Otte, D. Accident Research Unit Medical University Hanover

ABSTRACT

A large number of cars used in today's road traffic have by now been fitted with airbags for frontal and side impact. In case of an accident, the built-in sensor in the vehicle registers the decelerations and directions of impact taking place and activates either the front or the side airbag during the accident. The airbag is by no means always activated in accordance with the accident. A documentation of a scientific team of researchers of the Medical University Hanover has shown different collisions configurations and analysed the correct or incorrect deployment of airbags.

Through detailed analysis and computer aided reconstruction of the course of the accidents it was possible to reproduce the moving behaviour and the deformation characteristics of the vehicles and to evaluate whether there really had been a faulty activation or whether the cause of non-deployment could be found in different impact parameters.

The analysis shows that often the vehicles skidded before the collision, mainly collided diagonally with the accident partner, where during the compression phase of the deforming vehicle structures the airbag was activated as a consequence of the increase in deceleration. However, the whole deformation phase can only be considered as being finished when the compression is completed with an exchange of the impact impulse and only then do the real deformation characteristics ensue.

The special time characteristics of the relative movements of the passengers and the injury mechanics during the collision phase are discussed in the paper. Proposals for optimisation of the airbag system are made.

Key words; In-depth investigation, accident analysis, airbag deployment, airbag non-deployment, airbag in juries

A CONSIDERABLE NUMBER of cars on the road today are equipped with front airbags and side airbags. Many cars involved in accidents have an airbag system. Accident studies show that approximately ¹/₄ of all cars involved in accidents are equipped with driver and passenger airbags. Since approximately 1996, some cars involved in accidents have been equipped with side airbags too. In 1999 3% of cars involved in accidents were equipped with side airbags (Figure 1). It also shows that the airbag was released in only about 1/3 of vehicles equipped with airbags.



Figure 1 Frequencies of equipment and deployment of air bag systems in cars distributed according to accident year (in-depth study Hanover)

In the case of an accident, the sensor installed in the vehicle registers the deceleration or acceleration and directions of impact. Then, it activates the front or side air bag as the accident takes place. To release the relevant airbag, on the one hand, the degree of seriousness of the accident is registered in the speed change caused by the collision Delta-V and, on the other hand, the impact impulse transfer, which occurs in the form of the resulting deceleration or acceleration signal. While impact directions of approximately \pm 30 ° to the longitudinal axis of the vehicle for the front air bag and also approximately \pm 30 ° to the cross axis of the vehicle serve as trigger limits for the side airbag, the threshold values, at which an airbag should be released differ from manufacturer to manufacturer. Thus, there are vehicles, in which the air bag is generally released when the relevant configuration occurs. As a result of various studies (Otte, 1995), which, in part, postulate an increase in the degree of seriousness of injuries in the case of a low Delta-V, a release limit of approximately 20 to 30 km/h Delta-V has been suggested.

Analysis of past accidents has clearly demonstrated that non-accident conforming releases of the air bag are definitively possible (Otte, 1994). For example, there are head-on and side collisions, during which the relevant air bag is not deployed. This was previously attributed to the non-conforming collision conditions of frontal or side collisions. However, there are cases where during head-on collisions, the side air bag was deployed instead of the front air bag. Similarly, there have been side collisions, where the front air bag was deployed and not the side air bag. These cases will be analysed in detail within the framework of this study and, reasons for these will be presented, insofar as it is possible in the context of investigations at the scene of the accident.

EVALUATION METHODS

Using an interdisciplinary team of scientists, consisting of medical and technical experts¹, accidents have been documented for many years in the general area of Hanover and comprehensive data concerning vehicle deformations, injuries and accident processes have been made available in a database. Injuries are classified according to AIS (American Association of Automotive Medicine, 1990) and deformations according to the CDC (CDC, 1985). With the help of scale drawings of the accident traces, the final positions of the vehicles and the accident locality, driving and collision speeds of the vehicles and collision severity values such as EES and Delta-v have been determined

¹ In order of Federal Highway Institute (BAST), Bergisch-Gladbach

and the temporal process of the collision evaluated. It has to be pointed out that the estimation of Delta-v within real accident analysing process is only possible with some tolerances. This is calculated out of the impulse vector analysis on the basis of outrun traces on the road.

By means of a detailed individual case analysis and computer-aided reconstruction of the accident process for each of these cases, the movement conduct and the deformations characteristics of these vehicles was worked out and, in an individual case, the false release or its influence parameters were evaluated. The time processes of the occupant-relative movement and the injury mechanisms which occurred were analysed.

To the extent possible, the sensor systems were examined in co-operation with manufacturers and the algorithms responsible for the release observed.

DATA BASIS

12309 car accidents from the years 1988 up and including July 1999, in which either in the case of a head-on collision a front air bag was not deployed (n = 66) or during side collisions, a side air bag was not deployed or here the front airbag was deployed (n = 18) were evaluated. So that non-deployment of airbags during accidents, with low degree of seriousness were not included in the data, vehicles with Delta-v up to 10 km/h were basically excluded from the study. In case of descriptions of real cases the presented results are not weighted in statistical manner.

RESULTS

HEAD-ON COLLISION, IN WHICH A FRONT AIR BAG WAS NOT DEPLOYED During the analysis of 66 cases of head-on collisions, in which a front air bag was not deployed, in 64 of these cases, this could be attributed to collision conditions and/or the low impact intensity. Thus, the figure below shows that almost all values of collision-related speed change are below 30 km/h (Figure 2), thus, predominant lower degree of accident severity does exist for these cases.



Figure 2 Delta-v distribution of cars in frontal collision (n=66), in which an air bag was not deployed

Also, 82% of impulse angle was primarily $\pm 30^{\circ}$ to the longitudinal axis of the vehicle (Figure 3), only in n = 12 cases (18%) was an oblique impulse transfer greater than 30° observed.



Figure 3 Impulse angle of cars according to delta-v during frontal collision (n=66), in which the frontal air bag was not deployed, marked is the ± 30° trigger area

Analysing the frontal collisions with non-deployment of frontal air bags, it can be established, that the trigger level for deployment of the air bag was not obtained. This can be seen by the calculated mean decelerations of the car body with a maximum of only 20 g (Figure 4), calculated by speed change value and the maximal deformation depth.





As a whole, the analysis of head-on collisions, in which a front air bag was not deployed, indicates that in the most cases these were older cars with the year of first registration up to 1996 (Figure 5). This means that such situations will probably not so often occur in newer vehicles with optimised systems.



Figure 5 Distribution of year of production for cars involved in frontal collisions with no air bag deployment (n=51, 15 years of production not known)

Still, when the front air bag was not deployed during a frontal collision, objective assessment of the collision and injury mechanisms, show that there were in 64 of the 66 cases no disadvantages for passengers, if seriousness of accident were low. 35 (55%) of these 64 drivers did not suffer any injury, the most often injuries were strain of cervical spine (23%) and soft tissue injuries of head (20%) and thorax (19%), all injuries of AIS 1 grade. Only 2 drivers (3%) suffered a concussion, an AIS 2 injury (see tabulate 1).

type of injury	n	%
no injuries (MAIS 0)	35	55%
strain of cervical spine (AIS 1)	15	23%
soft tissue of head (AIS 1)	13	20%
concussion (AIS 2)	2	3%
soft tissue thorax (AIS 1)	12	19%
soft tissue upper extremities	7	11%
soft tissue lower extremities	8	13%
soft tissue abdomen	1	2%

Tabulate 1 Injuries of 64 drivers with non-deployment of air bag in frontal collision (100% all drivers)

They were not injured or at the most slightly injured and suffered injuries AIS 1 caused by the seat belt retaining strength. In two cases, the severity of injuries were greater. In fact, one person was killed. This passenger was sitting in a vehicle, which was involved in multiple collisions. It is presented as example below.

Example: Fatal accident

While overtaking, a Rover car had to brake strongly, owing to which it began to skid. As result, it collided frontally with the car to its right. Subsequently, both cars were driven off the road. The Rover collided with two trees (Figure 6). The driver of the Rover was fatal injured during this second collision that was a lateral impact and clamped in the vehicle.



Figure 6 Example fatal accident

The reconstruction of the accident, showed that during the primary collision with the other car, the Rover was travelling at 118 km/h. The vehicle collided frontal with the right front part of the rear of the other vehicle. Delta-v and ESS were approximately 10 km/h only. Then, the Rover collided with the left side of the vehicle near the A-pillar with a tree, the speed of impact was approximately 80 km/h, Delta-v and ESS were around 60 km/h. During this collision, the front part of the vehicle was torn off.

It is very difficult to assess just how much the driver would have been protected during this collision if the front airbag had released. This case clearly illustrates the problems associated with multiple collisions. During the first collision, the severity of the accident with approximately 10 km/h was not sufficient to deploy the front air bag. During the secondary collision, only a side air bag would have been helpful.

FRONTAL COLLISION AND DEPLOYMENT OF SIDE AIR BAG - Among the accident cases examined here, there was one case involving a car with just the driver, during a front collision, where the front airbag was deployed and both side airbags. This case is described here.

A BMW 328 collided against a tree following in a longitudinal deceleration, without rotation. All three airbags were released on the driver's side, front airbag in the steering wheel, the side airbag in the driver's side door and the upper side airbag in the roof frame (Figure 7).



Figure 7 Impact situation of a car with deployment of all driver related air bag systems

During the reconstruction (Figure 8), on the basis of the final position and the traces on the road, vehicle and environment a collision speed of approximately 55 km/h was determined at Delta-v and ESS of approximately 50 km/h.



Figure 8 Reconstruction of an accident of a car with deployment of all driver-side air bags

The driver was protected by a seat belt and the steering wheel air bag. The driver suffered a neck strain so called whiplash in jury (AIS 1), no other injuries were found.



Figure 9

Car with deployment of all driver-side air bags (steering wheel, door and Inflatable Tubelar Structure ITS)

The deployment of the side air bags may be the result of a small side-related part of the impact. This case is a good example for full fire theory of all existing air bags. The deployment of the side bag instead of a frontal collision had no negative consequences to the injury result of the driver.

SIDE COLLISIONS WITH DEPLOYMENT OF SIDE AIR BAG - There were side airbags in four cases. The airbag was released in these cases. During side collisions, there was always a correct release on the impact side.

SIDE COLLISION UND SIDE AIR BAG NOT AND/OR FRONT AIR BAG DEPLOYED - Side collisions with a deployment of the front air bag were observed in 18 cars, 10 of these cars were additional equipped with an air bag on the front passenger side. In 6 of these cases a side air bag would have protected the occupants.

The 18 cases registered under these collision conditions had a seriousness of injury from MAIS 0 to MAIS 4, whereby one person was fatal injured. The detailed deformation characteristics show clearly in all cases a resulting side deformation with resulting lateral impact impulse direction, however mostly oblique impact run-in direction. In all cases a frontal component was determined during the first part of deformation process, which could be explained by the difference of impulse and impact run-in angle. 2/3 of the vehicles swerved before the accident and show a rotation around the high axis, right or left rotating. The resulting direction and the vehicle structure deformed, so that during the deformation period the car rotated further to maximum deformation while impact impulse transfer. Within the framework of the accident reconstruction, the angle of the directions of the first contact and the angle of the resulting impulse transmission was evaluated from the deformation characteristic (Figure 10).







Only one third of the cars (n=6) did not rotate before collision and no difference between impulse and run-in angle could be established. In the other cases this difference was between 2 and 17 degrees (Figure 11).





Almost 80 % of the cars involved in side collisions and head-on collisions, collided with a Delta-v of up to 40 km/h (Figure 12).





The distribution of the resulting impulse angle shows two frequent occurrences in the areas, inclined front right (130 to 150 degrees) and inclined left (220 to 250 degrees) without a significant influence of the accident severity (Figure 13). Only for 2 cars the impulse angle was in longitudinal direction within ± 30 degrees.





Example:

An individual case is reported in which a BMW 316i Touring slipped on an icy road in a long right-hand bend around the vertical axis and drifted onto the opposite side of the road where the car hit a VW Passat coming from the opposite direction and travelling at a speed of approximately 75 km/h. The Passat hit the right side of the BMW head-on almost at an impulse direction of nearly 90 degree, respectively rectangular. The BMW was travelling at approximately 40 km/h at this time. The driver of the BMW hit with his head against the right B-pillar and broke his head open by way of a visible injury and also suffered a serious craniocerebral trauma and died 4 hours later in a hospital.

Examination revealed considerable bleeding in both hemispheres with displacement of the ventricle and subarachnoidal bleeding as well as massive contusion on the right with haematothorax and pneumothorax. The side airbag installed in the car was not deployed, the front airbag was deployed.

The car had a huge dent on the right side, starting from the frontal A-pillar and extending to the rear C-pillar, running into the area of the rear axle. The deformation characteristic made it possible to recognise an almost even deformation characteristic with a clear imprint of the front of the opposite car. There was a maximum side penetration of 85 cm in the area of the middle of the front passenger door. The right B-pillar moved approximately 60 cm into the inside of the car at the height of the lower edge of the window frame (Figure 14).



Figure 14 Side impact with deployment of frontal air bag and non-deployment of side bag

The exact accident reconstruction by means of PC crash² showed a change in speed as a result of the collision amounting to approximately 60 km/h as well as a right-angle impact impulse transfer (Figure 15).



Figure 15 PC-Crash-Analysis with collision position and movement after impact

The driver, who was protected by a seat belt was held back in the pelvis area only, while the driver's shoulder belt goes from the left shoulder to the right iliac crest and consequently the top part of the body cold move out to the middle region of the interior. Contrary to this relative movement, the right side of the car was deformed and the passenger's side door moved in, so that the upper part of

² Software by Dr. Steffan Datentechnik, Graz, Austria

the body banged head first against the right B-pillar and the thorax was put under pressure in the area of the right front passenger back rest. The front passenger seat was completely pushed diagonal over the middle tunnel area towards the driver's side. The sensor and release module for the side airbag on the front passenger side including the deployed airbag module were removed and insofar as retrospectively possible from the accident analysis a time analysis of the occupants' kinetics was performed. The evaluation of the algorithm resulted in the fact that the data relevant to the crash in the central control equipment as well as in the satellite sensor, had registered a head-on collision, thus the front airbag had been deployed, but no lateral impact was detected. This took place between 7 and 15 ms after the first contact. In the case described above it was not possible for a front and side airbag to be deployed simultaneously and for some milliseconds there was no continual analysis of the impact signal. Thus, in this case, the impact characteristic of a side collision compiled by the sensor system and resulting from the collision sequence could not be identified. By contrast, the detected primary head-on impulse component started the deployment of the front airbags which served no purpose here.

The investigation of to what extent a deployed side airbag in this case would have been able to protect the body of the driver which was exposed to the impact could be assessed in the analysis of the occupants' relative movement and the time history of the deployment procedure of the effective airbag geometry. The airbag would have required approximately 25 ms to unfold its full volume and then to maintain this over a period of 30 ms. Thus a protective function for a maximum of 55 ms can be established. According to a critical estimate, however, the driver's impact did not take place until after deformation of the vehicle, in other words after 80 ms following first contact which means that protection in the case of the above accident for an occupant of the car subjected to impact cannot be confirmed.

CONCLUSION

Looking at the ratio of vehicles in traffic accidents, it is striking that around ¹/₄ of all vehicles are equipped with front airbags, but only about 40% of the airbags are deployed. The proportion of deployed airbags increases with increasing speed change Delta-v (Figure 16), for instance in Delta-v range of 21 to 30 kmph 60.2% of the vehicles equipped with air bags had a deployment of the bag.





Approximately 40 % of all collisions involving cars result in a speed change of less than 10 km/h. Thus, so as to not increase repair costs due to the airbag and to avoid injuries caused by the deployment of airbags, where the seat belt offers sufficient protection, deployment of an airbag seems to unnecessary if seriousness of accident is low.

Analysis of accidents show that on the whole seat belt and airbag offer good protection during accidents. Analysis of accidents have not revealed any negative effects from airbag systems. In earlier studies, it has been determined that during accidents with low seriousness of injury, in which normally seat belts sufficiently protect occupants, use of airbags lead to minor injuries, even up to degree of severity AIS 2. The most recently performed analysis confirm these findings, however in less pronounced form. For example Figure 17 shows often higher AIS values of occupants in comparison to situation without release of airbag up to speed changes of approximately 30 kmph. However, compared to earlier studies, this difference is almost balanced. As a result, it can be assumed that the release threshold has been lowered or that the total system seat belt and airbag has been optimised.





As this study shows, there are accident situations, in which an airbag function malfunctions in a non-accident conforming way or in which it would be favourable if the airbag was deployed.

This is not attributed to detects of devices for activation or not sensor compatible collision situations, it is based on incorrectly recognition by sensors, concerning to the fact that types of collisions content complex movements of the vehicle and deformation behaviour in real accidents. Within the context of this study, 66 cases were evaluated, in which the installed front airbag was not released in spite of a head-on collision. The analysis revealed that the release threshold is not sufficient, to activate the airbag. For example, mean load of the passenger cell was a maximum of 20 g. The non deployment of the airbag had mainly no negative effects on resulting severity of injuries.

Moreover, 18 side collision cases were evaluated, in which the side air bag was not deployed, but the front air bag was deployed. In 1/3 of these cases, a protective function would have been offered by the side airbag. In all cases, the movement process at the beginning of the collision changed and started with a frontal component following in a clearly lateral impact impulse transfer, showed rectangular.

The detail analysis revealed an angle change between run-in upon first contact and time of maximum deformation with impact impulse exchange. This is attributed to a rotation of the vehicle

upon the deformation process. 2/3 of vehicles slipped before impact. During deformation, the vehicle rotates further. If the sensor system cannot detect this change of motion, the airbag is erroneously deployed to early. A "Full Fire Concept", an intelligent sensor system or two sensors, operating independently of one another could prevent this from happening. It is extremely important as regards optimum protective function that the airbag is deployed correctly. The resulting occupants' movement normally opposes the impact impulse transfer. In real accidents, collisions can occur, which are separated from one another by time. In 80% of these, the time interval is more than 0.4 seconds, and in 50% it can be more than 1 second.

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