POINTERS TOWARD THE IMPROVEMENT OF SAFETY IN BUSES, DERIVED FROM AN ANALYSIS OF 371 ACCIDENTS INVOLVING BUSES IN GERMANY AND FROM CRASH TEST RESULTS

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ABSTRACT

DEKRA accident research division has carried out in-depth analyses of 371 accidents involving 395 buses which occurred from 1985 to 1997 in Germany. From these, pointers were derived toward possible improvements in the active safety and, in conjunction with crash test results, in the passive safety of buses.

With regard to the pre-crash phase of the accidents, findings emerge on, among other things, the relative significance and frequency of the following characteristics: speed being driven before collision, critical situation triggering the accident (accident type), consequences of bus occupants and opposites. From these findings, potential benefits of technical aids and bus equipment can be assessed.

A main focus of actual accident occurrences involving buses concerns in which buses topple over their side. On this point, relevant characteristics resulting from the accident assessments are also described. The results of actual accident simulations carried out at the DEKRA crash centre involving the overturning of a moving bus onto its side complete this topic.

From the collision parameters (kind of opposite, driving and collision velocity etc.) pointers emerge regarding the performance of appropriate crash tests for the analysis of internal bus safety. In this context there is also a discussion of the results of bus crash tests carried out at the DEKRA crash centre (vehicle damage, seat- and passenger-stresses).

Lastly, using actual accident occurrences, there is a discussion of external bus safety. A description of the relevant characteristics of collisions with other traffic participants (trucks, buses, cars, two-wheeled vehicles, pedestrians) provides pointers to potential improvements.

INTRODUCTION

The current official categories of road users in Germany contains five types of buses:

- **Kraftomnibus** (Motor coach or bus) seating more than 9 persons including the driver (this category covers all buses which can be separated to „Reisebus“ (coach), „Linienbus“ (public service bus) or „Schulbus“ (school bus).

- **Reisebus** (coach)

- **Linienbus** (public service bus)

- **Schulbus** (school bus)

- **Oberleitungsomnibus** (trolley bus)

These details have only recently come to light, as part of an endeavour to be able to show the incidence of accidents involving buses separately within the official traffic accident statistics. It has been possible to obtain separate accident figures for coaches, public service buses and school buses from official statistics since 1995.

For long-term statistical overviews of total figures covering accidents involving coaches and buses, the figures shown separately for the former German countries are still the most suitable (STATISTICAL OFFICE, 1997). **Figure 1** shows the trend in the number of drivers and passengers involved in accidents who were either seriously injured or killed during the period 1957 to 1996. **Figure 2** shows the reference figures coaches and buses shown in the official statistics for the former countries for the same period.

The number of bus passengers who have been either killed or injured either inside or outside urban areas is declining over the long-term. However, the number of bus passengers killed outside their urban areas has in particular been subject to considerable fluctuations in certain years. As can be seen from Figure 1 in the former countries the number of bus passengers killed outside of their local area per year since the late 60's, with the exception of 1985 and 1992 has been consistently less than 30. In 1985, 38 bus passengers were killed, in 1992, the figure was 35. During the following year, in 1993, three bus passengers were killed outside of urban areas. The reasons behind such fluctuations are isolated tragic incidents during which many victims were either injured or killed in a bus involved in an accident. In both 1985 and

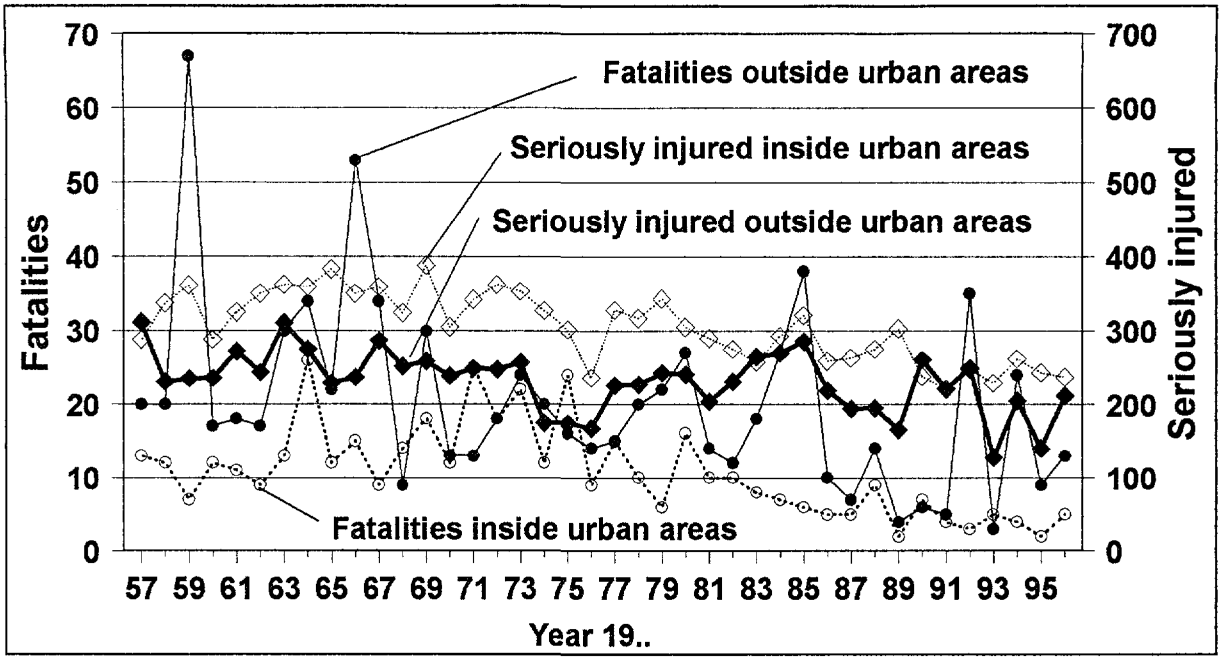

Figure 1. Absolute Frequency of fatal injured or severely injured occupants in buses in the former German countries within the period 1957 to 1996 (Source: German Federal Ministry of Statistics)

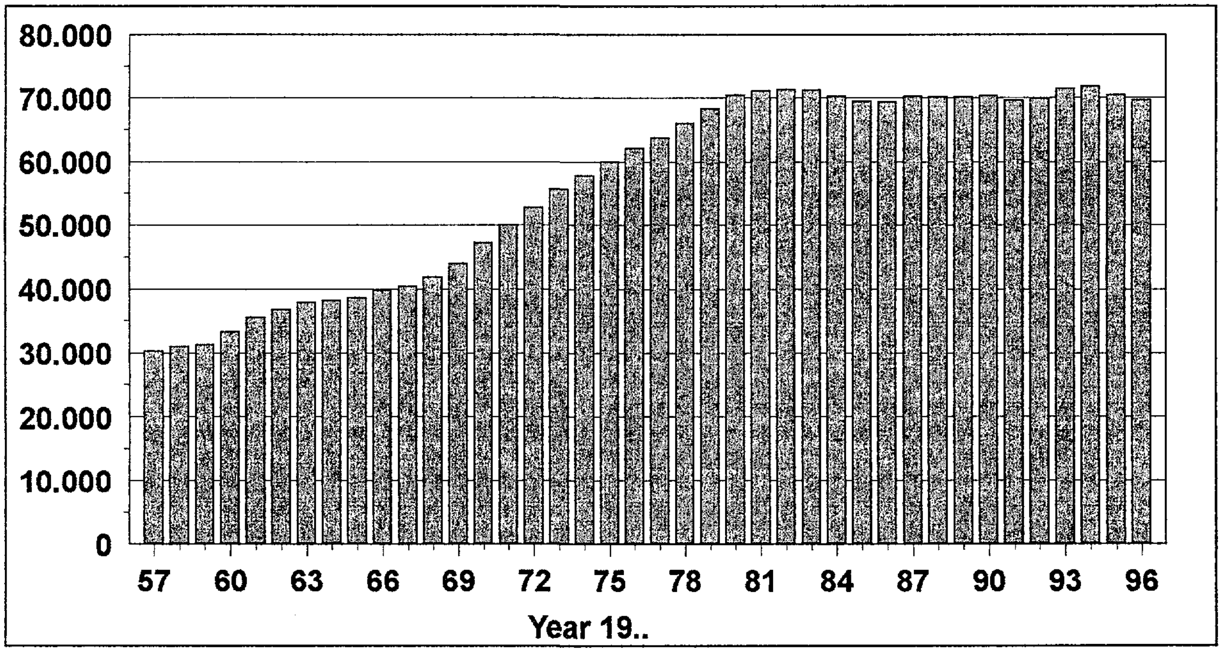

Figure 2. Absolute Frequency of registered buses in the former German countries within the period 1957 to 1996 (Source: German Federal Ministry of Statistics)

1992, 20 people were killed in one single accident. If these two accidents are excluded, the figures for the two years do not stand out from the general trend. Such accidents are reported repeatedly and in detail by the media. There is also enormous and lasting public interest in such incidents.

The number of buses registered in the former countries increased rather steadily from around 30,000 in 1957 to approximately 40,000 in 1967. This was followed by an almost linear, significant increase to around 70,000 registered buses in 1979. Since that time, the number has remained fairly constant. Transport performance in kilo-

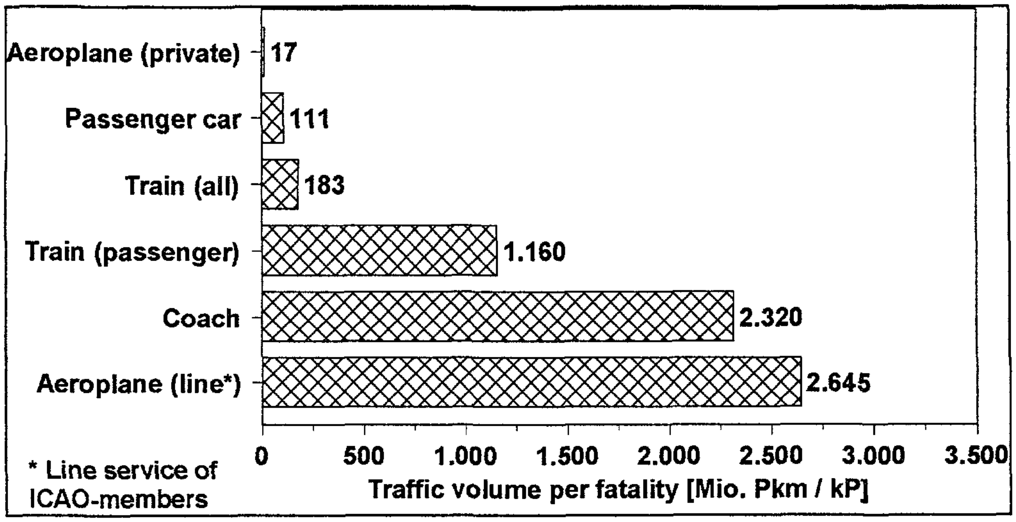

Figure 3. Comparision of the safety of means of transportation (Source: Schesky and Zernick, 1997)

metres per person per fatality shows the coach as one of the safest forms of transport, equal to an aircraft flying scheduled routes, **Figure 3.** (SCHESKY and ZERNICK, 1997). Correspondingly, the risk of a car passenger being killed is approximately 21 times greater than the equivalent risk to a coach passenger.

Nevertheless, improvements to the safety of coaches and buses is an important subject, on the one hand to further limit the potential consequences of isolated coach accidents and on the other, as part of a comprehensive accident research, to take into account the consequences for the other accident vehicle. Hence, DEKRA Automobil AG has carried out an in-depth analysis of 371 accidents involving buses which occurred in Germany between 1985 and 1997. The results obtained from real simulated, instrumented bus crash tests and overturn tests with buses supplement the knowledge derived from the accident analysis.

DEKRA DATABASE

The data sources for the real accident tests are accident analysis reports produced by DEKRA experts in Germany. These reports are being evaluated for scientific purposes in compliance with the Data Protection Act. **Figure 4** shows the relative frequency of individual accidents and in the case of accidents involving a second party, the other vehicle concerned, as represented by the official statistics for road traffic accidents where physical injury has occurred (these are accidents whereby people have been either killed or injured) and for accidents with serious damage to vehicles in Germany during 1996. As a comparison, the same diagram shows the corresponding frequency distribution for 371 bus accidents in the DEKRA database. The vehicle most often colliding with the bus is the car (57.1 % in official statistics, 53 % in DEKRA statistics). Individual bus accidents, bus/bus accidents and bus/heavy goods vehicle accidents occur more frequently within DEKRA than in official statistics. Bus/bicycle and bus/pedestrian accidents occur less frequently in the DEKRA database than in official statistics. Accidents which are relatively safe for bus passengers seldom occur in the DEKRA database.

The distribution of accidents over months shown in **Figure 5** shows a slightly higher number of bus accidents during the months before and after the main holiday period (July and August). This trend which is recognized in the official statistics is given even stronger recognition in the DEKRA data. The number of accidents during the months of May, September, October is significantly different from the figure for other months. **Figure 6** shows a balanced distribution of the road characteristics for bus accidents. A deeper examination of accidents on bends showed that the number of accidents occurring on left-hand bends is almost double that occurring on right-hand bends. This issue which is discussed in the Report by GRANDEL and NIEWÖHNER (1995) is to be clarified by a corresponding number of car/bus collisions. A car travelling too fast around a right-hand bend moves onto the wrong side of the road and collides with an oncoming bus which from it's own point of view, is travelling a left-hand bend.

PRE-CRASH PHASES

Cases of collisions with other road-users or with fixed objects, or if the bus overturns autonomously are all gen-

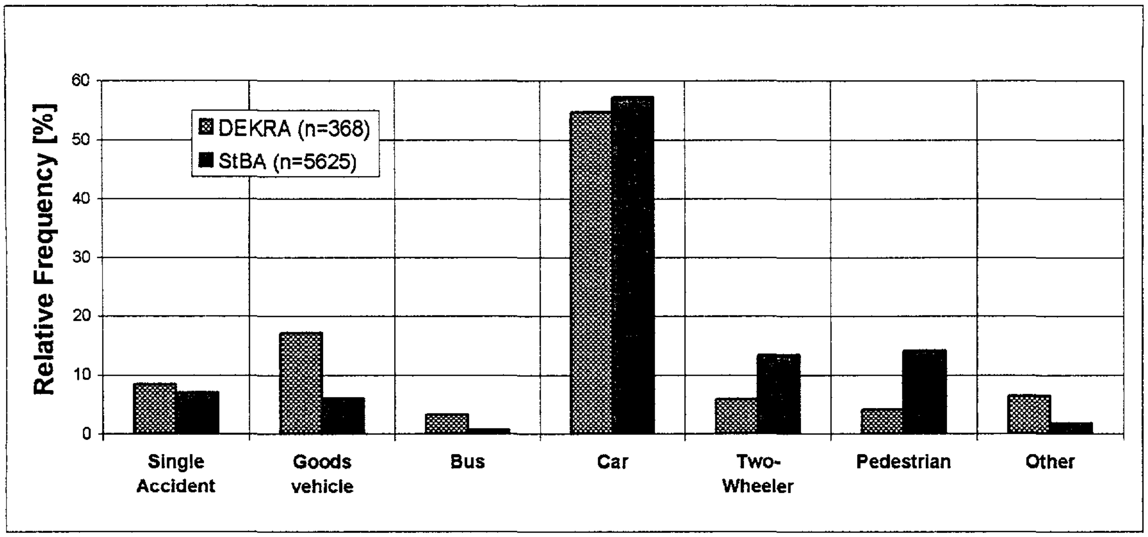

Figure 4. Single accidents of buses and bus opponents in accidents with two involved parties, comparison between German federal statistics (1996) and DEKRA database

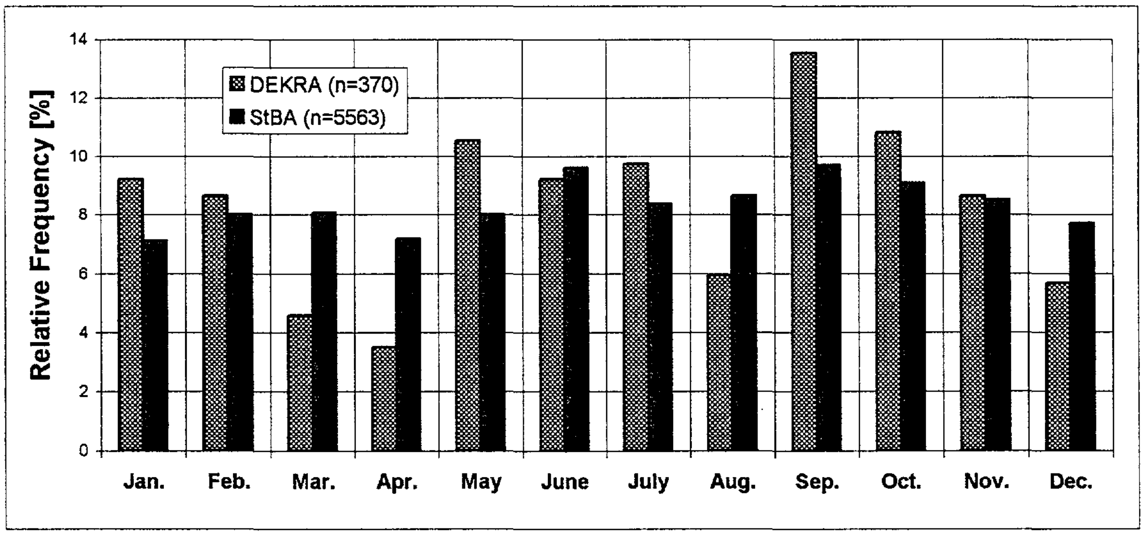

Figure 5. Relative frequency of monthly happened bus accidents, comparison between German federal statistics (1996) and DEKRA database

erally preceded by the pre-crash phase. If it is possible to take corrective action during this phase, the great potential for active safety to avoid the accident and therefore all its consequences is exploited.

Figure 7 provides information on the speed travelled by the bus during the pre-crash phase in the DEKRA examination material. This shows that the majority of buses are travelling at speeds of 91 to 105 km/h preceding accidents on motorways. The corresponding speed on secondary roads is between 61 and 75 km/h. On local roads, the speed is 31 to 45 km/h.

The distribution of accident types in **Figure 8** provides information on the critical situation preceding bus accidents. Within the sense of the official road traffic accident statistics, the type of accident is described, "the conflict situation which resulted in the accident, i.e. a phase in the traffic situation where the further course of events could no longer be controlled because of improper action or some other cause". The most frequent type of bus accident occur within the group of accidents in lateral traffic. This group describes those accidents in which the vehicles involved are travelling in either the same or an opposing direction.

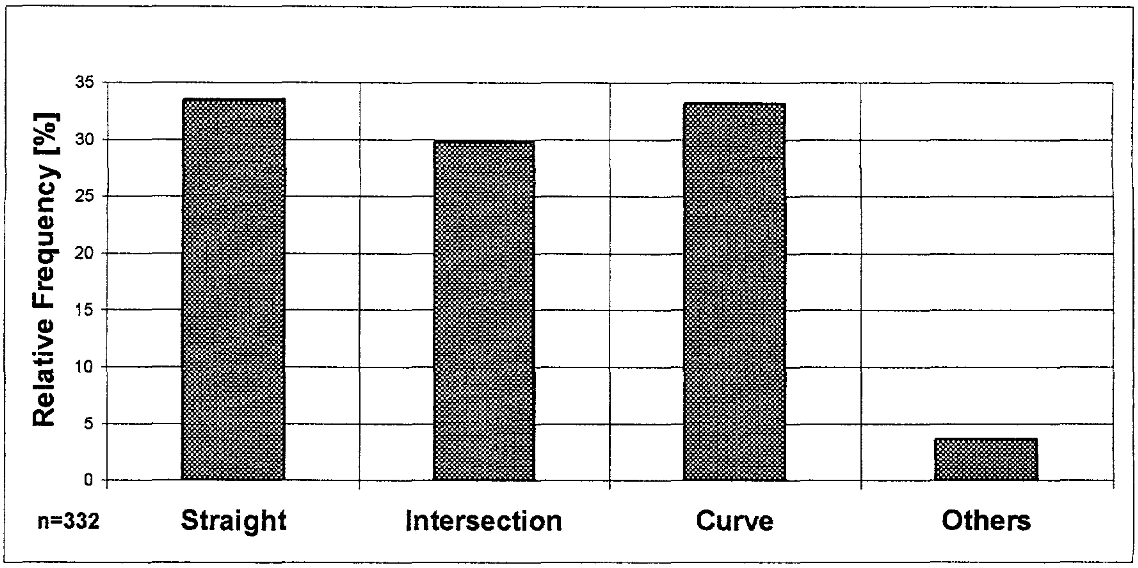

Figure 6. Relative frequency of road characteristics

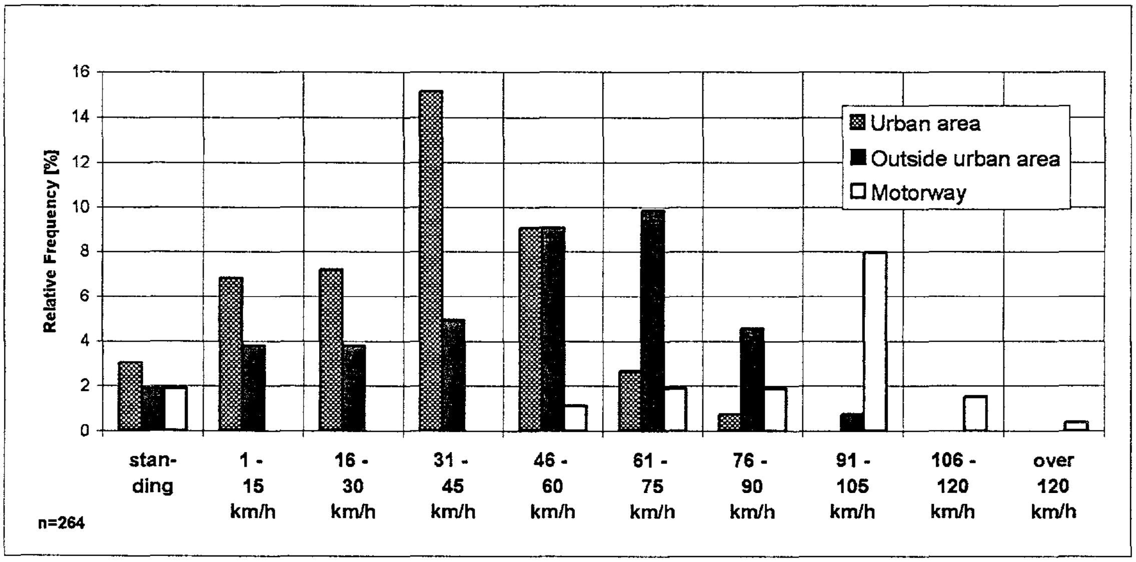

Figure 7: Relative frequency of driving speed separated to (urban area, outside urban area, motorway)

The majority of bus drivers involved in accidents (78 %) took no evasive action before the collision, **Figure 9.** Almost one of five bus drivers (18 %) was able to initiate at least one evasive manoeuvre before the collision occurred. In contrast to the evasive manoeuvre, three of five bus drivers (61 %) applied the brakes, **Figure 10.** In the majority of these cases, the brakes were fully applied.

FINDINGS FROM THE PRE-CRASH PHASES

The behaviour of the driver of a bus has an important influence on the safety of its passengers. He should possess appropriate qualifications, start the journey in a rested condition and always carry out his functions as a driver in a responsible manner. In addition to driving safety, active safety criteria include condition safety, awareness safety and operating safety. Bus drivers are subject to the same regulations as truck drivers in respect of rest times.

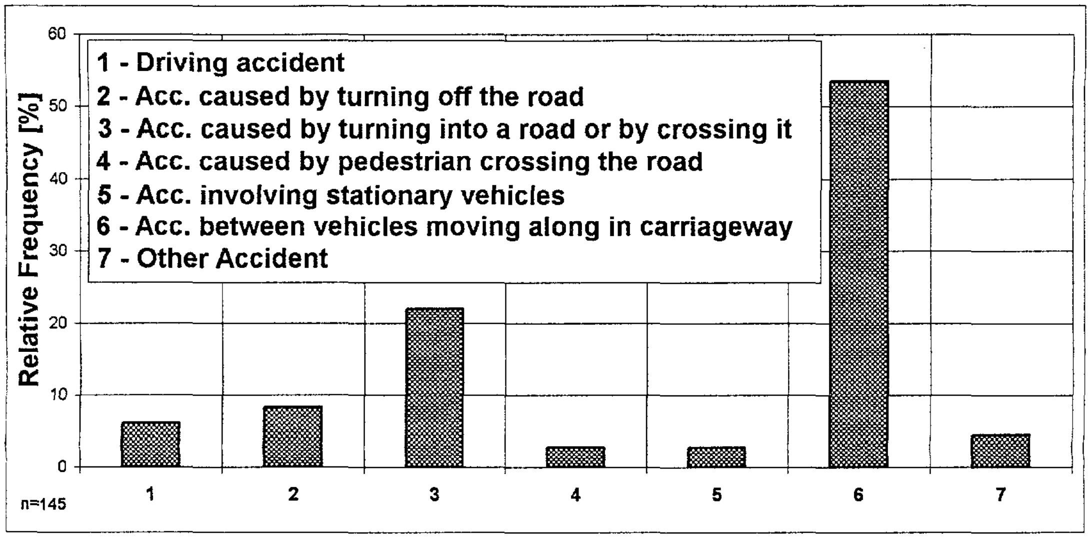

Figure 8. Relative frequency of accident types

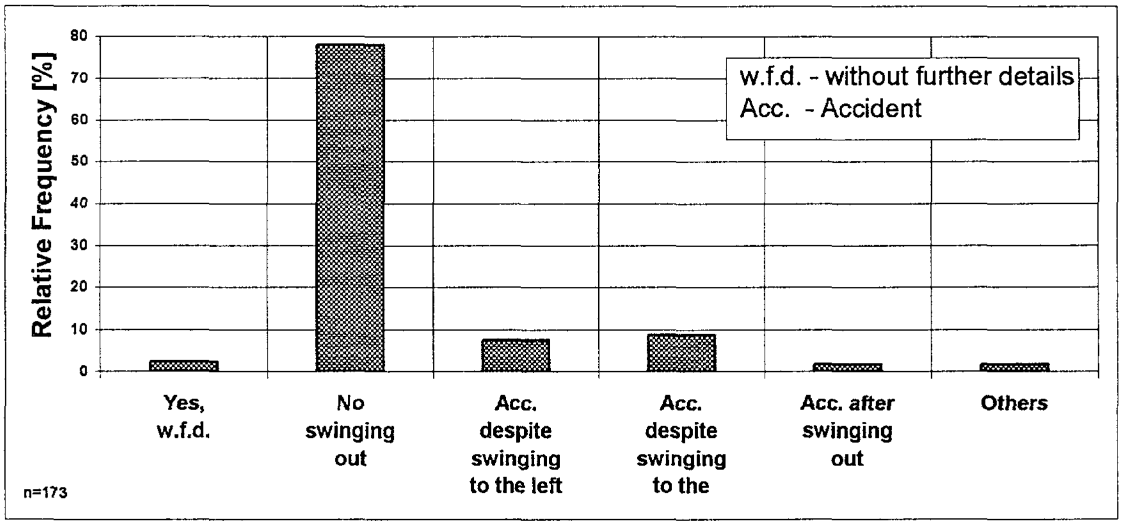

Figure 9. Relative frequency of swinging out manoeuvres

Increasing use is being made of technical equipment to support the driver in critical situations and/or in order to prevent such situations from occurring at all. Some of this equipment was initially developed for use on cars and subsequently adapted to the particular requirements of commercial vehicles, hence it is also suitable for buses. A classic example is the anti-lock braking system ABS. The technical equipment currently being fitted mainly into new cars (e.g. the vehicle dynamics control described by MÜLLER et al., 1994, or the brake assistant, KIESEWETTER et al., 1997) can therefore provide pointers for other technical improvements to active safety, the potential of which can be used to further increase active bus safety using information on accident occurrence.

Features of the active safety of modern buses include efficient chassis with lateral acceleration of more than 0.6 g to the top limit and brake systems, e.g. with pressure operated disc brakes on the front axle, which on a 16 t loaded bus from 100 km/h, facilitate full brake deceleration of 0.7 g, RIECK, 1994). Modern commercial vehicle brake systems with high deceleration values also have a corresponding user potential in the bus which is shown by the high number of buses (58 %) which brake before accidents. Every meter of distance braked can therefore minimize the consequences of accidents. Currently, several technical devices are officially specified for all buses in Germany, the most important of which are listed below:

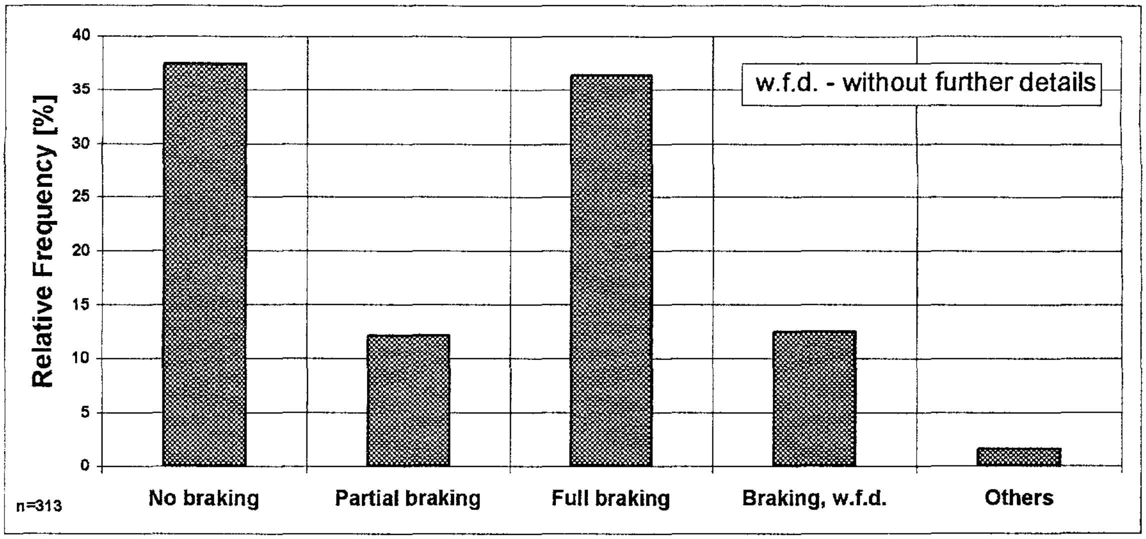

Figure 10. Relative frequency of braking

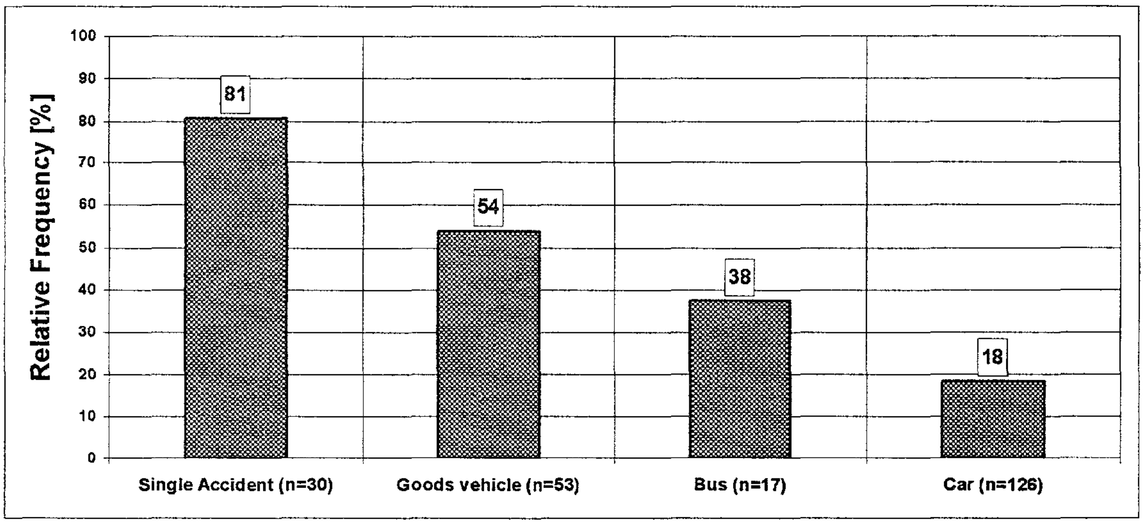

Figure 11. Share of accidents with severe injured or killed bus occupants separated to bus opponents

- ABVs (automatic anti-lock systems) are specified for all buses and coaches with a permissible total weight of over 12 t which were registered after 1991-09-30 (71/320/EWG, § 41 b StVZO).

- Since January 1994, all new buses with a total weight in excess of 10 t, the designed maximum speed of which is over 100 km/h, must be fitted with automatic speed limiters. From 1996, even older buses (first registration 1988-01-01) have had to be retrofitted with automatic speed limiters. The speed is regulated at 100 km/h (EC Directive 92/6, StVZO § 57c, 50. Ausn. Vo. 19 StVR-ÄVo).

- Increased permanent brake effect for passenger-carrying vehicles with more than eight passenger seats and a total weight in excess of 10 t (71/320/EWG/G. App. II).

In 3.2 % of the cases analysed, it was possible to prove that the maximum permissible vehicle speed of 100 km/h had been exceeded. Therefore, the level of potential usage of speed limiters in buses should be categorized as rather low. Nevertheless, speed limiters can be justified as a preventative measure to avoid serious accidents which could occur when the bus is travelling at a significantly increased speed.

OVERTURN/ROLLOVER - ACCIDENTS

From the point of view of passenger safety, individual accidents involving overturn and/or rollover, have a significant meaning. Given the size of the vehicle and the higher seat position, the bus provides a high degree of protection for its passengers in the event of a collision with most other vehicles (motorcycles, cars, vans). By contrast, the risk to passengers is twice as great if the bus overturns. If the bus overturns or rolls over, the passengers not wearing seat belts will usually fall from the rows of seats turned upwards into the danger zone below. Passengers sitting in this danger zone will then collide with the falling persons and objects which for example escape from luggage racks, and are forced into the impacted side of the bus. On this side, the rails, upper and lower window runs and also the side panes are under extreme pressure. Should external components from the road and objects located on the road edge (e.g. protective plank posts) project inside the bus, fatal consequences can ensue for the passengers directly behind this area.

From the bus accidents investigated by DEKRA, bus passengers were seriously injured or killed in 81 % of individual accidents (see **Figure 11**). At 54 %, the risk of being killed or seriously injured in bus/truck accidents and at 38 % in bus/bus accidents, is essentially lower than in individual bus accidents. Only in 18 % of bus/car accidents the bus passengers were serious injured or killed. This figure of 18 % may initially appear high, given the type of the other vehicle involved. It must be understood however, that after colliding with a car, the bus can become unstable and the passengers will sustain serious injuries as a result of the subsequent crash.

In order to investigate the dynamics of the passengers and also the impact to the seats and the supporting structures when a bus overturns, DEKRA performed dynamic tests in the crash centre at Neumünster. In contrast to the static tests carried out in accordance with ECE-R 66, in the tests carried out by DEKRA in the crash centre, the buses overturned dynamically on its side. As an example **Figure 12** shows a test carried out using a Neoplan N 216 coach.

The vehicle was accelerated by means of a cable drive from the DEKRA crash centre to a speed of 40 km/h and run with a constant transverse control of the movement over the vehicle's own steering system along an optically tracked guide mark with the right front wheel on a ramp. After the vehicle was also run with the right rear axle on the ramp, the traction cable was unhooked. Due to its inertia, the bus continued to run without drive and by means of the transverse control, with the right wheels further up on the ramp up to the tilt limit, which it reached at a sustained speed of 30 km/h. The bus then tilted to the left and skid into the final position, **Figure 13**.

Five dummies (D1 to D5, **Figure 14.**) were placed inside the bus. Two of the dummies (D2 and D3, both hybrid III, 50 % male, instrumented) were restrained in aisle seats by means of two-point belts. An unbelted dummy D1 (also hybrid III, 50 % male, instrumented) sat behind dummy D2. As with ECE-R 80, this arrangement was used to examine the potential risk of a belted passenger through a passenger sat behind without a seat belt. In this area, between the two right doors of the bus, the vehicle manufacturer retrofitted the seats (shown in Figure 14) and the support structures so that they conformed to state of the art in accordance with ECE-R 80.

The remaining seats and respective support structures were left in their older original condition (year of manufacture 1981). The unbelted dummy D4 (Hybrid III, 50 % male, instrumented) was placed in an aisle seat in the second row behind the right door. Dummy D5 which was also unbelted (Hybrid III, 50 % male, not instrumented) sat on the right side of the vehicle in the fifth row, in a window seat behind the driver.

Figure 12. Bus tip over on a ramp

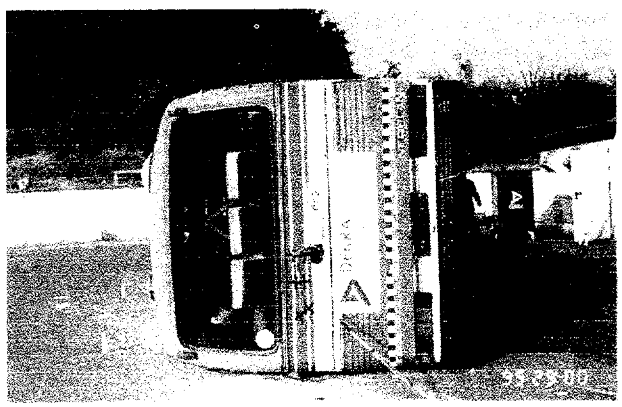

Figure 13. Bus in final position after tip over

In order to obtain more information on facial loadings caused by direct contact with the seat or bus structures using the standard options of the instrumented dummies (D1 to D4) (according to GRÖSCH et al., 1990), pressure-sensitive film (known as Fuji film) was used, **Figure 15.**

Also, several acceleration sensors were fitted to some of the relevant seat fittings in the bus. To record the acceleration on the level of the centre of gravity at the front of the vehicle, at the vehicle's centre of gravity and at relevant points on the frame, a total of ten triaxle acceleration sensor units were installed.

The measured values of the instrumented dummies D1 to D4 are summarized in **Table 1**.

The measured values of the belted dummies are significantly lower than those of the unbelted dummies and would therefore indicate that the belt reduces passenger injury.

The injury reducing effect of the belt is recorded on high speed film inside the bus whilst it is overturning. As the bus starts to tilt, the unbelted dummies D1 and D4 turn to the left towards the centre aisle. They are temporarily restrained by the arm rests on the seats. As the side of the bus hits the road, the arm rest on the seat of dummy D4 breaks and the dummy is thrown head-first over the opposite seat downwards towards the side window at the point of impact. For any reason, the head remains unaffected from the hard impact, as the head decelerates, no increased values are given. As the bus is overturning, dummy D1 slides against the bending arm rest on its seat, over the centre aisle and its knees take the impact of the frame of the seat opposite where it eventually lands. This collision is characterized by increased thigh forces. When the side of the bus hits the road, dummy D1 is thrown downwards and the back of its head hits the luggage rack (increased head deceleration). Also, dummy D1 is thrown against the non-instrumented dummy D5. The consequence being that the head and torso of Dummy D5 is pushed against the side window.

	Dummy D1 (not belted)	**Dummy D2** (belted)
Head injury criterion HIC-36	476	76
Resultant head deceleration (3 ms peak)	90 g	45 g
Resultant chest deceleration (3 ms peak)	7 g	6 g
Resultant pelvis deceleration (3 ms peak)	7 g	6 g
Femur force Left/right (max.value)	1.43 kN / 2.14 kN	0.37 kN/ 0.28 kN
Belt force (max. value)		2.15 kN
	Dummy D4 (not belted)	**Dummy D3** (belted)
Head injury criterion HIC-36	20	5
Resultant head deceleration (3 ms peak)	25 g	7 g
Resultant chest deceleration (3 ms peak)	11g	7 g
Resultant pelvis deceleration (3 ms peak)	14 g	8 g
Belt force (max. value)		1.90 kN

Table 1. Loadings of the dummies D1 to D4, seating positions see Figure 14, in a dynamic overturn test

Dummy D5 is exposed to an extreme risk of injury from projecting external parts.

As the bus is overturning, Dummies D2 and D3 also tip towards the centre of the vehicle, their heads, torsos, arms and legs project into the centre aisle. They are how-

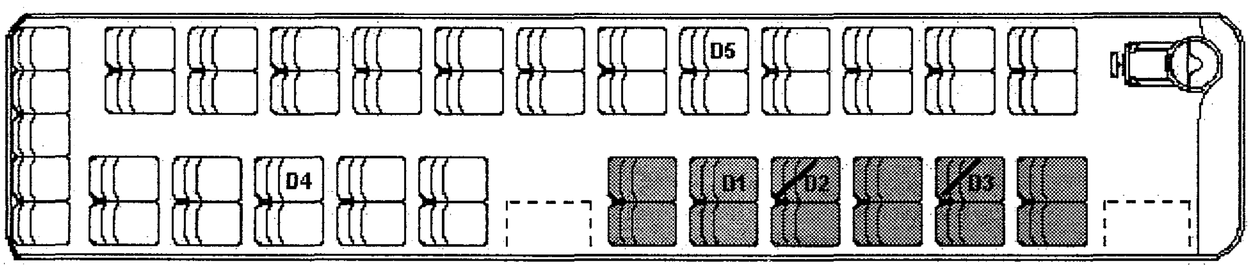

Figure 14. Seating positions of the dummies in the bus

ever held in their seats by the seat belts. This prevents the dummies falling into the highly dangerous areas on the side of the bus taking the impact.

In terms of the results of the film evaluation and the dummy measured values, the evaluations correspond to the pressure film. No increased impact loadings can be ascertained on belted dummy D3. The unbelted dummy D4 sustains contact loadings on the chin, noise and fore-head, which is not however categorized as potentially injurious. The damage sustained as a result of the back of the unbelted dummy's head (D1) colliding with the luggage rack is categorized as potentially injurious in view of the possible skull fracture.

Figure 16 shows the bus interior with the dummies in the end position after the bus has overturned.

Figure 15. Dummy head with applicated pressure detection foil

FINDINGS FROM OVERTURN TESTS

The tests carried out confirm the known risks to passengers arising from real accidents where the bus overturns. Here, two-point seat belts (lap straps) for the rows of seats which turn upwards when the bus overturns, have a significant far-reaching protective effect. Static overturn tests in accordance with ECE-R 66 (RIEBECK and BREITLING, 1997) and numerical simulations (APPEL et al, 1996) also provide similar results. Given the current status of knowledge, two-point seat belts offer advantages over the three-point belt (shoulder/lap belt). The particular dynamics with side overturns and rollovers can lead to the torso of the belted passenger becoming free from the shoulder strap. This causes the entire belt to become loose and there is also the risk of the passenger becoming released by the belt around the hips.

The belts must be integrated into the existing restraint system. This type of seat belt system is already available. Obviously, it is hoped that passengers travelling in buses with existing seat belts will fasten them, as currently is the case with air travel.

In the case of the seats located on the side of the bus which impacts the road as it overturns, a two-point belt cannot prevent the heads, torsos, arms and hands of passengers colliding with rails or side windows. On the one hand, the effect of this can be minimized by flexible design and padding. On the other hand, if the side structures fail, e.g. a window breaks, the risk is greater when the bus impacts the road. Three-point belts on the outside seats, could, if the seat belts are tightened with a simulated rollover and if certain threshold values are exceeded (GRÖSCH et al, 1996) hold the passengers in their seats. Therefore the possibility is given to hold the passengers

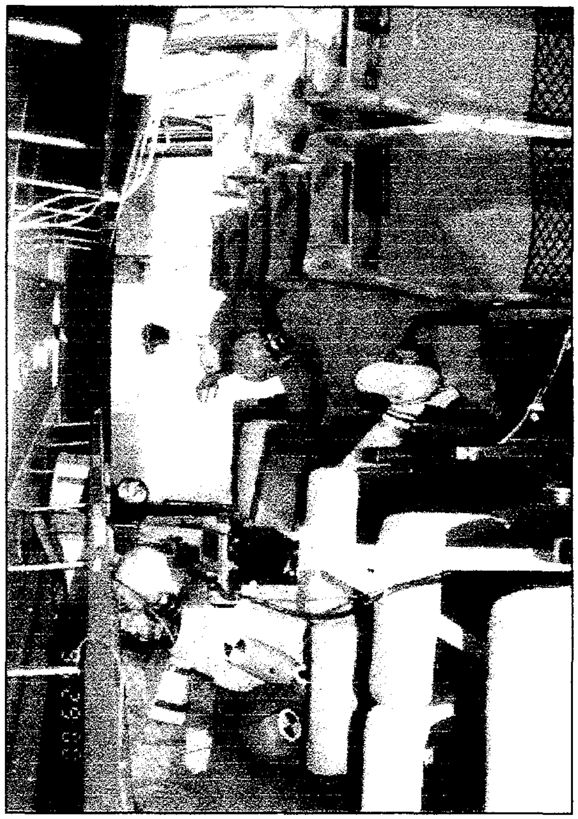

Figure 16. Final positions of the dummies in the bus after tip over

away from the side bus structures and the road. This means that the risk of injury to the majority of the exposed passengers is further reduced, provided that no external parts penetrate the bus when it overturns.

With the dynamic overturn tests so far carried out in the DEKRA crash centre on the ramp, the damage to the bus structure in the area of the side wall columns and also the upper and lower window runs is less than that found from the static test according to ECE-R 66 and from many real accidents. In order to increase the structural damage during the dynamic test with lateral movement components during overturn, thereby better adapting to the "worst case" of the real accident, the ramp should be elevated. Furthermore, in this type of test, various obstacles could be placed on the road. Currently, interest is being shown in confirming whether protective devices (crash barriers) from steel or concrete walls, can be differentiated in terms of their aggressive nature, in respect of the overturning bus.

FRONTAL CRASHES

Essential parameters for describing the seriousness of an accident-related collision and/or simulation of same as part of a test, are the location of the main damage, the accident geometry and the collision speeds. The frequency distributions illustrated in **Figure 17., 18.** and **19.** provide further information on internal bus safety.

The distribution of major damage areas on the potential other vehicle (Figure 17.), shows that in the case of the individual accident, the major damage is predominantly sustained in the side areas of the vehicle. In the case of individual accidents, the explanation lies in the frequent number of overturns. In the case of a collision with a truck, most of the damage is sustained at the front. With this accident group (bus/truck), the causes lie in frontal collisions (front bus/front truck) and rear end collisions (front bus/rear truck). Primary collisions between buses and cars cause the most serious deformation, virtually equally distributed between front and side areas. Some of this damage is caused by secondary collisions (also see Figure 11.). In the case of motorcycles and pedestrians, most of the damage is sustained at the front and is caused almost exclusively as a result of direct contact with the other vehicle.

85.6 % of buses collide at a max. speed of 60 km/h (Figure 18.). Collision speeds above this level occur only seldom.

The overturn speeds of the examined buses are distributed over the full speed range. There are more overturn speeds in the 31 to 75 km/h speed range (Figure 19.).

A typical accident geometry is the rear of the bus on the rear of a moving or stationary utility vehicle. In these cases, there is a considerable risk of death or injury for the bus driver and persons seated near to him.

In the DEKRA crash centre, two tests involving front collisions with buses have been carried out. In one of the tests, the bus (Büssing, year of manufacture 1975, weight 10 t) travelling at 40 km/h and 70 % frontal overlap, collided into the rear of a stationary 16 t truck with its brakes on, **Figure 20.** In the other test, the bus (Neoplan N216, year of manufacture 1981) travelling at 31 km/h at 30% frontal overlap, colliding with the fixed concrete barrier at the crash centre, **Figure 21.**

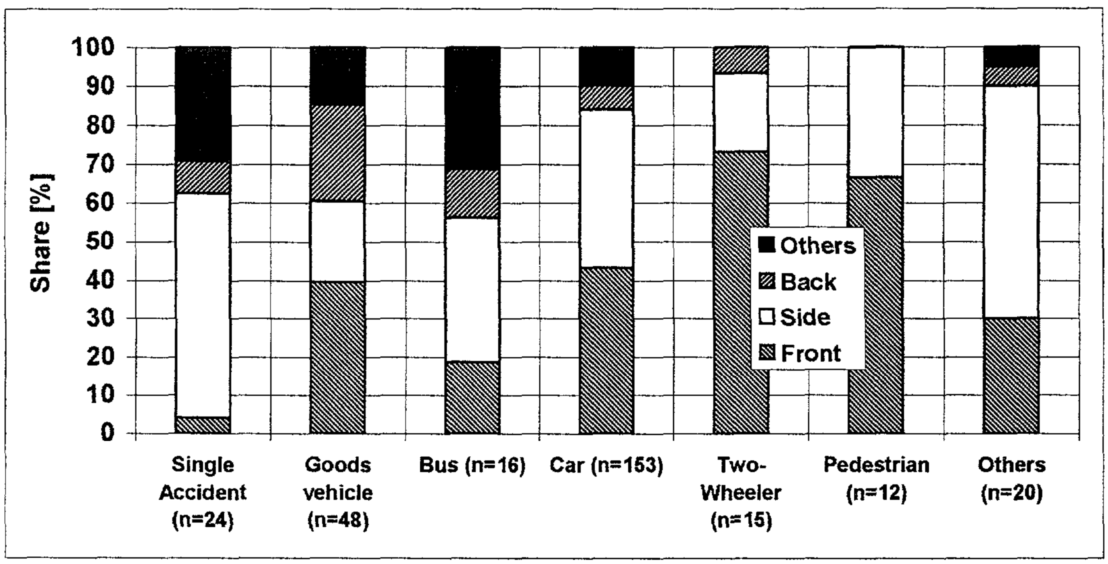

Figure 17. Relative frequency of main damaged bus areas separated to the different opponents

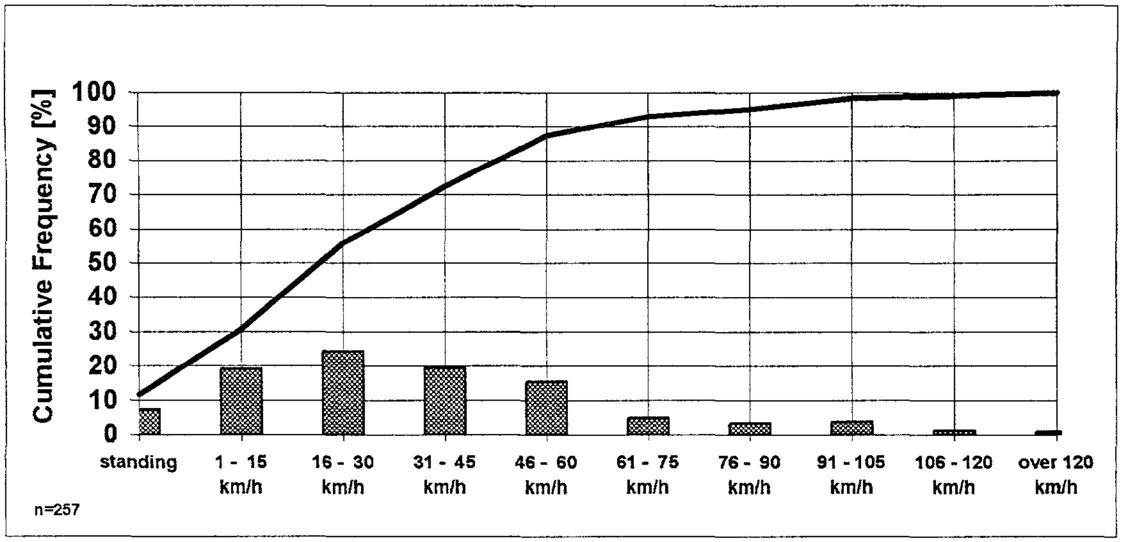

Figure 18. Cumulative frequency of bus collision speeds (containing all accident configurations)

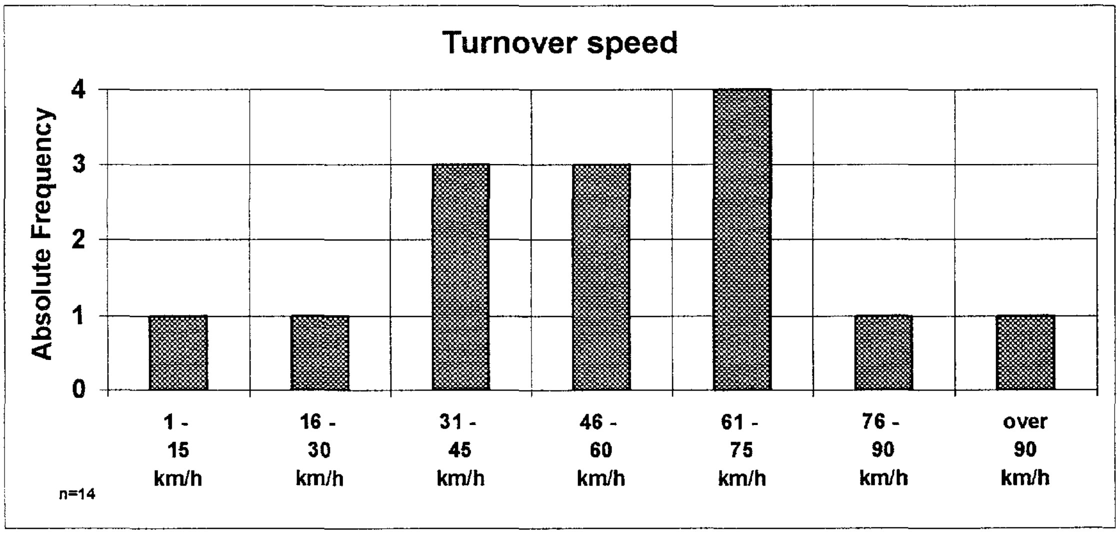

Figure 19. Absolut frequency of the speed when the bus turned over

The lateral deceleration measured at the total centre of gravity in the buses is illustrated in **Figure 22.**, together with the deceleration channel specified for checking seats and restraint systems in accordance with ECE-R 80 for skid tests. Due to the very flexible front structure of the buses (Deformation path Büssing: approx. 0.8 m, deformation path Neoplan: approx. 1.2 m), the deceleration of the centre of gravity is significantly less than the maximum decelerations specified in ECE-R 80 and lasts correspondingly longer.

Two hybrid III dummies (50 % male, instrumented) were placed inside the Büssing bus. One of these dummies (DI) was restrained in a seat by a two-point belt (lap belt) and no seat was located in front. The other dummy (DII) sat unbelted in a seat in front of which was located another seat. This arrangement produced a restraining effect of the back rest of the seat in front.

The damage measured on the two dummies is shown in **Table 2.**

All measured loadings of the unbelted dummies DII are greater than the corresponding damage values of the belted dummy DI. Since there is no seat in front of dummy DI, its head and torso can move forwards freely

	Dummy DI (belted)	Dummy DII (not belted)
Head injury criterion HIC-36	14	88
Resultant head deceleration (3 ms peak)	11 g	46 g
Resultant chest deceleration (3 ms peak)	6 g	12 g
Resultant pelvis deceleration (3 ms peak)	10 g	17 g
Femur force Left/right (max. value)	0.68 kN / 0.76 kN	2.16 kN/ 3.12 kN
Belt force (max. value)	2.5 kN	

Table 2. Loadings of the dummies D1 and D2, in a bus/truck crash test (Büssing bus frontal to rear end of truck, see Figure 20.).

	Dummy D1 (not belted)	Dummy D2 (belted)
Head injury criterion HIC-36	281	62
Resultant head deceleration (3 ms peak)	23 g	57 g
Resultant chest deceleration (3 ms peak)	8 g	10 g
Resultant pelvis deceleration (3 ms peak)	15 g	7 g
Femur force Left (max. value)	0.97 kN	0.93 kN
	Dummy D4 (not belted)	**Dummy D3** (belted)
Head injury criterion HIC-36	31	66
Resultant head deceleration (3 ms peak)	31 g	41 g
Resultant chest deceleration (3 ms peak)	8 g	10 g
Resultant pelvis deceleration (3 ms peak)	8 g	10 g

Table 3. Loadings of the dummies D1 to D4, seating positions see Figure 14., in a frontal bus impact (Neoplan) with a rigid barrier.

without impact. The increased forces in the thighs of the unbelted dummies are typical, these occur on impact with the back rest of the seat in front. This causes slippage in the pelvis of dummy DI which is greater than that of dummy DII restrained by the seat belt. Due to the relatively low vehicle deceleration, there is no measured value in the area of the corresponding protection criterion.

On collision with the barrier, the Neoplan bus occupied by the instrumented dummy D1 (not belted), D2 and D3 (belted) and D4 (not belted) and also the non-instrumented dummy D5 (not belted) as in the dynamic overturn test, Figure 12. **Table 3.** shows an overview of the damage measured on the instrumented dummies. The level of damage is generally low and a long way from injury criteria threshold values.

The higher damage values are sustained by the dummies' heads and chests. This correlates with the impact on the back rests of the seats in front of the dummies. As the high-speed film shows, the heads of the belted dummies collide with the holding bar and ashtray as they are restrained at the hips by the seat belts.

The unbelted dummies propel forward with hip and torso and then the knees, followed by the torsos collide with the backrest of the seat in front. In one of the old rows of seats, on collision with dummy D4, the seat breaks away. On the new, retrofitted seat, which is damaged as a result dummy D2 being restrained by the lap strap and the impact of the unbelted dummy D1 sat behind, only slight deformation to the base of the seat. There are clearly further loading reserves here. The seat can therefore effectively restrain the passenger sat in it and there is no additional risk from the passenger sat behind.

The evaluations of the pressure film applied to the dummy heads agree with the collision observed in the film. Especially for those passengers wearing seat belts, there is a risk of injury from the awkwardly fitted holding bars and ashtrays, **Figure** 24. On the right forehead of dummy D3, a pressure of approx. 6.5 N/mm^2 occurs on collision with the hard plastic components of the ashtray and the holding bar. As with the contact damage on the right cheeks, such type of damage is not criteria for injury. In contrast, collision damage with the nose at a pressure of around 13 N/mm^2 would suggest a potential nose fracture.

FINDINGS FROM FRONTAL CRASH TESTS

The frontal crash tests carried out confirm that the particularly exposed seats occupied by the bus driver and the persons sitting next to him are at increased risk as a result of intrusions in the front area of the bus. The flexibility of the front structures of the bus lead to a relatively low level of deceleration in the passenger area behind. This means that belted as well as unbelted passengers are at a relatively low risk of injury.

Especially when there is sufficient room in front of the seat for the head and torso to move, lap belts can offer passengers protection in the event of front collision with the bus. If the back rests of other seats are positioned in front of the passengers, it must be ensured that no awkwardly positioned and designed components present an unnecessary risk of injury. If the seat is positioned correctly and with the correct shape and padding, the back rest can be designed as part of the restraining system for the passengers sitting behind and so effectively support the restraining effect of the lap belt (KRÜGER, 1986). The double loading when the passenger is restrained and simultaneous collision with the passenger sitting behind can clearly be withstood by the state of the art seats and seat restraints.

Another technical option for integrating the back rests into the restraining system of the passenger seated behind is offered by the airbag. There is however a considerable cost involved with development and fitting into the relevant seats of the bus. Therefore, fundamental cost/benefit - analyses are necessary before any of the measures described here are converted.

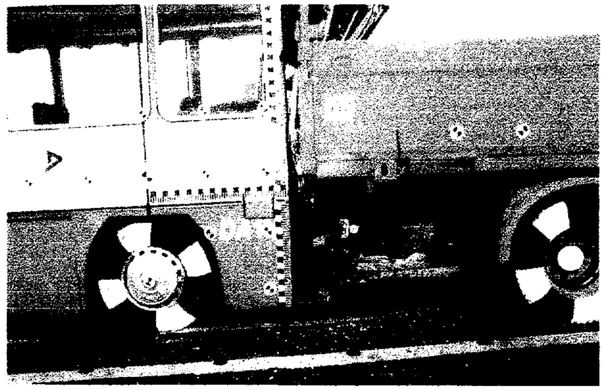

Figure 20. Bus in final position after impact to rear end of a truck

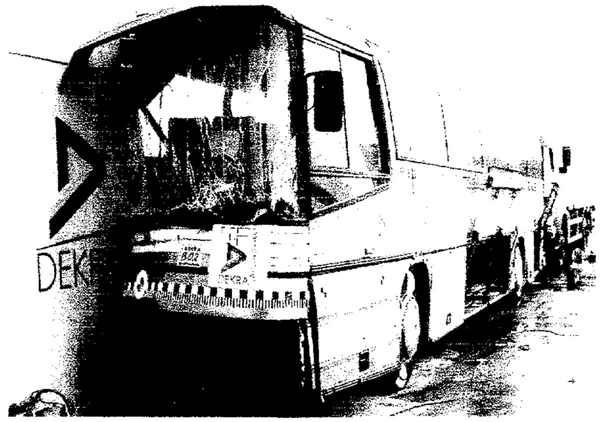

Figure 21. Bus in final position after an offset impact to a rigid barrier

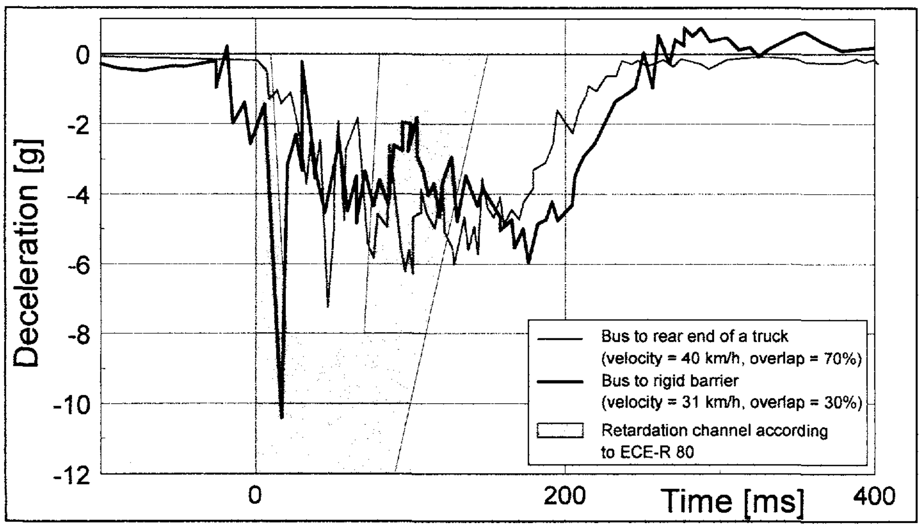

Figure 22. Retardation of buses in crash tests in comparison to the retardation channel according to ECE-R 80

EXTERNAL BUS SAFETY

The number of people injured and killed in individual accidents and accidents with two participants can be taken from the official road traffic accident statistics. These figures are separated into accidents within the urban areas, outside urban areas, and on motorways. For 1996, the figures shown in Figure 22 for accidents in Germany, show the number people in the other vehicle who were either killed or injured.

With the exception of cars and trucks, with all other vehicles involved in accidents with buses, the highest number of people are either killed or injured within urban areas. The motorcyclist and the pedestrian are of particular importance. It is not yet possible to use official statistics to differentiate between bus and coach. One can however correctly assume, that the other vehicle involved the motorcycle or pedestrian accidents shown in Figure 4 was usually a bus travelling within urban areas. By the very nature of their intended purpose, buses travel almost exclusively within the inner city area. These buses travel in close proximity to cyclists and pedestrians when at bus stops and also on the road. Therefore, the probability of a collision with these un-motorized road users is relatively high. In addition, only public transport has access to traffic free zones in town and city centres and the un-motorized road user moves around carelessly and without paying attention.

Given these facts, measures for the bus for minimizing the consequences of collisions with pedestrians and cyclists appear to have little future. Since the body of the front of the bus, at the rear and the sides all project onto

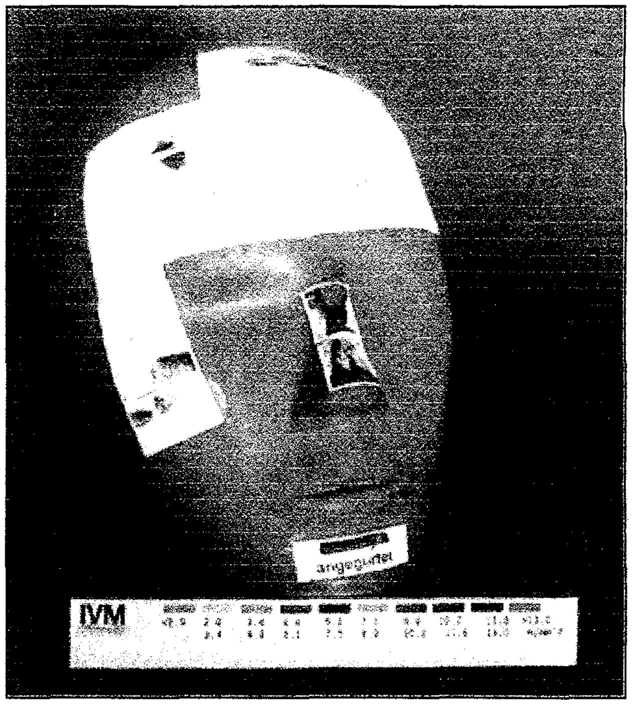

Fig 24. Pressure imprints to head of dummy D3

the road, thereby rendering rear and side protectors useless, not many options exist for avoiding the opponent in a collision.

As a matter of priority, particular attention must be paid to avoiding collisions between buses and pedestrians and/or cyclists. In this regard, the direct and indirect fields of vision for the bus driver through the windows

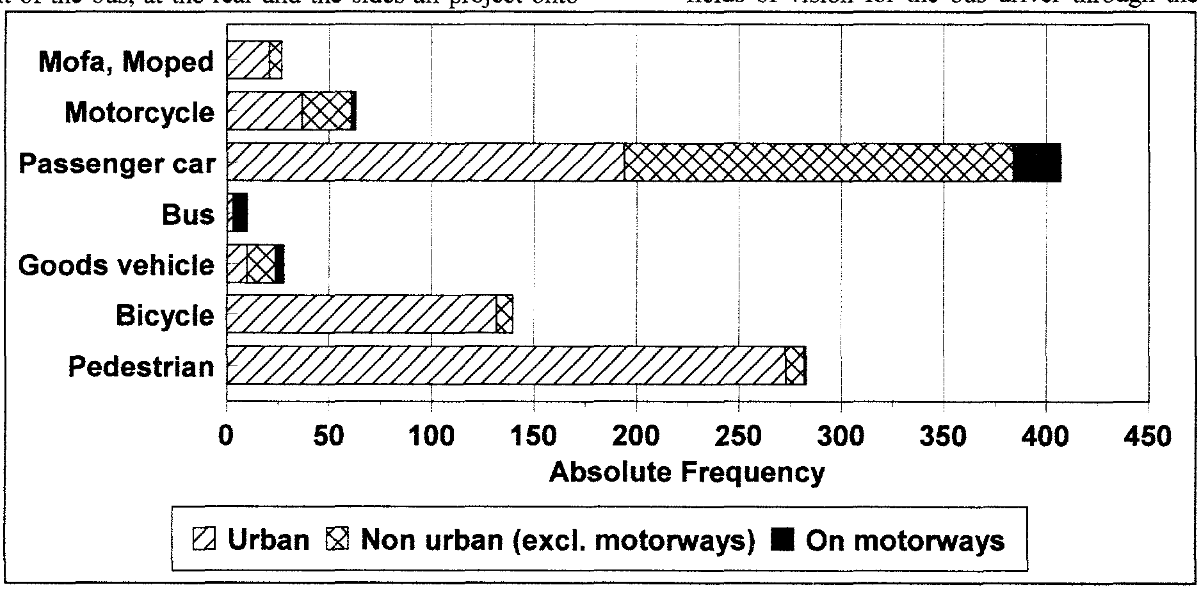

Figure 23. In accidents with buses killed and severe injured opponents

and the mirror is of particular significance. However, further measures can also be considered such as additional mirrors at bus stops, additional cameras or sensors for detecting persons and objects which are likely to collide with the bus, and also audible warning devices which signal that the bus is about to pull out.

The car is the most common accident opponent of the bus. The number of people either killed or seriously injured in accidents with buses is roughly halved between inside and outside urban areas, **Figure 23.** In those accidents occurring outside urban areas, it is assumed that the coach and not a public service bus is the most common vehicle colliding with the car.

In modern buses, measures are being implemented to protect the front of on-coming vehicles. It is therefore possible, to effectively restrain a car on colliding at 50 km/h and 50 % frontal overlap by using the deformation structure on the car, so that the car passengers can survive without serious injury, RIECK (1994).

CONCLUSIONS

1. The long-term trend in the number of passengers killed in bus accidents is falling.

2. Most bus drivers can perform a braking manoeuvre before a collision. Improved braking systems therefore have a high level of potential. Evasive action seldom occurs.

3. Accidents involving overturns have a greater risk of death and serious injury to passengers.

4. Accidents between buses and cars can cause injury to passengers, which then occur through a secondary collision of the bus.

5. Seat belts are advisable. In the event of an overturn, they prevent passengers being thrown into the centre of the bus. Seat belts can reduce the high number of those killed and injured in serious accidents.

6. In the case of public service buses, it is important to avoid collisions inside urban areas with unprotected road users such as pedestrians and cyclists.

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