few seconds, consideration should be given to ensuring that the control systems can operate over such a time period, especially when considering deployment of different restraint sytems at different times or re-inflating airbags.

CONCLUSIONS

1. Current regulatory and consumer information crash test programmes, as well as retrospective safety rating systems, usually only consider single impacts against other cars or fixed objects.
2. When analysing real world accident data, it is common to categorise accidents according to the 4 simple, single impact modes of frontal impacts, side impacts, rear impacts and rollovers. In practice, the situation is more complicated because of the large number of vehicles which suffer multiple impacts. It is therefore proposed that a more reliable way of categorising accidents is to consider multiple impacts and single impacts as separate categories.
3. Multiple impact crashes are a substantial proportion of accidents (nearly 30%) and this proportion is expected to increase as the latest countermeasures, developed primarily for single mode impacts, take effect.
4. Multiple impacts represent the greatest proportion of serious injury accidents in the German data and the second highest proportion in the UK data.
5. Over 60% of multiple impact sequences consist of only two impacts.
6. In general, in impact sequences involving both rollover events and impacts, the rollover element occurs following an initial impact. Only a small proportion of cases involved an impact sequence which started with a rollover event.
7. Compared to a single impact there is a comparable or higher risk of being seriously injured in a multiple impact.
8. The head is the body region most frequently injured in multiple impacts. It is also the region most frequently sustaining serious injuries in German data and one of the two regions most frequently seriously injured in UK data.
9. A substantial number of occupants received injuries to the neck, chest and upper extremities in multiple impacts. It was also noted that there were some very severe head, neck, chest and abdominal injuries.
10. When considering possible countermeasures for occupant protection in multiple impacts, there are a number of issues which should be taken into account.

ACKNOWLEDGEMENTS

The Co-operative Crash Injury Study is managed by TRL on behalf of the Department of the Environment, Transport and the Regions (Vehicle Standards and Engineering Division) who fund the project with Ford Motor Co. Ltd, Autoliv, Toyota Motor Europe, Honda and Volvo Cars Corporation. The data were collected by teams at the Vehicle Safety Research Centre, Loughborough University, The Accident Research Unit, Birmingham University and the Vehicle Inspectorate.

The Medical University of Hannover study (MHH) is funded by the Federal Highway Institute (BASt). A second team was set up in Dresden (TUD) and is funded by FAT (Forschungsvereinigung Automobiltechnik or Automotive Industry Research Association). The German In-Depth Accident Study (GIDAS) is a co-operation between the two projects.

REFERENCES

Adams, T G, Huang, M, Hultman, R W, Marsh, J C and Henson, S E (1990), The development of an advanced air bag crash sensing system, Proceedings of the XXIII Fisita Congress, Torino, May 1990, pp 159 - 164.

BASt/FAT (2000), GIDAS (German In-Depth Accident Study), Information Brochure, Bergisch Gladbach, (Germany), 2000.

Cameron, M, Newstead, S and Skalova, M (1996), The development of crashworthiness ratings in Australia, Proceedings of 15th Enhanced Safety of Vehicle Conference, Melbourne, May 1996, pp 1444 - 1457.

DeSantis Klinich, K, Schneider, L W, Moore, J L and Pearlman, M D (2000), Investigations of crashes involving pregnant occupants, Proceedings of the 44th Conference of the Association for the Advancement of Automotive Medicine, Chicago, October 2000, pp 37 - 56.

DETR (2000), Road Accidents Great Britain: 1999, The Casualty Report, The Stationery Office, London, September 2000.

Fildes, B N and Vulcan, A P (1990), Crash performance and occupant safety in passenger cars involved in side impacts, Proceedings of the IRCOBI Conference, Bron-Lyon, September 1990, pp 121 - 130.

Frampton, R J, Welsh, R H, Thomas, P D and Fay, P A (2000), The importance of non struck side occupants in side collisions, Journal of Crash Prevention and Injury Control, 22, 2000, pp 151-163.

Hell, W and Langwieder, K (1998), Reported soft tissue neck injuries after rear-end car collisions, Proceedings of the IRCOBI Conference, Göteborg, September 1998, pp 261 - 274.

Hobbs, C A (1980), Car occupant injury patterns and mechanisms, Proceedings of the 8th Experimental Safety Vehicle Conference, Wolfsburg, 1980, pp 755 - 768.

Hobbs, C A and McDonough, P J (1998), Development of the European New Car Assessment Programme (EURO NCAP), Proceedings of the 16th Enhanced Safety of Vehicles Conference, Windsor, May 1998, pp 2439 - 2453.

Jakobsson, L, Norin, H, Jernström, C, Svensson, S, Johnsén, P, Isaksson-Hellman, I and Svensson, M (1994), Analysis of different head and neck responses in rear-end car collisions using a new human-like mathematical model, Proceedings of the IRCOBI Conference, Lyon, September 1994, pp 104 - 125.

Kullgren, A (1996), Crash pulse recorder – results from car acceleration pulses in real life frontal impacts, Proceedings of the IRCOBI Conference, Dublin, September 1996, pp 211 - 222.

Mackay, G M, Galer, M D, Ashton, S J and Thomas, P D (1985), The methodology of in-depth studies of car crashes in Britain. SAE Technical Paper Number 850556, Society of Automotive Engineers, Warrendale, PA, 1985.

Mackay, G M (1997), A review of the biomechanics of impacts in road accidents, Crashworthiness of Transportation Systems: Structural Impact and Occupant Protection, edited by Ambrosio, J C et al, Kluwer Academic Publishers, Netherlands, 1997, pp 115-138.

Neilson, I D and Lowne, R W (1984), Some design requirements for side impact dummies intended for legislative testing and research, Proceedings of the IRCOBI Conference, Delft, September 1984, pp 325 – 335.

Otte, D (1988), Change in injury situation for belted front-seat car passengers in the course of development in vehicle construction, Proceedings of 32nd Stapp Car Crash Conference, Georgia, 1988, pp 125-137.

Otte, D (1994), The Accident Research Unit Hannover as example for importance and benefit of existing in-depth investigations, SAE Paper 940712, SP 1042, Detroit (USA), 1994.

Otte, D, Pohlemann, T and Blauth, M (1997), Significance of soft tissue neck injuries AIS 1 in the accident scene and deformation characteristics of cars with delta-V up to 10 km/h, Proceedings of the IRCOBI Conference, Hannover, September 1997, pp 265 – 283.

Otte, D (1998), Biomechanics of upper limb injuries of belted car drivers and assessment of avoidance, Proceedings of the IRCOBI Conference, Göteborg, September 1998, pp 203 – 216.

Rosman, D L and Ryan, G A (1998), Are recent Australian cars safer or are they just bigger?, Proceedings of the IRCOBI Conference, Göteborg, September 1998, pp 43 – 55.

Stcherbatcheff, G, Boulaire, J P, Tarrière, C, Fayon, A, Got, C and Patel A (1977), Severity of head-to-car and head-to-ground impacts of pedestrians, Proceedings of the IRCOBI Conference, Berlin, September 1977, pp 93 – 107.

Stolinski, R B, Grzebieta, R H and Fildes, B (1998), Side impacts protection – Occupants in the far side seat, International Journal of Crashworthiness, 3, 1998, pp 93-121.

Temming, J and Zobel, R (1998), Frequency and risk of cervical spine distortion injuries in passenger car accidents: significance of human factors data, Proceedings of the IRCOBI Conference, Göteborg, September 1998, pp 219 – 233.

UN-ECE (1998), Regulation 94, Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision, 1998.

Vallée, H, Thomas, C, Sacreste, J, Henry, C, Tarrière, C, Got, C and Patel A (1981), Characteristics of objects struck by the head of moped riders or motorcyclists, Proceedings of the IRCOBI Conference, Salon-de-Provence, September 1981, pp 176 – 183.

van Kampen, L T B (1993), Availability and (proper) adjustment of head restraints in the Netherlands, Proceedings of the IRCOBI Conference, Eindhoven, September 1993, pp 367 – 378.