ECBOS

Enhanced Coach and Bus Occupant Safety

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- Politecnico di Torino
- Technical University Graz
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1 EXECUTIVE SUMMARY

Objectives:
Based on the background of the European Vehicle Passive Safety Network a consortium of 7 European Research Institutes and Universities was formed to investigate the field of current bus and coach accidents as well as to propose new cost effective test methods and suggestions for improved regulations to decrease the injury risk for the bus occupants.

In the EC 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 EU countries cover collisions, single accidents as well as “normal” driving manoeuvres.

For this investigation the research project ECBOS which was structured in a science part (4 work-packages) and in a management part (1 work-package) was initiated.

Work performed:
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.
Achievements:
A report of the statistical accident data of 8 European countries for the years 1994 to 1998 was generated. This document enables an international comparison on different convincing evaluation criterions. A bus accident database containing a representative number of real world accidents, including reconstructions and evaluations has been generated. Several series of experimental tests were performed to investigate material and crash behaviour of bus components and seats. These data were used as INPUT for a number of numerical simulations dealing with new approaches and for verification of current standards. The findings from all these simulations formed the basis for the new suggestions and demands for current regulations and directives on bus and coach safety.

Exploitation plans:
The main area of exploitation of this research project is the development of safer buses. This shall be obtained through the European Regulatory Agencies and ISO standard committees as this project will deliver the bases for new and released regulations. Some of the results of this work 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.
2 OBJECTIVES AND STRATEGIC ASPECTS

Optimisation of Road Transport safety is an important objective within key action 2 “Sustainable Mobility and Intermodality”. A high level of safety is required to reduce the impact of mobility demands on society and individuals: 45,000 reported deaths and 1.5 million injured per annum as a result of road traffic accidents in the European Union. This problem can be controlled considerably if adequate attention is given to injury prevention (i.e. secondary or passive safety) strategies and measures. Development and promotion of new technologies and tools as foundation for harmonised safety regulations is foreseen by this RTD proposal. This proposal is referring to Task 2.2.3/6 “Safety / Further development of road vehicle safety standards”. The general objective of this proposal, to enhance coach and bus occupant safety, is in agreement with the description and expected results of the above-mentioned task. See also the Annex to Part C of this proposal describing the clustering of projects.

In the EC approximately 20000 coaches in the size of more than 5000 kg are involved in accidents with personal injuries. Every year more than 30000 persons are injured within these accidents. Over 150 occupants of buses and coaches suffer fatal injuries annually. In contrast to other accident data, no tendency for a significant reduction can be found.

In total seven ECE regulations and 5 corresponding EC directives deal currently with the structural and seat design for buses and coaches. Therefore the general objective of this project is 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

The overall objective will be achieved by developing cost effective test and evaluation methods for the assessment of the protection offered to the bus occupant and driver in frontal, oblique and rollover accidents.
Additional emphasis will be put on the various passenger sizes, in order to consider optimisation of restraint designs for occupants other than the 50\textsuperscript{th} percentile 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 will be 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, will be the major result of this project. They will be based on the new and extended test methods developed and evaluated.

Their efficiency will be demonstrated through numerical models of an improved bus design.
3 SCIENTIFIC AND TECHNICAL ASSESSMENT

Following overview describes the technical state of the research with emphasis on the achievements. The actual work performed and the original description of work were compared by means of the achieved and stated objectives (milestones, deliverables) and is presented task by task.

3.1 Workpackage 1

**General:** Investigating governmental databases of different countries, a relation between injury risk and accident type should be found. As also the injury mechanisms are not well known for many of these different accident situations, in-depth studies of specific accidents will be performed, which will be selected from extended databases. As there is currently no general European Database for bus accident available this workpackage will provide all necessary information to be able to determine the priorities for consideration during the project.

3.1.1 Task 1.1 – Accident Analyses

**Planned:** Out of the governmental accident databases of each involved partner country, a statistical analysis of all bus accidents will be performed regarding the following criteria which are relevant for active and passive safety.

- Region where accident occurred
- Accident type (speed, severity; crash or operational related)
- Road type
- Weather conditions
- Bus type and equipment
- Bus interior design
- Intrusion level and deformation
- Restraint system
- Occupant data (e.g. age, sex, size)
- Injury severity and type
- Passenger ejection
- Quality of accident documentation

The last 5 available years of accident data will be investigated.
**Performed:** The Task 1.1 report takes an overall view of the statistical accident data collection. It does so by using partners' analyses of the data within their respective countries. The data and explanations behind specific findings for each country are to be found in the document for each individual country. The data from eight countries has been included (from the 6 partner countries Austria, Germany, Great Britain, Italy, the Netherlands and Spain and 2 subcontracted countries, France and Sweden). The document includes a description of the difficulties that arise when making international comparisons, with national differences in data collection, processing and analysis. This report has achieved comparison across these eight countries by sometimes taking the essence of countries' data and drawing general conclusions.

Firstly the numbers of casualties in buses and coaches are 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 are injured than car occupants and in all the countries, when a casualty occurs 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 is then considered, by age, gender and injury severity. In all eight countries many more women than men are 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 is then investigated. More passengers are injured than drivers in all countries. In France, Germany and Great Britain a higher proportion of driver casualties sustain a serious or fatal injury than passenger casualties. The circumstances of bus and coach accidents with injured occupants are then studied. This report has been able to support further work in the ECBOS project 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 occur on urban roads; however most fatal injuries occur on rural roads.

Data are also presented on environmental conditions at the time of the injury accident to give a complete picture of when and in what weather conditions injuries occur.

**Assessment:** The outcome of task 1.1, is a report which enables a comparison of accident data of 8 European countries, which represent nearly 90 percent of the population, for the first time. This knowledge is important insofar, as common ECE regulations have to cover the accident behaviour of all EC countries. The report fulfils herewith the planned delivery N°1 and milestone N°1.

The reason for extending this task, was based on the big differences in data collection in the countries. In that the accident data forms look quite different and have different evaluation targets, the work to find comparable and meaningful results was very complicated. In addition the data acquisition was not so easy as previously planned. This fact has been considered insofar, as a lot of discussions were put on this topic during the first project phase which resulted in a common decision to extend this important task. This change also caused the relocation of some other tasks which depended on the results of task 1.1. The new time schedule was presented in the 12monthly progress report.

In that the number of spent man-months did not change dramatically, the influence on the financial balance between the tasks was insignificant.
3.1.2 Task 1.2 – Selection of cases for in-depth studies

**Planned:** Based on the results in Task 1.1 approximately 100 significant accidents will be selected for in depth studies from the Extended data base. Therefore the partners active within this task will review the extended databases to identify suitable cases for detailed reconstruction.

**Performed:** The outcome of the task 1.1 analyses supported the definition of the cases for the in-depth analyses. Each task involved partner was invited to investigate national sources for the data collection. During this term an intermediate report on the success of investigation was performed which showed a very limited access to real accident data. This fact forced the consortium to reduce the number of cases to be in line with the project schedule. Since the definition of the database integration offered a dynamic database, all partners were invited to update the database whilst the ongoing project with actual bus accident data. The basic work on this task has been finished and the report of the selected cases will be presented together with the database integration due to their interconnection.

**Assessment:** Based on the results of task 1.1, national sources (courts, police, experts) were contacted to collect data from real world bus accidents. Since the task 1.1 results were only on statistical basis it was not possible to find a direct correlation to the accident cases wanted. So, all available information was gathered and then evaluated if suitable or not. The cases were listed by means of a table with added descriptions. The collection and tabulation of the real world accident cases has been fulfilled and can be counted as delivery N°2.
3.1.3 Task 1.3 – Database integration

**Planned:** The data from the various sources (governmental- and extended) databases will be integrated into a general bus accident database by partner GDV.

**Performed:** After intensive discussion on the contents of this task a database was generated by means of a special software tool. This database contains pictures and all important data from the real world accidents.

Two main directions of investigation were defined:

- Accidents with collision
- Accidents without collision

Each case was subdivided in information on: general, infrastructure, accident, vehicle data bus, opponent/obstacle, personal/injury, pictures/reconstruction and output basis. The figure below shows the INPUT mask of the accident database.

![Input mask of accident database](image)

All data information are stored in an MS Access database format and can be used for other visualisation purposes later on. The pictures and sketches from the
accident scene were converted into .jpg graphic format. The output page shows the main information as well as two significant photographs of the accident. For print purposes a summary or detailed version is eligible.

**Assessment:** The generated database enables a very good possibility to evaluate the information on bus accidents due to the detailed investigation on several accident relevant data. In principle, the ongoing is in line with the schedule and the report will be presented in time. Both, the database as well as the cases for the in-depth study will be presented on a report CD.

The database represents milestone N°5 of the ECBOS project.

### 3.1.4 Task 1.4 – Accident reconstruction using simulation methods

**Planned:** In this task the selected cases from task 1.2 will be reconstructed by means of computer simulation in order to identify the main relevant accident conditions and data such as impact velocities of the involved vehicle(s), principle direction of force (PDOF), change of velocity $\Delta v$ due to collision, vehicle deformations, road contacts, vehicles energy absorption due to collision (Energy Equivalent Speed) and the three dimensional bus movement pre- during and after collision (kinematics).

Special emphasis will be put on the breaking of windows during rollovers.

**Performed:** 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, which show the end position of the vehicles and the tyre marks have been loaded too. After defining the operation sequences, the correct boundary and initial conditions the calculations were performed. The results were generated as tables, graphs as well as 3-dimensional video animations.

The figures on the next page show a simulation 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.
Photographs of accident scene and marks on the street

Accident sequences
Assessment: The performance of the accident reconstruction yielded firstly a lot of information for the database integration and secondly a very good possibility to visualize the movement of the bus in the pre-, post- and impact phase. The work is basically in finalising stage and will be presented on a report CD soon. This CD will include all reconstructed cases in PCCrash file format as well as the animations in .avi video format.

Due to a later starting of this task there is a slight delay of approximately two months. However this has no negative influence on the ongoing of the project. The outcome of this task represents delivery N°3 and milestone N°2.
3.2 Workpackage 2

General: Based on the in-depth studies, performed in WP 1, new numerical simulation models will be developed. These numerical models in combination with accident and full scale reconstructions will generate the knowledge necessary, to understand the various occupant and driver injury mechanisms. Based on the findings in workpackage 1 the specifications for workpackage 2 will be clarified.

3.2.1 Task 2.1 – Component tests

Planned: The main possible contact areas in the three typical bus-types (M3, M2, City) will be measured (CIC) according to FMVSS 201 (Free motion head form test). The detailed acceleration measurements will be used to determine the local stiffness of the individual contact areas. ECE R80 tests will be performed (TUG, TNO) to determine seat and restraint data. If required additional component tests will be performed.

These parameters will mainly be used for calibration of the numerical model.

Performed: As preliminary work on the FMH testing (performed by CIC) 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. These tests 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.
TNO focused their activities on basic seat material tests and the frontal impact behaviour (figure right), whilst TUG analysed the rear impact performance. The tests in frontal direction were performed according to the ECE R80 conditions, varied by different configurations of the dummy placements. The rear impact tests (figure left) 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.

**Assessment:** The FMH tests, performed at Cranfield generated a good basic knowledge on the load transmitted to the head in case of a contact with bus interior components. These results will lead to discussions on improvements of risky bus interior components. Also the usage of laminated glass for the side windows is still under discussion.

The sled tests for the study on frontal and rear impact behaviour of the bus seats generated also new knowledge. This know how will be used to define suggestions for an improvement of the design and properties of a bus seat.

This task had a delay of about 3 month, because the planned performance of rear impact tests could not be carried out in time since the specified seats for these tests were destroyed in the frontal impact tests. TUG had to make a new contact to a seat manufacturer which provided the project with coach seats later on. Immediately after confirming the support of test material all further test equipment was organized. The tests were carried out together with the midterm meeting to enable firstly a presentation of the laboratory and secondly an economical participation possibility of the project partners.

The report of task 2.1 has been finished in the meanwhile and has been sent out to the partners in electronically form on a CD. This report represent delivery N°4 of the ECBOS project.
3.2.2 Task 2.2 – Full scale reconstruction

**Planned:** Approximately five full scale case reconstructions, selected according to the results in Workpackage 1, will be performed. Each bus-type (M3, M2, City) will be used for at least one test. CIC will perform M2 tests, UPM will perform two rollover tests and TNO will be responsible for the frontal accident reconstruction. As far as possible existing accident data from crash-tests, which can be provided by the involved partners will be used. These reconstructions and measurement data will on the one side permit to compare real occupant injuries to physical parameters measured on the dummies, and on the other side provide validation data for the simulation of occupant movement performed in task 2.4.

**Performed:** 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 will be a frontal impact pole test, which will be performed soon.

A further test series is planned on bay sections of a real coach. Due to organisation and effort, these tests are still in preparation phase and will be carried out during the next partner meeting in Madrid in autumn.
The originally planned full scale test on frontal impact for M3 buses has been altered in generating a mathematical model of a bus structure. TNO presented a research proposal for this new approach. This process was intensive discussed within the consortium and agreed at the Munich meeting. In the meanwhile the progress of this task section is good and will be finished soon.

**Assessment:** The work for this task shows a lot of solid progress and is good in line with the planned activities. In that the time schedule of testing is heavily dependent on the material supplier a slight delay may occur due to the providing of the coach bay sections.

### 3.2.3  Task 2.3 – Numerical simulation model for vehicle structure

**Planned:** A numerical model of the bus structures, seats including occupant mass, if restrained, will be generated with the main emphasis on coaches (M3). CIC and TNO will develop the numerical model for frontal impact and UPM and POLITO will provide the rollover model.

**Performed:** The work of Cranfield involved creating a detailed finite element model of a M2 minibus that was test during Task 2.2. The model was set up to simulate the two full-scale reconstructions that were performed by CIC during Task 2.2 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. From the comparison of the simulation and test values it can be seen that the peak values and general trends are very similar between test and simulation.

Other observations that show similarities between the test and simulation, and hence give further confidence in the model, are as follows:-

- The simulation shows a similar (although slightly lower) longitudinal displacement of the pole barrier into the vehicle.
- The plastic crease at the top of the A-pillar is reproduced by the model.
- The door deformation is similar.
- The vehicle rebounds a similar distance and rotation from the pole barrier.

The numerical models from INSAI have been built with regard to the bay section tests carried out in task 2.2., including the structure geometry and properties, and the same test conditions. This will permit to validate and compare the results. Anyhow, once the models have been validated, they could be extrapolated to represent the behaviour of the full vehicle.

A model (see above) of the bay section was developed using the implicit finite elements software ANSYS.

A further numerical model of the bay section has been made using the explicit finite elements code PAMCRASH. Elasto-plastic beam elements are used to model the structure. Those are one-dimension elements, whose position and length are defined by two extreme nodes.
Another more detailed model of the bay section has been made using the explicit finite elements code MSC-DYTRAN. In this case, elasto-plastic shell elements are used to model the bay section, including panels and the detailed geometry of joints. The structure is modelled using 4-nodes shell elements. Those are two-dimension elements, whose geometry is defined by the position of the four nodes, and just the thickness has to be introduced.

The bay section numerical models from PoliTo were developed using MADYMO v5.4 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 methods employed to build the CIC bay section model were substantially the same as used for the former bay section model. So, in this case, the hybrid technique was employed and FE and MB were put together. All the necessary information about the bay section geometry and the materials properties, together with the experimental tests results, were provided by CIC.

The method employed to build the INSIA bay section model are substantially the same as used for the first and the CIC bay section models. The information about the bay section geometry and the materials properties, together with the experimental tests conditions and some time histories of the kinematic quantities they have measured, were provided by INSIA.
For the full-scale simulations a bus model developed by TNO was used. In the simulation, all three busses are represented, but to increase the robustness of the simulations, all busses have the same geometry and physical parameter values, such as mass and inertia. The figure on the right side shows a picture of the bus model as used in the MADYMO simulations.

**Assessment:** Several numerical models have been generated and numerous calculations have been performed. The models have been validated by using the results of the full scale reconstructions. New approaches on the configuration of the computer models have been generated. During the last meetings some of the models were presented and discussed within the consortium. The progress of this task is quite well and will be continued and finalised by using the results from the full scale reconstructions. The final report of this task represents delivery N°6.

### 3.2.4 Task 2.4 – Numerical simulation model for occupant behaviour

**Planned:** Numerical models of the bus interior including passengers, seats and restraint systems will be generated for the three specific bus types (M3 by TNO front and UPM rollover, M2 by CIC, City by TUG). The models must also contain the capability to allow prescribed, time dependent intrusions. They will be validated within the full scale crash tests performed in task 2.2. Special emphasis will be put on occupant movement, contacts and loads. Intrusions will be specified as inputs. The vehicle movements will be derived from tasks 1.3 and 2.2.

**Performed:** CIC’s rollover occupant model simulated one of the 50th percentile Hybrid III dummies that was inside the full-scale M2 rollover reconstruction of Task 2.2. 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).

The frontal impact occupant model simulated one of the 50th percentile Hybrid III dummies inside the full-scale M2 frontal impact reconstruction of Task 2.2. 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.

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 determine 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 deflection 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).

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.

TNO’s frontal impact simulation models of a bus and a bus interior were created and evaluated using test results. Using those simulation models, the most significant seat parameters were optimised. The target of the optimisation was to reduce the injury values recorded in the dummies. An optimal set of characteristics for the most significant seat parameters was defined.

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 enable 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 created within Task 2.4 of the ECBOS project 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 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. 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.

**Assessment:** Several models for simulation of the occupant behaviour have been generated since beginning of this task. Different approaches due to the accident constellation and the placement of the occupants have been considered. The ongoing work is basically good in line with the proposal and promises to yield with interesting results.

The outcome of this task will represent milestone N° 3 of the ECBOS project.
3.2.5 Task 2.5 – Cause of injury summary

**Planned:** With the results of tasks 2.3 through 2.4 it should be possible to summarise the most important mechanisms, causing the injuries found within the accidents in Tasks 1.1 and 1.2.

**Performed:** This work takes an overall view of the data that has been collected in Tasks 1.1 and 1.2 of the ECBOS project and investigates the results of Tasks 2.3, 2.4 and 2.6, to establish the injury mechanisms that are causing problems in M2 and M3 vehicles. In Task 1.1 it was possible to use national statistics to indicate the most harmful accident circumstances, and for completeness the main conclusions are repeated here. 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 cases from Tasks 1.2 and 1.3. 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. During Tasks 2.3 and 2.4, vehicle and dummy models have been created and validated for both M2 and M3 vehicles, rollover and frontal impacts. The results of simulations performed in these tasks are used here to illustrate possible contacts and the injury criteria of the dummy models indicate where injury criteria limits are being exceeded. In Task 2.6, 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 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. It is still difficult though to pinpoint ECBOS Task 2.5 some injury mechanisms. Descriptions are therefore given, by the partners who collected the in depth cases, of any clear injury mechanisms discovered in the cases.
**Assessment:**

This study summarises the basic reasons to suffer injuries during an accident in a bus of category M2 and M3. The correlation between the occurrences of the real world accidents and the investigated injuries of the occupants was revealed. The most causations were more or less easy to identify and some few had to be estimated. However, this study represent a milestone in bus accident investigation and formed the basis for the further work on improved test methods.

### 3.2.6 Task 2.6 – Parametric Study

**Planned:** Using the model developed in task 2.1 through 2.4 a parametric study will be performed to see the influence of the injury risk on the following parameters: Vehicle structure, Intrusions, Padding, Seat characteristic, Window design (e.g. laminated glass), Restraint system (e.g. belts) and finally the Occupant size and position.

**Performed:** For CIC’s M2 vehicle models the validated vehicle and occupant model both for rollover and frontal impact were taken as the baseline models for assessing the sensitivity of certain parameters to the resulting occupant injuries. This set of rollover simulations shows that for a typical rollover (where the vehicle does not significantly intrude into the occupant survival space), the injury loading to the occupants can be kept low by suitable restraint systems and ensuring no ejection from the vehicle.

PoliTo used their numerical model of a coach bay section developed for Task 2.3, a to perform a parametric study and to analyse the influence of some significant parameters on the injury risk during a rollover accident. The parameters taken into account are e.g. the strength of the vehicle structure pillars, the occupant (dummy) position, the kind of restrain system and the occupant (dummy) size.
TNO’s parameter optimisation consisted of a study, in which seat parameters are determined that result in the lowest injury values. This optimisation is performed for the 5th, 50th and 95th percentile dummy models. The result of the optimisation was one optimised set of seat parameters for each dummy. In the parametric study which followed the optimisation, simulations were performed using these optimised interiors.

The optimisations have shown that in the three point belt configuration, a higher recliner stiffness is required and in an unbelted situation, a lower recliner stiffness is required. Furthermore, the 5th percentile dummy injury values are higher in an unbelted configuration than in a two or three point belt configuration. Thus, the objective of the combined optimisation is to find a recliner stiffness characteristic that is stiff enough for the 95th percentile, three point belt situation and relaxed enough for the 5th percentile, unbelted situation.

TUG’s bus model acted as baseline model for assessing the sensitivity of certain parameters to the resulting occupant injuries. Following parameter were taken into account: occupant size, occupant position, occupant action and the material characteristic of bus interior. The chosen bus model is a typical representative of the 12m sized city bus fleet and was taken due to the good documentation of the design and vehicle interiors.

All original technical specifications and dimensions were implemented into the PCCrash simulation model to calculate the trajectory of the bus during the emergency braking. These dynamic parameters (positions, orientations) were then used as input data for the occupant simulations.
3.3 Workpackage 3

**General:** In WP 3 the numerical models, component- and full-scale tests, performed in WP 2 will be used to develop new numerical and experimental test methods for the validation of driver and occupant safety in buses. The various test methods will also be compared through a cost benefit analysis.

3.3.1 Task 3.1 – Numerical test methods

**Planned:** Based on the mathematical model derived in task 2.3 and 2.4 possible numerical test methods will be evaluated and classified. Task 3.1.1 refers to structural rollover tests where starting from the existing numerical method for ECE R 66 possible developments for additional criteria will be assessed (mainly M3 coaches). Task 3.1.2 refers to the assessment of new structural tests by using the results from task 1.1 and 1.2 (mainly M3 coaches). Finally, Task 3.1.3 refers to the passenger movements and loads must will be demonstrated as a function of vehicle movements derived in tasks 1.4 and 2.2. For these subtasks the numerical models derived in Tasks 2.3 and 2.4 will be extended so that component tests allow the definition of structure and design in order that the models can be adopted to the individual bus in a rather simple manner.

**Performed:**

**CIC:** This task was undertaken 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 developed during Task 3.3.1, 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.
**INSIA:** In this report the conclusions obtained by INSIA in relation to the structural numerical test for rollover of coaches are described. The results from the rollover tests carried out in task 2.2 have been analysed and compared, and the models built in task 2.3 have been used. 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:** Using the numerical models of the CIC coach bay section developed for Task 2.3, 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.

**TNO:** One of the task in this project is to make a 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.

**TUG:** This task was undertaken in order to extend the numerical models derived in Tasks 2.3 and 2.4 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 simulation will demonstrate 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.

**3.3.2 Task 3.2 – Component test methods**

**Planned:** For Task 3.2.1 a test method similar to the FMVSS 201 – Free Motion Head Form will be assessed and important contact areas will be derived through numerical simulation. In Task 3.2.2 the possible extensions of the existing sled test procedure ECE R 80 to non frontal impacts (definition of oblique, side impact and rollover crash pulses) with and without usage of the restraint system will be assessed.

**Performed:**

**CIC:** Within Task 3.2.1 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 were created and validated using the data from Task 2.1 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 of Task 2.4 and 2.6 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.

**TNO:** This report 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. 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.

**TUG:** This task was undertaken in order to investigate 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 that of the rear end impact sled tests performed by TU Graz during task 2.1. 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.
### 3.3.3 Task 3.3 – Full-scale test methods

**Planned:** For Task 3.3.1 the regulation ECE R 66 will be extended to include interior design and dummy movement as well as other accident situations. (for M3 coaches). In Task 3.3.2 a suggestion for a simplified frontal impact test will be derived to guarantee limited accelerations for the passengers and a suitable deformation to decrease also the drivers injury risk. (M2, M3 and city buses will be considered)

**Performed:**

**CIC:** The aim of this 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 (R66) rollover test procedure. The objectives were to calculate 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.

**INSIA:** This report describes the conclusions obtained by INSIA in relation to the extended rollover test of coaches. The results from the rollover tests carried out in task 2.2 and the models built in task 2.3 have been analysed and compared. The results obtained in task 3.1.1 have also been used to write this report. In the present report 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:** One of the tasks in this project is to make a 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.

**3.3.4 Task 3.4 – Test procedures for City buses**

**Planned:** Special test procedures will be generated for standing persons and people moving inside the bus. Normal operation conditions will be considered. The main goal is to reduce the induced loads on body segments in all situations.

**Performed:**

**TUG:** This report details the work performed by Technische Universitaet Graz on Task 3.4 (Test Methods: Test procedures for city buses) of the ECBOS project. 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.
3.3.5 Task 3.5 – Cost benefit analysis for different test methods

Planned: For all proposed test methods a cost benefit analysis will be performed with respect to the analysed accident data gained in Task 1.4. In addition practicability and reproducibility will be investigated. Each test procedure will be demonstrated through at least one sample case.

Performed:
GDV: The following report describes the work performed by GDV in the frame of task 3.5 of the ECBOS project. It presents a cost/benefit analysis for different test procedures according to the current Regulations ECE R66 and ECE R80. Previous studies of the project 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>
<thead>
<tr>
<th>Regulation No</th>
<th>Type of Test / Simulation</th>
<th>Required tests per year in EU</th>
<th>Achievable tests</th>
<th>Achievable tests Required tests</th>
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<tr>
<td>ECE R66*</td>
<td>Bay section</td>
<td>408 ... 1,224</td>
<td>2,012 ... 5,668</td>
<td>4.6 ... 7.1</td>
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<td></td>
<td>Full scale</td>
<td>408 ... 1,224</td>
<td>190 ... 320</td>
<td>0.3 ... 0.5</td>
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<tr>
<td></td>
<td>Simulation</td>
<td>408 ... 1,224</td>
<td>422 ... 3,333</td>
<td>1.0 ... 2.7</td>
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<tr>
<td>ECE R80*</td>
<td>Sled test</td>
<td>4,080 ... 8,160</td>
<td>2,730 ... 8,625</td>
<td>0.6 ... 1.0</td>
</tr>
</tbody>
</table>

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.

3.3.6 Task 3.6 – Occupant size influence on all type of test procedures

**Planned:** The influence of body sizes will be demonstrated by means of numerical simulations of the occupant kinematics and kinetics for Hybrid III 50%, 5%, 95%, as well as TNO Q6 Dummies. The final choice of dummies will be influenced by ongoing EC Projects. Numerical simulations and component test methods will be used for demonstration.

**Performed:**

**CIC, TNO, TUG:** This report details the work performed by the ECBOS consortium on Task 3.6: ‘Occupant Size Influence on All Types of Test Procedures’. The involved partners were CIC, TUG and TNO. However, relevant results from POLITO have also been included in this report.
3.4 Workpackage 3

**General:** In WP 4 written standards will be suggested based on the newly developed test methods. Their efficiency will be demonstrated by means of numerical models for improved bus and coach designs.

3.4.1 Task 4.1 – Suggestions for new regulations and written standards

**Planned:** Based on the different numerical structural and component test methods developed in Workpackage 3 the most efficient will be suggested and formulated according to the results of Task 3.5 as well as Task 3.6.

**Performed:**

From the research carried out inside the ECBOS Project (analysis of accidents, simulation models and tests), a list of suggestions for new Regulations and written standards have been written jointly by all the partners. In this report they are described the conclusions obtained by the partners involved in the Task 4.1 to sustain that points in the list of recommendations in which they have been involved during the Project.

<table>
<thead>
<tr>
<th>Obligatory use of seat belts</th>
<th>European Directive</th>
<th>ECE Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat belts anchorages</td>
<td>76/115-96/38/EC</td>
<td>14 R05</td>
</tr>
<tr>
<td>Seats, seat's anchorages and headrest</td>
<td>74/408-96/37/EC</td>
<td>80 R01</td>
</tr>
<tr>
<td>Safety belts and restrain systems</td>
<td>77/541-2000/3/EC</td>
<td>16 R04</td>
</tr>
<tr>
<td>General construction of large passenger vehicles</td>
<td>2001/85/EC</td>
<td>36 R05</td>
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<tr>
<td>Double Decker</td>
<td></td>
<td>52 R01</td>
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<tr>
<td>Rollover resistance</td>
<td></td>
<td>107 R00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>66 R00</td>
</tr>
</tbody>
</table>

First of all an overview on actual standards related to buses and coaches is presented. That overview has been made inside other tasks and by other partners during the Project, but it is interesting to remember them again because we are going to talk about proposals of modification in Directives and Regulations. After that, the reasons for each modification proposed for the actual European Regulations and Directives are added to each headline, when each partner has been involved on the research to support it. At last some ideas on future research that must be done presented as opened points (that could be a seed of future new standards).
3.4.2 Task 4.2 – Mathematical models of improved bus design

**Planned:** Based on the validated mathematical model of task 2.3 and 2.4 including all important components of a bus-interior and if applicable occupant restraint systems, a parametric study will be performed to develop a set of preliminary design guidelines. Parameters to be varied include test condition (frontal and rollover), seat and restraint design, stiffness and damping characteristics of interior cushioning, occupant size and sitting (standing) position, intrusions etc. This parametric study will show the influence and effect of design changes to the occupant performance.

**Performed:**

**CIC:** 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 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.

**INSIA:** The aim of this task was to create 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).

**PoliTo:** This report details the work performed by Polito within the frame of Task 4.2 (Mathematical model of improved bus design) of the ECBOS project. In task 3.3.1 and 3.6 the influence of the passengers mass on the results of a standard ECE66 rollover test was analysed by CIC and INSIA. 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). In the following table the K factors calculated by CIC and INSIA are shown. Also the K factor proposed by the R-66 Ad Hoc Expert Group was reported.

**TNO:** The work described concerns the simulation work performed 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.

**TUG:** This task was undertaken in order to draft design guidelines which represent a better (safer) impact behaviour for the sitting or standing occupants. For this purpose the numerical city bus model created within task 2.4 including all important components of bus interior was taken for a parameter study varying the material characteristics, interior designs and the occupant sizes.
4 LIST OF DELIVERABLES

Following chapter shows a list of deliverables of any tasks completed. As a result of the modifications of the time schedule (see below), the date of delivery refer to this updated version.
List of deliverables

Delivery No°1 (Milestone 1): Task 1.1: Statistical Collection

A statistical summary of real world accidents from all partner countries as well as 2 further European countries was created and analysed for the use in several tasks.

Delivery No°2: Task 1.2: Selection of cases for in-depth study

At least 36 well documented bus or coach accidents from different partner countries were selected for in-depth study.

Delivery No°3 (Milestone 2): Task 1.4: Accident reconstruction

All within Task 1.2 selected real world accident cases have been subject of an accident reconstruction. This was done to understand the circumstances of the occurrences and to calculate the vehicle dynamics.

Delivery No°4: Task 2.1: Component tests

The results of this task showed the impact behaviour of bus and coach interior component as well as the stability and deformation characteristics of coach seats under different impact conditions.

Delivery No°5: Task 1.3: Database Integration

A database was created which contains all the major results gained within the accident reconstruction and a following assess of the injuries of the occupants. Available photographs from the accident scene completed this work.
List of deliverables

Delivery N°6: Task 2.2: Full-scale reconstruction

Rollover full-scale tests with bay section under different boundary conditions were performed. Main result was the evaluation of the influence of the belted occupants to the deformation of the roof structure

Delivery N°7 (Milestone 3): Task 2.3, 2.4: Numerical simulation models

Several numerical models for bus structures as well as for the evaluation of the occupant movement were created. The models were validated by means of the results of the component tests (T 2.1).

Milestone 4: Task 5.2: Exploitations

At mid term a review over the first 18 months of the project were done to check the expected success of the project. Based on the excellent performed work the project was processed due to work proposal

Delivery N°8: Task 2.5: Cause of injury summary

Based on the data gained within the accident reconstruction (T 1.4) and the medical reports an estimation of the main injury causing factors was performed. This work was supported by diagrams from the statistical analysis.

Delivery N°9 (Milestone 5): Task 3.2: Component test methods

These results describe the procedure of a free motion headform (FMH) testing as well as the possibilities on improved sled tests for longitudinal testing of bus and coach seats.
**Delivery N°10: Task 3.4: Test procedures for city buses**

This study deals with a detailed description of the interior testing for city buses. Several components which were defined as possible injury causing part were taken into account and assessed for impact testing.

**Delivery N°11: Task 2.6: Parametric study**

Within this study the influence of different parameters like occupant size, sitting / standing position, vehicle stiffness and restraint systems for different bus types like M2, M3 and city bus were evaluated.

**Delivery N°12: Task 3.1: Numerical test methods**

Different new approaches for the type of testing were analysed. Studies were performed on changing the structural moment of inertia, the falling height for R66 testing, the inclination of the impact surface and the numbers of jointed bay sections.

**Delivery N°13 (Milestone 6): Task 3.3: Full-scale test methods**

Main achievements within this task was the proof of the influence of the belted occupants on the structural deformation. That fact must be taken into account for future bus designs because of the use of seat belts.

**Delivery N°14: Task 3.6: Occupant size influence on all type of test procedures**

The new proposed test procedures were taken for a variation simulation with different occupant types like male, female or child. The different behaviour were pointed out and demonstrated by means of diagrams and videos.
**Delivery N°15: Task 3.5: Cost benefit analysis for different test methods**

Using the procedures of the new proposed test methods an analysis was performed to compare the testing costs with the caused social cost. Main result was the positive balance for the improved tests.

**Delivery N°16: Task 4.1: Suggestions for new regulations and written standards**

Based on the results gained within WP1 to WP 3 a list of recommendations and suggestions was written which refer to current regulations and directives on rollover and frontal impact issues. In addition a further chapter on general remarks was proposed.

**Delivery N°16: Task 4.2: Mathematical models of improved bus design**

The models created within this task contain improvements taken from the WP 3 results and represent the basis for additional research.

**Milestone 7: Task 5.2: Exploitations**

The final review will summarise all the performed work and will list the main results. This work is still in progress and will be finalised within the next weeks.

All initially planned deliverables and milestones were worked out and put into action. Therefore no deviations from the proposal occurred and the performance of the project was achieved well.
5 MANAGEMENT AND CO-ORDINATION ASPECTS

5.1 General performance

The consortium, which represented all individual partners was always in close contact and performed the work on ECBOS on a task by task basis. This means that the WP-leader was mainly responsible for the work within the workpackage, whereas the task-leader co-ordinated the work within the tasks. Depending on the task involvement of the individual partners common and bi-lateral meetings were carried out to discuss general project matters and also specific items.

Each project meeting was summarised by written minutes which included a detailed action list for the future project period. The action list contained all actions, dates and responsibilities. This list always got checked at the next meeting. All information from the individual partners which was important for the whole group was circulated by the project co-ordinator.

Beside the Kick Off, MidTerm and Final meeting a further 15 consortium meetings have taken place over the project term.

From the co-ordinators point of view, the project has been finalised well in accordance with the proposal and all planned deliverables and milestones have been produced. Further material, especially for dissemination purposes (e.g. posters, leaflets, INFO CDs) were made and handed out.

Finally it can be said that the cooperation with the project consortium was excellent and that the gained results of the ECBOS project will have important influence in current and future definitions of safety regulations and directives.
### 5.2 Updated Contact List

<table>
<thead>
<tr>
<th>Cranfield Impact Centre Ltd.</th>
<th>CIC</th>
</tr>
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<td>e-mail: <a href="mailto:j.c.anderson@cranfield.ac.uk">j.c.anderson@cranfield.ac.uk</a></td>
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<tr>
<th>Gesamtverband der Deutschen Versicherungswirtschaft</th>
<th>GDV</th>
</tr>
</thead>
<tbody>
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<td>Mr. Johann Gwehenberger</td>
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<td>Germany</td>
<td>e-mail: <a href="mailto:j.gwehenberger@gdv.org">j.gwehenberger@gdv.org</a></td>
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<table>
<thead>
<tr>
<th>Loughborough University</th>
<th>VSRC-Loughborough</th>
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<tbody>
<tr>
<td>Mrs. Rachel Grant</td>
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<td>e-mail: <a href="mailto:R.H.Grant@lboro.ac.uk">R.H.Grant@lboro.ac.uk</a></td>
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<tr>
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<th>Polito</th>
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<tbody>
<tr>
<td>Mr. Giovanni Belingardi</td>
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6 RESULTS AND CONCLUSIONS

6.1 General

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.
6.2 Suggestions for new regulations and written standards

From the research carried out during this study (analysis of real world accidents, component tests, numerical simulations of vehicle structure and occupant behaviour) a list of suggestions for new regulations and written standards has been drawn up. Following headlines summarise the proposed issues:

Recommendations about Rollover

1. Use of seat belts strongly recommended
2. Mass of occupants has to be considered for calculation and testing
3. M2 buses included in the rollover test
4. Child safety (adaptation of the restraint system)
5. Pendulum test should be deleted

Recommendations about Frontal / Rear End Impact

1. Use of a3-point belt system is recommended
2. Combination test for seats
3. Rigid platform is necessary for seat testing
4. Crash pulse for M2 vehicles
5. Child safety (adaptation of the restraint system)

Recommendations about New Regulations

1. Research for driver / co-driver frontal impact safety
2. Compatibility between bus/coach and other vehicles
3. Double-deck coaches (superstructure resistance)
4. Harmonised accident database
5. Guidelines for using Numerical Techniques
6. Partial ejection out of the bus (side window / windscreen) should be avoided
7. Contact load with side (window or structure) should be as low as possible
8. Development of a rollover dummy is necessary to predict injury criteria
9. Further research on driver’s impact on accident avoidance
10. Further research on possibilities for general rating of the passive safety
6.2.1 Addressed Regulations and Directives

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

The table below showed the actual European Directives and Regulations that can be affected by the recommendations made from the research done inside this study.

<table>
<thead>
<tr>
<th>European Directive</th>
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<tr>
<td>Obligatory use of eat belts</td>
<td>91/671 – 2003/20/EC</td>
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<td>Seat belts anchorages</td>
<td>76/115 – 96/38/EC</td>
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<td>Seats, seat’s anchorages and head restraint</td>
<td>74/408 – 96/37/EC</td>
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<td>Safety belts and restrain systems</td>
<td>77/541 – 2000/3/EC</td>
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<tr>
<td>General construction of large passenger vehicles</td>
<td>2001/85/EC</td>
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<tr>
<td>&gt; 22 + 1</td>
<td>36 R03</td>
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<tr>
<td>&lt; 22 + 1</td>
<td>52 R01</td>
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<tr>
<td>Double-deck</td>
<td>107 R00</td>
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<td>Rollover resistance</td>
<td>66 R00</td>
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A brief abstract of the principal items in each regulation that affect to buses and/or coaches and that can be related to the list of recommendations:
**Directive 91/671-2003/20/EC:** All the passengers older than three years must be belted when they are seated in the vehicles of category M2 and M3. All the passengers must be informed of that obligation (by the driver, the guide, audiovisuals methods or pictograms).

**Directive 76/115-96/38/EC and Regulation 14R05:** The scope is the seat belts anchorages for seats in frontal or rear position for vehicles of category M and N, except for vehicles of category M2 and M3 conceived as urban or to transport stand passengers. It is indicated: the minimum number of seat belts anchorages, the location of the effective anchorages and the tests depending on the type of belt (simulating a frontal impact). The seats must be tested mounted on the vehicle (or a test structure representative of the vehicle).

**Directive 74/408-96/37/EC and Regulation 80R01:** The scope of the Directive are all the seats for vehicles of category M and N, except for vehicles of category M2 and M3 conceived as urban or to transport stand passengers. The Regulation is for M2 and M3, except for those conceived as urban or to transport stand passengers. The seats and their anchorages (in frontal position) must be tested to determine if the passengers are conveniently restrained by the frontal seat and/or the seat belts. When the tests to admit the seat belts anchorages have been made (14R05 or 96/38/EC), the seat’s anchorages are accepted. The seats can be tested independently from the vehicle. It can be chosen between static or dynamic tests. For seats to be installed in M2 vehicles, the Directive permits to choose between the requirements for M1 or for M3. There are some items opened in those standards: Development of seat strength requirements specific to M2 vehicles, based on experience and accident research. Performance of seats subjected to the combined loading of a restrained occupant and an unrestrained passenger behind. The inclusion of the neck injury, as a performance criterion, based on the use of the Hybrid III dummy. It is needed a research programme to work on a new static test method that obtains the same security level as in the dynamic ones.
Directive 77/541-2000/3/EC and Regulation 16R04: The scope is the seat belts and restrains systems to be installed in vehicles of category M and N and to be used individually for adults. The requirements for the belts, buckles, retractors, devices to pre-stress, installation and type of belt are included.

Directive 2001/85/EC and Regulations 36R03, 52R01, 107R00: The Regulations 36, 52 and 107 includes the requirements about the general characteristics of construction. The scope for Regulation 36 is the vehicles of category M2 and M3 with more than 22 passengers plus driver, for Regulation 52 is the vehicles of category M2 and M3 until 22 passengers plus driver and for Regulation 107 is the double deck vehicles of category M2 and M3 with more than 22 passengers plus driver. The requirements include: mass distribution and load conditions, area for passengers, number of seated or stand passengers, fire protection, exits, inner conditioning, lights, manoeuvring capability and so on. The Regulation 52 includes requirements about the superstructure: it must bear a static load on the roof. The Regulation 107 includes a tilt test. The Directive 2001/85/EC includes all the requirements for vehicles with more than 8 passengers plus driver, including the general construction requirements (not exactly the same as in the Regulations) and the mechanical resistance. In the Directive the tilt test is mandatory for all the vehicles of category M2 and M3, the requirements for the accessibility of passengers with reduced mobility are included and the static load on the roof for vehicles until 22 passengers plus driver is not included.

Directive 2001/85/EC and Regulation 66R00: The 66 Regulation establish the requirements concerning to the mechanical resistance of the superstructure subjected to rollover. The scope are one deck vehicles to transport 16 passengers (stand or seated) plus driver and crew. It can be chosen between a full vehicle rollover test, a representative bay section rollover test, calculation methods or a pendulum test. The Directive includes the same requirements but the scope is one deck vehicles to transport 22 passengers (vehicles of class II and III).
6.2.2 Suggestions 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.

ABOUT 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.

DIRECTIVES THAT CAN BE AFFECTED:
REGULATIONS THAT CAN BE AFFECTED:
Regulation 14R05, Regulation 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 passengers 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.

DIRECTIVES THAT CAN BE AFFECTED:
Directive 2001/85/EC

REGULATIONS THAT CAN BE AFFECTED:
Regulation 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.

DIRECTIVES THAT CAN BE AFFECTED:
Directive 2001/85/EC

REGULATIONS THAT CAN BE AFFECTED:
Regulation 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.

**DIRECTIVES THAT CAN BE AFFECTED:**
- Directive 2001/85/EC

**REGULATIONS THAT CAN BE AFFECTED:**
- Regulation 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.

**DIRECTIVES THAT CAN BE AFFECTED:**
- Directive 2001/85/EC

**REGULATIONS THAT CAN BE AFFECTED:**
- Regulation 66R00
ABOUT 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.

DIRECTIVES THAT CAN BE AFFECTED:
REGULATIONS THAT CAN BE AFFECTED:
Regulation 14R05, Regulation 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.

DIRECTIVES THAT CAN BE AFFECTED:
Directive 96/38/EC
REGULATIONS THAT CAN BE AFFECTED:
Regulation 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.

**DIRECTIVES THAT CAN BE AFFECTED:**
- Directive 96/37/EC

**REGULATIONS THAT CAN BE AFFECTED:**
- Regulation 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.

**DIRECTIVES THAT CAN BE AFFECTED:**

**REGULATIONS THAT CAN BE AFFECTED:**
- Regulation 80R01, Regulation 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.

DIRECTIVES THAT CAN BE AFFECTED:
REGULATIONS THAT CAN BE AFFECTED:
  Regulation 80R01, Regulation 16 R04

ABOUT 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.
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