FRONTAL OCCUPANT SAFETY SIMULATIONS FOR COACH AND BUS PASSENGERS

C.G. Huijskens
M. Schrooten
P. de Coo
TNO-Automotive
The Netherlands

Paper no. 284

ABSTRACT

In the EU each year approximately 20000 coaches of over 5000 kg are involved in accidents that result in personal injuries. Each year more than 30000 persons are seriously injured in these accidents, and over 150 occupants of buses and coaches suffer fatal injuries. In contrast to other accident data, no tendency for a significant reduction can be found.

Only three EC Regulations (Appendix A) currently influence the structural and seat design for buses and coaches. The general objective of the EC RTD project "Enhanced Coach and Bus Occupant Safety" is to generate new knowledge that will allow further minimization of the incidence and cost of injuries caused by bus and coach accidents.

One of the main tasks in this project is to make a detailed study of the occupant behavior by performing MADYMO simulations, so that the injury causes in frontal impact can be determined. A detailed bus and occupant model are used to investigate the following items:

- The effect of different type of restraint systems, 2-point and 3-point seat belts.
- The interaction between several restraint systems and different sizes of adult occupants, and, as a special case, of children in (school) buses.
- Recommendations for improving ECE/R.80.

These investigations have led to a virtual interior assessment with multiple coach occupants, including optimization of seat design parameters. Simulation models like this can play an important role in identifying the benefit of new designs by application of new test methods and regulations.

INTRODUCTION

Initiated within the European Vehicle Passive Safety Network a consortium of 7 European Research Institutes and Universities was formed to investigate current bus and coach accidents as well as to propose regulations and new or improved cost effective crash test methods to decrease the injury risk for the bus occupants [1]. This project was initiated because approximately 30000 bus and coach occupants are injured every year within Europe. Some 150 of these occupants suffer fatal injuries.

The task of TNO Automotive in the "Enhanced Coach and Bus Occupant Safety" project (ECBOS) is to suggest improvements to bus restraint systems and methods to evaluate safety of the bus passengers (M3 type). The work reported here is concentrated on the effect of impact crashes of a type where the bus remains in the upright position. This means that cases were the bus is overturned, either directly, or because it drives off the road and then overturns, is not taken into consideration. This choice was made because overturning accidents lead to deformation of the passenger compartment and to specific types of injury. Secondly, passengers impacting each other or passengers being trapped between the bus and the ground may cause injuries. This paper focuses 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.

METHOD

The main task of TNO Automotive in the ECBOS project is to investigate how the implementation of restraint devices in M3 buses can reduce serious injury in frontal impacts.

A number of sub-tasks have been identified:

1. Develop a model of a typical ECE-R.80 passenger seat as a basis for the optimisation process.

2. Develop a mathematical occupant model, using the standard seat, a variety of dummy sizes, and various restraint systems.
3. Optimise the protection offered to the occupant through study of key seat and restraint design parameters. This was done for various dummy sizes.
4. Develop a generic model of a bus, which is able to reproduce the kinematics of selected cases present in the ECBOS accident database.
5. Combine bus structure model and occupant model to 'reconstruct' a selected number of cases from the ECBOS database. Verify that the combined model is able to predict the observed injuries.
6. Using the verified models, investigate how improvements determined in sub-task 3 could be used to improve occupant safety in real-world accident scenarios.

The occupant model is needed to obtain the estimates of the injuries due to the loading of the vehicle from change of velocities. The models must be capable of describing the behaviour of different dummy sizes and different restraint systems like 2-point belt and 3 point belts.

The bus structural model is used to predict the global kinematics of the bus in different impact configurations, like full front wall impact, trailer back barrier impact or offset impact. The model consists of a multibody MADYMO model with tire characteristics, wheel suspension characteristics and global crash parameters of the vehicle front

Finally, a first draft of new numerical test methods as well as component- and full-scale test methods is developed to improve the existing ECE Regulation 80 and additionally to propose new (simplified) test procedures for frontal impacts.

SIMULATION MODELS-M3 VEHICLES

A series of baseline sled tests was performed according to the requirements of ECE-R.80 (Table 1) in order to be able to evaluate the dynamic performances of bus seat frames with both belted and unbelted occupants (Figure 1).

Table 1.
ECE-R.80 requirements

Chest/Head displacement	**< 1.6 m from SRP**
HIC	**< 500**
ThAC	**< 30g**
FAC	**< 10 kN (all time)**

Also a series of component tests was carried out for measuring the stiffness and strength characteristics of the main seat elements such as the seatback, seatbase and seatpan/belt anchorage's as required input variables for modelling (Figure 2).

Figure 1 ECE-R.80 test

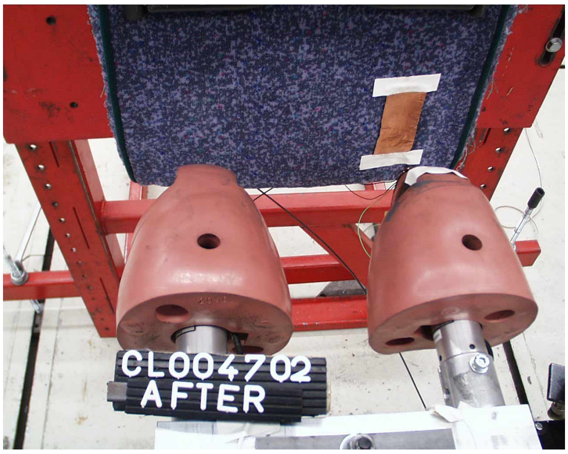


Figure 2 Component test

Vehicle (Figure 3) and occupant (Figure 4) models have been created and validated for M3 buses in frontal impacts. The results of simulations performed in these tasks are used here to illustrate possible contacts.

The injury parameters of the dummy models indicate where injury criteria limits are being exceeded.

Parametric studies have 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.

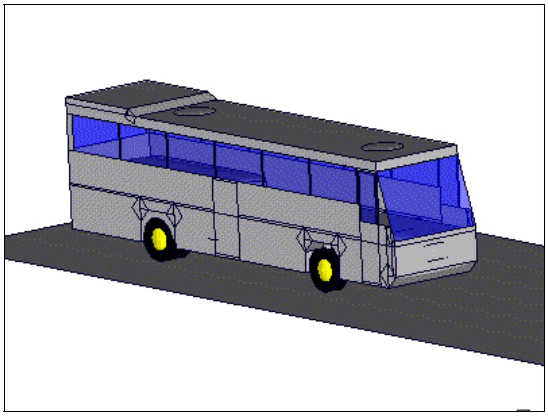


Figure 3 Vehicle model

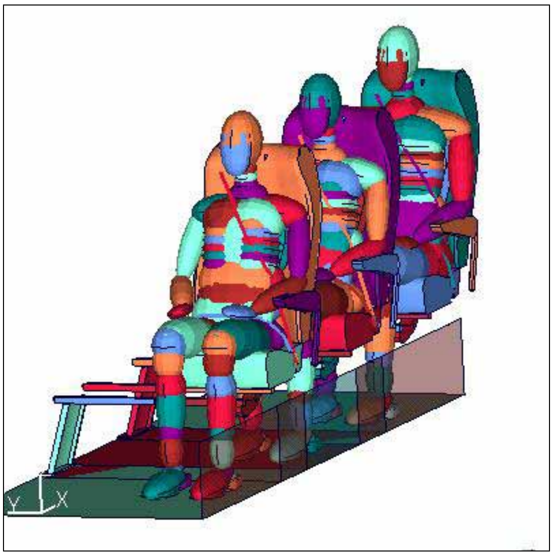


Figure 4 Dummy model

ACCIDENT DATABASE-M3 VEHICLES

The ECBOS database describes a number of serious accidents that have occurred on the roads in Europe. These accidents have taken place in various European countries.

The data from each selected case was entered into a record of the ECBOS database:

1. vehicles involved.
2. make and type of bus, mass, weight, etc.
3. crash scenario, impact locations, and deformations of vehicle.
4. passenger data, including sitting position, age, and sustained injuries.

In the development of the ECBOS database, each selected case is investigated using the PC-CRASH program. The program allows a reconstruction of the accident and determines the most likely initial velocities of the vehicle, describes gross vehicle motion, orientation and accelerations during the impact. In this way, the dynamics and kinematics of the passenger compartments of the vehicles involved were determined.

These in-depth accident studies have generated very valuable data. The data has been used to improve and validate the simulation models. However, the occupant injury data was limited. Therefore it is not fully safe to summarise the most important injury causing mechanisms found within the studied accidents. Taking this into account, a ‘sensitivity analysis’ was performed to provide the most important parameters for the head, neck, thorax and upper leg injuries.

In-depth database analysis shows that single accidents and overturning, which are combined in the majority of the cases, cause the highest risk for severe injuries. Frontal and rollover accidents cause a similar proportion of fatalities but rollover has a much higher risk (+ 42%) of MAIS 3+ injury severity.

INJURY MECHANISM-M3 VEHICLES

Frontal accident

A sensitivity analysis was performed to determine the influence of a number of parameters on the injury values.

It is concluded that for the upper part of the human body, the recliner stiffness has the biggest influence on the injury values. When the occupant is unbelted, the head-ashtray contact also has a large influence on the injury values (Figure 5)

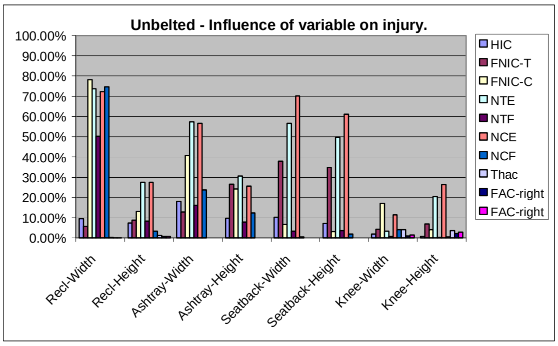


Figure 5 Influence on the injury values-unbelted

For the lower part of the body, the seat back to knee contact stiffness is the most critical parameter.

The kinematics of one occupant during the crash can be affected by the presence of another occupant. This was found to be especially relevant when occupants are wearing a two-point belt, as the occupants can introduce an additional loading to the recliner in front of them and thereby influence the kinematics of the occupant in front of them.

From different research studies [4, 5, 6] it is known that the most common mechanism of fatal or serious injury in frontal accidents for M3 vehicles has been found to be direct intrusion. Many of the investigated cases feature large amounts of intrusion and structure deformation, with impacts with trucks being a particular problem. In these cases, it is very difficult to suggest simple prevention, due to the collapse of the bus structure in the area of the impact caused by the high energy involved.

Rollover accident

In order to be able to generate preliminary recommendations for wearing 2 points or 3 points seat belts in buses and coaches, it is important to understand the difference in occupant injury mechanism during frontal and rollover accidents. Therefore the results of the analysis of rollovers accidents are also presented in this chapter to prevent possible conflicting consequences in the next chapters.

Simulations performed by the ECBOS partner 'POLITO' [1] showed that for head injury neither 2 point nor 3 point seatbelts prevent a HIC value over 1000 for the occupant seated by the impacted side, the head always strikes the side window. If any seatbelt is used the injury levels for occupants in the seats on the other, non-impacted side of the bus, are always below the HIC limit. The real advantage of restraint use here is the prevention of occupant movement and the loading of other occupants.

For the occupant in the inboard seat, near the impacted side, a 2 point belt does not prevent the head injury mechanism of striking the side, but a three point prevents this contact.

In simulations an interesting injury mechanism of high load to the pelvis is indicated caused by impact and contact with the armrest.

Intrusion of the roof and therefore direct contact gives very serious and fatal injuries. There is no doubt that if the roof structure does collapse crush injuries will occur to those occupants in the area of intrusion.

Hand luggage causing injury is also a possibility during rollover accidents, although the falling of luggage from overhead racks will also be likely in frontal accidents.

It is observed that the use of restraints would prevent many serious injuries by preventing the high degree of occupant interaction, interaction with the interior and ejection that occurs in rollovers. The use of laminated glass may also help to prevent contact with the ground and the ejection of occupants.

THE EFFECT AND CONSEQUENCES OF

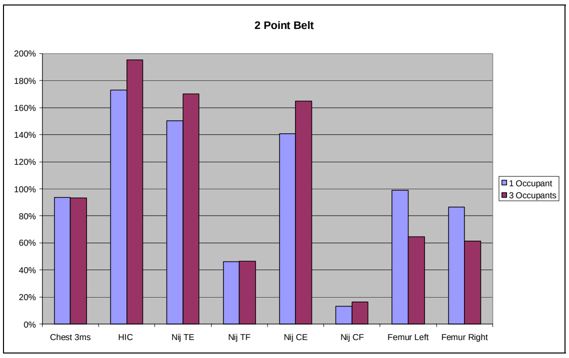
USING 2-POINT OR 3-POINT BELTS

General

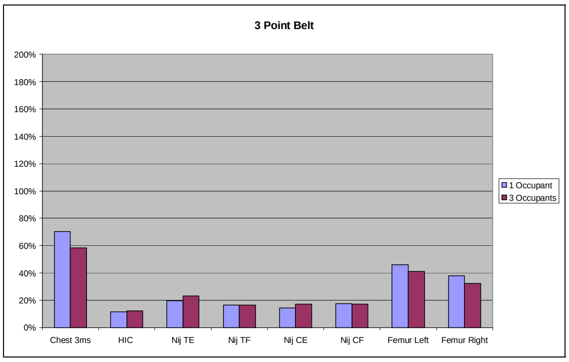
It is observed that wearing a safety belt, 2 point or 3 point is safer than wearing no belt. The main advantage of wearing a belt in a bus or coach is preventing ejection during a rollover accident as well as during a frontal accident.

Wearing a 2 point or 3 point seat belt in a bus or coach during a frontal impact poses a number of risks for the head and neck. A 95th percentile dummy wearing 3 point belts was positioned in the third seat row (Figure 4). Wearing a 2 point seat belt show a higher risk of neck loading and

head contacts during frontal impacts compared to a 3 point seat belt (Figure 6).
Additionally, wearing a 3 point seat belt reduces the head injury of the behind-row passenger and the energy absorption capabilities of the seat backrests in front of the occupant are not always enough to avoid injuries.



2 point belt



3 point belt

Figure 6 Front and rear seat occupant influence

Integration of 3 point belt systems requires a strong reinforcement of the seat backrest. The consequence of the impact between an unbelted occupant, and a seat backrest optimised for 3 point belts (more rigid) has also been evaluated. It appears that a seat backrest optimised for 3 point belts will contribute to high injury levels in the thorax, but lower on the head. Seats that are not optimised for 3 point belts will do the opposite. Therefore it is difficult to define any advantage of low stiffness recliners against more rigid ones, in the case of unbelted occupant.

An extreme scenario will occur when an unbelted 95th percentile occupant is seated at the auxiliary seat, and a belted 50th percentile occupant at the front seat. Under such loading conditions, the seat anchorage of the front seat will experience extreme forces and may rupture under high severity crash. The rupture of just one seat is likely to produce the rupture of the seats in front of it. It is therefore absolutely necessary to prevent it.

With all tested belt configurations, it is also observed, especially in the performed full scale sled tests, that the load path (belt-seat-floor) allows too much deflection, which may result in extensive head excursions. In the 3 point belt configurations little differences in the results are found when changing the seat pitch. Femur loads are reduced as the pitch increases. This is due to the decreased interaction of the dummy with the forward seat.

When the 3 point belt optimised parameters are applied to 2 point belt configurations the benefits are no longer apparent. This is because increased seat back recliner stiffness needed for best results with the 3 point belt configurations.

Bulkhead

To evaluate the effect of a bulkhead in front of the dummy, a bulkhead model was used to replace one row of seats in the occupant model. The bulkhead structure was placed in front of the occupant, 72-cm forward of the rearmost point of the seat base structure. The geometry of the seat model is shown in Figure 7. The model was evaluated with the 5^{th}-percentile, 50^{th}-percentile, and 95^{th}-percentile dummy models in the three point belt configuration.

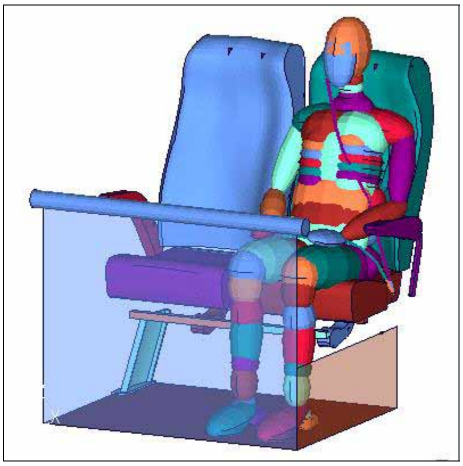


Figure 7 Bulkhead model

Compared to a configuration with a row of seats it appears that the risk of injury to the femur is decreased when the bulkhead configuration is with integrated three point belts.

Children

Using a 3 point belt in combination with a child below the age of 12 years requires specific adaptations. An adult 3 point belt system may not be able to protect child, and can even be more harmful than protective when no specific adaptation is defined. It is therefore essential to evaluate the risk caused by not adapted three point belt systems, and the benefits of adaptable systems. Simulations have been carried out in order to evaluate the benefit of three point belt systems for children.

In case no adaptation is made to the adult seat belt, the child occupant will have no choice but to wear a seat belt with a very high shoulder attachment point. The main risk is that the child occupant will experience major neck loads, due to direct contact between neck and belt. Also severe throat injuries, which cannot be predicted by simulation models, may result from such loading conditions. In any case a 3 point belt must offer the possibility to lower the shoulder attachment point. This adaptation is of interest not only for children, but also for small adults.

Simulations with 3 and 6 years old dummies wearing an adapted 3 point belt system (Figure 8) have shown that good kinematics could be obtained. However, the load on the thorax and resulting injury criterions are high due to the fact that the seat backrest and seat belt stiffness were optimised for an adult 50th percentile occupant.

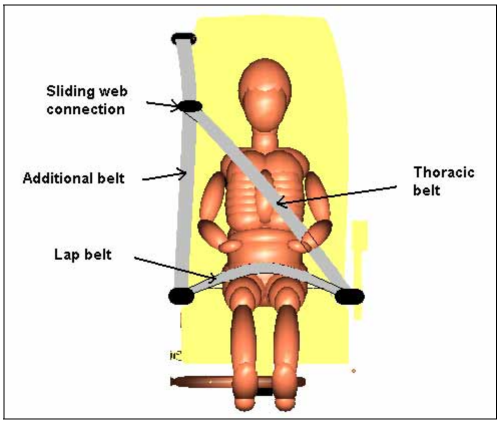


Figure 8 Proposal for shoulder point adaptation

In fact, 3 point seat belts adapted for children require specific solutions to be designed for (school) buses and coaches.

RECOMMENDATIONS FOR IMPROVING

ECE-R.80

It is clear that passive safety of bus and coach occupants will be improved if the following recommendations could be implemented in ECE-R.80:

- Combined dynamic test configuration;
- Worst-case seat/floor/sled combination;
- Requirements for child and small occupant restraint systems.

A sled test configuration could be two rows of seats, the front with restrained passengers (50th percentile dummies) and the rear with unrestrained passengers (50th percentile dummies).

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. Tests 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 ECE-R.80 [7].

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 ECE-R.80 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.

The feasibility of implementing these recommendations should be analysed.

CONCLUSIONS

Direct intrusion, seat ruptures due to the impact of other passengers and ejection of the passengers are the three main causes of injuries during a bus or coach accident. Ejection out of the bus or coach through side window or windscreen is not only found in rollover accidents, but also in frontal accidents and causes fatal injuries to the passengers. That's why the use of seat belts, 2 points or 3 points, is strongly recommended for adult as well as for child passengers.

Additionally, it would be better to have all children restrained during an accident, even with a 2 point belt, than having them unrestrained, as the biggest risk to be injured is by ejection.

Making 2 point or 3 point belt systems obligatory in buses and coaches requires sufficient strength of the bus structure regarding the seat belt load path. The seat to floor attachments should be sled tested on a rigid floor at 50 km/h and 20g as this represents the worst case.

Finally, 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.

ACKNOWLEDGEMENTS

The work described in this paper form part of the EC funded research programme ECBOS [1] conducted by the Safety Department of TNO Automotive.

The help and co-operation of the Dutch bus manufacturer BOVA is gratefully acknowledged.

The authors want to acknowledge also that the collaboration of the partners CIC (Cranfield Impact Centre, UK), GDV (Gesamtverband der Deutschen Versicherungswirtschaft, DE) INSIA (Universidad de Madrid, ES), POLITO (Politecnico di Torino, IT), TUG (Technische Universitaet Graz, AT) and VSRC (Loughborough University, UK) has been essential to complete this paper.

REFERENCES

1. ECBOS, Enhanced Coach and Occupant Safety, EC project within Framework 5; Project No: 1999-RD.11130.

2. Matolcsy M, Scientific Society of Mechanical Engineers (GTE), "Frontal collision of buses – problems, questions, regulations", 33rd Meeting of Bus and Coach Experts International Conference on Vehicles Safety and Reliability, 2-4 September 2002, Keszthely Hungary.

3. Mitsuishi H, Sukegawa Y, Matsukawa F, Japan Automobile Research Institute, Okano S, Japan Automobile Manufactures Association, Inc., "Crash-Safety Performances of Bus Passengers", 33rd Meeting of Bus and Coach Experts International Conference on Vehicles Safety and Reliability, 2-4 September 2002, Keszthely Hungary.

4. Langwieder K, Gwehenberger J, Bende J, "Coaches and buses in the accident scene – Results of a study regarding passenger protection", 33rd Meeting of Bus and Coach Experts International Conference on Vehicles Safety and Reliability, 2-4 September 2002, Keszthely Hungary.

5. Páez Ayuso F.J, Aparicio Izquierdo F, Garcia Gracia A, INSIA-UPM, "Injury mechanism analysis in accidents with buses involveld", 33rd Meeting of Bus and Coach Experts International Conference on Vehicles Safety and Reliability, 2-4 September 2002, Keszthely Hungary.

6. Mayrhofer E, Geigl B, Institut fuer Mechanik, Technische Universitaet Graz, Austria, Steffan H, Dr.Steffan Datentechnik, Linz, Austria, "Enhanced Coach and Bus Occupant Safety through analysys of current test procedures and real world accident incidents", 33rd Meeting of Bus and Coach Experts International Conference on Vehicles Safety and Reliability, 2-4 September 2002, Keszthely Hungary.

7. Vogelsitze GmbH, Karlsruhe, Germany, "Compliance wit European safety requirements for coach seats", 33rd Meeting of Bus and Coach Experts International Conference on Vehicles Safety and Reliability, 2-4 September 2002, Keszthely Hungary.

8. Crasas C, Ferrer I, IDIADA Automotive Technology SA, "Application of accident reconstruction in the assessment of the use of seat belts in buses", European Automotive Congress, Bratislava 18th-20th June 2001.

APPENDIX A
RELATED REGULATIONS AND DIRECTIVES

Based on a resolution of the European Conference of Transport Ministers the co-ordination of technical specifications for coaches was taken up by the ECE Working Party 29 in 1967 as their terms of reference. In the process, a high level of safety was supposed to be obtained. Nine ECE Regulations dealing with occupant safety requirements for buses and coaches resulted from these negotiations (Table 2).

ECE Regulation	**EC Directive**	**EC Last Revision**	**EC New**	**Scope**	**Remarks**
14R05	76/115	96/38		M1-3, N1-3	Safety-belt anchorage's
16R04	77/541	96/36	2000/3	M1-3, N1-3	Safety-belts and restraint systems
36R03			2001/85	M2, M3 (> 22+1)	Uniform provisions concerning the approval of large passenger vehicles w.r.t. their general construction
43	92/22			M1-3, N1-3	Safety glazing materials
52R01			2001/85	M2, M3 Single-deck (< 22+1)	Uniform provisions concerning the construction of small-capacity Public Service Vehicles
66R	-	-	2001/85	M2, M3 (> 22+1)	Uniform provisions concerning the approval of large passenger vehicles w.r.t. the strength of their superstructure
80/R01	74/408	96/37		M2, M3	Seats of large passenger vehicles, their anchorage's and installation of seats
107R			2001/85	M2, M3 Double-deck (> 22+1)	Uniform Provisions concerning the approval of double-deck large passenger vehicles w.r.t. their general construction

Table 2 Overview of existing Regulations and comparable Directives.

These ECE Regulations came into force between 1976 and 1989. The application of some of these ECE Regulations is still not obligatory in all countries within the EC. For the passive safety of single decked touring cars (M2, M3) there are only three ECE Regulations today which are of importance: Regulation No. 80 (Seats of large passenger vehicles, their anchorage's and installation), Regulation 14 (Safety-belt anchorage's) and Regulation 16 (Safety-belts and restraint systems). Although, these Regulations (and comparable EC Directives) are not compulsory in all European countries, but they are taken into account by most bus manufacturers in the development of new bus and coach model types and by most authorities for approval.