Coaches and Buses in the Accident Scene

Results of a Study Regarding

Passenger Protection

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Abstract

In the past years, the growing demands on transport safety have led to more safer buses and coaches in Germany. A comparison of means of transport regarding the fatality risk per billion of passenger kilometers shows in this context that coaches are 20 times safer than cars.

However, each year in Europe 30,000 coach and bus occupants sustain injuries and 150 to 200 get killed in accidents, a fact that shows a further potential in increasing bus and coach passenger safety. In the light of this background, the Institute for Vehicle Safety Munich (IFM) has performed a total evaluation of all bus and coach accidents with injured persons in Bavaria from the year 1998. Furthermore, the IFM is involved in the project Enhanced Coach and Bus Occupant Safety (ECBOS), in the frame of which it established a database for particular serious accidents.

The following paper introduces a study being currently carried out on the Bavarian accident data and, additionally in this context, nationally and Europe wide findings of the ECBOS project. The Bavarian study, of which main objectives are to identify current major safety problems and to derive measures for an enhanced passenger protection, focuses on accident characteristics (e.g. type of accident, accident location) on the one side and injuries to bus occupants respectively the opponent party under consideration of category (e.g. double-decker coach), manufacturer and operation type (e.g. school bus) of the involved buses/coaches on the other side. Basically, two main accident groups could be identified: firstly, collision accidents as the major part of the study and, secondly, non-collision incidents (accidents which did not involve a collision of the bus with another road user).

An ad hoc evaluation has revealed in a first step that bus accidents turn out lightly for passengers. However, particular single accidents with tipping over/rollover may result in serious or fatal injuries due to roof intrusions, structure deformations and broken side windows. Moreover, unrestrained occupants may be ejected out of the vehicle. The risk of being killed or seriously injured is also given by collisions with traffic participants of similar masses (e.g. trucks, trailers, coaches/buses, etc.). Regarding non-collision incidents, it has been observed that serious injuries (e.g. femur fracture,

head laceration) might occur to city bus passengers when the bus performs a breaking or starting maneuver.

The paper closes up with requirements and suggestions for a better protection of coach and bus passengers with respect to active and passive safety, whereby further research activities planned for the future will be presented.

1 Introduction

Passenger transport by means of buses and coaches is nowadays very diversified. This is reflected in the many different bus and coach types which, depending on design and intended usage, may range from minibuses which are registered in the same way as private cars (up to 9 seats) through midibuses and city buses to touring coaches which also exist as high-deck or double-decker variants. In accordance with guideline 70/156/EWG, passenger transport vehicles are subdivided into different classes (M1, M2 and M3) depending on their gross vehicle weight (GVW) and their total number of seats [1, 2]. Figure 1 shows an overview of this classification.

Buses and coaches are considered to be a safe means of transport. Despite this, spectacular bus or coach accidents are reported in the media every week. Experience shows that serious coach accidents immediately arouse public attention, often casting doubt on the positive safety image that bus and coach travel has acquired.

The question of the real level of safety that bus and coach travel affords can be answered if we consider bus and coach accident statistics for Bavaria, Germany and the whole of Europe. This study starts with an examination of the associated figures. Furthermore, an analysis of collision accidents and non-collision incidents is also presented. This is followed by an analysis of serious coach accidents and countermeasures and recommendations for further safety enhancement.

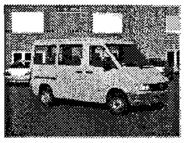
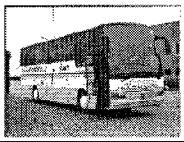
M1	Vehicles for public transport with not more than 8 seats apart from the driver's seat	
M2	Vehicles for public transport with 8 seats or more apart from the driver's seat and GWV ≤ 5 t	
M3	Vehicles for public transport with 8 seats or more apart from the driver's seat and GWV ≥ 5 t	

Figure 1: Classification of buses and coaches by gross vehicle weight (GVW) and maximum number of seats in accordance with guideline 70/156/EWG [1,2]

2 Statistics on bus and coach accidents

2.1 German statistics

According to federal German statistics, the bus and coach accident occurrence over the last 20 years has been characterized by a decrease in the number of fatalities [3] (Figure 2). However, these numbers are extremely volatile since just a few events may be enough to alter statistics dramatically (consider, for example, the dreadful year of 1992 during which 58 bus and coach passengers died). If the number of minor and serious injuries is considered, then the years 1990 (5,300 victims of bus/coach accidents) and 1999 (5,200 victims) immediately spring to mind.

A comparison of the risks posed by different modes of transport in terms of the number of fatalities per billion person kilometers emphasizes how safe buses and coaches are (Figure 3). Thus coaches, whose safety rating is approximately equivalent to that of passenger trains or airliner, proves to be 20 times safer than the private car [4]. According to "Eurostat", the same comparison depicts the coach to be 15 times safer than the car.

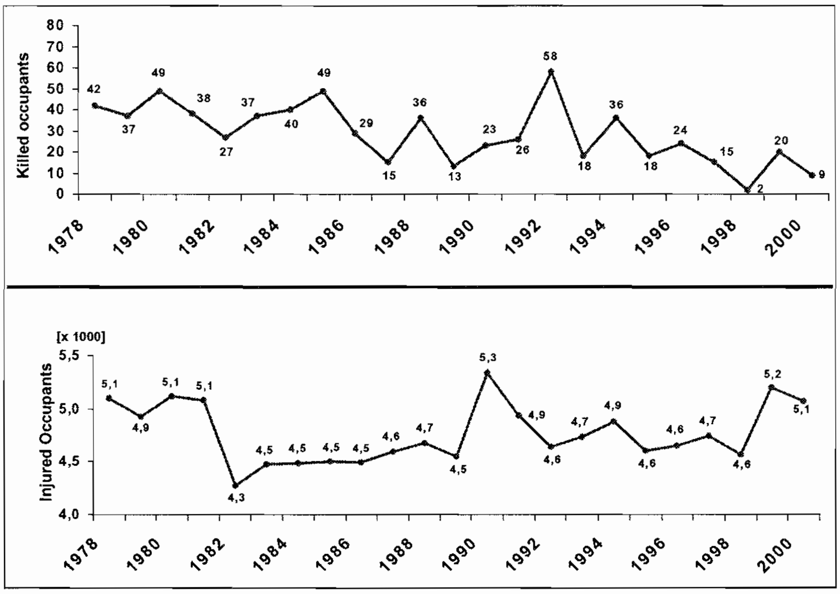


Figure 2: Evolution in the numbers of bus/coach occupants killed or injured in Germany in the years 1978 to 2000 [3]

In this statistical comparison, coaches benefit from the fact that they enable the transport of more passengers than private cars do - the average number of occupants per bus or coach in 1997 was 17.5 compared to 1.66 for private cars) - [5]. A risk comparison[1] between modes of transport that, for example, examined the number of fatalities per individual journey would be much less favorable to coaches.

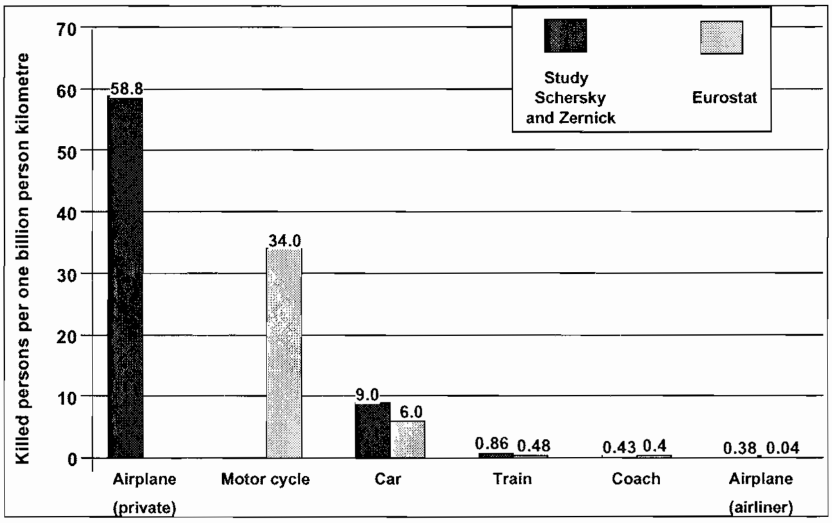


Figure 3: Risk comparison of modes of transport in 1997 [4, 5]

[1] The general problem involved in comparing different modes of transport becomes more clear when pedestrians are compared with buses/coaches. According to Eurostat, bus/coach occupants are 100 times safer then pedestrians, which accord for 40 fatalities per one billion person kilometers.

The fact that buses and coaches undoubtedly are a very safe mode of transport becomes clear, however, from a comparison of accidents resulting in personal injury to the occupants of bus and car passengers (Figure 4). Thus, for example, the risk of being killed in a bus accident in a built-up area is, at 0.1 %, five times lower than the equivalent risk to car occupants (0.5 %). Outside of built-up areas, the risk is about 2.5 times less. The risk of sustaining a serious injury in a built-up area when traveling by bus or coach is, at 8.5 %, approximately 1.3 times lower than the risk facing car occupants (11.7 %). Outside of built-up areas, the risk to bus or coach occupants is 16 %, i.e. 1.7 times smaller than for car passengers (27.2 %). For both buses/coaches and cars, it has been shown that the most frequent injuries are minor injuries and that, when the relative frequency of injury as a function of accident location is considered, there are more fatalities and serious injuries outside than inside of built-up areas.

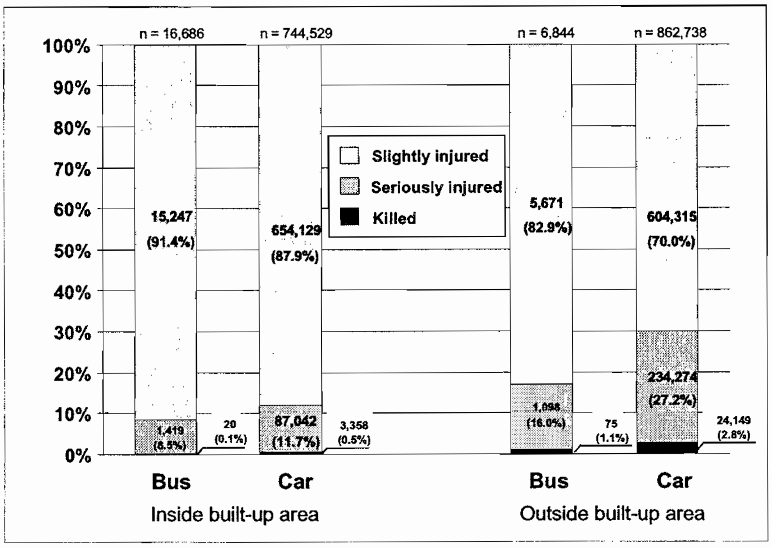


Figure 4: Personal injury to bus/coach and car occupants as a result of an accident in Germany between 1994 and 1998 as a function of location (inside/outside a built-up area) [3]

If bus and coach accidents are compared further on with other means of transport in terms of the primary responsibility for causing the accident per 1000 parties involved (Figure 5), then it can be observed that buses/coaches come off well, accounting for around 400 drivers responsible for accidents. Cyclists exhibit a slightly higher level at 428, while truck drivers, with the primary responsibility for 571 accidents, reach the highest level.

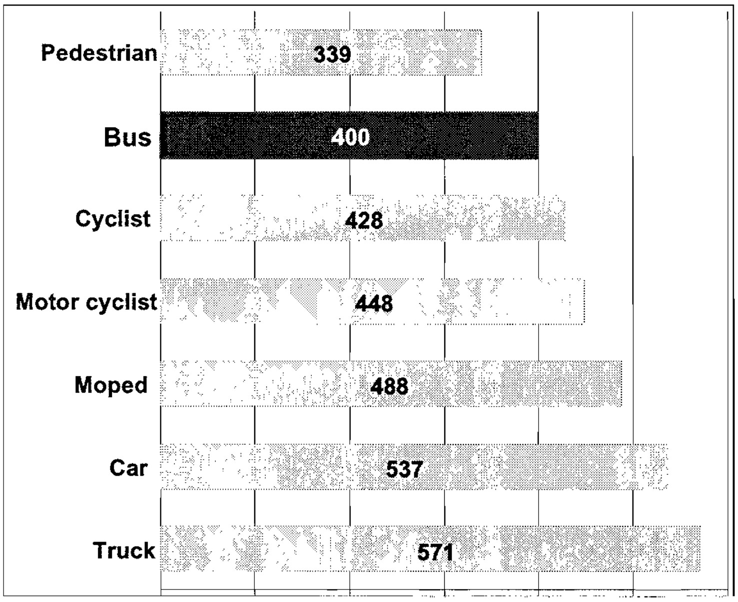


Figure 5: Primary responsibility for accidents per 1000 involved parties in accidents resulting in personal injury in Germany in 1999 [3]

2.2 European statistics

Any assessment of the risk to bus or coach occupants must take account of the fact that coach travel does not stop at the German border, in particular where tourism is concerned. Moreover, the number of accidents, and in particular serious accidents, is relatively small, thus making it impossible to come to any statistically significant conclusion. It is therefore necessary to consider bus and coach accidents throughout the EU countries.

As part of the European ECBOS research project, promoted by the EU Commission, IFM, together with six partners from England, the Netherlands, Spain, Italy and Austria, was able to perform a first European comparison of bus and coach accidents during the period 1994 to 1998 [6]. The examined countries (A, F, D, GB, I[2], NL, E, S) represent approximately 80 to 85 % of bus and coach accidents throughout the European Union.

The initial results permitted only restricted direct comparison of international bus/coach accidents. On the one hand, this was due to the differing definitions of

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[2] No Italian figures were available for 1994. Consequently, the period 1995 to 1998 was considered and the values extrapolated to cover a period of 5 years

injuries and, on the other, to differing accident recording methods and statistical groupings.

For all 8 countries, it was possible to establish a comparison of the so-called "killed and seriously injured rate" (KSI) between bus/coach occupants and other road users. The seriously injured rate indicated that the risk of being seriously injured in a bus or coach due to an accident resulting in personal injury was only approximately half as great as for other transport users (Figure 6). The "killed" rate indicated a similar result with the chance of being killed in a bus/coach accident being even lower. In this respect, the numbers were the most favorable in Germany and Great Britain with buses and coaches being 4 to 5 times safer than other means of transport.

Furthermore, for five countries the distribution of bus/coach accidents and killed occupants as a function of the involved accident party could be determined. Overall, it could be observed that, as expected, the private car is the most frequent party involved in an accident with a bus/coach. However, considering the severity of the accidents or the number of killed bus/coach occupants in relation to the involved accident party (Figure 7) then it becomes clear that single accidents (i.e. accidents involving no other party) and accidents involving heavy road users such as trucks represent a particular risk to bus/coach occupants.

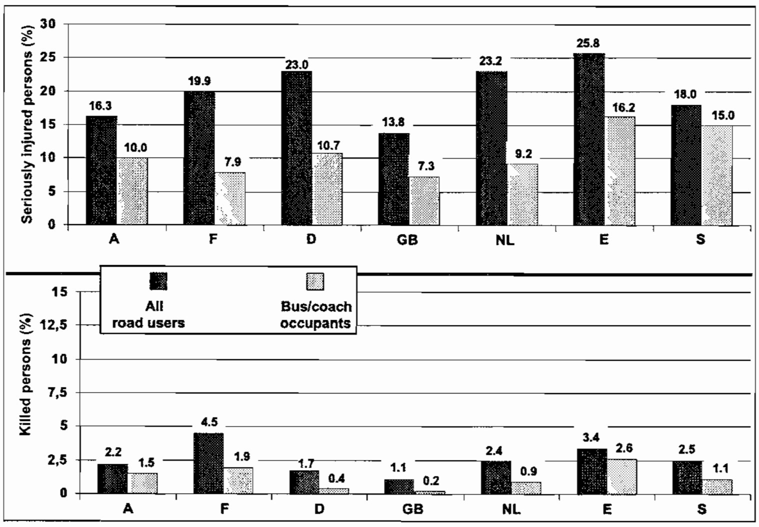


Figure 6: Killed and seriously injured rate for bus/coach occupants and other road users involved in accidents for the years 1994 to 1998 in 8 EU countries [6]

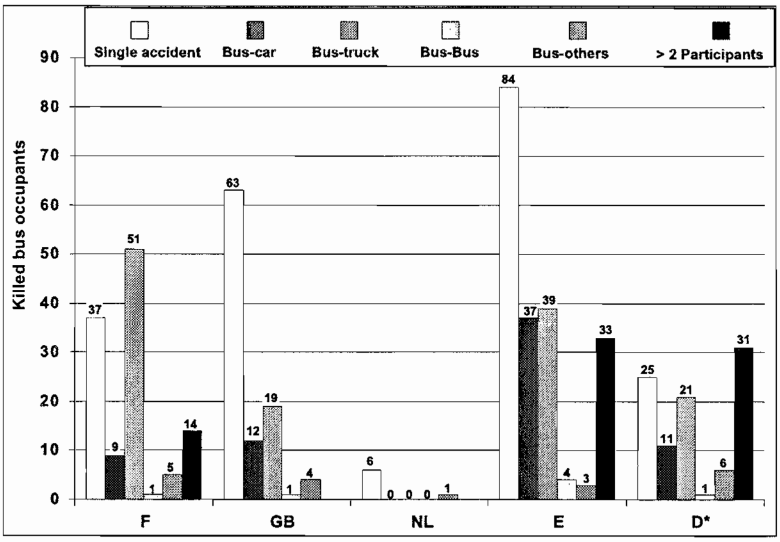


Figure 7: Killed bus/coach occupants distributed by the other accidents party involved in the years 1994 to 1998; *: While in all other EU countries it is the number of buses/coaches involved that are used as the basic value, German statistics are calculated on the basis of the number of accidents [6]

Conclusions from the statistical comparison:

This first European comparison of bus/coach accidents revealed considerable problems of comparability. This necessarily results in the requirement for an EU-wide harmonization of accident recording, statistical data and exposure data (e.g. the data stock). In particular in the case of serious bus/coach accidents, of which absolute numbers are small in the various countries in question, a European database is indispensable in order to improve the value of statistical analyses.

In summary, however, following points from the European comparison could be determined:

- Every year, approximately 200 bus/coach occupants are killed in road accidents in the EU.
- In all countries the risk of being seriously injured or killed in a bus/coach is smaller than in a private car.
- The evolution in the numbers of bus/coach occupants being victims of accidents in Germany improved during the period 1994 to 1998 (reduction of 8 %).
- In all eight countries, more women than men suffer injuries in bus/coach accidents but the severity of the injuries is greater in the male passengers.
- There is an over-proportional number of elderly victims.

- In all the countries, bus/coach occupants suffer more injuries in built-up areas but serious accidents resulting in fatalities primarily occur outside of built-up areas.
- Single accidents and collisions with heavy road users are the most dangerous types of accidents for bus/coach occupants.

From the view of accident research, overall, bus/coach safety has reached a high level. At the same time, however, the acceptance of bus/coach accidents is very low. One main reason for this might be that bus/coach passengers are not autonomous, i.e. they are not themselves in a position to intervene when dangerous traffic situations arise. In addition, there are frequent catastrophes which cause enormous human suffering. Therefore, a further safety profit is urgently required, which has to be seen internationally and in two respects:

1) Accident frequencies must be reduced and
2) The consequences of serious accidents must be attenuated.

In order to achieve the desired safety profit, the Institute for Vehicle Safety is currently conducting an analysis of bus/coach accidents in Bavaria for the year 1998. It is also taking part in a Europe-wide analysis of bus/coach accidents as part of the ECBOS project. The initial results, together with requirements and recommendations derived from this analysis of bus/coach accidents with a focus on active and passive safety, are now presented for the three major topics bus/coach collision accidents, non-collision city bus incidents and serious coach accidents.

3 Total evaluation of all bus and coach accidents with injuries to persons in Bavaria in 1998

The total evaluation of all bus and coach accidents with injuries to persons in Bavaria in the year 1998 was conducted in cooperation with the police and the Bavarian Ministry of the Interior and reveals a total of 950 accidents.

3.1 Accident Data

The basis of the accident data was constituted by the accident reports as part of the accident record together with accident notifications and witness testimonies (e.g. from bus/coach drivers, passengers, uninvolved road users) and, where appropriate, accident expert's reports. Here it should be pointed out that the traffic accident record performed by the police is intended to be used as the basis for any rulings in civil, employment and welfare law as well as for the prosecution of offenses and transgressions of traffic regulations. Complete accident evaluations in terms of accident research are therefore not always possible. In addition, witnesses' statements were often contradictory, in particular in the case of non-collision incidents (e.g. when boarding or alighting and incidents with people tripping or slipping in the vehicle). In order to achieve an objective appraisal of the accidents, however, all the information sources were checked very carefully and compared with each other on critical aspects. Doubtful cases were usually rated as "unclear" or "ambiguous".

Out of all the accident material, 804 cases were evaluated on an ad hoc basis (Figure 8). 579 of the accidents did involve a collision of the bus/coach with other road users and in an additional 225 cases, the bus/coach occupants sustained injuries without a collision between the bus/coach and any other road user (e.g. due to braking maneuver, starting maneuver).

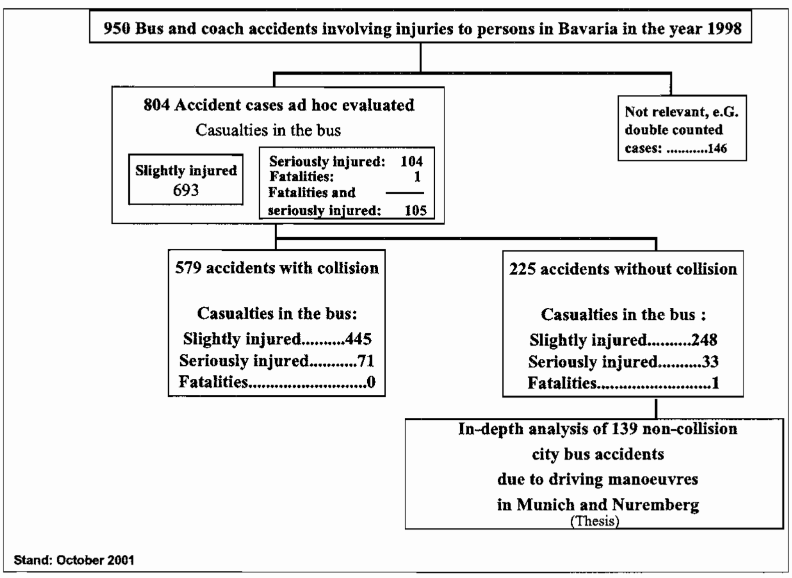


Figure 8: Accident material used by IFM

3.1.1 Bus/coach accidents involving a collision

The ad hoc evaluation revealed that coach/bus occupants predominantly suffer minor injuries at accidents involving a collision. Of the 516 bus/coach occupants sustaining injuries (see Figure 8), a total of 71 (13.7 %) were seriously injured. The proportion of those suffering slight injuries (n = 445) was 86.2 %. No fatalities among bus/coach occupants were recorded. This is primarily due to the fact that in 1998 in Germany not a single bus or coach occupant was killed in an accident.

A comparison of the frequency of accidents and the severity of resulting injuries to bus/coach occupants inside and outside of built-up areas revealed that accidents involving a collision with another road user were twice as frequent inside (67.9 %) than outside (32.1 %) built-up areas (Tab. 1). It is noteworthy, however, that 62.2 % of injured bus/coach occupants suffered their injuries outside of built-up areas. 37.8 % of the injured parties sustained their injuries inside a built-up area. In addition, the proportion of seriously injured bus/coach occupants in accidents outside of built-up areas (77.5 %) was higher (factor 3.4) than the proportion of occupants who sustained serious injuries in an accident within a built-up area, these accounting for 22.5 %.

Accident location	Accidents		Killed bus occupants	Severely injured bus occupants		Slightly injured bus occupants		Total injured	
	Number	%		Number	%	Number	%	Number	%
inside built up area	393	67.9	0	16	22.5	179	40.2	195	37.8
outside built-up area	186	32.1	0	55	77.5	266	59.8	321	62.2
Total	579	100.0	0	71	100.0	445	100.0	516	100.0

Tab. 1: Accidents involving collisions with other vehicles and injured bus/coach occupants subdivided by location and severity of injury

The evaluation of the accidents as a function of the usage of the bus or coach involved revealed that most of the accidents (59%) occurred with city buses (Tab. 2). 21.8 % of the buses/coaches involved in a collision were school buses, while 17.1 % were acting as coaches. However, in 98 cases, the vehicle usage was unknown.

Bus/coach usage	Accidents		Killed bus occupants	Seriously injured bus occupants	Slightly injured bus occupants
	Number	%			
City bus	286	59.0	0	18	191
Coach	83	17.1	0	40	139
School bus	106	21.8	0	8	87
Others	10	2.1	0	0	1
Total	485*	100.0	0	66	418
unknown	98	-	0	5	27

Tab. 2: Accidents involving a collision and injured bus/coach occupants categorized by bus/coach usage and injury severity; *: there were 4 bus/bus collisions registered

Accidents involving coaches accounted for 40 seriously injured occupants (60.6 %). The illustration of the so-called seriously injured rate (Figure 9) emphasizes this result and indicates an increased risk of serious injury for coach passengers. Accordingly, the highest rate was determined for accidents with buses acting as a coach (22.3 %) followed by accidents involving city buses (8.6 %) and school buses (8.4 %).

The evaluation also revealed that collisions with unprotected road users (pedestrians, cyclists and motorcyclists) were rather harmless to the bus/coach occupants. In these collisions, no seriously injured buses/coaches occupants were registered.

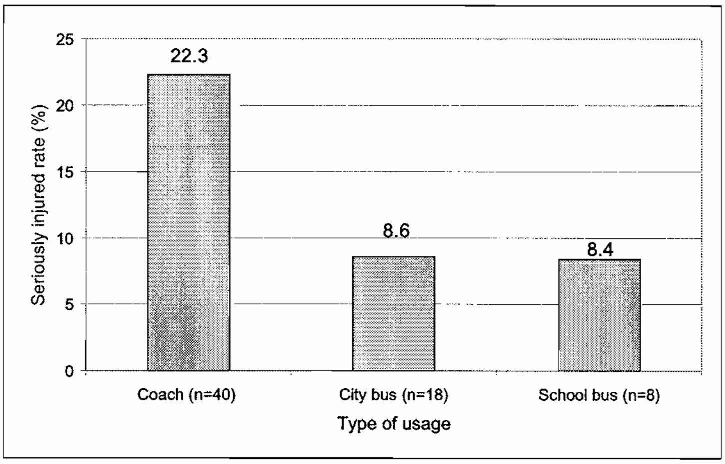


Figure 9: Seriously injured rate categorized by the usage of the buses/coaches involved in collision accidents

Accident involved party	Accidents		Fatalities		Seriously injured persons		Slightly injured persons	
	Number	%	**Bus**	Other party	**Bus**	Other party	**Bus**	Other party
Single accident	13	2.2	**0**	0	**16**	0	**76**	0
Pedestrian	90	15.5	**0**	6	**0**	31	**5**	51
Car	325	56.1	**0**	13	**24**	75	**175**	245
Truck/trailer	47	8.1	**0**	0	**28**	4	**148**	23
Bus/Coach	4	0.7	**0**	0	**2**	0	**26**	0
Motorised two-wheeler	37	6.4	**0**	4	**0**	11	**1**	22
Cyclist	56	9.7	**0**	2	**0**	13	**5**	42
Agrucultural vehicle	2	0.3	**0**	0	**0**	1	**4**	0
Ohters	5	0.9	**0**	0	**1**	0	**5**	1
Total	579	100.0	**0**	25	**71**	135	**445**	384

Tab. 3: Accidents involving a collision categorized by accident involved party and injury severity for bus/coach occupants and the other party

Serious injuries to bus/coach occupants (n = 24 serious injured persons) occurred in collisions with private cars (Tab. 3). This indicates, however, a comparatively large number of collisions between buses/coaches and cars (n = 325 accidents). Far more dangerous for bus/coach occupants are collisions with trucks, accounting for 28 seriously injured persons and single accidents (16 seriously injured persons).

Thereby, it remarkable that 22.5 % (n=16 injured persons) of all seriously injured bus/coach occupants from a collision sustained their injuries from single accidents (n=13 accidents). Ten of these serious injuries occurred due to tipping over/rollover of the bus/coach (n = 4 accidents).

3.1.2 Non-collision incidents with city buses

3.1.2.1 Background

An initial analysis of all bus/coach accidents with and without a collision with another road user recorded by the police in Munich and Nuremberg in the year 1998 revealed that non-collision incidents caused injuries to the bus occupants twice as frequently as collision accidents (Figure 10). It is remarkable that the accident severity in the two accident groups followed approximately the same distribution. These results prompted the Institute for Vehicle Safety to analyze the group of non-collision incidents in greater detail as part of a diploma thesis [7].

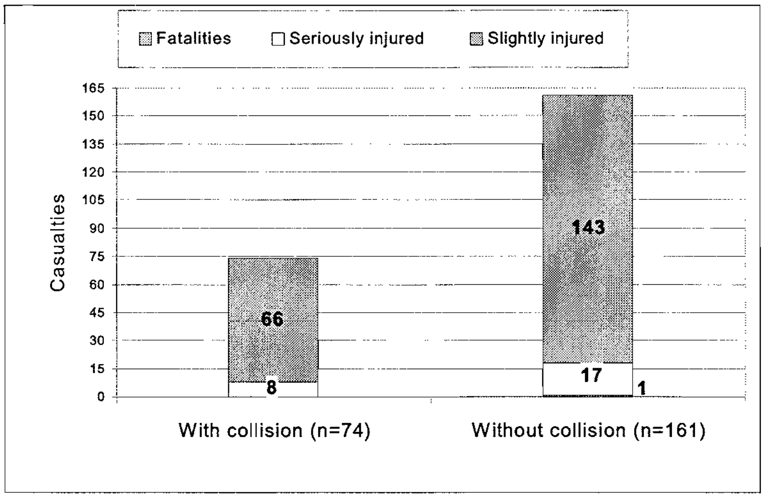


Figure 10: Share of injured coach/bus occupants in collisions and in non-collision incidents by their injury severity

3.1.3 Results of the analysis

3.1.3.1 Driving maneuvers

The study revealed that injuries to bus/coach occupants were primarily caused by braking maneuvers (72 %) followed by starting maneuvers (15 %) (Figure 11). A similar result was indicated by a DaimlerChrysler accident analysis [8] conducted using the internal data recorded by a major public transport company (braking approx. 70 %, starting maneuvers 17 %).

Furthermore, it has been shown that standing passengers are at greater risk than passengers who have a seat. In approximately 60 % of cases, the injured passengers were standing at the time of the accident (Figure 12). In many cases falls occurred, although the passengers were holding on tightly. In this respect, from an earlier study [9] it is known that particularly elderly people are more susceptible to falls due to decreased body reflexes, muscle strength and tone. In addition, their gaits are less-coordinated. All these factors reduce their ability to avoid a fall. Even an experimental investigation has revealed that elderly standing passengers in particular are not able to develop sufficient arm forces for holding on enough during a braking maneuver and therefore a falling can be hardly prevented from [10]. In addition, simulations in PC Crash and MADYMO have shown that even a bus or coach deceleration equivalent to 0.65 g can result in passengers being thrown from their seats [11].

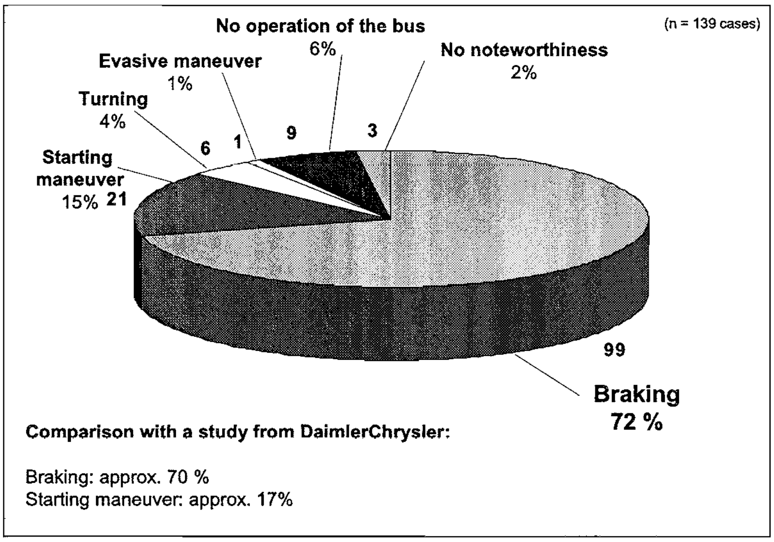


Figure 11: Non-collision incidents with city buses in Munich and Nuremberg in 1998 by type of driving maneuver

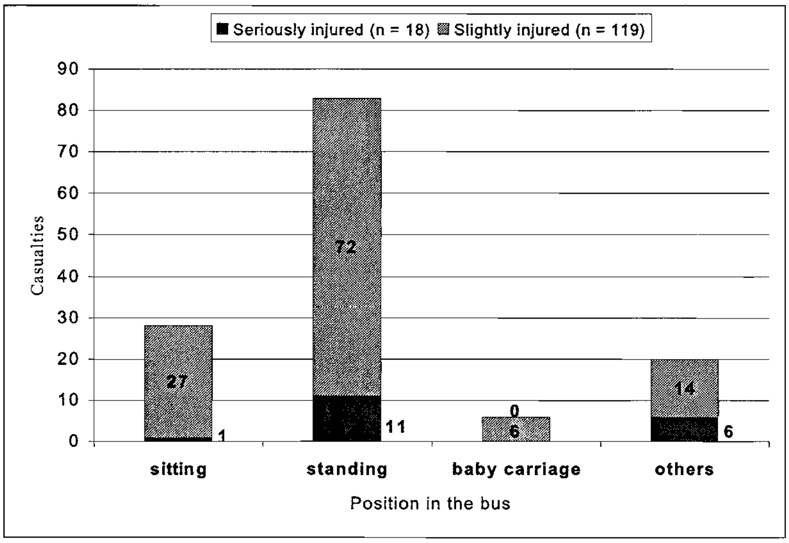


Figure 12: Share of injuries to bus/coach occupants in non-collision incidents in Munich and Nuremberg in 1998 by their position in the bus

3.1.3.2 Injured passengers

In order to examine the injured passengers, firstly a comparison of non-collision incidents in Munich and Nuremberg with all accidents in built-up areas in Germany was performed. This comparison clearly indicated that non-collision incidents from the Bavarian data more frequently resulted in injuries to persons aged over 55 than it was the case for all accidents in built-up areas in Germany (Figure 13).

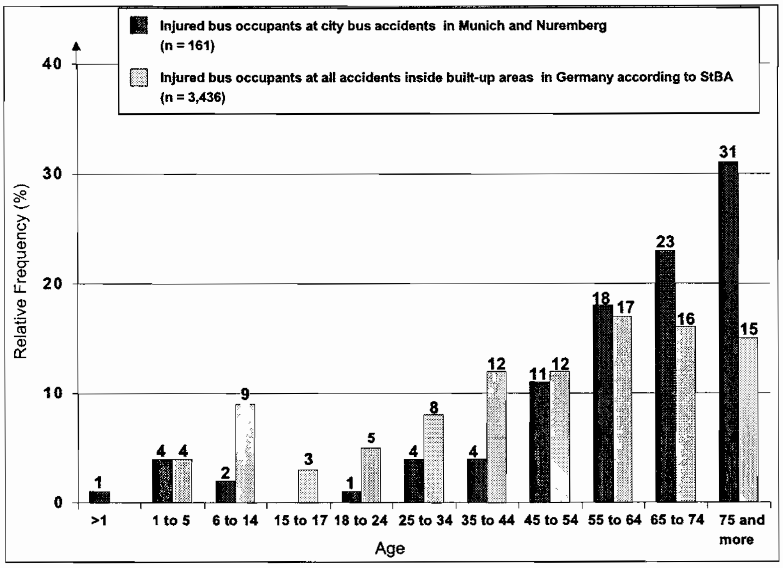


Figure 13: Comparative age distribution of injured passengers in non-collision incidents in Munich and Nuremberg and passengers injured in all accidents in built-up areas throughout Germany in 1998 [3]

Furthermore, injuries to females account for 80 % of the total (Figure 14). However; an EMNID investigation (conducted for MVV) of the m/f injury distribution indicated a ratio of 64 % female passengers to 36% male passengers [12]. This result indicates that female passengers are exposed to a significantly greater risk of injury in the event of abrupt maneuvers.

Similarly, the analysis conducted by the IFM and the comparison with the EMNID age category study gives elder people higher exposure to injuries due to abrupt maneuvers than to younger people. About 80 % of the injured passengers were older than 50, however approximately 50 % of the passengers were older than 50.

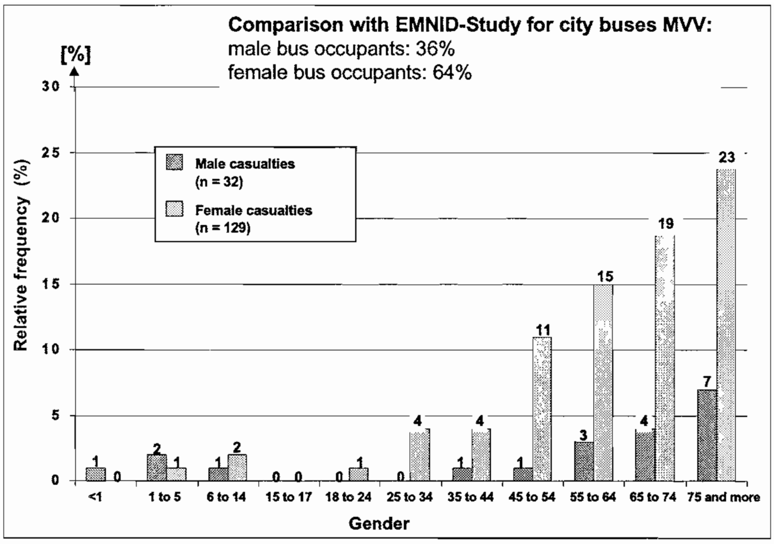


Figure 14: Gender distribution as a function of the age in non-collision incidents in Munich and Nuremberg [7, 12]

An examination of the course of the injuries revealed that "fallen" occupied first place with 104 cases (Figure 15). In 36 cases, passengers collided with interior parts of the bus and in two cases they were struck. The list of the other 36 injury events includes, for example, twisting of the foot at bus stops, slipping out of the seat, falling from push chairs and tripping or slipping when boarding or alighting. 54.6 % of the overall injuries were caused by the floor surface, followed by 15.6 % caused by support rails for standing passengers and 6.4 % occasioned by seat rails. The large number of injuries caused by the floor is due to the dangers of standing in a bus and the long distances standing passengers may fall.

Figures 16 provides a summary of the different injuries. Overall, the majority of injuries were minor (186 individual injuries). Nevertheless in a number of cases passengers suffered serious injuries (22 individual injuries). With one exception[3] there were no fatalities in any incident. In addition, multiple injuries were frequently recorded as a result of falls.

[3] The fatality related to an 84-year-old woman who died in hospital, presumably from complications not directly related to her injuries.

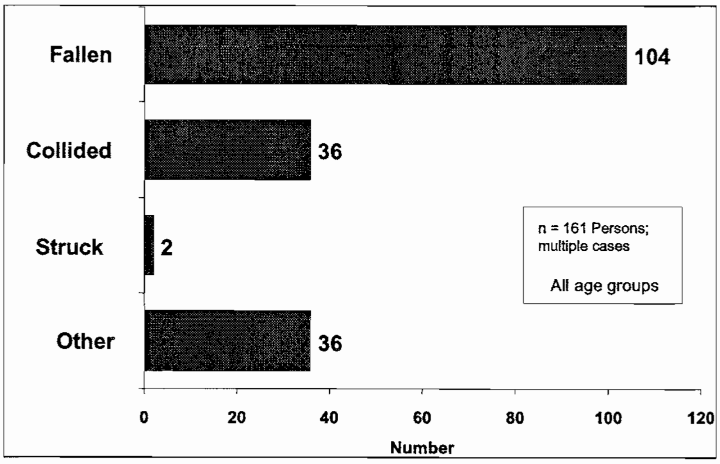


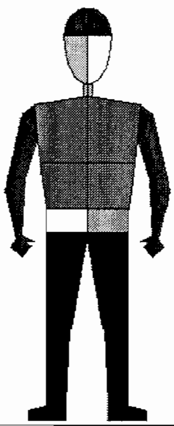
Figure 15: Course of injuries in non-collision incidents in Munich and Nuremberg

The minor injuries mostly included contusions, abrasions and lacerations. The most frequent sites of injury were the pelvis and lower extremities followed by the extremities and head injuries. The serious injuries primarily affected the pelvis and lower extremities, followed by the head. Fractures to the femur, lumbar spine, arms or ribs in the region of the thorax were also frequently observed.

Slight injuries

(n = 186 injuries)

Body region	Number	Examples
Head	40	Laceration/contusion
Face	13	Contusion
Neck	15	Contusion/whiplash
Thorax	25	Abrasion
Upper Extremities	42	Contusion
Abdomen	3	Contusion/Hematoma
Pelvis+Lower Extremities	48	Contusion



Severe injuries

(n = 22 injuries)

Body region	Number	Examples
Head	5	Laceration/ concussion
Neck	1	Whiplash
Thorax	4	Rib fracture /strain
Upper Extremities	4	Arm fracture
Abdomen	1	Fracture to lumbar spine
Pelvis+Lower Extremities	7	Fracture to femur

Figure 16: Summary of minor and serious injuries by body region

3.1.4 Measures

Th investigations of the Institute for Vehicle Safety have resulted in the identification of the following technical and individual measures:

3.1.4.1 Technical measures

- Electronic brake control (to permit the fine adjustment of the braking force)

- Non-slippery, energy-absorbing vehicle floor surfaces
- Suitable seat upholstery (non-slippery and energy-absorbing)
- Energy-absorbing holding fittings
- More seats for the elderly and people with impaired mobility

3.1.4.2 Individual measures

- Raising bus drivers' awareness of the difficulties experienced by female and elderly passengers
- Raising passengers' awareness with respect to the need for consideration for and a readiness to help elderly passengers

Finally, additional research is needed to develop alternative restraint systems other than the "difficult to implement" safety belt in city buses that will reduce the particularly great danger of falling and the long distances that passengers standing in the center aisle of city buses are exposed to. One example here is the use of reversible restraint nets such as are already being tested by one leading bus/coach manufacturer [8]. Another way of reducing the danger of falling might, for example, consist in the use of standing seats [13].

4 Serious coach accidents

4.1 Background

As part of the European ECBOS project, coach accidents occurring in the EU are currently being integrated into an accident database which can be evaluated on the basis of 120 fields and more than 1,000 attributes [14]. The initial results indicate two groups of problems involved in serious coach accidents:

1) Accidents involving tipping over and rollover
2) Collisions with heavy vehicles

In the case of accidents involving tipping over or rollover of the coach, the occupants sustain serious injuries in particular as a result of contact with interior parts of the coach or with intruding external objects. In addition, there is a considerable risk of being ejected out of the vehicle. Figure 17 presents two examples of serious accidents involving coaches that have tipped over.

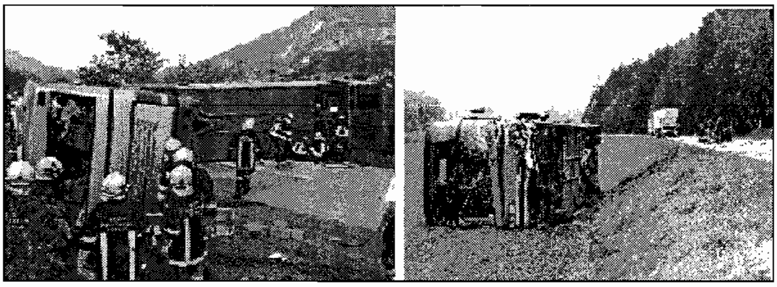


Figure 17: Examples of accidents with tipping over of the coach/bus

An initial evaluation of the ECBOS accident data (n = 35 cases) indicated the exposure of bus/coach occupants to serious and fatal injuries when the vehicle turns over. 58 of overall 124 casualties (46.7 %) had suffered their injuries from an rollover of the vehicle (Tab. 4). Considering this figure in relation to the overall number of accidents, it can be seen that the ratio between number of killed occupants and number of accidents with rollover is 1,5 times higher than the same ratio relating all other accidents. This can be also observed for the ratio number of seriously injured persons/number of accidents. At rollover accidents, this ratio lies 1,8 times higher.

Rollover of the bus/coach	Accidents	Fatalities in the bus/coach	Seriously injured bus/coach occupants	Slightly injured bus/coach occupants	Total of injured bus/coach occupants
Rollover	13	58	137	277	472
No rollover	20	60	118	317	495
unknown	2	6	16	29	51
Total	**35**	**124**	**271**	**623**	**1018**

Tab. 4: Accidents with and without bus rollover from the ECBOS material categorized by injury severity of the casualties

In the case of collisions with heavy vehicles, occupants also suffer injuries through contact with the back support of the seat in front of them, through the fact that seats are consequently ripped from their anchor points or that unbelted drivers or passengers in exposed seats (at the front) are hurled against, or even ejected out through the windshield (Figure 18).

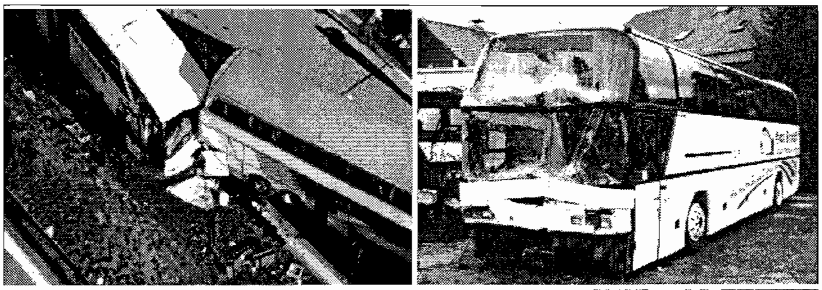


Figure 18: Examples of collisions with heavy vehicles

4.2 Passive safety – current situation and shortcomings

4.2.1 Safety belt

One key measure for an enhancement of coach occupant safety is equipping all seats in coaches of 3.5 tons GVW or more with safety belts, which is prescribed in Germany in connection with §21a of the road traffic regulations since 1st October 1999, and, in this respect, being obligatory for coach occupants to use these. In addition, from the 1st October 1999 on it has been compulsory for new coach types with GVW up to 3.5 tons to be equipped with three-point safety belts in all seats and, indeed, from 1st October 2001 on, all newly registered coaches in this weight category have also been subject to this regulation. In this respect, it is particularly important to make passengers aware of the safety instructions (safety belts, emergency exits etc.) prior to departure in the same way as on scheduled and charter flights.

The benefits of safety belts for passengers sitting in exposed seats have been demonstrated by several accident simulations. A PC Crash/MADYMO simulation [15] of a rear end collision with a closing speed of approximately 30 km/h showed that a unbelted dummy sitting on the tour guide's seat was hurled against the windshield whereas a dummy secured with a three-point safety belt remained held to the seat. The strains to which the belted dummy was exposed were good tolerable.

Two simulations of accidents with tipping over of the vehicle performed in accordance with ECE-R66 [16], in which one of the dummies was secured by a lap belt and the other was not, indicated that unsecured passengers fall from their seats and injure others. Passengers opposite to the side towards which the vehicle tips over

(Figure 19) fall approximately 2.30 m. Passengers wearing seat belts remain fixed to their seats and are not ejected out of the coach's side windows.

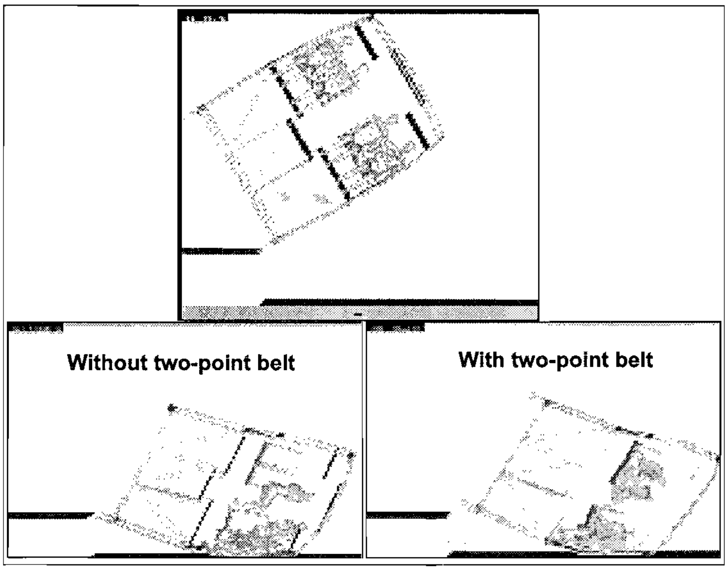


Figure 19: Rollover simulation in accordance with ECE-R66 with belted and unbelted dummies [16]

4.2.2 Structural rigidity

Regarding bus/coach accidents involving a tipping over or a rollover of the vehicle, it has become imperative that the structural rigidity of the passenger cabin complies with all existing legal regulations. The European regulation (ECE-R66) specifies a defined survival space following tip testing and permits a number of different test procedures: a quasi-static tip test from a platform (800 mm above the ground), a pendulum impact test or component tests combined with a digital simulation (Figure 20) [17, 18].

Problematic in this respect is the fact that ECE-R66 is not yet binding in all EU member states. Moreover, the conditions regulating the digital simulation such as minimum friction values for the impact surface and the determination of the energy that has to be converted are sometimes inadequate [19].

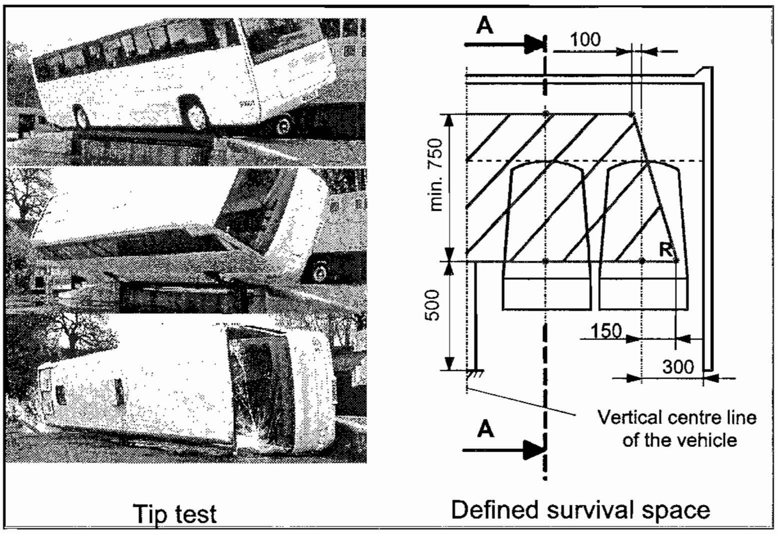


Figure 20: Improved structural rigidity in accordance with ECE-R66 [18, 20]

Finally, ECE-R66 is primarily concerned with bus/coach accidents involving lateral tipping. It does not deal with accidents in which vehicles roll over and rotate by significantly more than 90 degrees about the central axis thus resulting in lateral impacts to the vehicle.

4.2.3 Stability of seats and protection

Furthermore, in the case of collisions with heavy vehicles and rollover accidents it is necessary to improve the retention of seats and their anchor mechanisms. This subject is dealt with by European regulation ECE-R80 which provides for the testing of the required seat resistance and specifies the necessary protection criteria on the basis of a static and dynamic test procedure (Figure 21). In the static test, the seat is subjected to a test load at predefined points and a predefined level of deformation must not be exceeded. The dynamic test, which is performed using sled tests with a mean deceleration of 6.5 g to 8.5 g, is designed to prove that, in the event of a frontal collision of the bus/coach with an obstacle at approximately 30 km/h, the seat anchor mechanisms remain firm and the necessary protection criteria are met [21]. Unfortunately, ECE-R80 is also optional in most EU countries.

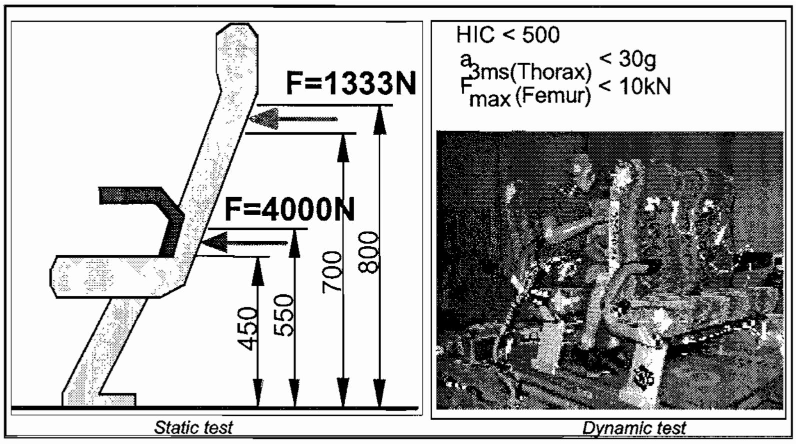


Figure 21: Retention of seats and anchor mechanisms in accordance with ECE-R80 [20, 22]

4.2.4 Side windows

Real-world accident situations have shown that when a vehicle tips over, it is almost always the windows on the side towards which the vehicle tips that shatter (Figure 22, left), thus resulting in the risk that passengers may suffer cuts or may be thrown out of the bus/coach.

In the future, it will therefore be necessary to fit shatterproof side windows (e.g. dual panel laminated safety glass). This will also improve the structural rigidity. This measure must be combined with the implementation of an emergency exit possibility at window level. This could, for example, take the form of a pyrotechnic mechanism close to the window seal which could be triggered by pressing a button in the event of an emergency (Figure 22, right) [23].

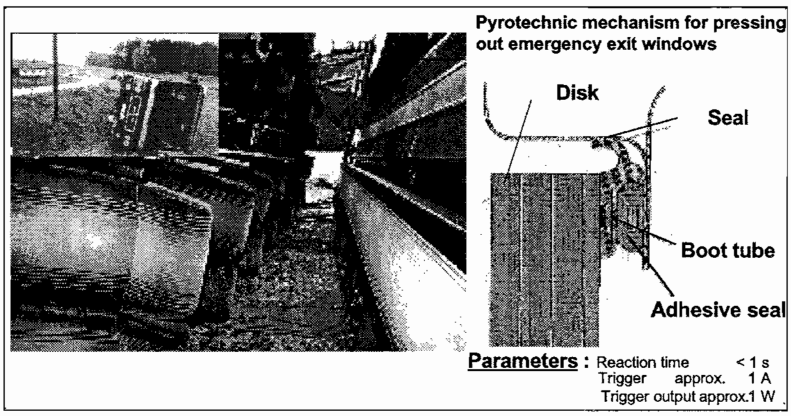


Figure 22: Shatterproof side windows with a pyrotechnic mechanism for pressing out emergency exit windows [23]

4.2.5 Requirements and recommendations

Given the current passive safety state of modern coaches and the active safety systems that are now possible, we can formulate the following requirements and recommendations for improvements in coach safety:

- Introduction of vehicle dynamics regulators with tip stabilization
- Introduction of tire pressure monitoring systems
- Obligatory EU-wide introduction of the tilt safety regulation in accordance with ECE-R66
- Performing tip simulations in accordance with ECE- R66 for double-deck coaches as well
- Obligatory EU-wide introduction of the regulation governing the retention of seats and their anchor mechanisms in accordance with ECE-R80
- Obligatory introduction of the accident data recording systems in coaches (in particular for reconstructing accidents in order to learn from them in the same way as black-boxes are used in aircraft)
- Introduction of automatic accident report systems with a panic button for the immediate alerting of the emergency and rescue services together with the provision of information relating to the number of passengers and the final location of the coach
- Side windows made of shatterproof glass coupled with the implementation of emergency exits
- Inform passengers of emergency exits and safety belts before departure in the same way as on aircraft ("Safety demonstration and information")

Further research is required into the subject of coach safety. This includes examinations of rollover safety (instead of tip safety), of improvements in the retention capabilities of the seats, and of the benefits of three-point safety belts.

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