The Best Location for a Side Airbag Crush Sensor

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Abstract

An analysis of a sample of lateral collisions has demonstrated that the optimum position for a side impact airbag sensor is in the lower rear quadrant of the front door. Positioned thus, some 88% of AIS 3+ injury cases would be covered, and some 91% of all AIS 4+ cases of front seat occupants would be covered. Analyses of injury sources and anatomical regions receiving injury, especially the head, demonstrate the great preponderance of the door as the prime source followed by exterior objects such as the striking car, trees and poles. Ideas for a predictive analysis of side airbag effectiveness are reviewed.

AIRBAGS FOR FRONTAL CRASHES, NORMALLY located in the steering wheel and facia have been available for some time, and their benefits in terms of injury reduction are now becoming apparent. However, such systems have decreasing effectiveness as crash forces are applied from an increasingly lateral direction. For different impact configurations, different types of protection are required. Hence the development of a side airbag which is designed to optimally provide protection in lateral collisions.

A prototype side airbag was developed by Warner et al (1989) who found that a door-mounted inflatable air cushion and pad system resulted in modest head and chest accelerations even in moderately severe impacts. Olsson et al (1989) developed a

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side airbag system in which a significant decrease in Thorax Trauma Index (TTI) was observed as well as a reduction in partial ejection of the head and improvements in pelvic acceleration. Overall, the system was estimated to reduce the collision force experienced by the chest area due to door impact by some 20-30% for a given experimental crash test.

Haland and Pipkorn (1991) documented the development of a side airbag system and observed that an inflated 8 litre chest airbag generally gave lower loadings to the head, neck and chest when compared to static polyethylene padding. Further reductions in loadings to the same body regions were observed in a ventilated 12 litre airbag which was developed by Haland (1993). Research and development work indicates therefore that reductions in injury severities can be achieved through side airbag deployment. However, there remains the question of an appropriate location for the impact sensor to function effectively in the real world of collisions. Sensor position is critical since bag deployment must be achieved much more quickly than is the case in frontal impact airbags. Haland (1993) notes that the airbag must be fully inflated when there is still 80-100mm of clearance between the door inner wall and the occupant. Normally in a typical 50km/h car-to-car side impact, there is still 80-100mm of clearance some 10-12 msecs after the first contact but thereafter, the clearance reduces rapidly. Nitro-cellulose based gas generators can inflate the bag within 7-8msecs. Therefore triggering of the inflation mechanism must take place within 2-5msecs of the initial impact in order to achieve full inflation before the required clearance begins to diminish.

Some authors have examined damage patterns on the struck side in car-to-car impacts and such studies can be of use when determining the optimum sensor location. One such study was performed by Hartemann et al (1976). They observed that such impact points were distributed about a centre point with a maximum impact probability located 55cm rearward of the A-pillar which is about 20cm frontward of the H-point of an average European 'sedan'. They also noted that, in the case of car-to-car impacts in which a severe-to-fatal injury occurred, the centre point was located about 65cm rearward of the A-pillar almost at the level of the H-point.

Danner and Langweider (1976) performed a detailed analysis of the location of damage that occurred to vehicles in car-to-car side impacts which sustained damage between the A and C pillars. They observed that in 80% of impacts, there was damage to the front door at the approximate location of the H-point while the maximum intrusion was normally at the door centre line.

Harms et al (1987) studied damage location on vehicles involved in side impacts. They found that of 236 vehicles in which AIS 2 or 3 injuries occurred, 62 (26%) did not have direct contact specifically on the passenger compartment, while of 33 vehicles where the maximum severity was AIS 4+, all had direct contact on the passenger compartment. When studying fatal accidents, they found that the damage location most commonly involved in direct contact was narrowly concentrated between the B-pillar and slightly forward of the vehicle wheel base which corresponded to some portion of the front door.

The Sensor

This study is concerned with identifying the optimum location of a commercially available sensor. The sensor is of a pyrotechnical non-electrical type (40mm diameter) which is designed to trigger in cases of door intrusion and hence where there is injury risk. The sensor element is a percussion cap that fires above a certain impact speed (typically 1.0-1.6m/s) and above a certain collision force (typically 1 kN). Within 1 ms from sensor contact, flame from the percussion cap is distributed to two gas generators by means of shock tubes.

Method

Interrogation was made of a database containing information on 4231 vehicles in which there were 7092 occupants involved in traffic crashes. The data form part of an ongoing study (the Co-operative Crash Injury Study, CCIS) into vehicle crash performance and occupant injury undertaken between November 1983 and August 1991 (Mackay et al, 1985). The cars were examined at garages within a few days of the collision to analyse the nature of each accident and understand the causes of occupant injuries. Injury data was obtained from hospital medical records and injury severities were rated according to the Abbreviated Injury Scale (AIS), 1985 revision).

Case Selection Criteria

The vehicles suitable for inclusion in the study were selected by applying the following criteria;

(i) The occupant was exposed to an impact between the A and the C Pillars on the struck side.
(ii) The vehicle received a direct impact to the sides with a principle direction of force between 1 and 5 o'clock to the right side and 7 to 11 o'clock to the left side. Rollovers were excluded from the study.
(iii) Only occupants with an injury rated as AIS 3 or greater were included in the study.
(iv) Only vehicles receiving a maximum crush of over 50mm were included.
In all, 246 vehicles were available for analysis.

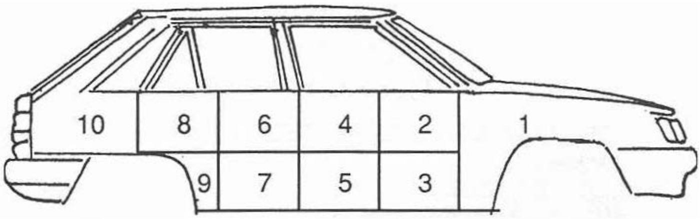
Location of Damage

The damage location was recorded in terms of particular areas of the vehicle sides damaged rather than in quantitative terms due to the procedure used for identifying areas of damage. The sectors of the side struck for recording the damage are shown in figure 1. The location of the damage was identified after reviewing the case records and slides. The damage areas were identified as being in one or more of the pre-defined sectors of the vehicle side as shown in figure 1. The sides of the vehicle were divided as follows;

The front wing was considered as one sector. Similarly, the back part of the car from the rear vertical edge of the rear door frame to the rear of the car was considered as another sector. In hatchbacks, this sector was considered as being from a vertical line passing through the apex of the rear wheel arch to the rear of the car. The front and rear doors were considered as being made up of four equal sectors. These sectors covered the areas of the doors between the bottom edge of the window and the bottom edge of the door. In hatchbacks, the rear panel was substituted for the absence of the rear door. This area extended from the vertical rear edge of the front door frame to a vertical line through the apex of the rear wheel arch. The damage to the B pillar was assigned as damage to areas 4, 5, 6 or 7 on an individual case basis.

Damage to the vehicle was recorded to have been direct or induced. This information was then computerised to allow cross-file analysis of the data.

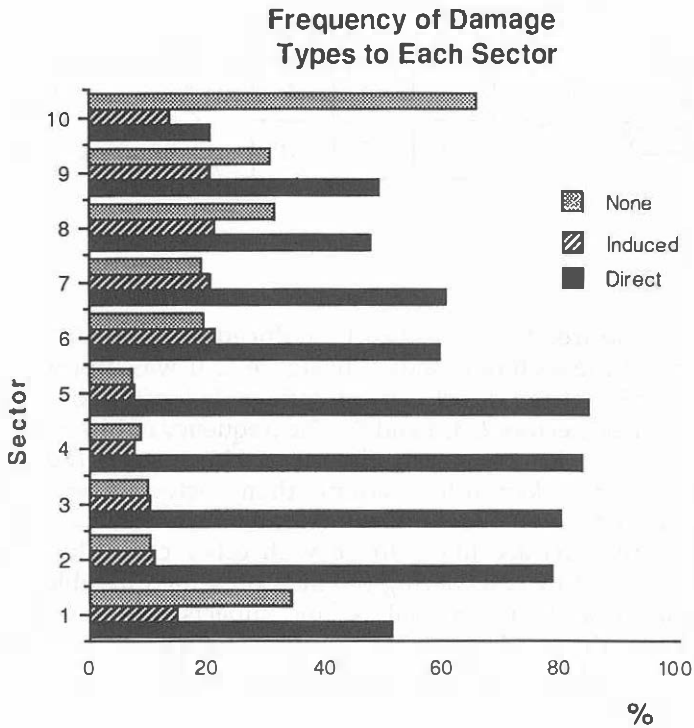
Figure 1; Vehicle Sector Classification



Results

The frequency of 'direct', 'induced' and 'no damage' to each of the sectors is shown in figure 2. It was observed that over 75% of the direct contact damage is located to the front door area (sectors 2, 3, 4 and 5). The frequency of hits to each of the sectors is very nearly the same. However, if the object struck is taken into account, then sectors 3 and 5 will experience more hits than sectors 2 and 4 since the majority of the collisions are likely to be with other cars. This can be ascertained by considering the data presented in table 1. This table shows that over half of the impacts were car-to-car or car-to-light goods vehicles collisions compared to collisions with tall objects such as trucks, poles, trees, etc.

Figure 2



Theoretically, any of the 4 sectors of the front door could be selected for the location of the sensor. However, further consideration of object struck in terms of their dimensions would indicate that sectors 3 and 5 are more suitable, since over half of the collisions are with cars. Furthermore, side impact collisions of this nature tend to occur at intersections which implies that it is the bumper area of the bullet car which makes contact with the target car. The height of the bumper would approximately correspond to the height of sectors 3 and 5 above ground level. Collisions with taller objects such as trucks, buses, trees and poles would include sectors 2 and 4 anyway.

Table 1. Frequency of Object Struck

Type of Object Struck	Frequency	%
Car	114	46.3
Light Goods Vehicle	14	5.7
Truck	30	12.2
Public Service Vehicle	7	2.8
Other Vehicle	2	0.8
Lamp-post/pole	36	14.6
Wall	6	2.4
Tree	28	11.4
Other road furniture	9	3.6
Total	246	100

A sensor would only need to be located in either sector 3 or 5. Locating a sensor in sector 5 is preferable since it is the site of the highest incidence of impacts (figure 2). Furthermore, sector 5 is more proximal to the H-point of the seated driver or front seat passenger. A sensor located in sector 5 will also cater for impacts in sector 7 and sector 3. However, a sensor located in either sectors 3 or 7 may mutually exclude airbag firing in the other sector.

Having selected sector 5 as the optimum position for locating the sensor, it has to be ensured that in addition to covering impacts in this sector, impacts in other sectors when there is no impact in sector 5 are also covered. This is verified in table 2 which examines frequency of AIS 3 or greater and AIS 4 or greater injuries sustained in impacts to different combinations of sectors to restrained and unrestrained occupants.

Table 2 Front seat occupants with injuries of AIS 3+ and AIS 4+

Total No. of Injuries AIS 3+ = 783
Total No. of Injuries AIS 4+ = 311

		Sector			
		5	5+3	5+7	5+3+7
Restrained	AIS 3+	517	521	519	523
	%	*66.0*	*66.5*	*66.3*	*66.8*
	AIS 4+	221	221	222	222
	%	*71.1*	*71.1*	*71.3*	*71.3*
Unrest.	AIS 3+	155	155	167	167
	%	*19.8*	*19.8*	*21.3*	*21.3*
	AIS 4+	55	55	59	59
	%	*17.7*	*17.7*	*19.0*	*19.8*
Total	AIS 3+	672	676	686	690
	%	*85.8*	*86.3*	*87.6*	*88.1*
	AIS 4+	276	276	281	281
	%	*88.8*	*88.8*	*90.3*	*91.1*

Sector 5 only represents all cases with damage to sector 5. Sector 5 + 3 represents all cases with damage to sector 5 plus all cases with damage to sector 3 when there is no damage to sector 5. Sector 5 + 7 represents all cases with damage to sector 5 plus all cases with damage to sector 7 when there is no damage to sector 5. Sector 5 + 3 + 7 represents all cases with damage to sector 5 plus all cases with damage to sector 3 when there is no damage to sector 5 plus all cases with damage to sector 7 when there is no damage to sector 5.

As can be seen from table 2, 88.1% of all AIS 3 or greater injuries are covered by a combination of impacts to sectors 3, 5 and 7 while 91.1% of all AIS 4 or greater injuries occur when there is a impact to a combination of sectors 3, 5 and 7.

Injuries and Contact Sources

Injuries and their respective contact sources were examined for impacts in each of the sectors and the respective combinations of sectors. Table 3 shows the body regions affected by impacts to the different sectors. Head, chest, abdomen and lower limb injuries (including the pelvis) feature prominently. Injuries to the chest region have the highest incidence followed by injuries to the head when direct impacts are experienced to sectors 5, 3 or 7 or a combination of these. There is very little difference in the incidence of injuries due to direct contact impacts to any of the sectors.

Table 3: All Front Seat Occupants - Body Regions Afflicted in Direct Contact Impacts.

Sector	5		5+7		5+3		5+3+7	
AIS	3+	4+	3+	4+	3+	4+	3+	4+
Head	171	84	171	84	175	85	175	85
C. Spine	12	10	12	10	12	10	12	10
Face	9	1	9	1	10	2	10	2
Neck	3	0	3	0	3	0	3	0
Chest	242	132	243	132	249	134	250	134
T. Spine	4	1	4	1	4	1	4	1
Abdomen	69	45	69	45	70	46	70	46
L. Spine	0	0	0	0	0	0	0	0
Pelvis	50	3	50	3	50	3	50	3
U. Limbs	24	0	24	0	24	0	24	0
L. Limbs	88	0	91	0	89	0	92	0

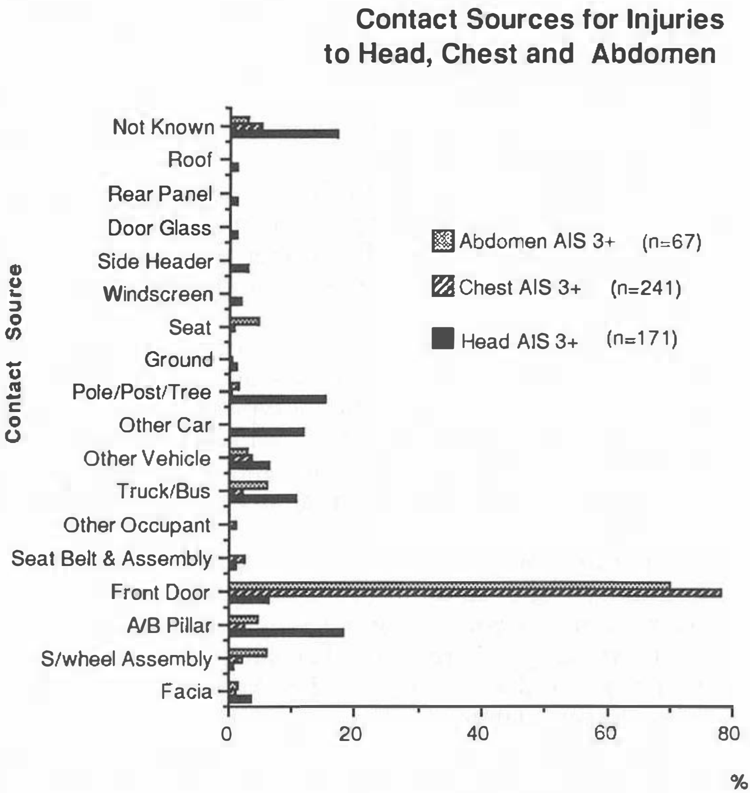
An analysis of contact sources for impacts to different sectors and combinations of sectors was also made. The relative frequency of injuries to different body regions are shown in table 4.

Table 4: Contact Source by Belt Use by AIS for Sector 5 Contacts

	Used		Not Used		Total	
	3+	4+	3+	4+	3+	4+
Windscreen	3	2	0	0	3	2
L.Facia	10	4	5	3	15	7
Footwell	10	0	3	0	13	0
S/Wheel	5	1	7	5	12	6
A Pillar	19	7	1	0	20	7
B Pillar	18	9	9	3	27	12
C Pillar	1	1	3	2	4	3
Side Header	1	1	5	2	6	3
Front door	286	120	85	26	371	146
Door glass	0	0	2	0	2	0
Rear Panel	2	1	0	0	2	1
Roof	2	0	0	0	2	0
S/Belt web	6	3	0	0	6	3
Deceleration	1	1	2	2	3	3
Other Occ.	4	1	0	0	4	1
Other car	74	40	2	2	76	42
Pole/Post	18	9	17	8	35	17
Other ext. object	1	0	4	1	5	1
Penetrating obj.	6	3	0	0	6	3
Ground	3	0	0	0	3	0
Crush	1	0	0	0	1	0
Seat back own	4	3	3	0	7	3
Not known/ Other	40	15	4	0	44	15
Self	0	0	1	1	1	1
S/belt swivel	0	0	2	1	2	1

This table shows that the front door provides by far the most frequent contact source for both restrained and unrestrained occupants. This is to be expected because of the proximity of the occupant to the front door, but it is also justification for locating the airbag in the door itself.

Figure 3



A Discussion of the Injury Reduction Potential of a Side Airbag

Following the analysis presented in table 4, contact sources for specific body regions, head, chest and abdomen were further examined in order to ascertain potential benefits of the side airbag. The contact sources are shown in figure 3 above. The front door area is the most frequent source of injury for all of the chest and abdominal injuries. For head injuries, if the individual contacts (i.e. trees/poles, A and B pillars) are included together, then the general front door area is the source of most head injuries. However, it is the chest region which is of concern since airbag deployment provides optimum protection to this body region, although the airbag will have some benefits for mitigation of injuries to the head and abdomen as well. In the case of the head, this is because an early loading from the airbag on the chest has the effect of diminishing the relative lateral motion of the head. That results in a lower frequency of impacts on the head and a diminished contact velocity even when such contacts occur. Similarly for the abdomen, an early loading on the chest will diminish the forces applied at abdominal levels as well.

Estimating the benefits in the real world of a safety benefit such as the side impact airbag is a complex predictive analysis which will be the subject of a further paper. However some observations are appropriate related to the data presented in this study.

Experimental studies by one of us (Haland, 1993) demonstrated that in comparing a side airbag with 50mm of static padding, both mounted on a typical European car door, the door speed in a simulated lateral collision could be 25% greater for the same chest deflection and viscous criteria values on a Biosid dummy with the airbag in comparison to the static padding.

Further dynamic tests demonstrated that the lateral excursion of the head of a Biosid dummy was reduced by some 30mm if a side impact airbag was used in comparison to 50mm of static padding. Alternatively, Haland demonstrated that with an airbag, the door velocity had to be increased by 15% to obtain the same lateral displacement of the head.

The application of such experimental results to a sample of real world collisions presents a number of difficulties. One assumption is that the actual sample of crashes analysed is close to the baseline condition of 50mm of static padding. A second set of assumptions as to effectiveness would be necessary in considering a distribution of crash severities from the field study. These assumptions would address the effectiveness of the airbag across the whole range of crash severities. At the top end of collision severities, for example at velocity changes of more than 55km/h, would the same reductions in door velocity be achieved?

Then there is the question of the relationship of door velocity to injury exposure for the population of people exposed in side impacts. The experimental condition examined by Haland (1993) represents the onset of AIS 3 injuries for whatever segment of the population is represented by the Biosid dummy. There is little knowledge on the actual biomechanical variability of the exposed population for this type of loading.

Then there is the question of the field accident data. The velocity of the inner door panel is clearly the parameter which most closely relates to injury risk. Post facto analysis of an accident sample does not allow that parameter to be assessed. In practice we have velocity change of the struck car computed in a proportion of cases, crush measurements in every case, but often little information on the deformations to the striking vehicle. The actual, over-the-road velocity of the striking vehicle could well be a better parameter than velocity change of the struck vehicle, at least at the higher velocities. This will be explored in further analyses.

Just as a guide to effectiveness estimates, we have examined the Delta-V distributions for AIS 2 and AIS 3 chest injuries. The mean values were as follows;

AIS 2	34.2kph
AIS 3	47.6kph

As a start, an assumption could be made that the side airbag would reduce AIS 3 chest injuries by one value on the AIS scale. Applying that proposition to the distribution curves, and assuming it would apply at all crash severities, results in a prediction of a saving of 25% of all AIS 3 injuries currently occurring.

Examining the benefits of the side airbag on head injuries is more problematic for two reasons. Firstly, there are concerns that the Biosid dummy does not replicate real head excursion; people are more compliant in terms of cervical and thoracic spine deflections as well as chest compressions laterally than is the Biosid dummy. Secondly, the head injury exposure is related to the presence or absence of a head contact rather than head acceleration and thus depends very much on initial sitting position. We have demonstrated that the head positions of the actual population in side impacts is not adequately represented by a single point 50th percentile male dummy (Parkin et al, 1993). We intend, however, to examine such issues in future analyses.

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