STATUS OF THE SECONDARY SAFETY OF COACHES – UPDATED STATISTICS, CURRENT STANDARDS AND ADDITIONAL TECHNICAL MEASURES

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Paper Number 13-0341

ABSTRACT

Although integrated safety has become more important, secondary (passive) safety is still relevant in ensuring that the consequences of the crashes which always happen on our roads are as low as possible. This is particularly true for coaches that may be occupied by many passengers. Attention has also to be paid to the safety of driver and tour guide sitting in foremost position of the compartment.

To give an overview of the accident situation, results of updated statistical analyses are displayed for Europe and (in a more detailed form) for Germany. Combined with the results of in-depth studies it can be seen that rollover and frontal impacts are still the most relevant scenarios encountered in severe bus/coach accidents.

Regarding rollover, the superstructure design of new coaches has to be improved to meet the requirements of the revised ECE-R 66-02. This is illustrated by an example.

On a voluntary basis, few OEMs have improved the structure of the front end in relation to frontal impacts by using pendulum tests and full-scale crash tests in combination with advanced numerical simulation techniques. As a result, a new safety system called Front Collision Guard was developed and implemented in the latest series of Setra and Mercedes-Benz coaches.

For best safety performance in all kinds of accidents occupants should buckle up in their seats. Seats and restraint systems used in coaches have to meet the requirements of ECE-R 14 and ECE-R 80. To address this, updated results of a literature review and examples of seats and restraint systems used in modern coaches show the state of the art.

The article gives a short but complete updated overview of the most relevant aspects of the secondary (passive) safety of coaches. The main part describes the design and evaluation of the performance of the Front Collision Guard which may bring the secondary (passive) safety of coaches to a new level.

1 INTRODUCTION

The evaluation of accident statistics reveals that the bus and, in particular, the long-distance coach is a very safe means of transport. Nevertheless, severe accidents involving buses always attract considerable public interest. It has long been known that – with the exception of catastrophic incidents – passengers involved in a bus collision accident are very well protected and are only injured on rare occasions. However, the risk of being injured in a bus accident rises if the bus tips or rolls over and, for example, guard rail posts penetrate the interior from outside. Since the seats for the driver and – if appropriate – the tour guide are located right at the front of the vehicle, a front-end collision presents a special problem for their occupants. In order to protect all the occupants of a bus and – in the event of a particularly severe accident – to reduce the number of dead and injured as far as possible – the preservation of the survival space in the bus and full use of the safety belts are regarded as essential.

The homologation and licensing of buses essentially requires compliance with the harmonised international regulations established by the European Union (EEC, EC, EU Regulations) or the Economic Commission for Europe at the United Nations (UN ECE Regulations). In addition, consideration must be given to the existing National German Road Regulation (StVZO). Today the latter corresponds overwhelmingly to the international regulations.

To improve the secondary (passive) safety of buses and coaches, special regulations and tests have been imposed in the past and some of these have been since revised. This has led to a minimum standard being established that guarantees a high level of safety for the passengers of buses/coaches. Beyond this, few OEMs have voluntarily carried out supplementary tests to still further improve the safety of their vehicles.

The following section gives a current overview of the statistical evolution of accident occurrence and the associated magnitudes of risk levels. This is followed by a description of the relevant regulations, technical measures and current technical developments concerning the secondary (passive) safety of buses/coaches. All the matters discussed relate to the safety of the occupants – no reference is made to primary (active) safety and the safety of third parties involved in bus accidents.

2 ACCIDENT STATISTICS

2.1 Bus/coach occupant fatalities in the European Union

In the European database CARE (Community database on road Accidents Resulting in death or injury) the current number of traffic fatalities for the year 2011 was recorded on November 29, 2012 as a total of 3,135 [1]. The data came from 26 member states of the EU (EU 27 without Latvia [Lietuva]) and they are being continuously updated by the latest available national statistics. On the stated day there was a total of 87 killed bus/coach occupants of which 23 were drivers (26%) and 64 were passengers (76%), Table 1. Relative to the total of 31,125 fatalities in the aforementioned member states, killed bus/coach passengers represent a proportion of 0.3%.

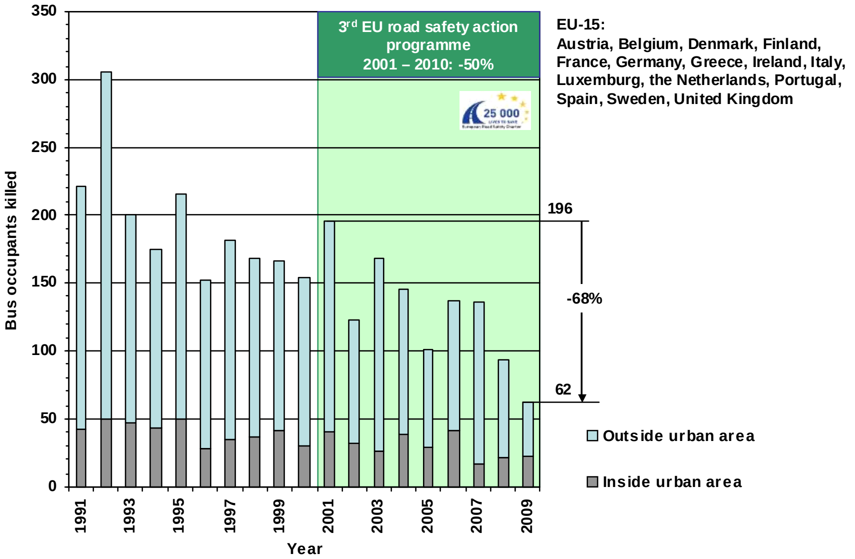
In the case of 15 EU member states it was possible for CARE to identify the number of bus/coach occupants killed annually from 1991 until 2011 and broken down according to the location of the accidents, Figure 1. The maximum was recorded in 1992 with a number of 305 killed bus/coach occupants. In 2009, the number fell to 62. Most bus/coach occupants died in accidents which occurred outside urban areas. The proportion in 2009 amounted to 65% (i.e. 40 out of a total of 62 fatalities).

The 3rd European Road Safety Action Programme set the objective of halving the number of killed traffic participants for the whole of the European Union (EU 27) over the period 2001 - 2010 [2]. This objective was almost attained by a reduction of 44% from 54,000 to 39,500. In the member states considered here (EU 15) the number of bus/coach occupants killed fell from 196 in 2001 to 62 in 2010, i.e. by 68%. This means that bus/coach occupants participated in the general development towards steadily increased safety levels on the roads of the EU.

Table 1: Current figures of bus/coach drives and passengers killed per year in road accidents in the member states of the EU (Source: CARE [1] as of November 29, 2012)

State	Belgique	Bulgaria	Ceská Republica	Danmark
Year	2011	2009	2011	2010
Driv.	2	0	2	0
Pass.	0	0	2	0
State	Deutschland	Eesti	Éire	Elláda
Year	2011	2009	2010	2011
Driv.	1	0	1	1
Pass.	9	2	0	3
State	Españia	France	Italia	Kýpros
Year	2010	2011	2010	2004
Driv.	0	0	2	0
Pass.	5	0	7	0
State	Latvija	Luxembourg	Magyarország	Malta
Year	2011	2011	2010	2010
Driv.	0	0	3	0
Pass.	1	0	9	0
State	Nederland	Österreich	Polska	Portugal
Year	2009	2011	2011	2011
Driv.	0	0	3	0
Pass.	0	0	9	0
State	România	Slovenijya	Slovensko	Suomi
Year	2011	2010	2010	2011
Driv.	3	0	0	1
Pass.	6	0	0	1
State	Sverige	Great Britain	**EU-26***	
Year	2009	2010	-	
Driv.	0	4	**23**	
Pass.	0	10	**64**	
***EU-26 = EU-27 without Lietuva (not reporting)**				

Figure 1. Evolution of the absolute figures of occupants of buses/coaches killed per year in road accidents inside and outside urban area in 15 member states of the European Union (EU-15) from 1991 until 2009 (data source: CARE [1] with last update on 29/Nov/2012)



2.2 Fatalities and casualties suffered by bus/coach occupants in Germany

In 2011 a total of 4,009 traffic participants died on German roads and 68,925 were seriously injured. Bus/coach occupants formed a very low proportion of these casualties with 10 fatalities and 427 severe injuries – namely 0.25% and 0.62% respectively, Figures 2 and 3. Occupants of buses/coaches are defined as those travelling in a vehicle with more than 9 seats, including the driver seat.

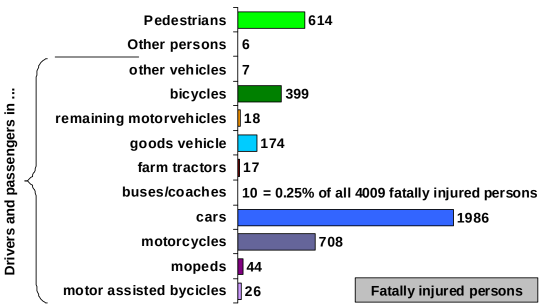


Figure 2. Road users fatally injured in accidents on German roads in the year 2011 (data source: Federal Statistical Office [3, 4, 5])

The number of persons killed and injured in road accidents since 1957 can be extracted from the publications of the Federal Statistical Office [3, 4, 5]. Figures 4 and 5 show the long-term evolution of the numbers of road users killed and severely injured up to 2011. The numbers given for 1991 and afterwards apply to the Republic of Germany after re-unification in 1990 – i.e. both old and 'new Laender'.

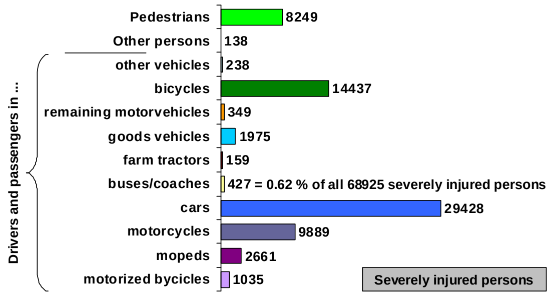


Figure 3. Road users severely injured in accidents on German roads in the year 2011 (data source: Federal Statistical Office [3, 4, 5])

The number of killed bus/coach occupants certainly remains at a very low level but the individual annual figures vary a great deal. The maximum number of fatalities during the stated period was 74 recorded in 1959. In that year there occurred the most serious bus accident since the 2nd World War. In Lauffen am Neckar a bus travelling over a level crossing was struck by the locomotive of an express train, killing 45 of the bus occupants [6, 7].

The previous minimum was 2 bus/coach occupants killed in 1998. The substantial variation over time of the numbers of fatalities is significantly influenced by individual serious accidents in which a relatively large number of occupants were killed. Table 2 contains four examples for 1959, 1992, 2007 and 2010.

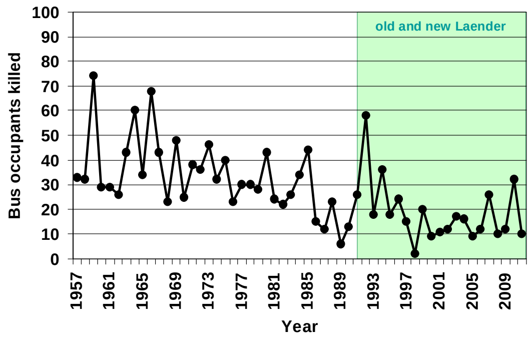


Figure 4. Bus/coach occupants killed in accidents on roads in the Federal Republic of Germany per year from 1957 until 2011 (data source: Federal Statistical Office [3, 4, 5])

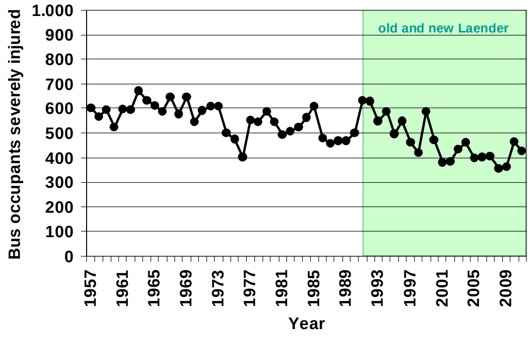


Figure 5. Bus/coach occupants severely injured in accidents on roads in the Federal Republic of Germany per year from 1957 until 2011 (data source: Federal Statistical Office [3, 4, 5])

When interpreting these numbers it needs to be noted that only those killed in traffic accidents are included in the statistics. For example, in Hanover 20 people died in a bus disaster on the A2 Autobahn in 2008. This was not the result of a traffic accident – the bus caught fire [8].

The long-term pattern of severely-injured bus occupants in Figure 5 is less apparent than the number of persons killed as influenced by annual variations. In the 'old Laender' of the Federal Republic of Germany (1957 -1990) brief periods of falling numbers were followed by some clear increases.

In the period shortly following reunification, sustained falls in the number of severely injured occupants could be observed over a lengthy period. This means that bus/coach occupants shared in the general trend offering greater vehicle and traffic safety on German roads.

Table 2. Examples of single catastrophic bus accidents which significantly influenced the figure of killed bus occupants in the corresponding year

Date	Accident description	Bus/coach occupants killed in the accident	Bus/coach occupants killed during the year	Percentage of bus/coach occupants killed during the year
June 1959	Bus struck on a railway level crossing by the locomotive of an express train	45	74	61%
Sept. 1992	Coach tilts after forcing a car and crashes into a guardrail	21	58	36%
June 2007	Truck crashes into the rear end of a coach	13	26	50%
Sept. 2010	Coach crashes into a car and a bridge post after evasion manoeuvre	13	32	41%

Further differentiation can be made between buses and coaches in terms of their particular function. The official German statistics differentiate between coaches, urban buses, school buses and trolley buses. There is also a category for "other buses" that covers buses/coaches which the police attending accidents were unable to assign to one of the above-mentioned categories.

According to the available statistics, the low numbers of fatalities differ, Figure 6. In the individual years of 1998, 2001 and 2006 not a single killed coach occupant was registered in the official statistics. In other years, such as 2002, 2003, 2007 and 2010 the number of coach occupants killed dominated compared with the total number of all bus/coach occupants killed.

In 1996 to 1998, 2000 to 2006, 2008 and 2010 no occupant of a school bus lost his/her life in a road accident. There are no records of trolley bus occupants being killed during the same period.

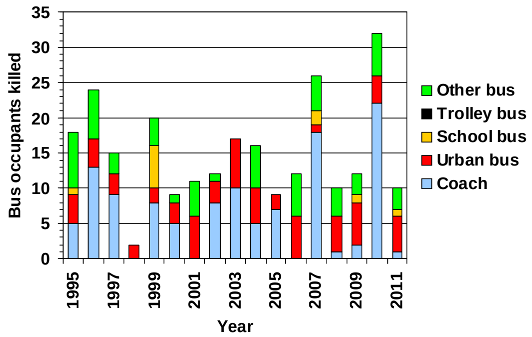


Figure 6. Fatalities in buses/coaches in Germany per year from 1995 until 2011 broken down into sub-groups corresponding to the categories of road users (data source: Federal Statistical Office [5])

The larger number of casualties (i.e. injured and killed) are dominated by the occupants of urban buses, Figure 7.

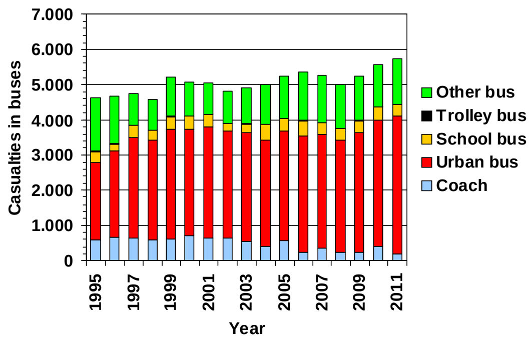


Figure 7. Casualties in buses/coaches in Germany per year from 1995 until 2011 broken down into sub-groups corresponding to the categories of road users (data source: Federal Statistical Office [5])

In individual years the number of fatalities or other casualties associated with "other buses" is always relatively high. For example, in 2010 six fatalities (19%) of the total of 32 killed bus/coach occupants were registered as occupants of "other buses". It can, therefore, be assumed that the number of occupants in urban buses, coaches and, where appropriate, school buses could have been greater than shown by the statistics.

The over-riding objective is to steadily reduce the absolute number of persons killed in traffic accidents. That is reflected by Vision Zero, a worldwide strategy promoted in Germany by the German Road Safety Council (DVR) [9]. The Accident Statistics already show that Vision Zero had already become a reality, not only for the occupants of trolley buses and school buses, but also for coach occupants on German roads during individual years.

At the same time, accident records for coaches demonstrate the importance of the constantly expressed statement that every traffic death is one death too many. The public memory retains severe individual coach accidents for a long time but takes no account of the individual years in which no coach occupants die. Consequently, severe coach accidents always provide occasion to refer to the fact that “according to the statistics, the long-distance coach is one of the safest forms of transport”. However, in view of the current dramatic real consequences of accidents, the abstract statistics fade into insignificance and so there is only a limited opportunity to persuade the public to accept on a sustained basis the desired image that coach travel is "the safest way to make a land journey". In view of this it can be seen that there needs to be an over-riding strategic aim for all those involved – namely, to take appropriate measures to ensure that the number of bus accidents remains low, but also that the consequences of a serious accident, which can never be entirely eliminated, are kept to an absolute minimum.

2.3 Typical accident scenarios

In past years many examinations and studies of bus/coach accidents were undertaken as individual research projects and these were based upon individual case documentation [10, 11, 12, 13, 14, 15]. These amounted to a supplement to the official statistics. In order to contribute to a uniform and accessible presentation, DEKRA Accident Research teamed up with the OEM Evobus GmbH (Daimler Buses) to draw up a proposal in 2006 [16]. Use was made of a scheme originally developed by Volvo Accident Research to describe accident events involving heavy goods vehicles in Sweden. This scheme has also been used in a work-group project to analyse accident events involving heavy goods vehicles in the context of the European Research Initiative eSafety [17].

This allows the representation of bus/coach accidents within three groups: accidents resulting in death and injury to occupants of the buses/coaches concerned, accidents resulting in death or injury of occupants in cars involved and accidents resulting in death or injuries of unprotected road users involved (pedestrians, cyclists, riders of powered two-wheelers). To deal only with the safety of bus/coach occupants in the context of the present paper, 121 accident reports held in the DEKRA databases were reviewed and allocated within eight typical accident scenarios, Figure 8.

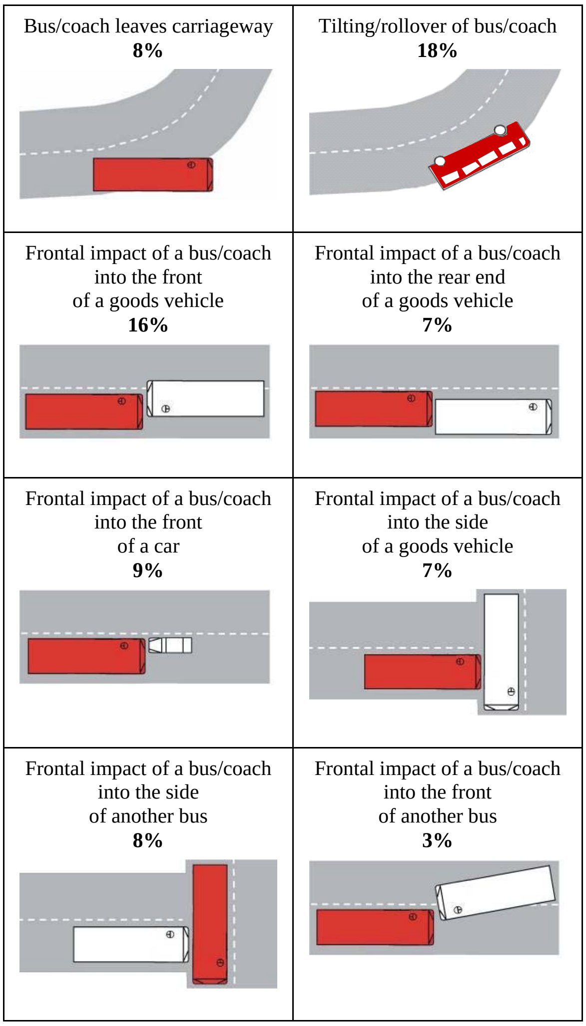


Figure 8. Proportions of typical bus/coach accidents scenarios resulting in fatal or severe injured bus/coach occupants (source: [16])

The highest proportion (18%) of the accidents which result in fatalities or severely injured bus/coach occupants are those in which the bus/coach tilts on its side or rolls over. The second highest proportion (16%) results from a frontal collision with an oncoming goods vehicle. Other scenarios include frontal collisions of the bus/coach with an oncoming car (9%), accidents in which the bus/coach leaves the carriageway and when the front of the bus/coach impacts with the side of a goods vehicle (both 8%), others when the bus/coach drives into the rear of a goods vehicle and when the side of the bus/coach impacts with the side of a goods vehicle (both 7%). In 3% of the cases a bus/coach crashed into the front of another bus/coach. Overall, frontal collisions by buses/coaches play a dominant role. Associated individual cases are described in [16].

3 RISK INDICES

To be able to compare the safety of drivers and passengers in vehicles it is customary to devise different risk indices. Illustrations of how three of the most significant indices have developed over time are given below.

Fatalities per 100,000 vehicles registered is an index which is relatively easy to calculate. It relates the number of fatal injuries of vehicle occupants on German roads to the number of registered vehicles. The index itself and the two numbers required to determine its value can be found in the published official accident statistics [3, 5].

Figure 9 compares the development of the risks related to the rolling stock of buses/coaches, cars and goods vehicles from 1962 to 2011. Since the collection of data for rolling stock numbers only applies to re-unified Germany from 1993 onwards, for the time up to and including 1992 only the numbers recorded in the ‘old Laender’ of the Federal Republic of Germany (FRG) have been taken into account.

Here, too, the influence of single severe bus/coach accidents causing a strongly varying pattern for bus/coach occupants killed per 100,000 vehicles can be seen. Conforming to the general pattern of evolution towards a higher level of safety for vehicles and occupants there was a significant reduction in the 1980s for all the three vehicle categories studied. After that curves flattened out.

It is noteworthy that the numbers of car occupants killed per 100,000 cars and the comparable index for the occupants of goods vehicles have converged to almost similar values. In 2011 both were close to 5 occupants killed per 100,000 vehicles. In 1998 when only 2 occupants were killed and the number of buses/coaches registered in the rolling stock was 83,000 the relevant index was 2.4 persons killed per 100,000 buses/coaches. No such favourable result was achieved in any other year when the index for buses/coaches was greater than for cars and goods vehicles. This was due to the significant unfavourable influence exerted by the relatively large number of occupants of buses/coaches who were killed in individual accidents.

The risk related to the total rolling stock of vehicles is indeed suitable as an abstract indicator for recognising and comparing different categories of vehicles. However, it does not permit the derivation of the actual level of risk to which individual vehicles and their occupants are exposed because that risk is related to both mileage covered and the number of occupants.

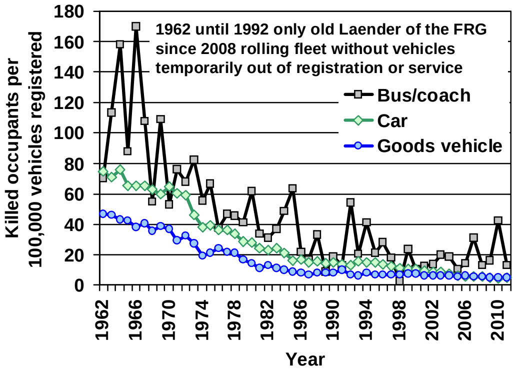


Figure 9. Risk indices for the occupants of buses/coaches, cars and goods vehicles calculated as killed occupants per 100,000 vehicles registered in the rolling stock (Federal Republic of Germany, 1962 until 2011)

Fatalities per billion kilometres travelled is a risk index determined by the relation between the number of vehicle occupants killed and the total mileage travelled per vehicle category per year (in 1 billion = 10^9 vehicle kilometres). This rate of occupants killed, also with respect to the vehicle kilometres travelled, can be clearly defined: the reciprocal index corresponds to the average risk that an individual occupant of a vehicle will be killed in a traffic accident after travelling a specific mileage. Data suitable for the calculation of this risk index associated with buses/coaches operating in public road traffic over the period 1991 - 2011 can also be found in the official accident statistics [5]. For cars and goods vehicles the travel data are available up to 2010 inclusive. The progression of the rate of fatal injuries relative to distance travelled can be seen in Figure 10.

The indices for all three vehicle categories display a downward trend which reflects the general evolution towards greater safety in road traffic. There is particularly strong evidence for this in relation to cars. As far as buses/coaches are concerned, there are further indications of the extent to which the situation can vary widely as a result of individual severe accidents. Without exception, the indices for goods vehicles are low. In 2010, based on a mileage of 1 billion km (10^9 km) of each vehicle, 9.7 occupants of buses/coaches, 3.2 car occupants and 2.1 occupants of goods vehicles were killed. In 2011, the corresponding fatality rate for buses/coaches was 3.1.

While the index considered here for car occupants – namely, 13.7 in 1991 – was far greater than for the occupants of goods vehicles (5.5) and the occupants of buses/coaches (6.6) in the 1990s and 2000s, the values approached so closely to one another that one can assume almost similar risk levels for the occupants of buses/coaches, goods vehicles and cars. Clearly this can be attributed to relatively substantial advances in improving the safety of car occupants.

A bus/coach is normally occupied by many more passengers than a car or goods vehicle. In that case, therefore, a level of risk based only on the mileage of a vehicle does not reflect the risk of an individual occupant being killed in an accident.

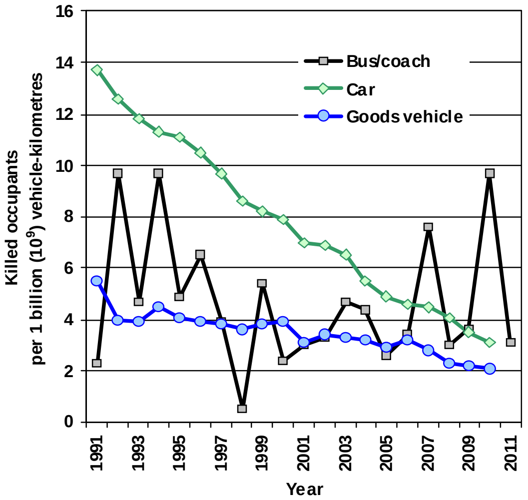


Figure 10. Risk indices for the occupants of buses/coaches, cars and goods vehicles calculated as killed occupants per 1 billion vehicle-kilometres (Germany, 1991 until 2010/2011)

Fatalities per billion person kilometres is a further index by which the overall transport performance (in billions = 10^9 person-kilometres) of the vehicles can be considered. This is the "classical" measure which shows the bus/coach with its large number of occupants to be the safest means of land travel. In a manner corresponding to the numbers published in the official statistics the evolution of this index for cars, goods vehicles, coaches in non-scheduled traffic (long-distance coach) and urban buses in line traffic between 1995 and 2010/2011 can be found in Figure 11. The relevant calculations assume a constant 1.5 occupants per vehicle-kilometre for cars and constant 1.0 occupant per vehicle-kilometre for goods vehicles.

Here it can be seen that for the occupants of urban buses very low risk factors are given, without any exception. In 2010 that risk factor was 0.1 occupants killed per billion person kilometres. Generally, the risk for occupants of long-distance coaches is low. In this instance, however, because of the relatively high number of persons killed in individual years (2007: 18 fatalities, 2010: 22 fatalities), the risk attached to these vehicles is in some years significantly greater than for urban buses. For 2010 there is a figure of 1.0 occupants in long-distance coaches killed per billion person-kilometres. For 2011 this figure is 0.05.

In earlier years risk indices related to transport performance for the occupants of cars and goods vehicles were still significantly higher than for the occupants of buses/coaches. As a consequence of the sustained evolution towards higher levels of safety for vehicles and traffic as a whole, the risk indices for the occupants of these vehicles has further approached that for the occupants of buses/coaches. The latest indices for cars and goods vehicles are around 2.0 – 2.1 occupants killed per billion person-kilometres and based on values of the year 2010.

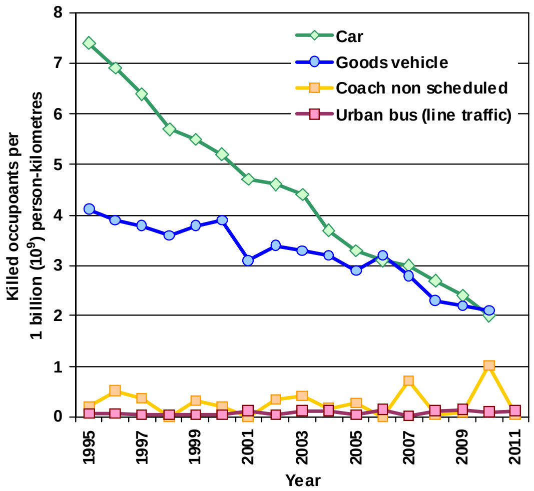


Figure 11. Risk indices for the occupants of urban buses, coaches, cars and goods vehicles calculated as killed occupants per 1 billion person-kilometres (Germany 1995 until 2010/2011)

4 STRENGTH OF THE SUPERSTRUCTURE

The basic prerequisite for effective protection of the occupants - even in a severe accident - is the preservation of the survival space in the vehicle. In that context, the ECE-R 66 requires evidence of the strength of the superstructure of large passenger vehicles [18, 19]. This regulation applies to single deck, rigid- or articulated vehicles belonging to categories M_2 or M_3, Class II or III or Class B able to carry more than 16 passengers. At the request of the manufacturer, this regulation may also apply to any other M_2 or M_3 vehicle that is not included in the scope described above, for example a double-decker coach.

The basic approval method in accordance with ECE-R 66 is defined as the rollover test on a specific vehicle. In order to prove that the necessary structural strength exists, the vehicle is slowly lifted sideways from an initial horizontal position until its centre of gravity passes beyond the tipping axis. It then tips into a ditch having a dry, smooth horizontal concrete surface and a nominal depth of 800mm, Figure 12. The superstructure of the vehicle has to be designed in such a way that the residual space as defined by ECE-R 66 is preserved at all times and along the entire length of the vehicle.

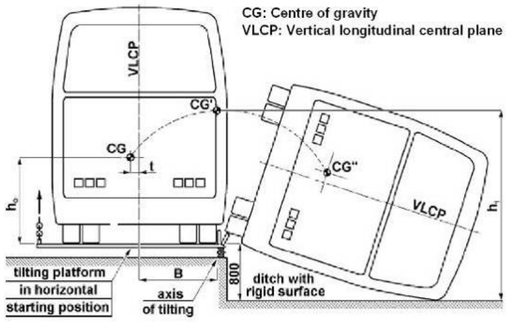


Figure 12. Rollover test on a complete vehicle in accordance with ECE-R 66 [18, 19]

ECE–R 66 first came into force on December 1st 1986. It was ratified in Germany on July 16th 1988. This was preceded by a number of examinations of real-world accidents in the course of which the bus/coach structure had deformed after it had tipped or rolled over. The behaviour of bus/coach structures in such accidents had been examined earlier in the 1970s and 1980s in countries such as Hungary under corresponding conditions and the results analysed comprehensively [20]. Similar activity had been carried out in Germany and in the UK. Rollover tests under various conditions had been performed at Daimler, for example. Figure 13 shows a test using a Mercedes-Benz coach O 303. The test conditions were as prescribed by ECE-R 66.

The amended Series 01 of ECE-R 66 came into force on the 15th October 2008. New vehicle types have had to satisfy this version of the regulation from November 19th 2010 [19].

The major difference compared with the original version is the fact that now 50% of the passenger mass has to be taken into account because the mass of belted passengers acts on the structure. This leads to a considerable increase of energy input into the structure compared with the situation described in the original version when only an empty vehicle had to be tested.

Figure 13. Rollover test on a Mercedes-Benz O 303 in accordance with ECE-R 66 conducted in 1987

In the most recent amendment (Series 02) the scope was extended to include minibuses (Category M_2) and double-decker coaches. For the latter the application of the regulation is optional. The ECE-R 66-02 came into force on August 19th 2010. From November 9th 2017 the registration application for a new vehicle may be refused if it does not comply with ECE-R 66-02.

The Setra Comfort Class 500 shown in Figure 14 is the first coach series from the manufacturer Daimler to comply with the new regulation. One major development target was the reduction of fuel consumption and the CO_2-emission rate. Since the vehicle weight has a considerable influence on those matters, considerable attention was paid to lightweight design. Figure 15 shows the superstructure of the new coach series. The most important elements are the U-shaped roll bars, which form the safety cage of the vehicle. In case of a rollover they will carry most of the load and will absorb a high proportion of the kinetic energy by means of plastic deformation. In order to maximise the potential of energy absorption, high-strength steel is used as indicated in Figure 15.

Beginning from the conceptual phase and throughout the complete design process, numerical simulations helped to optimize the superstructure. Results from tests on sections (see Figure 16) were taken to verify the finite element models used for the rollover simulation. Consequently, for type approval the method described in Annex 9 of ECE-R 66-02 was chosen (i.e. computer simulation of rollover test on a complete vehicle as an equivalent approval method).

Figure 14: Coach Setra ComfortClass 500

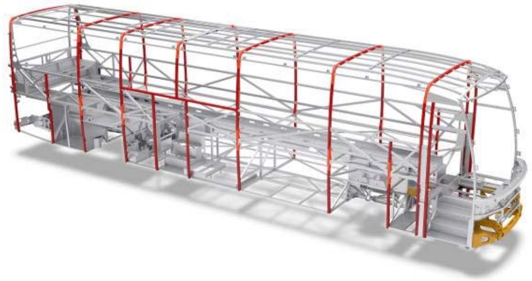


Figure 15: Superstructure of the new Coach Series Setra ComfortClass 500

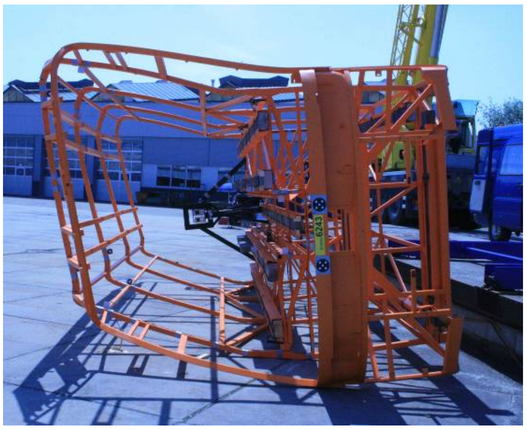


Figure 16: Test of a segment of the superstructure (prototype version)

Finally, it can be summarized that in comparison to the preceding series the strength of the superstructure has been greatly increased in order to comply with the most recent amendment of ECE-R 66. Although this has led to a weight increase of the side wall structure, the total weight of the body in white could be reduced by 5%. As mentioned above this has been achieved by intensive numerical simulations, which helped to identify regions with potential to weight reduction.

5 FRONTAL IMPACT PROTECTION

On its own initiative and without the compulsion of a legal requirement, the bus manufacturer EvoBus has developed a special protective system to improve passenger safety in the event of a frontal impact. It has been installed under the name “Front Collision Guard” in the series production of current vehicles of the Setra TopClass and Setra ComfortClass types and also in the Mercedes-Benz Travego. The system embraces the different elements front underrun protection, crash structure and rigid platform, Figure 17.

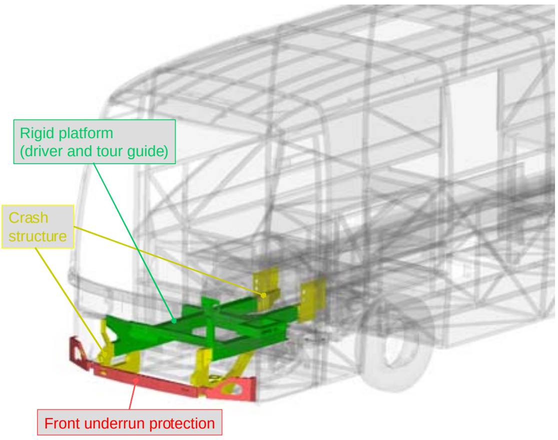


Figure 17: Elements of the Front Collision Guard installed in the Setra ComfortClass 500

The system was developed in view of the fact that buses/coaches have virtually no front-located deformation structure (crumple zone). In the event of a frontal impact the system ensures that no intrusions into the internal space at the front of the bus will reach the area where the seats for the driver and the tour guide are located. To this end the immediate front area has been designed to be extremely stiff and the crash structure behind it can absorb controlled deformation energy.

The rigid platform serves to provide further protection of the survival space of the driver and tour guide. Essentially, it consists of a stiff frame structure which carries the driver seat and the steering column. When an impact occurs, the whole platform can be forced passively backwards and thereby preserving the original volume of survival space.

The front underrun protection – which is not prescribed by law for buses – prevents cars from sliding under the front of the coach in a head-on collision. It consists of a beam-like structure that is located on the same level as a typical car bumper thus utilizing the energy absorbing mechanism of the car’s front structure (crumple zone) in the best possible way.

The development of the Front Collision Guard has been based upon numerical simulations and physical crash tests for validation defined by reference to real-world accident scenarios. All the tests were carried out by DEKRA at the Neumünster Crash Test Center and commissioned by EvoBus. In those tests the weights of the individual trial buses were, as a rule, 70% of the total weight of the heaviest vehicles in the series. The weight of the occupants was simulated by sandbags which were firmly secured to the seats. In this way, the inertial effect of their mass begins immediately after the start point of the collision. When occupants in buses/coaches are restrained by an appropriate system there is a time delay before this has an effect on the loadings and this moderates the maximal strains imposed on the seats and the structure of the vehicle. The seats of the driver and the tour guide were occupied each with a buckled-up instrumented dummy (Hybrid III, 50^{th} percentile male). The vehicle impacts at a speed of 25 km/h with its full width of the front a stationary rigid barrier. 80% of the corresponding real-world accident scenarios involving frontal impacts conform to these parameters (see Figure 8). Further details concerning the front collision guard and the related testing are reported in [21].

Compared to the previous series the Front Collision Guard of the Setra ComfortClass 500 series has undergone further optimisation. This has resulted in an extension of the rigid platform to the right side including the tour guide place. Two crash tests have been performed in accordance with the above-mentioned specification. The most recent test was conducted in June 2012. The deformed structure of the tested vehicle, a Setra 515 HD, is shown in Figure 18.

The effect of the impact forces shortened the vehicle length by 380 mm. The survival space for the driver and the tour guide was not affected. The peak value of the deceleration of the bus between its axles was about 18 g. The stresses suffered by the instrumented dummies were without exception less than the bio-mechanical limit values prescribed in relevant technical regulations. The values for driver and tour guide are shown as a bar diagram in Figure 19. Each value is related to its corresponding threshold of the Standard FMVSS 208

On a voluntary basis and without any legal requirement to do so the full-scale crash tests were supplemented by pendulum impact tests in accordance with ECE-R 29. The kinetic energy of the pendulum was 44 kJ. Figure 20 gives both an internal and an external view of a Mercedes-Benz Travego after the test. It can be seen that the impact led only to minor deformations. The survival space of the driver and tour guide was completely preserved.

Figure 18: Coach Setra 515 HD after a full-frontal impact with a stationary rigid barrier at 25 km/h

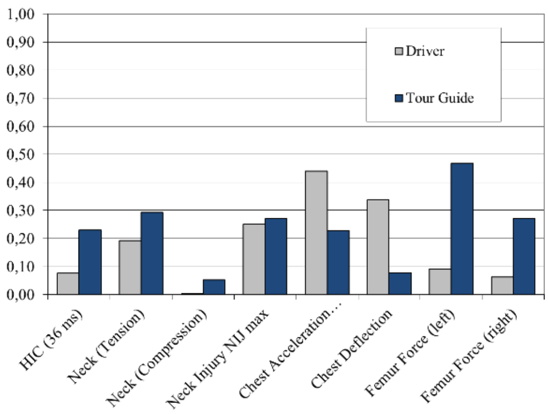


Figure 19: Occupant loadings relative to threshold values from the Standard FMVSS 208

For the Setra ComfortClass 500 the impact energy has been increased to 55 kJ. It could be shown by computer simulation that the requirements have been met. For this reason no physical pendulum test has been conducted.

Overall the Front Collision Guard system has set new standards in the area of the passive safety of coaches. The current configuration of the new Setra ComfortClass 500 series resulted in a further improvement of the secondary (passive) safety.

Complete preservation of the survival space is guaranteed for all front occupants in the context of the selected test conditions.

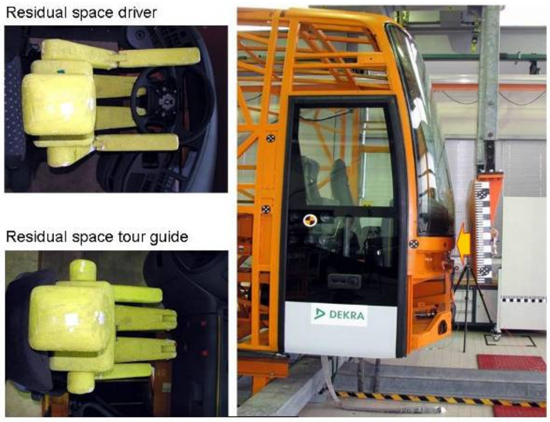


Figure 20: Mercedes-Benz Travego after frontal pendulum-impact test

6 RESTRAINT SYSTEMS

Assuming that the survival space is unaffected when an accident occurs, it is also necessary that the occupants are held in their seats to receive the highest possible level of protection. Consideration must be given not only to restraint during frontal collisions but also in the event of other types of accident in particular those involving a rollover. The analysis of real-world accidents has frequently shown that it is generally safer for the occupants to be retained in the vehicle in case of a rollover as distinct from being ejected out of the vehicle. In trials with buses being rolled over it has also been observed that belted dummies remain protected in their seats while unbelted ones are thrown out through a broken window [22].

In a coach when another seat is positioned in front of a particular seat, the back of the seat in front can act as part of the restraining system. In such seats it is sufficient to provide the equipment with 2-point lap belts. Figure 21 illustrates the combined effect of the lap belt and the back of the seat in front in restraining the movement of an occupant when a frontal collision occurs.

Buses that have been registered for the first time after October 1st 1999 need to comply with the EC-Directives 74/408/EEC "Seat Anchorages", 76/115/EEC "Seat Belt Anchorages" and 77/541/EEC "Seat Belts" in their relevant editions, according to the current requirements for registration in Germany. This results in a 3-point belt for driver and crew members (see Figure 22) and either 2-point or 3-point belts for the passengers (see Figures 23 and 24), depending on the bus operator's choice. In the case of 2-point belts parts which are positioned in a reference zone, i.e. a predefined area describing where the passenger might hit an obstacle because the lower half of his body is retained on the seat while the upper torso moves towards the front of the vehicle, need to be energy absorbing.

Under German legislation buses without specific luggage rooms or with an area for standing passengers larger than the gangway plus an area larger than the area for two double seats are exempted from mandatory compliance with the three EC-Directives mentioned above.

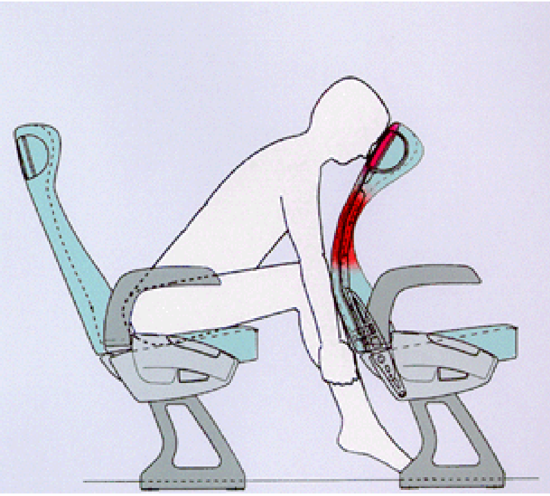


Figure 21: Function of a 2-point lap belt combined with the seat back in front as a restraint system for occupants in coaches

Figure 22: Coach driver seat fitted with 3-point-belt

In the case of frontal impacts the seat structure with the associated seat and belt anchorage must be able to hold the entire mass of the passenger occupying the seat. The loads on the anchorage points are then correspondingly greater.

Figure 23: Coach passenger seats fitted with 3-point belts

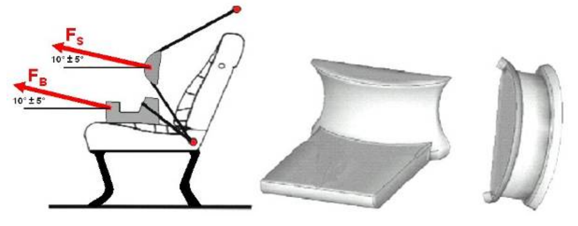
Figure 24: Coach passenger seats fitted with 2-point lap belts

The effectiveness of 3-point seat belts in rollover accidents still continues to be a controversial subject. On the one hand, the shoulder element of a 3-point system can fail to retain the upper body of an occupant when the vehicle has rolled over or is resting on its side. In such a situation the whole system becomes ineffective. In that context it needs to be noted that with the automatic seatbelts currently used the retractor not only blocks when it experiences large extraction speeds (when a frontal collision begins) but also when a vehicle tilts laterally. This means that the risk of the shoulder belt being displaced can be reduced.

Belt tensioners such as those used in cars are not necessary for belt systems in coaches because of much lower deceleration rates.

The mechanical strength of the seat and belt anchorages is prescribed by ECE-R 14 [23]. Static tests are carried out and these take account of the different strength levels required for different classes of vehicles, Table 2.

Table 2: Static forces to test the strength of the seat and seat-belt anchorages in motorized vehicles according to ECE-R 14



Vehicle category	M_1, N_1	M_3, N_3	Other vehicles
Test force F_S	1,350 daN*	450 daN*	675 daN*
Test force F_B	1,350 daN*	450 daN*	675 daN*
Additional forces in tests for belt anchorages located wholly within the seat structure or dispersed between the vehicle structure and the seat structure	Consideration of the inertia load of the mass of the seat by an additional test force: M_3, N_3: Force equal to 6.6 times the mass of the complete seat M_2, N_2: Force equal to 10 times the mass of the complete seat Other vehicles: Force equal to 20 times the mass of the complete seat		
* ± 20 daN			

For cars (M_1) and light goods vehicles up to 3.5 tonnes (N_1) the test forces applied to both shoulder and lap belts amounts to 1,350 kN. As a rule, the occupants of heavier vehicles involved in accidents – e.g. for vehicle-vehicle collisions – experience lower levels of deceleration. Accordingly, the test forces used to evaluate belt-anchorages in such vehicles are at a lower level. For coaches of 5 tonnes upwards, (Class M_3) the test force is 450 daN.

If the belt anchorages are completely integrated into the structure of the seat or distributed to the structures of vehicle and seat, higher test forces must be applied to take account of the greater loads imposed on the belt anchorages by the deceleration effect of the mass inertia experienced during an accident. In the case of coaches the value is 6.6 times mass of the complete seat unit.

The relevant properties of the seatbelts themselves can be found in ECE-R 16 [24]. These apply to all types of vehicle classes.

ECE-R 80 [25] contains special requirements relating to the seats of motorized buses/coaches (Categories M_2 and M_3 Classes II, III and B) and their anchorages. This directive was introduced in 1989 and ratified by Germany in 1990. At the present time the second version of the Modification Series 03 and dated July 26th 2012 is in force.

The regulation requires that every type of seat must undergo either a dynamic test (Appendix 1, ECE-R 80) or a static test (Appendices 5 and 6, ECE-R 80). This includes testing the performance of the seat anchorage. It should be noted that a static comparison test does not correspond to a real-world accident scenario.

The dynamic testing simulates a front impact test using a sled. This requires a testing platform on which the seat to be tested and its anchorage are mounted. A second seat is mounted behind the first seat (auxiliary seat). Two tests are carried out at an impact speed of the sled of between 30 and 32 km/h. During the test the deceleration must run along a defined corridor and have a maximum value of between 8 and 12 g.

For the first test an unbelted dummy sits in the auxiliary seat. In a simulated impact it is restrained only by the back of the seat under test (see test using 2 dummies in Figure 25). For the second test a belted dummy occupies the auxiliary seat (see test using 2 dummies in Figure 26). In this case both the belt and back of the seat under test restrain the dummy.

Figure 25. Dynamic test of a coach seat bench according to ECE-R 80 with 2 dummies unbelted impacting the back rest of the tested seats in front

ECE-R 80 does not require the additional occupation of the seats under test by a belted dummy when an unbelted dummy impacts the back of the seat from behind (see also [20]).

According to current enquiries made in individual vehicles the proportion of passengers in coaches who wear their seatbelts is only around 25% [26]. Higher belt-use rates may be reached by specific information and safety instructions resulting in better exploitation of the existing safety potential.

Figure 26: Dynamic test of a coach seat bench with 2 belted dummies according to ECE-R 80

SUMMARY

Although the safety-levels of cars and goods vehicles have improved considerably, the bus/coach remains the safest means of travelling on the road. The safety of buses/coaches has been at a very high level for decades now.

ECE-R 66 was legally prescribed for the superstructure to resist the consequences of a lateral rollover. This was supplemented by restraint systems which satisfy the requirements of ECE-R 14, ECE-R 80 and ECE-R 16.

Amendment series ECE-R 66-01 and -02 constituted further steps to improve the superstructure on a very high level taking into account the loading of belted occupants. Beyond that, additional measures were undertaken on a voluntary basis by certain OEMs without legal requirements. Confirmed by crash and pendulum tests, the safety in the event of a frontal impact has been improved significantly. As this paper shows, the introduction of the Front Collision Guard system has set a new standard in the area of secondary (passive) safety of coaches.

For all these measures to become fully effective it is necessary that all occupants wear their seatbelts throughout the journey. Therefore, it is important to increase the proportion of passengers using their belts.

Recently, essential improvements of the safety of coaches and buses have been achieved by primary (active) safety systems such as Active Brake Assist 2, Lane Departure Warning and Attention Assist (drowsiness warning). Supplemented by the secondary (passive) safety systems described above modern coaches are safer than at any time before and will keep their status as the safest means of road transport.

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