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ECBOS

Summary Report

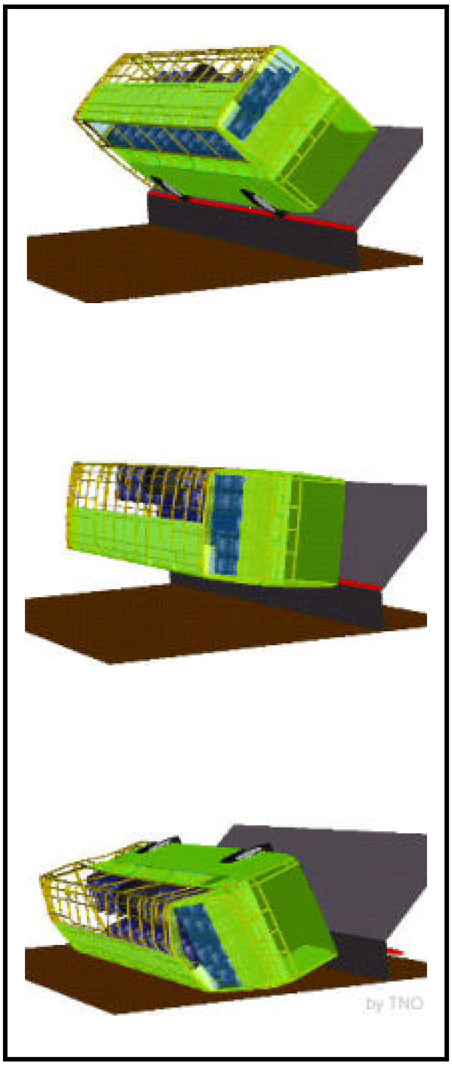
Enhanced

Coach and

Bus

Occupant

Safety



European Commission
5th Framework

COMPETITIVE AND
SUSTAINABLE GROWTH

Project N°: 1999-RD.11130

ECBOS

Project N°: 1999-RD.11130

Starting Date: January 1st 2000
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Title: ECBOS – Enhanced Coach and Bus Occupant Safety

PROJECT CO-ORDINATOR:

- *Technical University Graz*

PROJECT CONTRACTORS:

- *Cranfield Impact Centre*
- *Gesamtverband der Deutschen Versicherungswirtschaft*
- *Loughborough University*
- *Politecnico di Torino*
- *Technical University Graz*
- *TNO Automotive*
- *Universidad Politecnica de Madrid - INSIA*

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FINAL PUBLISHABLE REPORT

Workpackage 1

Task 1.1 – Statistical Collection Overview

Undertaken on behalf of

DG TREN

Executive Summary

This document takes an overall view of the data that has been collected in Task 1.1. 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.

This 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, around 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, these are 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.

Overview of Bus and Coach Accidents in Eight European Countries

1 Introduction

1.1 Task 1.1 Report Structure

This document takes an overall view of the data that has been collected in Task 1.1. 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.
These individual documents have been compiled so that a common format runs throughout. Therefore up to header level 2 all reports have the same sections. This has been done to enable the reader to quickly find comparable sets of data between different countries. This overview document uses the same section headings for the same reason.

1.1.1 Overview Report

Due to the difficulties in collecting the same information across all eight countries this document will look at the data presented by different countries and both present figures and make comments on overall trends in the data. For many of the analyses it is impossible or limiting to try and draw graphs when the strict data definitions vary so much. This is particularly evident when trying to describe the types of accident that occur. In such cases the essence of the data from each country will be used.

1.1.2 Analysis from each Country

Most of the tables in the eight documents have a column for number of vehicles (buses and coaches) and then information on numbers of casualties. This is done to try and give a measure of risk when that circumstance of accident occurs to the vehicle. Some countries give this number as the number of vehicles in the accident whilst others have just given the number of buses and coaches, which is more appropriate. Due to the potential numbers of occupants in a bus or coach it is very important to have as high a number of vehicles as possible. For example there might be 100 casualties in impact type 1 and 100 in impact type 2. In type 1 there are 20 fatalities and in type 2, 20 fatalities. If in impact type 1 we have 5 vehicles and in type 2, 20 vehicles involved then it is important to know this. Of course the ideal would be to have data on the numbers of uninjured occupants, but this is only possible in Spain.

1.2 Special Considerations

Work which uses international comparison is extremely useful but must also be used with great care. This is due to national differences in the collection, processing and analysis of data.

1.2.1 Data Collection – Sampling

The most important point to bear in mind throughout this document is the way in which data are collected in different countries. At the most simple level data is always collected according to a sampling plan. Generally at the first level this is based on injury severity. For example, the National Data from Great Britain is collected for all road users that have any injury from a road traffic incident on a public highway that requires medical treatment. The national data for the Netherlands is sampled so that 100% of the fatal accidents are included but 60% with a hospitalised person involved and about 5% of property damage only accidents. This should obviously be borne in mind when comparing any data between the two countries.

Even though it is at the moment impossible to quantify such things it is also generally thought that different levels of recording will take place in different countries. This is evident when comparing overall numbers of reported bus and coach casualties (See Figure 2).

1.2.2 Data Collection - Data Field Definitions

At the next level there are differences in the data definitions that are used. The most obvious example is again injury severity, for which there are differences between classification at all injury levels (fatal, serious and slight). For example, most countries here measure fatalities at 30 days, except for Italy at 7 days, France at 6 days and Spain at 24 hours. Where possible the internationally recognised weighting factors have been used to give measures of fatalities at 30 days. It is important to note that these weighing factors can only be used for analysis of fatalities. Any analysis that includes serious and slight injuries does not have this weighting factor applied, as it is uncertain what effect this has on serious injuries. Weighting factors are not available for the different definitions of serious and slight injuries.

At the risk of repeating information from the individual country documents it is important to summarise the main sampling and injury definition differences between the countries and this has been done in Table 1.

Table 1:	Austria	France	Germany	Great Britain	Italy	Netherlands	Spain	Sweden
Sampling	All injured bus or coach occupants.	All injured bus or coach occupants.	BASt: only injured bus or coach occupants. StBA: all injured people involved in bus accident.	All injured bus or coach occupants.	All injured bus or coach occupants	100% Fatalities, 60% of those hospitalised.	At least one bus and one injured road user involved.	For SNRA injury assessed by police officer at scene.
Fatal (Time after accident in which a death is recorded as a fatality)	30 days.	Less than 6 days (weighting factor to 30 days 1.057).	30 days.	30 days.	Less than 7 days (weighting factor to 30 days 1.08).	30 days.	24 hours after accident (no weighting factor available).	30 days.
Serious	More than 3 days in hospital or a discontinuation of normal business for more than 24 days.	More than 6 days in hospital.	All persons who were immediately taken to hospital for inpatient treatment (of at least 24 hours).	Hospital in-patient.	Only other severity is that an injury has occurred.	Admitted to hospital as an in-patient.	More than 24 hours in hospital.	Any injury that requires the person to be admitted to hospital.
Slight	Less than three days hospitalised.	Less than 6 days in hospital.	All other injured persons.	Receive or appear to need medical treatment.		Injured but not transferred to the hospital as an in-patient.	Less than 24 hours in hospital.	Minor or slight injury should not require admission of the patient to hospital.
Unknown Injury	Yes	No	No	No	No	Yes	Yes	No
Vehicles	M2 and M3.	Buses and coaches.	M2 and M3 vehicles with 9 or more seats.	M2 and M3 (but all over 16 passenger seats).	Buses and Coaches over 8 seats.	M2 and M3.		Vehicles registered to carry more than eight passengers.
Area Covered	All of Austria.	All of France.	Federal Republic of Germany.	Great Britain (not Northern Ireland)	All of Italy.	All of the Netherlands.	All of Spain.	All of Sweden.

1.3 Accuracy of information

A great deal of the data gathered for this project is from police records. This data is extremely valuable in giving the most complete information possible for whole populations. Problems do arise though in the accuracy of the information, especially when injuries are concerned. There is also the likelihood that if an injury is less severe the possibility of under-reporting of that injury is more likely to occur.

1.4 Data Used

Throughout the report the data analysed is for a five year period, 1994 to 1998, the only exception being Italy where 3 or 4 years of data are used. To enable inclusion of Italian data the figures have therefore been multiplied to reflect 5 years. A five year period has been used to maximise the data available, as some countries have a much smaller casualty population than others and trends will be shown more clearly.

Also when analysing data from different European countries it is generally agreed that the best figures to use are those for fatalities, as all these accidents are investigated and will probably be recorded well. It is therefore important to maximise the fatality numbers for analysis as much as possible.

Unfortunately it is difficult to gauge the change in the types of vehicles on the roads during that time and overall casualty figures have reduced in that time in Austria, France, Germany and Great Britain. However, due to the cost of operating and purchasing, the bus and coach fleet includes some very old vehicles and the proportion of old to new vehicles may vary between countries. Thus injury causation factors which may be considered to be associated with very old designs may still be reflected in the accident figures.

1.5 Current International Work

At the moment there are a number of long term projects in Europe that are concentrating on improving data collection methods in member countries.

1.6 Vehicles in the Study

This study looks at buses, coaches, city buses, and minibuses with all vehicles having more than 8 seats. These are M2 or M3 vehicles.

It was intended to look at these vehicle types separately in the study but this was not possible across all countries. This is unfortunate as we would expect to see differences in accident circumstances and levels of injury.

2 National Accident Overview

2.1 Comparison of All Road Users with Bus and Coach and Passenger Cars Occupants

The figures presented in this section give an indication of the relative importance of bus and coach accidents within each country involved in the study. In all figures the information is presented with the countries in alphabetical order.

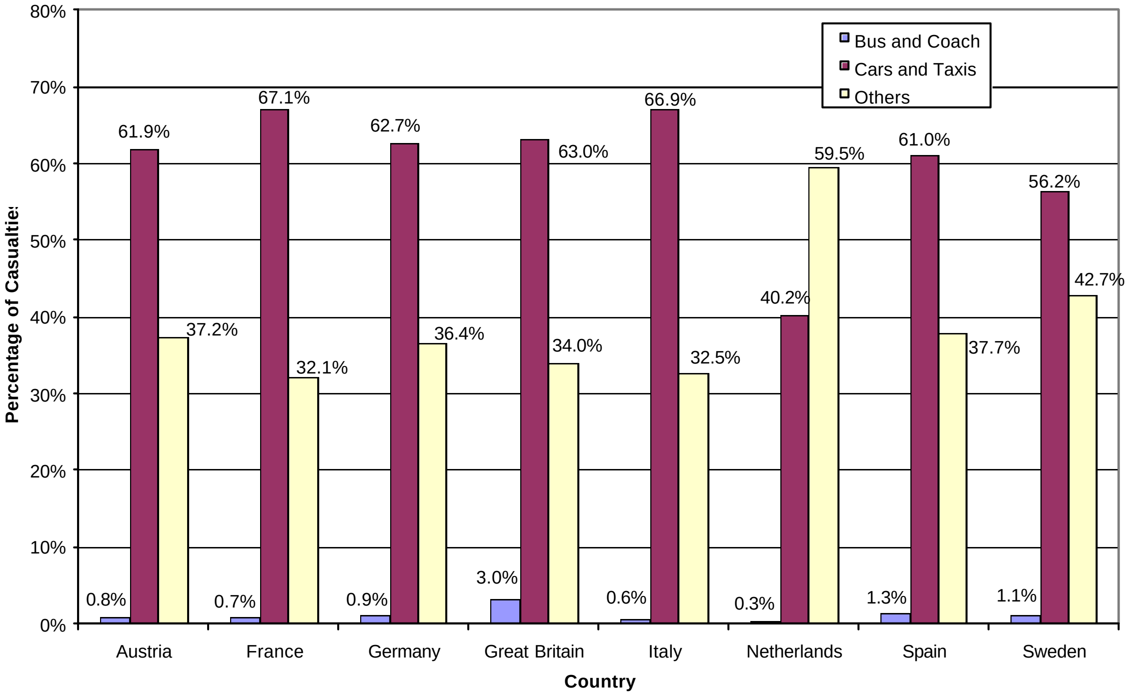


Figure 1: All Casualties

NB: For Spain the figures given are just for casualties. In the data supplied there are also figures for uninjured occupants, these have been removed. No fatality weighing factors are used for France, Italy or Spain in the above figure as the effect on serious casualties is uncertain.

All countries have lower numbers of bus and coach casualties for all injury categories than passenger car casualties and other road users. This may be due to a number of factors, a mixture of less bus and coach accidents, less risk of an injury when they occur (as has been borne out in the separate reports) and people travelling less distance on buses and coaches, especially compared to passenger cars.

This type of analysis will be sensitive to different levels of reporting within countries for different forms of transport. For instance, in Great Britain the level of reporting is high at all injury levels for buses and coaches, due to the responsibility of the driver in a commercial venture. There is also a legal obligation to report incidents to the Vehicle Inspectorate. This has been demonstrated by the monitoring of police telexes in the Nottinghamshire and Leicestershire areas of Great Britain during February to October 2000.

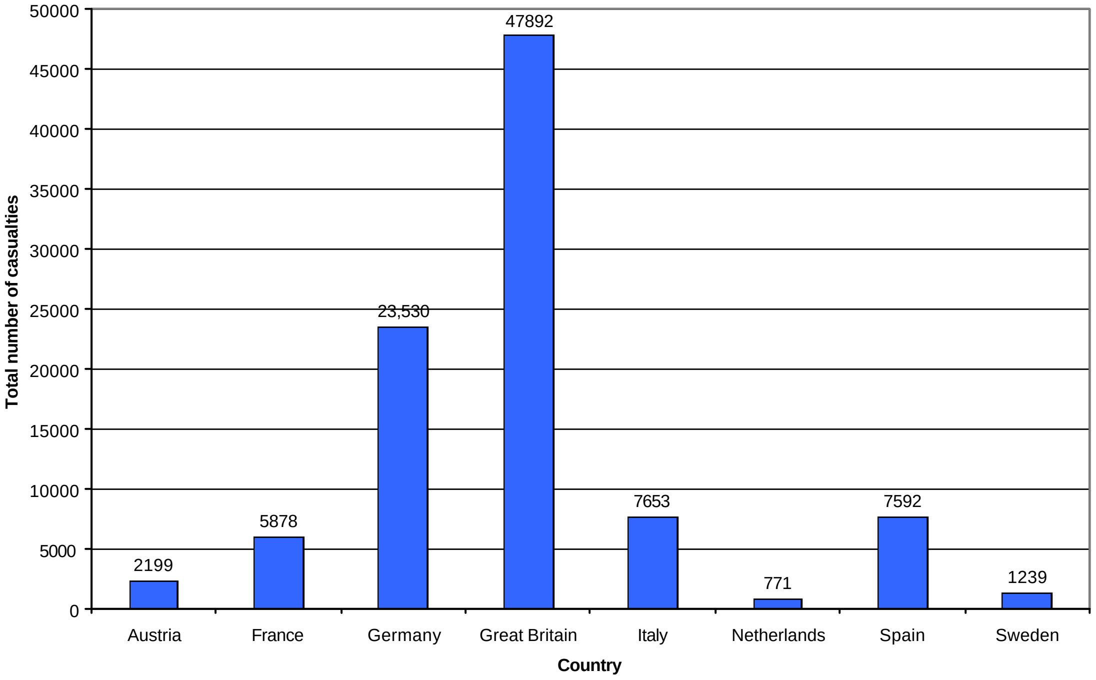


Figure 2: Number of Casualties in the Study

NB: To enable simple comparison over 5 years here the 3 year figures for Italy have been multiplied to reflect 5 years.

Figure 2 gives the overall numbers of casualties in buses and coaches that partners have presented to the study for analysis, for 1994 to 1998 (except for Italy where the figures have been adjusted for comparison). Here we see that the reported number of casualties in Great Britain is far greater than for any other country, especially France and Germany which have larger populations. A high level of commercial reporting is likely to contribute to this and in Great Britain casualties boarding or alighting the vehicle are also included, which may not be the case in other countries' police reporting systems. The explanation of the large differences in numbers evident in these types of comparison is a significant part of current and future European data harmonisation studies.

The same analysis is repeated just for fatalities. The use of fatality data is thought to be the most reliable method of international comparison. Fatal accidents are investigated fully and the information should therefore be recorded well.

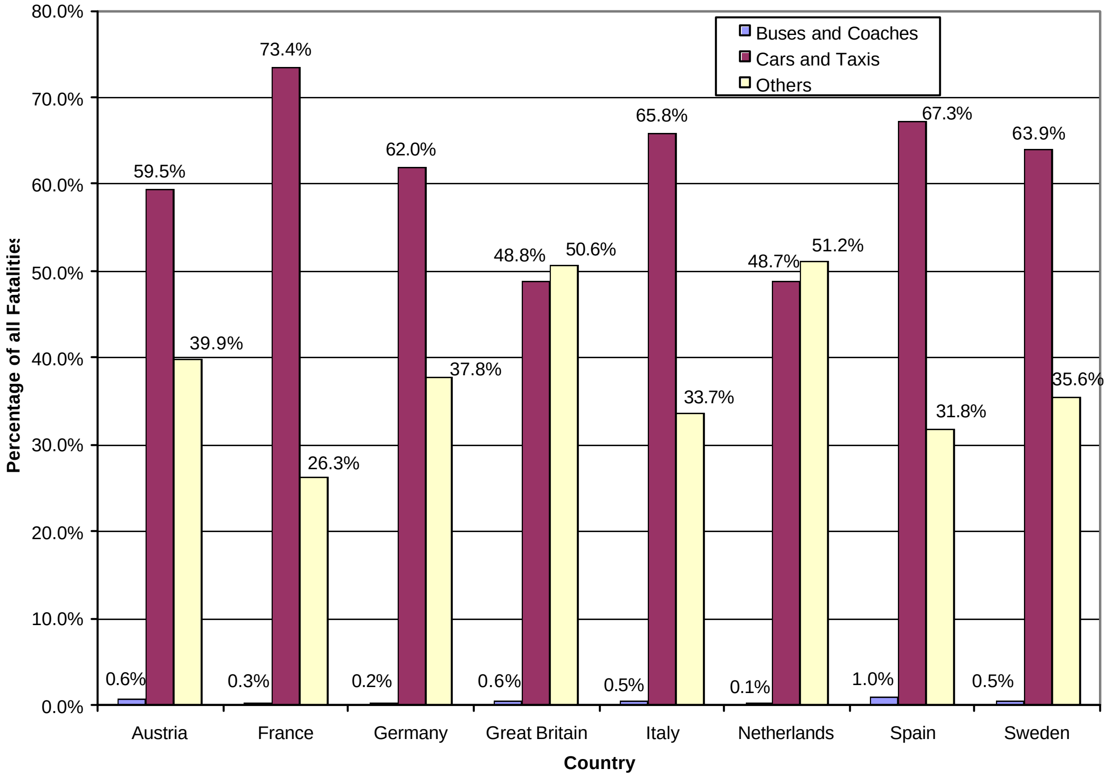


Figure 3: Fatalities

Compared to Figure 1 for all injuries, this figure shows that bus and coach casualties make up an even smaller proportion of the national fatality population than they do of the 'all injury' national population.

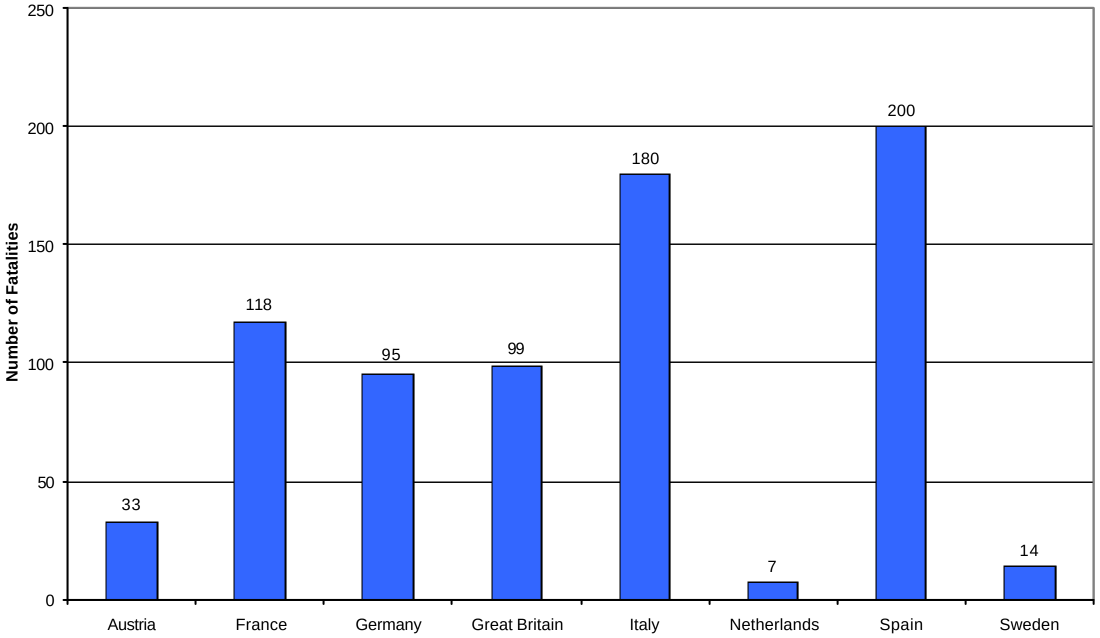


Figure 4: Numbers of Bus and Coach Occupant Fatalities in the Study

NB: Correction factors have been used for France and Italy to give a 30 day measure, but not for Spain. Only 3 years of Italian data has been made available so here the number has been multiplied to reflect 5 years, to enable simple comparison in this figure.

Considering the fatality definition of 24 hours it is important to note the high number of fatalities in Spain which, it is reasonable to assume, would be higher if the 30 day rule was used.

The similar numbers here for France, Germany and Great Britain are interesting as Great Britain has a much higher figure for all injury severities. This may indicate different national levels of reporting at lower injury severity.

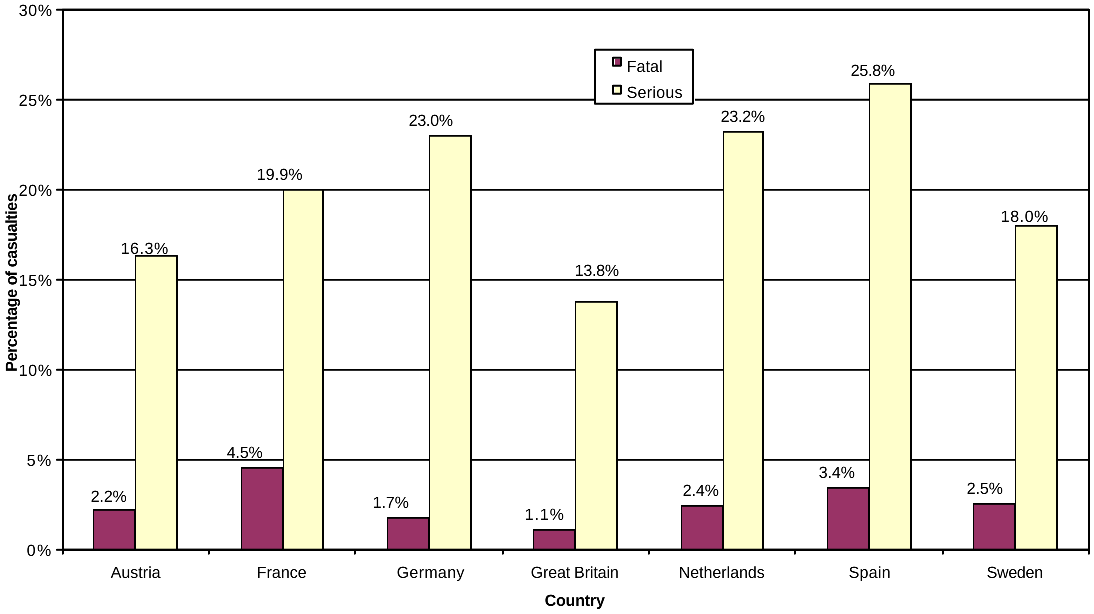


Figure 5: Injury Severity Distribution - All Road Users

NB: Unknown injuries are not shown for Austria, the Netherlands and Spain. Italy only has a serious and slight combined injury data field and has therefore not been included in this figure.

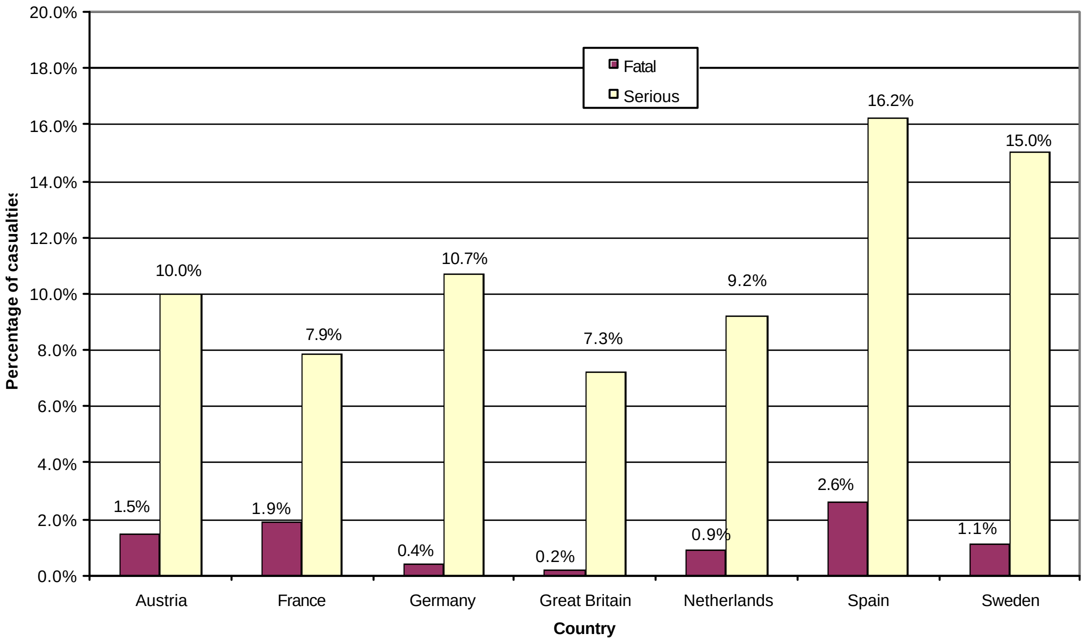


Figure 6: Injury Severity Distribution - Bus and Coach Casualties

This analysis shows very clearly the higher proportions of killed and seriously injured casualties when the whole road user casualty population is considered, compared to just bus and coach casualties. In all the countries shown, when a casualty occurs in a bus or coach the injury is likely to be less severe than for a general road user casualty.

Passenger Casualty Rates by Mode of Transport:

This table, published by the European Transport Safety Council, estimates how safe different forms of transport are within the EU, by fatality rates.

Table 2:

	EU Deaths per :	
	100 million person km	100 million hours
Motorcycle/ moped	16	500
Foot	7.5	30
Cycle	6.3	90
Road (total)	1.1	33
Car	0.8	30
Ferry	0.3	10.5
Air (public transport)	0.08	36.5
Bus and Coach	0.08	2
Rail	0.04	2

Ref 1: Priorities in EU Road Safety - Progress report and ranking of actions (2000) ETSC

These figures, which take exposure into account, show that bus and coach travel is estimated to be at least ten times safer than other forms of road transport and only rail travel is safer overall.

2.2 Bus and Coach Casualties by Year

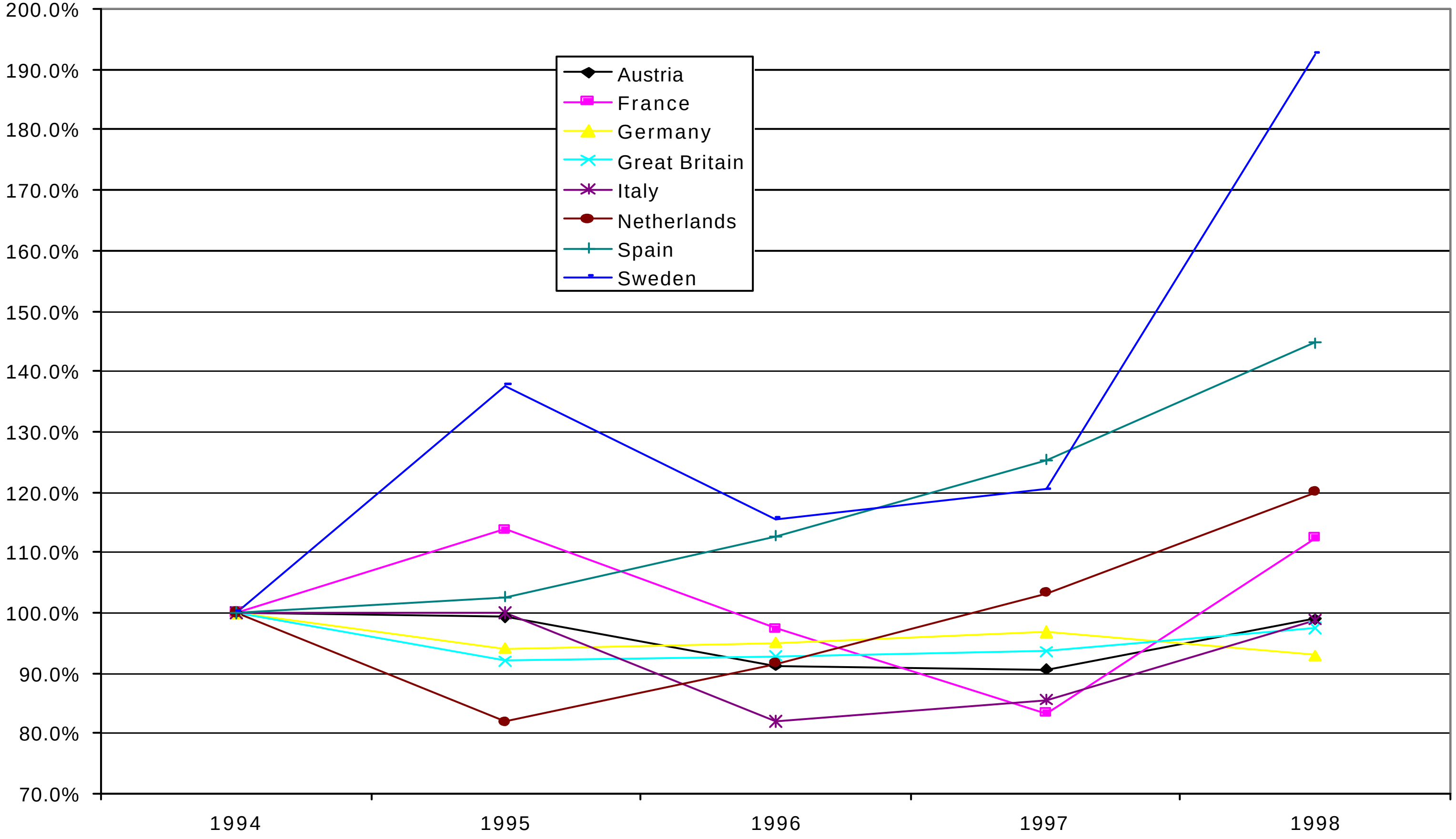


Figure 7: Change in Casualty Numbers During 1994 to 1998

Figure 7 gives the change in bus and coach casualty numbers, expressed as a percentage of the figure in 1994 (except for Italy, 1995).

Overall numbers of casualties have decreased slightly during this period in Austria, Germany, Great Britain and Italy. The casualty number has nearly doubled in Sweden over the five years.

For Austria, France and the Netherlands injuries reduced over the period to lowest points of 1996 for Austria, 1997 for France and 1995 for the Netherlands. All have increased however by 1998 to almost the same as in 1994 and higher than ever in the Netherlands.

2.3 Gender Distribution

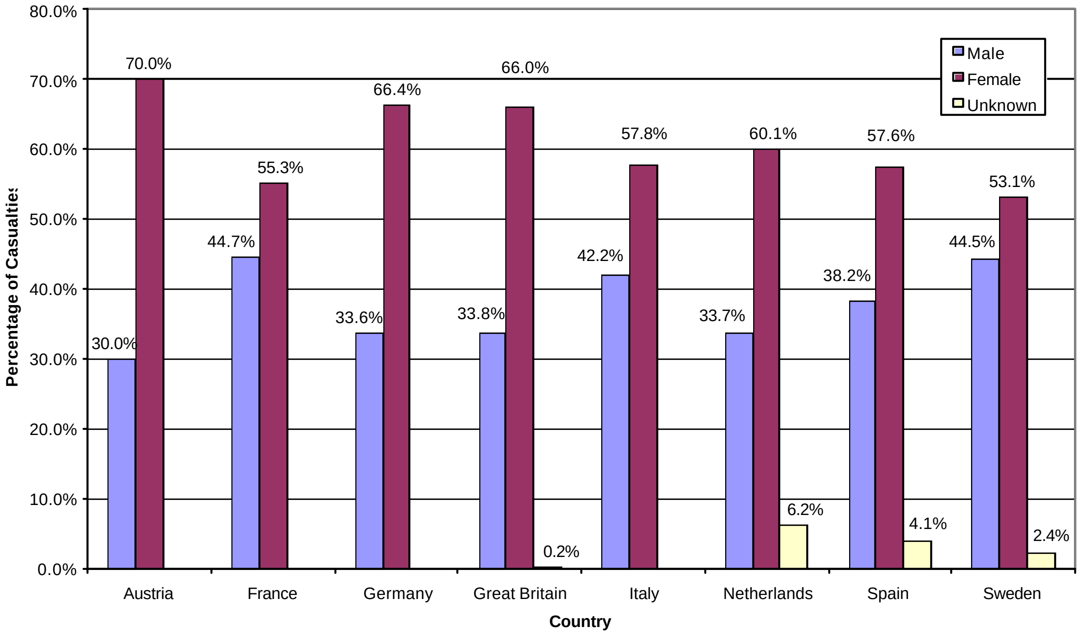


Figure 8: Gender Distribution for All Casualties

The pattern across the countries is very similar for all casualties, with the number of men injured always lower than the number of women. There is no known reason to suggest a sampling bias between sexes in any country.

A very simple reason for this trend could be that women travel more on buses and coaches than men. From transport statistics published by the British government it is clear that in Britain this is indeed the case. It is also generally accepted that women have a lower injury tolerance than men in most body areas, especially for older age where a higher degree of osteoporosis can be an important factor. (ref 2: In-car Safety and Personal Security Needs of Female Drivers and Passengers, Loughborough University 2000)

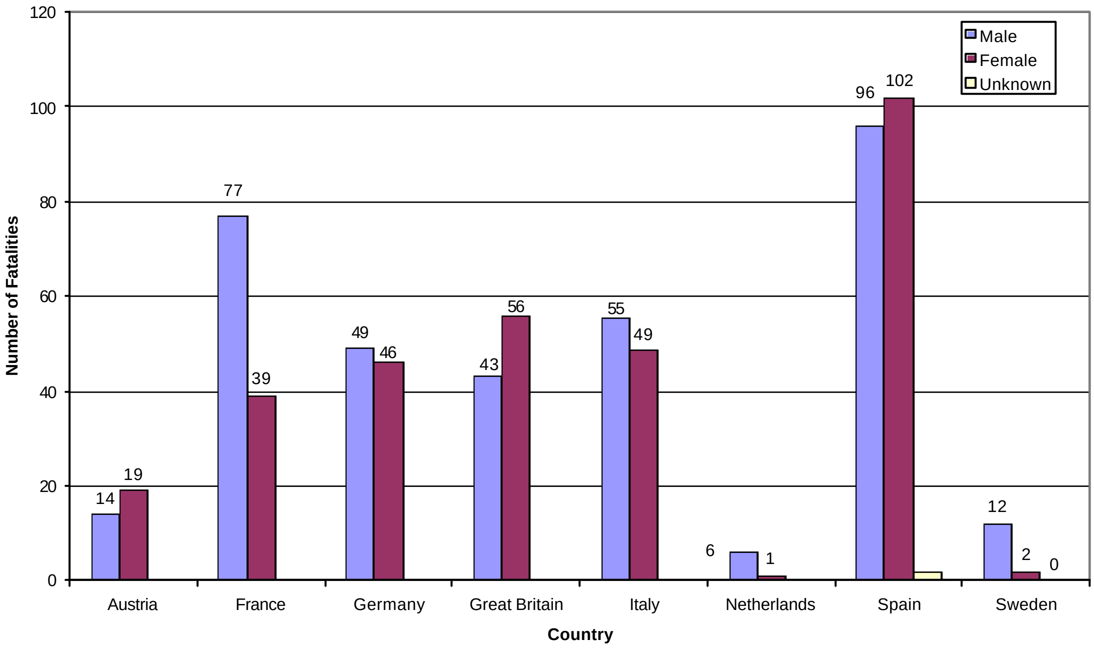


Figure 9: Gender Distribution for Fatalities

NB: France and Italy are weighted to 30 days, Spain is not.

Compared to all injuries, for fatalities there is much less of a distinct trend in gender across all countries.
During the five year period, women have many less fatal injuries than men in France and slightly less in Germany, Italy, the Netherlands and Sweden.
In the individual reports more female casualties with serious injuries are seen in Austria, Germany, Great Britain, the Netherlands, Spain and Sweden but less serious injuries than men are seen in France. Women have the highest number of casualties for each injury category in Great Britain and Austria.

The next figure shows the killed or seriously injured (KSI) rates for males and females within each country. It is clear that, when injured, males suffer a higher proportion of fatal and serious injuries than females in all represented countries, although the differences in Austria, Germany and Great Britain are small.

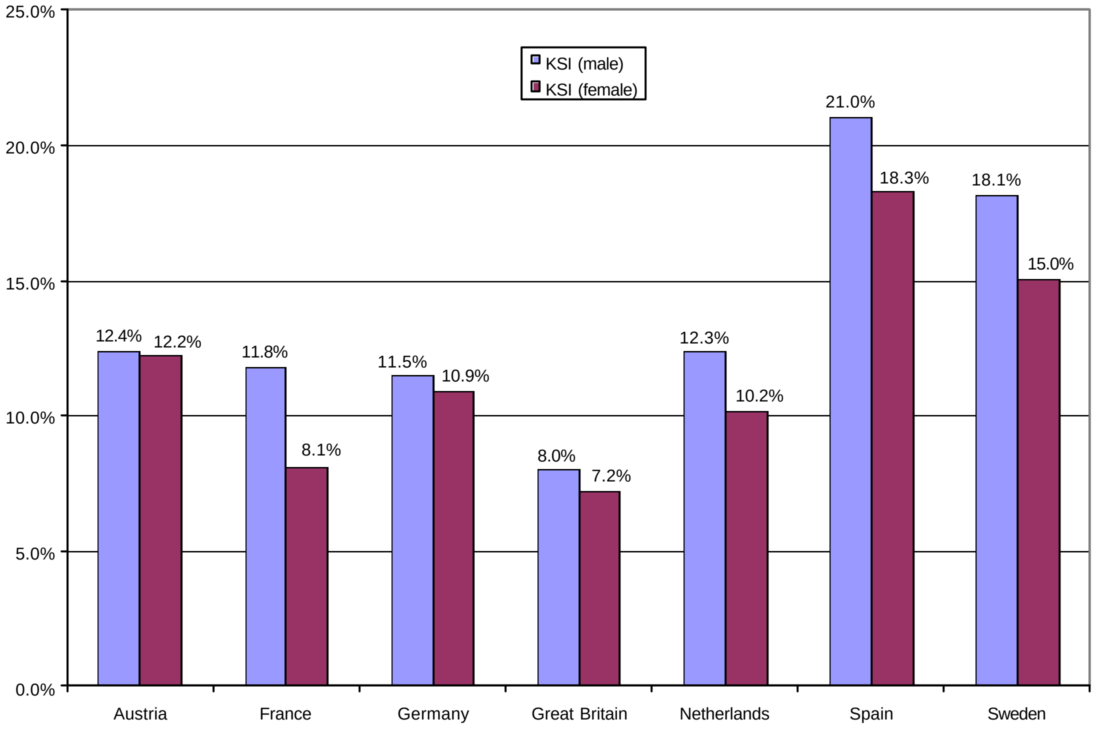


Figure 10: KSI rates by Gender

NB: Not possible for Italy as serious and slight injuries are together. Unknown injuries have been discarded for simplicity here, as the numbers are very low for the countries that have this injury category.

2.4 Numbers of Casualties Involved in Bus and Coach Accidents

With regard to the number of casualties known to be on each bus or coach there is information available for France (although just slight injuries are used), Great Britain, the Netherlands, Spain and Sweden (although there is no information from the national database so just Gothenburg (TIR) is used here). From Austria, Germany and Italy there is no information.

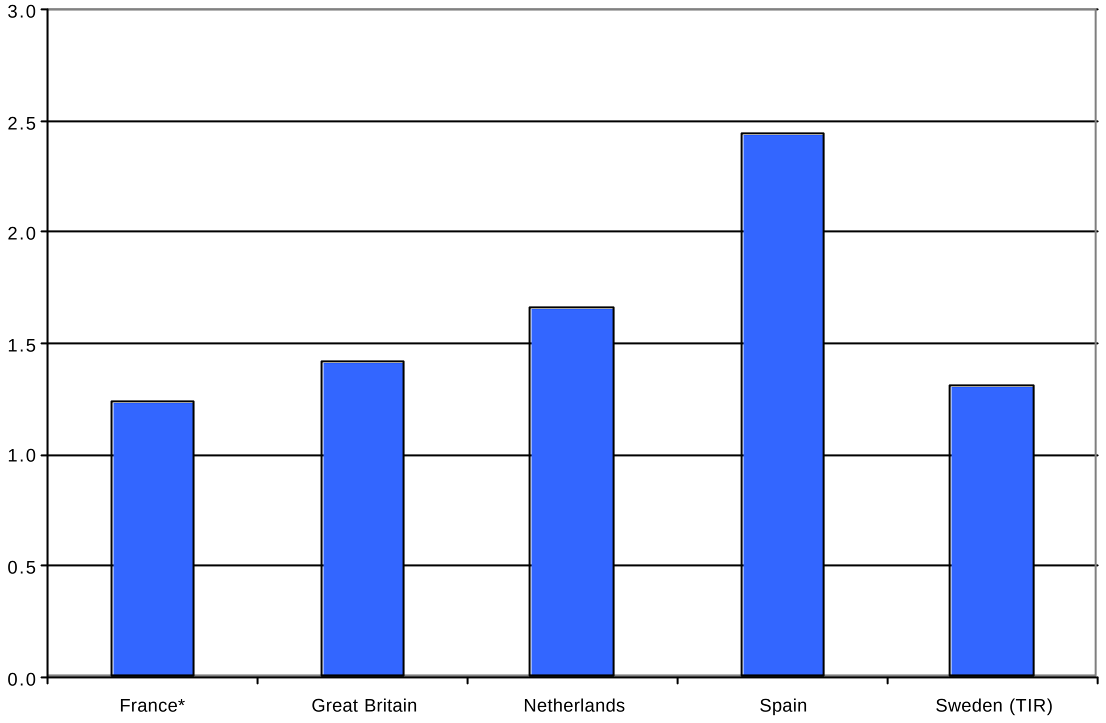


Figure 11: Average Number of Casualties per Bus or Coach

*France: just slight injuries.

The higher figure for Spain is borne out throughout this document.

3 Population Characteristics for Bus or Coach Casualties

Age Banding:

Figure 12, Age Distribution of All Casualties, is given overleaf.

Generally the Austrian, German and British data show a trend of peaks at school age and then a climb in the proportion of casualties that are elderly. Austria also has the highest proportion of 70+ casualties. The French data shows a high peak at school age but a decrease towards older age. In Spain the peak at school age is more difficult to observe and then there is a steady rise in the proportion of casualties towards older age. It is important to observe the larger proportion of casualties with unknown age in Spain.
Observing the data found in the individual reports:
In Sweden there is not such a large proportion of elderly casualties, but interestingly a much stronger representation of females than males.
In Italy there are a large number of casualties with unknown age which makes it very difficult to draw any conclusions.

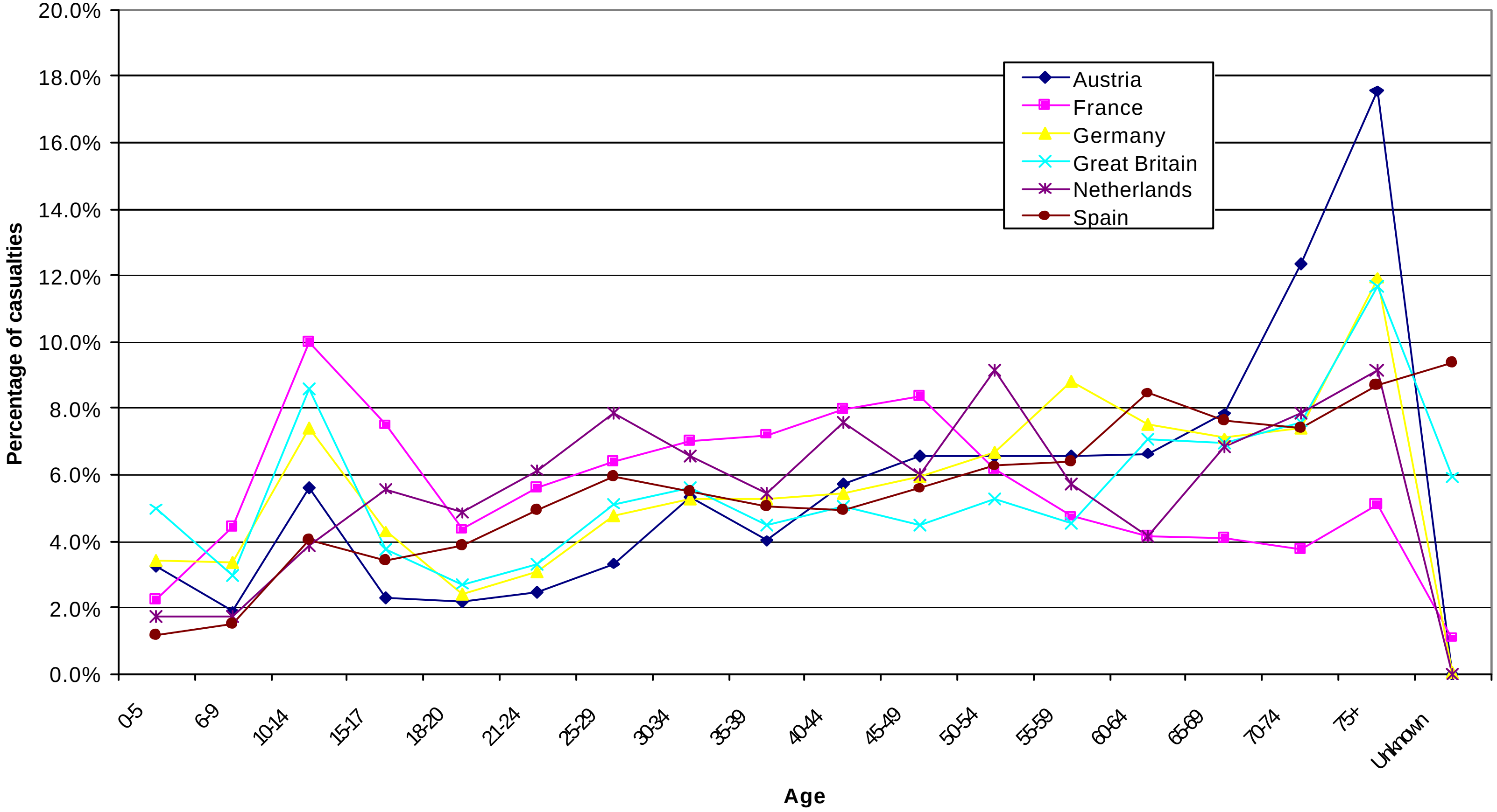


Figure 12: Age Distribution of All Casualties

NB: It is important to note that not all age bands are similar in size. It is difficult to include Italy and Sweden in the figure above due to the use of different age bands specified in the data collection.

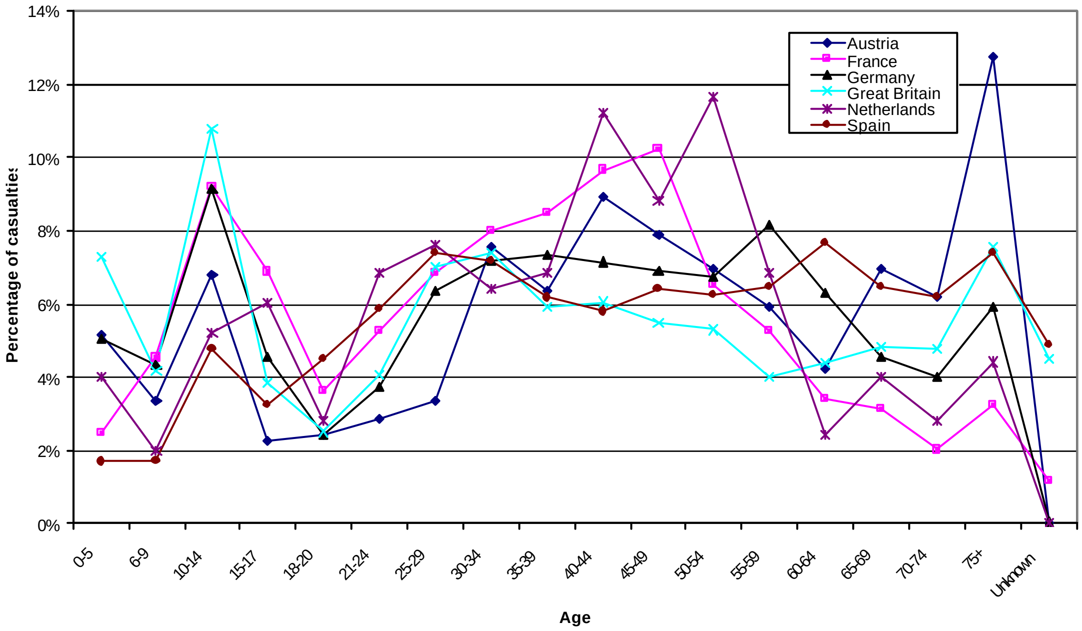


Figure 13: Age Distribution of Male Casualties

The ages for male casualties are generally more distributed than for females, as shown in the following figure. This is likely to be due to more drivers being male and their ages being more distributed than for passengers who are injured.

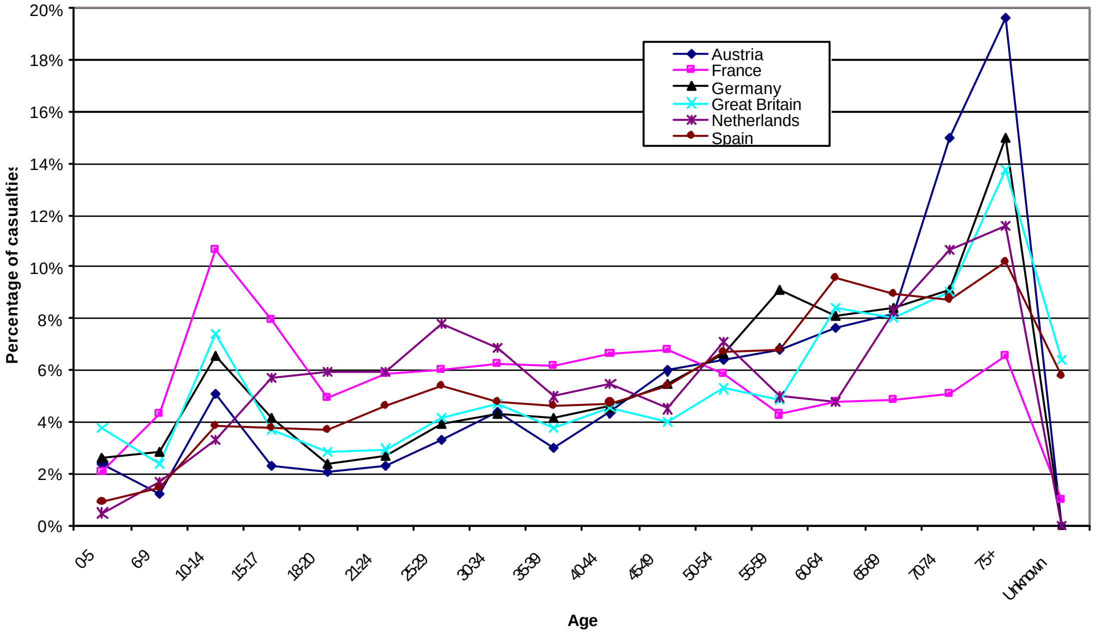


Figure 14: Age Distribution of Female Casualties

Austria, Germany, Great Britain and the Netherlands all have a similar distribution pattern with an increase in the proportion of elderly female casualties. This trend is only strong for males in Austria. In the Netherlands a familiar peak at school age is not apparent.

In Sweden the highest injury category for males is 15-24 but for females it is 45-54. Their younger age groups are more affected than their older groups, similar to France.

4 Injury Severity of Bus or Coach Occupants

4.1 Injury Severity by Occupant Position/Action

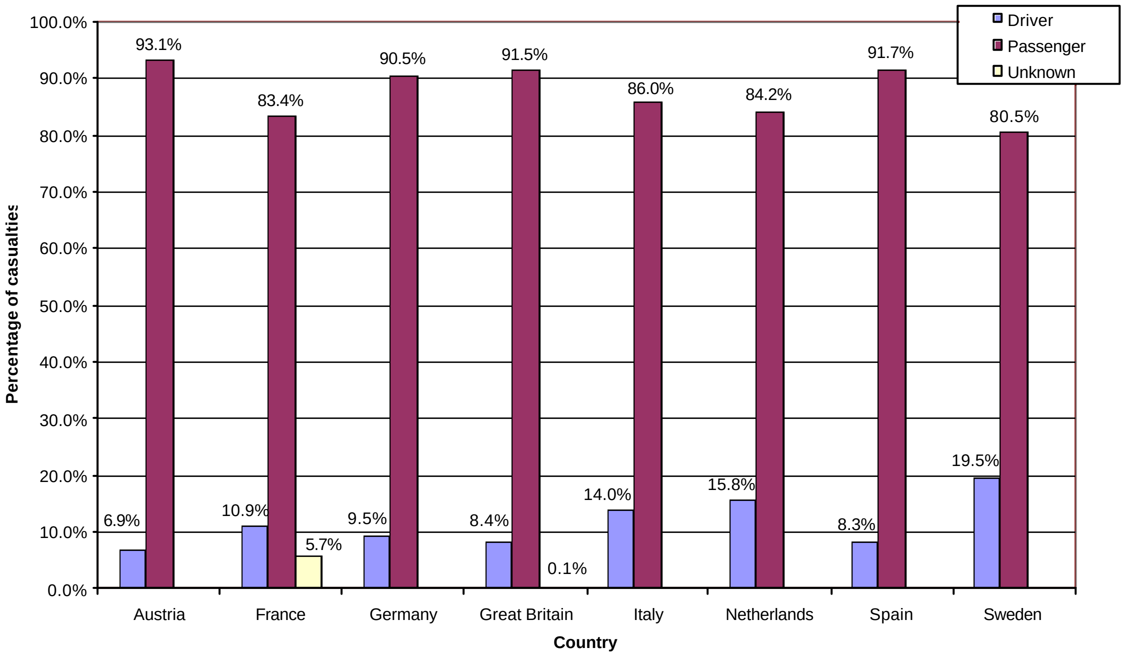


Figure 15: Distribution of Casualties between Drivers and Passengers

The figure above shows that across the eight countries there is a wide difference in the proportion of drivers to passengers injured, from 6.9% in Austria to 19.5% in Sweden.

As would be expected with only one driver on each vehicle, but possibly 50 or even more passengers, there are many more passenger casualties than driver casualties.

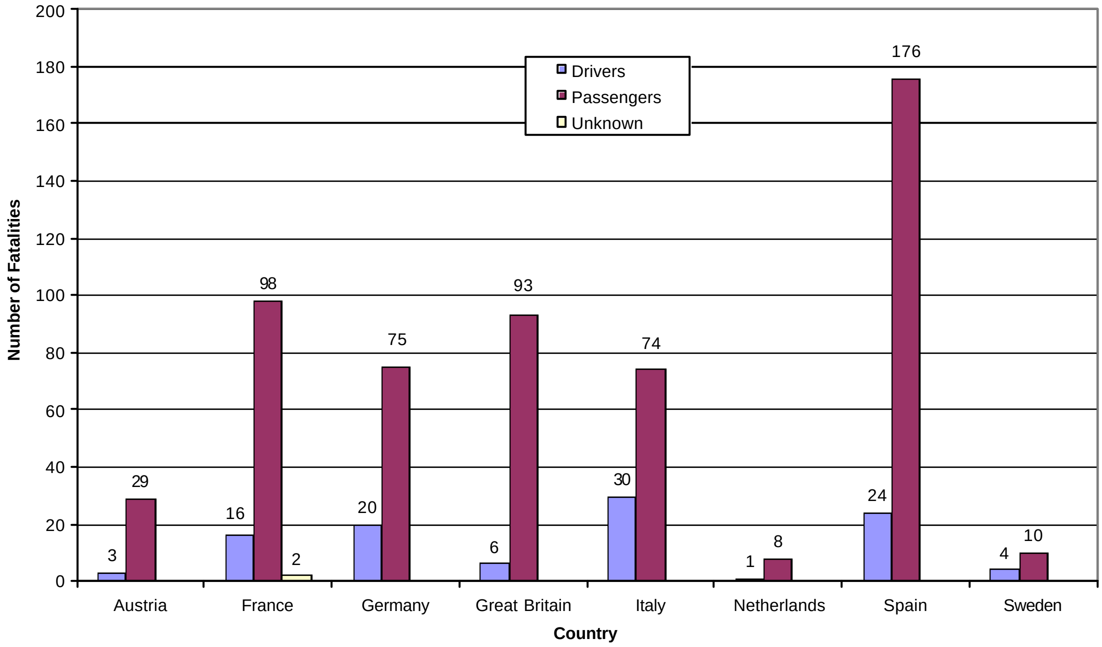


Figure 16: Distribution of Fatalities between Drivers and Passengers

NB: Fatality weighting factors have been used for France and Italy but not Spain. The four year figures for Italy have been multiplied to five years to enable simple comparison.

The figure above shows that many more passengers are killed than drivers in all countries. It is interesting to note the high numbers of drivers killed in Italy and Sweden compared to the number of passengers killed, although in Sweden the numbers are very low. Unfortunately it is not possible to see if this is reflected in the number of frontal accidents in Italy as this data is not available.

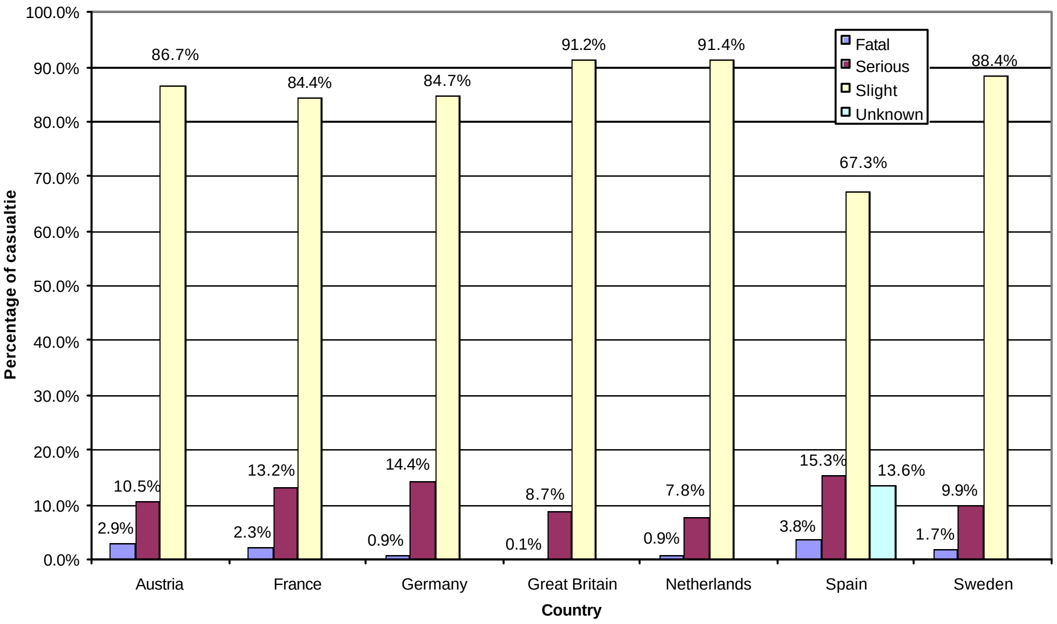


Figure 17: Distribution of Injury Severity for Drivers

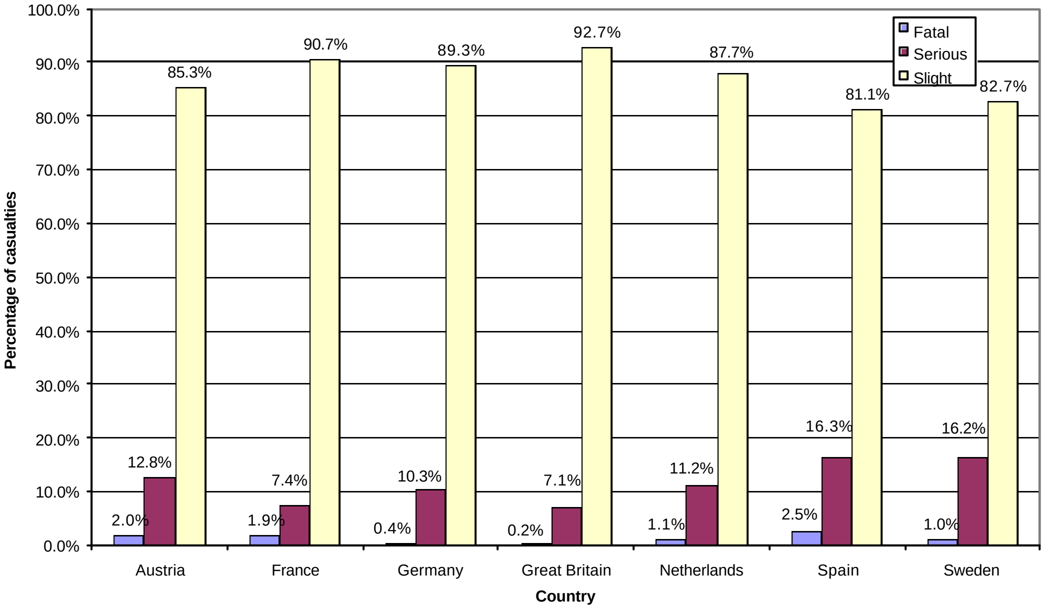


Figure 18: Distribution of Injury Severity for Passengers

In Austria there is a slight increase in the proportion of passenger to driver casualties suffering a fatal or serious injury, with a larger increase for the Netherlands and Sweden. In Spain large number of unknown driver injuries make any conclusions difficult. In France, Germany and Great Britain there is an increased proportion of driver casualties that have fatal or serious injuries compared to passenger casualties.

4.2 Injury Severity by Restraint Use

Spain and Austria have data available on restraint use.

Table 3: Spain

Year	Using seat belt		Not using seat belt		Use not known		Total
1994	63	2.2%	2426	82.9%	438	15.0%	2927
1995	71	2.3%	2518	81.3%	507	16.4%	3096
1996	89	2.8%	2390	76.1%	663	21.1%	3142
1997	83	2.4%	2472	72.1%	875	25.5%	3430
1998	144	3.7%	3027	77.1%	756	19.3%	3927
Total	450	2.7%	12833	77.7%	3239	19.6%	16522

Table 4: Austria

Year	Using seat belt		Not using seat belt		Total
1994	9	2.0%	449	98.0%	458
1995	7	1.5%	448	98.5%	455
1996	9	2.2%	409	97.8%	418
1997	4	1.0%	411	99.0%	415
1998	9	2.0%	444	98.0%	453
Total	38	1.7%	2161	98.3%	2199

Without any measures of collision severity and more numbers for belt use, it is not appropriate to try and carry out any analysis of restraint effectiveness. It would appear from the Spanish data that restraint use is increasing but with such a large proportion of casualties with belt use not known it is wrong to draw any firm conclusion.

Regarding the directive for seat belts in buses and coaches, the current available data in no way allows the evaluation of effectiveness of seat belt use, or different seat belt systems.

5 Circumstances of Bus or Coach Accident

5.1 Type of Accident

Unfortunately this is the most difficult section in which to try and pull together data in a format common enough to draw good figures. Therefore it is more descriptive.

Unfortunately in national data no information is available on the levels of intrusion in an accident.

No Italian data are available on accident type. Also it should be mentioned that in German statistics “type of accident” has a different meaning than in other countries (see German report).

5.1.1 Other / Unknown Accidents

It is important to note the high proportions of accidents in some countries with no information (other/unknown) in the data.

Table 5:

Country	% of Casualties in Other / Unknown Type accident	Proportion of these casualties that are KSI
Austria	29.7 %	14.1 %
France	5.4 %	5.3 %
Germany	19.4 %	16.1 %
Great Britain	1.0 %	13.2 %
Spain	25.6 %	16.8 %
Netherlands	9.2 %	5.9 %
Sweden	6.2 %	9.1 %

As in Austria, Germany, Great Britain and Spain the proportions of casualties with serious and fatal injuries are high in this category. These may be high severity or multiple accidents, where categorisation of the accident type is difficult, maybe due to the amount of vehicle damage present. In these countries the KSI injury rates are higher than for the general casualty population in that country.

5.1.2 Frontal Accidents

The main area of damage and the principle direction of force are to the front of the bus or coach.

Austria:

Frontal accidents only account for 4.1% of all bus and coach casualties but 6 out of 47 fatalities during the 5 year period. Unfortunately others/unknown is 29.7% of all casualties (including 16 fatalities) and this could include some of the higher severity frontals.

France:

Frontal accidents account for 71.2% of all bus and coach casualties. Of the 110 fatalities, 69 occurred in frontal accidents (at the 6 day recording level). Of occupants who have an injury in a frontal accident 9.2% sustain a fatal or serious injury. The average for all casualties is 9.7%.

Germany:

Due to a lack of specific data about frontal accidents, no information is available.

Great Britain:

Using the data which describes the first point of impact of the vehicle, frontal accidents account for 28.6% of all casualties for the whole casualty population but 59.8% of casualties when an impact takes place. Of the 99 fatalities, 34 occur in frontal accidents. Not including the fatalities in non impact accidents, frontals account for over half the fatalities (34 out of 65). Of the casualties that sustain an injury in a frontal impact, 7.2% have a KSI injury, which is slightly lower than 7.5% for the whole casualty population.

The Netherlands:

Frontal accidents account for 56.7% of all casualties on urban roads and 46.7% of all casualties on rural roads. There are only 6 fatals overall in the Netherlands but 5 of these are against an object on a rural road, which could be frontal impacts.

Spain:

Only 9.6% of all casualties are injured in frontal accidents, but 49 out of 200 fatalities occur in this type of accident. Running out of road without rollover is likely to involve frontal accidents and this accounts for 8.1% of all casualties and 21 fatalities.

Sweden:

The largest proportion of casualties (389 out of 1239) 31.4% are involved in single vehicle accidents, which could be frontal accidents, or then again could be rollovers. 'Oncoming vehicle' accounts for 14.0% of all casualties.

5.1.3 Rollover/Overturning

A vehicle suffers a rollover or overturns if at any time in the incident it is on its roof, side, front or rear.

5.1.3.1 Countries with No Definite Rollover or Overturning Data Fields

Austria:
A high proportion of seriously injured casualties (28.4%) are injured when the vehicle 'runs out of road' which is the accident category where overturning is most likely to be found. This type of accident accounts for 12 out of 47 of the fatals, and overall 5.7% of all casualties (134 out of 2360). The very large number of other / unknown accidents could include a number of overturning accidents if these accidents are thought to be of high severity and hard to categorise.

Germany:
A high proportion of killed or seriously injured casualties (26.0%) are injured when the bus or coach 'runs out of road', which is likely to be the type of accident that overturning occurs in. This type of accident accounts for 28 out of 95 fatalities and 7.7% of all casualties.

The Netherlands:
No obvious accident category that overturning would be recorded in. It has been suggested that the overturning of bus and coaches is not a common occurrence in the Netherlands.

Sweden:
'Turning off the road' is a indication that the vehicle left the road, which is the type of accident that overturning is likely to occur in. Out of 1239 casualties, 132 (10.7%) were involved in this type of accident, with no fatalities.

5.1.3.2 Countries with Definite Rollover or Overturning Data Fields

France:

There are very few rollovers at all with only 48 (0.82% of all casualties) injured in rollovers. This may be due to the first impact for instance being a side or frontal in the reporting system, possibly a tree impact, or simply that rollovers do not happen very often. There are no fatalities reported in rollover accidents.

Great Britain:

Whilst overturning is a factor for only 0.2% of vehicles that have an injury accident, overturning accounts for 1.2% of all casualties. When a bus or coach overturns and a casualty occurs, the mean number of casualties is 9.36 and serious casualties 1.75, this compares with 1.42 and 0.106 respectively for the whole bus and coach casualty population. In the five year period the data indicates that 59 vehicles overturned in Great Britain with 7 fatalities. However, work in task 1.2, the study of in-depth cases, has found two cases showing photographs of the coach clearly on its side or roof. These accidents were not recorded as overturning but add 23 fatalities to the 7 indicated in the data.

Spain:

Of the casualties involved in a rollover accident, 6.4% sustain a fatal injury, with 61 out of the 200 fatalities that occurred during the five year period. Also casualties injured in rollovers account for 12.6% of all casualties. When a rollover occurs the mean number of casualties is 7.7, compared to 2.5 for side and 4.5 in frontals. 93.6% of rollover casualties occur on inter-city roads as opposed to urban roads, and all the rollover fatalities occur on inter-city roads.

5.1.4 Side and Rear Impacts

The main area of damage and the principle direction of force are to the side or rear of the bus or coach.

Austria:
Side and rear accidents account for 6.5% and 5.9% of all bus and coach casualties respectively, but as with frontal accidents the large number of other/unknown accidents must be kept in mind. There is 1 fatality in a side accident and 6 in rear accidents.

France:
There are similar numbers of KSI casualties in both side and rear accidents (81 and 79), but 23 out of 110 fatalities occur in rear accidents compared to 15 in side impacts. In rear accidents 13.5% of casualties are KSI and in side accidents, 10.9%. Side accidents account for 12.6% all casualties and rear accidents 9.6%.

Germany:
'Turning' and 'Turning/crossing' type accidents account for 30.9% of all casualties, which are the accident types that are likely to include side impacts. 'Rear end with stopping vehicles' and 'Rear end with moving vehicles' are categories in the kind of accident data and 20.5% of all casualties are in these two categories.

Great Britain:
Side impacts account for 11.9% of all casualties and 20 out of the 99 fatalities over the five year period. Rear impacts account for 6.5% of all casualties with 10 fatalities.

The lowest injury risk is for rear impacts (4.5% KSI). There is quite a difference between the proportion of KSI casualties between right and left side impacts at 5.0% and 8.8% respectively.

Netherlands:
Side impacts account for 10.9% and rear impacts 10.6% of all casualties with a higher percentage of casualties on urban roads for side impacts and a higher percentage on rural roads for rear impacts.

There are very few serious casualties in side or rear impacts and no fatalities.

Spain:
Side impacts account for 18.9% of all casualties and 45 out of the 200 fatalities are from a side impact, only 4 less than in frontal accidents. 555 vehicles had a side accident compared to 163 in frontals. It has been indicated by INSIA that truck impacts into the side of buses and coaches is a problem in Spain.

Rear impacts account for 14.4% of all casualties, with only 4 fatalities.

Again it must be remembered that 25.6% of all casualties are in other/unknown accidents.

Sweden:
'Intersecting' type accidents account for 16.6% of all casualties with 7 out of 14 fatalities during the 5 year period. Of all casualties 12.4% are injured in rear impact.

5.1.5 Non-Collision Injuries

Occupant injuries where no impact takes place are a large part of the injury experience in some countries.

Austria:
The largest category of all for casualties is emergency braking with 40.4% of all casualties.
France:
No criteria.
Germany:
An in-depth study of city bus accidents in Bavaria (Munich and Nürnberg), which was carried out as part of a thesis (ref. 4), revealed that 50% of the casualties in buses are due to non-collision bus accidents. In over 70% of the cases emergency braking was the main cause of the accident in the bus. 72% of these casualties were older than 55 years.
Great Britain:
52.6% of all casualties were injured in 'did not impact' accidents along with 55.7% of all the KSI casualties with 35% of all fatal casualties.
Netherlands:
Single accidents with no impact locations account for 107 casualties (18.9% of all) (second largest category) on urban roads and 26 casualties (13.2%) on rural roads. This lower number on rural roads would be expected for this type of incident, which is likely to be associated with emergency braking and operational manoeuvres in urban areas.
Spain:
No criteria.
Sweden:
No criteria.

5.1.6 Overall

Unfortunately national data does not include any information on whether intrusion into the driver or passenger areas has occurred. This is likely to have large implications when discussing the types of accident in which occupants are seriously injured. Certainly impacts with trucks that cause serious injury are likely to feature intrusion that causes direct injury to occupants.

Frontal Accidents

This data shows that in most countries casualties in frontal accidents make up a considerable proportion of the whole casualty population. This is not evident in Spain, but frontal accidents account for nearly a quarter of fatalities. Also the number of frontal accidents in Austria is very low but 29.7% are unknown and 40.4% are emergency breaking.

When frontal accidents do occur, the proportions of casualties that have a fatal or serious injury are usually lower then for the whole casualty population.

Rollover / Overturning

Rollover or overturning accidents are not as common as the other types of accident but when these accidents occur there is an increased risk of serious or fatal injury. When at least one injury occurs on the vehicle there is a large increase in the number of occupants that sustain an injury.

Side / Rear Impacts

In all countries a higher proportion of casualties are injured in a side impact than a rear impact.

Non-Collision Injuries

It has been seen in this work that non-collision incidents are a major factor in the injury experience of bus or coach users in Austria, Germany (local study of city bus accidents) and Great Britain. These non-collision incidents are unfortunately very likely to be sensitive to reporting systems. Incidents where occupants fall on the bus or coach, or as they are boarding or alighting, may not be recorded as accidents, or may not be included in the data that has been presented for analysis.

5.2 Type Of Accident Opponent

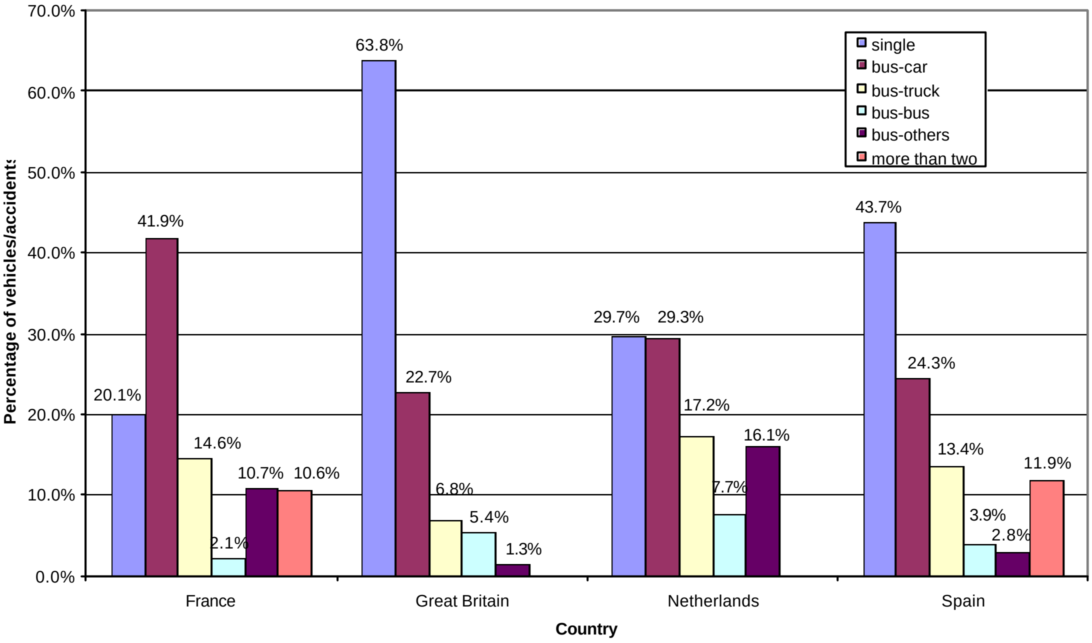


Figure 19: Accident Opponents

Unfortunately this analysis is limited to four countries due to difficulties in some countries of separating the casualties in the bus or coach from the opposing vehicle.

On a vehicle basis it can be seen that single accidents and those against cars make up the largest proportions of accident opponent for all countries, followed by trucks.

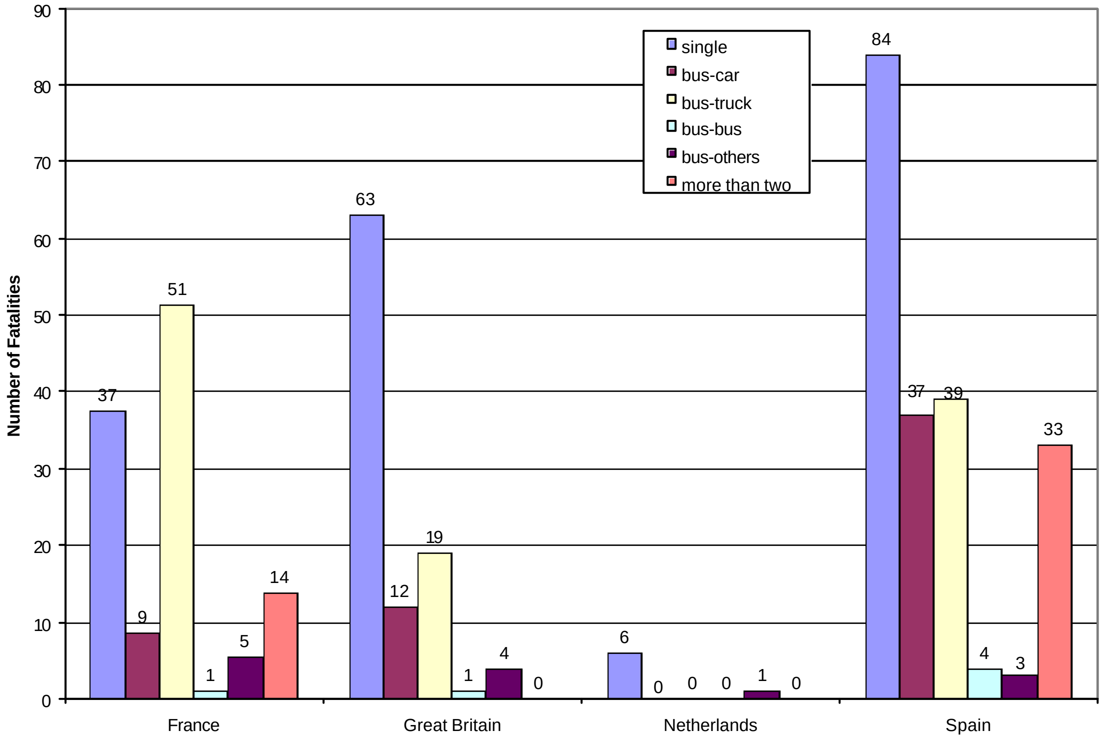


Figure 20: Number of Fatalities versus Accident Opponent

When looking at just fatalities it is observed that single accidents, make up a large proportion of the fatalities in the countries shown, followed by trucks and cars.

This is not really unexpected. 'Single accidents' is the category in which rollovers/overturning are likely to feature, along with frontals that occur due to the bus or coach leaving the road. Then the size and structural aggressiveness of trucks are important factors. It is likely that in collisions with trucks intrusion will play a large part in the injury experience of occupants. Even though it is not possible to illustrate the data here, the German report indicates that collisions with trucks are an important factor on serious injuries.

It is felt that cars feature prominently in both these figures due to the large numbers on the roads. Here it is obvious that whilst cars are an accident opponent in more accidents than trucks, they are less aggressiveness when considering fatalities.

5.3 Location and Road Type

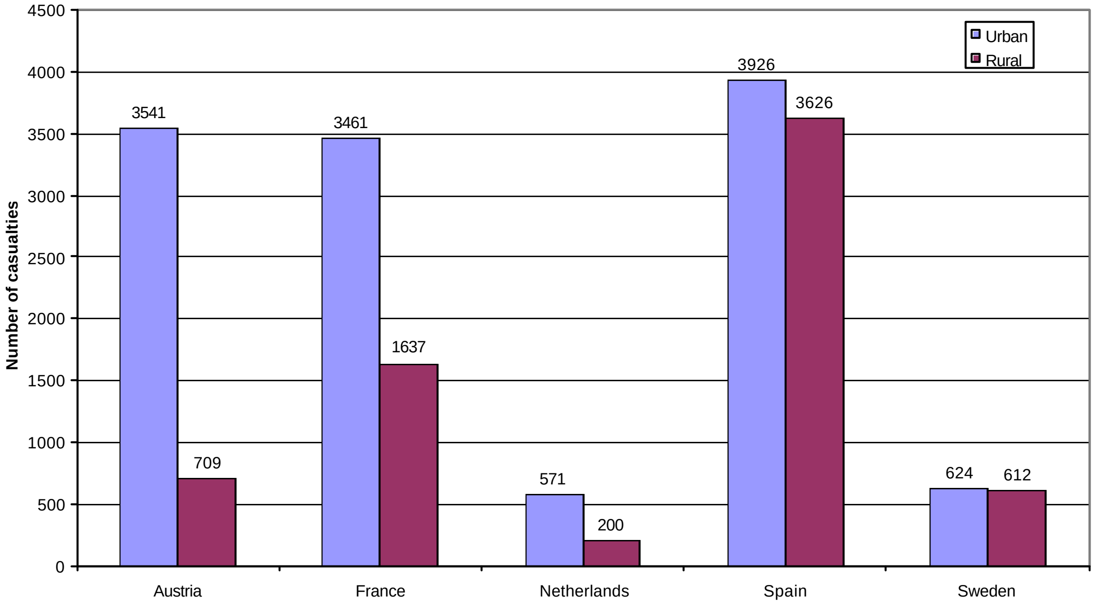


Figure 21: Distribution of Casualties by Urban / Rural Location

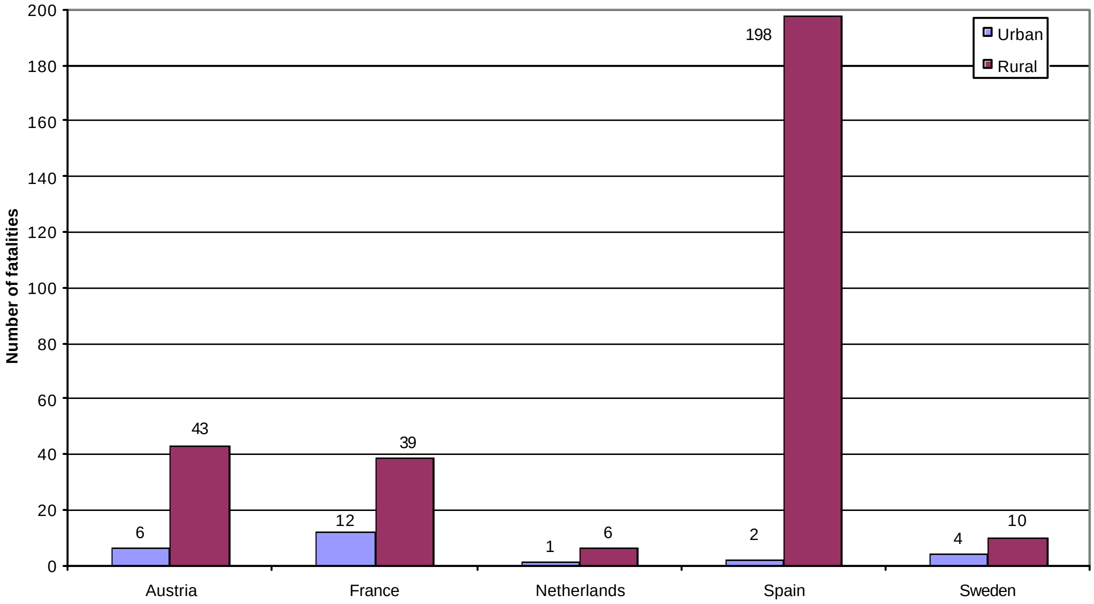


Figure 22: Distribution of Fatalities by Urban / Rural Location

Full data is not available from Great Britain or Germany. In Great Britain the great majority of casualties (82.7%) occur on 50 kph (30 mph) roads, but with around 50% of fatals on higher speed roads. The main trend here is that most casualties occur on urban roads, however most fatalities occur in rural accidents.

5.4 Objects Hit During Accident

Germany, Great Britain and Spain have information on objects hit.

As may be expected with buses and coaches being such heavy vehicles, objects struck on or off the carriageway, such as small trees and road signs, will not have a large influence on the injury experience of occupants.

It would require a greater level of analysis than is possible here to distinguish whether injuries are due to the object or other circumstances of the event. For instance in Great Britain it is known through in depth work that although 10 fatalities occurred when a coach hit a roundabout, they were due to the coach overturning and the occupants were all elderly.

6 Environmental Conditions at Time of Accident

Whilst it is acknowledged that the following analyses are not fundamental to vehicle design (certainly it is impossible to do anything about the weather), it is felt that they are important to give as full a picture as possible of the types of accidents that occur and differences between countries.

6.1 Light Conditions

Austria:

In darkness there is a very high fatality rate at 10% and serious injury risk rate of 20%. 14.7 % of casualties are injured in darkness.

France:

There is a very high fatality rate in darkness, at 8.9% (1% in the daytime) and this is at the 6 day cut off for a fatality. Accidents in darkness account for 25.3% of casualties.

Germany:

13.4% of injury accidents to occupants occur at night, with 4.9% at dusk or dawn. The poorer the light conditions are, the higher the risk of serious injury, 10.3% in daylight against 15.5% for darkness.

Great Britain:

Of all casualties, 11.6% are injured at night and 12.4% of vehicles have their injury accident at night. There is an increased KSI rate for darkness, 9.7%, over daylight, 7.2%.

Italy:

No data available.

Netherlands:

There is an increase in severe injury risk in dark conditions, but with small numbers, 82.8% of casualties are injured in daylight.

Spain:

Of the casualties that occur at night without sufficient or any lighting, the fatality rate is very high at 7.3%. This is at the 24 hour limit as well. 71.2% of casualties occur in daylight.

Sweden:

No data available.

6.2 Weather Conditions

Austria:
Most casualties, 87.5% of all, occur during normal, fine or cloudy, weather. For adverse conditions numbers are small.

France:
72.8% of casualties occur in fine weather with no increased injury risk for poor weather.

Germany:
Very low numbers, difficult to draw any conclusion.

Great Britain:
9.8% of vehicles have injury accidents in the rain with a slight decrease in the risk of serious injury. 0.5% of casualties occur in snow conditions.

Italy:
No data available.

Netherlands:
86.0% vehicles have an injury accident in dry fine conditions. No increased serious injury risk for adverse weather conditions but the numbers are low.

Spain:
Rain and drizzle are the weather conditions in 27.4% of all fatalities. 84.4% of casualties occur in good weather.

Sweden:
73.4% of casualties are injured in accidents in dry weather. 9.6% in snow but with no increased injury risk.

6.3 Road Surface Condition

Austria:
Dry road when 78.2% of casualties occur and wet/damp in 15.0% of cases.

France:
Slightly increased serious injury risk when road is wet/damp. Dry conditions account for 73.5% of casualties.

Germany:
Dry road conditions make up 76.8% of the casualty population with increased KSI rates when the road is not dry, especially when the road is 'slippery'.

Great Britain:
The only significant change in road surface condition from dry is that 21.4% of buses or coaches have injury accidents on wet or damp roads, but with no increase in the risk of serious injury.

Italy:
No data available.

Netherlands:
Majority on dry roads, some wet/damp but no increase in serious injury risk.

Spain:
84.1% of bus casualties occur when the road is dry. There is a higher fatality and serious injury risk when the road is wet and these conditions account for 29.5% of all fatalities.

Sweden:
No data available.

7 Conclusions

The aim of this task was to compare national data sets. In order to do this it was necessary to strictly define a set of common tables so that partners would be able to supply data that both described the injury experience of bus and occupants in their own country and enabled comparison with other countries in the study. Within the limitations imposed by the availability of information this has been achieved and this work stands as the most comprehensive collection of bus and coach casualty data to date.

The limitations of this exercise are clear and lie fundamentally in the lack of harmonisation across Europe concerning accident records.

No sets of data fields are exactly the same across all countries and it is especially important to recognise differences in the definitions of injury severity. But this work has found that generally countries collect the same type of data to describe the accident, for example vehicle opponent, and even though they are not strictly the same, trends can be compared.

What has proved extremely difficult though has been trying to make any meaningful comparisons with such disparate accident numbers between each country. It has also been very difficult, especially with such a wide spread of vehicle types, to define the occupants for analysis. Due to the record structure within some countries, it has been difficult to separate casualties in accidents involving a bus or coach with casualties actually on-board the vehicle.

The following conclusions can be made:

Any international comparisons must be made with great care and consideration. It is obvious from this work that even the most basic data definitions of injury severity can be very different. This report has achieved comparison across these eight countries by sometimes taking the essence of countries' data and drawing general conclusions.

Bus and Coach Casualty Population:

- For the years 1994 to 1998, on average, around 150 bus or coach occupants were killed per year in the eight countries in the study as a whole.
- In all eight countries far fewer bus or coach occupants are injured than car occupants. The proportion of all road casualties that are injured whilst using a bus or coach ranges from 0.3% in the Netherlands to 3.0% in Great Britain. For fatalities, figures range from 0.1% in the Netherlands to 1.0% in Spain (even though fatalities are counted at 24 hours).
- In all represented countries the likelihood of a serious or fatal injury to a casualty when an injury takes place is lower than for the whole road casualty population. The European Transport Safety Council estimates bus and coach travel to be at least ten times safer than other forms of road transport and only rail travel is safer overall.
- From 1994 to 1998 the number of casualties has risen in the Netherlands, France, Spain and Sweden.
- In all eight countries many more women than men are injured as bus or coach occupants. This trend is not borne out in fatality figures though.
- In all represented countries men have a greater likelihood of a serious or fatal injury when an injury occurs.
- The ages of male casualties are more evenly distributed than those of female casualties. In some countries peaks in age can be ascertained at school age and towards elderly age, these are more obvious for female casualties than male casualties.
- In all countries more passengers are injured than drivers. In France, Germany and Great Britain a higher proportion of driver casualties sustain a serious or fatal injury than passenger casualties.

Bus and Coach Accident Circumstances:

- Whilst it is difficult to definitely confirm which accident types are most important this report has been able to support further work in the ECBOS project on rollovers and frontals, whilst also identifying the need to appreciate the high levels of non-collision injuries in general.
    - From the data available with definite rollover/overturning data fields it has been established that these types of accident do not 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 (this is supported by ref. 3, 'Safety Belts in Touring Coaches' Appel et al. Technical University of Berlin & Volkswagen AG, Wolfsburg 1996 IRCOBI Sept 11-13th Dublin, Ireland).
- It is also apparent that collisions with trucks are a major influence on the fatal injury experience of bus and coach casualties, with INSIA reporting that this is a particular problem for side impacts in Spain.
- In Austria, Germany and Great Britain non-collision accidents have been identified as important in the injury experience of bus and coach users, especially for older users.
- For the countries with data available, most casualties occur on urban roads; however most fatal injuries occur on rural roads.
- Generally the KSI rate in darkness is higher than in daylight.

Future Further Work of the ECBOS Project:

- The use of in-depth cases to establish more detail on injury mechanisms, over and above the general data fields given in National data. The effect of intrusion and the crashworthiness of vehicle structure can only be investigated at an in-depth level.

8 References

1. 'Priorities in EU Road Safety - Progress report and ranking of actions (2000) ETSC
2. In-car Safety and Personal Security Needs of Female Drivers and Passengers, Loughborough University 2000
3. 'Safety Belts in Touring Coaches' Appel et al. Technical University of Berlin & Volkswagen AG, Wolfsburg 1996 IRCOBI Sept 11-13th Dublin, Ireland.
4. J. Bende: “City Bus Safety - A Casualty Study from the View of the Accidents Research”, thesis for the GDV, Institute for Vehicle Safety Munich, January 17, 2000

Workpackage 2

Task 2.5 - Cause of Injury Summary

Undertaken on behalf of

DG TREN

Executive Summary

This task brings together the information from work packages 1 and 2 of the ECBOS project to comment on the causes of injuries and injury mechanisms in M2 and M3 vehicles.

Involved partners:
TUG, CIC, TNO, UPM, VSRC, GDV, PoliTo

9 Introduction

This document 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 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.

10 Summary of National Overviews

Taken from Task 1.1.

10.1 Bus and Coach Accident Circumstances

- From the data available with definite rollover/overturning data fields it has been established that these types of accident do not happen very often but when they do the number of seriously injured occupants can be high.
- Frontal impacts 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 major influence on the fatal injury experience of bus and coach casualties, with INSIA reporting that this is a particular problem for side impacts in Spain.
- In Austria, Germany and Great Britain non-collision accidents have been identified as important in the injury experience of bus and coach users, especially for older users.

11 In-Depth Database Analysis

Using the more specific injury data available from the in-depth database it has been possible to further investigate the severity of injury that occupants obtain in different accident circumstances.

The actual release of the database contains 36 real world accidents shared into 31 accidents with M3 buses (> 5 tons) and 5 accidents with M2 buses (< 5 tons) involved. Due to the differences in design, dimensions, structure and weight of M2 and M3 buses, the following analysis is split into both types of bus categories.

11.1 Bus and Coach Accident Circumstances – M2 Vehicles

The 5 real world accidents with M2 buses are distributed in 3 frontal and 2 side impacts. This classification refers basically to the impact direction and secondary to the main injury causing occurrence. The incident distribution was evaluated versus injury severity and casualty MAIS.

Since the information on the M2 buses is based on only 5 cases, 4 without overturning and 1 with overturning the definition of general statements shall take this small number into account.

11.1.1 General Injury Severity and MAIS Distribution

Figure 1 shows the general MAIS and injury severity distribution of 5 real world accidents with M2 buses. The evaluation of these 5 cases showed injuries for 100% of the occupants.

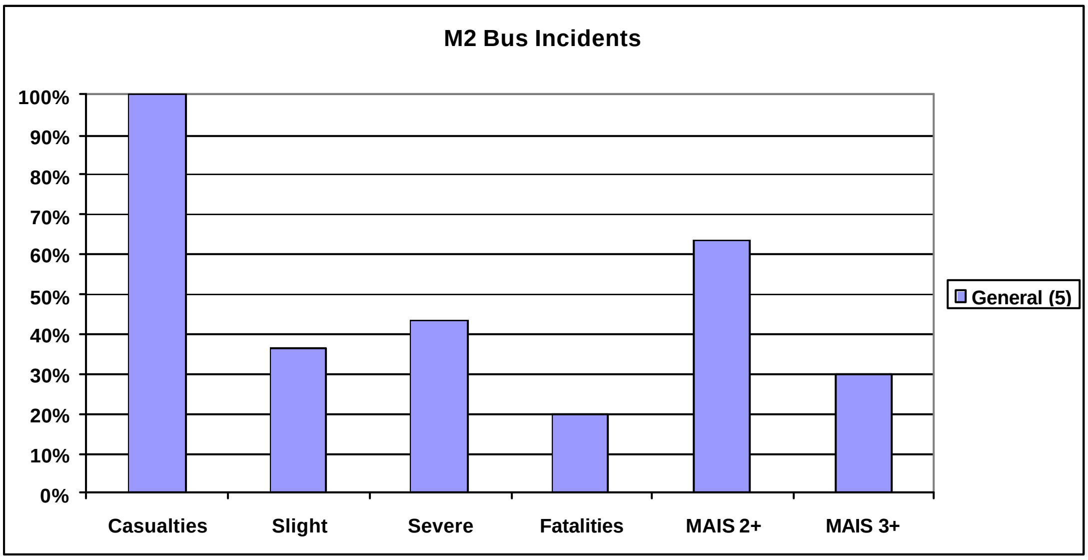


Figure 1: Injury Severity and MAIS by Incident

	Occupants	Casualties	Slight	Severe	Fatalities
General	30	30	11	13	6

Table 1: Injury Severity and MAIS by Incident

11.1.2 Injury Severity and MAIS Distribution for Different Opponents

Due to the small number of cases in some categories the comparison of the injury severities can only show tendencies.

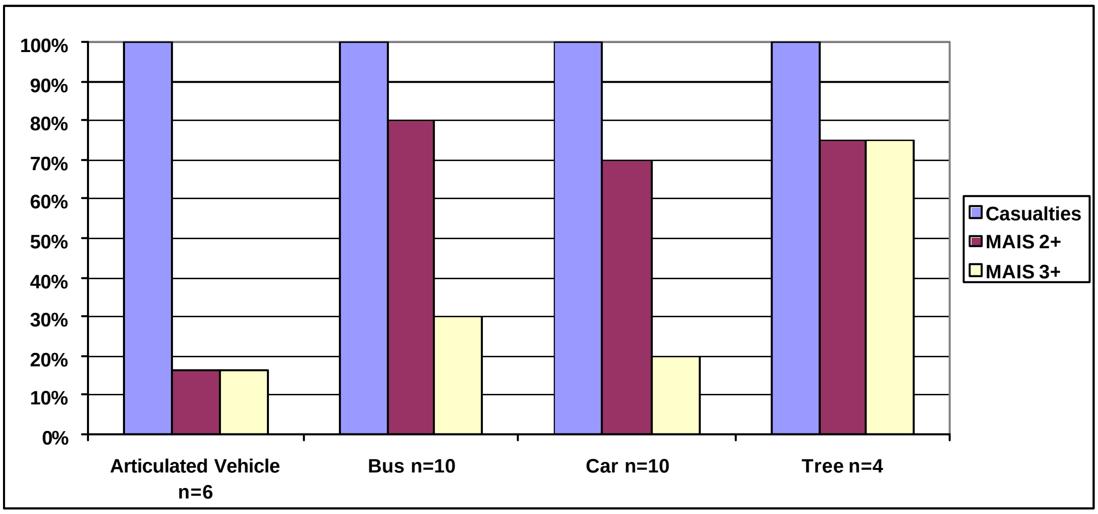


Figure 2: Casualty MAIS by Opponent (n=number of casualties)

Opponent	Accidents	Occupants	Casualties	MAIS 2+	MAIS 3+
Articulated Vehicle	1	6	6	1	1
Bus	1	10	10	8	3
Car	2	10	10	7	2
Tree	1	4	4	3	3

Table 2: Injury Severity by Opponent

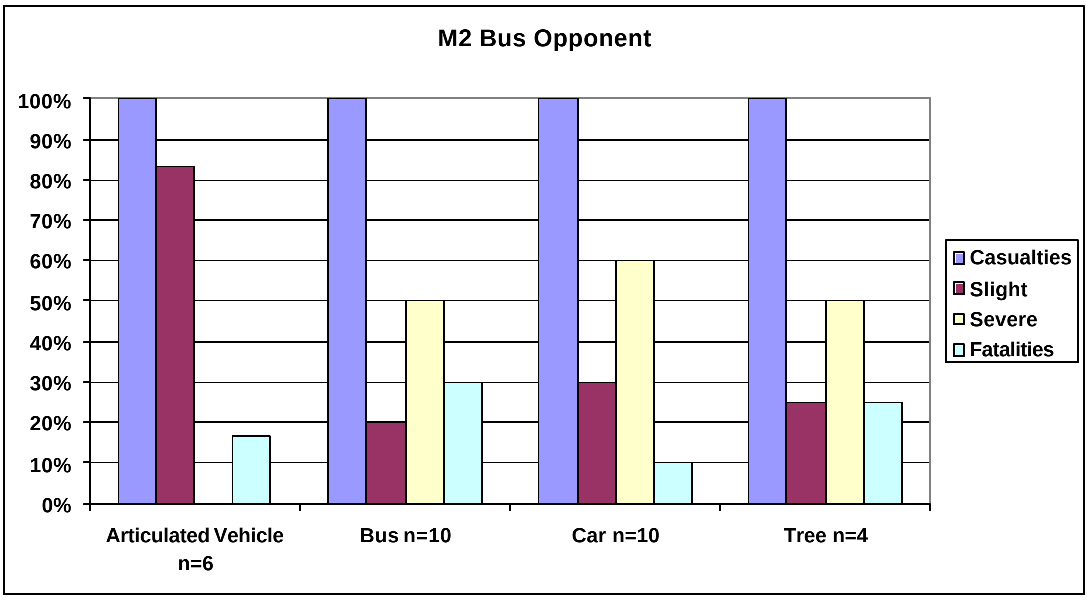


Figure 3: Injury Severity by Opponent for M2 Occupants

	Casualties	Slight	Severe	Fatalities
Articulated Vehicle	6	5	0	1
Bus	10	2	5	3
Car	10	3	6	1
Tree	4	1	2	1

Table 3: Injury Severity by Opponent for M2 Occupants

11.1.3 Injury Severity and MAIS Distribution for Different Accident Types

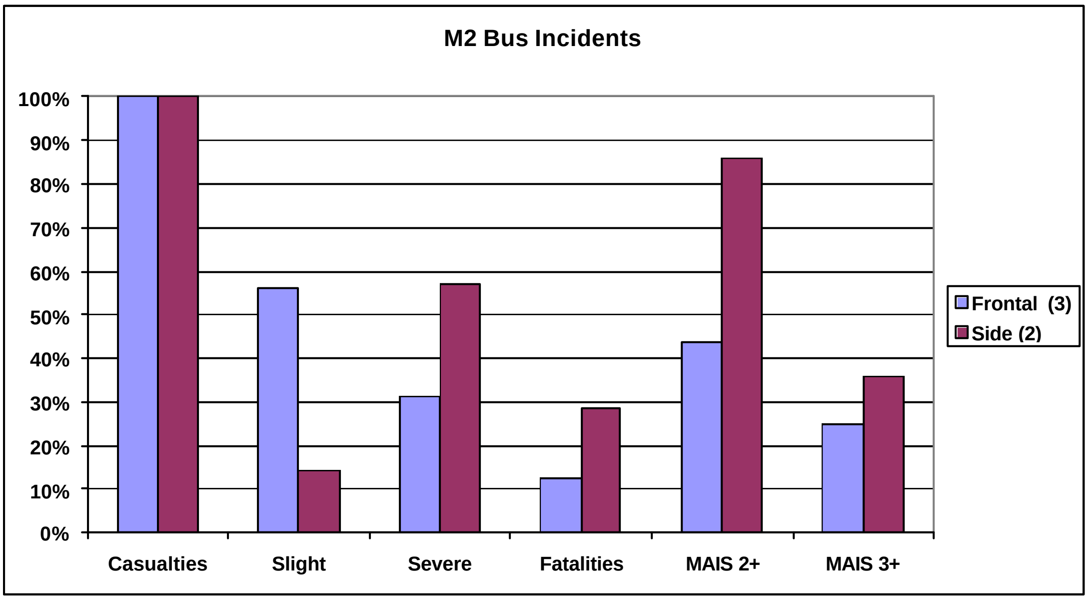


Figure 4: Injury Severity and MAIS by Incident

	Occupants	Casualties	Slight	Severe	Fatalities	MAIS 2+	MAIS 3+
Frontal	16	16	9	5	2	7	4
Rear	14	14	2	8	4	12	5

Table 4: Injury Severity and MAIS by Incident

11.1.4 MAIS Distribution Opponent versus Kind of Accident

Following diagrams show the distribution of accident opponent versus kind of accident. Since the number of cases is small, sometimes only 1, a general tendency cannot be evaluated. The presentation of the kind of accidents can be taken to detect relations between the locations of the occupants in the bus and the impact situation. Based on this investigation the main causes or the injury will be detected.

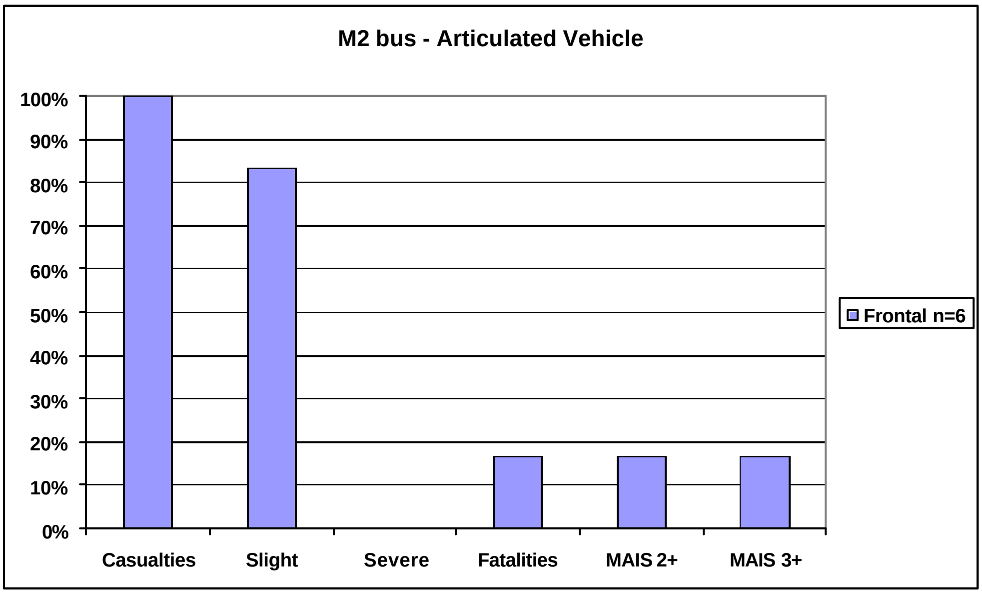


Figure 5: Opponent Articulated Vehicle

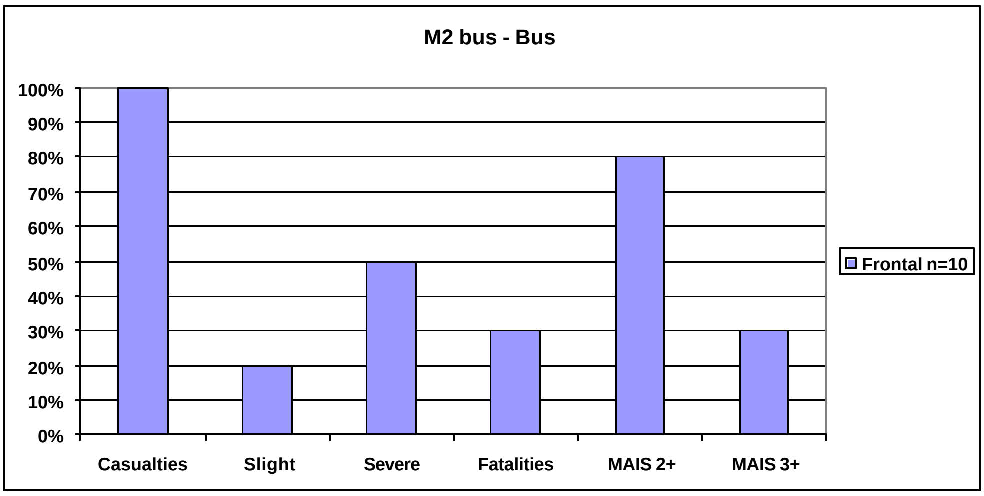


Figure 6: Opponent Bus

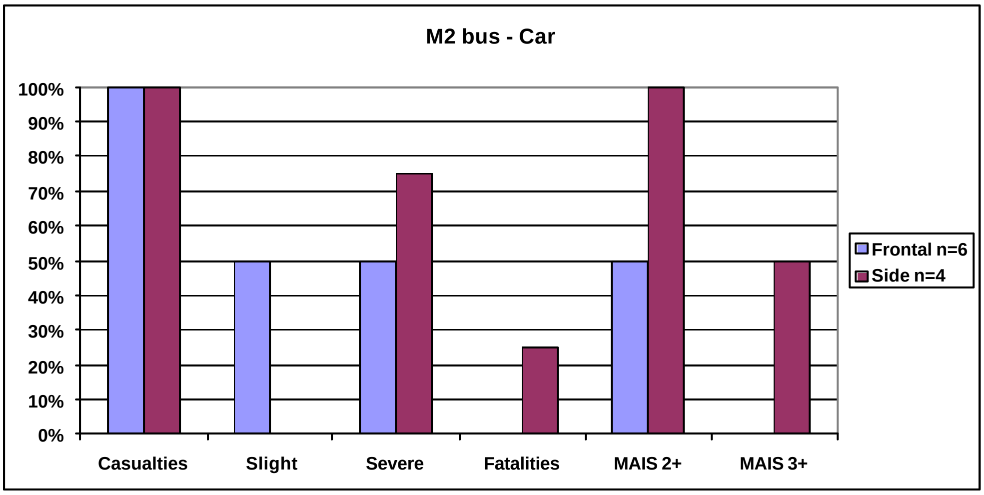


Figure 7: Opponent Car

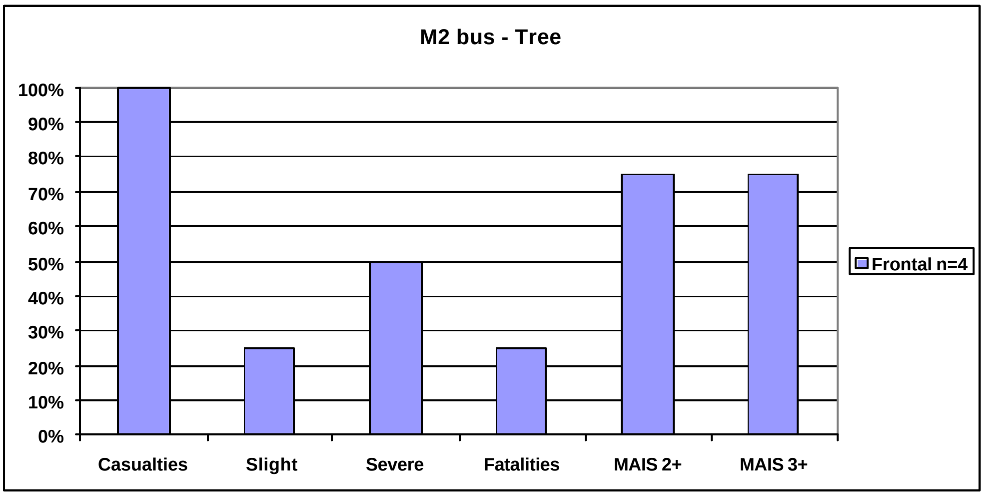


Figure 8: Opponent Tree

11.1.5 Body Region Injuries

Using the in-depth database a general picture is formed of which body regions are more susceptible to injury in M2 accidents. Figure 9 indicates a higher risk of serious injuries for the head and the extremity regions. These results are for all types of accidents.

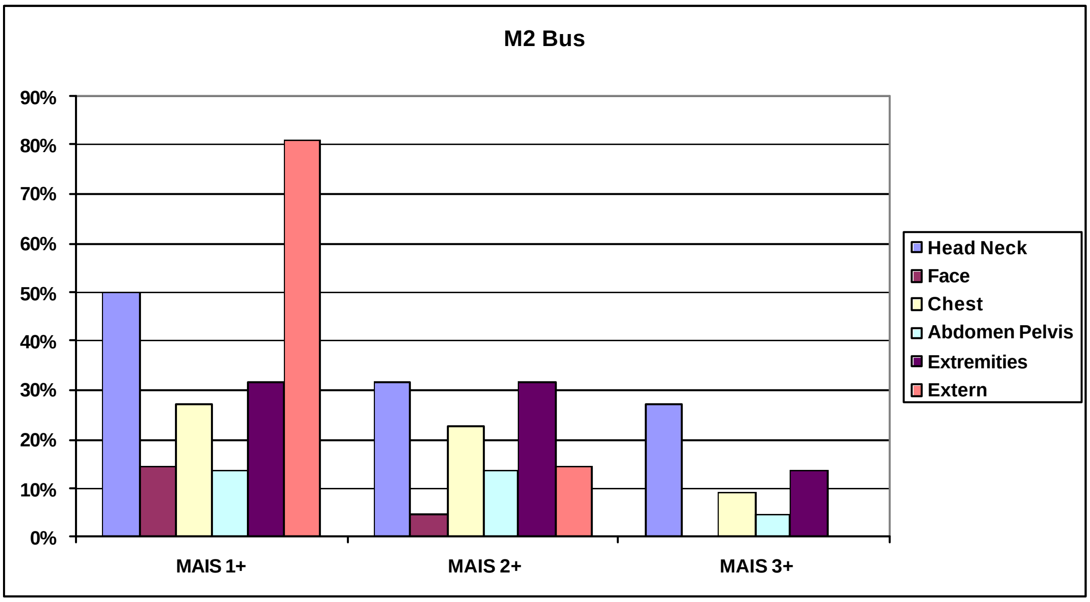


Figure 9: General Body Region MAIS

Frontal Impact:

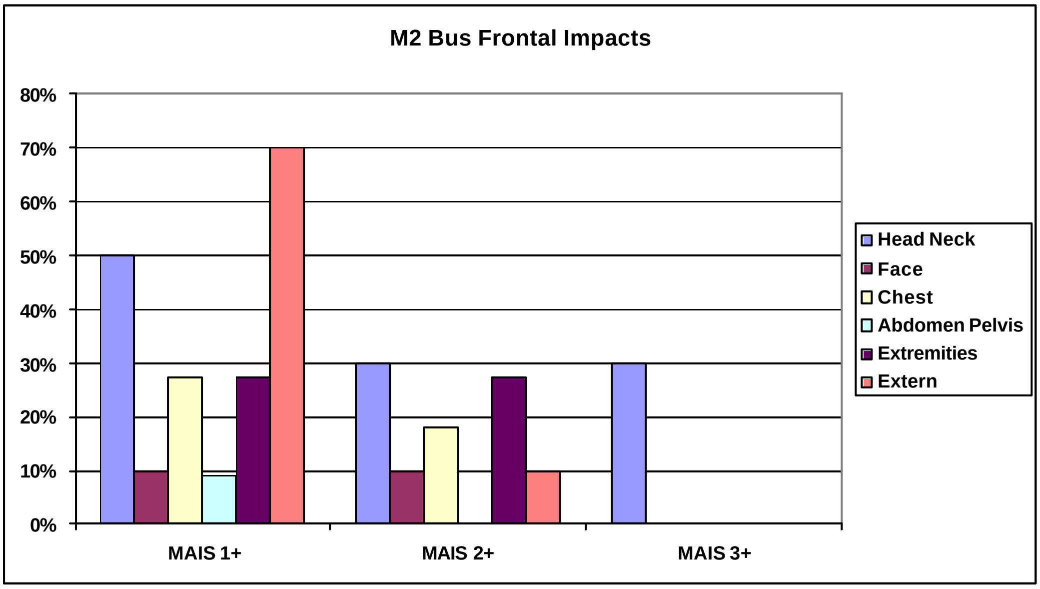


Figure 10: Body Region MAIS for Frontal Impacts

Frontal impacts indicate a higher injury risk for head and extremity regions.

Side Impact:

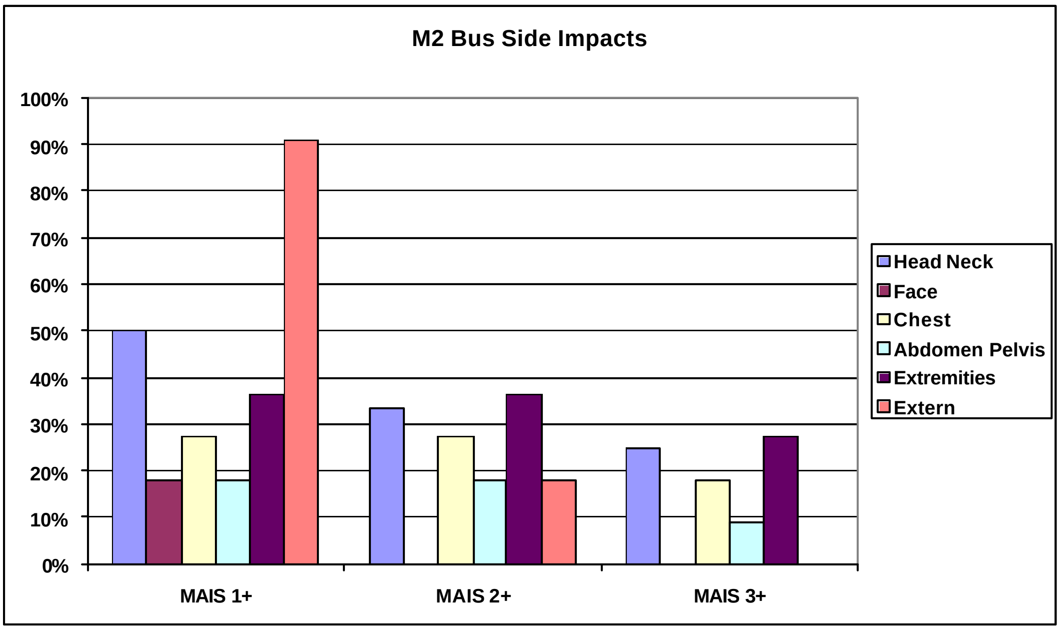


Figure 11: Body Region MAIS for Side Impacts

Side impacts indicate a higher risk for serious injuries for head, chest, pelvis and extremity regions.

11.2 Bus and Coach Accident Circumstances – M3 Vehicles

The 31 real world accidents with M3 buses are distributed in 15 frontal, 13 rollover, 2 rear end and 1 side impact. This classification refers basically to the impact direction and secondary to the main injury causing occurrence. The incident distribution was evaluated versus injury severity and casualty MAIS. After presentation of general results the path of investigation was directed to the accident opponent, the kind of collision and the location of the occupants.

11.2.1 General Injury Severity and MAIS Distribution

Figure 12 shows the general MAIS and injury severity distribution of 31 real world accidents with M3 buses.

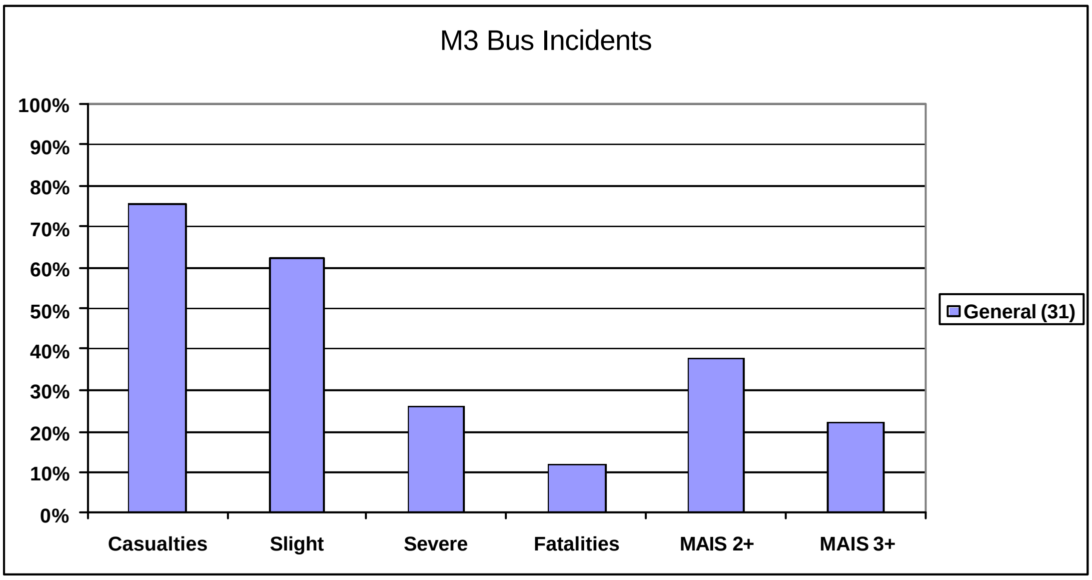


Figure 12: Injury Severity and MAIS by Incident

	Occupants	Casualties	Slight	Severe	Fatalities
General	1341	1015	632	264	119

Table 5: Injury Severity and MAIS by Incident

11.2.2 Injury Severity and MAIS Distribution for Different Opponents

In Task 1.1 it was identified that these vehicles are generally large and collisions with other large and heavy vehicles, such as trucks and buses, give the most serious injury outcomes. In addition the single accidents, where the driver lost control over the bus left the road and overturned into a ditch show the highest risk for severe injuries.

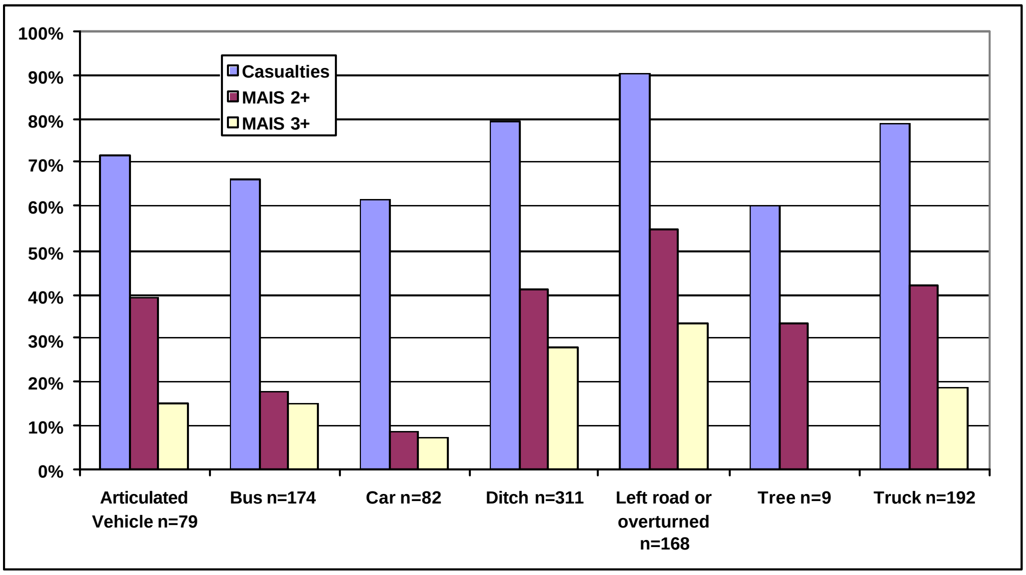


Figure 13: Casualty MAIS by Opponent (n=number of casualties)

Opponent	Accidents	Occupants	Casualties	MAIS 2+	MAIS 3+
Articulated vehicle	2	110	79	31	12
Bus	6	262	174	31	26
Car	4	133	82	7	6
Ditch	8	391	311	128	87
Left road or overturned	4	186	168	92	56
Tree	1	15	9	3	0
Truck	6	244	192	81	36

Table 6: Injury Severity by Opponent

Figure 13 shows that when the opponent is a car the proportion of occupants who sustain MAIS ≥2 and MAIS ≥ 3 injuries are lower than for other larger vehicles.

The following diagram shows the proportion of injury severity versus accident opponent.

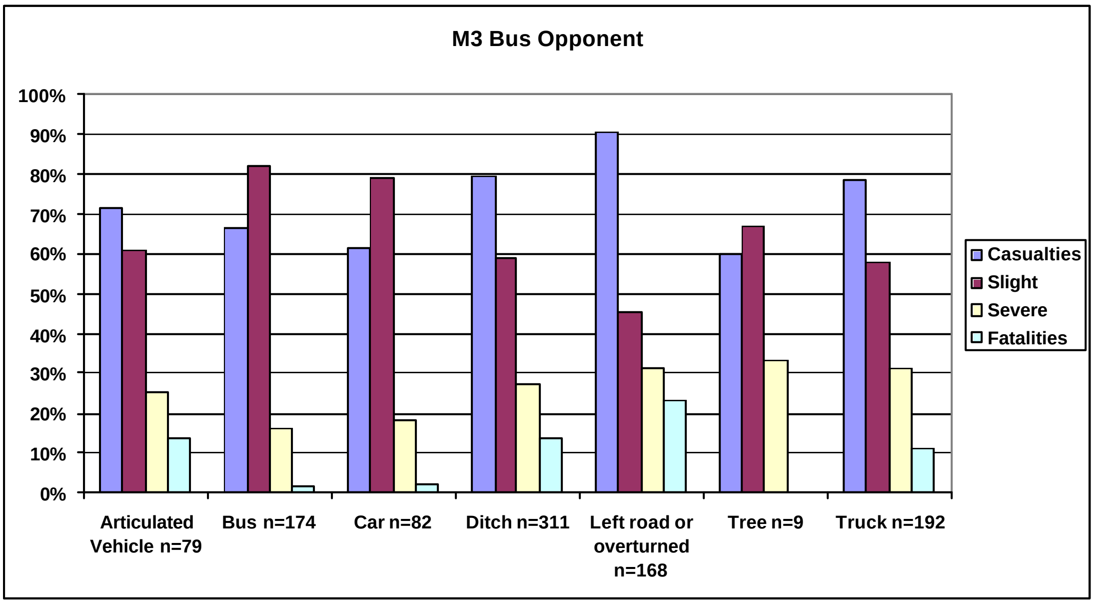


Figure 14: Injury Severity by Opponent for M3 occupants

The lower proportion of severe injuries for bus to bus collision results from the high number of slight injured occupants from the high share of rear end impacts. 50% more bus to bus accidents than bus car accidents compare to nearly 100% more severe injured occupants.

	Casualties	Slight	Severe	Fatalities
Articulated Vehicle	79	48	20	11
Bus	174	143	28	3
Car	82	65	15	2
Ditch	311	183	85	43
Left road or overturned	168	76	53	39
Tree	9	6	3	0
Truck	192	111	60	21

Table 7: Injury Severity by Opponent

Table 7 shows that a single accident and the overturning into a ditch, which both are in majority of the cases combined cause the highest risk for severe injuries.

11.2.3 Injury Severity and MAIS Distribution for Different Accident Types

Although the rear end impacts have the highest proportion of incidents the injury severity is mainly slight.

Since the counted side impact was not a typical one, a turning trailer from the oncoming traffic hit and slit open the left side of the bus, the following investigation is focused on the main incidents as they are frontal, rollover and rear. Another side impact, which resulted in a rollover, was numbered under rollover.

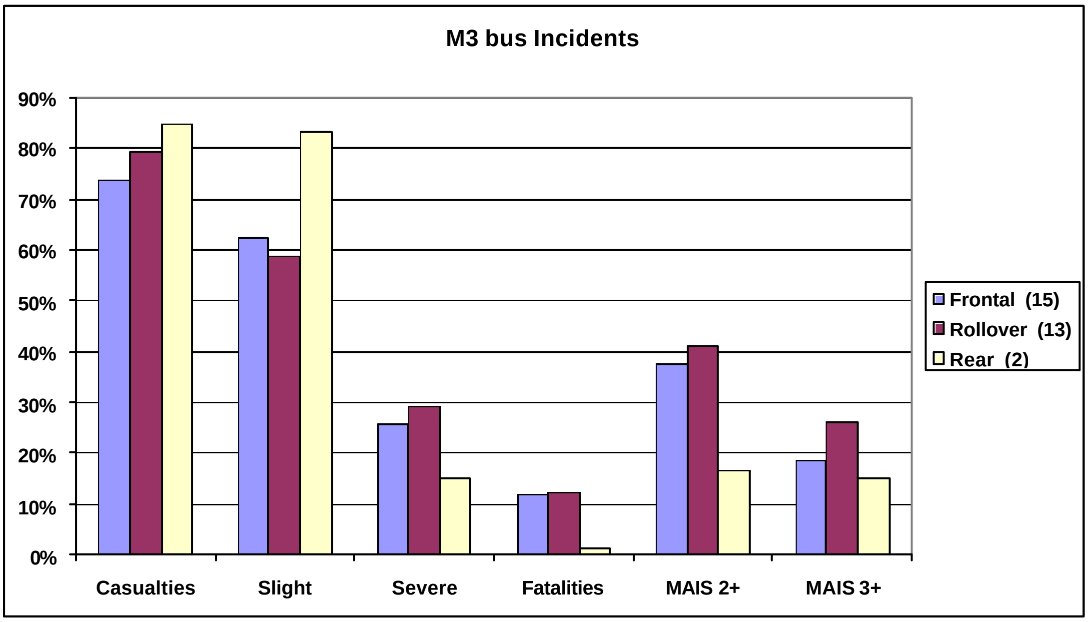


Figure 15: Injury Severity and MAIS by Incident

	Occupants	Casualties	Slight	Severe	Fatalities	MAIS 2+	MAIS 3+
Frontal	619	455	284	117	54	171	84
Rollover	575	457	268	133	56	189	120
Rear	85	72	60	11	1	12	11

The frontal and rollover accidents cause a similar proportion of fatalities whereas the rollover has a much higher risk (+ 42%) on MAIS 3+ injury severity.

To prove the outcome of this in-depth study the diagrams were compared with the corresponding available data of the accident statistics from Task 1.1. Even though only Austria and Spain had the required information, the correlation due to proportion is good (Figure 16, Table 8).

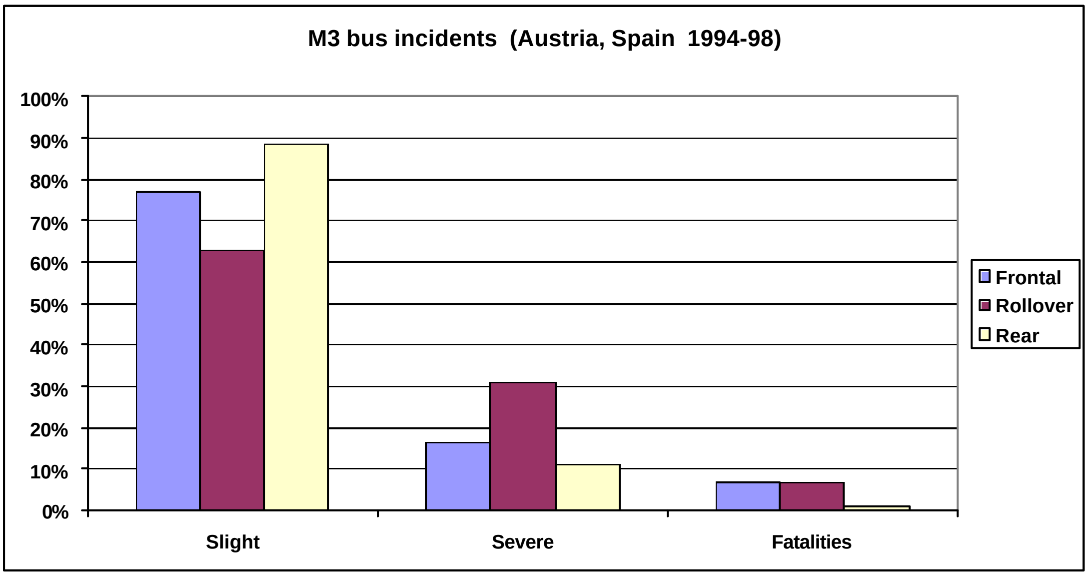


Figure 16: Statistical Injury Data

Austria-Spain (1994-98)	Casualties	Slight	Severe	Fatalities
Frontal	821	634	132	55
Rollover	957	600	296	61
Rear	1213	1074	130	9

Table 8: Statistical Injury Data

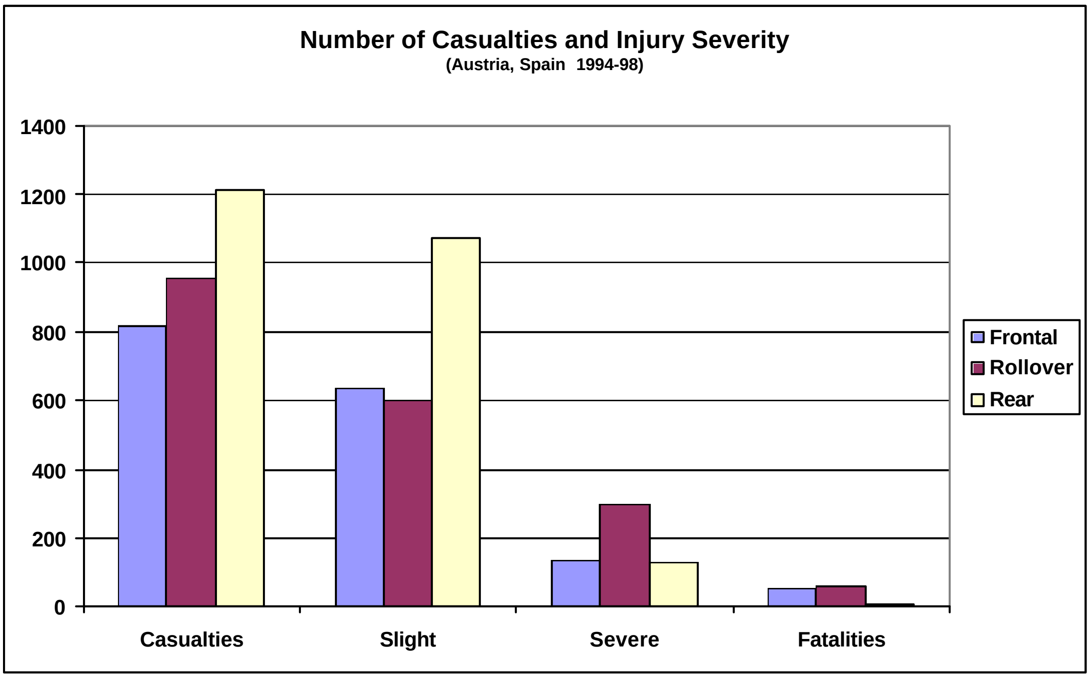


Figure 17: Statistical Incident Data

11.2.4 Overturning

In Task 1.1 and the section above it can be seen that a high risk of serious injury is associated with the vehicle overturning or entering a ditch, which can have the same effect.

This investigation represents a comparison of all rollovers against the other kinds of accidents, even though the primary collision was not a rollover.

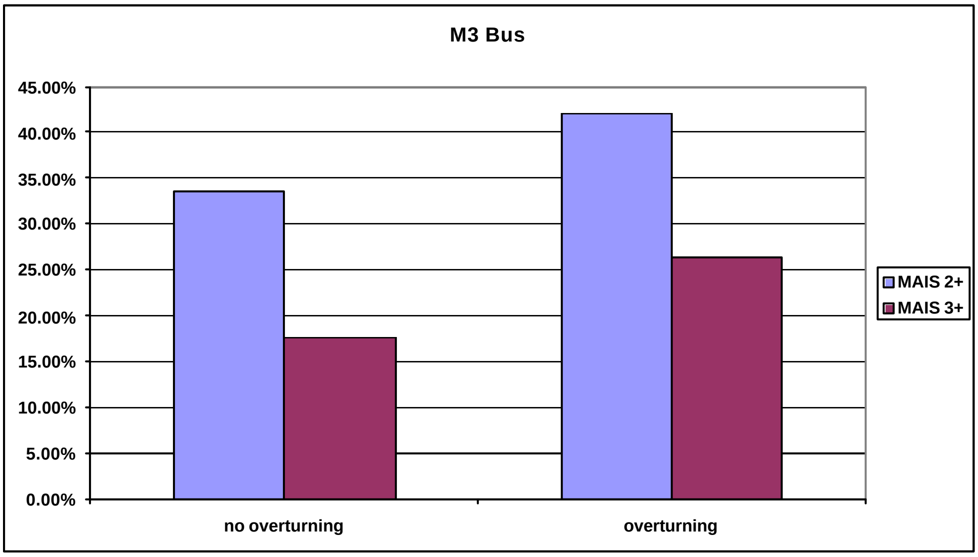


Figure 18: Casualty MAIS by Occurrence of Overturning

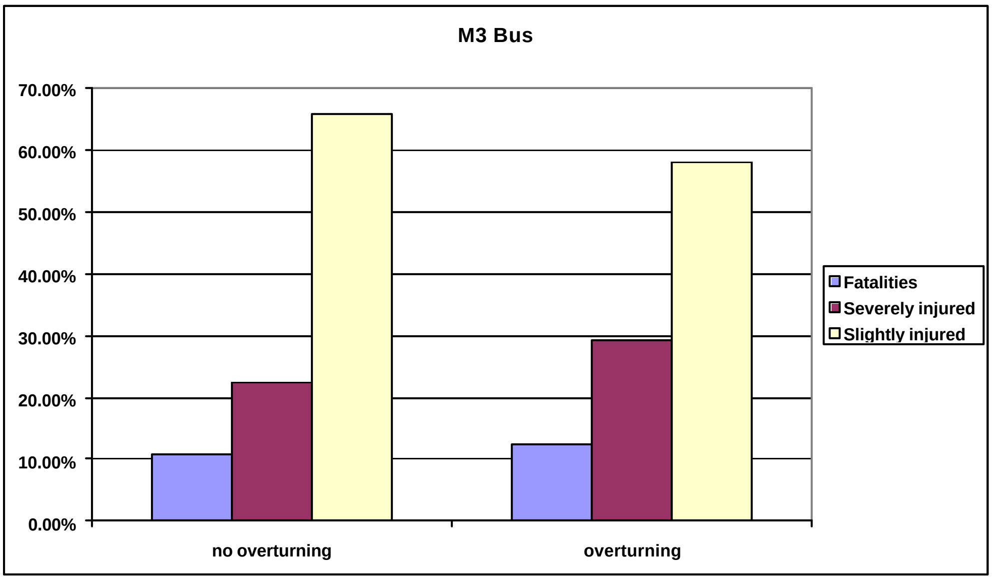


Figure 19: Casualty MAIS by Occurrence of Overturning

The figures above show that an overturned M3 bus increases the risk of injury severity.

11.2.5 MAIS Distribution Opponent versus Kind of Accident

The following diagrams show the distribution of accident opponent versus kind of accident. Since the number of cases is small, sometimes only 1, a general tendency can not be evaluated. The presentation of the kind of accident s can be taken to detect relations between the locations of the occupants in the bus and the impact situation. Based on this investigation the main causes or the injury will be detected.

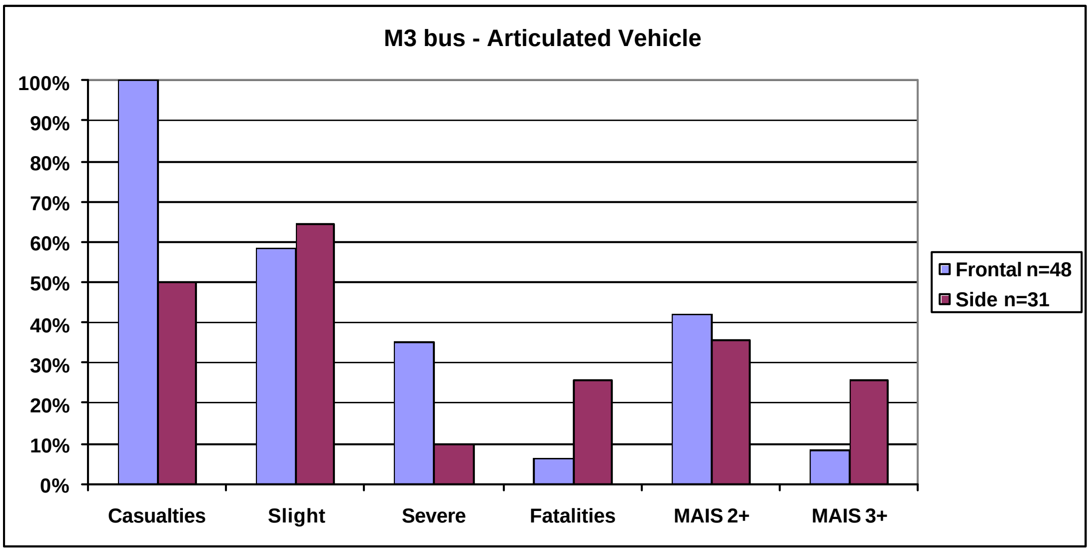


Figure 20: Opponent Articulated Vehicle

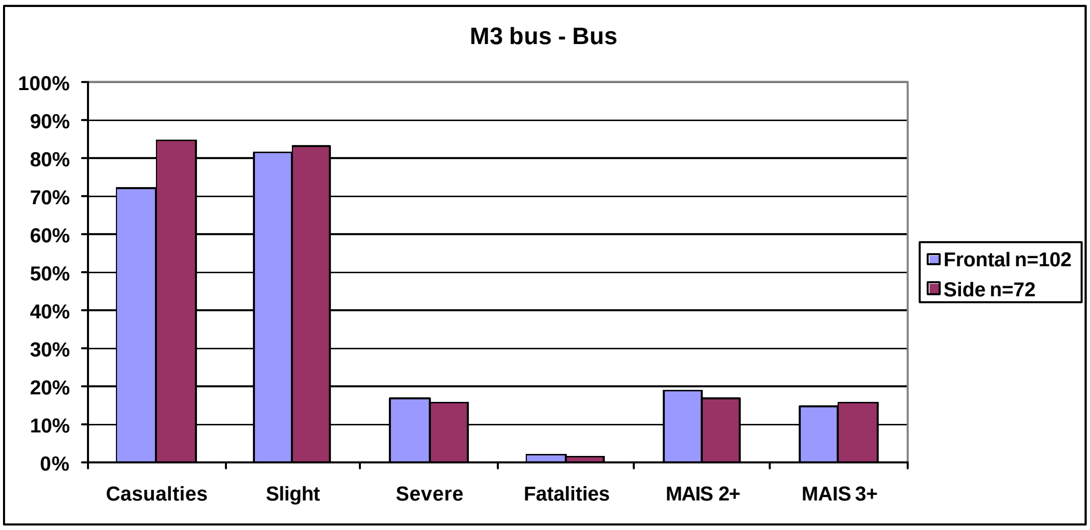


Figure 21: Opponent Bus

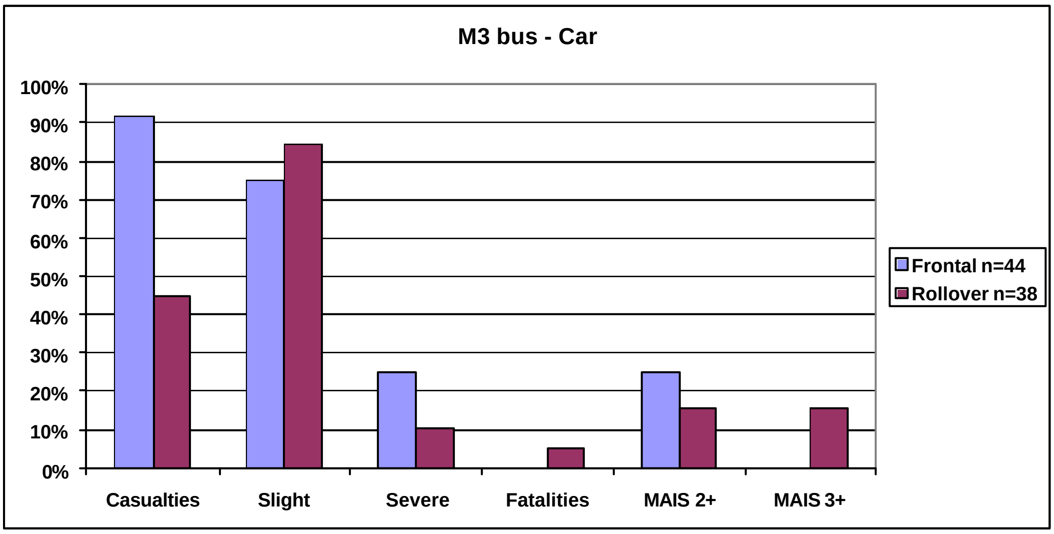


Figure 22: Opponent Car

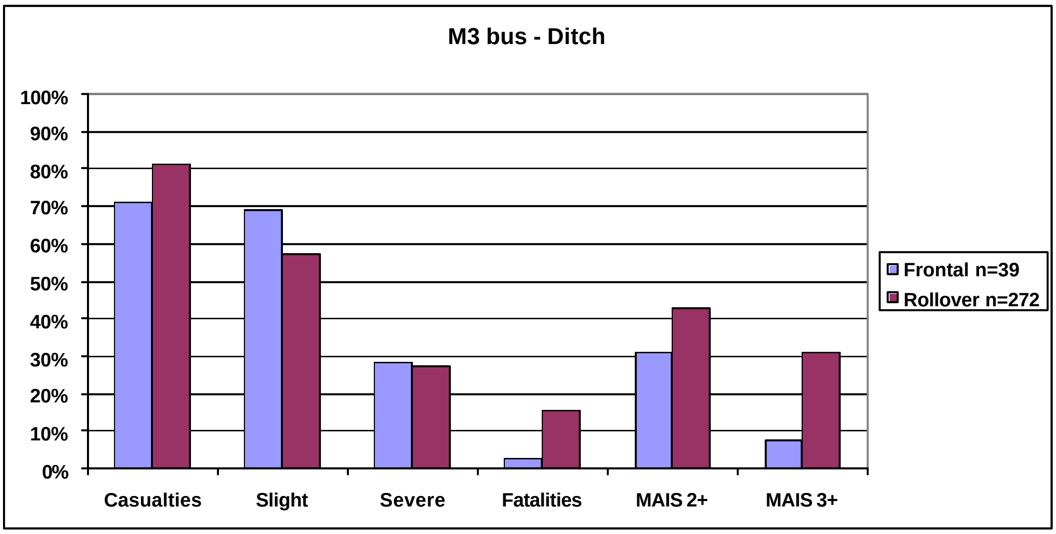


Figure 23: Opponent Ditch

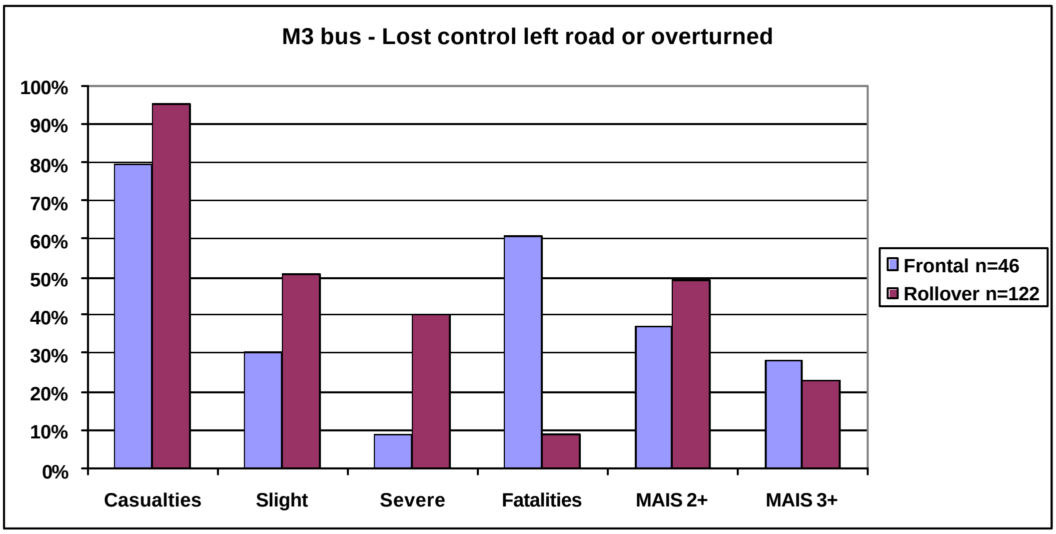


Figure 24: Opponent: Lost control left road or overturned

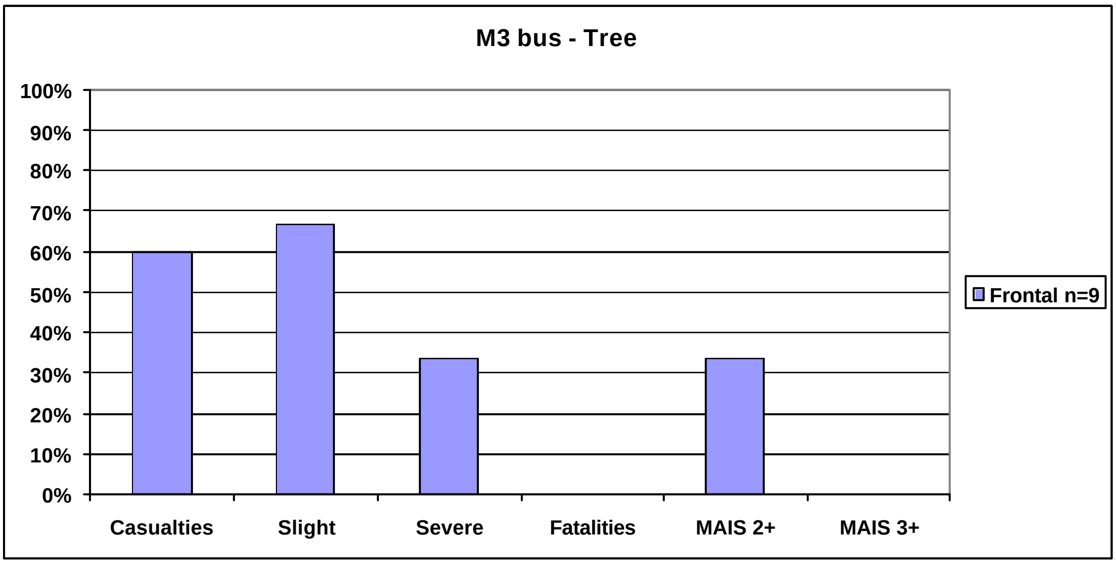


Figure 25: Opponent Tree

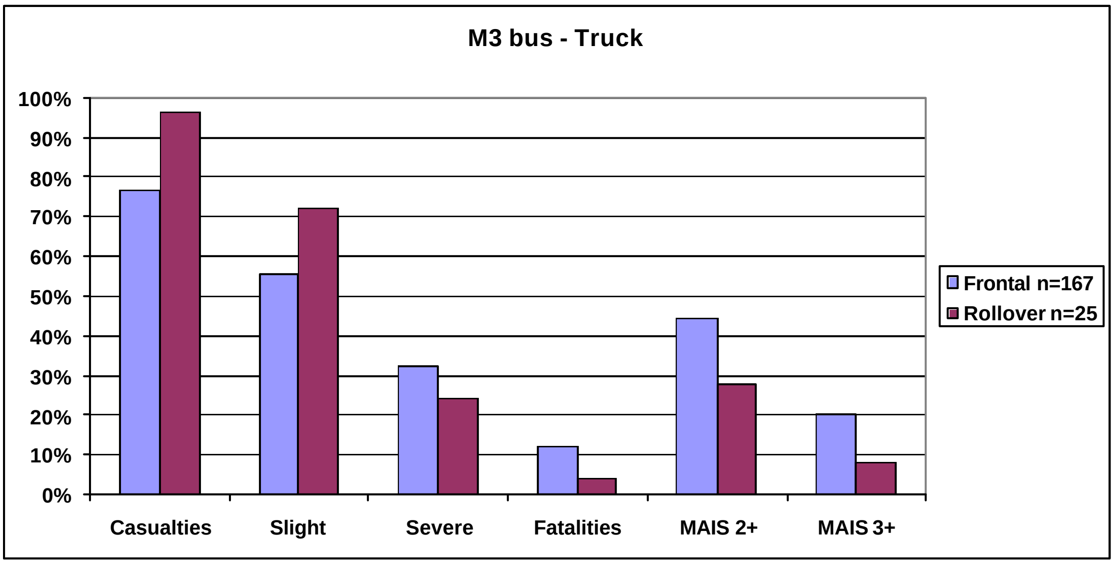


Figure 26: Opponent Truck

11.2.6 Body Region Injuries

Using the in-depth database a general picture is formed of which body regions are more susceptible to injury in M3 accidents. Figure 27 shows a general overview on the MAIS values relating to the body regions and indicates a higher risk of serious injury for the head, chest and extremity regions. These results are for all types of accident.

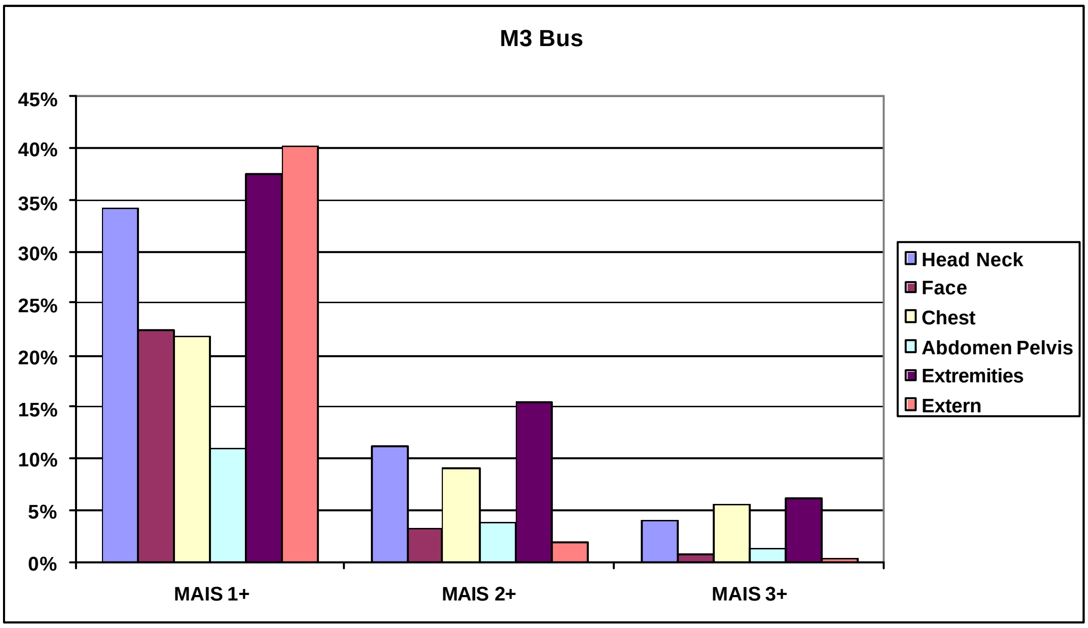


Figure 27: General Body Region MAIS

The following figures show the distribution of body region MAIS versus the different kinds of accidents.

Frontal Impacts:

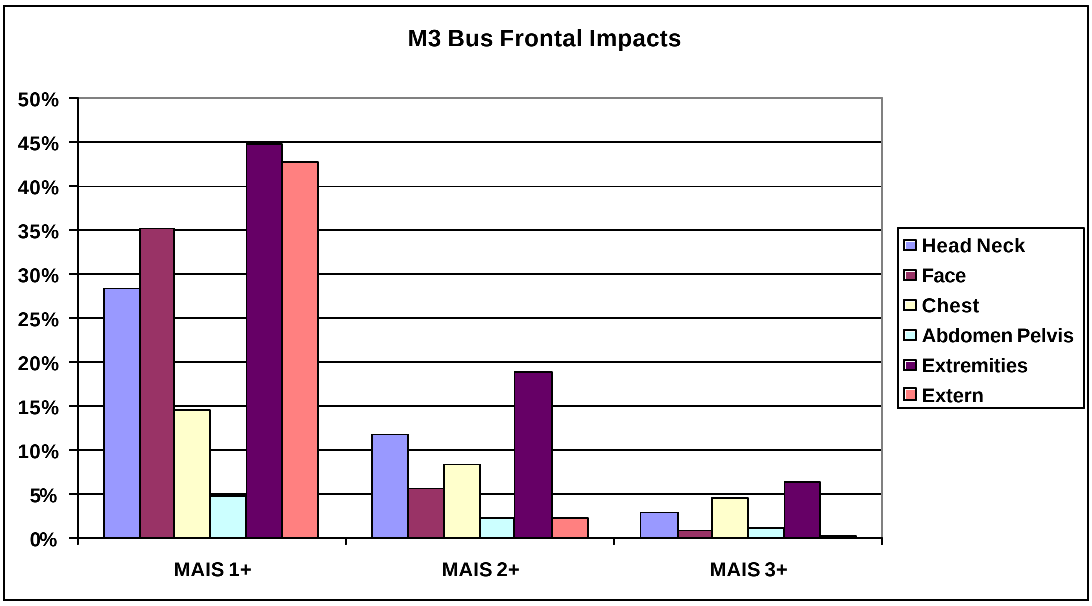


Figure 28: Body Region MAIS for Frontal Impacts

Rollover:

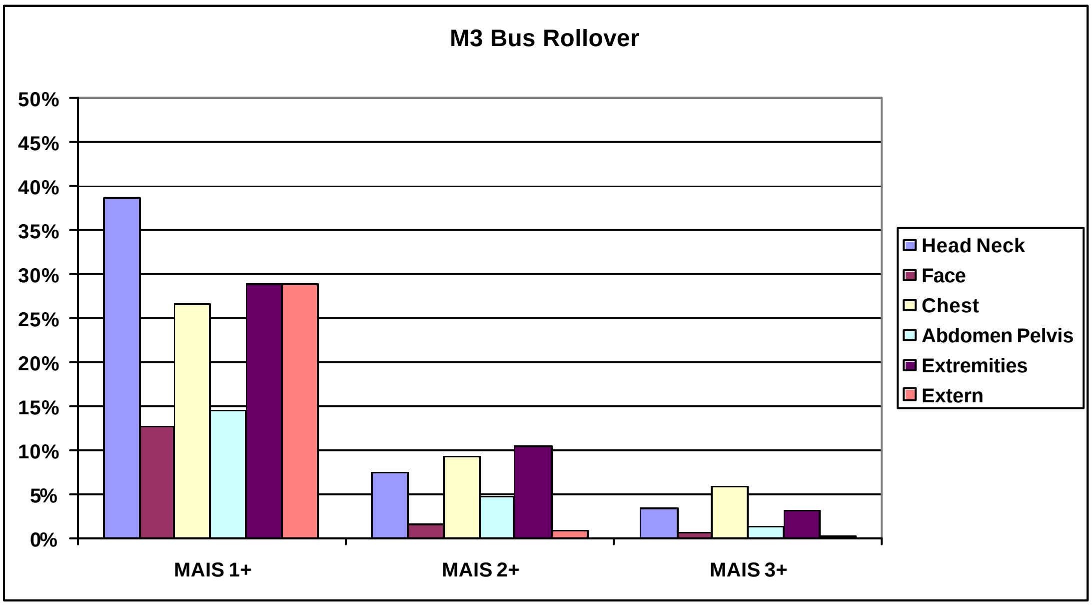


Figure 29: Body Region MAIS for Rollover Incidents

Rear End:

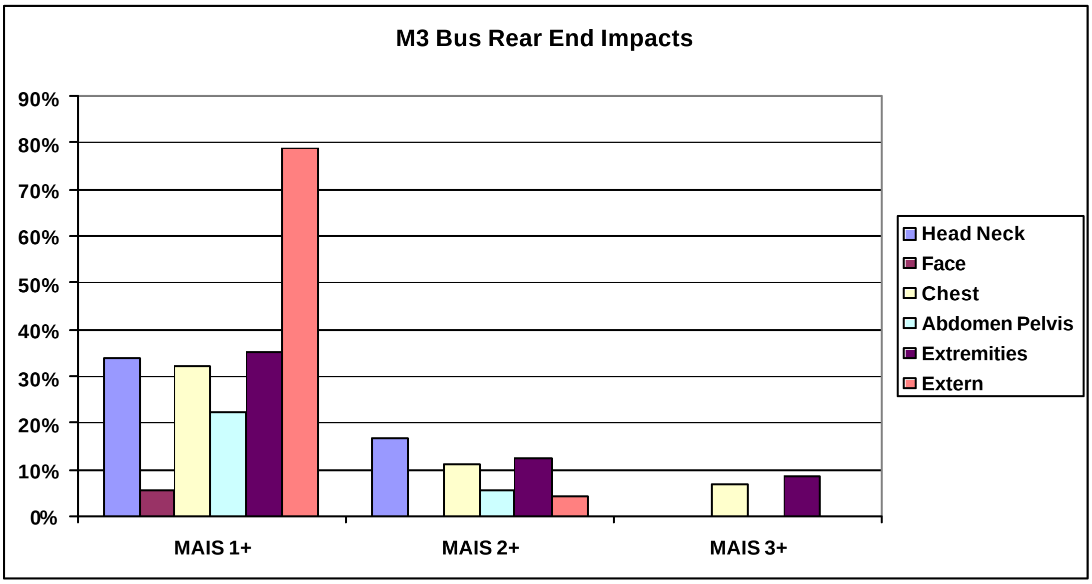


Figure 30: Body Region MAIS for Rear End Impacts

11.3 Citybus Accident Circumstances

The data presented in the following chapter are basically statistical since the investigation of "non spectacular" no collision accidents is very difficult. All data relate to the Austrian statistics and cover a 5 years period. The general kind of accident distribution shown in the figure below displays that more than half of all injuries are caused due to emergency braking. Since this is its own category in the accident data form it is assumed that no further impacts with other vehicles occur.

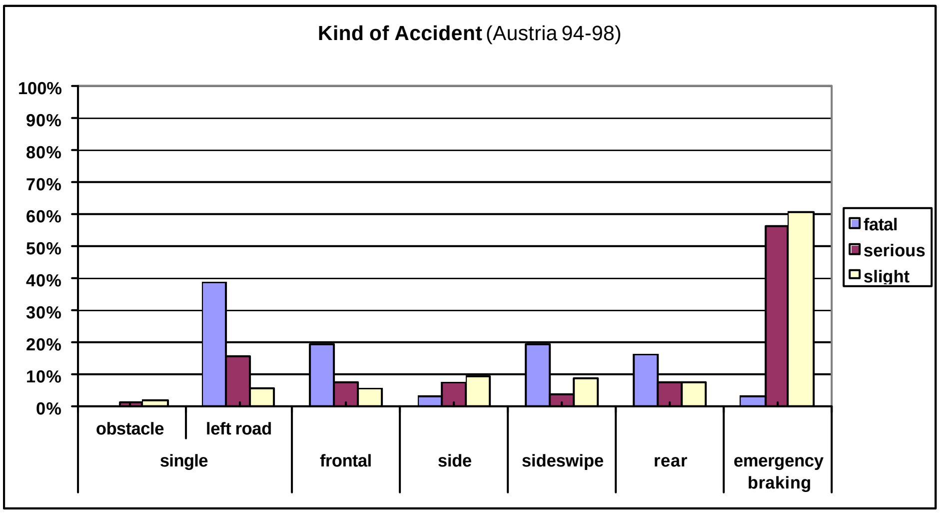


Figure 31 - Injury Percentage by kind of accident

The detailed distribution within the category 'No Collision Accidents' is shown in the figure below. More than 95% of all casualties are caused by emergency braking. Although the distribution of the fatalities seems to be more even the real cause for that distribution is the very low number of fatalities in that category. The total numbers that were taken for this diagram are shown in Table 9.

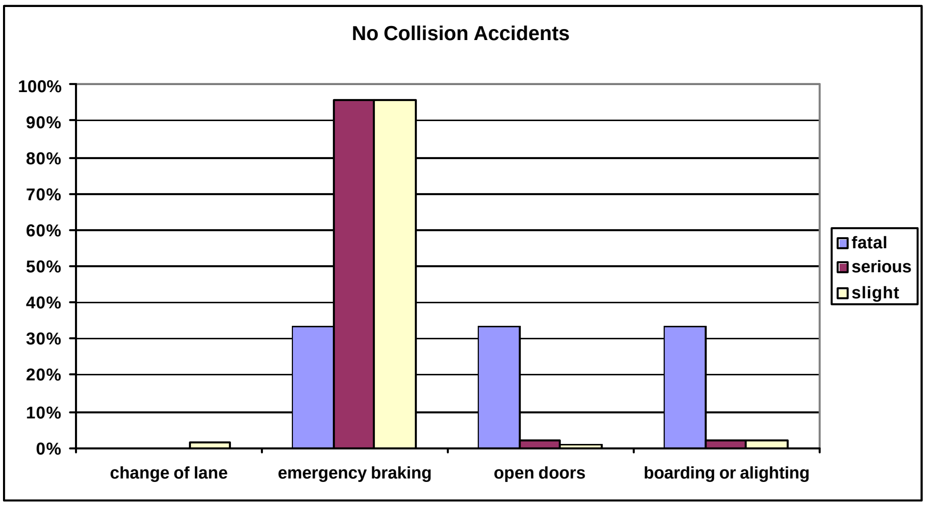


Figure 32 - Injury Percentage by kind of no collision accident

1994-98	Number of Casualties				
	Fatal	Serious	Slight	Unknown	Total
Change of lane	0	0	12	0	12
Emergency braking	1	93	819	41	954
Open doors	1	2	6	0	9
Boarding or alighting	1	2	17	0	20
total	3	97	854	41	995

Table 9 - Total numbers of casualties by no collision accidents

The evaluation of the category ‘Emergency Braking’ shows that nearly 90% of all casualties suffer slight injuries, about 10% suffer serious injuries and a very small share suffer fatal injuries. This distribution can be derived from the occupant impacts with interior parts under lower impact velocities due to weaker deceleration pulses of the vehicle and basically no intrusions.

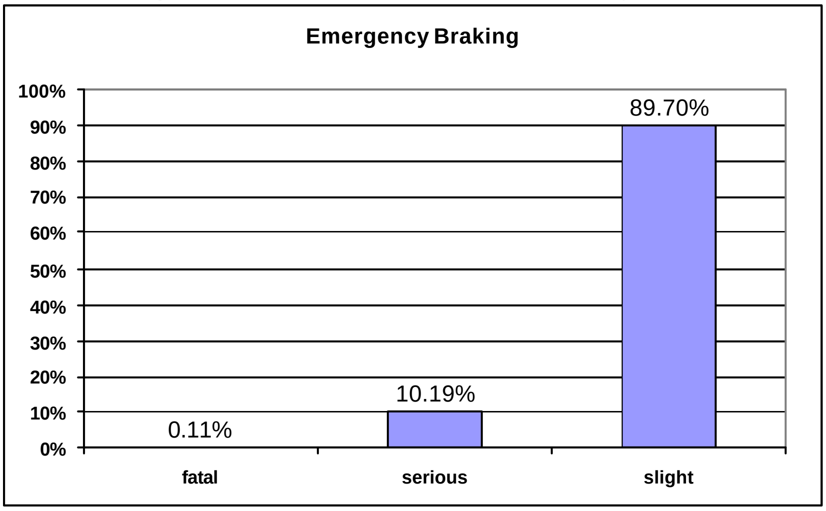


Figure 33 - Injury percentage by emergency braking

12 Frontal Impact Results

12.1 Frontal Impact Results - M2 Vehicles

12.1.1 Simulations

The following baseline frontal impact simulation was of a real world accident involving an M2 vehicle impacting a mature tree at approximately 45kph. Figure 34 shows the movement of the unbelted dummy at 50ms intervals.

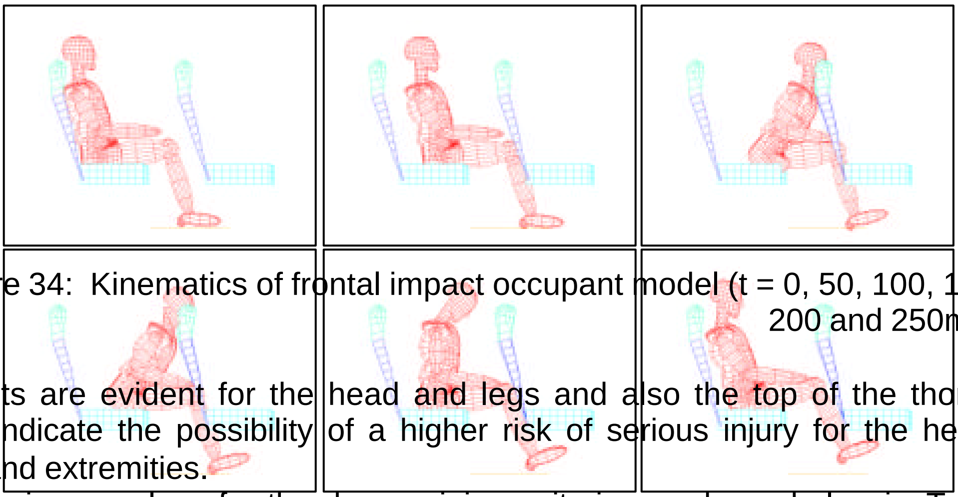


Figure 34: Kinematics of frontal impact occupant model (t = 0, 50, 100, 150, 200 and 250ms).

Contacts are evident for the head and legs and also the top of the thorax which indicate the possibility of a higher risk of serious injury for the head, chest and extremities.

The maximum values for the dummy injury criteria are shown below in Table 10, compared with the values obtained from the instrumented dummy in the full-scale frontal impact reconstruction and the injury criteria limits.

12.1.1.1 Comparison with Injury Criteria Limits

Injury criteria	**Simulation values**	**Test values**	**Criteria limits**
HIC	911	904	1000
Head accel. resultant (g)	162	173	N/a
Head accel.3ms (g)	130	103	80
Chest accel. resultant (g)	54	41	N/a
Chest accel. 3ms (g)	49	33	60
Pelvis accel. resultant (g)	42	37	130
Femur load (kN)	5.7	6.5	9.07

Table 10 - Peak values of occupant injury criteria during frontal impact (simulation and test).

The high HIC values, although lower than 1000, indicate a possibility of serious head injury when the head of an unbelted occupant strikes the seat in front.

Further M2 frontal impact configurations were performed by CIC during Task 2.6 and are analysed in the next section.

12.1.2 Parametric Studies

Each of the following models varied one parameter from the baseline model shown above. The resulting injury mechanisms have then been discussed.

12.1.2.1 Seat Back Padding Stiffness

When the baseline seat back padding stiffness was increased by 50%, it resulted in significantly higher injuries to the head (HIC increase of 53%) increasing the risk of serious/fatal head injury. Although the pelvis load increased by 57% it remained well below the accepted limit. Chest, pelvis and femur injuries would probably be minor.

When the baseline seat back padding stiffness was decreased by 33%, it resulted in significantly lower head injuries (HIC decrease of 62%) meaning a possible serious/fatal head injury would be avoided. Chest, pelvis and femur loads were very similar to those of the baseline dummy.

12.1.2.2 Seat Back Breakover Stiffness

The baseline seat back breakover stiffness used test data taken from an M2 seat with 3-point seatbelts which was relatively stiff in order to take the high shoulder belt loads. Therefore the parameter study reduced the baseline seat back stiffness to represent other potential M2 seats.

When the baseline seat back stiffness was reduced by 40%, it resulted in only a slight reduction of the injury loads. The HIC value decreased by 12% still leaving the possibility of a serious head injury. The other injury criteria remained within 5% of the baseline values.

When the seat back stiffness was reduced by 90% (i.e. stiffness was 10% of the baseline stiffness), it resulted in significant head and chest injury reductions where only minor injuries would have occurred. However, the seat back deformed significantly and did not restrain the occupant, leaving them free to impact other obstacles with a relatively high velocity.

12.1.2.3 Occupant Wearing a Seat Belt

The baseline model was for an unbelted occupant impacting into the back of the seat in front, resulting in head, chest and knee contacts along with their associated injuries.

When a lap-belt was used the pelvis was gradually slowed due to the belt's initial slack and stiffness. Although this caused the torso to rotate about the restrained pelvis, the impact velocity of the head onto the seat top was less than for the unrestrained baseline scenario. Hence the HIC value was lower by 19% leaving a risk of serious head injury. The femur and pelvis loads were significantly reduced as minimal contact occurred between knee and seat back.

When a 3-point belt was used, no head contact with the seat in front occurred. The other injury criteria were all below the accepted limits, however, it is likely the occupant would have sustained minor injuries such as bruising/whiplash due to the interaction with the seat belt.

12.1.2.4 Occupant Size

The baseline model used a 50%ile male Hybrid III dummy.

When using a 95%ile male dummy all the injury loads were reduced from the baseline values, except for the femur loads. The geometry of the dummy caused it's head to clear the top of the seat in front (see Figure 35 below), resulting in the chest contacting the relatively soft seat top. The femur loads were within 15% of the accepted limit, however, in a larger body such as this the bones and joints would also be larger and hence stronger, and so the risk of breaks or dislocations would be low.

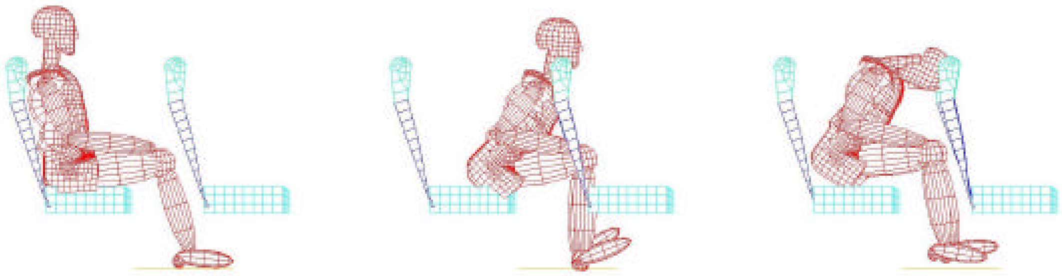


Figure 35 - Kinematics of 95%ile male dummy (t = 0, 100 and 200ms).

For the 5%ile female dummy all the injury levels increased from the baseline values. This would have resulted in a serious/fatal head injury along with other significant injuries in the other body regions. Figure 36 below shows the kinematics for the 5%ile female dummy.

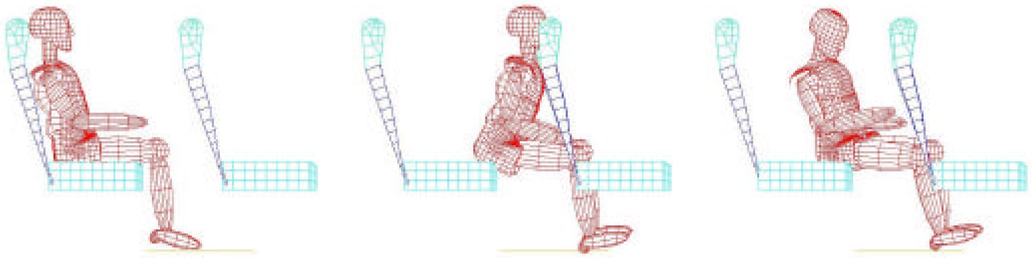


Figure 36 - Kinematics of 5%ile female dummy (t = 0, 100 and 200ms).

12.1.2.5 Crash Pulse

An increase in crash pulse caused the dummy’s head to glance the seat top and move above it. This resulted in relatively low head injuries, leaving the other body regions (i.e. chest, pelvis and femurs) to absorb the impact energy. The chest criteria was 10% above the accepted limit and so the risk of broken ribs and internal damage would be high.

The decreased crash pulse lowered all the injury levels slightly from the baseline values. This still left the occupant with risk of a serious head injury, with other body regions more likely to sustain only minor injuries.

12.2 Frontal Impact Results - M3 Vehicles

12.2.1 Simulations

The in-depth accident studies performed within the ECBOS project have generated a lot of very valuable data. During the simulation activities, the data has been subject to a detailed study, and has been used to improve and validate the simulation models wherever possible. However, to perform a complete accident reconstruction using computer simulations, as originally planned, the accident data and in particular the occupant injury data has proven to be of limited use. Taking this situation into account, it is not safe to summarise the most important mechanisms causing the injuries found within the studied accidents. Therefore TNO Automotive has performed a "sensitivity analysis" to provide the most influential parameter for the head, neck, thorax and upper leg injuries.

12.2.2 Parametric Studies - Sensitivity Analysis

A sensitivity analysis was performed to determine the influence of each variable parameter on the injury values. All optimisation variables were scaled to 90% and 110% of their optimised value for the 50th-percentile belted model. The results of this sensitivity study are presented in Figure 37.

From these analyses it can be concluded that for the upper part of the human body, the recliner stiffness has the most influence on the injury values. When the occupant is unbelted, the head-ashtray contact also has a large influence on the injury values.

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

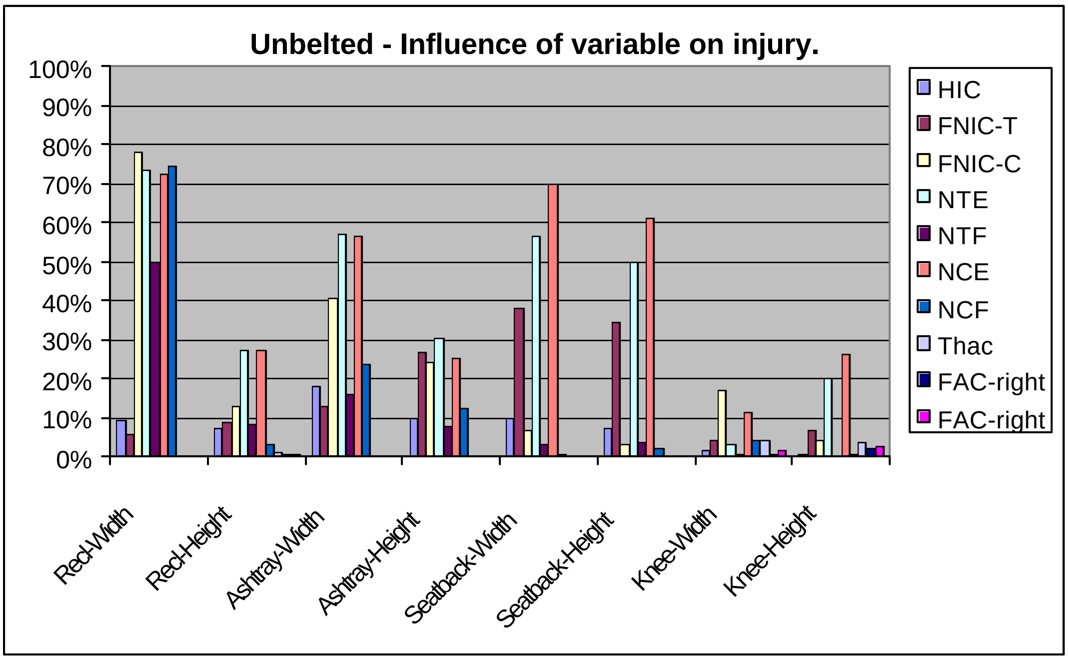


Figure 37

Occupant kinematics

The kinematics of one occupant during the crash can be affected by the presence of another occupant (Figure 38). This was found to be especially relevant when occupants are wearing a two-point belt, as the occupants can introduce an additional loading to the recliner in front of them and thereby influence the kinematics of the occupant in front of them.

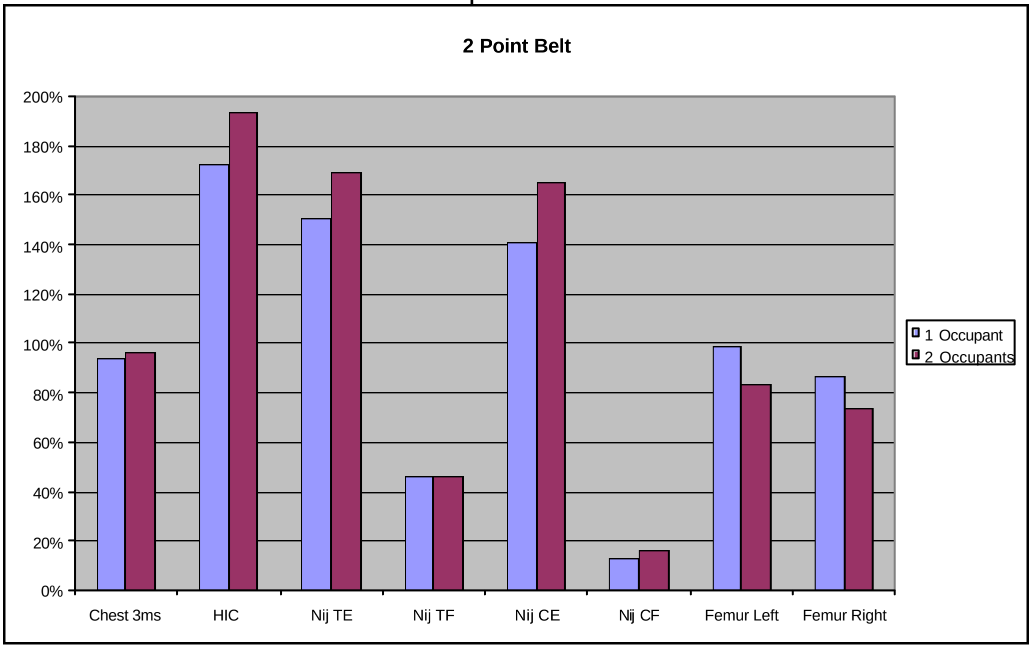


Figure 38

In general, when multiple occupants (Figure 39) are interacting during a crash, it was still found to be beneficial to use the optimised interior instead of the original seat characteristics.

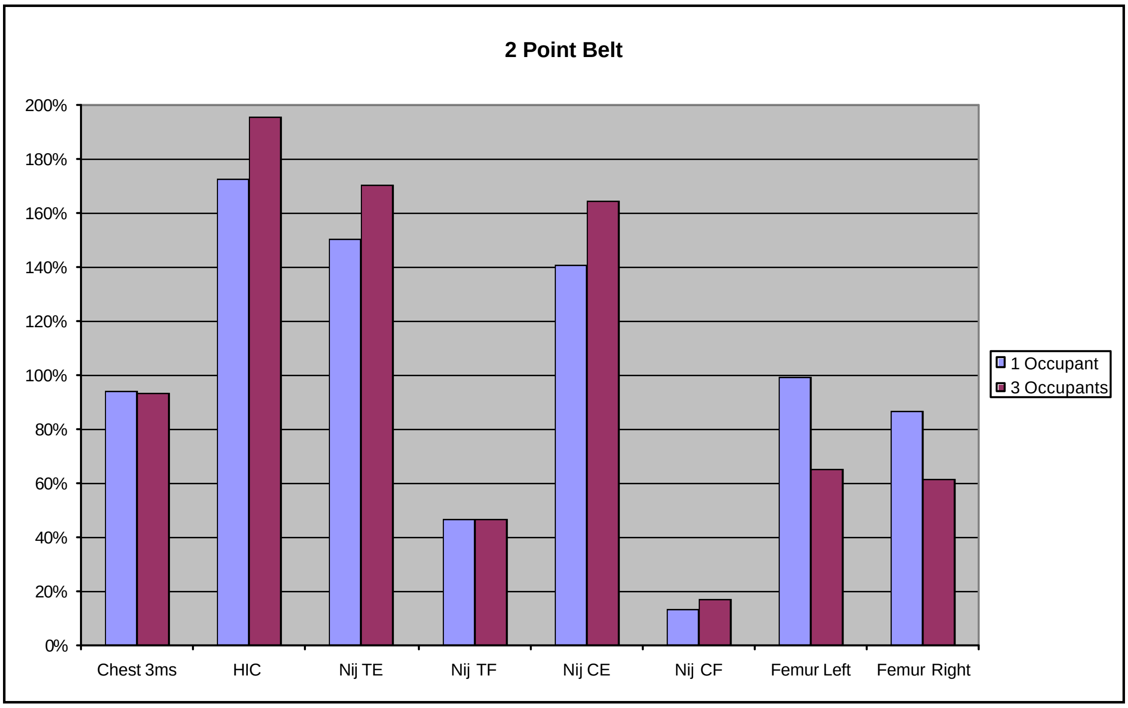


Figure 39

13 Rollover Results

13.1 Rollover - M2 Vehicles

13.1.1 Simulations

The following rollover simulation was for an M2 vehicle undergoing the UN-ECE Regulation 66 rollover test, which is designed for M3 coaches. Figure 40 shows the movement of the unbelted dummy at 60ms intervals.

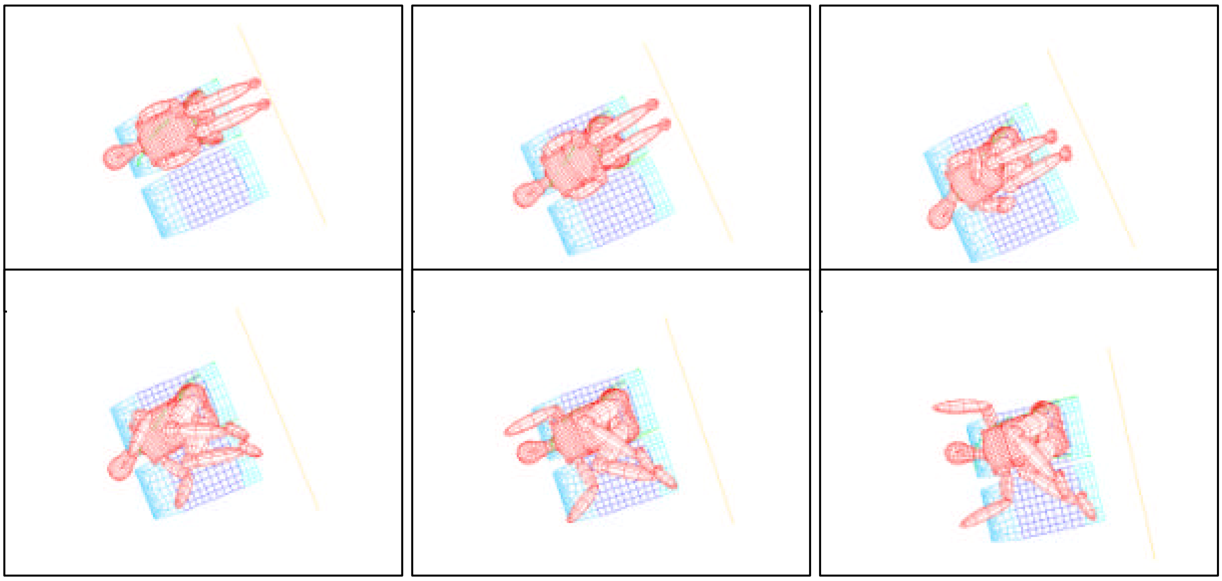


Figure 40 - Kinematics of M2 rollover occupant model (t = 0, 60, 120, 180, 240 and 300ms).

The baseline M2 occupant rollover model shows the occupant seated away from the ground contacting side of the vehicle and restrained by a 3-point seat belt. Both the simulation and test showed the occupant to be adequately restrained, removing any possibility of injuries through body contact with the vehicle structure or fixed interior components.

13.1.1.1 Comparison with Injury Criteria Limits

Injury criteria	**Simulation values**	**Test values**	**Criteria limits**
Head accel. resultant (g)	18.2	14.8	80
Neck moment X (Nm)	21.4	22.4	57
Neck moment Y (Nm)	17.8	14.7	57
Neck moment Z (Nm)	10.7	10.7	57
Chest accel. resultant (g)	17.0	14.3	60

Table 11 - Peak values of occupant injury criteria during rollover (simulation and test).

Injury criteria for the 3-point belted occupant are well within the accepted limits. The shoulder belt prevents any significant upper body rotation and so keeps the occupant close to the rotating seat. The M2 rollover crash pulse is not severe enough to cause any injuries through deceleration of the body segments.

Further M2 rollover configurations were performed by CIC during Task 2.6 and are analysed in the next section.

13.1.2 Parametric Studies

The occupant injury loads were generally within accepted limits during the M2 ECE-R66 rollover test. In general:-

- Two and three point belted occupants seated away from the ground contacting side of the vehicle were adequately restrained, resulting in relatively low injury loads to all parts of the body.
- Occupants seated next to the ground contacting side of the vehicle, whether belted or not, were effectively restrained by the sidewall of the vehicle. The occupant's shoulder would contact the sidewall before gaining a high velocity, resulting in rotation of the head and neck. However, head contact with the sidewall/side window was minimal.

Two configurations did however increase the occupant's injury loads. These were:-

13.1.2.1 Increased Stiffness of Sidewall

The normal stiffness properties for occupant head contact with the sidewall were taken from the FMH drop test onto toughened glazing. This was considered to be the most likely scenario due to the high proportion of glazing at a seated occupant's head height. The following simulation increased the sidewall stiffness by using the results from the FMH drop test onto an M3 window pillar, which included plastic interior trim.

Figure 41 shows the movement of the dummy at 100ms intervals.

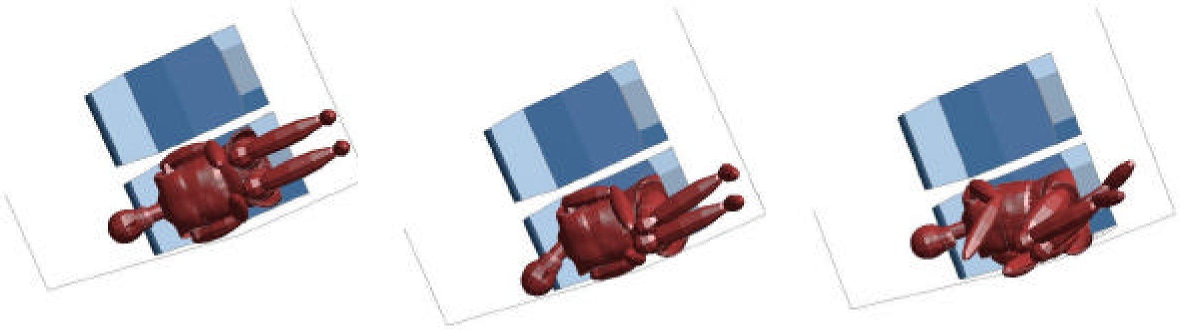


Figure 41 - Kinematics of M2 rollover occupant model seated next to sidewall with increased stiffness properties (t = 0, 100 and 200ms).

The initial window pillar stiffness was approximately three times greater than that of the glazing. This resulted in an increased HIC value of 224, compared to the original value of 74. Both these values are well within the 1000 limit, resulting in only minor head injuries, but the simulation highlights the importance of well padded interiors.

The particular window pillar used during the FMH tests was not well designed and resulted in a HIC value of 1956 (i.e. serious/fatal injury) when impacted at the test speed of 6.7m/s. The HIC value was much lower during the rollover scenario as the closing velocity between sidewall and head was approximately 0.5m/s.

13.1.2.2 Unbelted Occupant Seated Away From Sidewall

Here the occupant was seated one seat away from the sidewall and so gained a greater velocity before impact. Figure 42 shows the movement of the dummy at 100ms intervals.

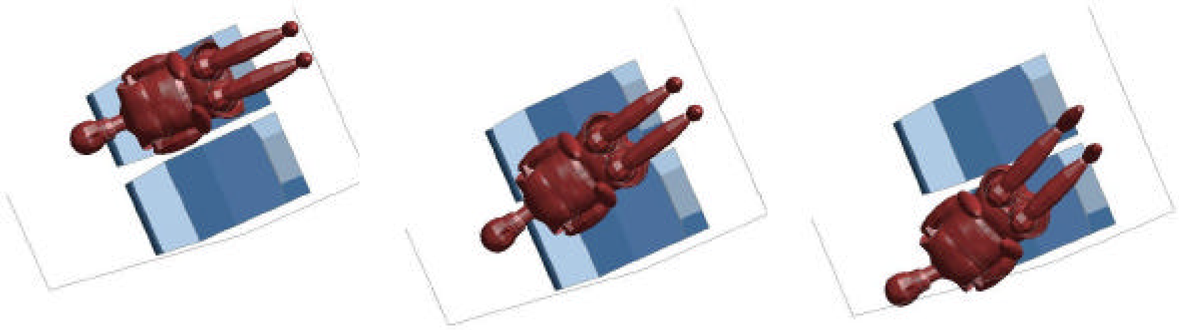


Figure 42 - Kinematics of unbelted M2 rollover occupant model seated away from sidewall (t = 0, 100 and 200ms).

Table 12 compares the injury loads sustained by the unrestrained and 3-point belted dummies seated one seat away from the vehicle sidewall.

	HIC	Head accel. (g)	Head accel. 3ms (g)	Neck moment (Nm)	Chest accel. (g)	Chest accel. 3ms (g)	Pelvis accel. (g)
3-pt seatbelt	(38)	19	18	20	17	16	21
Unrestrained	2092	152	134	247	33	28	24
Criteria limits	1000	-	80	57	-	60	130

Table 12 - Comparison of injury loads for occupant seated away from sidewall.

The upper body injuries were shown to be far greater when the seatbelt is not worn. The occupant gains momentum before impacting the sidewall resulting in greater impact velocities. The simulation also shows that the upper body rotates, as the dummy free-falls, causing the head to sustain serious/fatal injuries and the neck would probably be broken. Injuries to the chest and pelvis were within the accepted limits.

The risk of injury shown by this analysis would increase further still for occupants seated even further away from the ground contacting sidewall of the vehicle. Also ejection of occupants becomes more likely when the occupants are unrestrained.

13.2 Rollover - M3 Vehicles

13.2.1 Simulations and Parametric Studies

This document details the work performed by Polito within Task 2.5 (cause of injury) of the ECBOS project. Using the results obtained for Task 2.6 (Parametric study) it was analysed how a passenger interacts with the structure and how the type of restraint system and the position inside the bay section affect this interaction.

13.2.1.1 General Description

As explained in the Polito Task 2.6 report, several simulations of a standard ECE66 bay section rollover test with a EuroSID dummy positioned inside the bay section were performed. Starting from a standard configuration, which corresponds to the CIC bay section, some important parameters were submitted to quite large modification of their value, one by one, in order to evaluate their influence on the injury risk for passengers. For the purpose of this document the results concerning the following parameters were considered:

Restraint system: Three different configurations were examined:

- Two point belt (BASCON)
- Three point belt,
  a) third point of the belt over the right shoulder (RGT3PB)
  b) third point of the belt over the left shoulder (LFT3PB)

Position: Four different positions inside the bay section were examined.

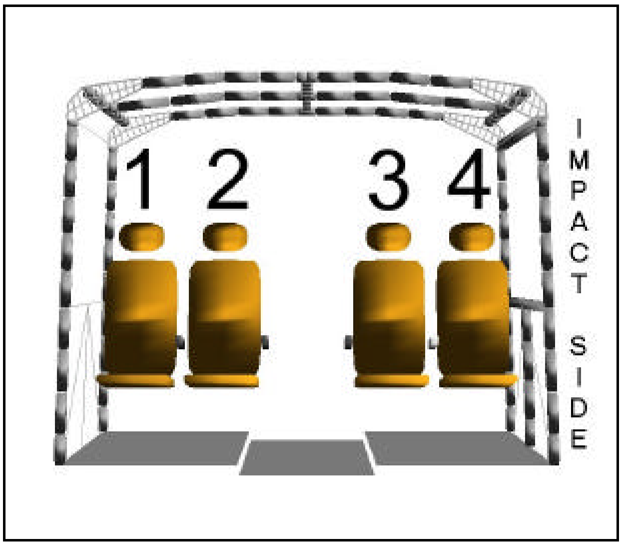
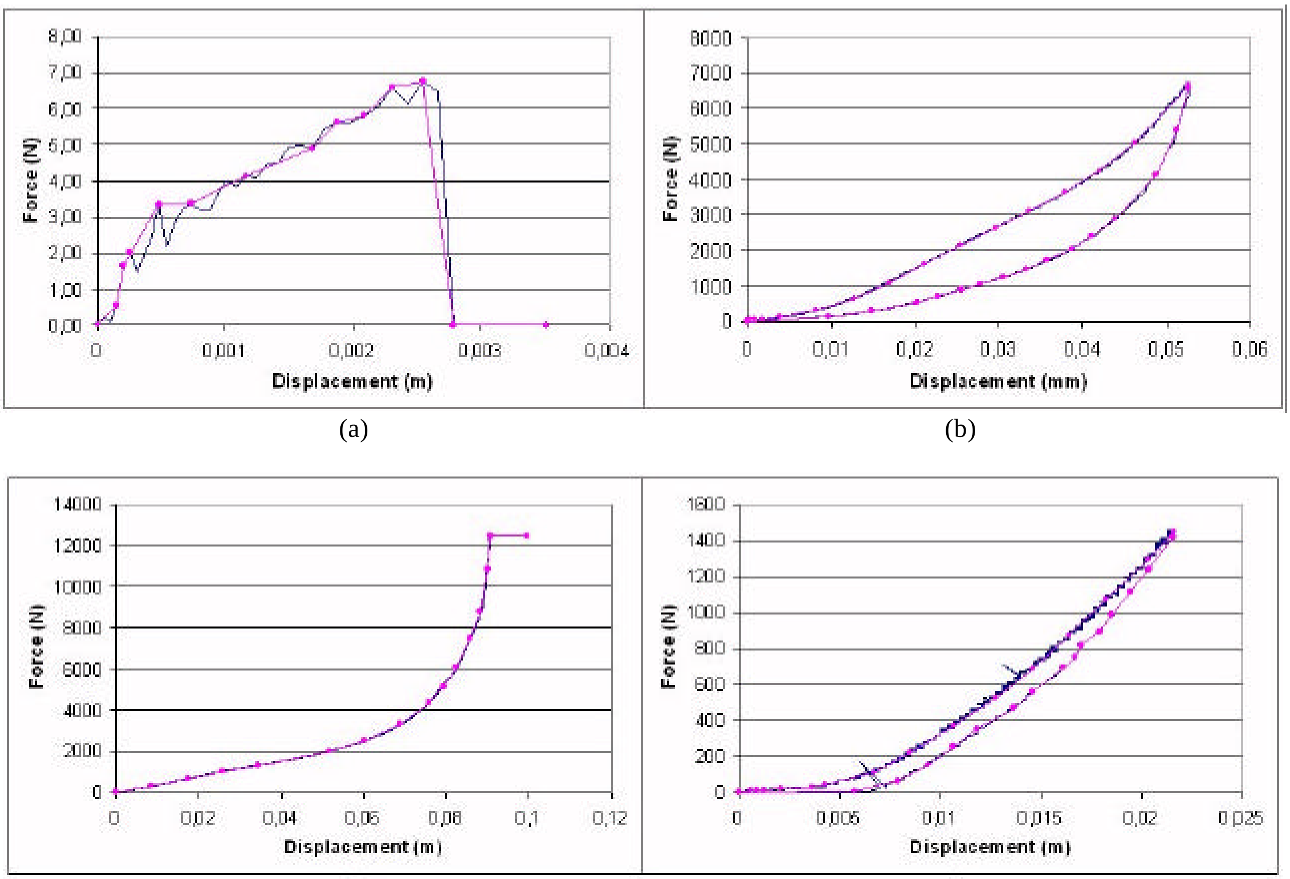


Figure 43 – Positions of the dummy inside the bay section

In all the simulations three ballast masses corresponding each to the weight of a 50th male EuroSID (about 72 kilos) were added to the mass of each seat in order to consider a fully occupied bay section.

In order to represent the interaction between the passenger and the internal parts of the coach (seats, side windows, pillars, etc.) some contact characteristics obtained from experimental tests performed by TNO and CIC for task 2.1 were included in the models. These characteristics are shown in following figures.

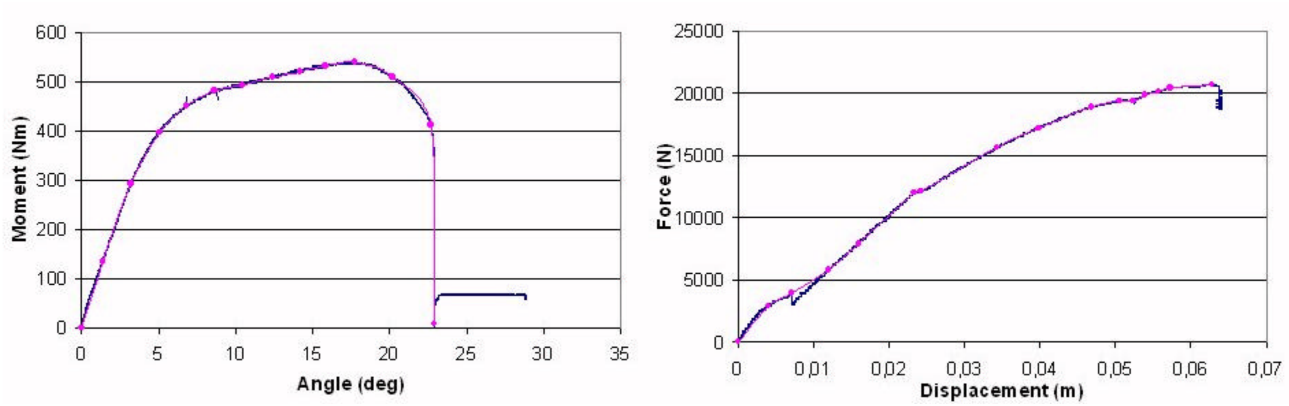


(a) (b)

(c) (d)

Figure 44 – Contact characteristics: (a) head – side window (CIC), (b) dummy – seat back (TNO), (c) dummy – seat base (TNO), (d) head – seat back (TNO)

To represent the structural behaviour of the seats during the rollover simulation two characteristics were assigned: the moment versus deflection curve of the seat back (Figure 45.a), the force – versus longitudinal displacement of the seat base (Figure 45.b). These characteristics were obtained from the experimental tests performed by TNO for task 2.1. In the transversal direction no information about the structural behaviour of a standard seat was available. Therefore, as the strength of the seat in this direction is lower than the one in the longitudinal direction, the same characteristic trend as shown in Figure 45.b was assumed to represent the structural behaviour of the seat in the transversal direction, but the force values were halved.



(a) (b)

Figure 45 – Seat characteristics: (a) seat back stiffness, (b) seat base longitudinal stiffness

13.2.1.2 Injury Parameters

In order to evaluate the injury risk for passengers the following injury parameters were calculated. As there isn't a regulation that fixes limit values of the previous injury parameters for a coach or a bus rollover accident, the limit values established by the directive 96/27/EC for a motorcar side impact were considered (limit values in parentheses).

- Head injury Criterion (HIC): 1000
- Thoracic Trauma Index (TTI): 90 g
- Viscous Injury Response (VC): 1 m/s
- Rib Deflection: 42 mm
- Pubic Symphysis Peak Force: 6000 N

It is important to underline that these limit values have to be intended as the values at which 80% of the corresponding human being does not suffer fatal injuries. If the index value results to be larger than this limit value the fatality or injury risk grows dramatically.

13.2.1.3 Results

For each position inside the bay section a simulation with a EUROSID dummy onboard was performed. The results of these simulations are shown in following tables and figures. In the figures the reference limit value is also shown to make easy the diagram interpretation, while in the tables the values over the limit are printed in red.

Dummy positions as in Figure 43.

POSITION 1		**BASCON**		**RGT3PB**		**LFT3PB**	
		Max Value	Time	Max Value	Time	Max Value	Time
		(abs)	(ms)	(abs)	(ms)	(abs)	(ms)
Upper Rib distance	(m)	7,66E-05	1676	8,42E-04	1733	3,12E-04	1750
Middle Rib distance	(m)	7,61E-05	1676	2,89E-04	1697	2,12E-04	1720
Lower Rib distance	(m)	7,56E-05	1675	3,37E-04	1697	2,30E-04	1718
HIC	(-)	8		51		50	
TTI (FIR100)	(g)	13		24		29	
VC - Upper Rib	(m/s)	6,79E-08	1687	1,42E-04	1696	1,67E-06	1742
VC - Middle Rib	(m/s)	3,29E-08	1680	6,61E-05	1696	1,67E-05	1701
VC - Lower Rib	(m/s)	4,56E-08	1680	9,80E-05	1695	3,02E-05	1699
Resultant Force Pubic Symphysis	(N)	10480	1710	12958	1690	14176	1694

POSITION 2		**BASCON**		**RGT3PB**		**LFT3PB**	
		Max Value	Time	MaxValue	Time	MaxValue	Time
		(abs)	(ms)	(abs)	(ms)	(abs)	(ms)
Upper Rib distance	(m)	7,33E-05	1652	8,97E-04	1710	3,29E-04	1750
Middle Rib distance	(m)	7,27E-05	1651	2,09E-04	1720	2,27E-04	1703
Lower Rib distance	(m)	7,27E-05	1651	2,45E-04	1703	2,71E-04	1698
HIC	(-)	56		52		55	
TTI (FIR100)	(g)	12		23		30	
VC - Upper Rib	(m/s)	4,39E-08	1663	1,22E-04	1681	1,60E-06	1728
VC - Middle Rib	(m/s)	2,90E-08	1655	1,63E-05	1679	3,04E-05	1681
VC - Lower Rib	(m/s)	4,94E-08	1655	3,91E-05	1677	5,71E-05	1680
Resultant Force Pubic Symphysis	(N)	9874	1679	3495	1674	11503	1673

POSITION 3		**BASCON**		**RGT3PB**		**LFT3PB**	
		Max Value	Time	Max Value	Time	Max Value	Time
		(abs)	(ms)	(abs)	(ms)	(abs)	(ms)
Upper Rib distance	(m)	5,91E-04	1694	9,45E-04	1750	3,66E-04	1750
Middle Rib distance	(m)	4,84E-04	1694	2,55E-04	1690	3,82E-04	1694
Lower Rib distance	(m)	3,74E-04	1694	2,91E-04	1689	3,02E-04	1691
HIC	(-)	6524		47		71	
TTI (FIR100)	(g)	36		26		35	
VC - Upper Rib	(m/s)	4,15E-04	1692	2,62E-04	1687	1,75E-05	1703
VC - Middle Rib	(m/s)	2,76E-04	1692	5,01E-05	1688	1,01E-04	1689
VC - Lower Rib	(m/s)	1,32E-04	1691	8,05E-05	1687	9,67E-05	1689
Resultant Force Pubic Symphysis	(N)	5126	1684	4846	1684	5933	1684

POSITION 4		**BASCON**		**RGT3PB**		**LFT3PB**	
		Max Value	Time	Max Value	Time	Max Value	Time
		(abs)	(ms)	(abs)	(ms)	(abs)	(ms)
Upper Rib distance	(m)	8,00E-03	1685	6,68E-03	1676	1,37E-02	1674
Middle Rib distance	(m)	1,48E-02	1660	2,16E-02	1671	2,02E-02	1652
Lower Rib distance	(m)	1,78E-02	1661	2,56E-02	1675	2,35E-02	1678
HIC	(-)	2055		1986		2398	
TTI (FIR100)	(g)	35		55		63	
VC - Upper Rib	(m/s)	3,48E-02	1649	2,45E-02	1652	7,32E-02	1650
VC - Middle Rib	(m/s)	8,18E-02	1655	2,17E-01	1650	2,55E-01	1648
VC - Lower Rib	(m/s)	1,42E-01	1658	2,95E-01	1649	2,31E-01	1648
Resultant Force Pubic Symphysis	(N)	8352	1654	10933	1653	9953	1653

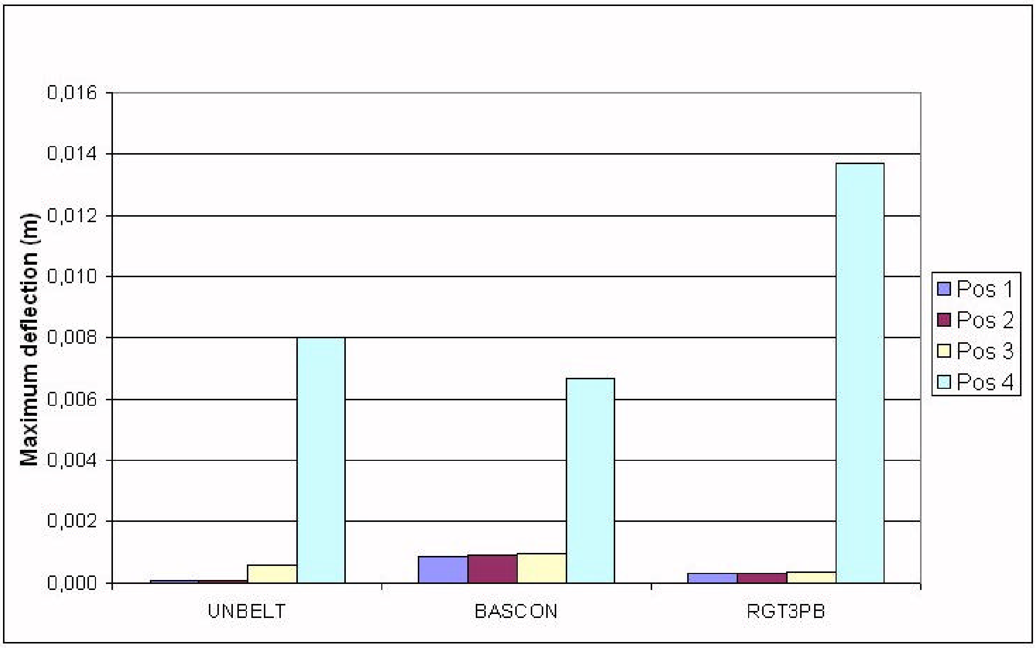


Figure 46 – Rib deflection (Upper Rib)

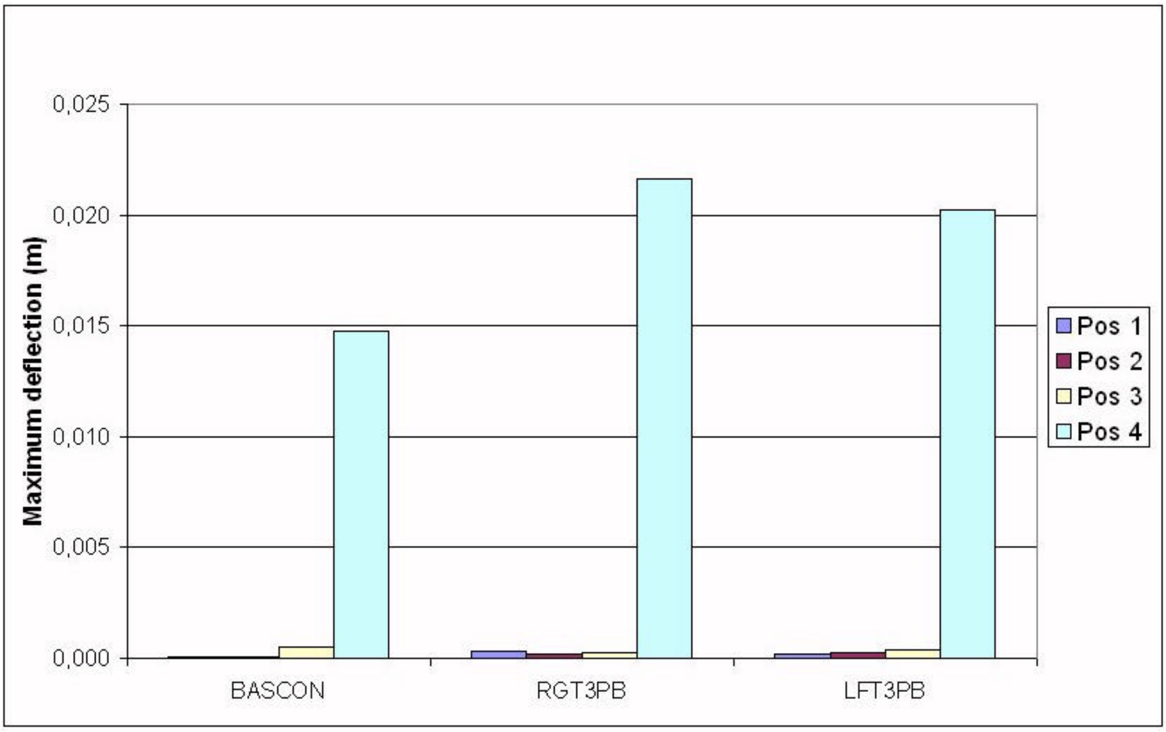


Figure 47 – Rib deflection (Middle Rib)

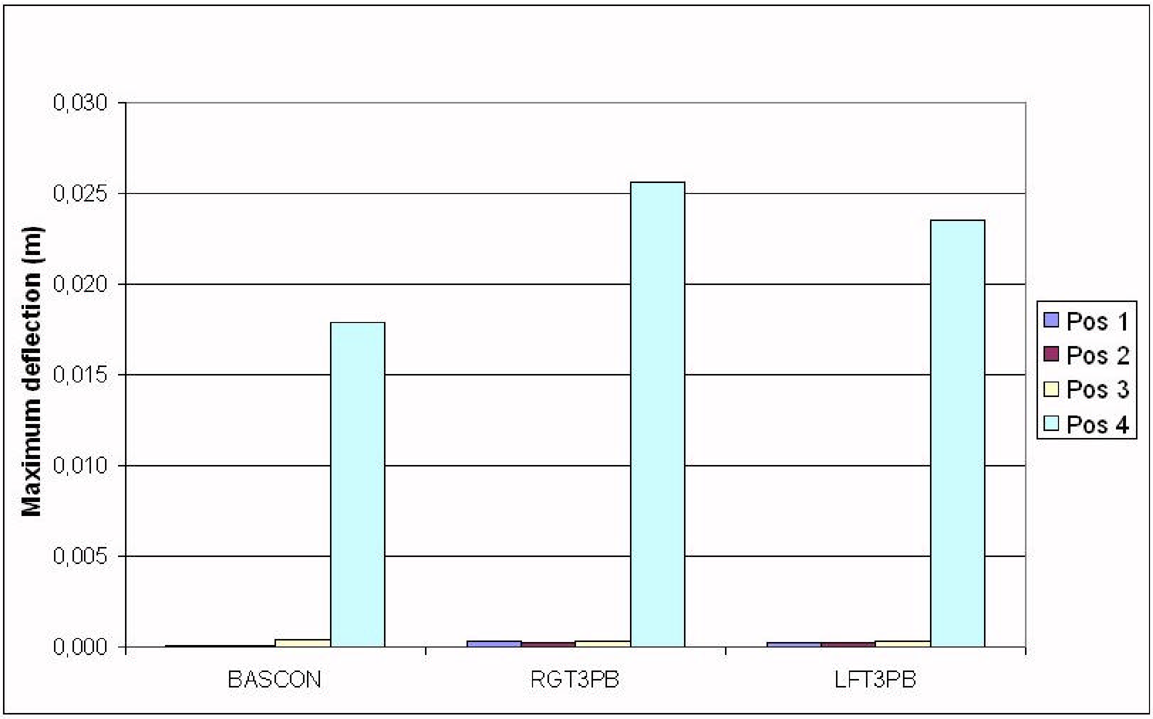


Figure 48 – Rib deflection (Lower Rib)

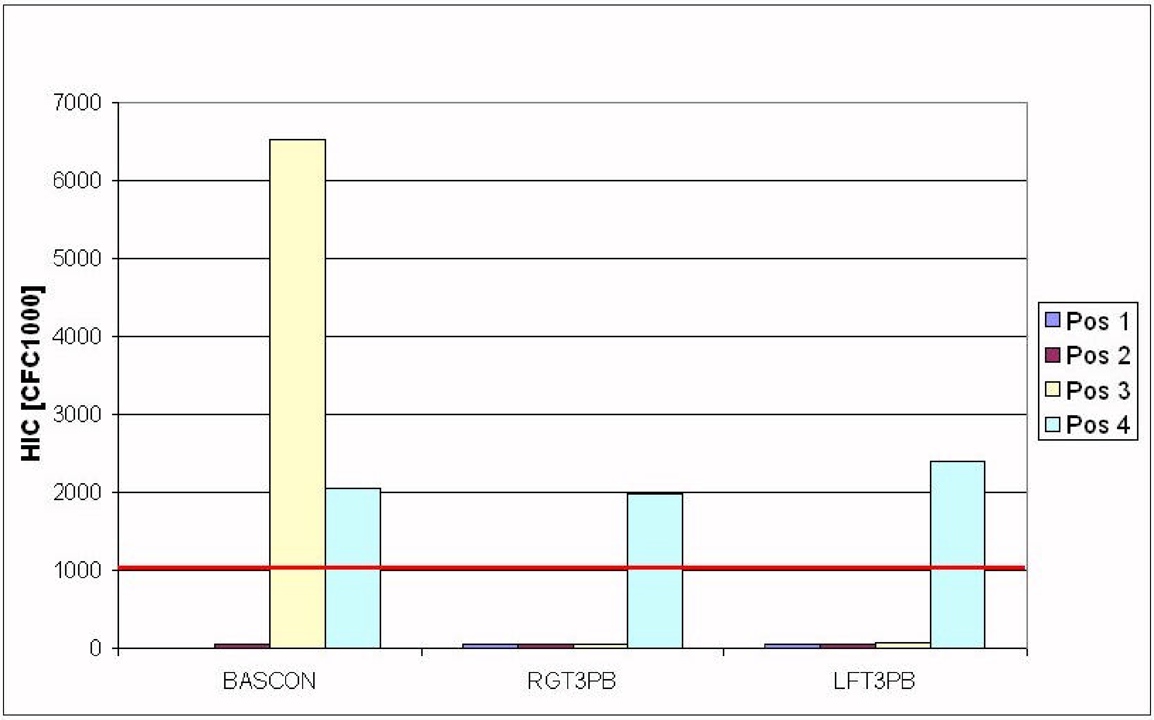


Figure 49 – Head Injury Criterion

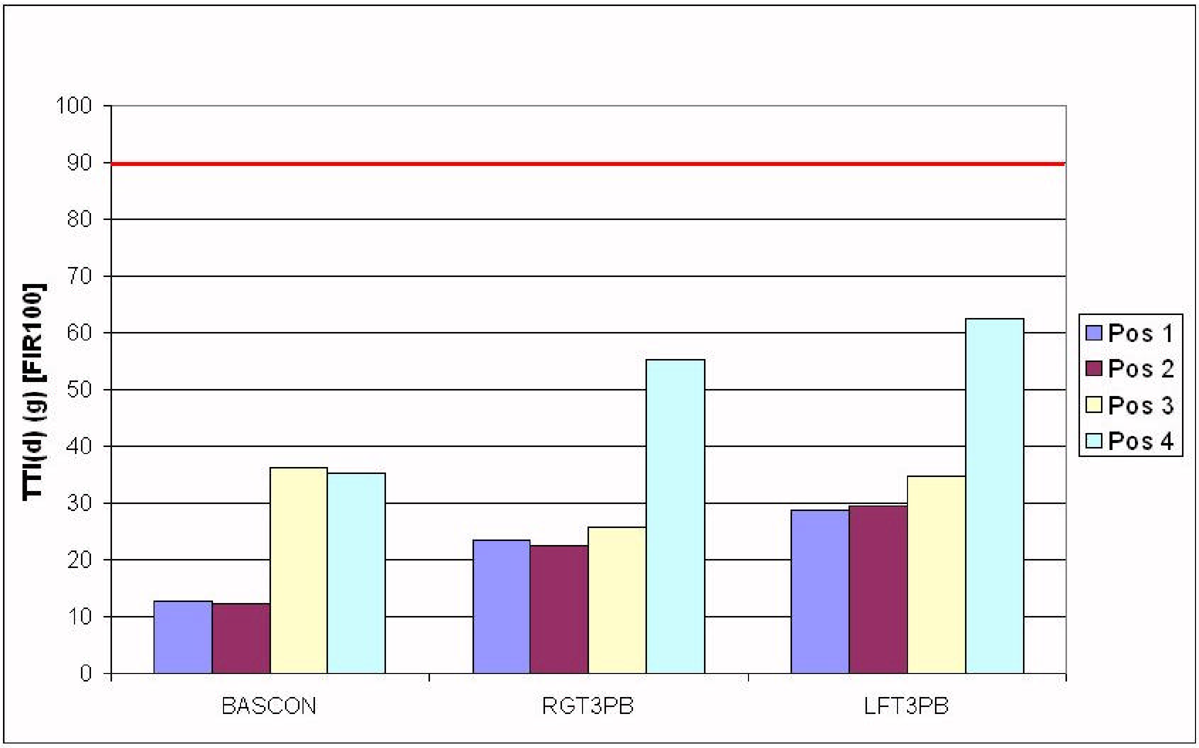


Figure 50 – Thoracic Trauma Index

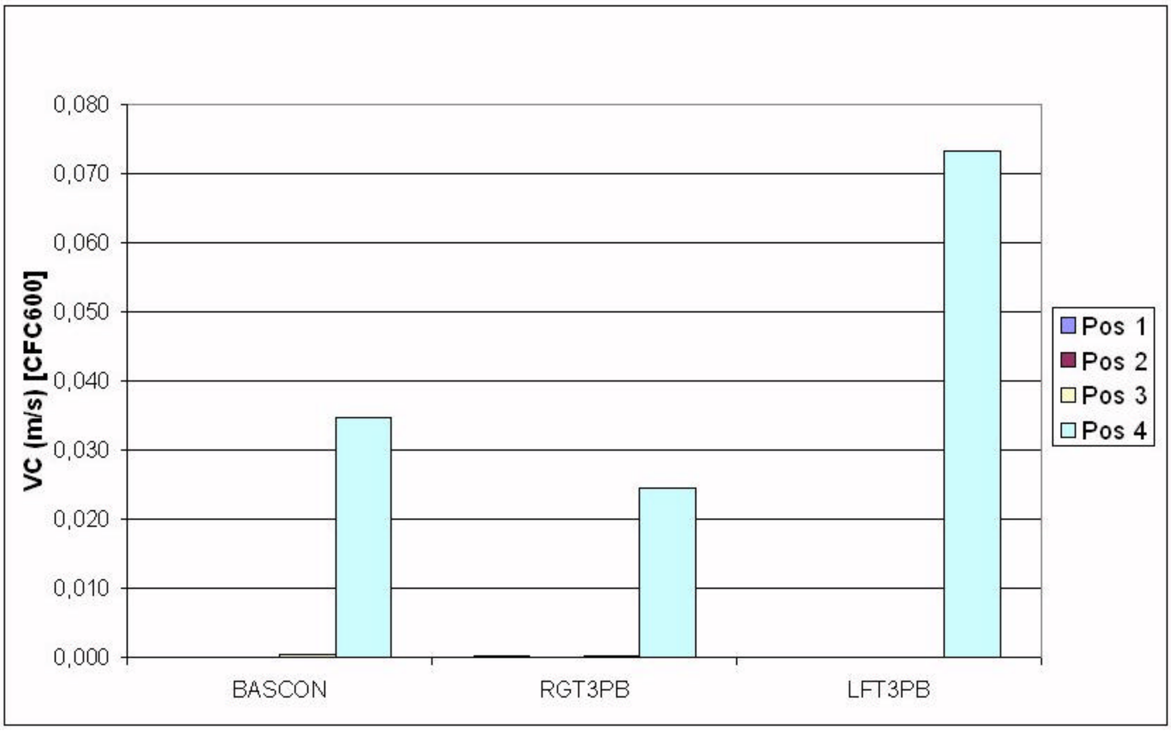


Figure 51 – Viscous Injury Response (Upper Rib)

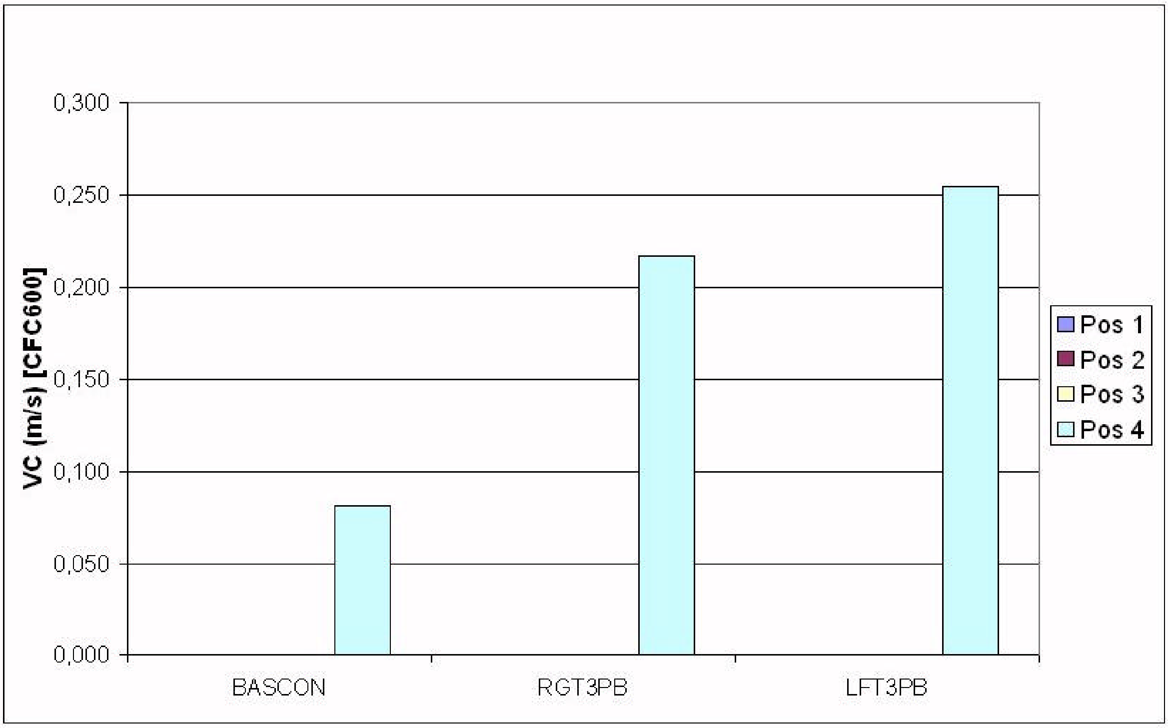


Figure 52 – Viscous Injury Response (Middle Rib)

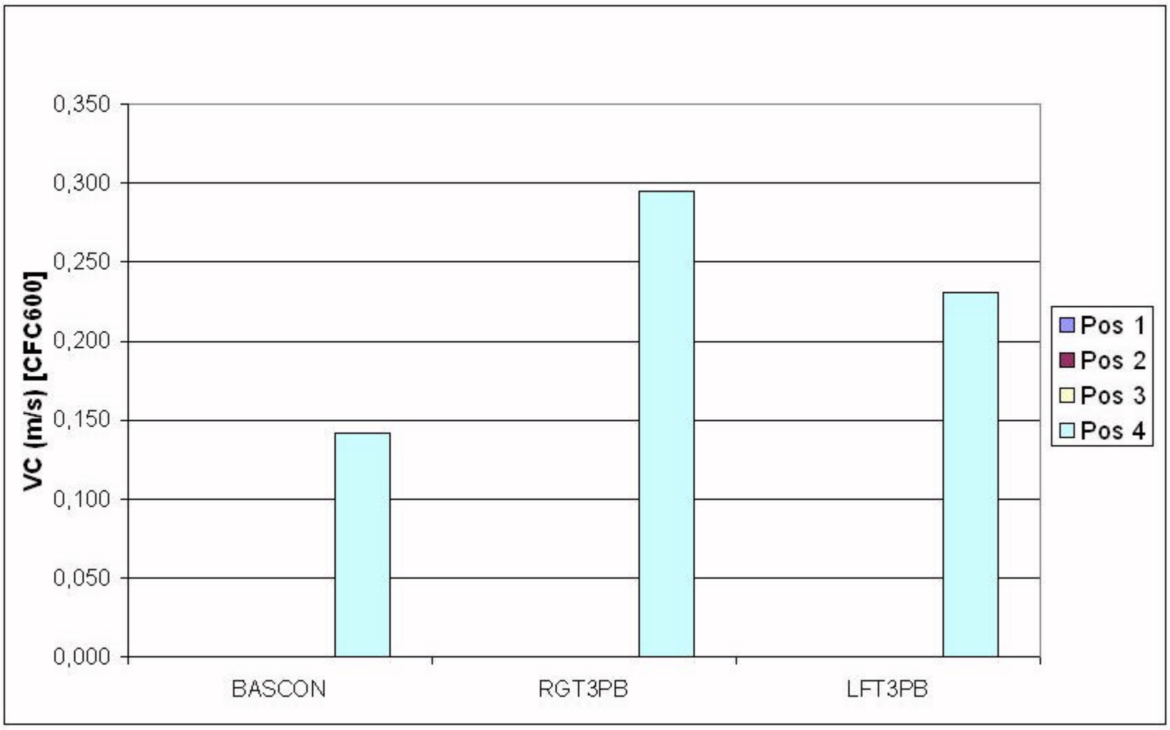


Figure 53 – Viscous Injury Response (Lower Rib)

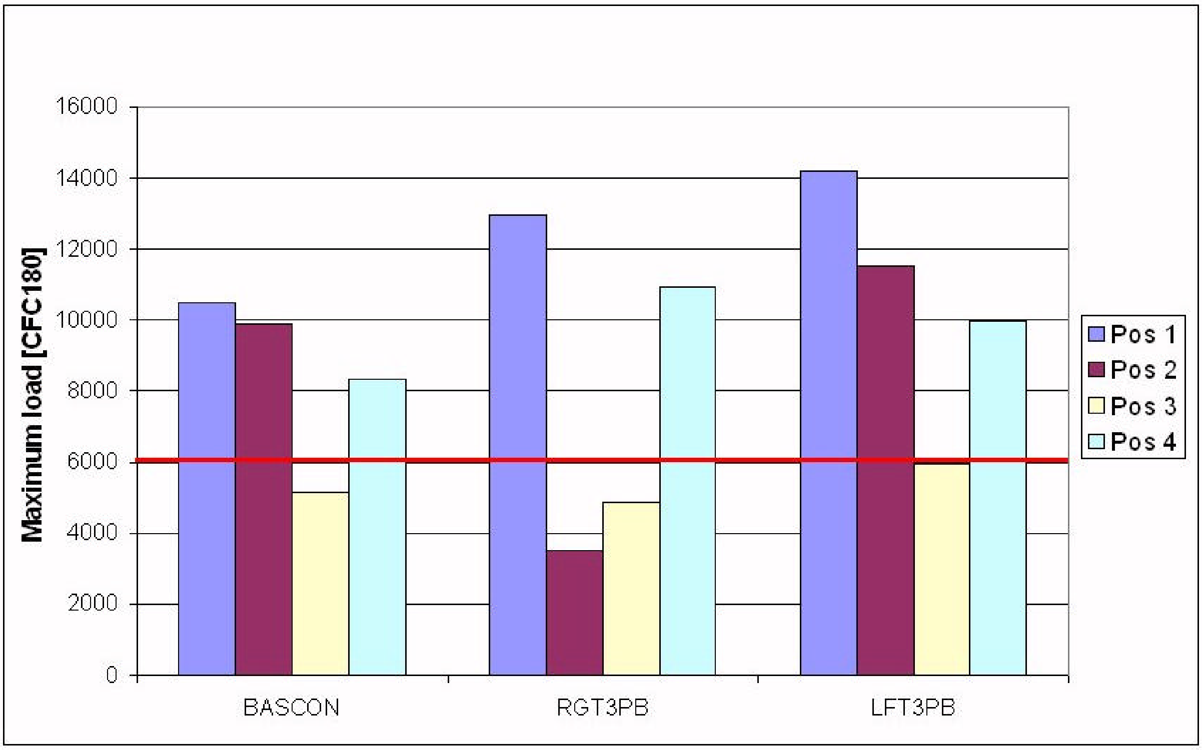


Figure 54 – Pubic Symphysis load

In all the examined configurations the maximum rib deflection (upper, middle and lower), the TTI(d) and the VC (upper, middle and lower) values are below the limits stated by the directive 96/27/EC. Furthermore it is possible to notice that the maximum deflection (middle and lower ribs), the VC (middle and lower ribs) and the TTI(d) values increase changing from two point belts to three point belts because with this kind of belt the upper torso of the dummy is more constrained to the seat and, as a consequence, during the impact the forces from the structure to the ribs and the lumbar spine are greater, and so, obviously, the accelerations.

For what concerns the HIC values, the results about the dummy seated in position three are very interesting. As it is possible to see, the HIC values for this position are still over the limit (1000) even with two point belts. Actually this kind of belt, in the considered event, is completely ineffective because it can’t prevent the impact between the head of the dummy and the side window (Figure 55). Instead three-point belt prevents the impact and, as a consequence, in the considered event, the HIC values drop below the limit (Figure 56 and Figure 57). The dummy seated in position four doesn’t benefit from the use of any kind of belts (two or three point belts) as they can’t prevent the impact of the head with the side window (Figure 58, Figure 59 and Figure 60). For the dummies seated in position one and two, the HIC values are always below the limit. But for these passengers the most important advantage of the use of belts (two or three point belts) is that they prevent the dummies from flying into the structure or against the other passengers.

Finally it is possible to see that the maximum load on the pubic symphysis is almost always over the limit. This is due to the impact of the lower part of the torso with the armrest (Figure 61).

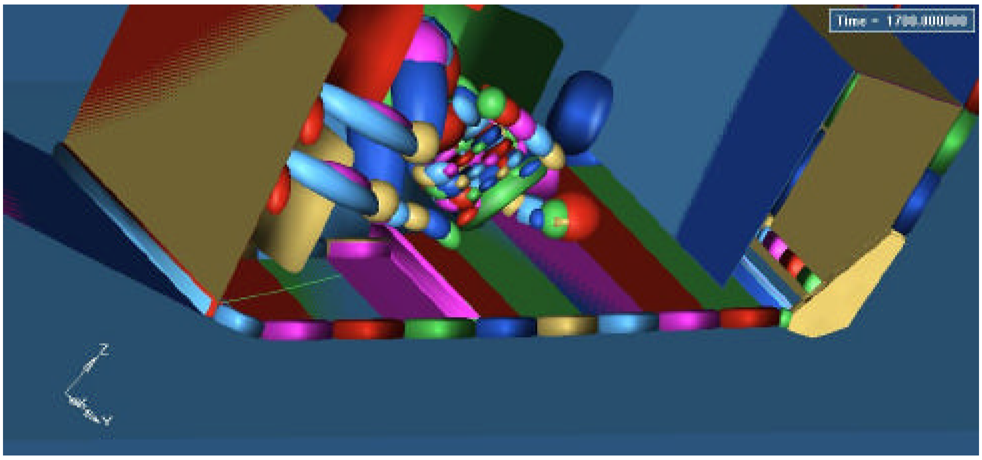


Figure 55 – Position 3 with two-point belt – Head contact

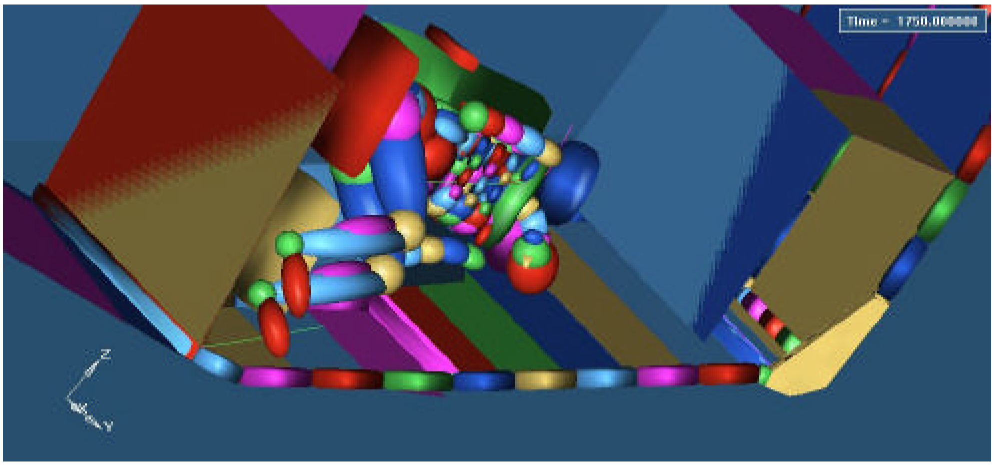


Figure 56 – Position 3 with three-point belt (third point right) – No head contact

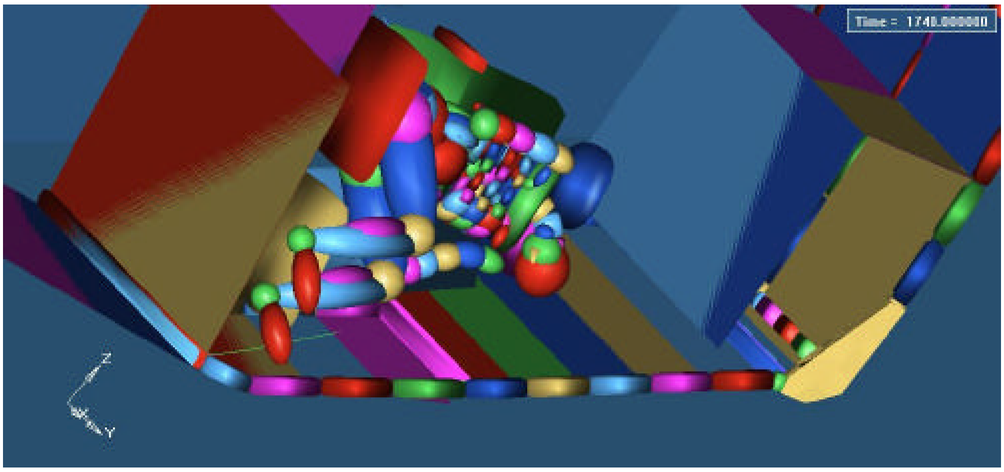


Figure 57 – Position 3 with three-point belt (third point left)- No head contact

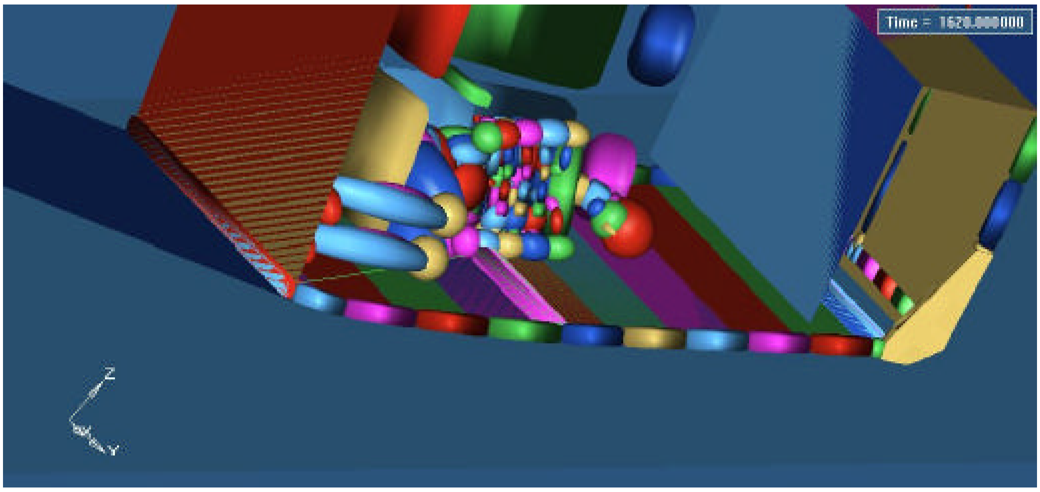


Figure 58 – Position 4 with two-point belt – Head contact

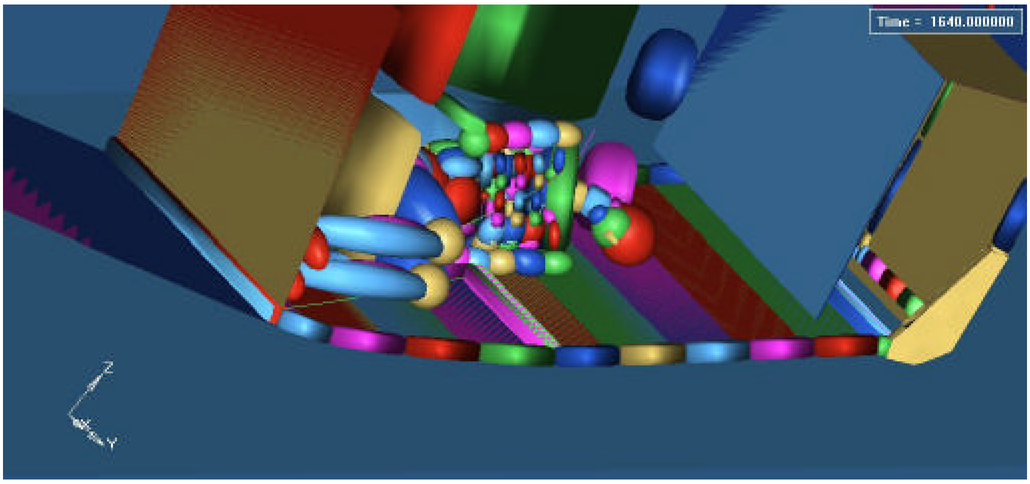


Figure 59 – Position 4 with three-point belt (third point right) – Head contact

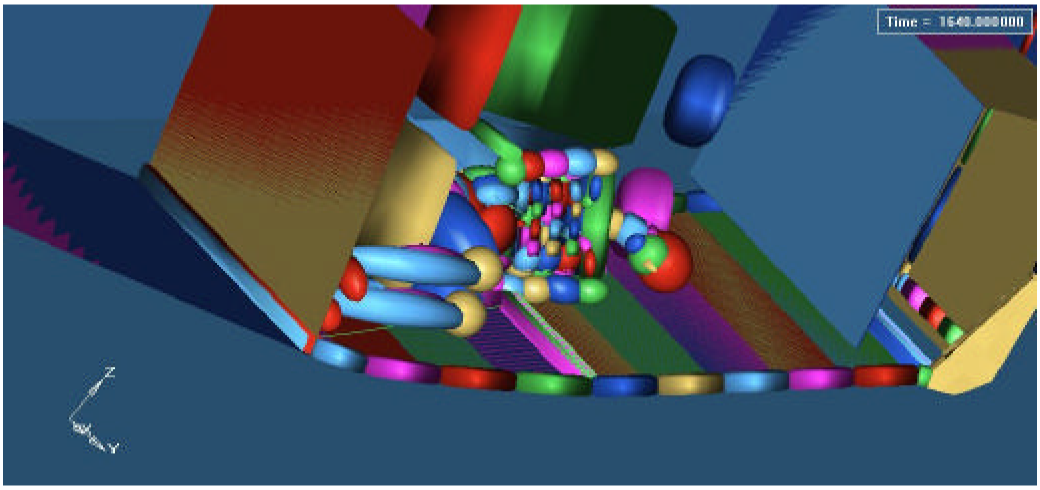


Figure 60 – Position 4 with three-point belt (third point left) – Head contact

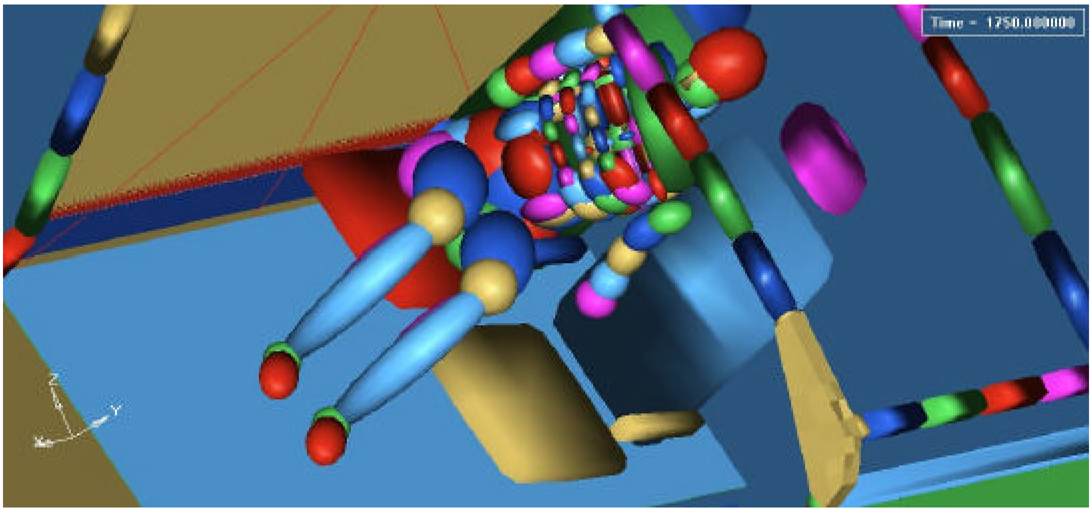


Figure 61 – Position 1 with two-point belt – Armrest contact

14 Citybuses

14.1 Simulations

The statistical data for bus and coach accidents in urban areas (Austria 94-98) show that about 50% of the serious and slight injured occupants suffer these injuries during accidents caused by emergency braking. Most of these accidents are simple no collision accidents without any further impact with another vehicle or obstacle. This type of accident was used as basis for this investigation. Figure 62 shows the share of injured occupants through emergency braking versus the total number of casualties in urban areas.

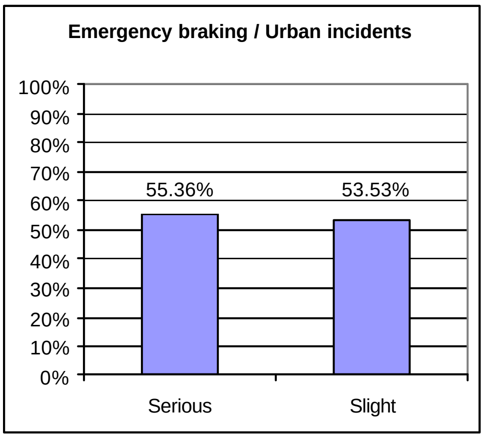


Figure 62 - Urban accident data (without motorway).

Figure 63 shows the real distribution of injuries within this accident type. The majority of these suffered injuries are slight which means in Austria a hospitalisation for less than 3 days or a discontinuation of normal business for less than 24 days. To analyse the injury risk in city buses a typical inner-city no collision accident scenario was investigated.

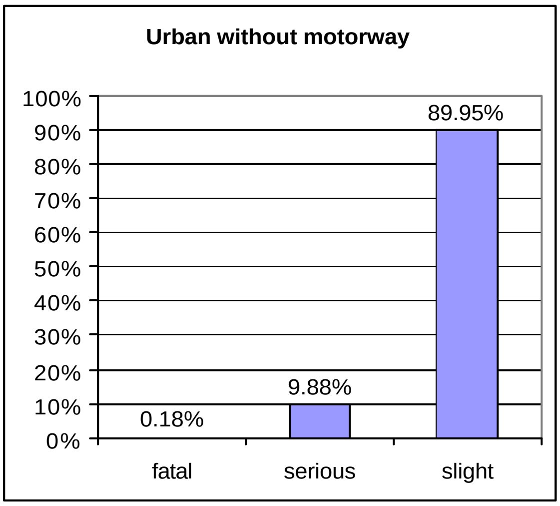


Figure 63 - Injury severity in urban emergency braking accidents

14.1.1 M3 Vehicle Simulations and Parametric Studies

The chosen city 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 emergency braking. These dynamic parameters (positions, orientations) were then used as input data for the occupant simulations.

The interior of the bus (seats, grab rails, space dividers) was generated by means of MADYMO®. The seats were generated as multi-body system and consist of a tree structure with 6 bodies. The chosen position of the connecting joints between the bodies enables a wide range of adjustment of the seat base and the seat back. This design enables the generation of a wide spread of seat types and bus interiors.

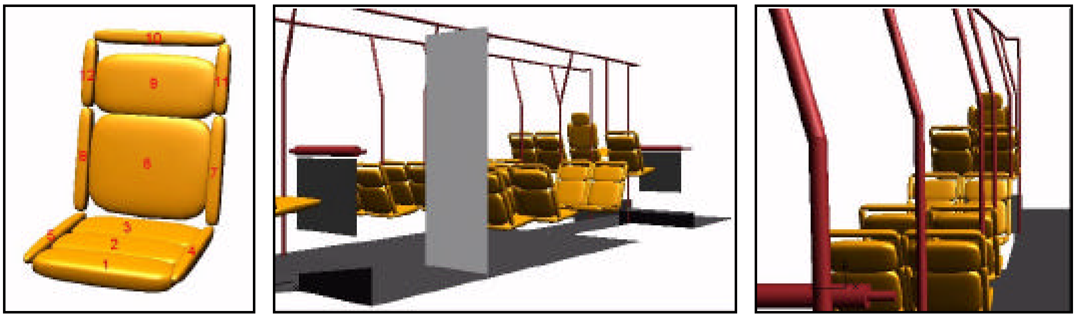


Figure 64 - Interior parts that were taken for the occupant simulations

Four different occupant positions and actions were observed to analyse the injury risk in city buses. At each case two simulations were performed with a sitting and a standing passenger. The sitting occupant was placed in a face to face double seat by looking in forward direction. Once in the front of the bus and another time in the rear area. The background for this analysis was the detection of an influence of the pitch angle on the occupant movement. The standing occupant was placed in front of a space divider and in front of a vertical grab rail.

Four types of dummies (5th-, 50th-, and 95th percentile Hybrid III, 6 year child dummy) were used to analyse the different behaviour of the occupants.
The following figures show the different movements of the specific dummies at different actions and bus locations.

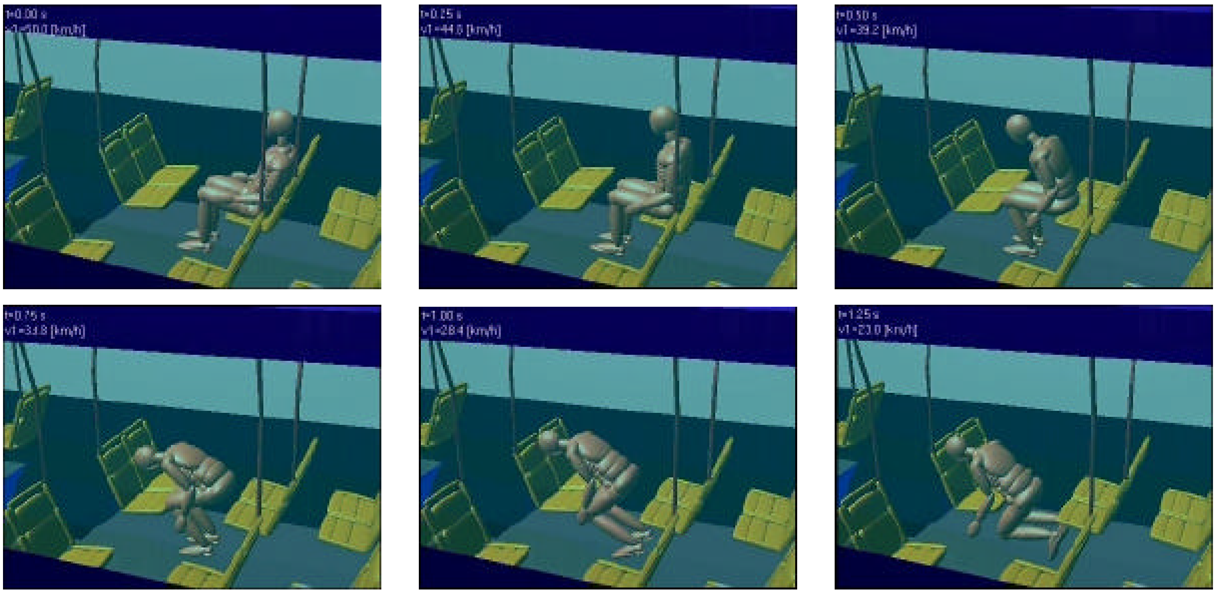


Figure 65 - 50th percentile HIII dummy sitting in the front area at 250ms intervals

The dummy moves forward and hits the opposite seat with the knees after slightly more than half a second. Then the body rotates over the pelvis joint in the direction of the seat back. The knees and upper legs slip under the seat and the head hits the seat back in the upper area.

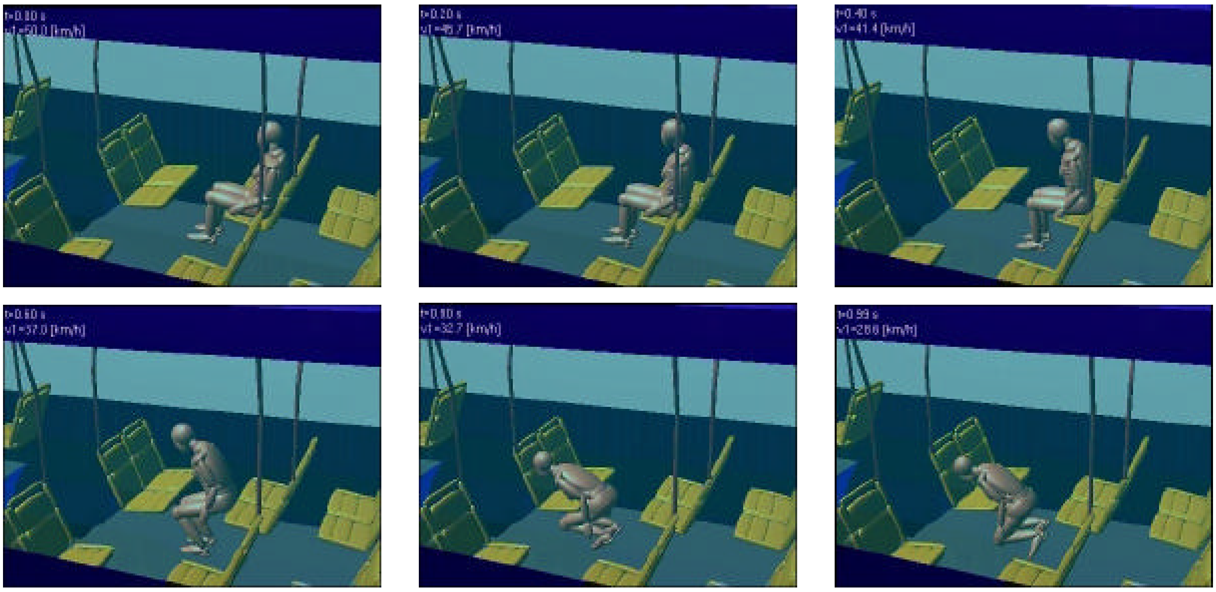


Figure 66 - 5th percentile H III dummy sitting in the front area at 200ms intervals

Due to the size of the 5th percentile dummy the legs move directly under the seat and the body hits the seat in stomach area and subsequent the head hits the seat back in the middle area.

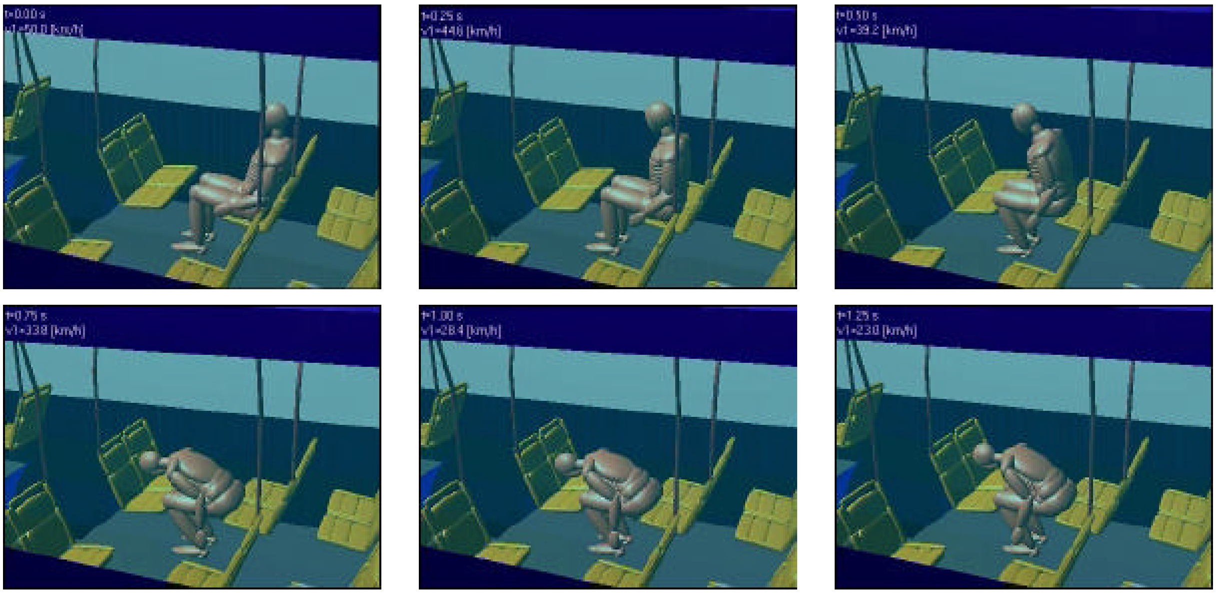


Figure 67 - 95th percentile H III dummy sitting in the front area at 250ms intervals

Due to the dimensions of the 95th percentile dummy the forward movement is basically stopped when the knees hit the opposite seat. Only a body rotation can be observed which doesn't result in impacts with interior parts.

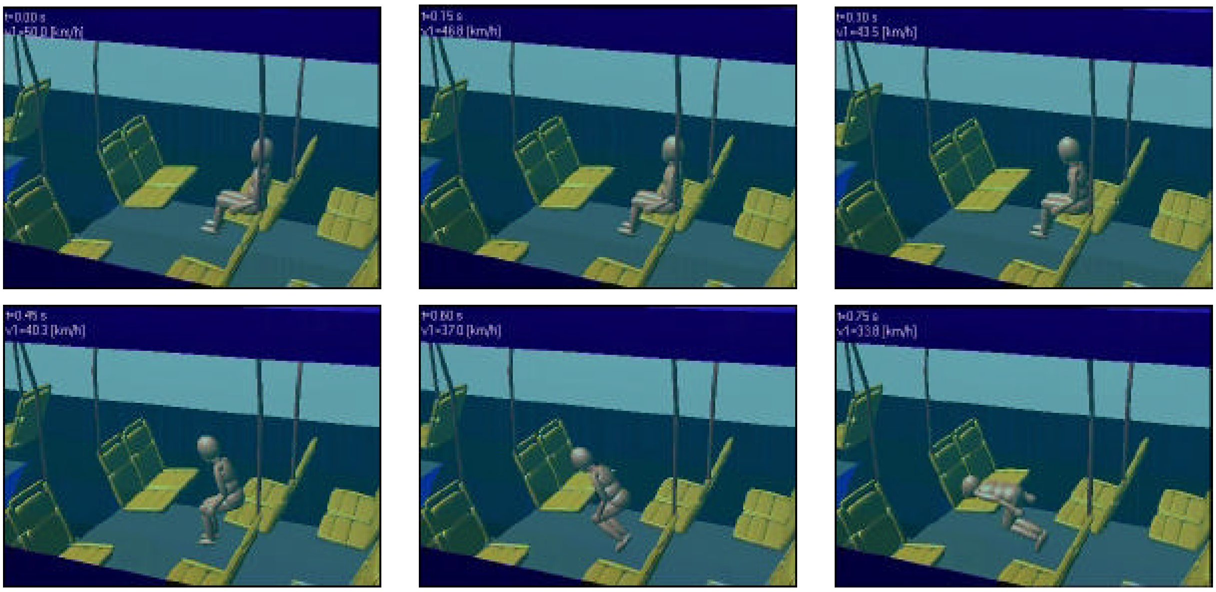


Figure 68 - 6 year child dummy sitting in the front area at 150ms intervals

The movement of the 6 year child dummy is similar to the female dummy behaviour. After slipping and falling from the seat the dummy moved straight and unhindered in the direction of the opposite seat where the head impacted the seat back in the middle area.

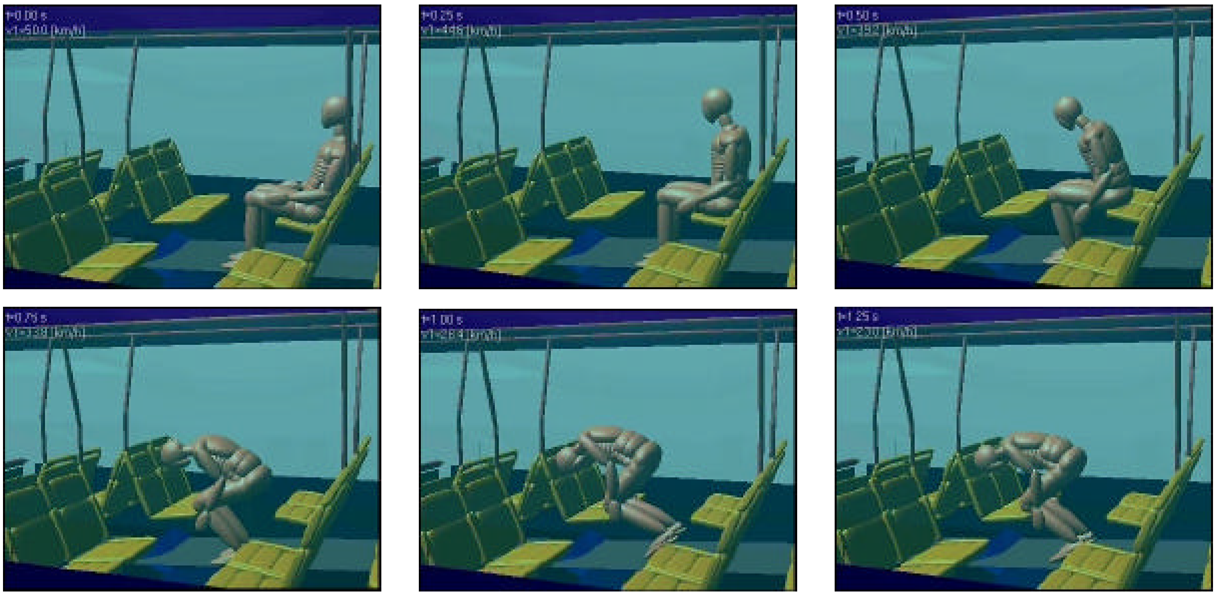


Figure 69 - 50th percentile H III dummy sitting in the rear area at 200ms intervals

Compared with the similar sitting front dummy the movement shows remarkable differences which are mainly caused by the slightly increased seat spacing, the pitch angle and the gradient seat configuration in the rear part of the bus. The head hits the seat back in a lower area and due to dummy movement the neck suffers a higher bending moment (flexion).

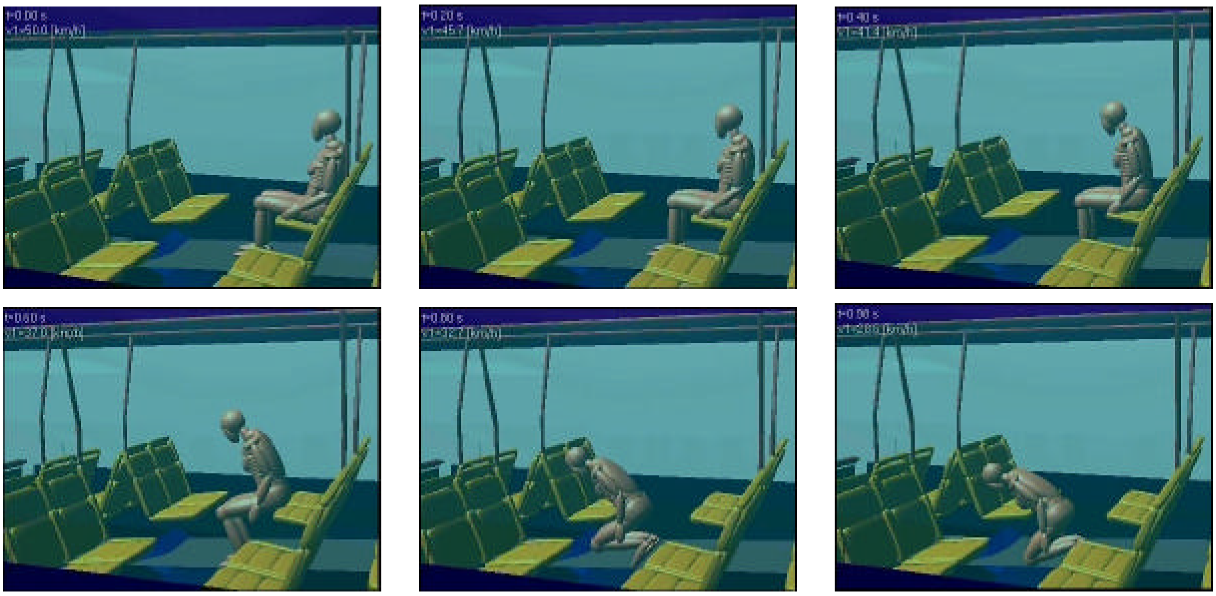


Figure 70 - 5th percentile H III dummy sitting in the rear area (200ms intervals)

The head and pelvis have nearly simultaneous contact with the opposite seat which leads to a higher load to head and neck.

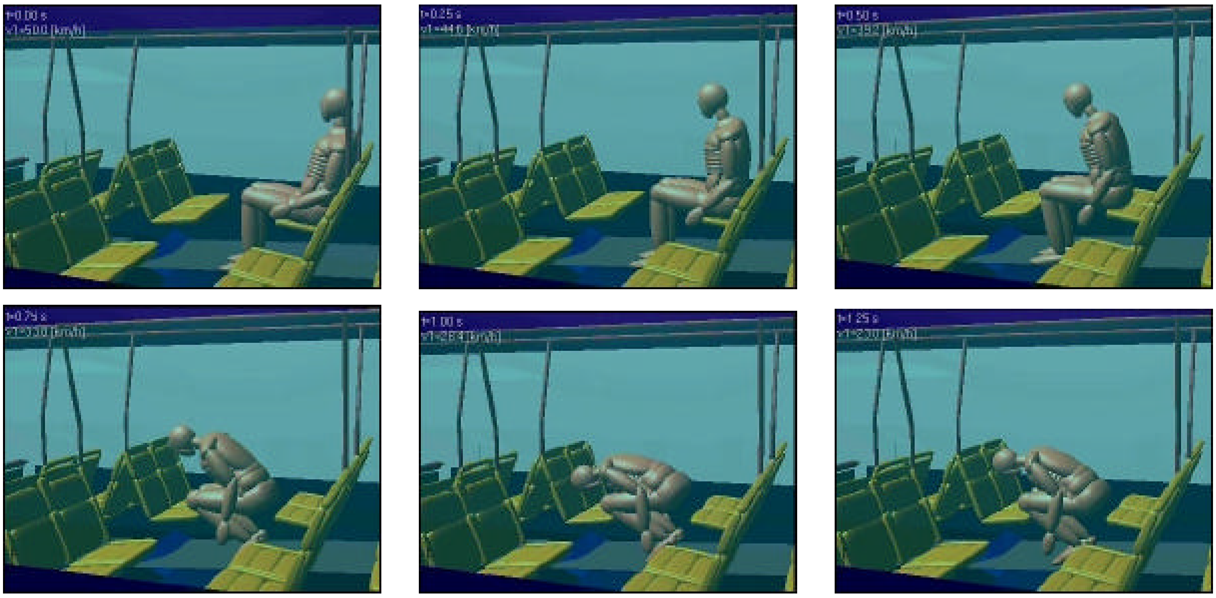


Figure 71 - 95th percentile H III dummy sitting in the rear area at 250ms intervals

Similar phenomenon as in the frontal area leads to no contact of the head with the opposite seat which results in less load.

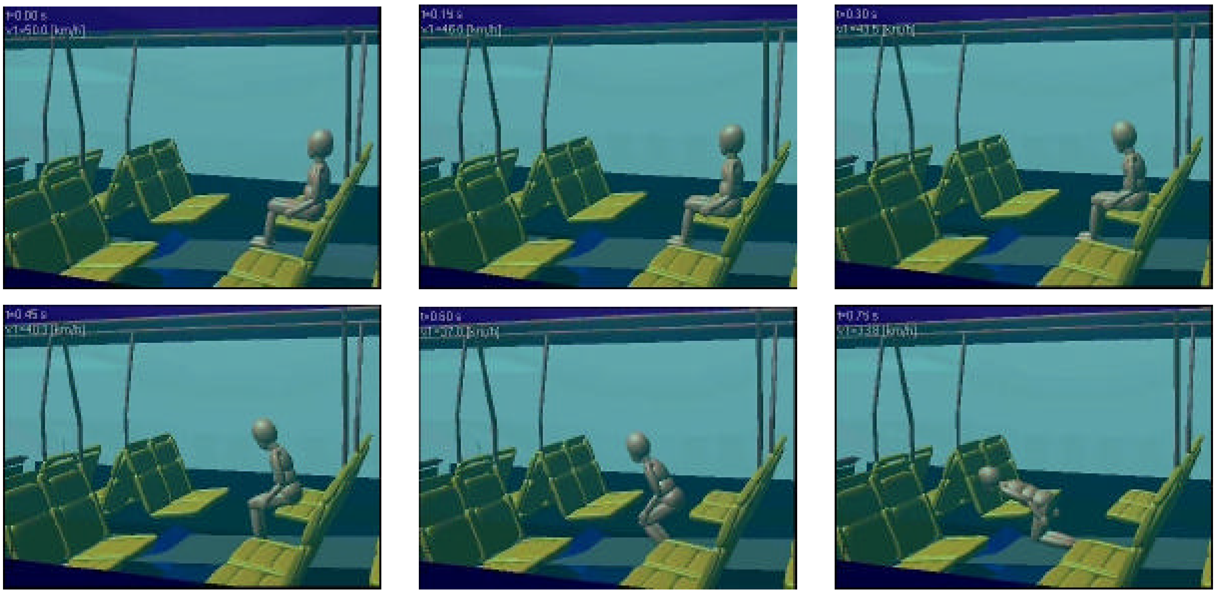


Figure 72 - 6 year child dummy sitting in the rear area at 150ms intervals

The movement of the 6 year child dummy is very similar to the child dummy behaviour sitting in the front. The head hits the seat back almost uninterrupted which leads to a neck bending moment that reaches the limit of a biomechanical experience.

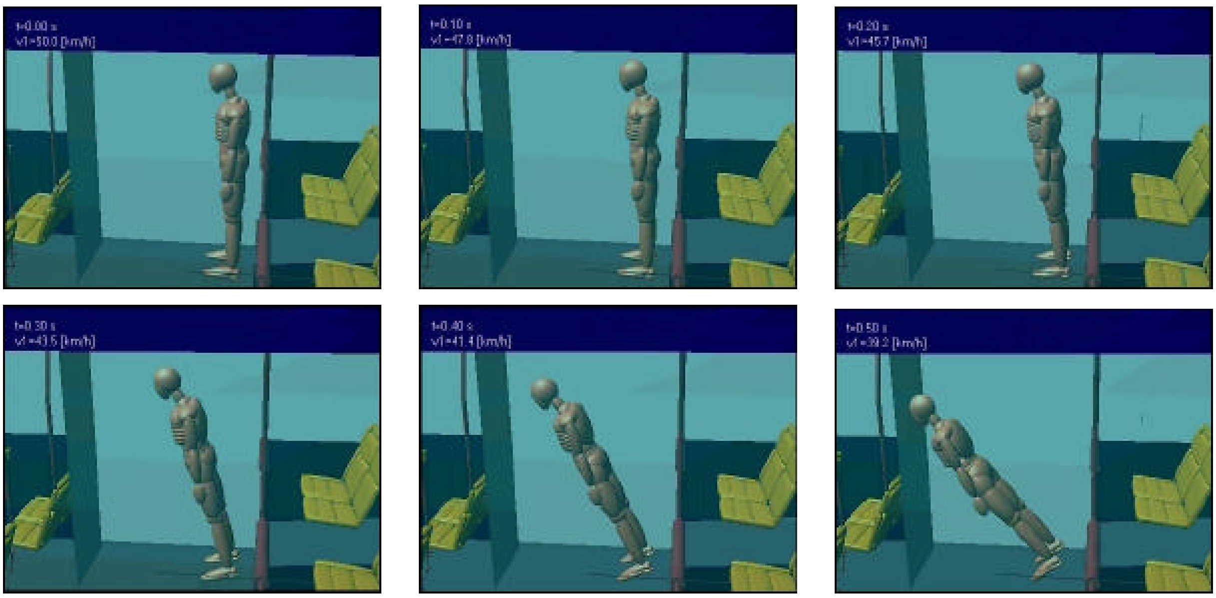


Figure 73 - 50th percentile H III dummy standing in front of a space divider at 100ms intervals

The dummy was positioned approximately 1 m in front of the space divider made of Plexiglas. To simulate the worst case for head and neck a possible firm up with the hands was disabled. The injury loads reached partly limits where serious injuries can occur.

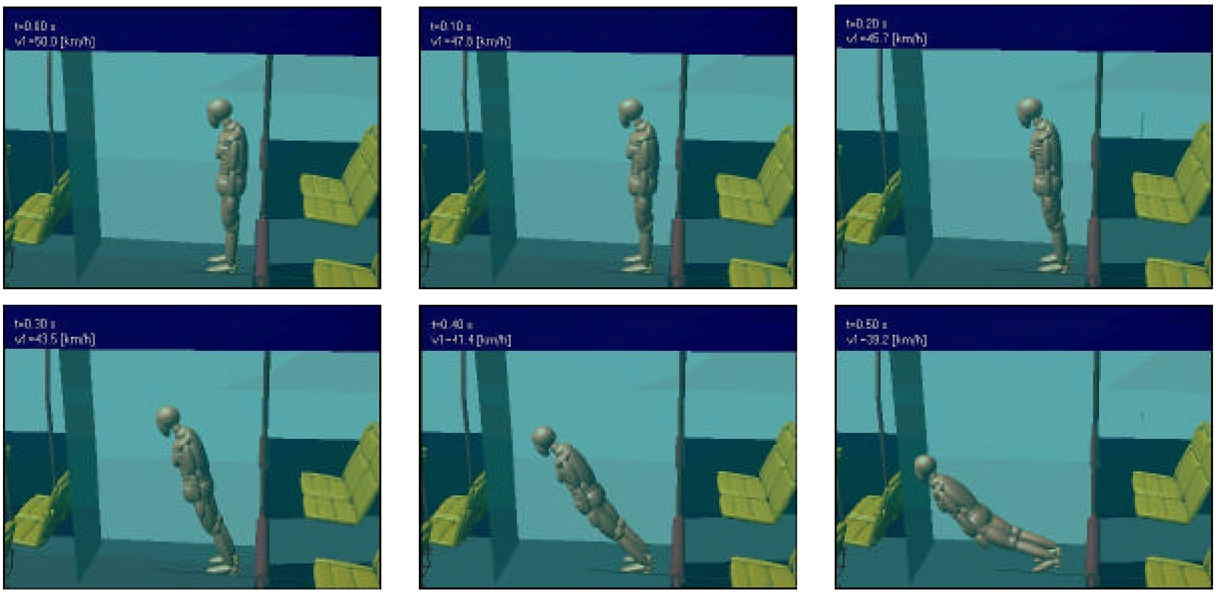


Figure 74 - 5th percentile H III dummy standing in front of a space divider at 100ms intervals

Movement similar as observed for the 50th percentile Hybrid III dummy. All simulations were run provided that no obstacle was between dummy and interior.

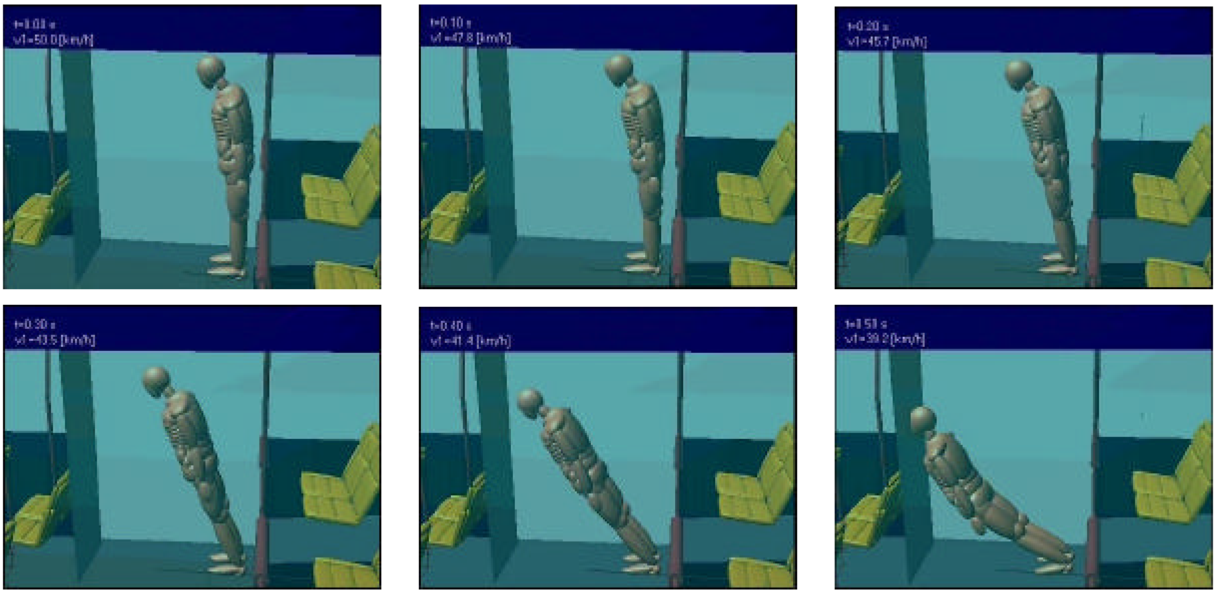


Figure 75 - 95th percentile H III dummy standing in front of a space divider at 100ms intervals

The 95th percentile Hybrid III dummy shows also a similar motion sequence as the prior simulations. Injury loads on equal high level.

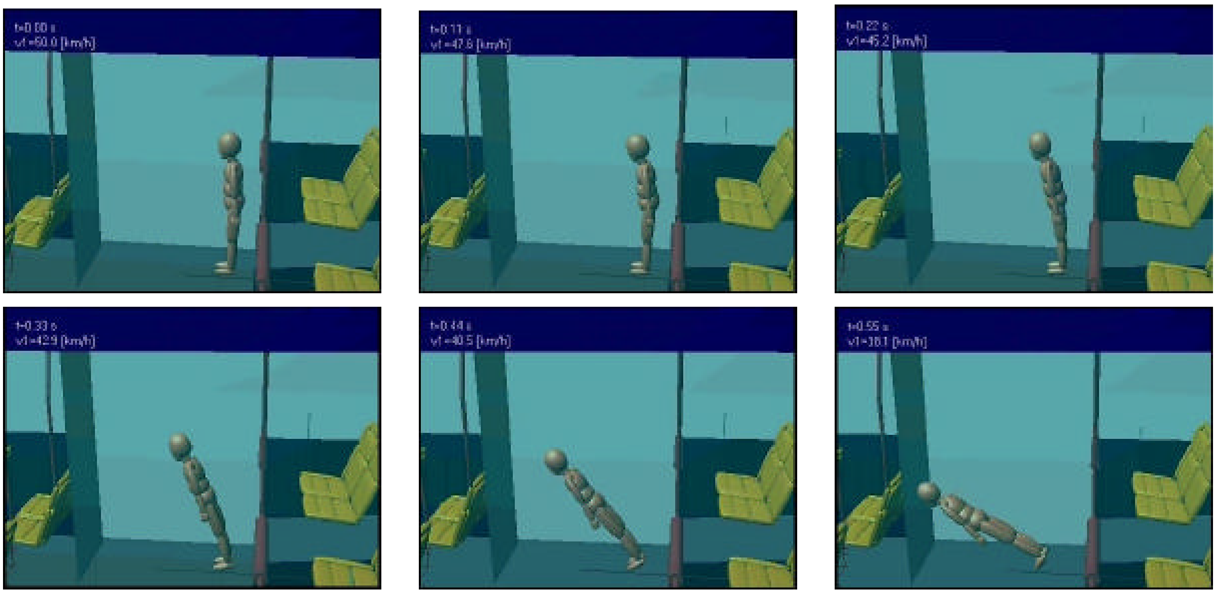


Figure 76 - 6 year child dummy standing in front of a space divider at 110ms intervals

Due to dummy size the impact area lays in the lower part of the space divider. As a result of the flat neck joint characteristic of the child dummy the neck suffers a strong extension.

Figure 77 - 50th percentile H III dummy standing in front of a vertical grab rail at 80ms intervals

The movement of the dummy shows similar behaviour as against the space divider. Since the distance between head and grab rail is only half a meter the impact energy is less which results in less load to head and neck.

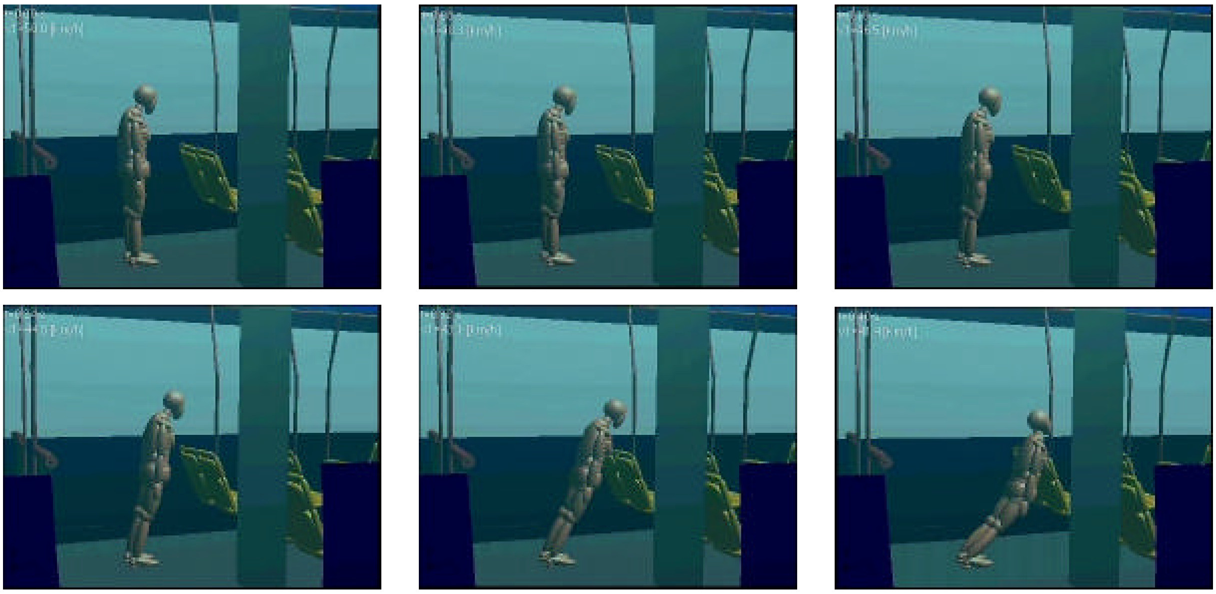


Figure 78 - 5th percentile H III dummy standing in front of a vertical grab rail at 80ms intervals

Peak values for head acceleration and HIC are well below the criterion limit; only the neck bending moment passed its limit.

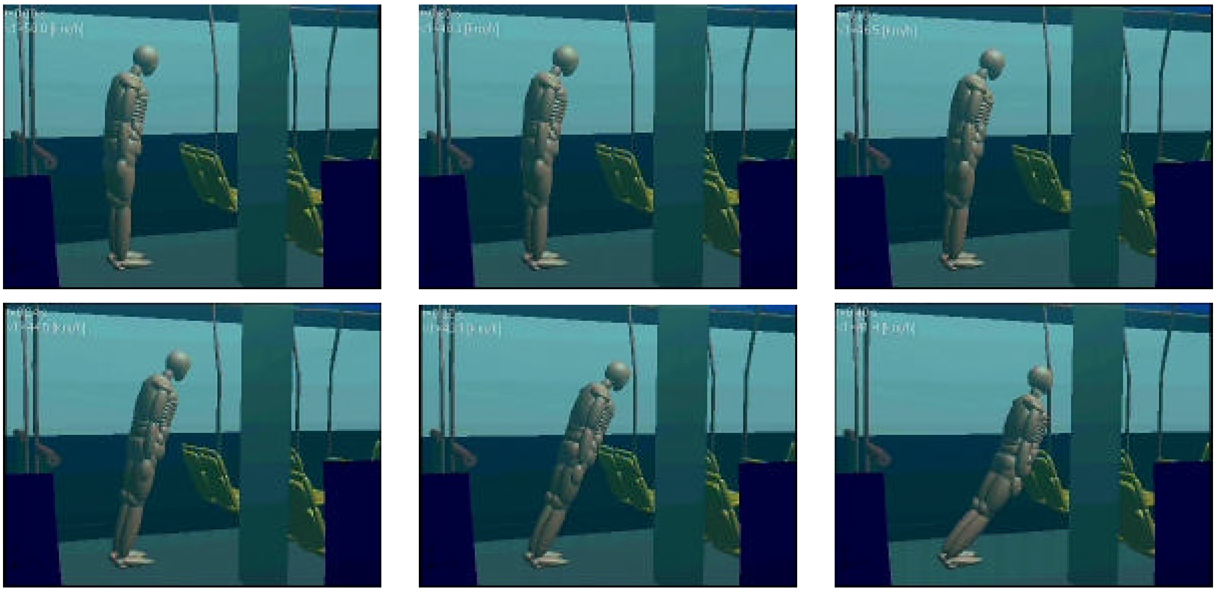


Figure 79 - 95th percentile H III dummy standing in front of a vertical grab rail at 80ms intervals

Similar results for the 95th percentile Hybrid III dummy as for the prior grab rail simulations. A supporting firm up with the hands would be more difficult due to the small diameter of the vertical grab rail.

Figure 80 - 6 year child dummy standing in front of a vertical grab rail 80ms intervals

The movement of the 6 year child dummy shows also strong similarities to the prior simulations.

Summary:

Independent of the varied locations and actions of the occupant in the bus the main contact area is evident for the head which indicates the possibility of a higher risk of serious injury for the head and neck area. Naturally may all impact areas suffer injuries in particular the extremities (bone fractures).

The maximum values for the injury criteria limits are shown below. A comparison with the values obtained from the numerical simulations are presented in the following chapter Parametric Studies.

Following criteria limits were taken into account:

HIC	500	[-]	(ECE R80)
Head acceleration	80	[g]	(FMVSS 201)
Chest acceleration	30	[g]	(ECE R80)
Pelvis acceleration	130	[g]	(FMVSS 214)
Neck bending moment (Extension)	57	[Nm]	(FMVSS 208)

Limits for the child dummy were taken from ECE R44, FMVSS 213 or above if more severe.

14.2 M3 Vehicle Parametric Studies

This analysis was performed to investigate the influence of the material behaviour (contact characteristic) on the injury risk of city bus occupants. For these purposes the stiffness of the seat cushions and interior parts was increased and decreases by 50% for each case.
The tables below show the calculated injury values for the different locations and occupant actions in the bus.

sitting front	5th B	5th S	5th W	50th B	50th S	50th W	95th B	95th S	95th W	6y B	6y S	6y W
HIC	27	29	19	3	2	1	1	1	1	41	45	30
a head 3ms (g)	28	28	22	9	6	4	3	3	3	28	30	23
a chest 3ms (g)	9	10	9	4	6	3	2	2	2	21	23	16
a pelvis 3ms (g)	17	19	15	11	14	7	6	8	4	-	-	-
Neck Moment (Nm)	19	19	14	28	30	12	9	10	7	19	**20**	19

Table 13: Injury values for the occupants sitting in front area

sitting rear	5th B	5th S	5th W	50th B	50th S	50th W	95th B	95th S	95th W	6y B	6y S	6y W
HIC	40	63	31	2	4	1	1	1	1	55	70	36
a head 3ms (g)	33	36	24	6	10	4	3	3	3	28	35	22
a chest 3ms (g)	12	19	10	3	10	3	2	3	2	20	25	15
a pelvis 3ms (g)	17	18	17	13	16	9	6	8	5	-	-	-
Neck Moment (Nm)	26	**57**	25	43	29	33	8	9	7	19	19	18

Table 14: Injury values for the occupants sitting in back area

standing entrance	5th B	5th S	5th W	50th B	50th S	50th W	95th B	95th S	95th W	6y B	6y S	6y W
HIC	259	371	139	182	319	72	244	350	123	67	78	34
a head 3ms (g)	74	**85**	60	66	**86**	45	70	**83**	54	48	51	36
a chest 3ms (g)	17	24	16	18	25	11	15	21	8	18	24	13
a pelvis 3ms (g)	18	16	16	11	11	9	19	20	15	-	-	-
Neck Moment (Nm)	**119**	**126**	**88**	**190**	**195**	**175**	**107**	**113**	**99**	17	17	16

Table 15: Injury values for the occupants standing at the entrance in front of a space divider

standing aisle	5th B	5th S	5th W	50th B	50th S	50th W	95th B	95th S	95th W	6y B	6y S	6y W
HIC	60	75	37	51	70	30	49	67	28	25	30	19
a head 3ms (g)	33	37	28	34	42	23	28	35	21	23	25	19
a chest 3ms (g)	8	9	6	12	13	10	7	8	5	12	13	9
a pelvis 3ms (g)	4	5	4	5	5	5	5	5	4	-	-	-
Neck Moment (Nm)	**82**	**87**	**69**	**149**	**154**	**137**	**90**	**93**	**84**	5	5	5

B … Baseline, S … Stiff, W … Weak

Table 16: Injury values for the occupants standing in the aisle in front of a grab rail

Injury values that reached or passed the criteria limits are shown in bold type. The majority of the values are below the individual injury limits which confirm the statistical data that approximately 90% of the injuries are slight. Critical levels concern mainly the neck bending moment of the adult dummies at the impact with the space divider and the vertical grab rail and some impacts 3ms head values. The impact with the ground may also cause bone fractures especially for elderly people.

Final Publishable Report

15 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.

16 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^{th}%ile male. There are currently no data relating specifically to the requirements for, or performance of, child restraint systems for children in buses. As various sizes of buses are used for public transportation different groups will be investigated according to ECE (M2-up to 5 tons and M3-more than 5 tons)

Special emphasis 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.

17 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.

17.1 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.

17.1.1 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.

17.1.2 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.

17.1.3 Task 1.3 – Database integration

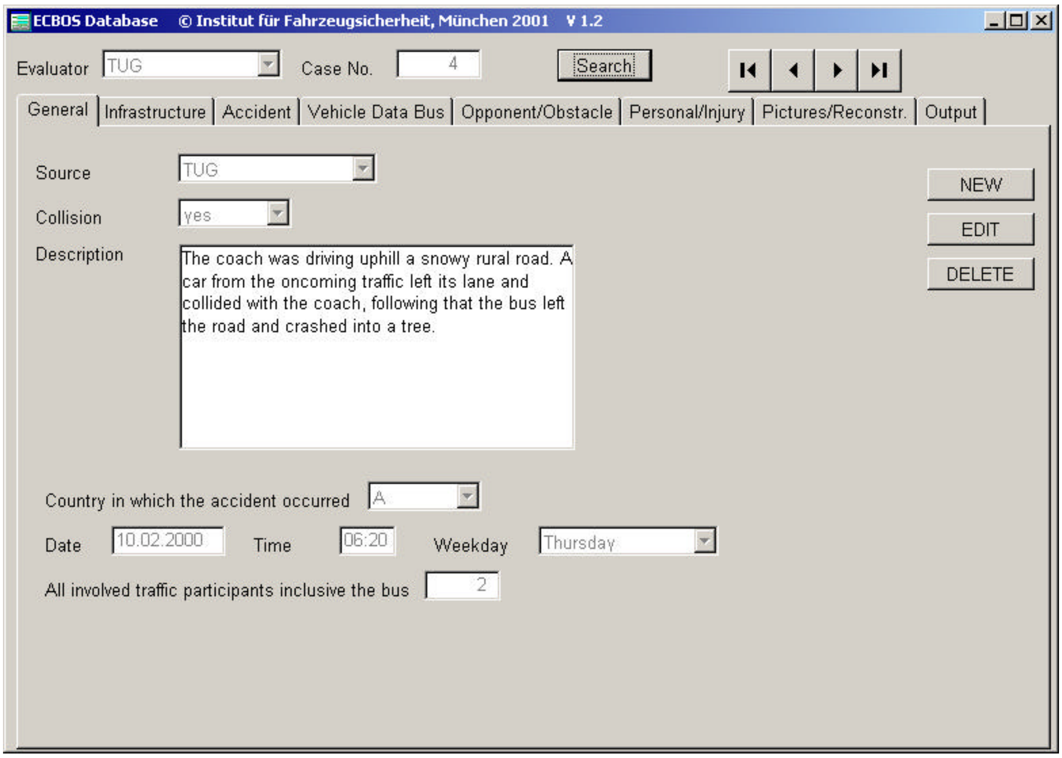
Planned: The data from the various sources (governmental- and extended) databases will be integrated into a general bus accident database by partner GDV.

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.



Evaluator: TUG
Case No.: 4
Source: TUG
Collision: yes
Description: The coach was driving uphill a snowy rural road. A car from the oncoming traffic left its lane and collided with the coach, following that the bus left the road and crashed into a tree.
Country in which the accident occurred: A
Date: 10.02.2000
Time: 06:20
Weekday: Thursday
All involved traffic participants inclusive the bus: 2

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.

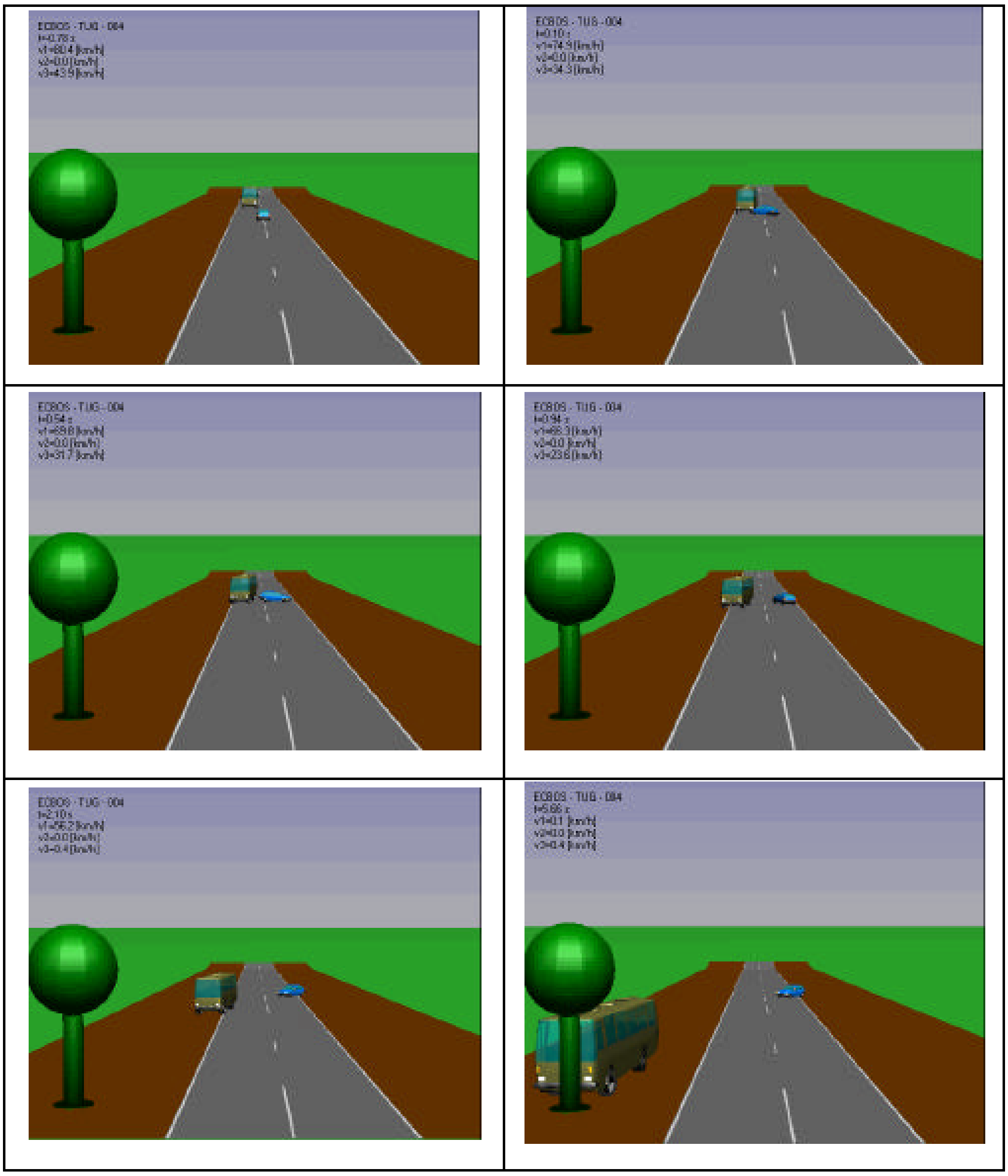
Assessment: The generated database enables a very good possibility to evaluate the information on bus accidents due to the detailed investigation on several accident relevant data. In principle, the ongoing is in line with the schedule and the report will be presented in time. Both, the database as well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

17.1.4 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 Δv 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.

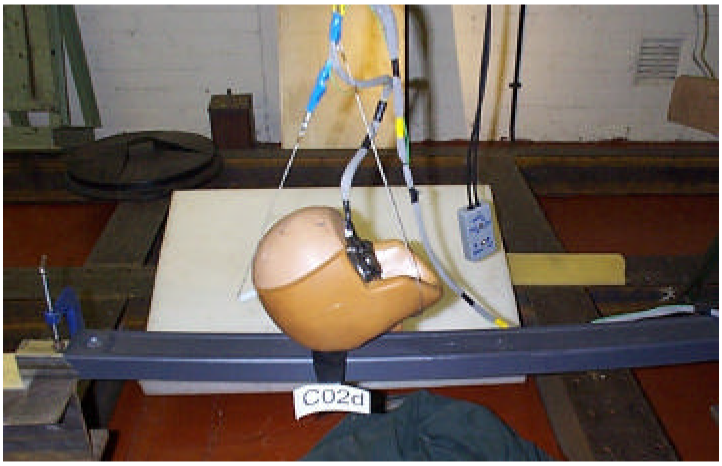
17.2 Workpackage 2

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.

17.2.1 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 test were done to measure accelerations and loads as well as to calculate the injury criterion HIC. In addition to these bus interior component test two series of tests on bus seat crash behaviour were performed.



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.

<u>**Assessment:**</u> 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.

17.2.2 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.

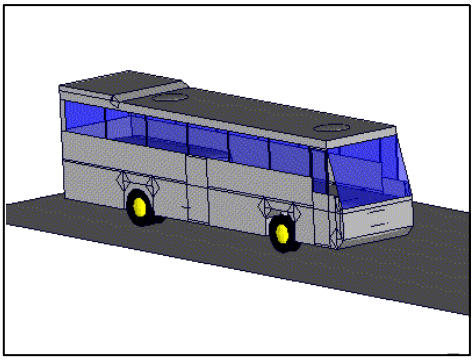
Performed: The first performed full scale test has been a rollover test on a M2 bus. This kind of testing represents a new approach, since such a test is currently required only for M3 buses. The boundary conditions were the same as for a standard ECE R66 test. A further new approach was the usage of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

Frontal Impact

Rollover

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.



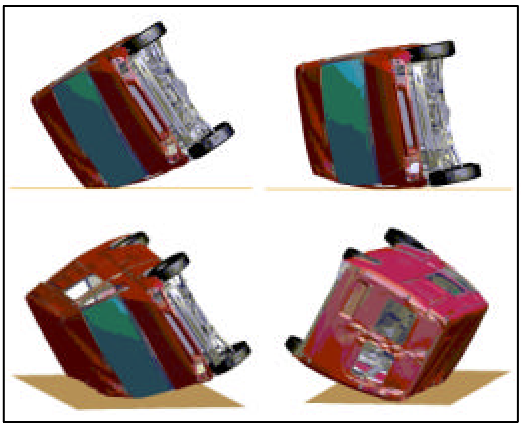
This process was intensive discussed within the consortium and agreed at the Munich meeting. In the meanwhile the progress of this task section is good and will be finished soon.

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.

17.2.3 Task 2.3 – Numerical simulation model for vehicle structure

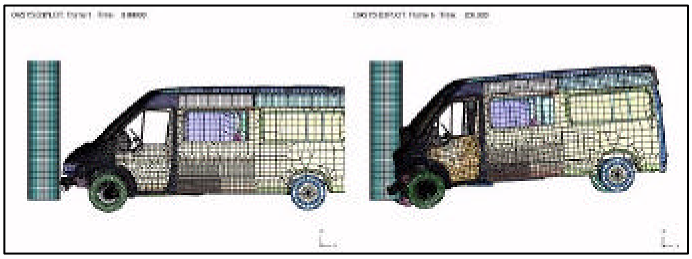
Planned: A numerical model of the bus structures, seats including occupant mass, if restrained, will be generated with the main emphasis on coaches (M3). CIC and TNO will develop the numerical model for frontal impact and UPM and POLITO will provide the rollover model.

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.



Rollover Model

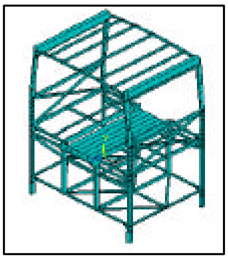
The main criteria for the model validation were the acceleration pulses obtained from the full-scale test vehicle. From the comparison of the simulation and test values it can be seen that the peak values and general trends are very similar between test and simulation.



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

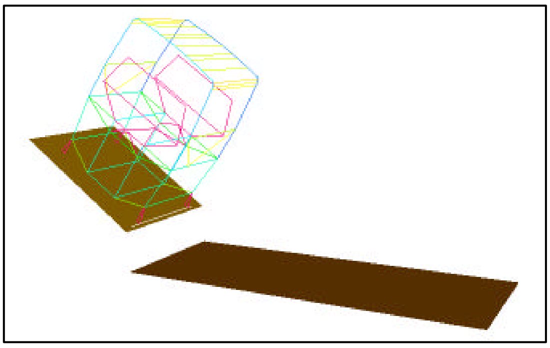
- The simulation shows a similar (although slightly lower) longitudinal displacement of the pole barrier into the vehicle.
- The plastic crease at the top of the A-pillar is reproduced by the model.
- The door deformation is similar.
- The vehicle rebounds a similar distance and rotation from the pole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

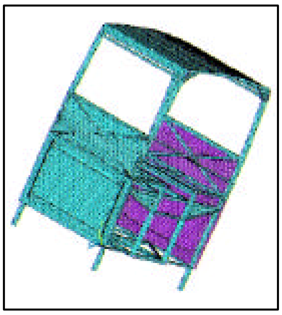
The numerical models from INSAI have been built with regard to the bay section tests carried out in task 2.2., including the structure geometry and properties, and the same test conditions. This will permit to validate and compare the results. Anyhow, once the models have been validated, they could be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

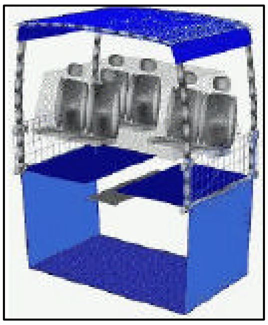
A further numerical model of the bay section has been made using the explicit finite elements code PAMCRASH. Elasto-plastic beam elements are used to model the structure. Those are one-dimension elements, whose position and length are defined by two extreme nodes.



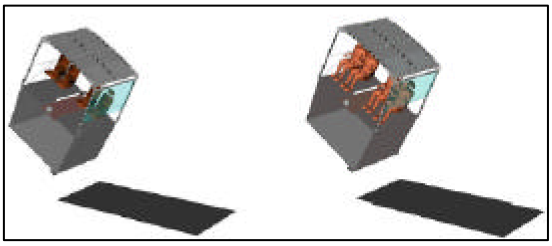


Another more detailed model of the bay section has been made using the explicit finite elements code MSC-DYTRAN. In this case, elasto-plastic shell elements are used to model the bay section, including panels and the detailed geometry of joints.

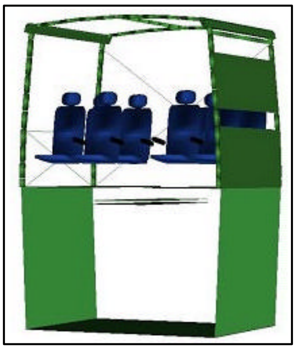
The structure is modelled using 4-nodes shell elements. Those are two-dimension elements, whose geometry is defined by the position of the four nodes, and just the thickness has to be introduced.



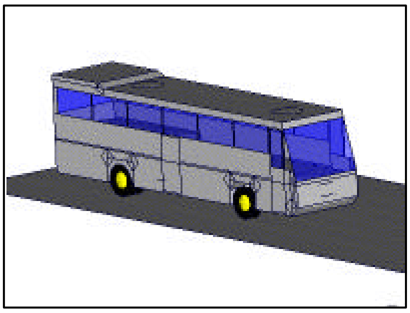
The bay section numerical models from PoliTo were developed using MADYMO v5.4 software. For the model shown on the right side both rigid bodies and finite elements were employed. The vertical and the roof pillars were modelled using rigid bodies connected each other by revolute joints.



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.

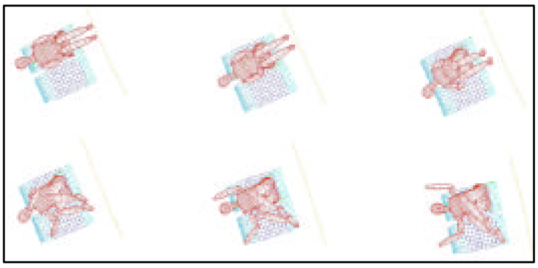
Assessment: Several numerical models have been generated and numerous calculations have been performed. The models have been validated by using the results of the full scale reconstructions. New approaches on the configuration of the computer models have been generated. During the last meetings some 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.

17.2.4 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).

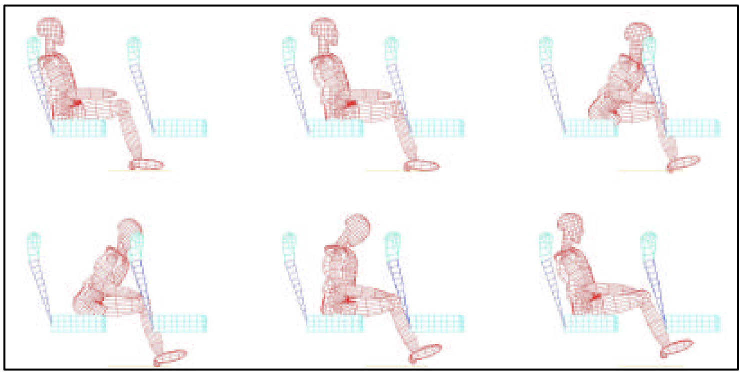
The models must also contain the capability to allow prescribed, time dependent intrusions.

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.

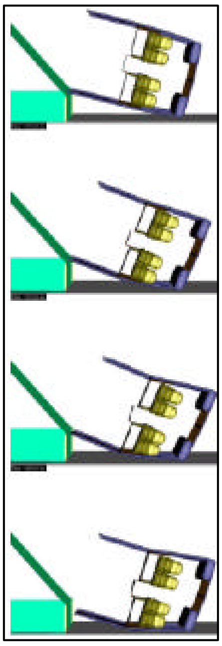


Performed: CIC's rollover occupant model simulated one of the 50th percentile Hybrid III dummies that was inside the full-scale M2 rollover reconstruction of Task 2.2. The dummy was seated away from the contacted side of the vehicle and wearing a 3-point belt with the shoulder belt over it's right shoulder (ie. the side closest to the ground contact).

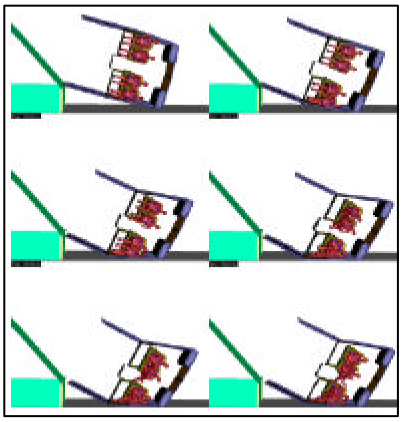
The frontal impact occupant model simulated one of the 50th percentile Hybrid III dummies inside the full-scale M2 frontal impact reconstruction of Task 2.2. The dummy was seated in one of the original minibus seats, with an unoccupied seat directly in front. The seat characteristics (geometry, breakover 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 determinate how the usage of a two points belt system and the original position of the occupant may affect to the severity of the injury suffered by the occupants.



This model was validated through a rollover test of ECE R66 performed in the INSIA facilities with a coach body section. The structure accelerations and deformations were used for validating the model. As a conclusion of the model without occupant validation it have been proved that the deflexion results are very similar in the model and in the test. Some of the accelerometers signals are similar in terms of behaviour (when the maximum and the minimum are reached) although the value is different.

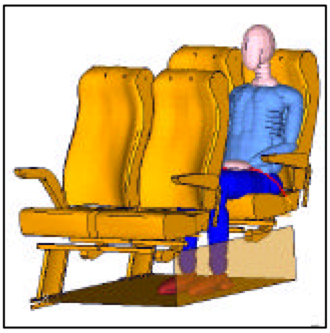


This model was validated through a rollover test of ECE R66 performed in the INSIA facilities with a bay section that has been loaded with passengers, and equipped with an instrumented

EuroSID-1 dummy. The effect of passenger's mass was represented by 7 ballast masses (68 kg).

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.

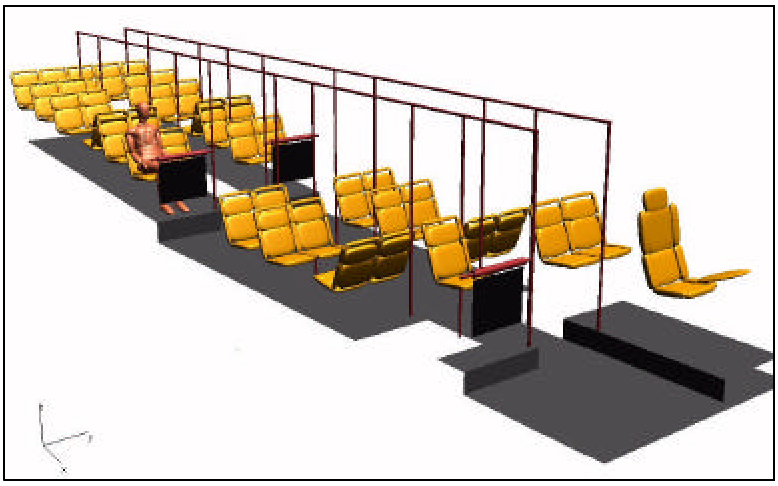
TNO's frontal impact simulation models of a bus and a bus interior were created and evaluated using test results. Using those simulation models, the most significant seat parameters were optimised. The target of the optimisation was to reduce the injury values recorded in the dummies. An optimal set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

17.2.5 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.

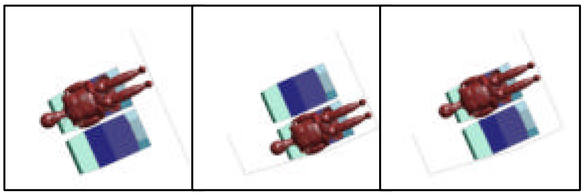
Assessment:

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.

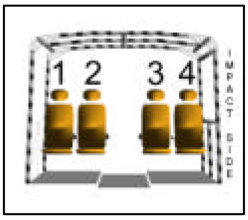
17.2.6 Task 2.6 – Parametric Study

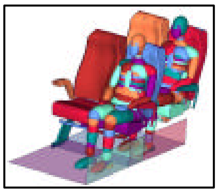
Planned: Using the model developed in task 2.1 through 2.4 a parametric study will be performed to see the influence of the injury risk on the following parameters: Vehicle structure, Intrusions, Padding, Seat characteristic, Window design (e.g. laminated glass), Restraint system (e.g. belts) and finally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

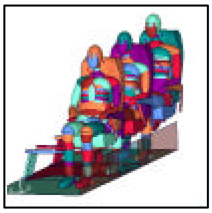
Performed: For CIC's M2 vehicle models the validated vehicle and occupant model both for rollover and frontal impact were taken as the baseline models for assessing the sensitivity of certain parameters to the resulting occupant injuries. This set of rollover simulations shows that for a typical rollover (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.





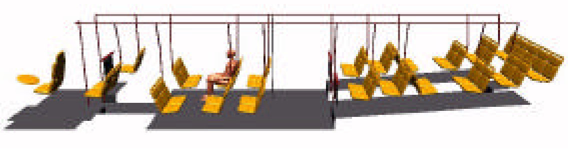


TNO's parameter optimisation consisted of a study, in which seat parameters are determined that result in the lowest injury values. This optimisation is performed for the 5th, 50th and 95th percentile dummy models. The result of the optimisation was one optimised set of seat parameters for each dummy. In the parametric study which followed the optimisation, simulations were performed using these optimised interiors.

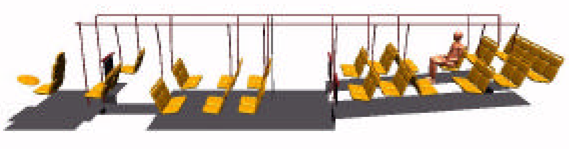
The optimisations have shown that in the three point belt configuration, a higher recliner stiffness is required and in an unbelted situation, a lower recliner stiffness is required. Furthermore, the 5th percentile dummy injury values are higher in an unbelted configuration than in a two or three point 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.

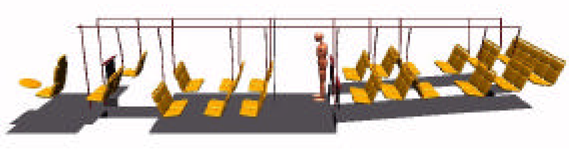
All original technical specifications and dimensions were implemented into the PCCrash simulation model to calculate the trajectory of the bus during the emergency braking. These dynamic parameters (positions, orientations) were then used as input data for the occupant simulations.



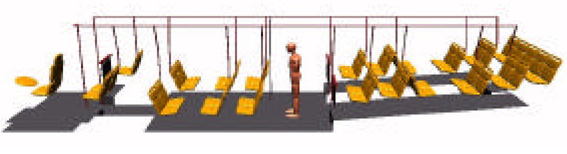
Face to Face front



Face to Face rear



Standing in front of space divider (entrance)



Standing in front of a grab rail (aisle)

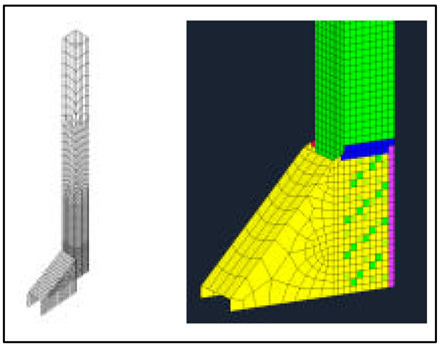
17.3 Workpackage 3

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.

17.3.1 Task 3.1 – Numerical test methods

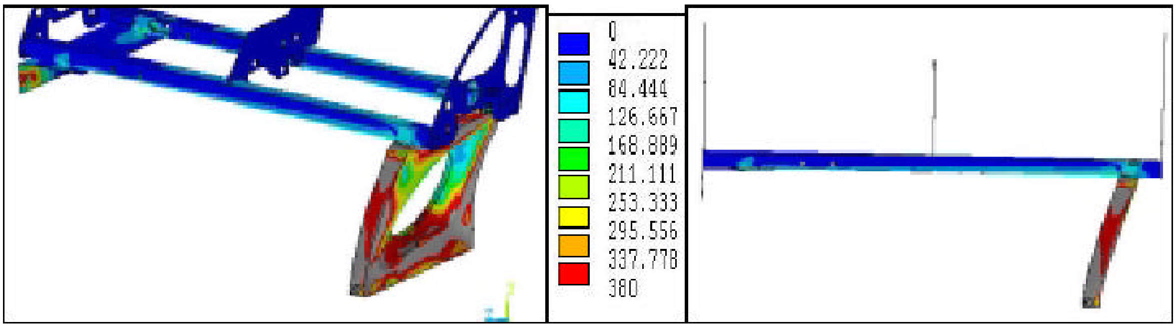
Planned: Based on the mathematical model derived in task 2.3 and 2.4 possible numerical test methods will be evaluated and classified. Task 3.1.1 refers to structural rollover tests where starting from the existing numerical method for ECE R 66 possible developments for additional criteria will be assessed (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:

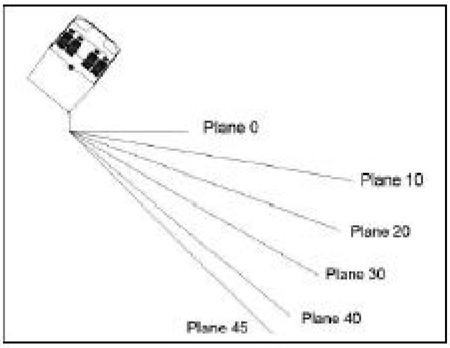


CIC: This task was undertaken in order to investigate the strength of the superstructure of a typical coach under rollover conditions. In particular the validated, with experimental evidence, finite element model of a coach bay section developed during Task 3.3.1, consisting mainly of three dimensional 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.

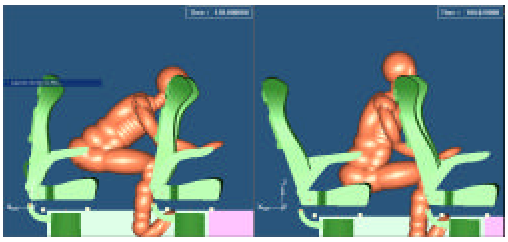
INSIA: In this report the conclusions obtained by INSIA in relation to the structural numerical test for rollover of coaches are described. The results from the rollover tests carried out in task 2.2 have been analysed and compared, and the models built in task 2.3 have been used.



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.

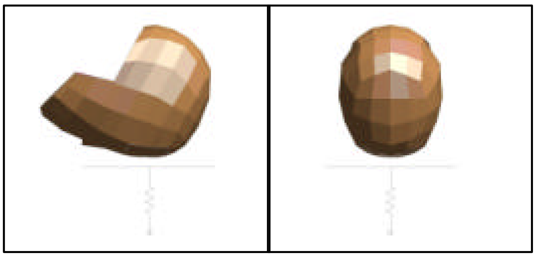


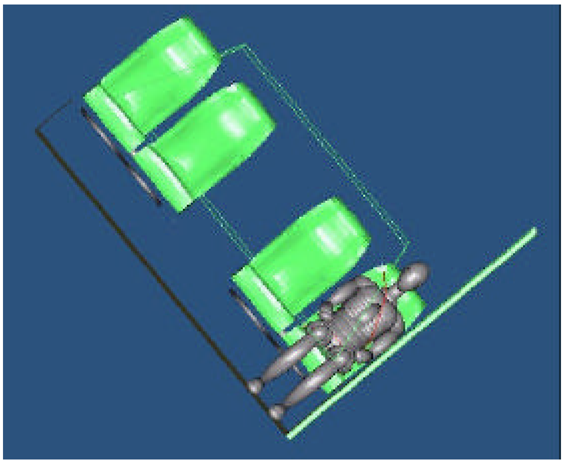
PoliTo: Using the numerical models of the CIC coach bay section developed for Task 2.3, a study was performed to verify the effects of some parameters relevant for the structural tests in order to point out the need of parameter specifications and the possibility of changes in the test conditions. In 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.

17.3.2 Task 3.2 – Component test methods

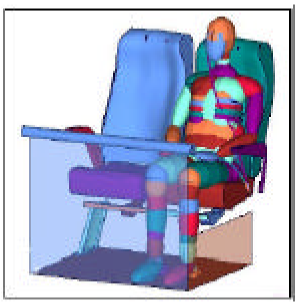
Planned: For Task 3.2.1 a test method similar to the FMVSS 201 – Free Motion Head Form will be assessed and important contact areas will be derived through numerical simulation. In Task 3.2.2 the possible extensions of the existing sled test procedure ECE R 80 to non frontal impacts (definition of oblique,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

Performed:

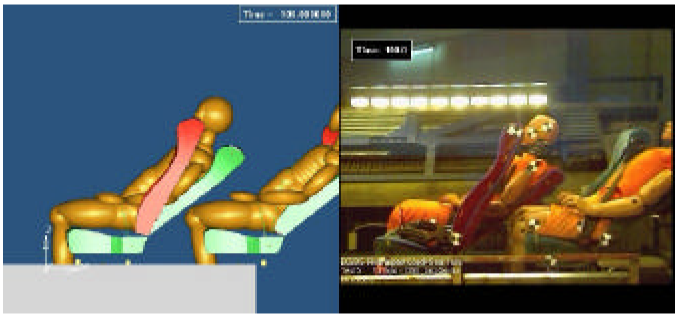
CIC: Within Task 3.2.1 guidelines for Free Motion Headform (FMH) drop tests have been developed for city-buses, coaches and minibuses, through the use of experimental data and numerical simulations.

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.



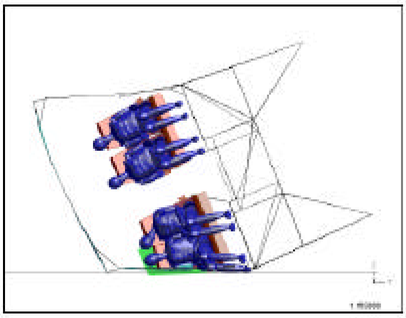
TUG: This task was undertaken in order to investigate the behaviour of sitting occupants under rear impact conditions. That can occur both for forward faced seats under rear end impact and for rearward faced seats under frontal impact conditions. TNO's validated frontal impact seat model formed the basis 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.

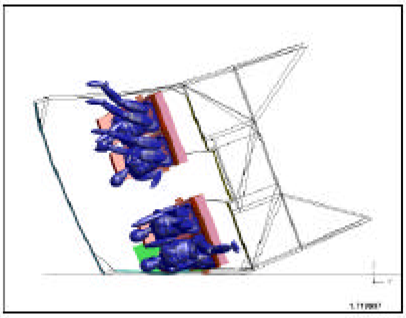


17.3.3 Task 3.3 – Full-scale test methods

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:

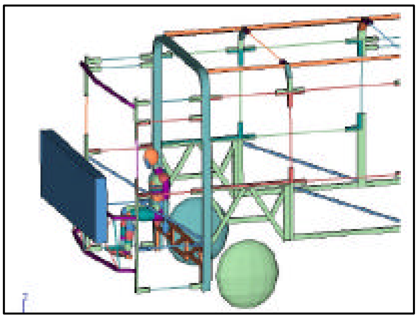




CIC: The aim of this work was to gain a better understanding of how the mass of passengers may effect the deformation of a coach structure during the UN-ECE Regulation 66 (R66) rollover test procedure.

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.

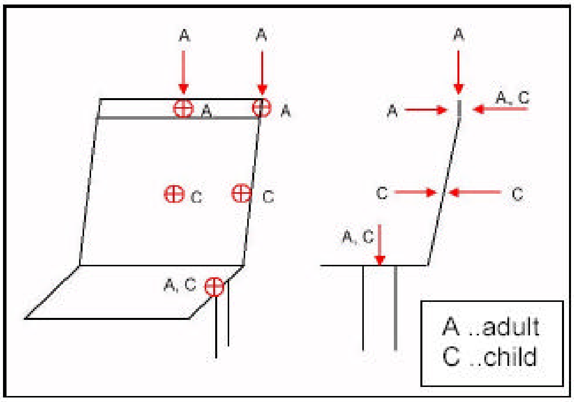


TNO: One of the task in this project is to make a preliminary feasibility study of the driver/co-driver safety in case of frontal collisions by performing MADYMO simulations and if possible to propose first ideas for evaluating the "survival space" for driver/co-driver during a frontal impact.
The feasibility 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.

17.3.4 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.

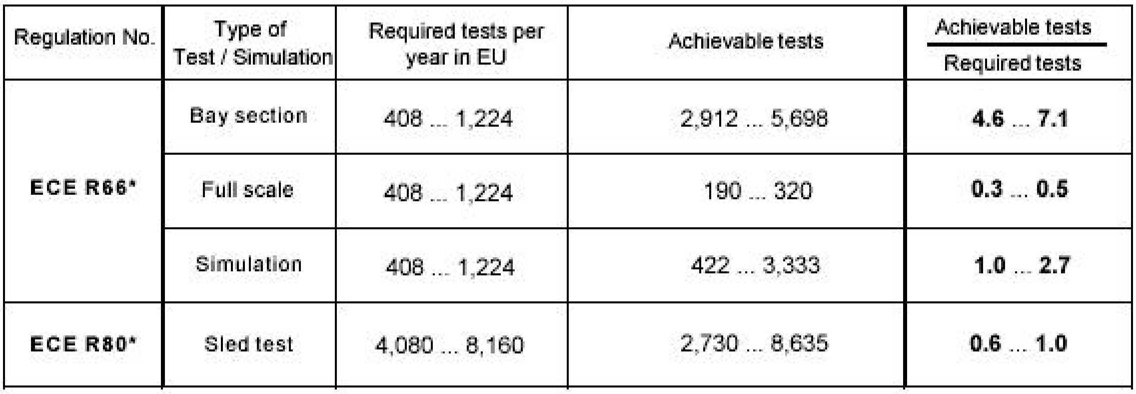


17.3.5 Task 3.5 – Cost benefit analysis for different test methods

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.



Regulation No.	Type of Test / Simulation	Required tests per year in EU	Achievable tests	Achievable tests / Required tests
ECE R66*	Bay section	408 ... 1,224	2,912 ... 5,698	**4.6 ... 7.1**
	Full scale	408 ... 1,224	190 ... 320	**0.3 ... 0.5**
	Simulation	408 ... 1,224	422 ... 3,333	**1.0 ... 2.7**
ECE R80*	Sled test	4,080 ... 8,160	2,730 ... 8,635	**0.6 ... 1.0**

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

17.3.6 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.

17.4 Workpackage 3

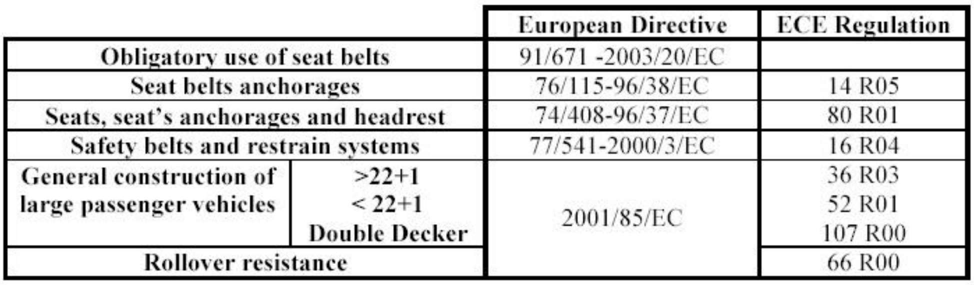
General: In WP 4 written standards will be suggested based on the newly developed test methods. Their efficiency will be demonstrated by means of numerical models for improved bus and coach designs.

17.4.1 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.



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

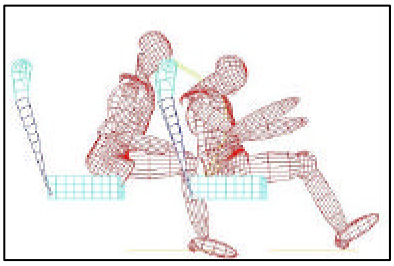
First of all an overview on actual standards related to buses and coaches is presented. That overview has been made inside other tasks and by other partners during the Project, but it is interesting to remember them again because we are going to talk about proposals of modification in Directives and 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).

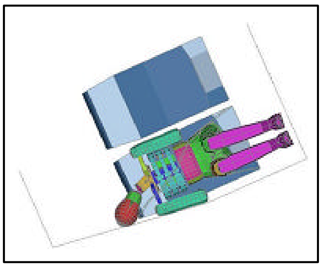
17.4.2 Task 4.2 – Mathematical models of improved bus design

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 roll-over), 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:

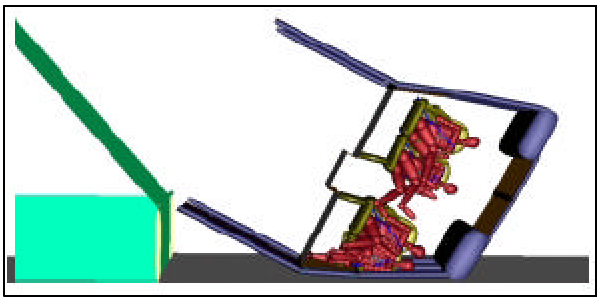
CIC: The objective of this task was to demonstrate the best practise design for M2 vehicles involved in frontal impact and rollover accidents. The original minibus vehicle was considered to perform well for both frontal impact and rollover. The frontal impact test into a barrier was an aggressive scenario 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.





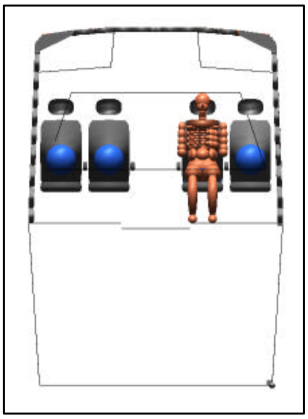
The scope of this task was not to assess or modify the structural performance of the M2 vehicle, as this would require far more time and effort to achieve. Instead, the original structural performance was accepted as a good design for which the interior could then be optimised.

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



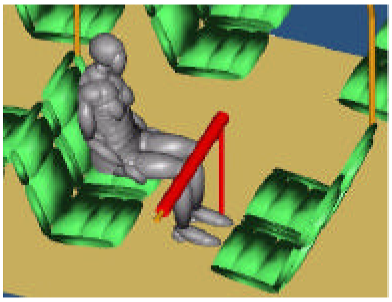
models were developed with the dummy placed in different locations and also with different restraint systems (two points belts and three points belts).

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.



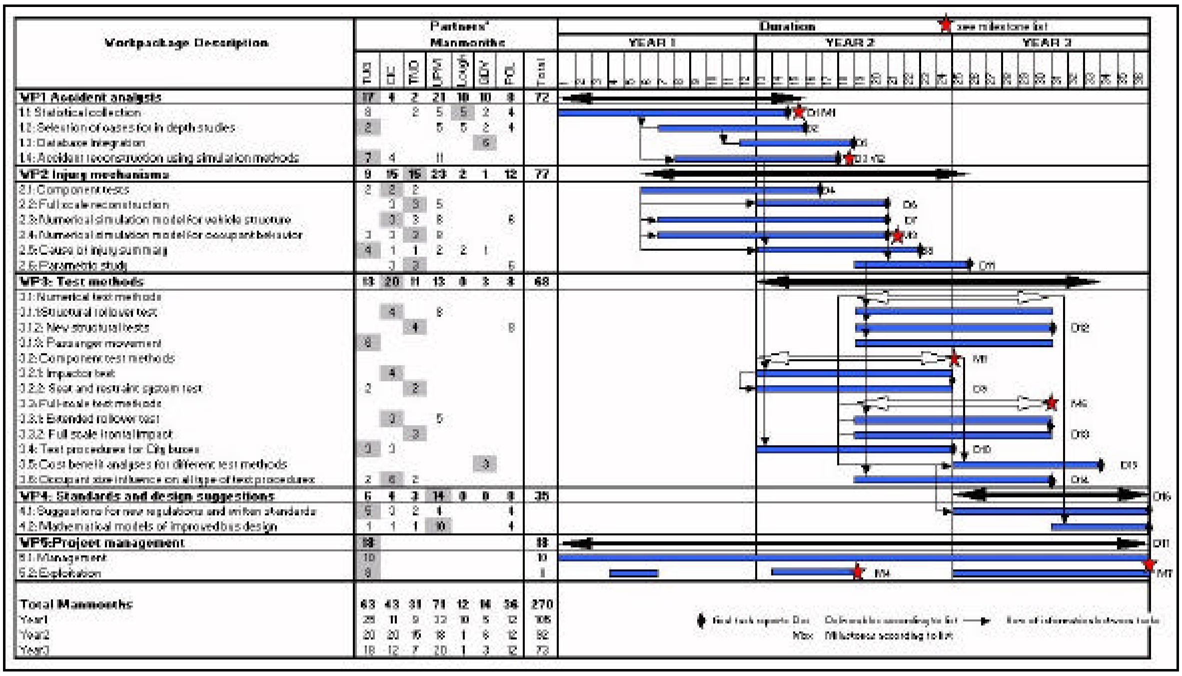
TNO: The work described concerns the simulation work performed to evaluate possible improvements to the existing ECE/R80. All simulations were oriented towards the final objective of providing design guidelines (recommendations) for bus seats as far as 3 points belt system requirement is involved. It 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.

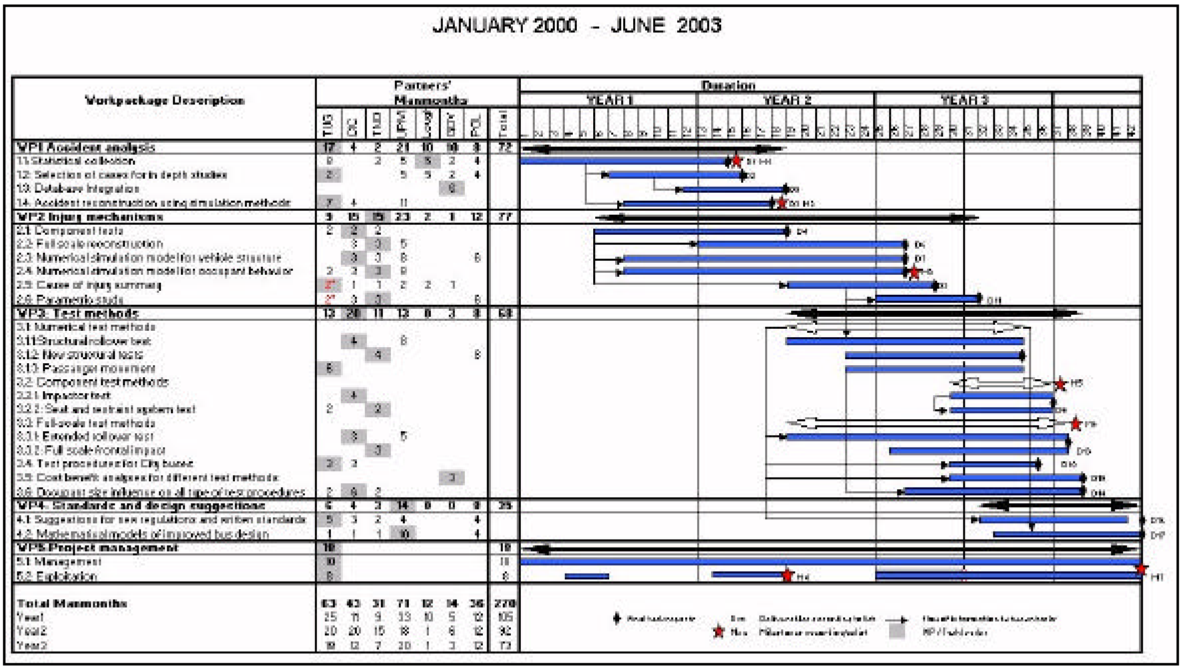


18 LIST OF DELIVERABLES

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.



Original Time Table



Performance Time Table

Delivery N°1 (Milestone 1): Task 1.1: Statistical Collection

A statistical summery 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 N°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 N°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 N°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 N°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

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.

19 MANAGEMENT AND CO-ORDINATION ASPECTS

19.1 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.

19.2 Updated Contact List

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20 RESULTS AND CONCLUSIONS

20.1 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.

20.2 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 accidence avoidance
10. Further research on possibilities for general rating of the passive safety

20.2.1 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.

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

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 passenger (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).

20.2.2 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:
Directive 2003/20/EC, Directive 96/38/EC, Directive 2001/85/EC
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 passenger s wearing 3-point belts. The mass must be considered as rigid joint and must be fixed at the theoretic centre of gravity of the passengers (about 200 [mm] above the cushion or about 100 [mm] above the R-point. Those 2 factors (the increment of the total mass and the height of the centre of gravity) increase the energy to be absorbed during rollover and must be taken into account in the tests and the calculation methods either.

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:
Directive 2003/20/EC, Directive 96/38/EC, Directive 2001/85/EC
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:
Directive 96/38/EC, Directive 2000/3/EC, Directive 2003/20/EC
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:
Directive 96/38/EC, Directive 2000/3/EC, Directive 2003/20/EC
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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