ENHANCED COACH AND BUS OCCUPANT SAFETY

Erich Mayrhofer
Hermann Steffan
Heinz Hoschopf
Graz University of Technology, Vehicle Safety Institute
Austria
Paper Number 05-0351

ABSTRACT

In the EC countries approximately 30000 persons are injured as bus or coach occupants in accidents with transportation in the size of more than 5000 kg every year. Some 150 of these persons suffer fatal injuries. The kind of accidents which occur throughout EC countries cover collisions, single accidents as well as "normal" driving manoeuvres. This study describes the results of an analysis of coach and bus occupant safety research and regulatory practices in Europe. The focus of this work is on occupant protection in several types of buses and coaches in both the scheduled and non-scheduled transportation.
For this purpose the connection between the occurrences at the real world accident scenes and the mandatory test methods has been analysed. The simple reason for that approach was the important feedback and usable knowledge of the accident incidents and their influence to improve current test procedures. Therefore an investigation was conducted on a number of topics including statistical collision data analysis, development of a bus accident database, reconstruction of real world accidents by means of an accident reconstruction software, component testing, full scale bay section testing, development of numerical simulation models for vehicle structure and occupant behaviour, parameter studies on occupant size influence, detection of injury mechanisms, cost benefit analyses for different test methods and finally the suggestion for improvements of current testing practices.
The main approach of this research work is the development of enhanced bus safety. This shall be obtained through the European Regulatory Agencies and ISO standard committees as this work will deliver the bases for new and released regulations. Some of the results of this study have already been taken to table an amendment to a current directive and will further be used to propose necessary improvements and additional research subjects either.

INTRODUCTION

This study describes the results of an analysis of coach and bus occupant safety research and regulatory practices in Europe. The focus of this work is on occupant protection in several types of buses and coaches in both the scheduled and non-scheduled transportation.
For this purpose the connection between the occurrences at the real world accident scenes and the mandatory test methods has been analysed. The simple reason for that approach was the important feedback and usable knowledge of the accident incidents and their influence to improve current test procedures.
Therefore an investigation was conducted on a number of topics including statistical collision data analysis, development of a bus accident database, reconstruction of real world accidents by means of an accident reconstruction software, component testing, full scale bay section testing, development of numerical simulation models for vehicle structure and occupant behaviour, parameter studies on occupant size influence, detection of injury mechanisms, cost benefit analyses for different test methods and finally the suggestion for improvements of current testing practices.

In total seven ECE (Economic Commission for Europe) regulations and 5 corresponding EC directives deal currently with the structural and seat design for buses and coaches.
Therefore the general objective of this work was to generate new knowledge to minimize the incidence and cost of injuries caused by bus and coach accidents.

This objective is relevant for:

- the bus industry since it will bring them safer buses
- the insurance industry since it will reduce their costs
- society due to the decrease in incidence and severity of injuries to bus and coach occupants

Additional emphasis was put on the various passenger sizes, in order to consider optimisation of restraint designs for occupants other than the 50th%ile male. There are currently no data relating specifically to the requirements for, or performance of, child restraint systems for children in buses. As various sizes of buses are used for public transportation different groups will be investigated according to ECE (M2-up to 5 tons and M3-more than 5 tons)
Special emphasis was also put on so called "City buses", where passengers are often standing. In

these buses injuries are the result of crashes and also vehicle operation, such as emergency braking, when injuries occur due to impacts of passengers against components of the bus interior.
Suggestions for new written standards, which increase the safety of buses, and which demonstrate and prove the increased safety were the major result of this research work. They are based on the developed and evaluated new and extended test methods. Their efficiency was demonstrated through numerical models of an improved bus design.

METHODOLOGY

Following study gives an overview of the technical state of the research work on bus safety with emphasis on the main achievements. The structure of the paper represents the chronology of the performed work.

Statistical Collection

First step was the analysis of statistical accident data. This was done by using the data from representative countries (Austria, Germany, Great Britain, Italy, the Netherlands, Spain, France and Sweden).
Firstly the numbers of casualties in buses and coaches were compared to the national pictures to give a measure of the relative importance. For the years 1994 to 1998, on average, approximately 150 bus or coach occupants were killed per year in the eight countries in the study as a whole. Fewer bus or coach occupants were injured than car occupants and in all the countries, when a casualty occurred in a bus or coach, the injury is likely to be less severe than for the whole road casualty population. From 1994 to 1998 the number of casualties has risen in the Netherlands, France, Spain and Sweden.
The bus and coach casualty population was then considered, by age, gender and injury severity. In all eight countries many more women than men were injured overall but this trend is not necessarily borne out in fatality figures. In all represented countries men have a greater likelihood of a serious or fatal injury when an injury occurs, with their ages more evenly distributed than those of female casualties. In some countries peaks in age can be ascertained at school age and towards elderly age, the latter being more obvious for female casualties than male casualties. The position of casualties was then investigated. More passengers were injured than drivers in all countries. In France, Germany and Great Britain a higher proportion of driver casualties sustained a serious or fatal injury than passenger casualties. The circumstances of bus and coach accidents with injured occupants were then studied. This specific study has been able to support further work in this study on rollover and frontal impacts whilst also identifying the need to appreciate the high levels of non-collision injuries seen in Austria, Germany and Great Britain (especially for elderly passengers).
From the data available with definite rollover/overturning data fields it has been established that these types of accident don't happen very often but when they do the number of seriously injured occupants can be high. Frontals are less serious in terms of injury than rollover/overturning but they happen more often and make up a large proportion of the casualty populations. It is also apparent that collisions with trucks are a significant influence on the fatal injury experience of bus and coach casualties. For the countries with data available most casualties occurred on urban roads; however most fatal injuries occurred on rural roads.
Data were also analysed on environmental conditions at the time of the injury accident to investigate when and in what weather conditions injuries occur.

Selection of cases for in-depth study

The outcome of the statistical collection supported the definition of the cases for the in-depth analyses. Although the access to real accident data was limited a reasonable number of cases could be analysed. This information was stored in a particular database for further process.

Accident reconstruction

By means of accident reconstruction software tools, especially PCCrash and SINRAT the selected cases have been analysed. For this purpose the accident involved vehicles and obstacles were loaded from a special database. Sketches or photographs of the accident scene (Figure 1) which showed the end position of the vehicles and the tyre marks were loaded too. After defining the operation sequences, the correct boundary and the initial conditions the calculations were performed. The results were shown in tables, diagrams as well as 3-dimensional video clips.
Figure 2 shows a simulation sequence of a frontal impact between a bus and a tree. The accident was caused by a car driver from the ongoing traffic who entered the wrong lane and hit the bus in the left front area.

Figure 1. Photographs of accident scene and marks on the street

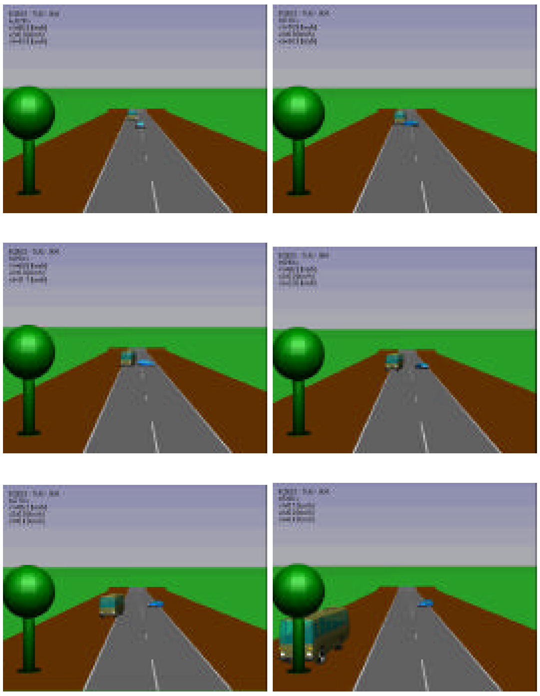

Figure 2. Accident reconstruction

Component Tests

As preliminary work on the FMH testing a huge number of photographs were taken from several bus interiors to show current European bus design. Based on this work a proposal was generated, describing the performance of the free motion headform testing. The tests were performed using several bus parts, where head contact is possible and can be critical due to injury risk.

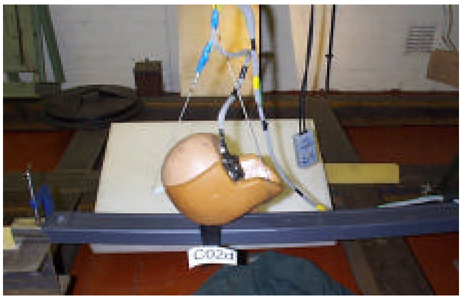

Figure 3. FMH testing

These test were done to measure accelerations and loads as well as to calculate the injury criterion HIC.
In addition to these bus interior component test two series of tests on bus seat crash behaviour were performed.
One series focused on basic seat material tests and the frontal impact behaviour (Figure 4), The tests in frontal direction were performed according to the ECE R80 conditions, varied by different configurations of the dummy placements.

Figure 4. Frontal impact testing

The rear impact tests (Figure 5) have been performed as new approach in seat testing. Background was the analyses of the seat behaviour, either in rear end impacts or in frontal impacts, when the seats are rearward faced.

Figure 5. Rear impact testing

Full Scale Reconstruction

The first performed full scale test has been a rollover test on a M2 bus. This kind of testing represents a new approach, since such a test is currently required only for M3 buses. The boundary conditions were the same as for a standard ECE R66 test. A further new approach was the usage of 2 dummies for measurement purposes. The second test has been a frontal impact pole test (Figure 6).

Figure 6. Frontal impact and rollover testing

Numerical simulation model for vehicle structure

The study of Cranfield involved creating a detailed finite element model of a M2 minibus (Figure 7) that was previously tested in the full scale test. The model was set up to simulate the two full-scale reconstructions ie. rollover conforming to ECE Reg. 66 and frontal impact into 60cm diameter pole barrier.

The main criteria for the model validation were the acceleration pulses obtained from the full-scale test vehicle. A comparison of the simulation and test values showed that the peak values and general trends were very similar between test and simulation.

Figure 7. Frontal impact and rollover model

The numerical bay section models from PoliTo were developed using MADYMO software. For the model shown on the right side both rigid bodies and finite elements were employed. The vertical and the roof pillars were modelled using rigid bodies connected each other by revolute joints. The lower part of the bay section was modelled using one rigid body because it was observed that this part has very small deformations during the rollover.

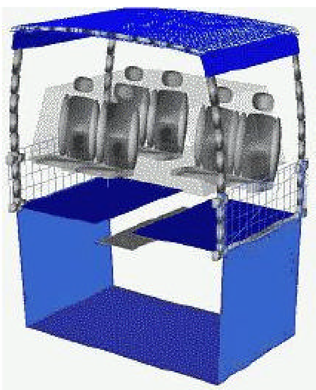

Figure 8. Bay section rollover model

Numerical simulation model for occupant behaviour

Cranfields rollover occupant model (Figure 9) simulated one of the 50th percentile Hybrid III dummies that was inside the full-scale M2 rollover reconstruction. The dummy was seated away from the contacted side of the vehicle and wearing a 3-point belt with the shoulder belt over it's right shoulder (ie. the side closest to the ground contact).

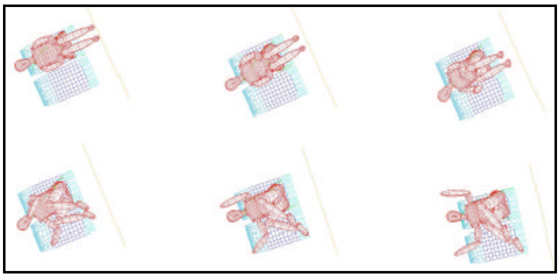

Figure 9. Rollover simulation (M2 bus)

The frontal impact occupant model (Figure 10) simulated one of the 50th percentile Hybrid III dummies inside the full-scale M2 frontal impact reconstruction. The dummy was seated in one of the original minibus seats, with an unoccupied seat directly in front. The seat characteristics (geometry, breakover stiffness and pitch) were taken from the tested vehicle. The model consisted of a validated Dyna3D Hybrid III dummy model, seated in a double seat, with a double seat in front.

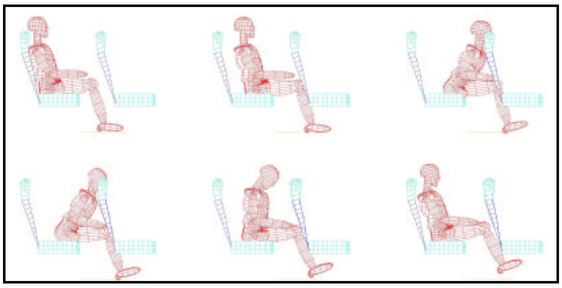

Figure 10. Frontal impact simulation (M2 bus)

INSIA created two types of numerical models, one consisting in the bay section occupants and another without occupants. For the case of bay section with occupants several models were developed to determinate how the usage of a two points belt system and the original position of the occupant may affect to the severity of the injury suffered by the occupants.

This model was validated through a rollover test of ECE R66 performed in the INSIA facilities with a coach body section. The structure accelerations and deformations were used for validating the model. As a conclusion of the model without occupant validation it have been proved that the deflexion results are very similar in the model and in the test.

Some of the accelerometers signals are similar in terms of behaviour (when the maximum and the minimum are reached) although the value is different.

This model was validated through a rollover test of ECE R66 performed in the INSIA facilities with a bay section that has been loaded with passengers, and equipped with an instrumented EuroSID-1 dummy. The effect of passenger's mass was represented by 7 ballast masses (68 kg).

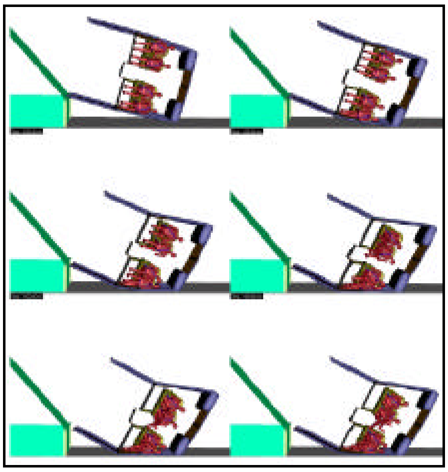

Figure 11. Rollover simulation (bay section)

The structure accelerations and deformations and the dummy signals registered during the test are used to validate the model. The model parameters of the structure are the same used in the previous test. To simulate the ballast and the EuroSID used in the real test, four EuroSID dummy models were placed in the front seats row of the structure.

TUG created a numerical occupant model to simulate the occupant kinematics in different kinds of City bus interior designs under usual non collisions incident situations like emergency braking, driving manoeuvres and acceleration jerks. By editing the predefined data files various kinds of City bus configurations can be generated. Especially the seat systems e.g. single seats or complete seat rows in line or in opposite configuration and the retaining systems like grab rails and space dividers can be modified and varied. The results of these calculations enabled the evaluation of the movement of the occupant, the detection of possible impacts with interior parts and the loads to the dummy.

The numerical simulation model for occupant behaviour represents a good possibility to analyse the injury potential of city bus interior areas during an extreme driving manoeuvres e.g. emergency braking.

For these purposes the interior of a city bus was generated (Figure 12) by means of a several multi-body systems within the MADYMO software.

The validated dummies, in seating and standing configuration were also taken and adapted from the MADYMO database. For the calculation of real world driving situations, the trajectory of the centre of gravity of the vehicle is determined by means of the accident reconstruction software PCCrash.

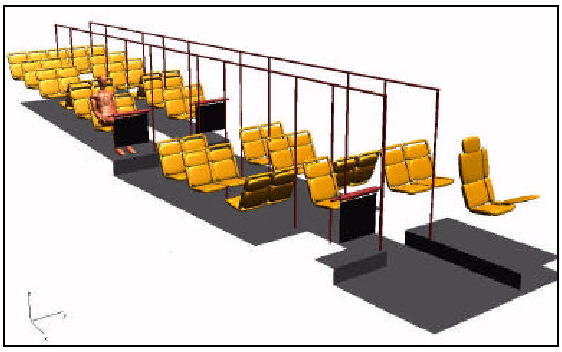

Figure 12. City bus model

By implementation of a special transformed coordinate system, the data from PCCrash can directly be taken as input data. The validation of the numerical model was performed by using the data of experimental tests. The resultant acceleration curves from the experimental free motion headform tests were used to define the contact functions of the model. Since only one head drop test was performed per interior part and no videos were available the validation is mainly based to quantify and to compare the injury risk during different impact situations. Although these results are generated with a simplified model, they are quite sufficient to detect lacks of safety matters.

Cause of injury summary

This work takes an overall view of the real world accident data and investigates the results of the numerical simulations to establish the injury mechanisms that are causing problems in M2 and M3 vehicles. At the national level though no information was available on injury severity to different body regions. Therefore analysis has been carried out using the in-depth study of 36 accident cases. As this database was created from available accidents and was not sampled the injury distributions are not comparable to the national pictures and therefore absolute figures of risk cannot be taken from the data. Care must be taken with the results from such a small number of cases, which are very diverse in their nature (e.g. different crash scenarios, classes of vehicles, occupant characteristics, restraint use). A general picture is formed though of which body regions are more susceptible to injury in M2 and M3 accidents. The results of simulations performed were used to illustrate possible contacts and the injury criteria of the dummy models indicate where injury criteria limits are being exceeded.

Parameter study

This task has been carried out to investigate the influence on injury risk when certain key parameters, such as vehicle structure, seat characteristics and stiffness are changed. These results indicate areas of the vehicles that could be improved and may be adding to an injury mechanism at the moment. Using the in-depth database it is possible to get injury data to body region level and from tests and simulations it is possible to analyse dummy movements to realise general dynamics.

Numerical test methods

This task was undertaken by Cranfield in order to investigate the strength of the superstructure of a typical coach under rollover conditions. In particular the validated, with experimental evidence, finite element model of a coach bay section consisting mainly of three dimensional highly non linear beam elements was used for a parametric study and further detailed modelling of some simplified features used to assemble this model. Also several finite element detailed models were created in an attempt to obtain theoretical information for the bending only, structural behaviour of components and joints.

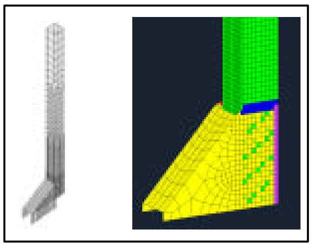

Figure 13. Pillar - structural behavior

The conclusions obtained by INSIA in relation to the structural numerical test for rollover of coaches are described. The results from the rollover tests have been analysed and compared, and new developed models have been used.

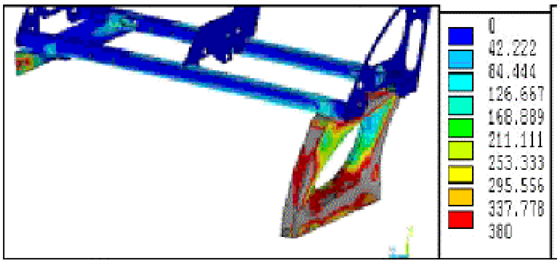

Figure 14. Seat frame - Structural behaviour

On the one hand, the effect of the belted passengers over the structural deformation and energy absorption has been quantified, and the way to introduce it in the numerical models has been discussed. On the other hand, it has been analysed some possible problems of different techniques for structural models, and some guidelines are proposed for the model conditions and the required validation tests.

PoliTo performed simulations by using the numerical models of the CIC coach bay section. A study was performed to verify the effects of some parameters relevant for the structural tests in order to point out the need of parameter specifications and the possibility of changes in the test conditions. In this way new structural tests could be figured. Investigation parameter were amongst others the moment of inertia, the falling height, the impact inclination and number of jointed bay sections.

This task was undertaken by TUG in order to extend the numerical models for vehicle structure and occupant behaviour so that the results of component tests which allow the definition of structure and design can be adopted to the individual bus in a rather simple manner. The numerical simulations demonstrated an easy approach to evaluate the interaction between passenger movement and deforming roof structure during a rollover impact. This tool can be used as pre-check of a new coach model both for assessment of the structural roof deformation and the contacts between occupants and the intruding structure.

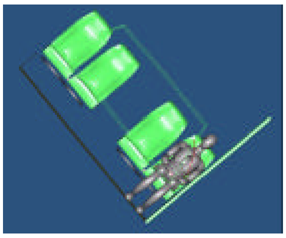

Figure 15. Rollover occupant behavior

Component test methods

CIC`s guidelines for Free Motion Headform (FMH) drop tests have been developed for city-buses, coaches and minibuses, through the use of experimental data and numerical simulations. The following steps have been undertaken: a) Numerical FMH models (Figure 16) were created and validated and used assess the influence of different impact speeds; b) A list of interior components commonly impacted by occupants for each vehicle type was compiled, including typical methods of construction and suggested methods of improvement; c) Head impact velocities and angles of impact were obtained from the numerical occupant models and used to define FMH test guidelines; d) FMH tests on a typical coach interior component were performed to assess the influence of impact speed, angle, local stiffness and possible padding.

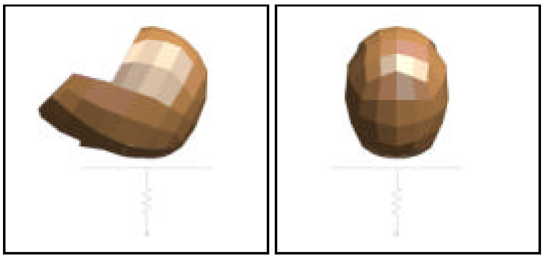

Figure 16. FMH simulation model

TNO's work focused on frontal impacts where the main interaction is between the passenger and the restraint system, the forward seat, a bulkhead or other solid object. Although this is a very limited subset of all injury causing loading conditions, it seems to be the only one for which the suitability and optimisation of restraints systems makes sense. Based on the best compromises between wearing a 2 point or a 3 point belt system, the use of 3 point belt systems is recommended for adult and child occupant passengers in buses and coaches.

Figure 17. Frontal impact simulation model

TUG investigated the behaviour of sitting occupants under rear impact conditions. That can occur both for forward faced seats under rear end impact and for rearward faced seats under frontal impact conditions. TNO's validated frontal impact seat model formed the basis for the further detailed modelling to create the rear impact model. The numerical seat model describes a geometry of a rigid platform and 2 rows of coach seats, one behind the other. This configuration corresponds to the performed rear end impact sled tests. The objective of the analysis was to investigate the injury risk in that type of impact incidence and to detect and point out the weak points.

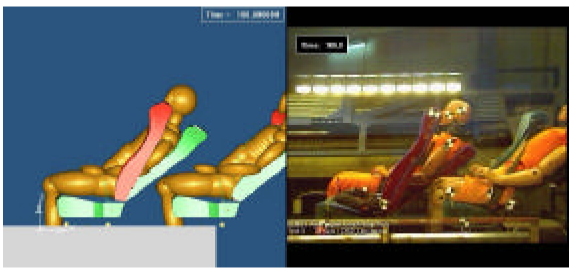

Figure 18. Rear impact simulation model

Full-scale test methods

The aim of this specific work was to gain a better understanding of how the mass of passengers may effect the deformation of a coach structure during the UN-ECE Regulation 66 rollover test procedure. Therefore Cranfield calculated the proportion of the occupant mass that is effectively coupled to the coach during an R66 rollover test for various passenger restraint configurations (unrestrained, lap-belted and 3-point belted) and to assess the influence of the passenger mass on the deformation of a typically fully laden coach.

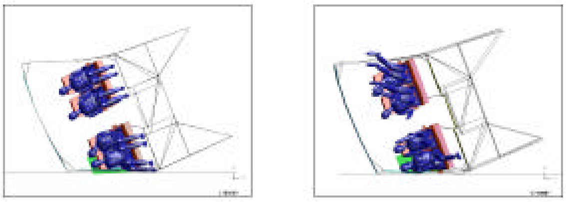

Figure 19. Bay section simulation model

INSIA's work describes the conclusions obtained in relation to the extended rollover test of coaches. The results from the rollover tests and simulations have been analysed and compared. It is quantified for different types of buses the energy increase that the superstructure must absorb because of the influence of the use of safety belts to fulfil the requirements of Regulation 66. Two different rollover test methods that let take into account the influence of the use of safety belts in buses and coaches already proved in previous tasks are presented. Other subjects such as the preparation of the bus to perform a full scale rollover test, the energy absorption capability of the seats and the driver's place are discussed.

TNO´s preliminary feasibility study of the driver/co-driver safety in case of frontal collisions by performing MADYMO simulations and if possible to propose first ideas for evaluating the "survival space" for driver/co-driver during a frontal impact. The feasibility study on the use of ECE/R.29 type of tests, even when a large margin of uncertainty is taken into account, has learned that current upper bus structures are far away from being crashworthy for frontal impact.

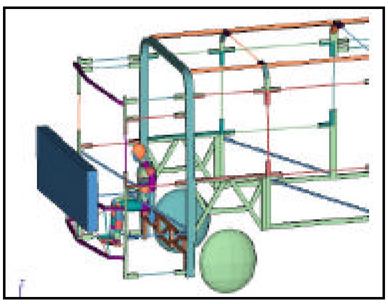

Figure 20. Frontal impact driver model

Test procedures for city-buses

This task was undertaken in order to draft a proposal for a basic test procedure for bus interior to measure and limit the impact load for standing, sitting and moving people especially under the conditions of an extreme driving operation namely the emergency braking.

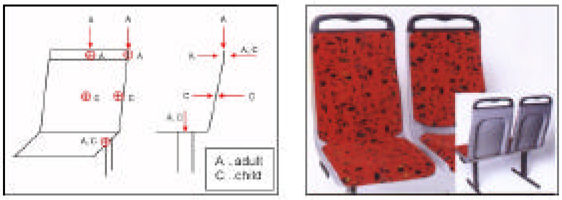

Figure 21. Proposal for test procedure

Cost benefit analysis of different test methods

The following part describes a cost/benefit analysis for different test procedures according to the current Regulations ECE R66 and ECE R80. Previous studies of this work revealed that, apart from the prescribed safety requirements in the mentioned regulations, a number of additional improvements can be suggested. The recommendations refer, for instance, to the use of seat belts, performing test procedures with dummies, etc. The cost/benefit analysis assessed on the one side the required costs for tests and simulations, considering the extension of the ECE R66 and ECE R80 with the additional improvements. On the other side, the analysis estimated the reduction of socio-economic costs due to less fatalities and seriously injured occupants in rollovers and frontal/rear impacts if safety requirements as prescribed in the improved Regulations are fulfilled.

Table 1.
Estimation on achievable tests versus required tests

Regulation No.	Type of Test / Simulation	Required tests per year in EU	Achievable tests	Achievable tests / Required tests
ECE R66*	Bay section	408 - 1224	2912 - 5698	4,6 - 7,1
	Full scale	408 - 1224	190 - 320	0,3 - 0,5
	Simulation	408 - 1224	422 - 3333	1,0 - 2,7
ECE R80*	Sled tests	4080 - 8160	2730 - 8635	0,6 - 1,0

In addition, the number of tests required for type approving all buses and coaches in the EU per year was estimated using the production figures for buses in the year 2000. The number of theoretically achievable tests could be determined on the basis of the saved socio-economic costs and the required costs for tests. The study showed that, apart from small exceptions, the socio-economic costs saved due to less fatalities and seriously injured bus occupants in rollover and frontal/rear impact accidents would be sufficient to cover the annual expenses needed for performing tests/simulations for type approving all produced buses and coaches. The report closes up with a theoretical consideration regarding the acceptance for bus and coach accidents, underlining the necessity of more tests and simulations.

Mathematical model of improved bus design

The objective of this task was to demonstrate the best practise design for M2 vehicles involved in frontal impact and rollover accidents. The original minibus vehicle from Cranfield was considered to perform well for both frontal impact and rollover. The frontal impact test into a barrier was an aggressive scenario resulting in a survivable accident for all the passengers, with just the driver's compartment intruded. The rollover according to ECE R66 was passed comfortably due to stable roof cross beams. The scope of this task was not to assess or modify the structural performance of the M2 vehicle, as this would require far more time and effort to achieve. Instead, the original structural performance was accepted as a good design for which the interior could then be optimised.

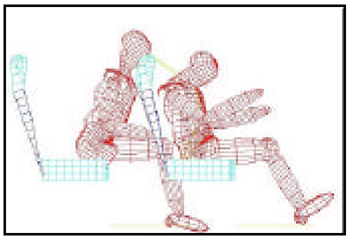

Figure 22. Improved M2 bus model

INSIA created a mathematical model that allows simulating the dummy response in a bay section rollover test according to the ECE-R66. In order to study the influence of different structures, the structure's model is made in parametric way. With the intention of to study the influence of the location of the dummy and its response, several models were developed with the dummy placed in different locations and also with different restraint systems (two points belts and three points belts).

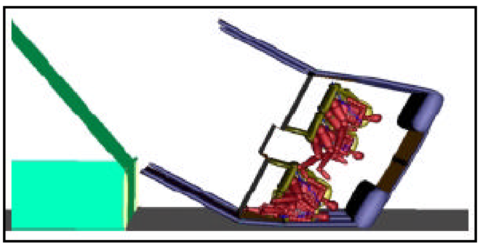

Figure 23. Improved bay section model

This part performed by Polito reports on the influence of the passengers mass on the results of a standard ECE66 rollover test. As a result of this study a K factor was calculated to represent the percentage of the passengers mass coupled to the structure during a rollover using different restrain systems (two point and three point belt).

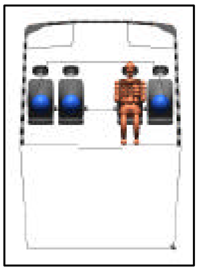

Figure 24. Improved bay section model

This work described the approach from TNO to evaluate possible improvements to the existing ECE/R80. All simulations were oriented towards the final objective of providing design guidelines (recommendations) for bus seats as far as 3 points belt system requirement is involved. It seems to be necessary to update ECE/R80 with respect to 3 points belt systems and the necessity to check their adaptation to children and small occupants. It must be verified if ECE/R.44 is able to certify safety of three point belt adaptable systems or if this needs to be addressed in ECE/R.80.

Figure 25. Improved frontal impact model

This task was undertaken by TUG in order to draft design guidelines which represent a better (safer) impact behaviour for the sitting or standing occupants. For this purpose a new developed numerical city bus model including all important components of bus interior was taken for a parameter study varying the material characteristics, interior designs and the occupant sizes

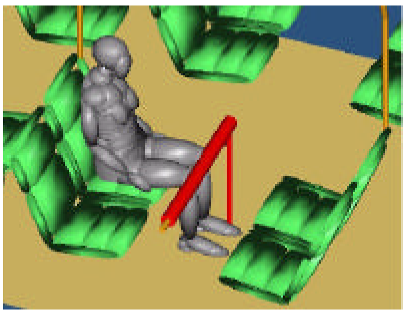

Figure 26. Improved city-bus model

ADDRESSED STANDARDS

The Economic Commission for Europe (ECE) of the United Nations elaborates the list of regulations known habitually as Geneva Regulations (www.unece.org/trans/main/wp29).
The European countries can adhere in a voluntary manner to each of these regulations, which will be mandatory in a particular country only if they are explicitly incorporated to his national regulation.
The European Directives are mandatory for all the members of the European Union when they are included in the Directive 70/156-2001/116/CE (homologation of the vehicles that includes the list of particular Directives for each type). Those Directives are issued by the European Parliament, Council or European Commission depending on the case, and they are approved in Brussels (www.europa.eu.int/comm/enterprise/automotive/directives/vehicles).
Table 2 below shows the actual European Directives and Regulations that can be affected by the recommendations made from the research done inside this study.

Table 2
Actual European Directives and Regulations

		European Directive	ECE Regulation
Obligatory use of eat belts		91/671 – 2003/20/EC	
Seat belts anchorages		76/115 – 96/38/EC	14 R05
Seats, seat's anchorages and head restraint		74/408 – 96/37/EC	80 R01
Safety belts and restrain systems		77/541 – 2000/3/EC	16 R04
General construction of large passenger vehicles	> 22 + 1	2001/85/EC	36 R03
	< 22 + 1		52 R01
	Double-deck		107 R00
Rollover resistance			66 R00

SUGGESTION FOR WRITTEN STANDARDS

This paragraph describes the suggestions for written standards in detail. These proposed improvements and ideas are based on the whole research carried out during this study. Main inputs were the results from the accident analysis, the component tests, the numerical simulations and the parametric studies. The following description is subdivided in 3 chapters, namely two to address directly existing regulations (rollover / frontal impact) and one for new and open issues.

Rollover

Use of seat belts is strongly recommended

The performed accidents analysis indicated that a part of the injuries in rollover accidents are caused by the impact of the occupants on the side panel and on the luggage rack and also by the effects of occupant interaction. The number of injured occupants and the injury severity of the casualties is less if the bus is equipped with a proper seat restraint system on condition that the belts were used. Studies based on the performed simulations indicated that at least a 2-point belt retains the occupants in their seats and avoids their free movement inside the vehicle during a rollover for three seat positions that are not closed to the impact side. The differences between lap belts and 3-point belts have been analysed and it can not be determined which of them is better under rollover conditions. When the passenger is situated in the rollover side near the aisle, a three point's belt could avoid the impact of the head with the side window. At least a lap belt increases the passengers' security under rollover. There are no recommendations of modification in the numbers of seat belts anchorages (2- or 3-points) that must be obligatory and the conclusion is that the actual regulations are sufficient for that point.
(Targets: Directive 2003/20/EC, Directive 96/38/EC, Directive 2001/85/EC, ECE 14R05, ECE 66R00)

Mass of belted occupants has to be considered for calculation and testing

The investigations within this study indicated that the introduction of belted passengers increases the energy to be absorbed during rollover significantly. That fact must be taken into account in the requirements made to the superstructure in the current Directives and Regulations. The influence of the belted occupants must be considered by adding a percentage of the whole passenger mass to the vehicle mass. That percentage depends on the type of belt system and is 70% for passengers wearing 2-point belts and 90% for passenger s wearing 3-point belts. The mass must be considered as rigid joint and must be fixed at the theoretic centre of gravity of the passengers (about 200 [mm] above the cushion or about 100 [mm] above the R-point. Those 2 factors (the increment of the total mass and the height of the centre of gravity) increase the energy to be absorbed during rollover and must be taken into account in the tests and the calculation methods either.
(Targets: Directive 2001/85/EC, ECE 66R00)

M2 buses included in the rollover test

The regulation 66R00 will be applied to single-deck rigid or articulated vehicles designed and constructed for the carriage of more than 22 passengers, whether seated or standing, in addition to the driver and crew. With the scope defined, vehicles of less than 22 passengers and double-deck vehicles will be not obliged to be approved according to R66 prescriptions. Another idea could be to define the scope according to masses and/or dimensions of the vehicle, as another regulation do. With the scope defined vehicles 10 [m] length but with only 20 passengers are not obliged to be approved according to R66 prescriptions. As tests have proved, a good designed M2 vehicle pass the rollover test nowadays. The proposal is to include M2 and M3 vehicles in the scope of rollover test.
(Targets: Directive 2001/85/EC, ECE 66R00

Child safety (adaptation of the restraint system)

This chapter deals basically with the same claim as child safety during frontal impact. It was proved as necessary to restrain children by means of an adapted belt system to protect them well. Main goal is the avoidance of ejection through side window or windshield and naturally also the protection of an uncontrolled free movement inside the bus.
(Targets: Directive 2001/85/EC, ECE 66R00)

Pendulum test should be deleted

Regulation 66 permit the evaluation of the rollover resistant of the structure by a full vehicle rollover test, bay section rollover test, calculation methods of by a pendulum test. Comparing the results obtained from simulations from rollover tests and pendulum tests it was found that at the end of the deformation process the energy absorbed by the joints is higher for the pendulum. Therefore, the two testing procedures are not equivalent and the less realistic pendulum test should be deleted.
(Targets: Directive 2001/85/EC, ECE 66R00)

Frontal / Rear End Impact

Use of a 3-point belt system is recommended

It is recommended to prevent the contact between passenger head and seat back in front in most cases. The validated models for frontal impact showed that, even for crash pulses higher than the 80 regulation one, which should be prevented when using a 3-point belt. The use of a 2-point belt produces a higher neck extension moment for a frontal impact than a 3-point belt. Attention must be paid to the correct restraining of children.
(Targets: Directive 2003/20/EC, Directive 96/38/EC, Directive 2001/85/EC, ECE 14R05, ECE 66R00)

Rigid platform for seat testing

Both the vehicle floor and the seat structure affect the crash behaviour of the combination to be tested. To avoid having to tailor the bus seat of a certain seat manufacturer to the various bus and coach structures, the bus seats should be designed for a

rigid floor structure that does not absorb energy during impact. Test performed on a combination of a rigid vehicle floor structure and seats specifically tailored to this structure are applicable to all kind of different floor structures. A special rigid floor structure and wall rail system should be defined for performing sled tests according to the regulation and directive.
(Targets: Directive 96/38/EC, ECE 80R01)

Combination test for seats

A sled test configuration could be: 2 rows of seats, the front seat (first row) with restrained passengers (50%ile dummies) and the auxiliary seat (second row) with unrestrained and restrained passengers. In practice it will be difficult to decide what the worst case configuration should be, because it depends on the type of seat. Therefore, it is recommended to perform at least two impact tests.
(Targets: Directive 96/37/EC, ECE 80R01)

Crash pulse for M2 vehicles

The best practise M2 restraint system is the 3-point seat belt. This has been proven for both frontal and rollover accidents. The 3-point belt allows the major body parts of the occupant to be directly coupled to the seat, giving a greater degree of control over the occupant's movement during a crash.
In order to achieve this control and therefore have an effective restraint system, the seat must also be capable of withstanding the loads transferred to it by the belt system. For frontal impact in an M3 coach this requires the seat + belt to adhere to ECE R80. It is proposed that a similar test should apply to M2 vehicles bus using the slightly higher test pulse developed by another EC project.
(Targets: Directive 96/38/EC, Directive 2000/3/EC, Directive 2003/20/EC, ECE 80R01, ECE 16R04)

Child safety (adaptation of the restraint system)

From the summary of ECE R80, it is clear that no interest is given to the necessary adaptation of 3-point belt systems to children or small occupants. This probably is the main concern related to this regulation, because wearing not adapted 3-point belt systems can not be considered as a solution for children. It seems therefore necessary to update the regulation and directives also with respect to 3-point belt systems and the necessity to either check the suitability of the belt system for children or to limit the access to 3-point belts for children.
(Targets: Directive 96/38/EC, Directive 2000/3/EC, Directive 2003/20/EC, ECE 80R01, ECE 16 R04)

Proposals for new Regulations

Even though the important progress related to the regulations and directives to homologate buses and coaches during the last years, and the increase on technical advances implementation and in the safety level of those vehicles, there is still a considerable gap from research, technological implementation and active and passive safety in vehicles of category M1. Although the accident statistics indicate that the transport by bus and coach is the safest mode of road transportation, there are still some important points that could increase the security level of that type of transport and that are implemented or advanced in other types.

Research for driver / co-driver frontal impact safety

The analysis of the real world accidents indicated that the occupants in the first row (driver, guide) can be ejected through the front window, or affected by the intrusion of coach elements. Assuming that both the driver and co-driver are belted, the major problem is the energy absorption of the frontal area and the intrusions through the wind screen.
The special risk of the driver's workplace in a lot of accidents, like frontal collisions, can be higher than the passenger's one. On the other hand, if the drivers were correctly protected, in such way that they remained conscious and were not seriously injured, they would keep the control of vehicle in manoeuvres after the accidents and would make easy the evacuation.
Special protection devices should be designed for the driver protection in the frontal of the coach because the driver's safety is not adequately considered in current regulations.
The research carried out with a frontal coach impact at 25 [kph] and the current R29 regulation (Protection of the cabin occupants in an industrial vehicle) has demonstrated that the actual designs are not capable of absorbing the applied energy. More research is needed to define the requirements for the structure, a suitable test for buses and to modify the actual designs to preserve the integrity of drivers in frontal of front-lateral impacts. Some ideas can be found in following references.

Compatibility between bus/coach and other vehicles

The proposals that must be studied about the driver's workplace must go hand in hand with the study on the compatibility with other vehicles (industrial and cars). First it is needed to guarantee the security of the driver in the bus or in the coach against very different obstacles (at different heights and with different energy to be taken into account). On the other hand to guarantee the security of the occupants in the vehicle that could impact against the bus or the coach. It is important to pay attention to the results that will be obtained inside another European project called VC Compact, who are studying the compatibility between car and car and between car and truck.

Double-deck coaches (superstructure resistance)

The superstructure of the double-deck coaches must currently not be tested under rollover conditions. It is necessary to analyse how resistant the actual designs are and the economical and social impact of including those vehicles inside the requirements of regulations and directives on rollover.

That is especially important if the mass of the belted passengers is taken into account, because the increase of the energy to be absorbed during rollover increased with the number of passengers and the height of the centre of gravity.

Harmonised bus accident database

The performed statistical accident data collection showed a big difference between the capture of the data within the European countries. That indicates the necessity of an integrated database of the accidents that could take into account the same parameters in all the accidents and provide data for a good study on new necessities of research and/or requirements on buses and coaches.

Guidelines for using Numerical Techniques

The regulation 66R00 and the directive 2001/85 allow the approval by numerical methods. Nowadays there is a great variety of numerical techniques (as finite elements method or multi-body method) and a lot of commercial programs that permit to calculate the superstructure behaviour of a coach under rollover.

During this study, quasi-static and dynamic modelling methods have been used and validated. That work aims the necessity of carrying out some guidelines for using numerical techniques for approval, especially about how to validate the models.

Partial ejection out of the bus (side window / wind screen) should be avoided

The analysis of the real world accidents indicated that the partial or total ejection is a severe injury mechanism. The injury severity of the casualties is less if the bus is equipped with a seat restraint system and with laminated glasses. Besides, a side airbag especially developed for rollover movement could prevent from the ejection of occupants.

Contact load with side (window and structure) should be as low as possible

The numerical rollover simulations showed that the impact between dummy and side panel as well as the direct hit of the intruding structure on the dummy cause high load and therefore a big injury risk. That fact can be responded by either an avoidance of direct contact between dummy and side panel or by a soften impact behaviour. A calculation of relevant injury criteria would increase the safety standard especially for rollover.

Development of a rollover dummy is necessary to predict injury criteria

In-depth studies have shown that the most common body parts injured in a rollover, when no ejection occurs, are the head, the neck and the shoulder. This behaviour has been confirmed with the simulations performed with the validated Madymo models. These models have been used to study different rollover configuration to analyse the most frequent injury mechanism and to estimate the expected injury reduction using different restraint systems (2- and 3-point).

One of the conclusions of these studies is the fact that the current side impact dummies are not ready to assess the injuries suffered by the occupants of buses in case of rollover. Especially two important regions should be improved, the neck and the shoulder region (shoulder and clavicle as a whole).

The simulations showed that during rollover the neck is subject to combined loads namely lateral bending, lateral shear and torsion. Nowadays, there are no injury criteria that take into account these types of loads. The response of the shoulder in the current side impact dummies is not human like, the biofidelity of this region should be improved and an injury criterion to assess injury severity should be created too. Further research should be done in the field of rollover dummies and its associated injury criteria. The creation of a specific rollover dummy should be developed in parallel to the definition of new test procedures and the implementation of these procedures in the different regulations.

Further research on driver’s impact on accident avoidance

The in-depth study of the real world accident cases showed that a serious number of incidents was more or less negatively influenced by the action of the driver. Consequently the question whether the drivers know what to do or how to react in such a situation is certain appropriate. A further issue is the big range of technical standards of buses and coaches which demands different level of driver trainings.

Further research on possibilities for general rating of the passive safety

This suggestion is directed at a new definition of bus and coach safety. Since newer buses and coaches that meet the current Regulations and directives as well as a big fleet of older vehicles are on the road, the passengers of non scheduled transportation or municipal authorities responsible for scheduled transportation are more or less dependent on the available vehicles and so they have no special distinction features or identification possibilities of selecting a safe bus type.

An adapted classification similar to the star rating of (Euro) NCAP would definitely increase the safety level of future vehicles and could furthermore support the travel agencies to simplify the hire of a safer bus or coach (sales argument and demands). Although it is a long way off for realization it should be content of a further research.

CONCLUSIONS

This study was undertaken to identify the correlation between the current test approvals on passive safety for buses and coaches and the real-world accident incidents. Reasons for that claim were on the one hand the missing tendency of the fatality and injury rate in bus and coach accidents over the last years and on the other hand a missing research study on general bus and coach safety. Although several studies on individual topics of passive safety for buses and coaches exist which explain the single problems well, a comprehensive study which takes the interaction of the main safety relevant issues (frontal / rollover) under consideration is for the first time presented by this study.

For that purpose a statistical accident analysis was performed in a first step to gain basic knowledge on several usable information out from governmental databases. Despite the different ways of data collection within the European countries, it was possible to work out a general overall pattern. The results of this chapter were used to perform an in-depth accident analysis including detailed accident reconstructions and the compiling of a new defined bus and coach accident database.

Next step was the investigation on the main injury mechanisms according to this crash type. For that purpose this chapter was structured in different sections. The first part reports from different kinds of component tests which were performed to analyse the impact behaviour of e.g. interior components, seat systems and structural parts. These physical and material data were used in a further step to validate new created numerical simulation models for vehicles structures and occupant behaviour. Parameter studies, including type of occupant, type of vehicle and type of restraint system completed this experimental and analytical work.

Based on the knowledge gained within the accident analysis and the assessment of the injury mechanisms different test methods were elaborated and verified by means of different numerical simulation methods. For all proposed improvements and changes the current status of the test approvals formed the reference. The financial quantification of the increased safety features was done by a cost benefit analysis and showed a proper ratio for the additional charge.

Some recommendations for current European Regulations and Directives have been made based on the research performed within this study, essentially inside the Regulation 66R00 (Directive 2001/85/EC) and the Regulation 80R01. Some of them (related to 66 Regulation) have been taken into account by the Ad-Hoc Experts Group and are going to be included in the proposals that will modify the 66 Regulation in a near future.

The state of the technique and consequently the current regulations are still far away from the ones related to other types of transport (especially M1 vehicles). The results of this study can be considered as a first step towards new research, future designs and regulations to enhance the safety level of buses and coaches.

The realisation of these actions and the definition of new targets and future research represent a big challenge for both the scientists (technical, medical) and the industry and can only be solved by using interdisciplinary methods.

ACKNOWLEDGEMENTS

The work described in this paper results from an EC funded research project on bus safety which was leaded by Graz University of Technology. Therefore the authors want to thanks also all former colleagues and partners from the ECBOS project as there are CIC (Cranfield Impact Centre, UK), GDV (Gesamtverband der Deutschen Versicherungswirtschaft, DE), INSIA–UPM (Universidad Politecnica de Madrid, ES), PoliTo (Politecnico di Torino, IT), TNO (TNO Automotive, NL) and VSRC (Vehicle Safety Research Centre, Loughborough University, UK)

REFERENCES

Anderson J., Hardy R.; Cranfield Impact Centre, Individual working reports from the ECBOS project, 2000 - 2003

Appel H.; Rau H.; Rietz C.; Rasenack W.: Safety Belts in Touring Coaches. Procc. International IRCOBI Conference on the Biomechanics of Impacts. Sept. 1996 Dublin, Ireland pp. 265 - 289

Auwärter, C.; Otte, D.; Hackenberg, N.; Lenz, W.; Sarnes, J.; Woschei, K.: Preliminary Investigations of the Level of Active and Passive Security in Touring Coaches - SMARAKD. NEOPLAN / SNV / TÜV Rheinland e.V., Cologne, 1990

Belingardi G, Martella P.; Politecnico di Torino, Individual reports from the ECBOS project, 2000 - 2003

Breitling, U.: Combined Effect of Construction, Computation and Testing in the Development of Coach Structures with Increased Passive Safety. 5th Coach Forum of the TÜV SW, 1994, 46 – 54

ECE Regulation R 66: Standardized Specifications for Approval of Motor Coaches with Respect to the Stability of Their Structure. FEE, 13th Supplement, January 1988

ECE Regulation R 80: Standardized Specifications for Approval of Seats in Motor Coaches and of These Vehicles with Repect to the Stability of the Seats and Their Anchoring. FEE, 17th Supplement, March 1990

Färber, B.; Heinrich, H.C.; Hundhausen, G.; Hütter, G.; Kamm, H.; Mörl G.; Winkler, W.: Safety in Tourist Coach Transportation. Reports of the Federal Traffic Institution. People and Safety, Issue M 40, 1995, 124 pages

Grandel, J.; Muller, C.-F.: Contribution to the Safety of Coaches. DEKRA Accident Research, Stuttgart, 1994, 42 pages

Grandel, J.; Niewöhner, W.: Inner Safety of Busses (Results of an In-Depth Investigation). DEKRA Accident Research, Stuttgart, Final Report, April 1994

Grant R., Kirk A.; Vehicle Safety Research Centre – Loughborough University, Individual reports from the ECBOS project, 2000 - 2003

Gwehenberger J, Bende J, Langwieder K.; Gesamtverband der Deutschen Versicherungs-wirtschaft, Individual working documents ftom the ECBOS project, 2000-2003

Hammer, G.: Technical Requirements for Coach Safety from the Perspective of the EU and the ECE. 5th Coach Forum of the TÜV Southwest, 1994, 35–40

Hamsten, B.: Are Safety Criteria for Structure Stability, Seat Construction and Restraint Systems Still Sufficient for Today? 5th Coach Forum of the TÜV Southwest, 1994, 41 – 45

Huijskens C., Twisk D., TNO Automotive, Individual reports from the ECBOS project, 2000 - 2003

Krüger Hans Joachim: The Development of Coach Seats as a Restraint System. Procc. International IRCOBI Conference on the Biomechanics of Impacts, Sept. 2 - 4 1986 Zurich, Switzerland pp. 177 ... 188

Langwieder, Kl.: Safety in Touring Coaches - Requirements for People and Technology from the Perspective of Accident Research. 5th Coach Forum of the TÜV Southwest, 1994, 9 – 14

Mayrhofer E., Geigl C.B, Steffan H.; Graz University of Technology – Austria, Individual reports from the ECBOS project, 2000 - 2003

Paez J., Martinez L., Sanchez M., Garcia A. Vicente T.; INSIA – Universidad Politecnica de Madrid, Individual reports from the ECBOS project, 2000 - 2003

Scheper, A.: On the Security of Touring Coaches, Accident Data Evaluation. Reports of the Federal Traffic lnsitution. People and Safety, Issue M 17, 1992, 52 pages

Stangl, G.; Hummel, H.: Possibilities for Increasing the Safety of Coaches from the Perspective of the Manufacturer. VDI-Reports 1188 1995, 261 274