D-1.2 – Conclusions of accident research study involving light vans

Project Acronym: **OPTIBODY**

Project Full Title: **"Optimized Structural components and add-ons to improve passive safety in new Electric Light Trucks and Vans (ELTVs) "**

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SUMMARY:

Traffic accidents are considered one of the major worldwide Public Health problems. Car occupant fatalities are decreasing in developed countries, especially in car to car crashes. However, more effort needs to be done in other types of accidents such as car to truck accidents, pedestrians, etc.

This document compiles the work performed in tasks 1.2 and 1.3 of the project. In task 1.2, a review of the accidentology in different geographical areas was performed: worldwide, Europe, Japan, Australia, U.S. and Canada. A research on the accident databases of these geographical areas was done in order to establish the most common accident scenarios involving ELTV vehicles, especially the European category L7e.

In task 1.3, a literature review of projects regarding crash compatibility was performed in order to determine the critical factors and consider the test procedures needed to improve crash compatibility in the OPTIBODY vehicle.

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1. Executive summary

Most of the existing Electric Light Trucks and Vans (ELTVs) adopt the powertrain lay-out used in classic thermal engine vehicles. Very conservative solutions and technologies are used in their development, mainly because it is done by small and medium sized companies. However, bigger companies are already introducing new solutions in the design of this type of vehicles, such as the implementation of in-wheel motors. This new design provides a considerable amount of space in the former location of the engine and is no longer necessary to accommodate some awkwardly-shaped mechanical components. These changes allow the engineers to concentrate on performance and safety when the new frontal part of the vehicle is designed.

Simplifying the vehicles enables engineering teams to perform changes that were considered impossible in the past. These changes include eliminating the entire engine block, reducing the weight, totally flat floor design, chassis design focused on passengers' safety and frontal design focused in vulnerable road users' safety. All these modifications, as well as the possibility of implementing specific systems and add-ons will increase the vehicle passive safety of ELTVs.

OPTIBODY has been defined as a new structural concept of ELTVs composed of a chassis, a cabin and a number of specific add-ons. The chassis will act as a key structural supporting element for any other components in the vehicle. The cabin will improve current levels of EVs' comfort, occupant protection and ergonomics. Finally, a number of add-ons will bring specific self-protection in case of front, rear and side impacts, as well as in case of rollover. Additionally, these add-ons will also provide partner protection in case of interaction with other vehicles (crash compatibility) or vulnerable users (pedestrian, cyclists and motorcyclists).

The OPTIBODY concept has, among others, the following objectives related to safety:

1. **Enhance crash compatibility for ELTVs**. The free room available after removing the thermal engine provides the opportunity to introduce new load paths and energy absorbing add-ons.
2. **Enhanced passive safety**. The introduction of specific add-ons will ensure the enhancement of pedestrians, cyclists and infrastructure protection (APROSYS).
3. **Establishments of the requirements for impact-safe ELTV's.** Technical requirements for an "OPTIBODY" quality marking will be determined.

And OPTIBODY will aim to improve and provide innovative solutions for **three main areas**.

1. **Pedestrian protection**: in order to improve this area, the extra space available will be used to incorporate new optimized front parts.
2. **Crashworthiness and compatibility:** In the automotive industry, for conventional vehicles as well as for electric vehicles, "crashworthiness" is a measure of the vehicle's structural ability to plastically deform and still maintain a sufficient survival space for its occupants in crashes involving reasonable deceleration load. "Compatibility" is a term that refers to the "quality" of structural interaction in collisions, and this "quality" depends on several factors that are common to all kind of vehicles. "Compatibility", with no differences for conventional vehicles and electric vehicles, means the good performance of traffic participants among each other in the event of an accident. Self-protection and partner protection can be improved by developing optimized crash energy absorbing add-ons.
3. **Reparability**. The main idea is to provide new basis for fully modular concepts like OPTIBODY.

In order to identify the most common scenarios involving the OPTIBODY category vehicles, an analysis on existing databases, focused on light trucks and vans was carried out in Task 1.2. The different databases used include information of different markets in order to study differences between the different geographical areas. This analysis found out the most common crash test scenarios in urban environments involving light trucks and vans.

In Task 1.3, a literature review of all published work on crash compatibility, especially on trucks and light vans, was performed. The particular situation of crash compatibility in light trucks and vans with a complete electric powertrain was studied. Different lay-out configurations were analyzed focusing on the capability of being compatible in case of frontal or lateral impacts. The main aspects were analyzed: total mass, weight distribution, front-end design, main load transfer paths during impact, vehicle's height, etc. A final ideal lay-out of body, chassis and powertrain configurations in terms of crash compatibility is proposed.

The accident data analyzed showed tends to reduce the number of fatalities in road accidents. A review of the Piemonte Region database, in Italy, showed that only one person died in accidents involving quadricyles. The small number of fatalities and injuries in accidents involving this category of vehicles might me due to: safety measurements integrated in the vehicles, small mass, low speed, they mostly circulate in urban areas and/or the number of vehicles in this category is very small. Frontal-side impact (Frontal with offset) and rear impact are by far the most frequent types of accidents. However, frontal impact and pedestrian accidents are much more severe causing more casualties and injuries than the other types of prevailing accidents.

The number truck accidents and the number of fatalities associated with those accidents are significantly higher than for quadricycles. Especial effort need to be done to reduce the number of pedestrian accidents in both quadricycle and truck cases. The applicability of the of the frontal add-on for pedestrian protection to other vehicle categories would help to minimize this problem.

Into the EU19 group 153,780 people died during the period between 2000 from 2009. According to CARE database, the number of deaths in lorries under 3.5 tons, was of 893 for the EU19 in 2009, 5.2% less compared to 2008. A total of 155 of those deaths occurred in urban areas. Accidents in urban areas represent a high number of deaths and they require especial attention due to the urban use that the OPTIBODY vehicle will have.

In the U.S., 3.6 times as many passenger car occupants were killed as LTV occupants in car-to-LTV collisions. When LTVs were struck in the side by a passenger car, 1.6 times as many LTV occupants were killed as passenger car occupants. On the other hand, when passenger cars were struck in the side by LTVs they were killed 18 times more than LTV occupants. Then, crash compatibility is a major issue to consider in the OPTIBODY design.

2. Glossary

ELTV – Electric Light Trucks and Vans

IRF - International Road Federation

IRTAD - International Traffic Safety Data and Analysis Group

UNECE - United Nations Economic Commission for Europe

CARE - Community Road Accident Database

CHILD - Child Injury Led Design

EACS - European Accident Causation Survey

ECBOS - Enhanced Coach and Bus Occupant Safety

ECMT - European Conference of the Ministers of Transport

ETAC - European Truck Accident Causation Study

MAIDS - Motorcycle Accident In-depth Study

PENDANT - Pan-European Co-ordinated Accident and Injury Database

RISER - Roadside Infrastructure for Safer European Roads

ISTAT - Istituto Italiano di Statistica (Regione Piemonte database)

FARS - Fatality Analysis Reporting System

NASS/GES - National Automotive Sampling System/General Estimates System

NASS/CDS - National Automotive Sampling System/Crashworthiness Data System

MIDS - Monash University Accident Research Center, (MUARC), In-depth Data System

LGV – Light Goods Vehicle

NHTSA – National Highway Traffic Safety Administration

SAB – Side Airbags

SUV – Sport Utility Vehicle

ESP – Electronic Stabilization Program

FUP – Front underrun protection

RUP – Rear underrun protection

GIDAS - German In-Depth Accident Study

ECE - Economic Commission for Europe

ODB – Offset Deformable Barrier

PDB – Progressive Deformable Barrier

FWRB – Full Width Rigid Barrier

FWDB – Full Width Deformable Barrier

3. Methodology

This deliverable is divided in two main parts. The first part is the analysis of different databases in order to describe the accidents involving ELTVs. This analysis describes the epidemiology and the most common scenarios depending on the geographical area considered. The second part is focused in ELTV's crash compatibility.

Different accident databases available for the different geographical areas were considered in the study. Worldwide, European, Japanese, North American and Australian databases are considered. In Table 3.1 the available databases for the global and European areas are shown.

AREA	DATABASE	
Worldwide	IRF	International Road Federation
	IRTAD	International Traffic Safety Data and Analysis Group
	UNECE	United Nations Economic Commission for Europe
Europe	CARE	Community Road Accident Database
	CHILD	Child Injury Led Design
	EACS	European Accident Causation Survey
	ECBOS	Enhanced Coach and Bus Occupant Safety
	ECMT	European Conference of the Ministers of Transport
	ETAC	European Truck Accident Causation Study
	Eurostat	Statistical Office of the European Communities
	MAIDS	Motorcycle Accident In-depth Study
	PENDANT	Pan-European Co-ordinated Accident and Injury Database
	RISER	Roadside Infrastructure for Safer European Roads
	ISTAT	Istituto Italiano di Statistica (Regione Piemonte database)

Table 3.1: Available databases for global and Europe areas

Other non-european databases used in this report are:

- FARS (Fatality Analysis Reporting System)
- NASS/GES (National Automotive Sampling System/General Estimates System)
- NASS/CDS (National Automotive Sampling System/Crashworthiness Data System)
- MIDS (Monash University Accident Research Center, MUARC, In-depth Data System)

Data extracted from previous research projects and a review of the existing literature was also considered.

4. Accident Research

4.1. World data

4.1.1. Road user fatalities long term trends

The International Traffic Safety Data and Analysis Group (IRTAD) published in July 2011 a database considering road user fatalities long-term trends. This database included fatalities since 1980 and provides a valuable perspective of road fatalities trends over the last 30 years in 30 different countries of all around the world.

In order to use the same inclusion criteria, deaths within 30 days after the accident were considered for the database, but some of the countries have different number of days as reference to consider a death as a consequence of a road accident. For this reason, IRTAD applies a certain correction factor in the data collected from these countries. The correction factors for the different countries are listed in Table 4.1:

COUNTRY	PERIOD	DAYS CONSIDERED	CORR. FACTOR
Italy	before 1999	7	+8,0%
France	before 1993	6	+9,0%
	1993 - 2003	6	+5,7%
	until 2004	6	+8,0%
Spain	before 1999	24 (hours)	+30,0%
Greece	before 1996	3	+18,0%
Austria	before 1983	3	+15,0%
	until 1991	3	+12,0%
Switzerland	before 1992	Unlimited	-3,0%
Japan	before 1993	24 (hours)	+30,0%
Korea	before 2000	3	+15,0%
Portugal	before 2010	24 (hours)	+14,0%

Table 4.1: Correction factors to consider deaths within 30 days as the inclusion criteria. Source: Own production from IRTAD database July 2011

Table 4.2 shows the number of road user fatalities from 1980 to 2009 of the 30 countries that reported their data. The data is sorted by the number of road user fatalities in 1980 in ascending order. Then, the countries have been grouped in four different categories: the first one includes countries that had less than 1000 fatalities in 1980, the second one between 1000 and 5000, the third one between 5000 and 10000 and the fourth includes countries over 10000 road user fatalities.

The number of fatalities over the years for each category has been graphed in Figure 4-1 for the first group of countries (countries that had less than 1000 fatalities in 1980), in Figure 4-2 for the second group, in Figure 4-3 for the third group, and Figure 4-4 for the fourth group.

In 1980 the higher number of fatalities corresponded to bigger countries in surface and higher level of development. These countries still have big numbers in terms of fatalities at this moment, even when an important decrease has been experienced during the last 30 years.

The global tendency is to reduce the number of road fatalities through the years. Some of the countries, such as Hungary, Greece, Czech Republic, Korea and Spain, showed an increase in the number of fatalities during the 80's or 90's in coincidence with an increase in their vehicle fleet according to a higher development level and a higher level of wealth in the country.

	Road user fatalities					
Country	1980	1990	2000	2005	2008	2009
Iceland	25	24	32	19	12	17
Luxembourg	98	71	76	47	36	48
Norway	362	332	341	223	255	212
Israel	425	418	452	437	412	314
Finland	551	649	396	379	344	279
Slovenia	558	517	314	258	214	171
Ireland	564	478	415	396	279	238
New Zealand	597	729	462	405	365	384
Denmark	690	634	498	331	406	303
Sweden	848	772	591	440	397	358
Switzerland	1209	925	592	409	357	349
Czech Republic	1261	1291	1486	1286	1076	901
Greece	1446	2050	2037	1658	1553	1456
Hungary	1630	2432	1200	1278	996	822
Netherlands	1996	1376	1082	750	677	644
Austria	2003	1558	976	768	679	633
Belgium	2396	1976	1470	1089	944	944
Portugal	2579	2646	1857	1247	885	840
Australia	3272	2331	1817	1627	1437	1490
Canada	5461	3963	2903	2898	2419	2209
Great Britain	5953	5217	3409	3201	2538	2222
Poland	6002	7333	6294	5444	5437	4572
United Kingdom	6182	5402	3580	3336	2645	2337
Korea	6449	14174	10236	6376	5870	5838
Spain	6522	9032	5776	4442	3100	2714
Italy	9220	7151	7061	5818	4725	4237
Japan	11388	14595	10403	7931	6023	5772
France	13636	11215	8079	5318	4275	4273
Germany	15050	11046	7503	5361	4477	4152
USA	51091	44599	41945	43510	37423	33808

Table 4.2: Road user fatalities from 1980 to 2009.
Source: Own production about IRTAD database, July 2011

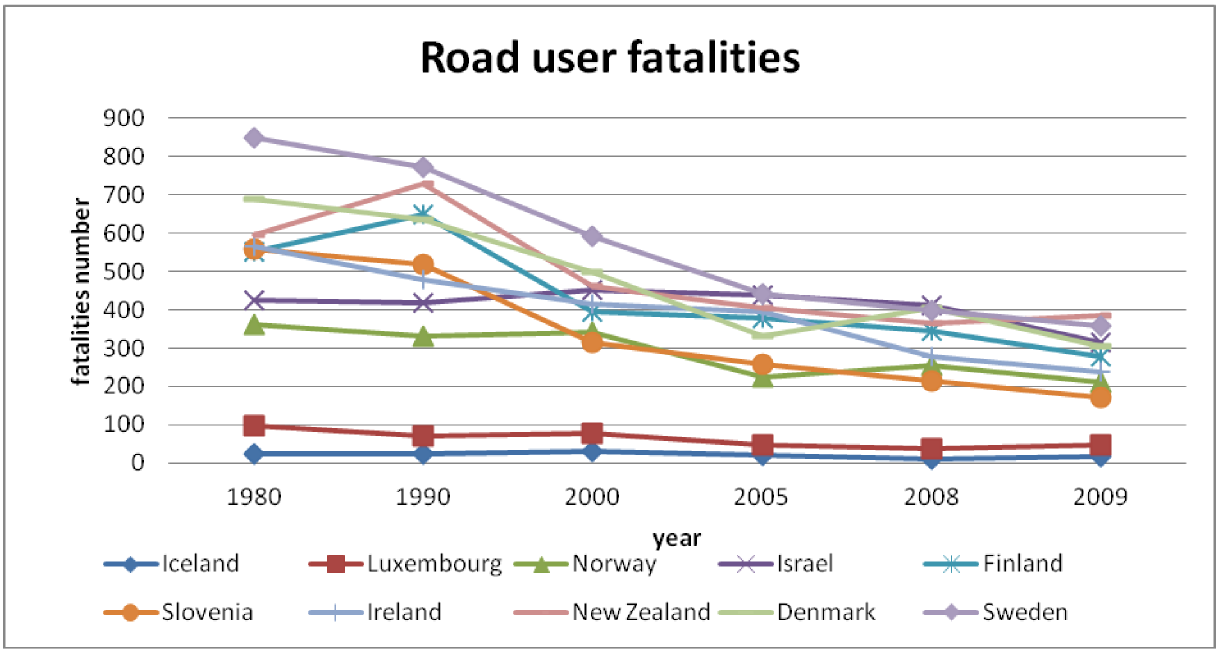


Figure 4-1: Road user fatalities from 1980 to 2009 for selected countries with less than 1000 fatalities in 1980.

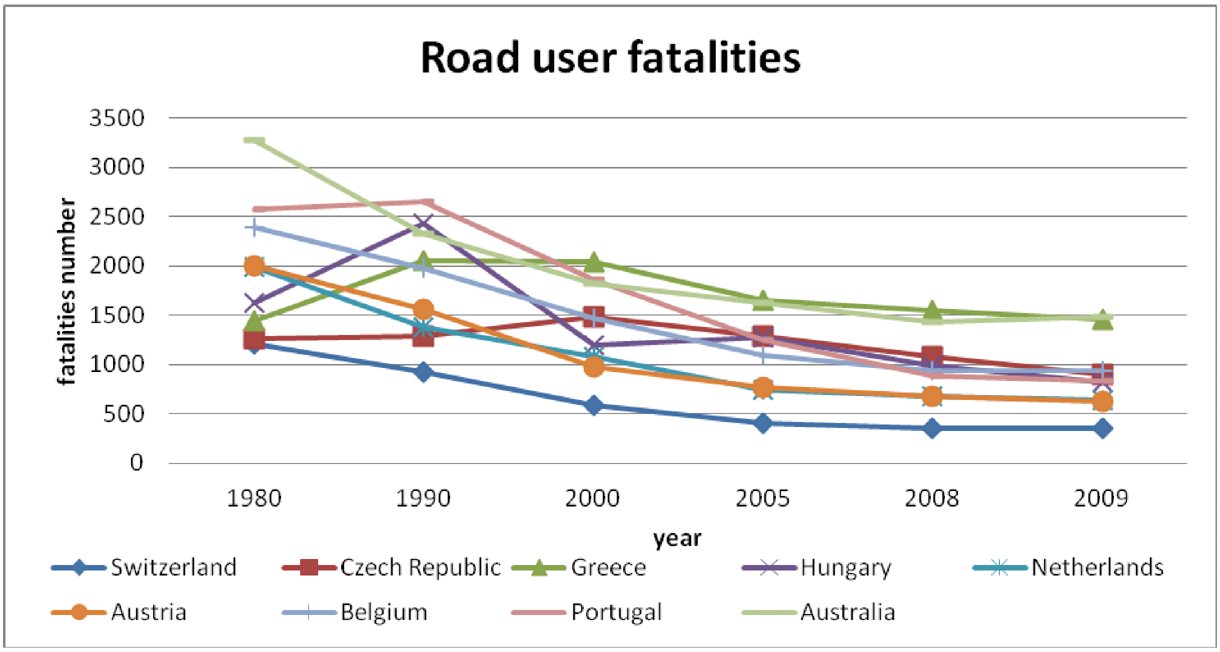


Figure 4-2: Road user fatalities from 1980 to 2009 for selected countries with a number of fatalities between 1000 and 5000 in 1980.

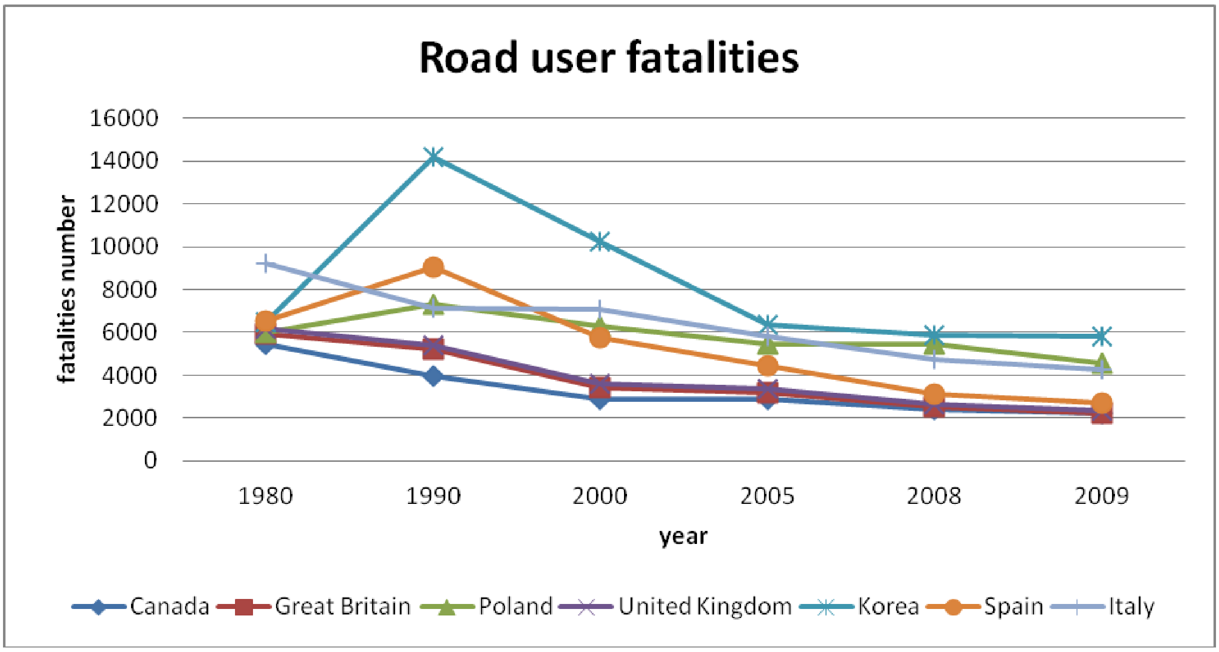


Figure 4-3: Road user fatalities from 1980 to 2009 for selected countries with a number of fatalities in 1980 between 5000 and 10000.

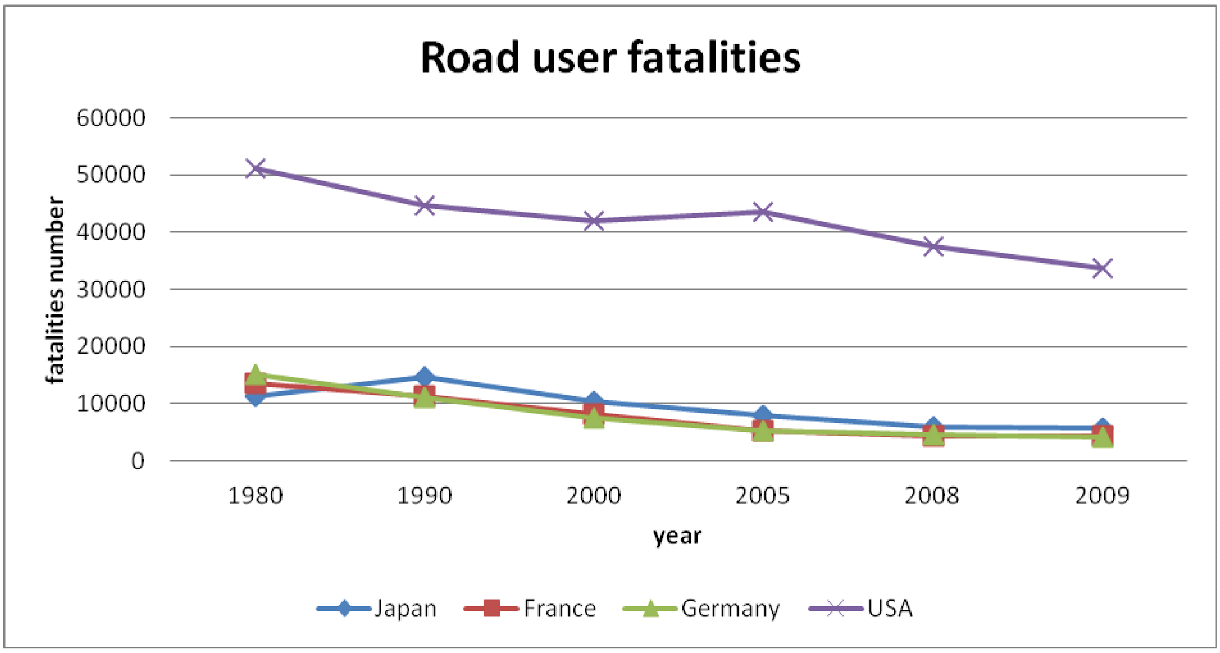


Figure 4-4: Road user fatalities from 1980 to 2009 for selected countries with number of fatalities on 1980 over 10000.

Table 4.3 shows the percentage change in the number of fatalities comparing 2009 with previous years. The countries are organized considering the higher reduction in fatalities in 2009 compared to 1980, so in the first row is Germany with a reduction of 72.41% and in the last row is Greece which shows similar numbers as in 1980.

Safer vehicles, road safety education programs, changes in laws like lower levels of alcohol allowed while driving, etc. are responsible for the big decrease of fatalities in countries such as: Germany, Switzerland, Slovenia, France, Austria, Netherlands, Portugal, Great Britain, United Kingdom, Belgium, Canada and Spain.

Cells in Table 4.3 are colored depending on the percentage change in the number of fatalities comparing 2009 with previous years. The colors used are:

- Green: Negative percentage change higher than -40%
- Yellow: Negative percentage change between -20% and -40%
- Orange: Negative percentage change between 0% and -20%
- Red: Positive percentage change (increase in the number of fatalities compared with the previous years)

COUNTRY	% CHANGE LATEST YEAR AVAILABLE COMPARED TO				
	1980 (%)	1990 (%)	2000 (%)	2005 (%)	2008 (%)
Germany	-72,41	-62,41	-44,66	-22,55	-7,26
Switzerland	-71,13	-62,27	-41,05	-14,67	-2,24
Slovenia	-69,35	-66,92	-45,54	-33,72	-20,09
France	-68,66	-61,90	-47,11	-19,65	-0,05
Austria	-68,40	-59,37	-35,14	-17,58	-6,77
Netherlands	-67,74	-53,20	-40,48	-14,13	-4,87
Portugal	-67,43	-68,25	-54,77	-32,64	-5,08
Great Britain	-62,67	-57,41	-34,82	-30,58	-12,45
United Kingdom	-62,20	-56,74	-34,72	-29,95	-11,64
Belgium	-60,60	-52,23	-35,78	-13,31	0,00
Canada	-59,55	-44,26	-23,91	-23,78	-8,68
Spain	-58,39	-69,95	-53,01	-38,90	-12,45
Ireland	-57,80	-50,21	-42,65	-39,90	-14,70
Sweden	-57,78	-53,63	-39,42	-18,64	-9,82
Denmark	-56,09	-52,21	-39,16	-8,46	-25,37
Australia	-54,46	-36,08	-18,00	-8,42	3,69
Italy	-54,05	-40,75	-39,99	-27,17	-10,33
Luxembourg	-51,02	-32,39	-36,84	2,13	33,33
Hungary	-49,57	-66,20	-31,50	-35,68	-17,47
Finland	-49,36	-57,01	-29,55	-26,39	-18,90
Japan	-49,32	-60,45	-44,52	-27,22	-4,17
Norway	-41,44	-36,14	-37,83	-4,93	-16,86
New Zealand	-35,68	-47,33	-16,88	-5,19	5,21
USA	-33,83	-24,20	-19,40	-22,30	-9,66
Iceland	-32,00	-29,17	-46,88	-10,53	41,67
Czech Republic	-28,55	-30,21	-39,37	-29,94	-16,26
Israel	-26,12	-24,88	-30,53	-28,15	-23,79
Poland	-23,83	-37,65	-27,36	-16,02	-15,91
Korea	-9,47	-58,81	-42,97	-8,44	-0,55
Greece	0,69	-28,98	-28,52	-12,18	-6,25

Table 4.3: Road user fatalities percentage change comparing 2009 to different years. Source Own production from IRTAD database

4.1.2. Road traffic, vehicles usage and damages in road accidents

The data obtained from "IRF World Road Statistics 2009", was used to determine the distribution of different vehicles in the fleet of some selected countries, and then it was possible to establish a relation between their percentage on the fleet and road accidents.

4.1.2.1. Road traffic

Before starting it is necessary to know how IRF defines some concepts in order to better understand the information provided in the following tables and figures:

- Road traffic is defined as "any movement of a road vehicle on a given network"
- Traffic volume is defined as: "weighted average daily flow of each vehicle type on each category of the road network, as determined from regular national stratified, classified traffic counts."
- Estimated traffic volume: "is estimated by dividing the annual consumption of motor vehicle fuel (in liters) used in the country by the number of vehicles in each category. The result is then multiplied by the average number of km/liter for that category."
- Vehicle-kilometer (veh-km): "unit of measurement representing the movement of a road motor vehicle over one kilometer."

Table 4.4 shows the traffic volume measured in vehicle-kilometer in year 2007 in some countries all over the world. The percentages over the total have been calculated too. Motorcycles and mopeds have not been computed on the total because some of the countries do not incorporate that data, so it would not be possible to compare it.

The boxes of the total road traffic column have been colored in three different colors:

- Red has been applied in boxes with a value lower than 10000 veh-km
- Yellow has been used in boxes between 10000 and 100000 veh-km
- And green are boxes over 100000 veh-km

The percentage of vans and lorries is represented has been also colored. Red color was used if the percentage was under the media and green if it was over the average.

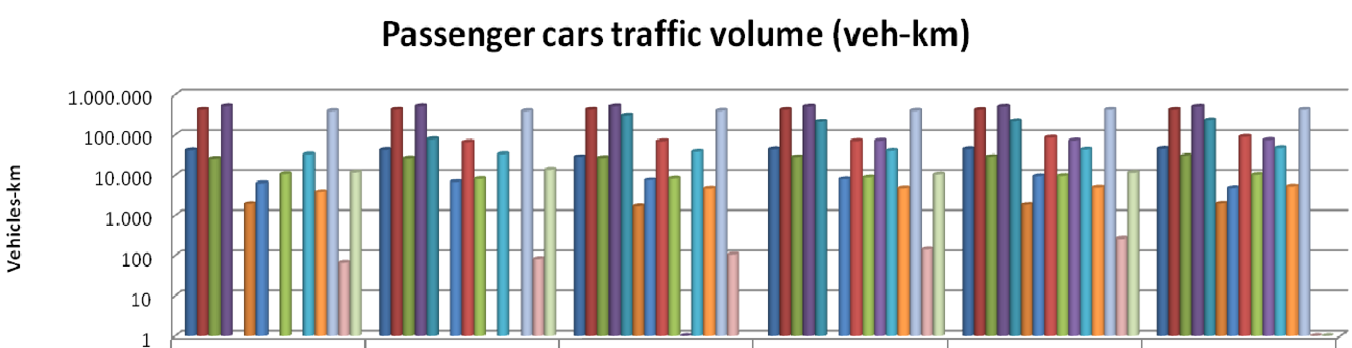
	ANNUAL TRAFFIC VOLUME PER VEHICLE CATEGORY AND COUNTRY (VEH-KM)							
YEAR 2007	Passenger cars		Buses and Motorcoaches		Vans and Lorries		Total	Motorcycles and Mopeds
COUNTRY	veh-km	%	veh-km	%	veh-km	%		
Armenia	192.40	36.96	210.20	40.38	117.90	22.65	520.50	
Ecuador	11299.00	44.24	983.00	3.85	13256.00	51.91	25538.00	
Finland	45560.00	85.56	580.00	1.09	7110.00	13.35	53250.00	
France	419000.00	75.97	2500.00	0.45	130000.00	23.57	551500.00	6000.00
Israel	30490.00	68.93	1370.00	3.10	12375.00	27.98	44235.00	761.00
Japan	514109.00	67.41	6655.00	0.87	241849.00	31.71	762613.00	
Korea, Republic of	233401.00	70.29	24037.00	7.24	74594.00	22.47	332032.00	
Kyrgyzstan	1982.00	70.88	457.50	16.36	356.60	12.75	2796.10	15.00
Latvia	4830.50	75.28	79.80	1.24	1506.10	23.47	6416.40	
Mexico	90650.00	77.38	6392.00	5.46	20108.00	17.16	117150.00	
Singapore	10335.00	67.68	560.00	3.67	4375.00	28.65	15270.00	1983.00
South Africa	75573.00	57.31	9007.00	6.83	47278.00	35.86	131858.00	1911.00
Turkey	47124.00	67.70	3499.00	5.03	18986.00	27.28	69609.00	
Ukraine	5302.90	35.21	2457.90	16.32	7299.80	48.47	15060.60	
United Kingdom	421813.22	79.98	5593.12	1.06	100000.27	18.96	527406.61	5588.00

Table 4.4: Annual traffic volume per vehicle category and country in 2007. Source: Own production from IRF data

Analyzing the data collected on Table 4.4 it is possible to conclude that higher road traffic volume measured in veh-km does not mean higher percentage of vans and lorries. That is going to be related to other factors such as the characteristics of the country, wealth, development, way of carrying goods, etc. In IRF, the vans and lorries category is defined as: “Rigid road motor vehicle designed, exclusively or primarily, to carry goods. This category includes vans which are rigid road motor vehicles designed exclusively or primarily to carry goods with a gross vehicle weight of less than 3,500 kg. This category also includes pick-ups.”

According to these data and focusing in European countries, the percentage of vans and lorries in road traffic may be considered around 20%. Japan has a little higher level of vans and lorries, close to 32%.

Table 4.5 compares road traffic volume of some countries and shows how richer countries have higher level of passenger vehicles over one kilometer.



	2002	2003	2004	2005	2006	2007
Finland	41676,00	42566,00	28480,00	44192,00	44610,00	45560,00
France	422000,00	425000,00	425000,00	420000,00	417000,00	419000,00
Israel	25542,00	26143,00	26500,00	28179,00	28857,00	30490,00
Japan	529208,00	529717,00	526319,00	520137,00	514109,00	514109,00
Korea, Republic of		79459,00	309652,00	214347,00	221577,00	233401,00
Kyrgyzstan	1936,00		1677,00		1848,00	1982,00
Latvia	6268,00	6809,00	7486,00	7979,00	9504,80	4830,50
Mexico		67825,00	70746,00	71334,00	86450,00	90650,00
Singapore	10804,00	8165,00	8347,00	8860,00	9645,00	10335,00
South Africa			0,00	72797,00	73447,00	75573,00
Turkey	33204,00	33802,00	38403,00	40490,00	43188,00	47124,00
Ukraine	3784,00		4697,00	4788,00	4995,00	5302,90
United Kingdom	392926,00	393049,00	398056,00	397191,00	419725,97	421813,22
Armenia	67,00	82,00	106,00	144,00	264,00	0,00
Ecuador	11827,00	13708,00		10542,00	11557,00	0,00

Table 4.5: Passenger cars traffic volume per country 2002-2007 veh-km. Source: Own production from IRF data

4.1.2.2. Vehicle in use

The *different* types of vehicles considered are:

- **Passenger cars:** road motor vehicle, other than a motorcycle, intended for the carriage of passengers and designed to seat no more than nine persons (including the driver). Includes microcars (need no permit to be driven), taxis and hired passenger cars, of less than ten seats.

- **Busses and motor coaches:** passenger road motor vehicle designed to seat more than nine persons (driver included). The statistics also include minibuses designed to seat more than 9 persons (driver included)

- **Lorries and vans:** rigid road motor vehicle designed, exclusively or primarily, to carry goods. This category includes vans which are rigid road motor vehicles designed exclusively or primarily to carry goods with a gross vehicle weight of less than 3500 kg. This category also includes pick-ups.

- **Road Tractors** (semitrailers): road motor vehicle designed, exclusively or primarily, to haul other road vehicles that are not power-driven (mainly semitrailers). Agricultural tractors are excluded.

- **Motorcycles or mopeds:** two or three wheeled road motor vehicles with or without sidecar, including motor scooter. Maximum 400 kg unlade weight.

The number of vehicles in use per category in year 2007 in different countries and fleet ratios (number of vehicles per 1000 people) are shown in Table 4.6. Countries have been sorted according to the total number of vehicles per 1000 people and three different groups were made.

- Countries under 100 vehicles/1000 people:
    - Bangladesh, Pakistan, Iran, Benin, China, Bhutan and Bolivia.
- Countries between100 and 500 vehicles/1000 people:
    - Moldova, Chile, Brazil, Hungary and Barbados.
- Countries over 500 vehicles/1000 people:
    - Japan and United States.

Japan and United States have high ratios in terms of number of vehicles per 1000 people but different behavior in terms of road user fatalities. Figure 4-4 shows that United States had, in 2008, a road user fatality number 6 times higher than Japan, but 2007 data obtained from IRF shows that the number of vehicles is 3 times higher in United States than in Japan. So it is possible to conclude that the number of vehicles is not proportional to the number of fatalities and additional data from the country that it is going to be analyzed is necessary.

YEAR 2007	VEHICLES IN USE PER CATEGORY					VEHICLES FLEET RATIO PER COUNTRY		
COUNTRY	Passenger cars	Buses and Motorcoaches	Vans and Lorries	Total	Motorcycles and Mopeds	Pass. cars/ 1000 peop	Total veh/ 1000 peop	Total veh/ km roads
Bangladesh	158109	31622	168649	358380	653515	1	2	1
Pakistan	1440072	170401	187054	1797527	2684272	9	11	7
Iran	920136	4903	179726	1104765	862626	13	16	6
Benin	1490310	1114	35656	1527080	15600	17	21	10
China	29616499	2343444	10540556	42500499	87217276	22	32	12
Bhutan	19637	179	5335	25151	7498	30	38	3
Bolivia	174912	6996	468763	650671	34982	18	68	10
Moldova	338944	21095	94828	454867	19068	89	120	36
Chile	1701036	170217	849282	2720535	63257	103	164	34
Brazil	30282855	1983761	5709063	37975679	10921686	158	198	22
Hungary	3012165	17899	829817	3859881	135865	300	384	20
Barbados	103535	631	15151	119317	2525	352	406	75
Japan	41469000	231000	34324000	76024000	1479000	325	593	64
United States	135932930	834436	110497239	247264605	7138476	451	820	38

Table 4.6: Vehicles in use per category and country and fleet ratio per country in 2007. Source: Own production from IRF

4.1.2.3. Road Accidents

Data shown in this subsection contains only injury accidents, so accidents incurring only material damage are excluded. As is defined by IRF, an injury accident is any accident involving at least one road vehicle in motion on a public or private road with public access, resulting in at least one injured or killed person.

The accidents included are:

- Collisions between road vehicles
- Collisions between road vehicles and pedestrians
- Collisions between road vehicles and animals or fixed obstacles
- Collisions between rail and road vehicles
- A multivehicle collision is considered as only one accident compound of successive collisions.

Table 4.7 shows data of injury accidents, persons injured and killed. Two different ratios are used for injury accidents: R1 (number of injury accidents per 100.000 people) and R2 (number of injury accidents per 100 million vehicle-km traffic) and a third one R3 (number of persons killed per 100.000 people) was used for person killed.

A person injured is any person who sustained an injury as a result of an injury accident, who normally needs medical attention and that does not result in death. A person killed is any person who died, immediately or within 30 days, as a result of an injury accident.

According to Table 4.7, India is the country with a higher number of persons killed. If ratios are considered, Kazakhstan is the country with a higher ratio of death people in road accidents, between the countries analyzed. Japan has the highest number of injury accidents, but the lowest ratio of deaths. Japan has the lowest ratio of death people in road accidents, and a higher ratio of injuries. Others countries like Kazakhstan, Russian Federation or Ukraine have high R3 ratio levels. This means that a higher portion of people compared to other countries result killed due to accident.

	ROAD ACCIDENTS FIGURES AND RATES PER COUNTRY					
YEAR 2007	**INJURY ACCIDENTS**			**PERSONS INJURED**	**PERSONS KILLED**	
COUNTRY	TOTAL	R1	R2		TOTAL	R3
Armenia	1943	64.57	373.29	2720	371	12.33
Costa Rica	69761	1563.38	568.25	19903	339	7.60
Croatia	18029	406.43	67.41	25092	619	13.95
India	479219	42.61		513340	114444	10.17
Israel	16016	223.06	36.21	32407	398	5.54
Japan	832454	651.52	109.20	1034445	6639	5.20
Kazakhstan	15942	102.96	24.56	18951	4365	28.19
Lithuania	6448	191.02	60.92	8042	740	21.92
Mauritius	2190	173.71		2915	140	11.11
Morocco	58924	190.94		85426	3838	12.44
Russian Federation	233800	164.53		292200	33300	23.43
Ukraine	63554	136.65	421.99	78528	9574	20.59

Table 4.7: Road accidents figures and rates per country.
Source: Own production from IRF

When the long term trends in last 30 years are considered, it can be noticed that the number of road user fatalities have decreased with especially big reductions in Germany (72.41%) or Japan (49.32%) as is shown in Table 4.2. If the period between 2002 and 2007 is considered, it can be observed a constant trend through this years and only Croatia has a clear decrease (Figure 4-5)

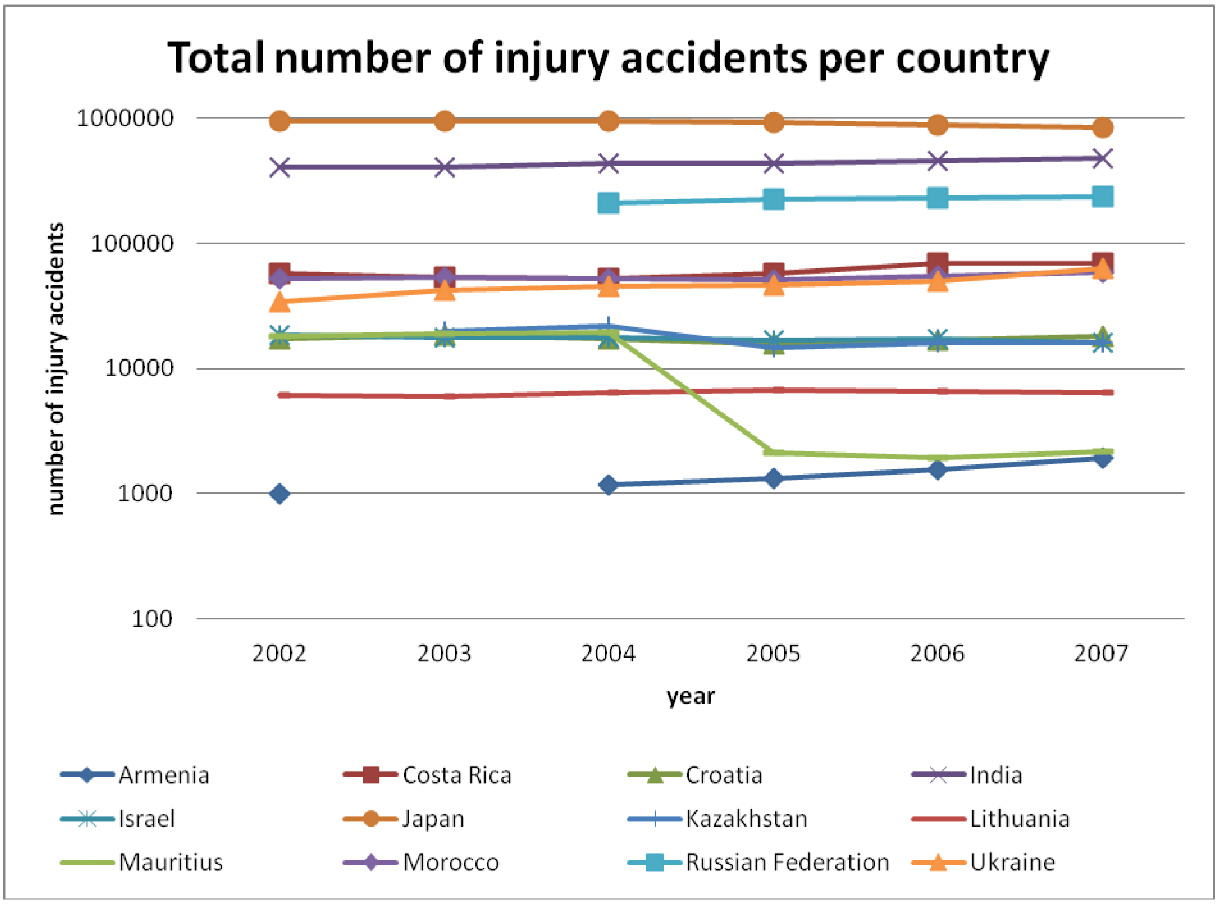


Figure 4-5: Number of injury accidents per country 2002-2007.
Source: Own production from IRF data

4.2. Europe data

Over the last years, the number of vehicles carrying goods by road has increased. The higher number of light vehicles in roads might be related to the increase in the participation of these vehicles in road accidents. The percentage of light vans and trucks over the total number of vehicles in the different countries has grown up as well as the number of accidents involving light goods vehicles. Light goods vehicles (LGVs) stock had increased by 36% in 2002 in comparison to 1995 while the total vehicle stock grew by 20%, according to the data appeared in the Report of the IMPROVER project [14]. In the same report it was also shown that the number of fatalities and injured users in LGVs in the same period of time increased by 4% and 16% respectively.

Data related to fatalities will be shown using the distinction between inside and outside urban areas due to the special interest for the category of vehicle consider in OPTIBODY.

Two different groups of countries have been considered attending to CARE data reported during the last two decades. The group EU14 is composed by 14 European countries that have reported in the Community Road Accident Database (CARE) between 1991 and 2009. The second group is EU19 and is composed of 19 European countries who have reported data between 2000 and 2009. The different countries included in each group are shown in Table 4.8.

COUNTRY NAME	COUNTRY CODE	EU14	EU19	COUNTRY NAME	COUNTRY CODE	EU14	EU19
Belgium	BE	Yes	Yes	**Luxembourg**	LU	Yes	Yes
Bulgaria	BG	No	No	**Hungary**	HU	No	No
Czech Republic	CZ	No	Yes	**Malta**	MT	No	No
Denmark	DK	Yes	Yes	**Netherlands**	NL	Yes	Yes
Germany	DE	No	Yes	**Austria**	AT	Yes	Yes
Estonia	EE	No	No	**Poland**	PL	No	Yes
Ireland	IE	Yes	Yes	**Portugal**	PT	Yes	Yes
Greece	EL	Yes	Yes	**Romania**	RO	No	Yes
Spain	ES	Yes	Yes	**Slovenia**	SI	No	Yes
France	FR	Yes	Yes	**Slovakia**	SK	No	No
Italy	IT	Yes	Yes	**Finland**	FI	Yes	Yes
Cyprus	CY	No	No	**Sweden**	SE	Yes	Yes
Latvia	LV	No	No	**United Kingdom**	UK	Yes	Yes
Lithuania	LT	No	No	**Switzerland**		No	No

Table 4.8: Countries included in CARE.
Considered or not in EU14 group and/or EU19 group

4.2.1. Road users

The total number of fatalities in the EU has decreased during the last twenty years. Focusing on the type of road user, fatalities trend for EU14 is shown in Figure 4-6 and for EU19 in Figure 4-10 . The total number of fatalities had decreased 24% in 2002 and 55% in 2009 compared to 1991 in EU14 countries. Fatalities number had decreased 41% in EU14 and 36% in EU19 when compared 2000 to 2009.

Driver fatalities trends for EU14 are shown in Figure 4-7. In 1991, 57% of fatalities in EU14 were drivers; 30% took place inside urban areas and a 70% outside urban areas. In 1999 and 2000 the percentage of driver fatalities had increased to 67%, and 28% of these deaths were registered inside urban areas. In 2009 the percentage had increased again in EU14 and was 67% over the total of fatalities. If EU19 is considered, the percentage of driver fatalities was 54% in 2000 and 32% of them occurred inside urban areas, as shown in Figure 4-11. In 2009 the percentage of driver fatalities in EU19 was 62% and the proportion of fatalities inside urban areas was kept in 32% of the total.

Figure 4-8 shows the trends for passenger fatalities in EU14 inside and outside urban areas. In 1991, 25% of the deaths registered were passenger and 24% of these deaths took place inside an urban area. In 2009 the percentage of dead passengers decreased to 22% and 20% of these deaths occurred inside urban areas. In 2009, 18% of the deaths were passenger and a 23% of these inside urban areas. In Figure 4-12 the trends for EU19 are shown. In 2000 and considering EU19, 22% of deaths were passenger and 24% of them died inside urban areas. The percentage of total passenger fatalities had decrease in 2009 to 19% and 27% occurred inside urban areas.

Figure 4-9 shows information about pedestrian deaths. In 1991 pedestrian deaths represented 18% over the total of road user deaths and 66% of these fatalities took place inside urban areas. In 2009, pedestrian fatalities decreased to 15% of the total but the proportion of them in urban areas grew up to 70%. In Figure 4-13, pedestrian fatalities trend between 2000 and 2009 in EU19 is represented the. The global number of fatalities decreased in this period, but the percentage over the total at the beginning and the end of the decade was 19%. In this group the higher percentage of fatalities took place inside urban areas (68-72%)

In summary, the higher percentage of deaths during 2008 and 2009 in Europe is registered in drivers. Attending to fatalities inside urban areas, pedestrians have higher percentage levels.

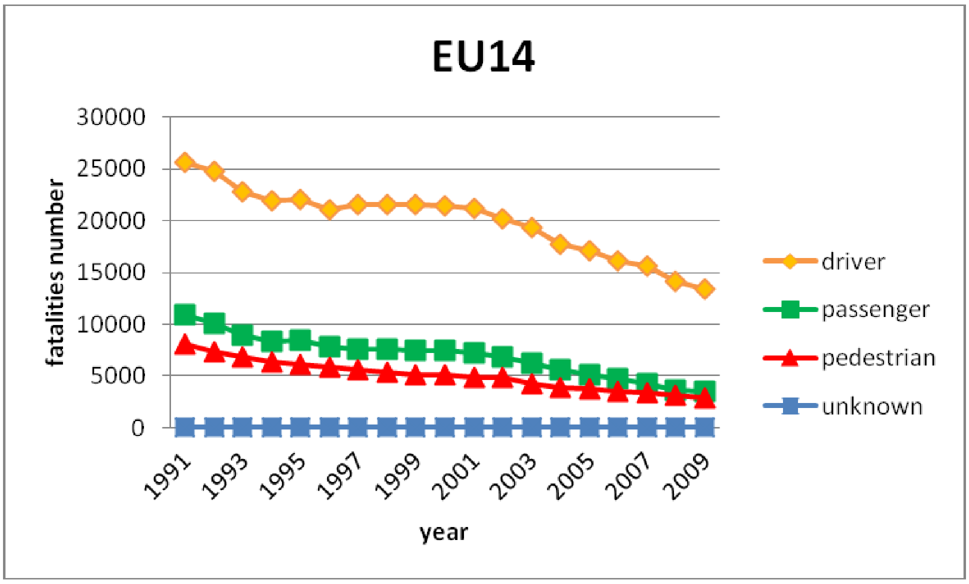


Figure 4-6: Fatalities reported in EU14 group by type of road user. Source: Own production from CARE data

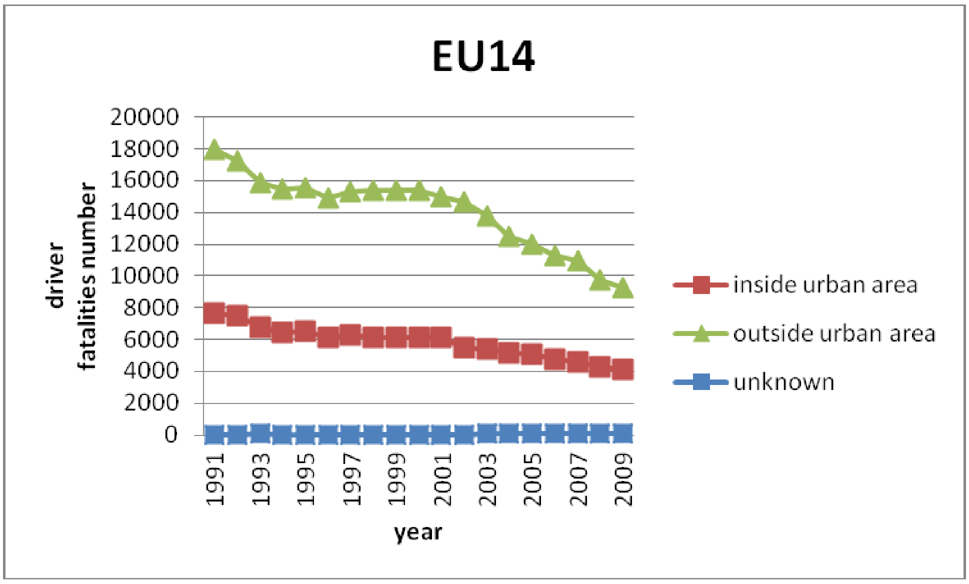


Figure 4-7: Drivers fatalities in EU14 group. Source: Own production from CARE data

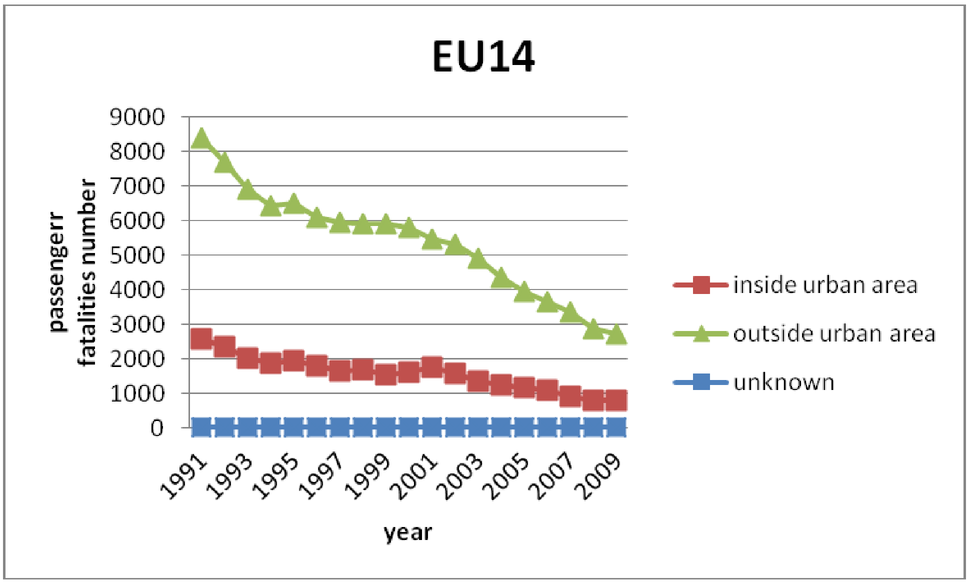


Figure 4-8: Passenger fatalities EU14 group.
Source: Own production from CARE data

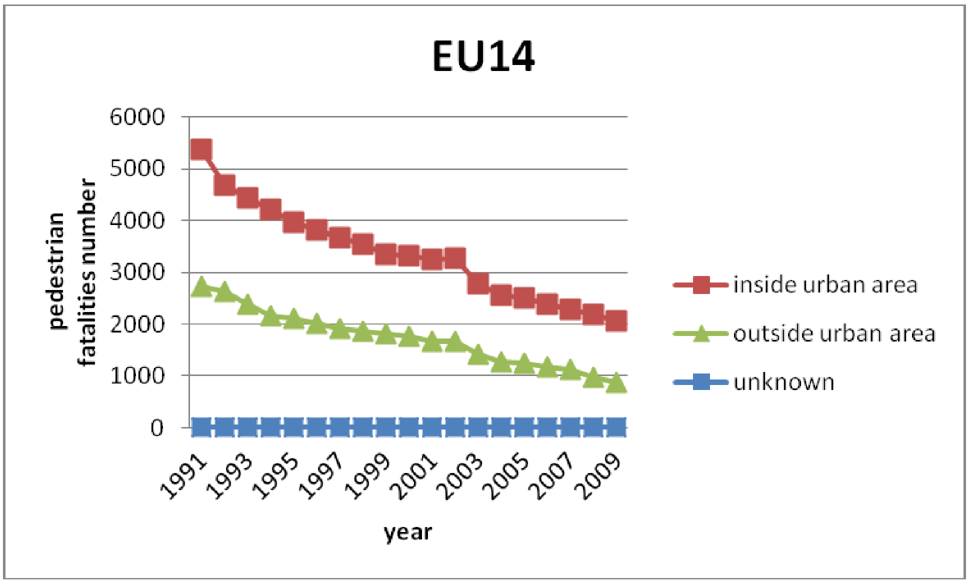


Figure 4-9: Pedestrian fatalities in EU14 group.
Source: Own production from CARE data

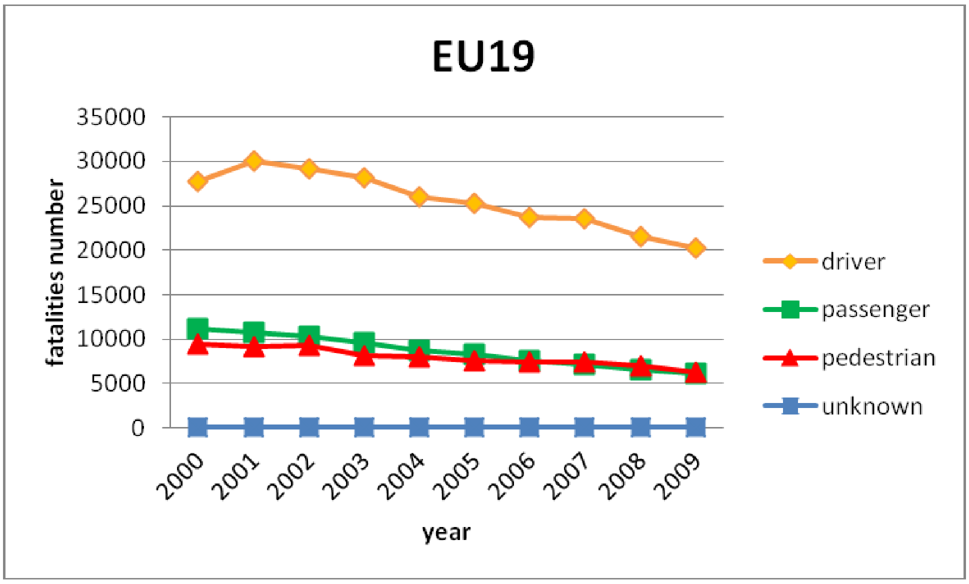


Figure 4-10: Fatalities reported in EU19 group by type of road user. Source: Own production from CARE data

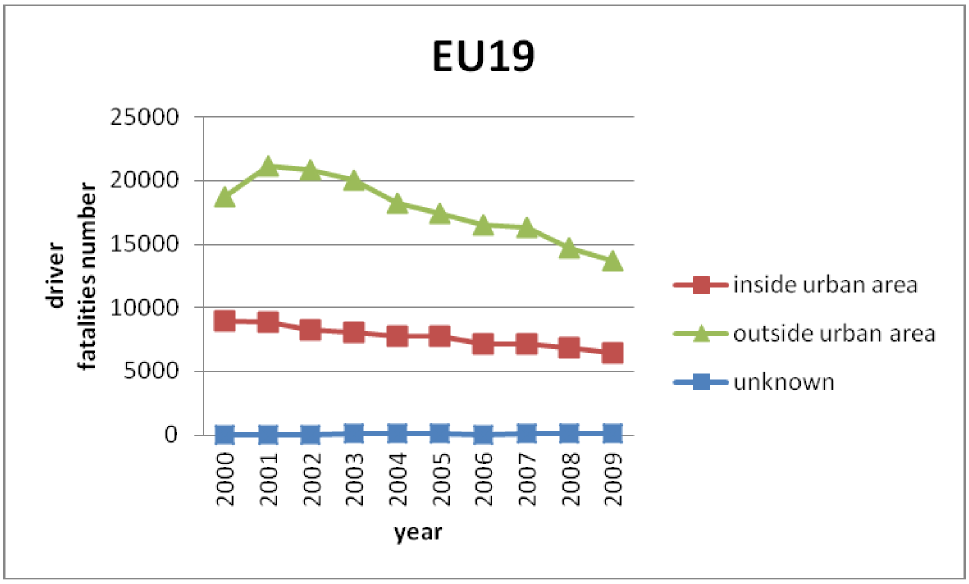


Figure 4-11: Drivers fatalities in EU19 group. Source: Own production from CARE data

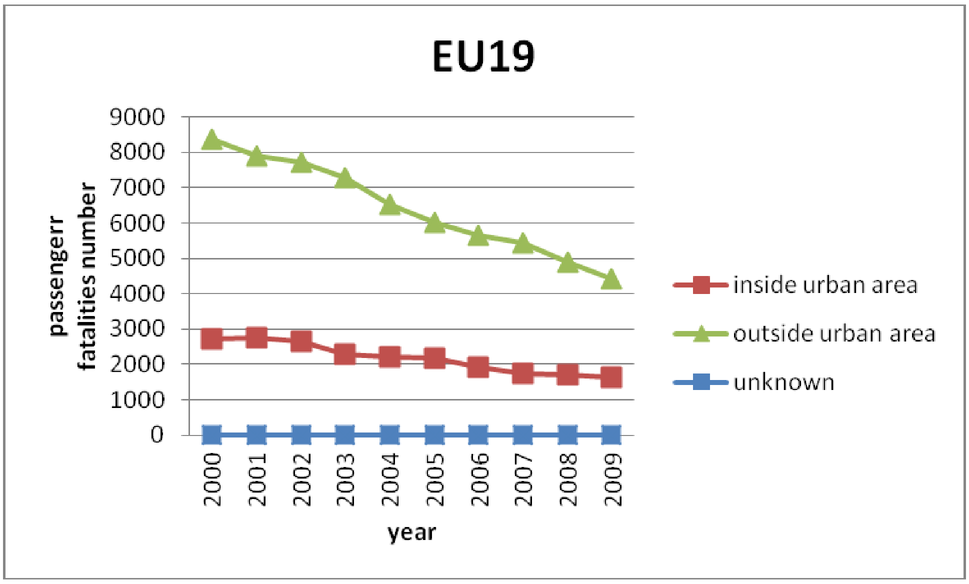


Figure 4-12: Passenger fatalities in EU19 group. Source: Own production from CARE data

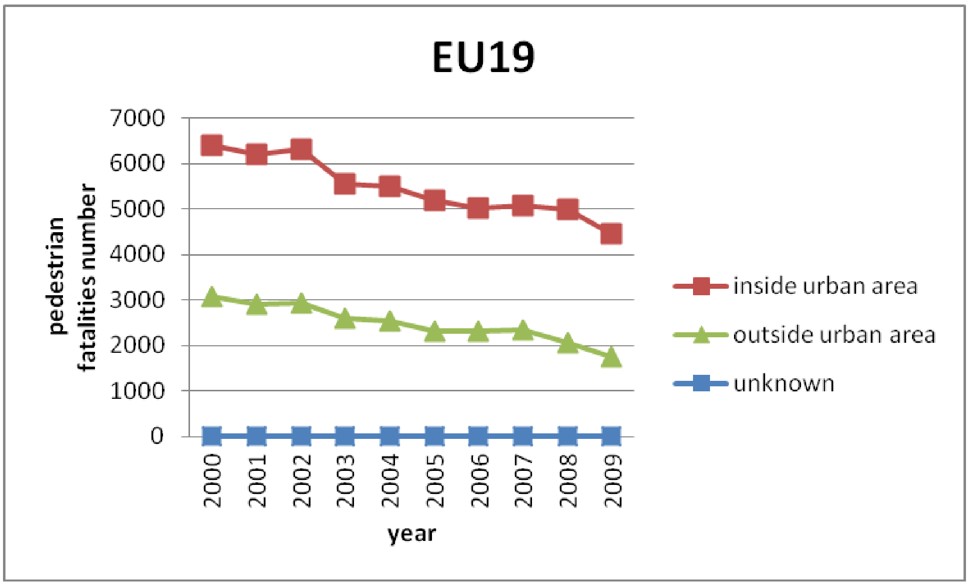


Figure 4-13: Pedestrian fatalities in EU19 group. Source: Own production from CARE data

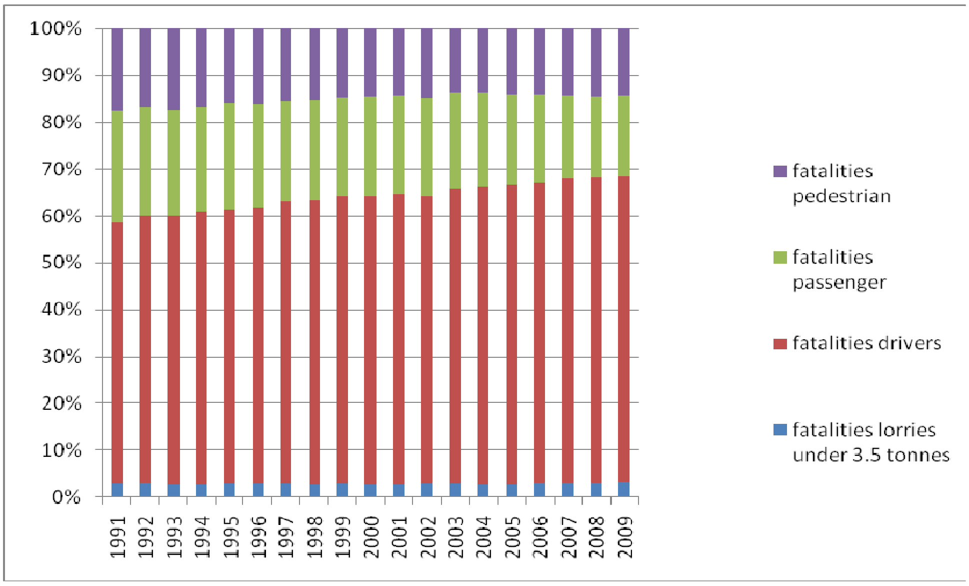


Figure 4-14: Fatalities distribution in EU14.
Source: Own production from CARE data

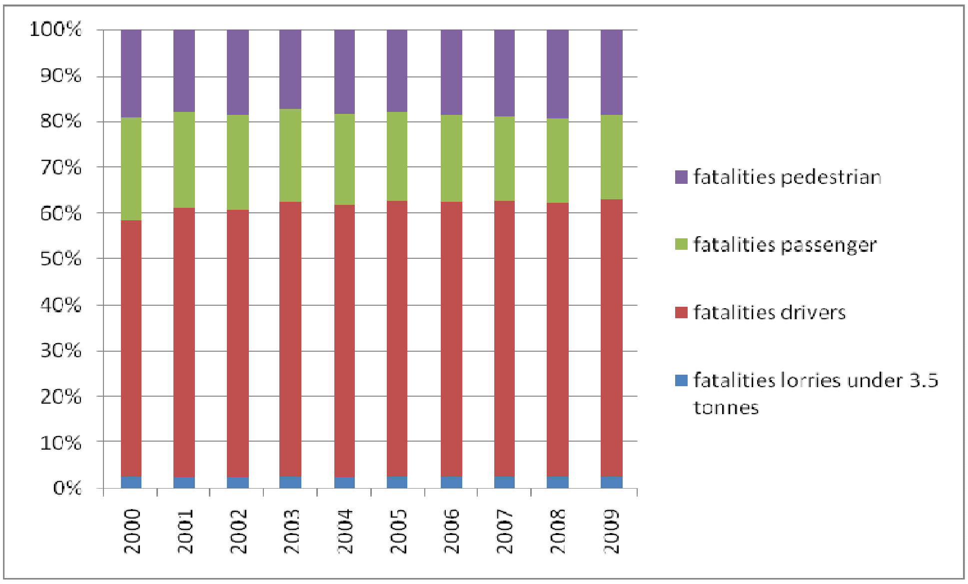


Figure 4-15: Fatalities distribution in EU19.
Source: Own production from CARE data

4.2.2. Transport mode: lorries under 3.5 tonnes

The transport mode classification made by CARE data has the following categories:

- Agricultural tractor
- Bus or coach
- Car+ taxi
- Heavy goods vehicle
- Lorry, under 3.5 tonnes
- Moped
- Motorcycle
- Other
- Pedal cycle
- Pedestrian
- Unknown

The target category due the purpose of this project is “Lorry, under 3.5 tones”. In order to study the data regarding this vehicle category, CARE data in EU14 (between 1991 and 2009) and EU19 (between 2000 and 2009) has been analyzed. Due to the characteristics of the project, the rate of fatalities occurring inside urban areas is especially interesting.

The percentage of fatalities registered in the last twenty years in lorries under 3.5 tones is relatively low. In Table 4.9 and Table 4.10 is compiled the data about EU14 and EU19 for lorries.

The percentage of fatalities in lorries over the total was 3.18% (1.421 fatalities) in 1991 in EU14 and 2.96% (1.005 fatalities) in 2000, but in 2009 it grew up to 3.50% (although the number of fatalities still decreased to 690). In EU19 the percentage was 2.43% (1.243 fatalities) over the total in 2000 and 2.75% (893 fatalities) in 2010. The percentage of lorries fatalities has grown up in spite of the number of fatalities has decrease in these years.

The percentage of fatalities in lorries inside urban areas has been oscillating around 15% over the years. The fluctuations in EU19 have been higher than in EU14, and in 2005 reached the maximum percentage with a 19% (200 fatalities). Considering EU14 the highest level was reached in 1996 with a value of 16.11% (175 fatalities). The percentage of fatalities inside urban areas for this particular type of vehicle is lower than the percentage of fatalities in urban areas when all the categories together are considered. During the last two decades the average of total fatalities in urban areas is 33.57% in EU14 with peaks of 38.51% (12.516 fatalities) in 2009 in EU19 group.

In the Figure 4-16 and Figure 4-18 lorries fatalities in EU14 and EU19 are shown. In both, lorries fatalities are focused on outside urban areas. The average for EU14 is 86% with a peak of 88.4% (660 fatalities) in 2007 during the period between 1991 from 2009. In EU19, this average is quite lower (84%) during 2000 to 2009. However, the number of fatalities represents a low percentage in total lorries fatalities.

EU14	TOTAL FATALITIES								FATALITIES IN LORRIES UNDER 3.5 TONNES								
YEAR	INSIDE URBAN AREA	OUTSIDE URBAN AREA	UNKNOWN	TOTAL	% INSIDE URBAN AREA /TOTAL	% OUTSIDE URBAN AREA /TOTAL	% UNKNOWN /TOTAL	% TOTAL	INSIDE URBAN AREA	OUTSIDE URBAN AREA	UNKNOWN	TOTAL	%LORRIES, INSIDE URBAN AREA/TOTAL LORRIES	% LORRIES, OUTSIDE URBAN AREA/TOTAL LORRIES	%LORRIES UNKNOWN /TOTAL LORRIES	% TOTAL	% FAT.LORRIES /TOTAL FAT.
1991	15632	29085	13	44730	34.95	65.02	0.03	100	218	1203	0	1421	15.34	84.66	0.00	100	3.18
1992	14573	27564	3	42140	34.58	65.41	0.01	100	228	1141	0	1369	16.65	83.35	0.00	100	3.25
1993	13258	25247	106	38611	34.34	65.39	0.27	100	174	947	2	1123	15.49	84.33	0.18	100	2.91
1994	12572	24117	9	36698	34.26	65.72	0.02	100	168	906	0	1074	15.64	84.36	0.00	100	2.93
1995	12442	24187	11	36640	33.96	66.01	0.03	100	171	967	0	1138	15.03	84.97	0.00	100	3.11
1996	11766	23073	26	34865	33.75	66.18	0.07	100	175	911	0	1086	16.11	83.89	0.00	100	3.11
1997	11553	23188	20	34761	33.24	66.71	0.06	100	157	893	0	1050	14.95	85.05	0.00	100	3.02
1998	11315	23230	8	34553	32.75	67.23	0.02	100	132	847	0	979	13.48	86.52	0.00	100	2.83
1999	11023	23124	6	34153	32.28	67.71	0.02	100	128	935	0	1063	12.04	87.96	0.00	100	3.11
2000	10961	22930	9	33900	32.33	67.64	0.03	100	137	868	0	1005	13.63	86.37	0.00	100	2.96
2001	11141	22138	7	33286	33.47	66.51	0.02	100	144	835	0	979	14.71	85.29	0.00	100	2.94
2002	10354	21630	12	31996	32.36	67.60	0.04	100	134	830	0	964	13.90	86.10	0.00	100	3.01
2003	9517	20122	89	29728	32.01	67.69	0.30	100	114	828	1	943	12.09	87.80	0.11	100	3.17
2004	8931	18155	134	27220	32.81	66.70	0.49	100	104	669	1	774	13.44	86.43	0.13	100	2.84
2005	8750	17196	79	26025	33.62	66.07	0.30	100	106	658	0	764	13.87	86.13	0.00	100	2.94
2006	8243	16128	59	24430	33.74	66.02	0.24	100	93	697	1	791	11.76	88.12	0.13	100	3.24
2007	7800	15455	75	23330	33.43	66.25	0.32	100	87	660	0	747	11.65	88.35	0.00	100	3.20
2008	7306	13563	78	20947	34.88	64.75	0.37	100	95	612	0	707	13.44	86.56	0.00	100	3.38
2009	6971	12865	74	19910	35.01	64.62	0.37	100	105	585	0	690	15.22	84.78	0.00	100	3.47

Table 4.9: Total and lorries fatalities and percentages in EU14 group.

Source: Own production from CARE data

EU19	TOTAL FATALITIES								FATALITIES IN LORRIES UNDER 3.5 TONNES								
YEAR	INSIDE URBAN AREA	OUTSIDE URBAN AREA	UNKNOWN	TOTAL	% INSIDE URBAN AREA /TOTAL	% OUTSIDE URBAN AREA /TOTAL	% UNKNOWN /TOTAL	% TOTAL	INSIDE URBAN AREA	OUTSIDE URBAN AREA	UNKNOWN	TOTAL	%LORRIES, INSIDE URBAN AREA/TOTAL LORRIES	% LORRIES, OUTSIDE URBAN AREA/TOTAL LORRIES	%LORRIES, UNKNOWN /TOTAL LORRIES	% TOTAL	% FATALITIES LORRIES /TOTAL FATALITIES
2000	18029	33165	9	51203	35.21	64.77	0.02	100	204	1042	0	1246	16.37	83.63	0.00	100	2.43
2001	17853	31999	7	49859	35.81	64.18	0.01	100	214	1023	0	1237	17.30	82.70	0.00	100	2.48
2002	17217	31545	12	48774	35.30	64.68	0.02	100	204	999	0	1203	16.96	83.04	0.00	100	2.47
2003	15950	29862	89	45901	34.75	65.06	0.19	100	157	1005	1	1163	13.50	86.41	0.09	100	2.53
2004	15475	27263	134	42872	36.10	63.59	0.31	100	159	854	1	1014	15.68	84.22	0.10	100	2.37
2005	15195	25729	79	41003	37.06	62.75	0.19	100	200	840	0	1040	19.23	80.77	0.00	100	2.54
2006	14133	24484	59	38676	36.54	63.31	0.15	100	171	898	1	1070	15.98	83.93	0.09	100	2.77
2007	14000	24101	75	38176	36.67	63.13	0.20	100	150	834	0	984	15.24	84.76	0.00	100	2.58
2008	13502	21633	78	35213	38.34	61.43	0.22	100	155	787	0	942	16.45	83.55	0.00	100	2.68
2009	12516	19912	74	32502	38.51	61.26	0.23	100	155	738	0	893	17.36	82.64	0.00	100	2.75

Table 4.10: Total and lorries fatalities and percentages in EU19 group.

Source: Own production from CARE data

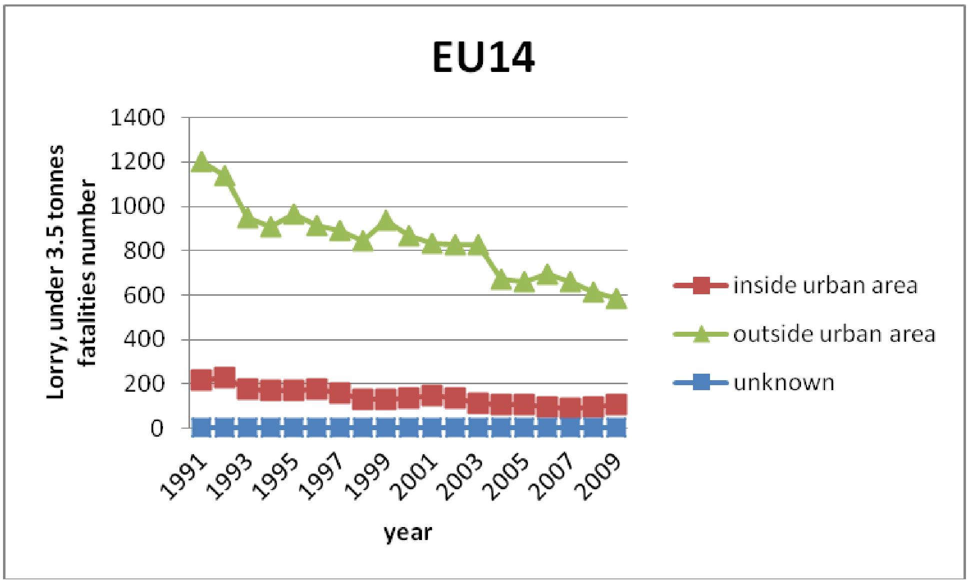


Figure 4-16: Lorries under 3.5 tonnes fatalities reported in EU14. Source: Own production from CARE data

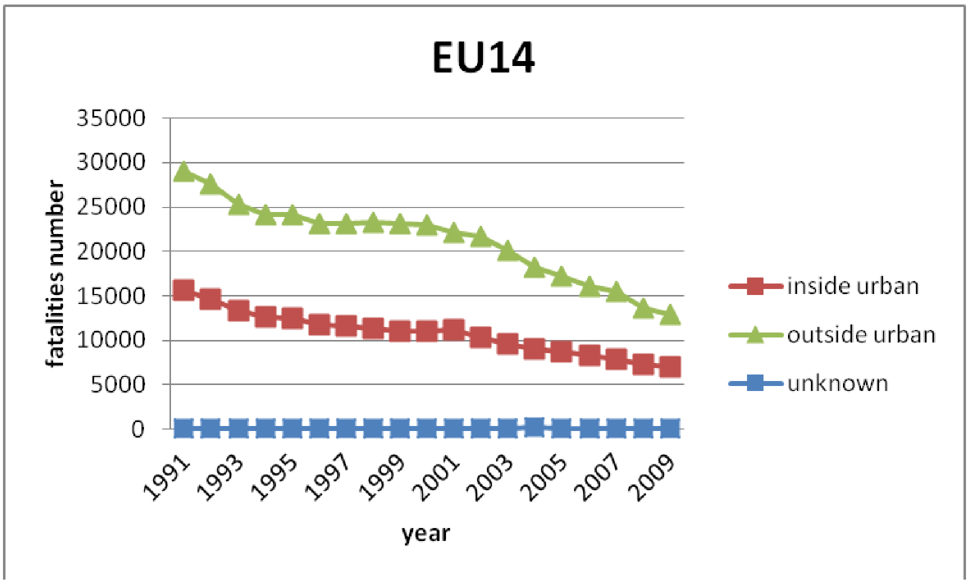


Figure 4-17: Total fatalities reported in EU14. Source: Own production from CARE data

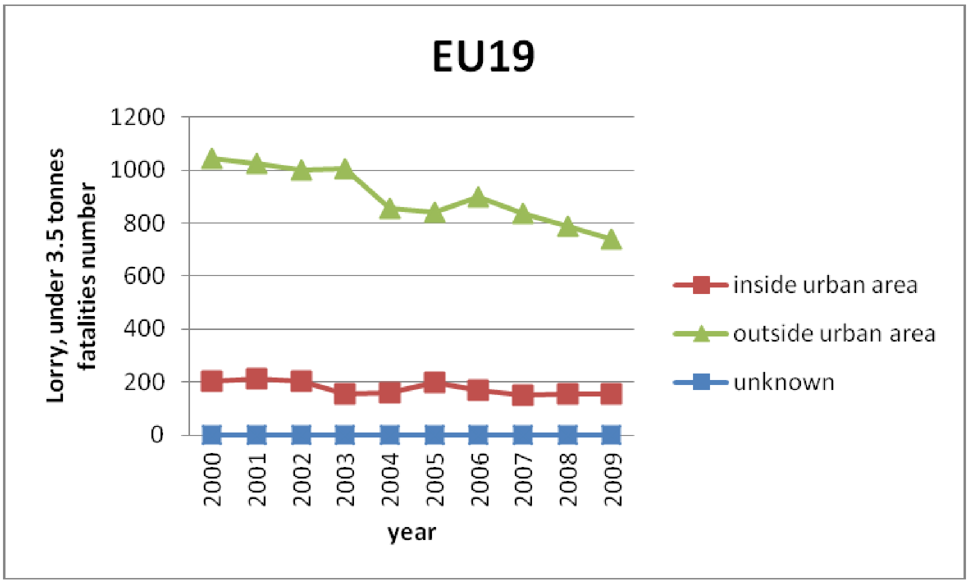


Figure 4-18: Lorries under 3.5 tonnes fatalities reported in EU19. Source: Own production from CARE data

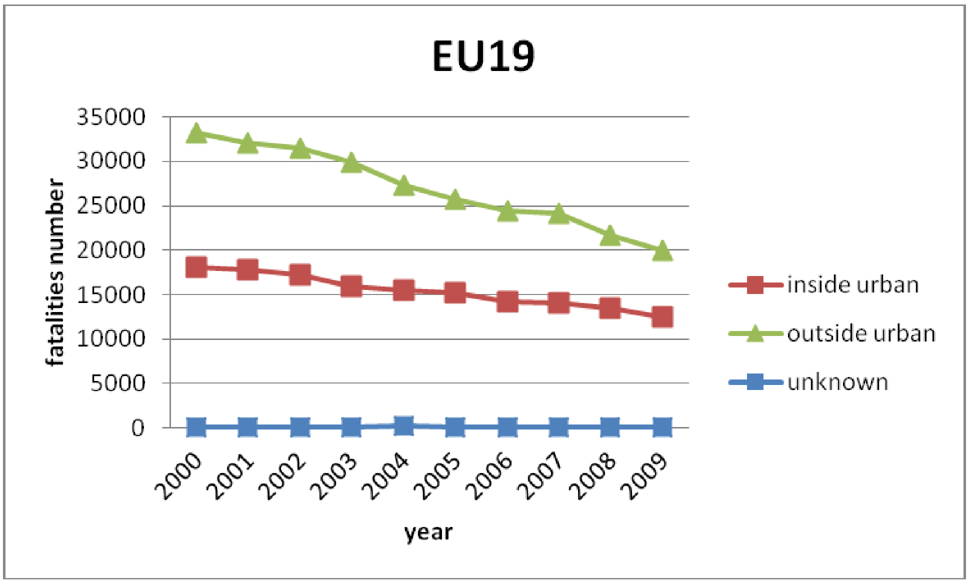


Figure 4-19: Total fatalities reported in EU19. Source: Own production from CARE data

4.2.2.1. Goods transport vehicles in Italy

Information related to accidents with good transport vehicles under 3.5 tones in Italy in 2009 is shown in Table 4.11. In this table, the total number of fatalities in incidents involving at least one commercial vehicle is shown as well as the number of pedestrian, commercial vehicle driver and passenger fatalities. The rest of fatalities related to other vehicle categories and motorcycles are not considered. It is important to highlight that most of the fatalities occurred in the opponent of the commercial vehicle, including pedestrians. The information about the type of crashes in all roads is shown in Table 4.12. Detailed information of the type of crash when the collisions occurred in urban areas is presented in Table 4.13.

	Involved commercial vehicles	Incidents with at least one commercial vehicle	With fatal incidents	Total dead in the incident	Total injured in the incident	Dead pedestrians	Injured pedestrians	Dead commercial vehicle driver	Injured commercial vehicle driver	Dead commercial vehicle passengers	Injured commercial vehicle passengers
Urban road	11032	10688	105	106	15256	30	924	9	2638	3	1121
Other roads in the area	2374	2270	47	53	3563	9	101	7	742	6	249
Total	**13406**	**12958**	**152**	**159**	**18819**	**39**	**1025**	**16**	**3380**	**9**	**1370**

Table 4.11: Accident data regarding good transport vehicles under 3.5 tonnes in Italy in 2009

Source: ISTAT (Istituto Centrale Italiano di Statistica)

	Incidents with at least one commercial vehicle	With fatal incidents	Total dead in the incident	Total injured in the incident	Dead pedestrians	Injured pedestrians	Dead commercial vehicle driver	Injured commercial vehicle driver	Dead commercial vehicle passengers	Injured commercial vehicle passengers
Frontal crash	834	24	30	1348	0	11	5	270	1	108
Frontal-lateral crash	5063	53	53	7455	1	28	3	1381	4	542
Lateral crash	1661	11	11	2082	0	7	0	278	0	113
Pile-up	3397	8	8	5570	0	33	0	954	0	414
Pedestrians	914	36	37	934	37	925	0	9	0	0
Collision with stopped vehicle	721	9	9	994	1	21	1	157	0	88
Collision with parked vehicle	44	0	0	51	0	0	0	36	0	15
Collision with obstacle	127	3	3	150	0	0	3	116	0	34
Road departure	189	8	8	227	0	0	4	172	4	55
Incident caused by sudden braking	2	0	0	2	0	0	0	2	0	0
Fall from the vehicle	6	0	0	6	0	0	0	5	0	1
Total	**12958**	**152**	**159**	**18819**	**39**	**1025**	**16**	**3380**	**9**	**1370**

Table 4.12: Accident data in all roads regarding good transport vehicles under 3.5 tones in Italy in 2009

Source: ISTAT (Istituto Centrale Italiano di Statistica)

	Incidents with at least one commercial vehicle	With fatal incidents	Total dead in the incident	Total injured in the incident	Dead pedestrians	Injured pedestrians	Dead commercial vehicle driver	Injured commercial vehicle driver	Dead commercial vehicle passengers	Injured commercial vehicle passengers
Frontal crash	655	13	13	994	0	11	0	184	0	60
Frontal-lateral crash	4324	37	37	6356	1	25	3	1159	2	482
Lateral crash	1421	8	8	1754	0	7	0	217	0	95
Pile-up	2548	5	5	4108	0	27	0	683	0	321
Pedestrians	826	27	28	849	28	841	0	8	0	0
Collision with stopped vehicle	635	9	9	863	1	13	1	140	0	78
Collision with parked vehicle	41	0	0	48	0	0	0	34	0	14
Collision with obstacle	100	2	2	118	0	0	2	91	0	27
Road departure	131	4	4	159	0	0	3	116	1	43
Incident caused by sudden braking	2	0	0	2	0	0	0	2	0	0
Fall from the vehicle	5	0	0	5	0	0	0	4	0	1
Total	**10688**	**105**	**106**	**15256**	**30**	**924**	**9**	**2638**	**3**	**1121**

Table 4.13: Accident data in urban roads regarding good transport vehicles under 3.5 tones in Italy in 2009

Source: ISTAT (Istituto Centrale Italiano di Statistica)

4.2.2.2. Accident database analysis for light commercial vehicles in Piemonte

For the analysis of light commercial vehicle accidents, the "*Regione Piemonte database*" was reviewed. Data was provided by the *Istituto Italiano di Statistica* (ISTAT) via the *Social Research Institute for Piemonte* (IRES).

The complete database reports of almost 15000 accidents per year (with a slight decrease over the years). Some of them involve commercial and light commercial vehicles. The database contains a lot of useful information (each record contains around 200 fields) not always easy to interpret.

The following analysis has been carried out on the basis of the two categories of interest for the OPTIBODY consortium. In particular, there are two categories of vehicles that can be associated to the light commercial vehicles of types L7e and N1. These are:

- 8 = trucks
- 21 = quadricycle

Other types of good transportation vehicles are 22 = trucks with trailer, and 23 = road-tractor with semi-trailer. Seldom if ever N1 vehicle carries a trailer so category 22 has been neglected in the analysis.

The analysis has then been carried out on the basis of the number of injured people and deaths. Unfortunately, there is no information on the severity of the injuries. About deaths, the only further useful information is related to the time of death: within 24 hours (the most) and within 30 days. This is an international standard, for which Italy was not consistent until some years ago.

For each accident, detailed information about the vehicle, or several vehicles involved was compiled. In the case of single vehicle accidents, the impacts were against a fixed obstacle or a pedestrian. In any case the first vehicle involved is named A, the second vehicle is named B and the third vehicle is named C. In the rare case of a fourth vehicle or more, additional fields are provided to add the additional number of injured or killed people.

Fields regarding date and location, characteristics of the vehicles, of the driver and passengers, etc. are also included. The complete list is available from ISTAT in [9].

Road accidents occurred in 2009 and 2010 were considered on the basis of the two categories that the OPTIBODY project is focused on and that can be associated to the light commercial vehicles of types L7e and N1. As mentioned before, in the considered database, these categories are trucks and quadricycles. The following analysis reviews the number of injured and killed people in road traffic accidents involving trucks and quadricycles.

Vehicle type 21 = quadricycle

In year **2009**, 51 accidents of a total of 14589 (0.34%) involved quadricycles. There was 1 fatality in these 51 accidents. This fatality was a 32 year old person driving a motorcycle that was involved in the accident. Due to these accidents, 23 drivers and 4 passengers in the front seat of vehicle A and 12 drivers and 4 passengers in the front seat of vehicle B were injured.

A total of 5 pedestrians were injured and there was 1 case where a pedestrian was impacted twice.

Most accidents involved a passenger car except:

- 4 accidents with trucks
- 4 accidents with motorcycles
- 1 accident with a bus (in this case the quadricycle driver was injured)

In year **2010,** there were 32 accidents out of 12173 involving quadricycles (0.26%). In this case neither drivers nor passengers died. There were also no pedestrians involved.

There were 6 injured drivers, 4 injured passengers in front seats and 1 injured passenger in the rear seat in vehicle A. 12 drivers and 3 passengers were injured in vehicle B and 4 occupants (seat position no specified) were injured in vehicle C

Almost all accidents involved a passenger car except:

- 1 accident with a taxi
- 1 accident with a truck
- 1 accident with a motorcycle

Vehicle type 8 = truck[1]

In year **2009** were 1718 out of 14589 that involved trucks (11.7%). In these accidents, 7 drivers died in vehicle A. More detail information of the injuries is provided in Table 4.14:

VEHICLE		TOTAL	DRIVER	FRONT SEAT PASSENGERS	REAR SEAT PASSENGERS
A	FATALITIES	7	7	-	-
	INJURIED	392	267	74	51
B	FATALITIES	-	-	-	-
	INJURIED	239	186	44	9
C	FATALITIES	-	-	-	-
	INJURIED	41	36	5	

Table 4.14: Summary of fatalities and injured occupants for accidents in 2009 involving trucks in the Piemonte region

In addition 7 pedestrian were killed and 101 had injuries of different severity. In 8 cases the pedestrian were impacted twice and in 3 cases they were impacted 3 times.

Most accidents involved a passenger car, but almost every other vehicle type was also involved.

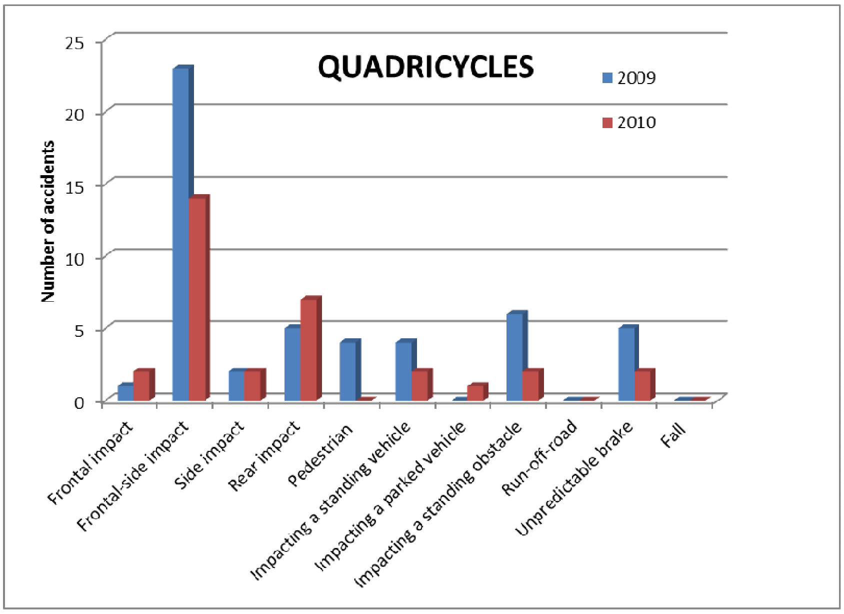
[1] it is not possible to distinguish whether it is an N1 light commercial vehicle or a generic bigger truck

In year **2010,** 1418 out of 12173 involved trucks in the Piemonte region. These accidents resulted on 17 deaths. A summary of fatalities and injured occupants is shown in Table 4.15.

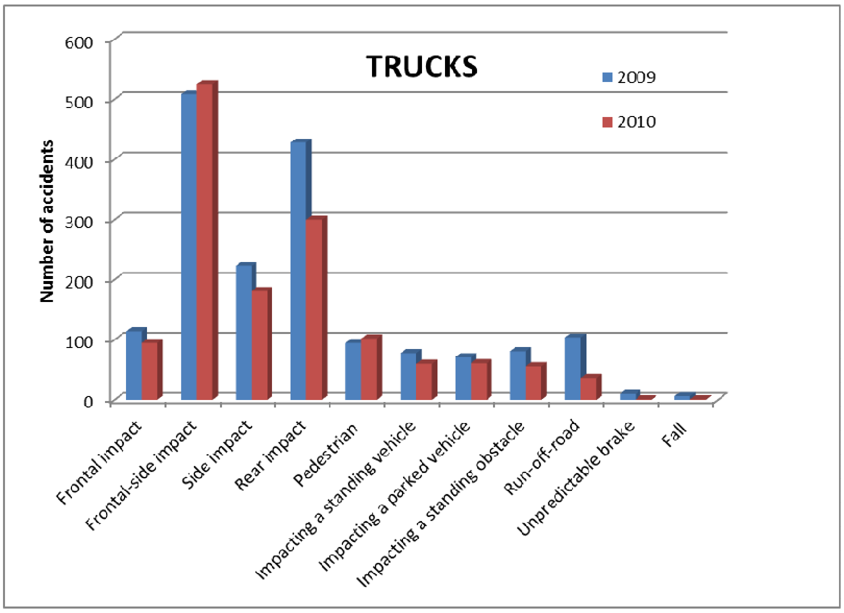
VEHICLE		TOTAL	DRIVER	FRONT SEAT PASSENGERS	REAR SEAT PASSENGERS
A	FATALITIES	6	5	1	-
	INJURIED	201	152	29	20
B	FATALITIES	2	1	-	1
	INJURED	185	149	23	13
C	FATALITIES	2	1	-	1
	INJURED	25	9	3	13

Table 4.15: Summary of fatalities and injured occupants for accidents in 2010 involving trucks in the Piemonte region

Figure 4-20, Figure 4-21, Figure 4-22 describe the different types of accidents. In Figure 4-20 the total number of accidents per type of crash and year is reported. Figure 4-21 shows the total number of injuries per accident type and year. In Figure 4-22 the number of deaths is reported only for trucks category as there were no fatalities in accidents with quadricycles.

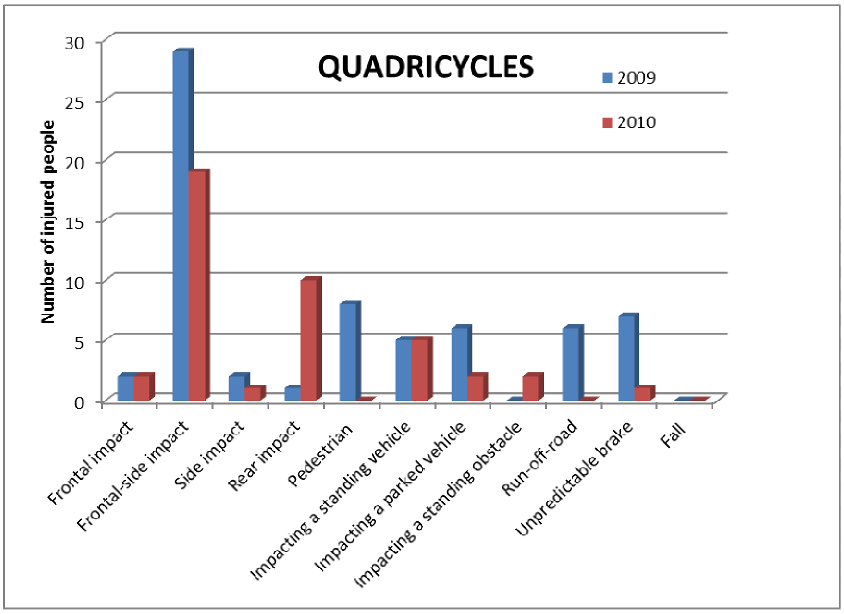


(a)

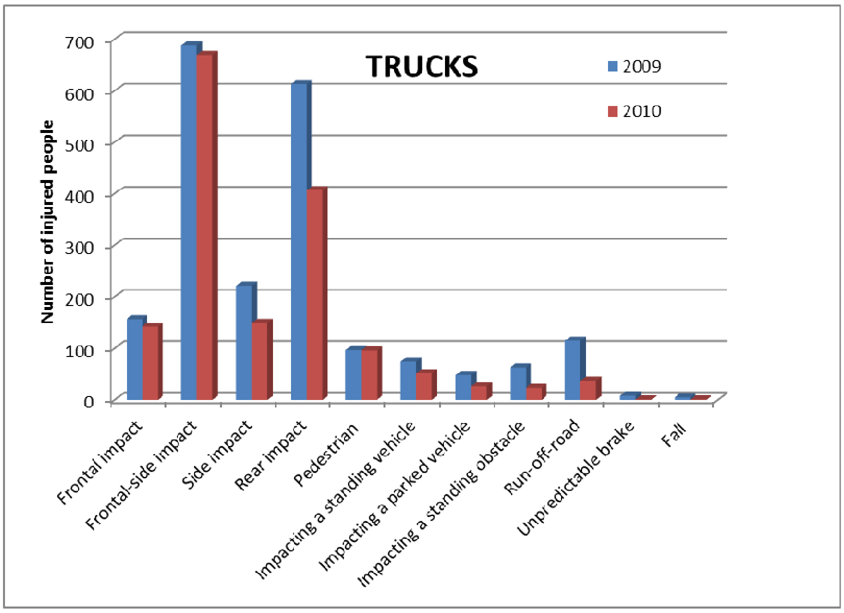


(b)

Figure 4-20: Total number of accidents per year and type of crash: (a) quadricycles; (b) trucks

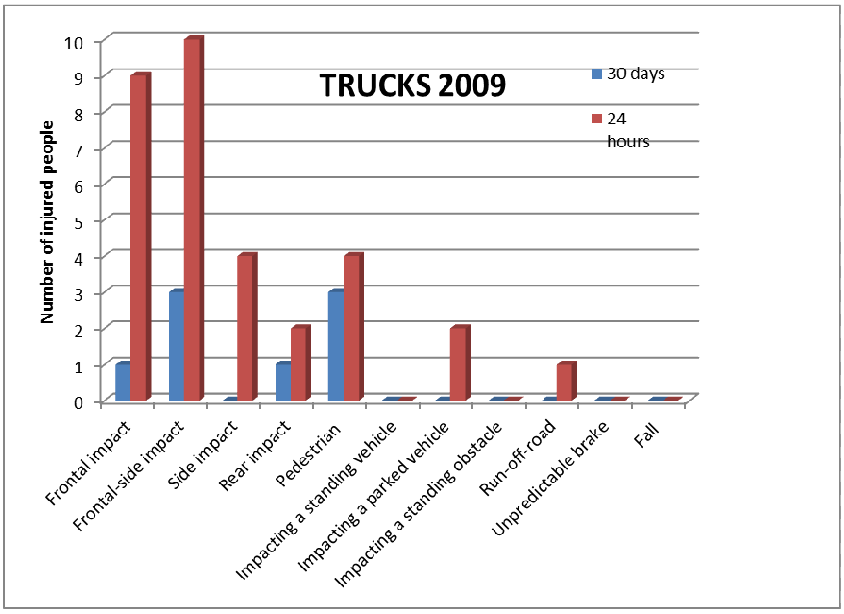


(a)

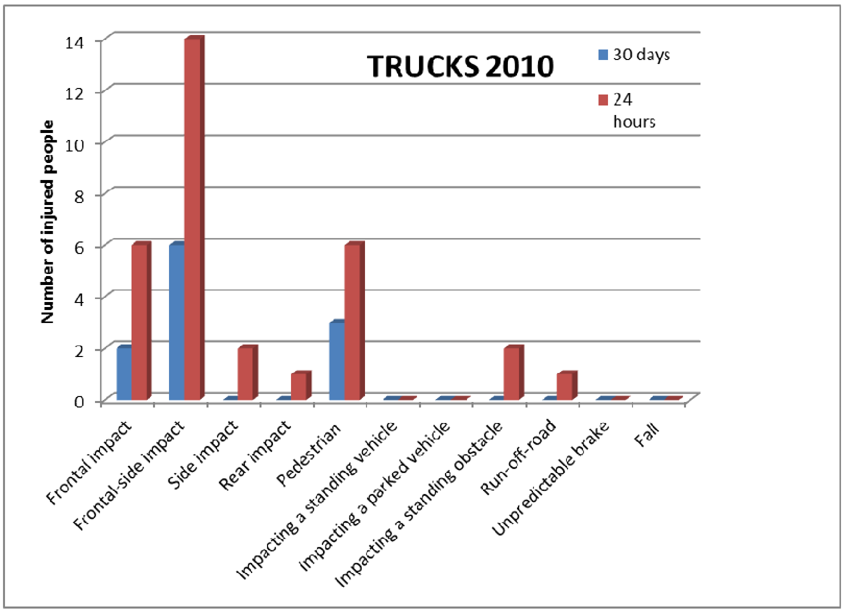


(b)

Figure 4-21: Total number of injured people per year and type of crash: (a) quadricycles; (b) trucks



(a)



(b)

Figure 4-22: Total number of deaths per type of accident in trucks: (a) 2009; (b) 2010

For quadricycles, no deaths were recorded in the Piemonte region (4.5 million inhabitants) and 78 people were injured in 2009 and 2010. The only fatality in accidents involving quadricycles was a person riding a motorcycle. This low number of fatalities and injuries might be due to a small number of vehicles registered in the region. Front-side (offset frontal) and rear impact are the most frequent types of accidents and the front impact and pedestrian impacts are much more severe and cause more casualties even though the number of accidents is lower.

It was not possible to find the number of quadricycles registered in the Piemonte region. The Year book of road accidents of May 2012 (ISTAT) shows that in 2010 there were 11.895 Goods motorvans and quadricycles and 7.747 Special/specific motor vehicles and quadricycles. In comparison, the number of goods trucks registered was 317.402 vehicles.

4.3. Lights trucks and vans in other geographical areas

4.3.1. U.S.A.

According to the Fatality Analysis Reporting System (FARS) and the National Highway Traffic Safety Administration (NHTSA) database, the number of lights truck vehicles (LTVs) is increasing during last years in the vehicles' fleet. LTVs include vans, minivans, light duty trucks, and sport utility vehicles. Users of such vehicles appreciate the extra size, utility and safety provided. Concerns about the effects of these LTVs on other passenger cars when they both collide are increasing.

When comparing these data with the data from European databases, it is important to keep in mind that the LTV vehicle in the US is different than the European [15].

An analysis of the road traffic statistics in U.S. based on the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System General Estimates System (NASS GES) has been performed. In 2007, 41,059 people were killed in motor vehicle crashes and 2,491,000 people were injured.

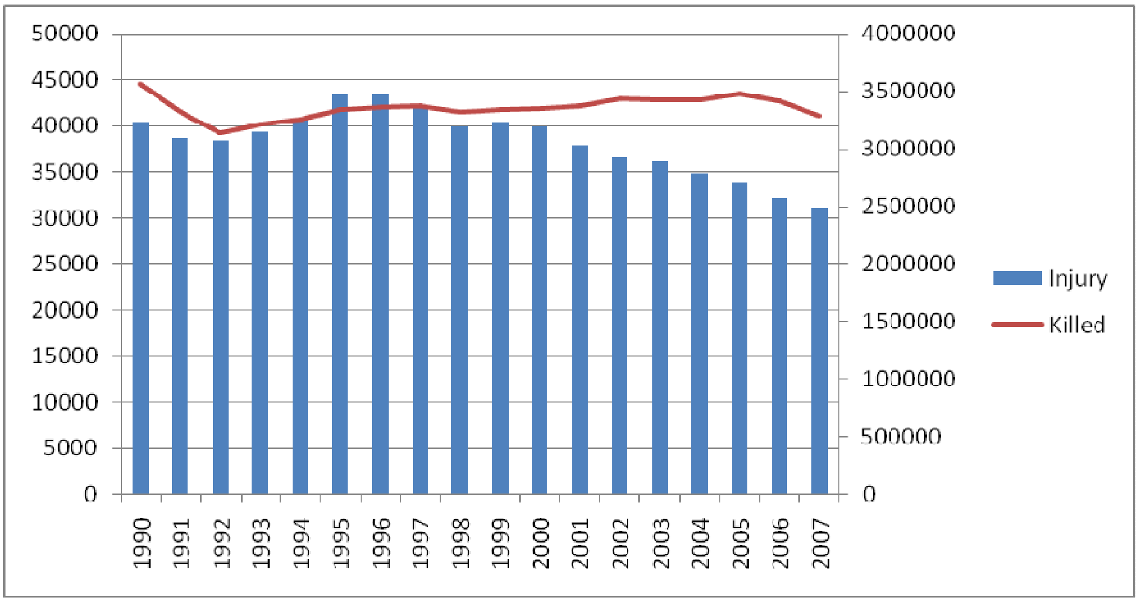


Figure 4-23 People Killed and injured in the US by Year.
Source: Own production from FARS database

TYPE OF VEHICLE	YEAR		CHANGE
	2006	2007	
Occupant killed	30,686	28,933	-5,71%
Passenger cars	17,925	16,520	-7,84%
LTVs	12,761	12,413	-2,73%
Vans	1,815	1,760	-3,03%
SUVs	4,928	4,809	-2,41%
Pickup trucks	5,993	5,830	-2,72%
Occupants injured	2,331,000	2,221,000	-4,72%
Passenger cars	1,475,000	1,379,000	-6,51%
LTVs	857,000	841,000	-1,87%
Vans	179,000	175,000	-2,23%
SUVs	387,000	380,000	-1,81%
Pickup trucks	276,000	271,000	-1,81%

Table 4.16 Passenger Vehicle Occupants Killed and Injured in Motor Vehicle Crashes, by type of vehicle.
Source: Own production from FARS database

The LTVs occupants killed in traffic accidents currently account approximately 45% of total occupants killed. On the other hand, the LTVs occupants injured account approximately 40% of total occupants injured.

As shown Table 4.16 the occupant fatalities in passenger cars decreased by 7.8%, while the occupant fatalities in LTVs decreased by 2.7%. Respect to occupants injured, FARS database shows a decrease of 6.15% for passenger vehicles and 1.87% for LTVs.

TYPE OF VEHICLE	2006	2007	% CHANGE
Passenger Vehicles	235.095.396	238.747.447	+1,55%
Passenger cars	136.881.809	137.773.353	+0,65%
Light Trucks and Vans	98.213.587	100.974.094	+2,81%
Vans	19.491.830	19.364.667	-0,65%
SUVs	37.173.383	39.252.954	+5,59%
Pickup trucks	40.678.320	41.315.998	+1,57%

Table 4.17 Registered Passenger Vehicle by Vehicle Type.
Source: Own production from FARS database

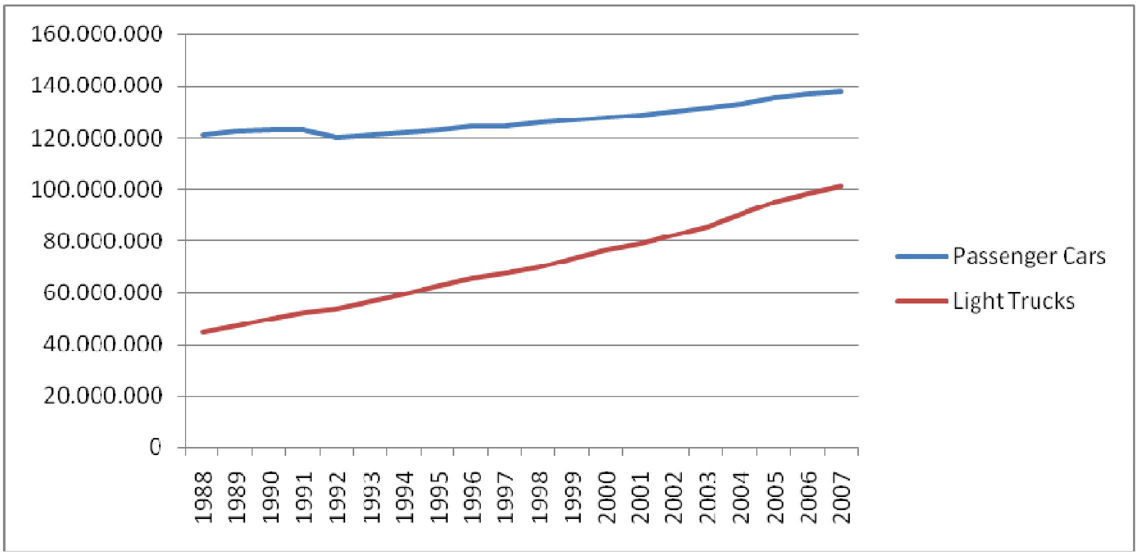


Figure 4-24: Passenger Vehicle Registration by Year.
Source: Own production from FARS database

In 2007, the number of registered vehicles increased for all types of passenger vehicles except vans. In the same year, among all types of passenger vehicles, SUVs had the largest increase (5.6%) in registrations.

As shown in Figure 4-24, during the period from 1988 to 2007, LTV registrations increased from 40,000,000 to 100,000,000. Light trucks and vans (LTVs) currently account for over one-third of registered U.S. passenger vehicles. Yet, collisions between cars and LTVs account for over one half of all fatalities in light vehicle-to-vehicle crashes. Nearly 60% of all fatalities in light vehicle side impacts occur when the striking vehicle is an LTV. As shown in Table 4.18, in 1996 LTV-car crashes accounted for 5,259 fatalities while car-car crashes led to 4,013 deaths and LTV-LTV crashes resulted in 1,225 fatalities.

YEAR	ALL CAR-CAR	ALL CAR-LTV	ALL LTV-LTV	TOTAL
1980	6506	3580	510	10596
1981	6510	3292	482	10284
1982	5437	3452	556	9445
1983	5137	3408	505	9050
1984	5340	3540	593	9473
1985	5174	3608	635	9417
1986	5450	3895	660	10005
1987	5489	4277	788	10554
1988	5320	4676	802	10798
1989	5175	4730	861	10766
1990	4726	4719	867	10312
1991	4482	4297	873	9652
1992	4208	4421	804	9433
1993	4364	4451	977	9792
1994	4219	4972	1059	10250
1995	4097	5238	1183	10518
1996	4013	5259	1225	10497

Table 4.18: Fatalities in Light Vehicle to Vehicle Crashes.
Source: Own production from Gabler (1998)

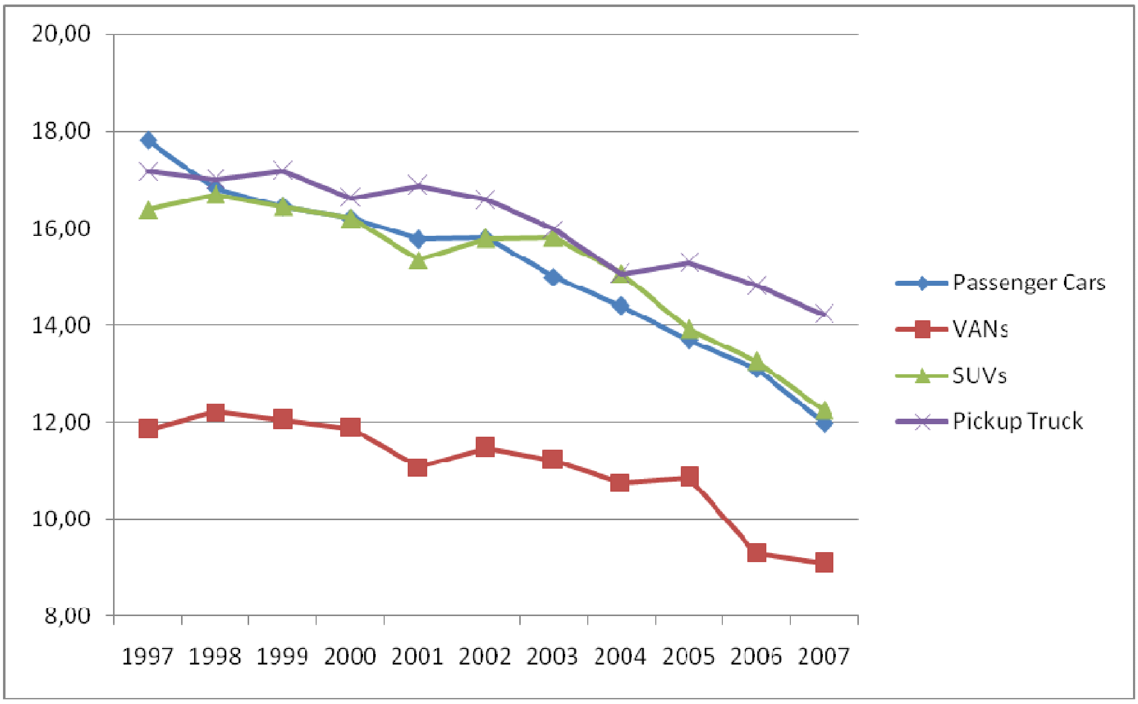


Figure 4-25: Passenger Vehicle Occupant Fatality by type of vehicle and year. Source: Own production from FARS

NHTSA (National Highway Traffic Safety Administration) has initiated a research program to investigate the problem of aggressive vehicles in multi-vehicle crashes. The near term objective of this program is to identify and demonstrate the extent of the problem of incompatible vehicles in vehicle-to-vehicle collisions. The goal of this research program is to identify and characterize compatible vehicle designs with the intention that improved vehicle compatibility will result in large reductions in crash related injuries. Specifically, the objective is to identify those vehicle structural categories, vehicle models, or vehicle design characteristics which are aggressive based upon crash statistics and crash test data. LTV-to-car collisions are one specific, but growing, aspect of this larger problem.

Comparison of LTV registrations and LTV-caused fatalities over the same period show that LTV impacts have always caused a disproportionate number of vehicle-to-vehicle fatalities. For example in 1980, LTVs accounted for 20 percent of the registered light vehicle fleet, but side impacts in which an LTV was the bullet vehicle led to 31 percent of all fatalities in side struck vehicles. The magnitude of this problem then is not only due to the aggressivity of LTVs in crashes, but also the result of the dramatic growth in the LTV fraction of the U.S. fleet.

In two-vehicle crashes involving a Passenger Car and an LTV, particularly in head-on collisions, 3.6 times as many passenger car occupants were killed as LTV occupants. When LTVs were struck in the side by a passenger car, 1.6 times as many LTV occupants were killed as passenger car occupants. On the other hand, when passenger cars were struck in the side by LTVs, 18 times as many passenger car occupants were killed as LTV occupants.

Frontal impacts crashes predominate in the U.S. development of secondary safety measures, such as air bags, advanced seat belts and crumple zones. This increase in security features do not forget to maintain chassis rigidity and strength that still supports vehicle items. But the development of safety features not only should be focused in frontal impacts, because side impacts produce substantial injuries in vehicle's occupants. Doors rigidity and side airbags (SAB) are designed to protect the occupant against such side impacts. Unfortunately, even with modern occupant protection features, serious injuries and fatalities are still occurring in a sizeable number of nearside crashes.

The weighted data of the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS), between 1999 and 2005, indicates that 16% of all crash occupants in the United States were in the nearside seating position of side impact crashes for the most significant impact event (Rank 1). When the same nearside crashes are analyzed by the delta-V for the nearside impact event (Rank 1) using 40 kph (25 mph) as a threshold, the breakdown shows 62% of the crashes occurring with a delta-V less than or equal to 40 kph and 14% over 40 kph with the remaining 24% having unknown delta-V's. For the nearside crashes occurring at or below 40 kph, the incidence of AIS+3 injuries is 3.33% (17,212 out of 516,165 occupants).

4.3.2. Japan

The report named “Statistics 2007. Road accidents Japan” analyzes the Japanese road traffic accidents database. This accident data was compiled by the Traffic Bureau and the National Police Agency from Japan. This report describes crash severity, number of fatalities and injuries in vehicle occupants and pedestrians in Japan. This data allow observing trends in the type, frequency and severity of accidents and developing measures to reduce accidents.

A total of 832,454 traffic accidents happened in Japan in 2007 with 5,744 fatalities (person who dies as a result of a traffic accident within 24 hours of its occurrence) and 1,034,400 injuries (the total of serious and slight injuries). In the same year, there were 91,166,120 vehicle registrations. These numbers mean a reduction in fatalities of 9.6% compared to 2006, and a reduction of 0.3 % in the number of injuries compared to the same year. When analyzing the traffic accidents involving primary parties (the driver, whether vehicle or train, or pedestrian among those initially involved in the traffic accident who is most at fault or, when fault is shared equally, who is less injured) the results obtained in the case of trucks are shown in Table 4.19:

<table>
<tr><th colspan="2" rowspan="2">Primary party vehicle type</th><th rowspan="2">Accidents</th><th colspan="2">Compared with 2006</th><th rowspan="2">Number of motor vehicles registered</th><th rowspan="2">Accidents per 10,000 motor vehicles</th></tr>
<tr><th>Change</th><th>Percentage change</th></tr>
<tr><td rowspan="7">Private vehicle</td><td>Truck</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Large-sized</td><td>1.248</td><td>-31</td><td>-2,4</td><td rowspan="4">5.798.089</td><td rowspan="4">106,6</td></tr>
<tr><td>Medium-sized</td><td>5.558</td><td rowspan="2">-6.145</td><td rowspan="2">-9,3</td></tr>
<tr><td>Ordinary</td><td>54.666</td></tr>
<tr><td>Trailer</td><td>352</td><td>14</td><td>4,1</td></tr>
<tr><td>Light</td><td>59.917</td><td>-4.576</td><td>-7,1</td><td>-</td><td>-</td></tr>
<tr><td>Sub-total</td><td>121.741</td><td>-10.738</td><td>-8,1</td><td>5.798.089</td><td>106,6</td></tr>
<tr><td rowspan="7">Commercial vehicle</td><td>Truck</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Large-sized</td><td>5.593</td><td>-353</td><td>-5,9</td><td rowspan="4">1.136.629</td><td rowspan="4">240,6</td></tr>
<tr><td>Medium-sized</td><td>8.306</td><td rowspan="2">-2.671</td><td rowspan="2">-12</td></tr>
<tr><td>Ordinary</td><td>11.256</td></tr>
<tr><td>Trailer</td><td>2.194</td><td>62</td><td>2,9</td></tr>
<tr><td>Light</td><td>4.656</td><td>27</td><td>0,6</td><td>-</td><td>-</td></tr>
<tr><td>Sub-total</td><td>32.005</td><td>-2.935</td><td>-8,4</td><td>1.136.629</td><td>240,6</td></tr>
</table>

Table 4.19: Traffic accidents involving primary parties.
Source: Own production from Japan database 2007

In Table 4.19 can be observed that there is a greater number of trucks registered as private vehicles than trucks registered as commercial vehicles. In the group of trucks as private vehicles, light trucks are the ones involved in more accidents, representing 49% of the total. In the case of trucks as commercial vehicles, the ordinary trucks are those involved in more accidents, 35% of the cases.

Table 4.20 shows the differences in the number of accidents depending on the driving experience, commercial or private use and type of vehicle used for transportation. If the use of the truck fleet to private or commercial use is compared; it is observed that most accidents occur in the private use without exception for all types of driver experience. For commercial vehicles, the highest number of road accidents occurs in ordinary vehicles with 35% of the cases whereas for light trucks this percentage drops to 6.8%. Regarding private vehicles, accidents occurring in ordinary vehicles and trailers represent 44.9% and 49.2%.

Primary Party		Driving experience								
		Less than 1 year	Less than 2 years	Less than 3 years	Less than 4 years	Less than 5 years	Less than 10 years	10 years or more	Unlicensed or unknown	Total
Commercial vehicle	Truck									
	Large-sized	55	57	80	67	121	707	4.506	-	5.593
	Medium-sized	102	197	217	149	241	1.136	6.260	4	8.306
	Ordinary	233	310	334	305	431	1.619	8.018	6	11.256
	Trailer	66	63	78	58	98	350	3.939	4	4.656
	Light	26	23	38	24	51	249	1.782	1	2.194
	Sub-total	482	650	747	603	942	4.061	24.505	15	32.005
Private vehicle	Truck									
	Large-sized	8	12	12	8	18	99	1.089	2	1.248
	Medium-sized	93	156	131	123	158	774	4.111	12	5.558
	Ordinary	1.106	1.442	1.528	1.378	2.041	7.938	39.054	179	54.666
	Trailer	1.482	1.350	1.349	1.036	1.381	5.199	47.829	291	59.917
	Light	4	8	6	6	7	64	257	-	352
	Sub-total	2.693	2.968	3.026	2.551	3.605	14.074	92.340	484	121.741

Table 4.20: Traffic accidents by the Driving experience in primary parties.
Source: Own production from Japan database in 2007

Table 4.21 shows the fatal traffic accidents of trucks involving primary parties. The more drastic percentage reduction takes place in accidents involving a trailer, which pass from 5 accidents to 3 (40%) being the largest percentage break. For light trucks the fatal accidents decreased from 674 to 635 (5.8%). In the commercial vehicles, the greatest reduction occurs in light vehicles with a reduction of 14 fatal accidents (45.2%) and large-sized vehicles with a decrease of 15 fatal accidents (7.3%).

<table>
<tr><th colspan="2" rowspan="2">Primary party vehicle type</th><th rowspan="2">Accidents</th><th colspan="2">Compared with 2006</th><th rowspan="2">Number of motor vehicles registered</th><th rowspan="2">Accidents per 10,000 motor vehicles</th></tr>
<tr><th>Change</th><th>Percentage change</th></tr>
<tr><td rowspan="7">Private vehicle</td><td>Truck</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Large-sized</td><td>36</td><td>8</td><td>28,6</td><td rowspan="4">5.798.089</td><td rowspan="4">0,84</td></tr>
<tr><td>Medium-sized</td><td>73</td><td rowspan="2">-17</td><td rowspan="2">-3,6</td></tr>
<tr><td>Ordinary</td><td>376</td></tr>
<tr><td>Trailer</td><td>3</td><td>-2</td><td>-40,0</td></tr>
<tr><td>Light</td><td>635</td><td>-39</td><td>-5,8</td><td>-</td><td>-</td></tr>
<tr><td>Sub-total</td><td>1.123</td><td>-50</td><td>-4,3</td><td>5.798.089</td><td>0,84</td></tr>
<tr><td rowspan="7">Commercial vehicle</td><td>Truck</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Large-sized</td><td>191</td><td>-15</td><td>-7,3</td><td rowspan="4">1.136.629</td><td rowspan="4">4,49</td></tr>
<tr><td>Medium-sized</td><td>160</td><td rowspan="2">-6</td><td rowspan="2">-2,3</td></tr>
<tr><td>Ordinary</td><td>98</td></tr>
<tr><td>Trailer</td><td>61</td><td>3</td><td>5,2</td></tr>
<tr><td>Light</td><td>17</td><td>-14</td><td>-45,2</td><td>-</td><td>-</td></tr>
<tr><td>Sub-total</td><td>527</td><td>-32</td><td>-5,7</td><td>1.136.629</td><td>4,49</td></tr>
</table>

Table 4.21: Fatal Accidents Involving Primary Parties.
Source: Own production from Japan database in 2007

Table 4.22 shows the relation between experience and fatal accident by type of vehicle. Fatalities in light vehicles represent 39.5 % of total fatalities involving trucks and most of the drivers have 10 or more years of experience (560 accidents). Ordinary vehicles have a high rate of fatalities (474 accidents), especially in accidents involving drivers with ten or more years of experience.

Primary Party		Driving experience								
		Less than 1 year	Less than 2 years	Less than 3 years	Less than 4 years	Less than 5 years	Less than 10 years	10 years or more	Unlicensed or unknown	Total
Commercial vehicle	Truck									
	Large-sized	2	2	2	6	5	27	147	-	191
	Medium-sized	4	2	2	2	5	19	126	-	160
	Ordinary	1	1	2	-	4	20	69	1	98
	Trailer	-	1	1	1	-	12	46	-	61
	Light	-	-	-	-	-	-	17	-	17
	Sub-total	7	6	7	9	14	78	405	1	527
Private vehicle	Truck									
	Large-sized	-	-	2	-	1	1	31	1	36
	Medium-sized	2	-	2	1	-	9	59	-	73
	Ordinary	6	7	10	12	15	50	274	2	376
	Trailer	-	-	-	-	-	-	3	-	3
	Light	13	5	9	7	6	45	543	7	635
	Sub-total	21	12	23	20	22	105	910	10	1.123

Table 4.22: Fatal Accidents by the Driving Experience of Primary Parties.
Source: Own production from Japan database in 2007

5. Crash Compatibility

5.1. Introduction

Traffic related fatalities and injuries remain a major problem throughout the world. Worldwide traffic fatalities are estimated in 1.2 million per year by the Word Health Organization [16].

Vehicle safety experts worldwide agree that significant reduction in traffic fatalities and injuries can be realized through implementation of improved active and passive safety systems.

Passive crash safety measures already have a proven track record in reducing road accident casualties through the introduction of safety belts, air bags, improvements in crashworthiness and energy absorption features within the occupant compartment. Passive safety measures still have a great potential in further reducing fatalities and injuries. None of these, however, will be of great significance unless disparities in crashworthiness among vehicles of different masses, sizes, and structural characteristics in mixed crash environments are successfully taken into account. This has been a research issue for many years, and it recently has gained much more momentum in view of rapidly increasing SUV, van, and light-truck populations relative to the number of passenger cars, and due to significant improvements in technologies that facilitate a better understanding of the dynamic interaction among widely differing size vehicles. The complexity of the subject requires the development of clear definitions, convergence of procedural directions, involvement of stakeholders from passenger car and heavy-vehicle manufacturers, research institutions, infrastructure suppliers, insurers and governments at the global level.

There are three main issues that can be detected in real world accidents, influencing vehicle compatibility. These issues are:

- Mass differences,
- Compartment integrity with regard to frontal car-to-car impact, and
- Differences in bumper and sill height in side impact.

Longitudinal mismatch in frontal impact, front end stiffness and other items which are from theoretical point of view responsible for vehicle aggressiveness are not seen influential from the point of view of real world accidents.

On the other hand, compartment collapse occurs, when there is not sufficient deformation energy available in vehicle front-end. And deformation energy is available, when it is provided by vehicle structures and when these structures interact. So compartment collapse can only be avoided, as long as sufficient deformation energy is available and is effective within the car-to-car collision.

In vehicle-to-vehicle crashes, two vehicle safety viewpoints have to be considered:

- Self-protection, the ability of a vehicle to protect its own occupants, both in vehicle-to-vehicle accidents and against other objects in the traffic environment,
- Partner-protection, the ability of a vehicle to protect the occupants of the opponent vehicle in vehicle-to-vehicle crashes.

Compatibility aims at finding an optimum for self-protection and partner-protection. It is generally accepted that this should take place without compromising self-protection. Partner-protection is often referred to as low aggressivity towards other traffic participants.

The primary goal remains to prevent accidents through active safety measures. Significant improvements have already been achieved over the past few years. Electronic Stabilization

Program (ESP), for example, has a significant influence, particularly in the reduction of single vehicle accidents [17]. It will be much more difficult to prevent vehicle-to-vehicle collisions with active safety measures.

The compatibility of a vehicle is understood as a combination of self- and partner protection in such way that optimum overall safety is achieved. This means: compatibility seeks to minimize the number of fatalities and injuries, regardless of the vehicle in which the injuries or fatalities occur. Additionally, customers expect further improvements in the level of self-protection. It will not be acceptable to reduce today's high levels of self-protection.

5.2. Structural interaction

With the grooving popularity of light trucks and vans (LTVs), the aggressivity of LTVs as an issue of concern is growing. Highly possible factor of aggressivity is geometric difference, in particular, height differences of structural stiff parts like side members. Recent studies on crash compatibility between vehicles have shown that the factors influencing crash compatibility performance are vehicle mass, stiffness and geometry. The majority of the studies have concluded that geometry is the most dominant factor. And of the geometric incompatibilities, height difference of stiff structural parts is a major concern. Height difference of some structural parts leads to override and/or underrun effects, where energy absorption efficiency of both vehicles is impaired and generating additional compartment intrusion. When a vehicle is overridden, the crash energy is absorbed only by the upper body, generating a significant upper body intrusion in cowl and instrument panel areas of the overridden car compartment, compounding injury and fatality risks to the occupants. For compatibility improvement, structural interaction to minimize override potential and effect, therefore, is very important.

Real world accident configurations are very varied – impact angle, overlap, impact point and speed are just a few of the parameters describing an accident. The concentration of structural stiffness in elements such as the frontal rail can adversely affect safety performance in accidents.

Misalignment of these stiff lower rails is normal and can result in high passenger compartment intrusion levels due to inadequate energy absorption by these stiff elements. This can manifest itself in a number of different ways, such as override, where one vehicle tends to ride up over the other, or the penetrating fork effect where the stiff members of one vehicle penetrate the soft areas of the other vehicle due to lateral misalignment.

Until vehicle designs enable structures to interact better in car to car impacts, any compatibility improvements in stiffness matching are unlikely to be fully realized. To achieve good structural interaction, the implications for car design are that they will require better vertical, lateral and shear connections. These connections will increase the number of active load paths into the main energy absorbing structures. This will help to ensure that predictable behavior occurs over a wider range of impacts, hence improving crashworthiness performance.

5.3. Study of the vehicle profiles

The compatibility towards other vehicles and pedestrians is, of course, strongly related to the shape and characteristics of the vehicle. In the case of pedestrian accidents, it is well known that kinematics of the impacted human body depends on the way the different parts of the front come in contact with it. Height of the lower and upper part of the front, inclination of the parts, longitudinal positions define the shape and, at the end, the characteristics of the vehicle. A generic front shape is represented in Figure 5-1.

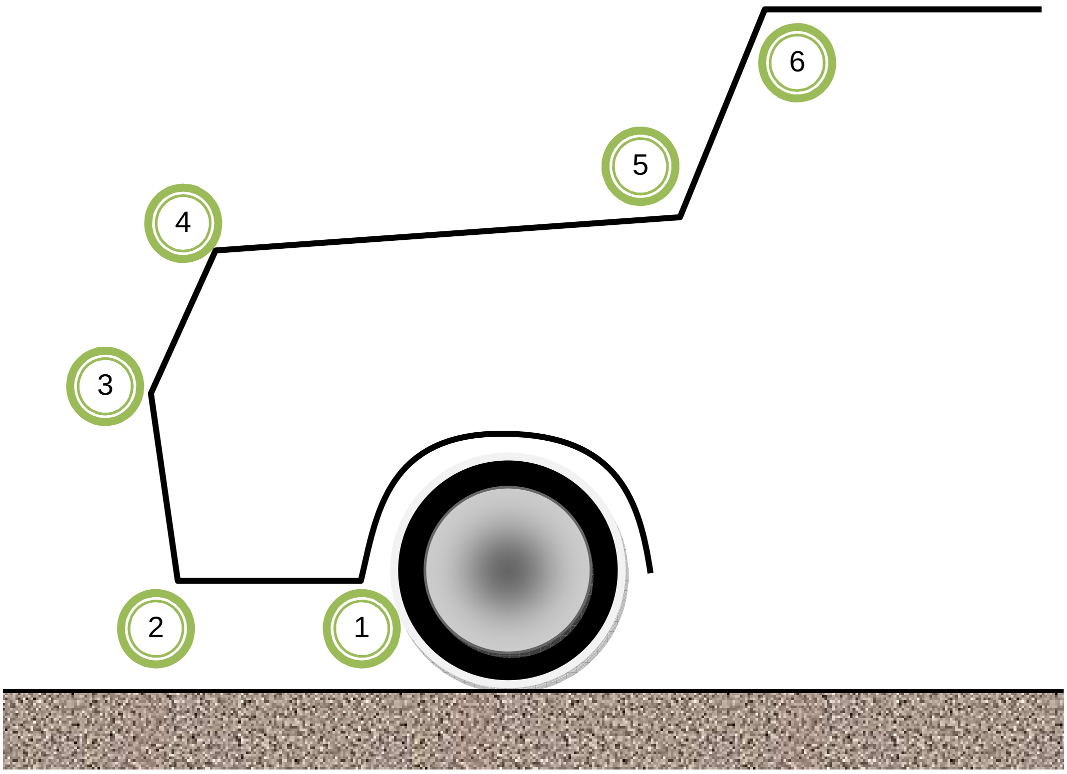


Figure 5-1: A generic front of a vehicle

In this very simple representation the vehicle front is divided in 5 segments, defined by 6 points. Segment 1-2 defines the front hangover, the remaining segments properly define the front shape: segments 2-3 and 3-4 define the lower part (bumper and grille), segment 4-5 is the bonnet (sometimes absent or almost absent in commercial vehicles), while segment 5-6 is the windscreen.

To define whatever front shape it requires 10 variables that can be reduced to 9 assuming that the overhang segment 1-2 is horizontal. This simplification is not very important especially for the aims of this work. And since the length of the 1-2 segment is not part of the front, only 8 variables completely define the shape, namely:

- (overhang length: L12)
- Bumper height, distance 2-3: L23
- Bumper slope, inclination of segment 2-3: S23
- Grille height, distance 3-4: L34
- Grille slope, inclination of segment 3-4: S34
- Bonnet length, distance 4-5: L45
- Bonnet slope, inclination of segment 4-5: S45
- Windscreen length, distance 5-6: L56
- Windscreen slope, inclination of segment 5-6: S56

Such analysis has been carried out on the vehicles sold on the market today. The analysis included vehicles of the classes N1 and L7e, even if N1 vehicles are outside the objectives of the project: they can, however, give important indications on the way such vehicles are designed for safety. In fact they are submitted to safety standard more restrictive than L7e vehicles.

5.3.1. Examined vehicles Classification

Both N1 and L7e categories include vehicles with quite different characteristics in terms of shape, size, and weights and, lastly, in terms of practical use. Classification is not straightforward since a standard does not exist. It exist conventional or commercial classifications usually adopted in which most of the available commercial products fall.

For N1 categories it is possible to define the following main categories:

- Small van (Citroën Nemo, FIAT Fiorino, Peugeot Bipper…)
- Intermediate van (Dacia Logan Pickup)
- Multispace (Citroën Berlingo, FIAT Doblò, Renault Kangoo…)
- Small-sized light commercial vehicle (Piaggio Porter, Nissan NV200…)
- Intermediate-sized light commercial vehicle (Citroën Jumpy, FIAT Scudo, Opel Vivaro…)
- Large-sized light commercial vehicle (Citroën Jumper, FIAT Ducato, Renault Master…)
- Pickup (Ford Ranger, Isuzu D-MAX, Nissan Navara, Mitsubishi L200, Toyota Hilux…)
- Light trucks (Mitsubishi Canter, Nissan Cabstar, Renault Maxity…)

For L7e it is possible to define two categories:

- Passenger-vehicle derived van
- Small van

5.3.2. Vehicles on the market and analysis

The list of commercial vehicles on the market at the time of the report is relatively contained including models for the EU market mainly; many are sold in the US market also. Vehicles produced in emerging countries, especially China, are difficult to track and analyze: moreover, they often reproduce, if not copy, European and American models.

Table 5.1 has a list of these N1 vehicles classified as before in 5.3.1, with many characteristics listed. Table 5.2 has a list of the, much less, L7e ELTVs. There are probably many new models from China and India but information about them is quite difficult to find. The US market does not propose yet any model, excepting, as far as is known to the partners, the Zerotruck (powered by Dowkokam batteries, http://dowkokam.com/resources/DK_CaseStudy_ZeroTruck.pdf) which is a large commercial vehicle that can be considered in the N1 category.

In Table 5.3 a collection of the results from Euro NCAP (November 2011) tests involving commercial vehicles has been reported. Of course, of the around 60 light commercial vehicle models on the market only one third, 21 to be precise, effective tests and reports have been done. In these 21 tests, some are repeated since they are the same vehicle of different brands with different names, so finally only 14, Euro NCAP effective tests are available.

Make	Model	Category	Width (mm)	Notes	Euro NCAP
Citroën	Berlingo	Multispace	1810	Same as Peugeot Partner	2008
Citroën	Jumper	Large	2050	Same as Citroën Jumper and Peugeot Boxer	
Citroën	Jumpy	Intermediate	1900	Same as FIAT Scudo and Peugeot Expert; AKA Dispatch in UK	
Citroën	Nemo	Small van	1720	Same as FIAT Fiorino and Peugeot Bipper	2010
Dacia	Logan pickup	pick up	1740		2005
Effedi	Gasolone	Small	1660		
FIAT	Doblò	Multispace	1830		2004
FIAT	Ducato	Large	2050	Same as Peugeot Boxer and Citroën Jumper	
FIAT	Fiorino	Small van	1720	Same as Citroën Nemo and Peugeot Bipper	Citroën Nemo
FIAT	Qubo	Small van	1720	Non-commercial version of FIAT Fiorino	Citroën Nemo
FIAT	Scudo	Intermediate	1900	Same as Citroën Jumpy and Peugeot Expert	
FIAT	Strada	Small van	1660	Derived from FIAT Palio	
Ford	Ranger	Pickup		Same as Mazda B-series, for the US market	2008
Ford	Tourneo	Multispace	1800		
Ford	Transit	Large	1970		
Giotti Victoria	Gladiator	Small	1560		
Hyunday	H-1	Intermediate	1920		
Isuzu	D-MAX	Pickup			2008
Isuzu	NLR/NMR/NNR/NPR	Light trucks	1982	AKA Grafter	
Iveco	Daily	Large	2000		
Mazda	BT-50	Pickup		Same as Ford Ranger, for the non US market	Ford Ranger

Make	Model	Category	Width (mm)	Notes	Euro NCAP
Mercedes	Sprinter	Large	1990	Same as Dodge Sprinter	
Mercedes	Vaneo	Multispace		Commercial first generation A-class version	2002
Mercedes	Vario				
Mercedes	Viano	Intermediate	1906	Base on Mercedes Vito platform	2008
Mercedes	Vito	Intermediate	1900		Mercedes Viano
Mitsubishi	L200	Pickup			2008
Mitsubishi	Canter	Light trucks			
Nissan	Atleon	Light trucks			
Nissan	Cabstar (aka Atlas)	Light trucks	1870	Same as Renault Maxity (and Samsung SV110, in Asia)	
Nissan	Interstar	Large	1990	Same as Renault Master	
Nissan	Navara	Pickup			2008
Nissan	NP300	Pickup			
Nissan	NV200	Small	1700	An electric vehicle based on NV200 will also be released	
Nissan	Primastar	Intermediate	1900	Same as Renault Trafic and Opel Vivaro	
Opel	Combo	Multispace	1680		Fiat Doblò
Opel	Movano	Large	2070		
Opel	Vivaro	Intermediate	1900	Same as Renault Trafic and Nissan Primastar	
Peugeot	Bipper	Small van	1680	Same as FIAT Fiorino and Citroën Nemo	Citroën Nemo
Peugeot	Boxer	Large	2050	Same as FIAT Ducato and Citroën Jumper	
Peugeot	Expert (aka Tepee)	Intermediate	1900	Same as Citroën Jumpy and FIAT Scudo	
Peugeot	Partner	Multispace	1810	Same as Citroën Berlingo	Citroën Berlingo
Piaggio	Porter	Small	1460		
Renault	Kangoo	Multispace	1830		2008
Renault	Kangoo Be Bop	Small van	1830	Special version of Kangoo	

Make	Model	Category	Width (mm)	Notes	Euro NCAP
Renault	Master	Large	2100	Same as Nissan Interstar	
Renault	Trafic	Intermediate	1900	Same as Nissan Primastar and Opel Vivaro	
Renault	Maxity	Light trucks	1870	Same as Nissan Cabstar (aka Atlas)	
Skoda	Roomster	Multispace	1680		2006
Tata	Xenon	Pickup			
Toyota	Hiace	Intermediate	1800		
Toyota	Hilux	Pickup			
Volkswagen	Amarok	Pickup	1940		2010
Volkswagen	Caddy	Multispace	1790		2007
Volkswagen	Caravelle	Intermediate	1900		
Volkswagen	Crafter	Large	1990		
Volkswagen	Multivan	Intermediate	1900		
Volkswagen	Transporter	Intermediate	1900		

Table 5.1: Light commercial vehicles classification: N1 category

Make	Model	Width (mm)	Length (mm)	Height (mm)	Weight w/o b (kg)	Weight w/b (kg)	Notes
Aixam	Mega city	1000	2890		460	645	France
Bellier	Docker	1350	2670-2870	1820			http://www.bellier.fr
Comarth	Cross Rider	1299	2795-3356	1750-1818	380-530	595-750	UK
FAAM	EVF	1239	2817	1774	370	750	Italy
GEM	eL/eL XD	1397	3658	1778-1804	450	570	www.gemcar.com;
Blucar	Golia Pickup	1180	3230-3880	1885-2005	605	1000	http://www.ecoblucar.com
Goupil	G3	1100-1330	3845	2000	550	925	http://www.goupil-industrie.eu/ (not L7e vehicle)
Mega	Chassis Cab	1476-1486	3102-3288	1800-1830	430-470	590-730	http://www.megavan.org/
Mega	eWorker	1250-1360	3165-3875	2500	N.A.	768-1009	http://www.megavan.org/
Mega	Van	1490-1545	3328-3753	1800-1830	540-640	670-900	http://www.megavan.org/
Melex	XTR	1210-1280	2710-3645	1725-1850	425-564	592-722	http://www.melex.com.au
Tazzari	Zero	1560	2880	1425	462	542	This is not a commercial vehicle
Zen'lib	Simply City	1460	3480	1700	348-548	600-800	http://simplycity.fr/
Zerocars	Little 4	1470	3116	1530	315-325	630-640	

Table 5.2: Light commercial vehicles classification: L7e category

Make	Model	Euro NCAP	Euco NCAP Category	Rating	Adult	Child	Pedestrian	Adult score	Child score	Pedestrian score	Kerb Weight (kg)	Front seatbelt pret.	Front seatbelt limiters	Driver frontal AB	Front pass. frontal AB	Side body AB	Side head AB	Driver knee AB
Citroën	Berlingo	2008	Small MPV	4	4	4	2	27	39	10	1482	Y	Y	Y	Y			
Citroën	Nemo	2010	Supermini	3				59%	74%	55%	1185	Y	Y	Y	Optional	Optional	?	?
Dacia	Logan pickup	2005	Small Fam. Car	3	3	3	1	19	31	5	1040			Y	Y			
FIAT	Doblò	2004	Small MPV	3	3	3	1	23	34	1	1400	Y	Y	Y	Y			
FIAT	Fiorino	Citroën Nemo	Supermini	3				59%	74%	55%	1185	Y	Y	Y	Optional	Optional	?	?
FIAT	Qubo	Citroën Nemo	Supermini	3				59%	74%	55%	1185	Y	Y	Y	Optional	Optional	?	?
Ford	Ranger	2008	Pick-up	5				96	86	81	2091	Y	Y	Y	Y	Y	Y	Y
Isuzu	D-MAX	2008	Pick-up	1.5	1.5	2	1	17	22	2	1875	Y		Y				
Mazda	BT-50	Ford Ranger	Pick-up	2	2	3	2	19	28	11	1845	Y	Y	Y	Y			
Mercedes	Vaneo	2002	Small MPV	4	4		2	27		10	1365	Y	Y	Y	Y	Y		
Mercedes	Viano	2008	Large MPV	4	4	3	1	31	36		2065	Y	Y	Y	Y			
Mercedes	Vito	Mercedes Viano	Large MPV	4	4	3	1	31	36		2065	Y	Y	Y	Y			
Mitsubishi	L200	2008	Pick-up	4	4	3	1	27	32	2	1880	Y	Y	Y	Y			
Nissan	Navara	2008	Pick-up	3	3	4	2	24	20	14	2063	Y	Y	Y	Y			
Opel	Combo	Fiat Doblò	Small MPV	3	3	3	1	23	34	1	1400	Y	Y	Y	Y			
Peugeot	Bipper	Citroën Nemo	Supermini	3				59%	74%	55%	1185	Y	Y	Y	Optional	Optional	?	?
Peugeot	Partner	Citroën Berlingo	Small MPV	4	4	4	2	27	39	10	1482	Y	Y	Y	Y			
Renault	Kangoo	2008	Small MPV	4	4	4	2	28	41	14	1429	Y	Y	Y	Y			
Skoda	Roomster	2006	Small MPV	5	5	4	2	34	40	14	1175	Y	Y	Y	Y	Y	Y	
Volkswagen	Amarok	2010	Pick-up	4				86%	64%	47%	1985	Y	Y	Y	Y	Y	Y	?
Volkswagen	Caddy	2007	Small MPV	4	4	3	2	27	30	13	1538	Y	Y	Y	Y	Y		

Table 5.3: Summary of Euro NCAP results for commercial vehicles

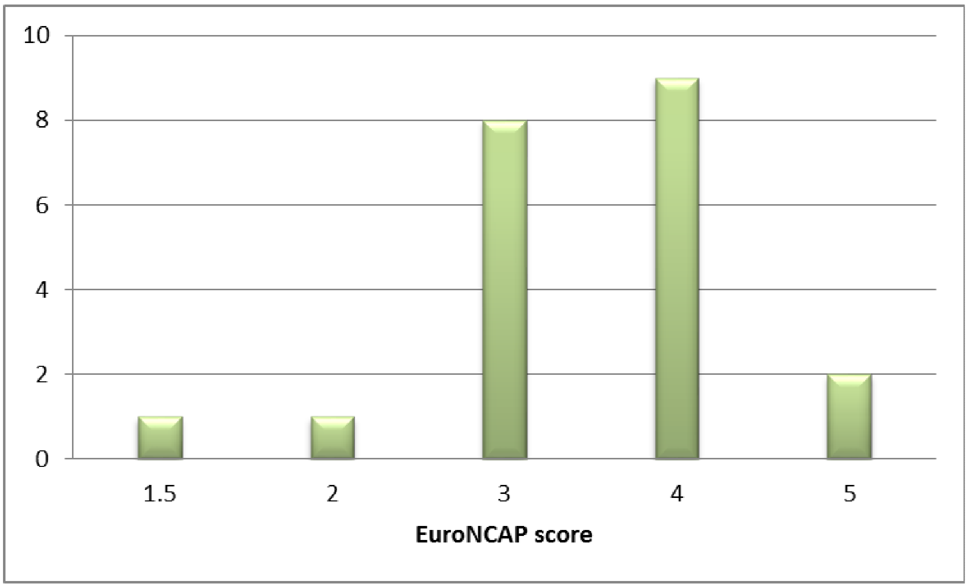


Figure 5-2: Distribution of the Euro NCAP "stars" for the tested commercial vehicle available (as of November 2011). The 1.5 and 2 stars vehicles were tested in 2006 and 2008; the 5 stars vehicles in 2006 and 2010. Y axis represents the number of vehicles with that number of stars.

Analyzing these Euro NCAP data it appears that there is a relatively wide scatter in the values, ranging from 1.5 stars (two models have 2 stars or less) to a couple of models with the full 5 stars (one of these with the new rating system introduced in 2009). Most of the results (see Figure 5-2) lie in the 3-4 stars range. It is hard to establish correlations between the obtained rating and the various parameters and draw any conclusion. There is no correlation with weight or with the type of vehicle: most of the 4 and 5 stars are in the Euro NCAP category "Small MPV"; however the categories "Supermini" and "Small family car" include only one vehicle each.

5.4. Frontal crashes

The mass factor has a predominant effect on crash compatibility. A restraint system is able to make crashes survivable as long as compartment deceleration is not too high. This means that the deceleration of the small vehicle must be restricted to a certain level. As long as the impact velocity of two vehicles is not too high (less than twice the barrier impact speed, for which the vehicles were designed), the amount of available deformation energy of the two vehicles is sufficient, regardless of the mass ratio. The deformation of the larger vehicle is possible in case of collision when the small vehicle is stiff enough to force this deformation before its own compartment collapses. It is therefore necessary to design the compartment stiffness sufficiently high so that the deformation force of the large vehicle is lower. But the first restriction has to be taken into account too. Both ideas form the basis of the following concept:

- Restrict force levels of the front-end of the vehicles in such a manner that a certain (e.g. 30g) compartment deceleration in the small vehicle is not exceeded (definition of a F_{max}).
- Design the compartment of a vehicle in such a way that does not permit excessive intrusion as long as the deformation force is less than this maximum force F_{max}.

This concept is capable of managing a vehicle-to-vehicle collision. When every vehicle is equipped with a restraint system that is able to sustain 30g without exerting excessive loads on the occupant a high number of vehicle-to-vehicle collisions will become survivable because no overcrushing and no excessive acceleration occurs.

This concept is in clear conflict with self-protection. The higher the degree of self-protection, the smaller the range of mass ratios to which this concept applies.

5.4.1. Interaction with Vulnerable Road Users (VRUs)

5.4.1.1. Analysis of the vehicles front shapes and profiles

To define the shape and size of the OPTIBODY concept, current state of the vehicle available in the market was analyzed in order to determine average and limits in both size and shape. First of all, this analysis is made in terms of planar size. This is reported in Figure 5-3. Most L7e vehicles lie in a relatively small corridor, especially in terms of width. Larger scatter is found in N1 vehicles, especially in terms of length. Width of N1 vehicles can be categorized as suggested in the previous section.

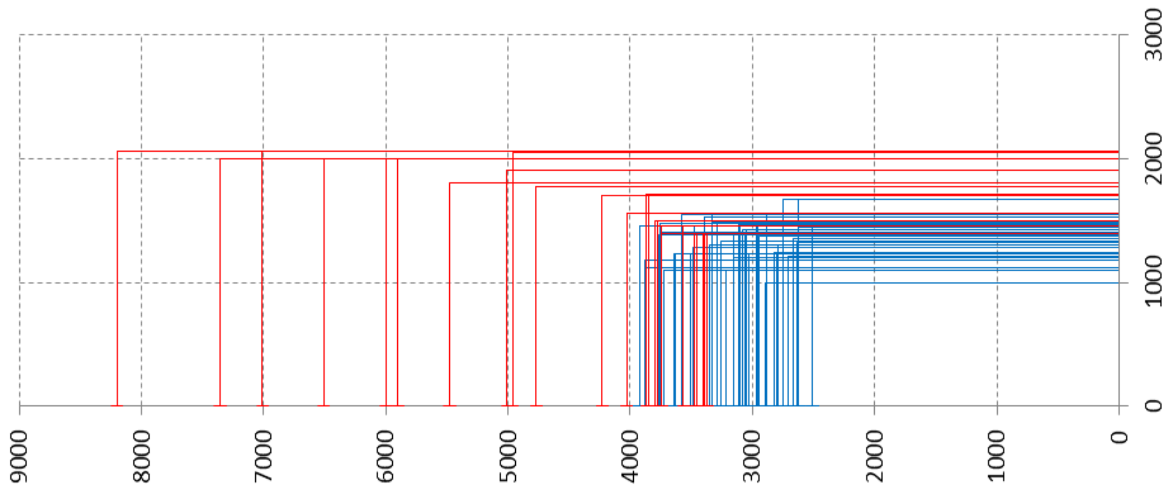


Figure 5-3: Plan shapes of the L7e (blue lines) and N1 (red lines) vehicles. A large scatter exists in the length of N1 vehicles that are available in several variants (short and long van, minibus…). X and Y axis represent the length and width of the vehicles in mm.

Analyzing the front shape, that has important influence on pedestrian safety, it is necessary to divide the vehicles into their different categories. If, in fact, all the vehicles of N1 categories are kept together, as in Figure 5-4, a comparison is difficult to make.

In order to allow a better comparison, the various shapes were split in 4 categories:

- Multispace (Figure 5-5)
- Pick-up (Figure 5-6)

- Intermediate vans (Figure 5-7)
- Large vans (Figure 5-8)

Other remaining vehicles are of little importance. It appears that especially for intermediate and large vans there is an almost standard shape with very few variations.

For L7e ELTVs it is possible to define two categories:

- Small L7e ELTVs (Figure 5-9)
- Large L7e ELTVs (Figure 5-10)

The yellow and red thick lines represent the minimum for the different geometries, as it is represented in Figure 5-4.

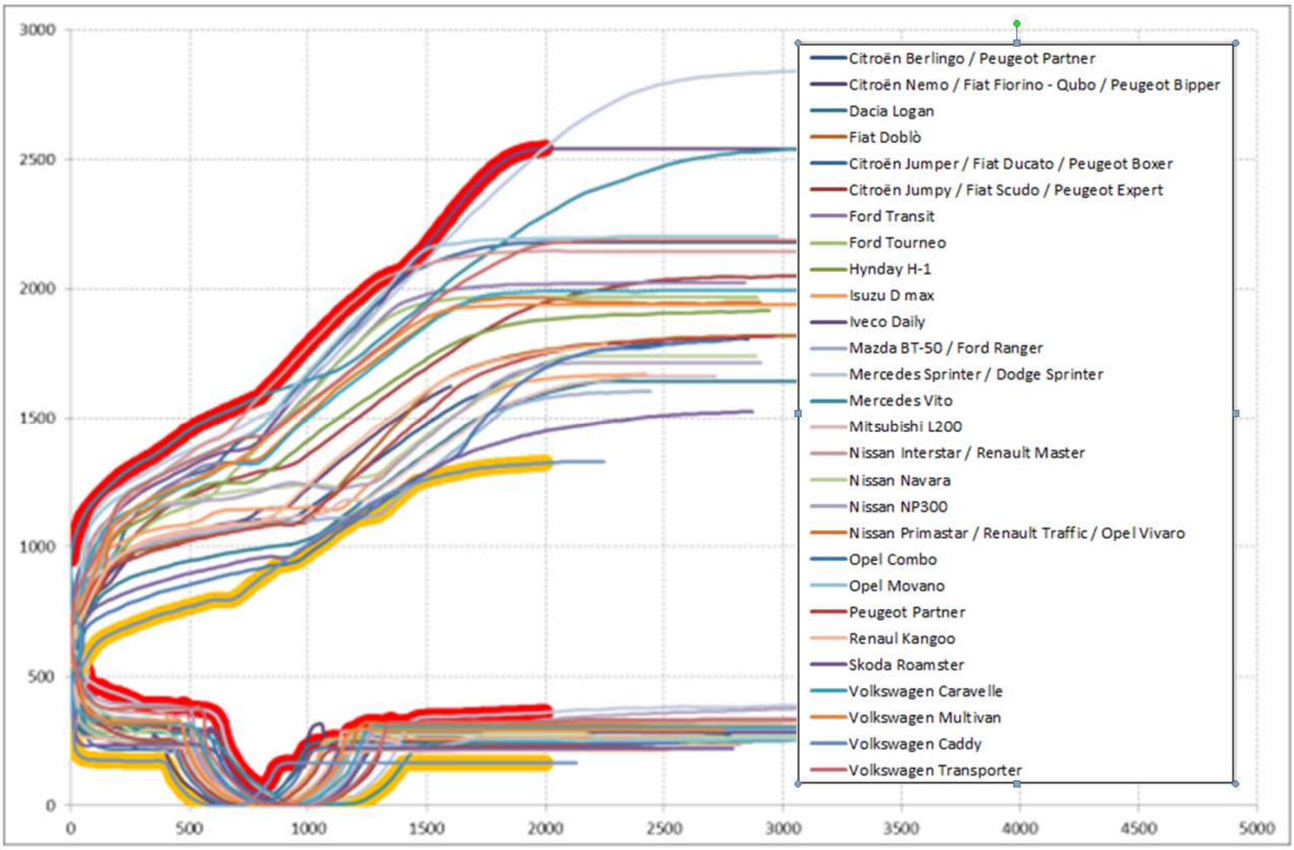


Figure 5-4: Front shapes of all the N1 vehicles available in the market (November 2011) Dimensions in mm

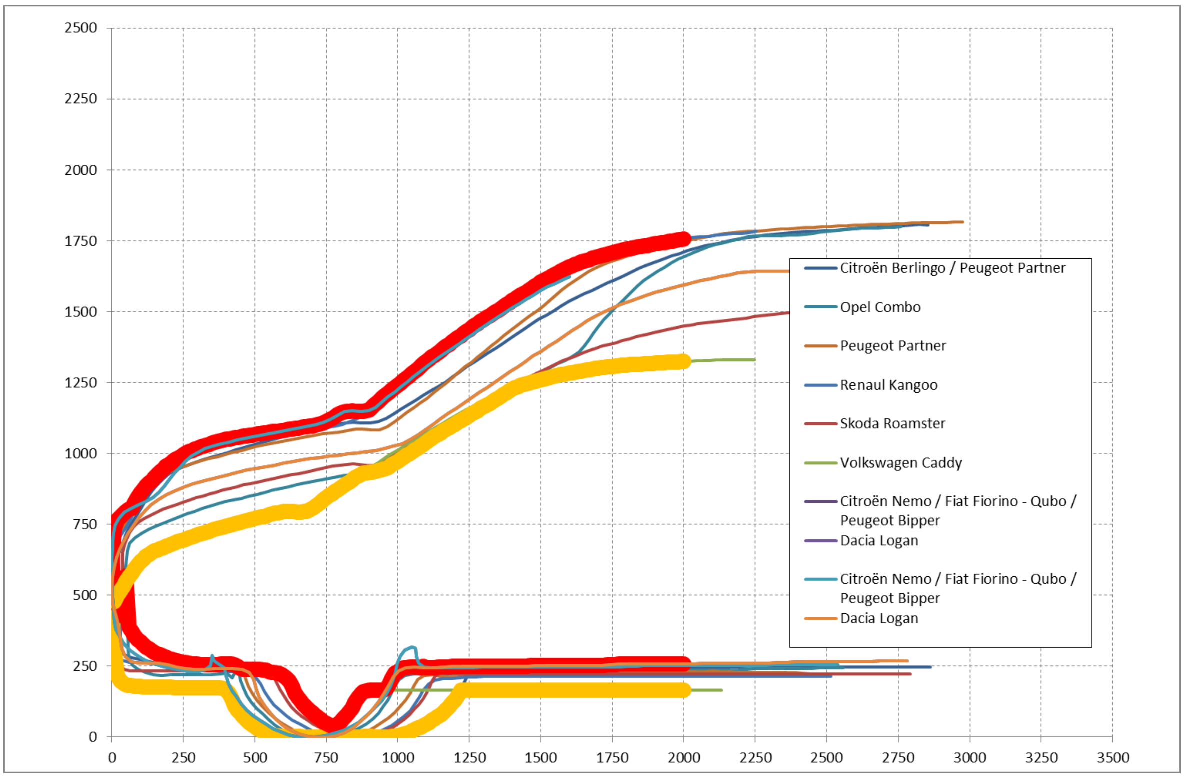


Figure 5-5: Front shapes of Multispace light commercial vehicles with corridors. Dimensions in mm

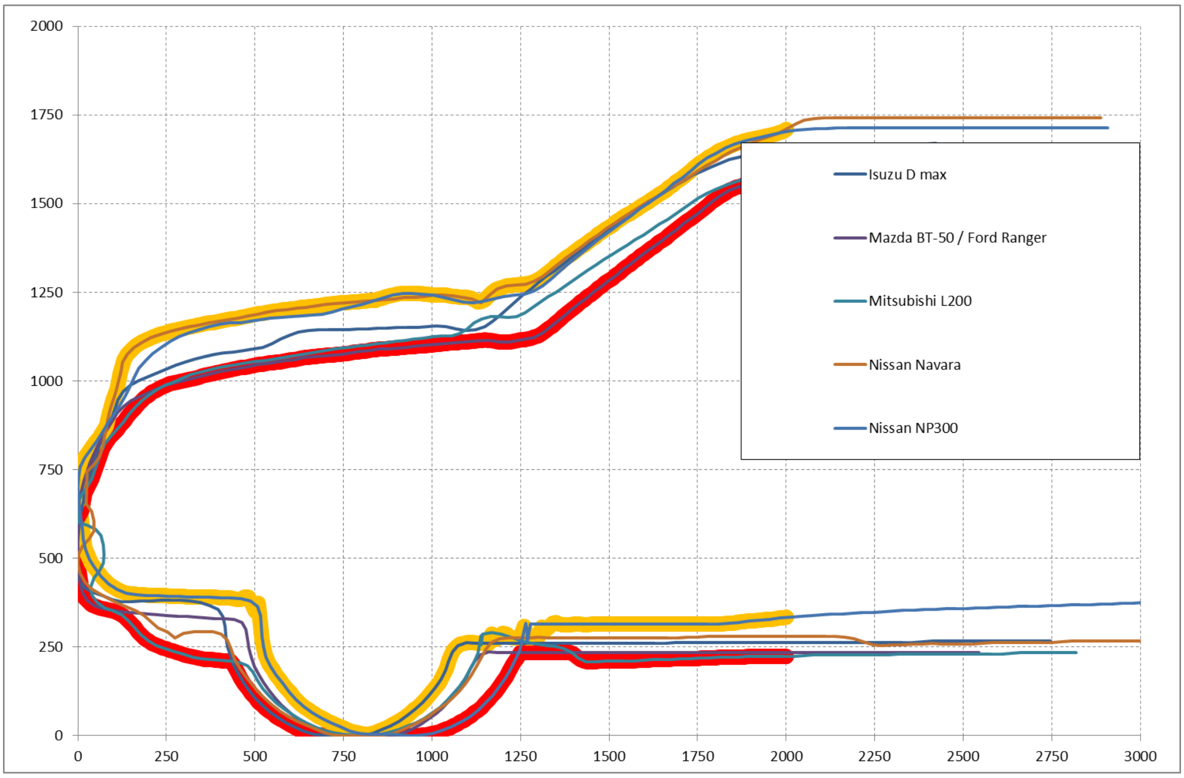


Figure 5-6: Front shapes of Pick-ups with corridors. Dimensions in mm.

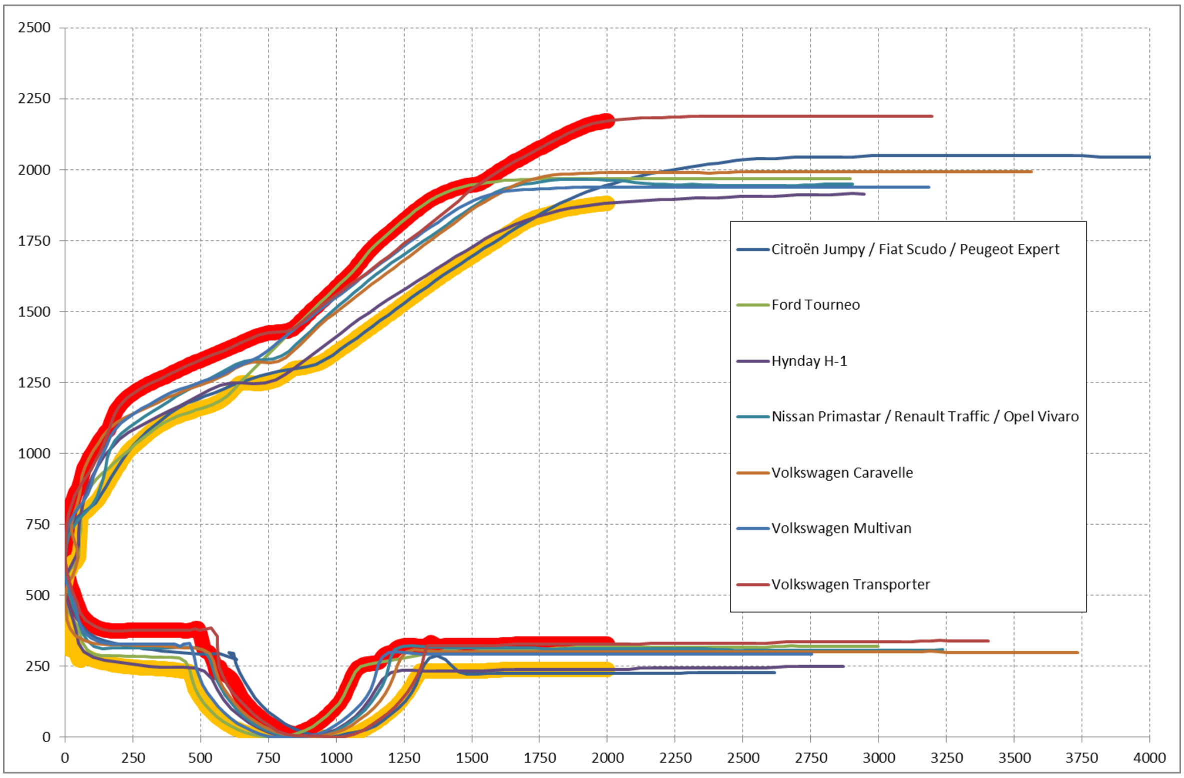


Figure 5-7: Front shapes of Intermediate Vans with corridors, Dimensions in mm.

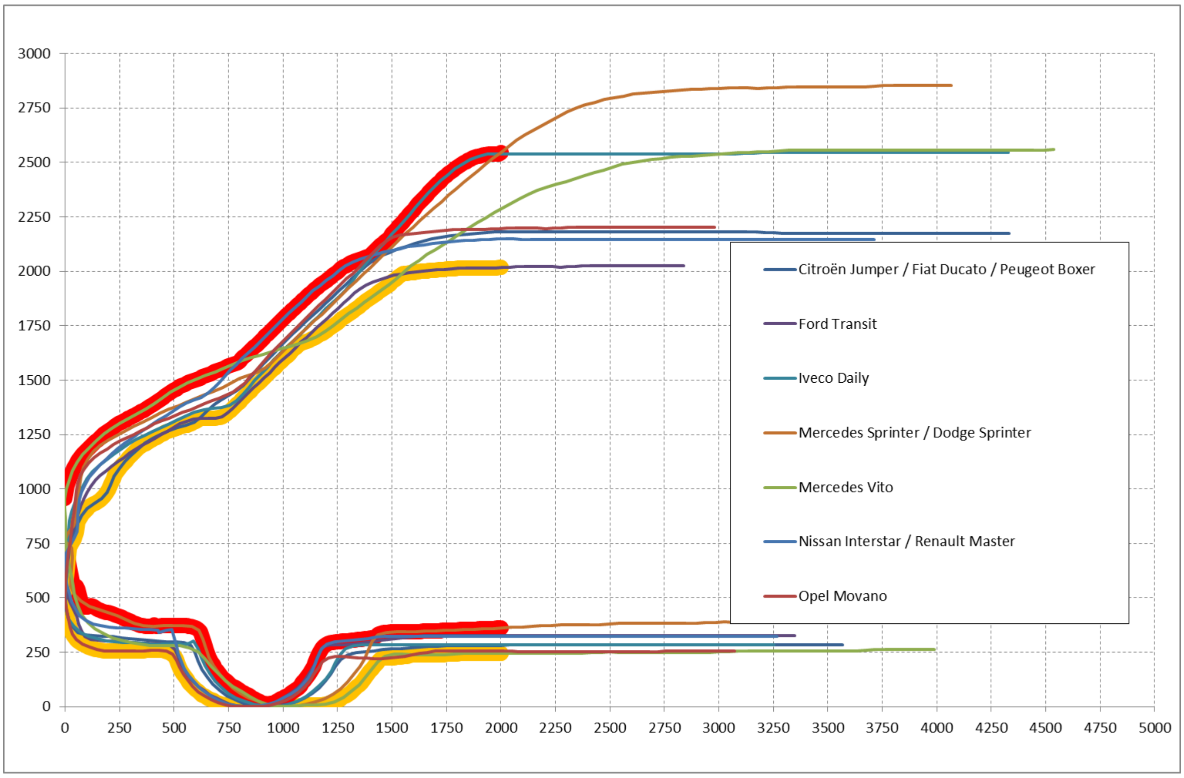


Figure 5-8: Front shapes of large Vans with corridors. Dimensions in mm.

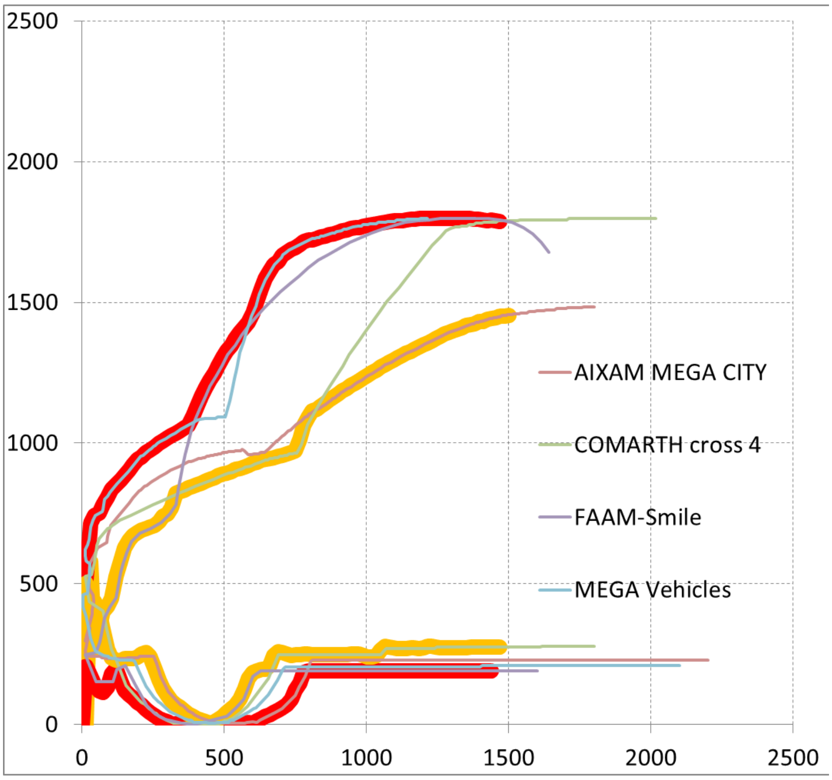


Figure 5-9: Front shapes of small L7e ELTVs with corridors. Dimensions in mm.

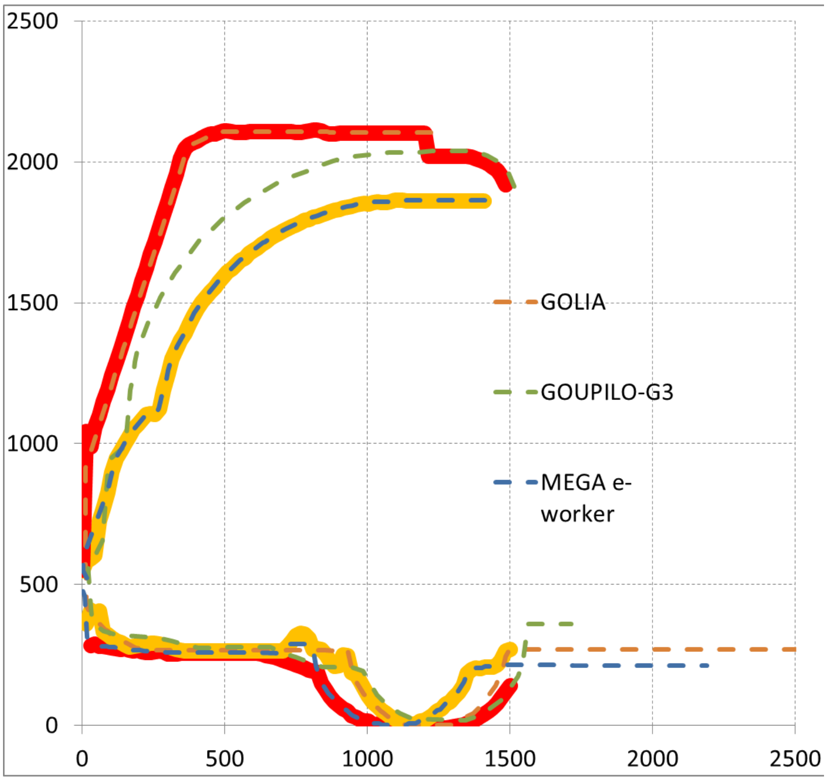


Figure 5-10: Front shapes of large L7e ELTVs with corridors. Dimensions in mm.

Smaller ELTVs are quite different and variable, and it is difficult to define typical shapes. The larger ELTVs instead are more uniform. In general small ELTVs have their front axle in a very advanced position: the longitudinal beams extend almost to the front end and the cabin is above the front axle. In the large ELTVs the front axle is behind the cabin. In this case the cabin is suspended and extends beyond the longitudinal beams. Coming back to N1, vehicle pick-ups are quite standard in shape, as well as vans.

5.4.1.2. Front shape analysis

The shape defined as in section 5.4.1 and Figure 5-1 can be described in a parametric way as was done. However, for simplicity and for a practical application, the lower part is not as interesting as the upper part because it is not varying significantly from vehicle to vehicle, it is difficult to be defined, and is less affecting the general front shape. Moreover, it is recognized that the upper part of the front is more important in terms of pedestrian safety since deaths and serious injuries occur mainly with head impacts and, in minor cases, with hip impact.

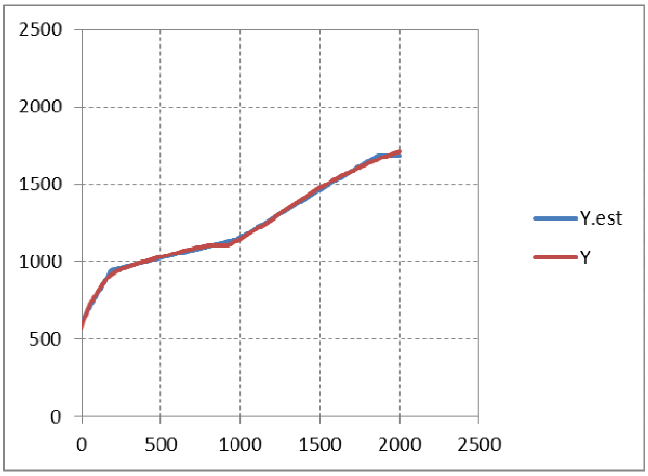
Therefore, the shape of the upper part of the vehicles' front can be defined by the six last parameters of the list in section 5.4.1 plus the height of point 3 from the ground, as follows:

- Grille lower height, height 3: y_3
- Grille slope, inclination of segment 3-4: α_{34}
- Grille height, distance 3-4: l_{34}
- Bonnet slope, inclination of segment 4-5: α_{45}
- Bonnet length, distance 4-5: l_{45}
- Windscreen slope, inclination of segment 5-6: α_{56}
- Windscreen length, distance 5-6: l_{56}

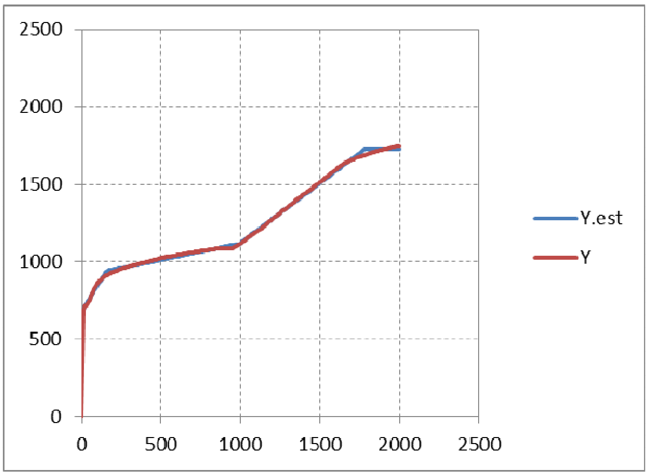
Identification of the 7 geometrical parameters has been performed on about 30 vehicles of the N1 class and 7 vehicles of the L7e category.

In practice the shapes are derived as in Figure 5-11, which reports some examples for the different categories for N1 vehicles. The red line represent the real vehicle profile and the blue line the estimation using the mentioned segments.

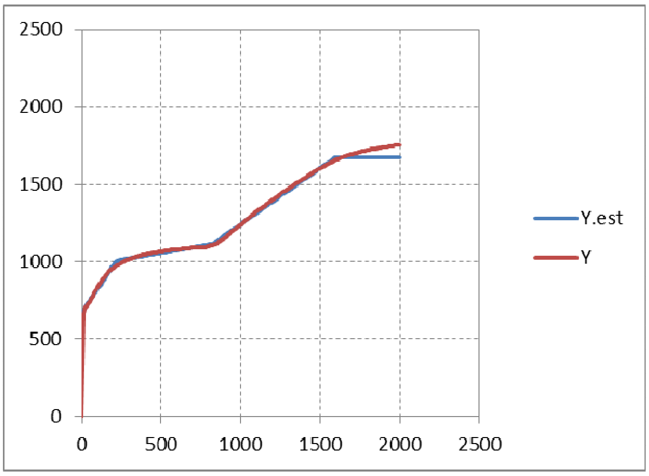
In Table 5.4 the results from the N1 vehicles' analysis are collected.



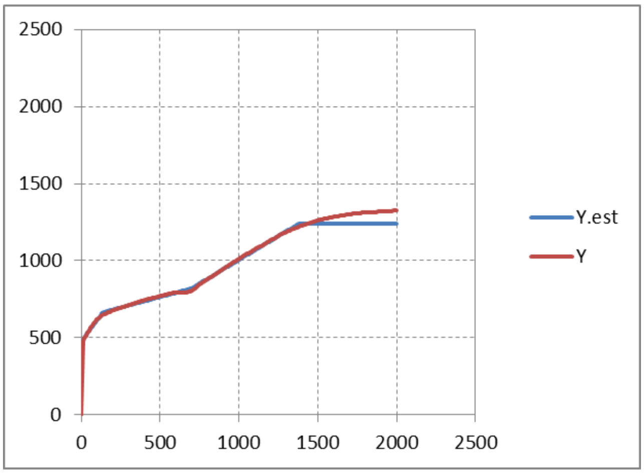
Citroën Berlingo / Peugeot Partner



Peugeot Expert / Citroën Jumpy

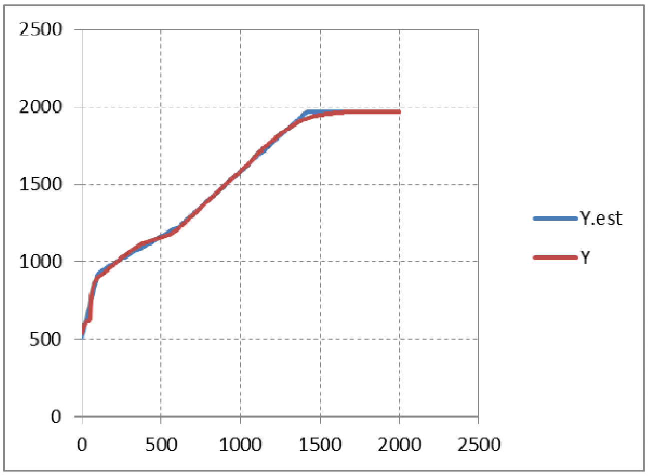


Renault Kangoo

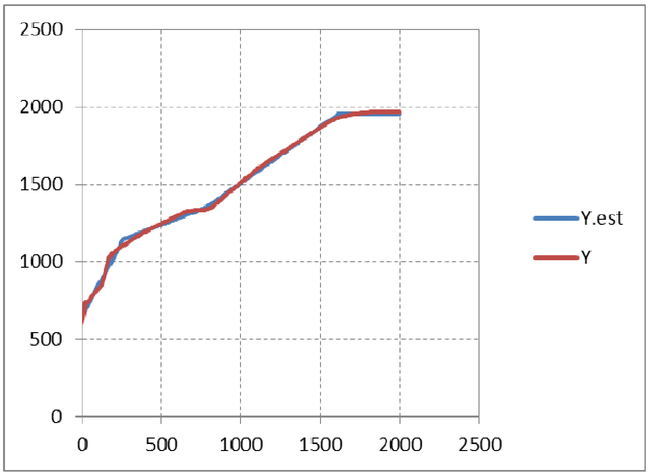


Volkswagen Caddy

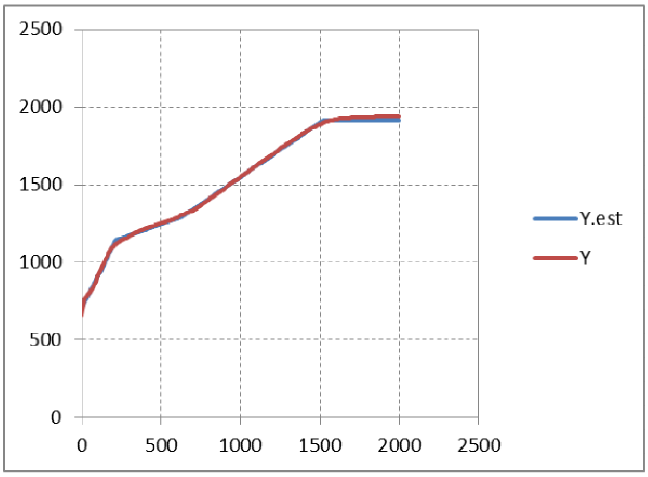
Figure 5-11: Front profile identification (multispace type)



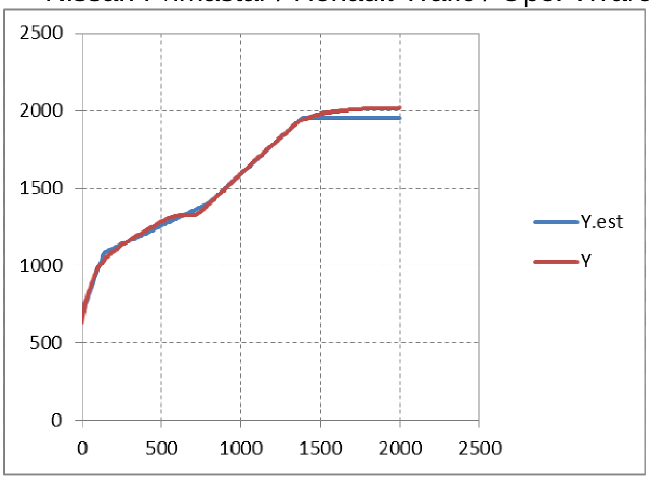
Ford Tourneo



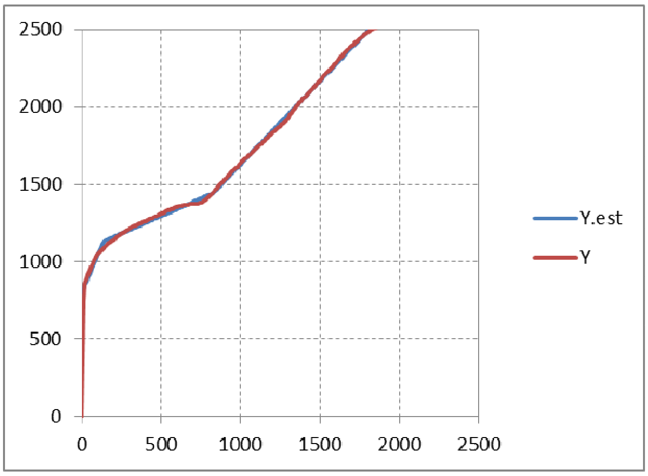
Nissan Primastar / Renault Trafic / Opel Vivaro



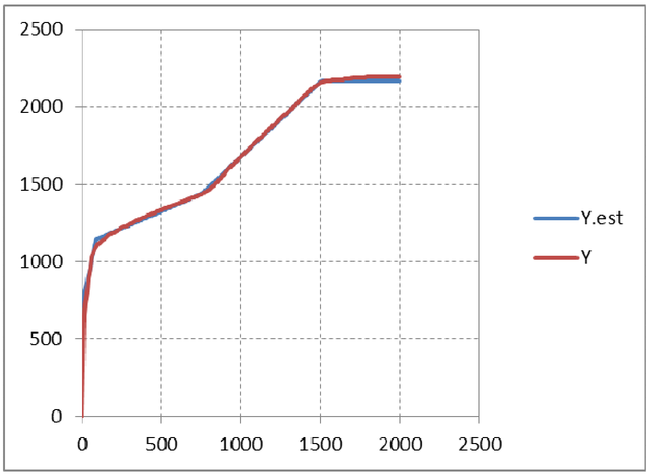
Volkswagen Multivan



Ford Transit

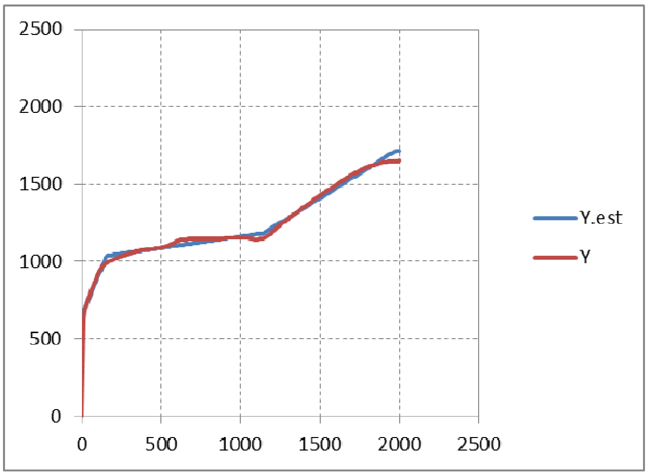


Iveco Daily

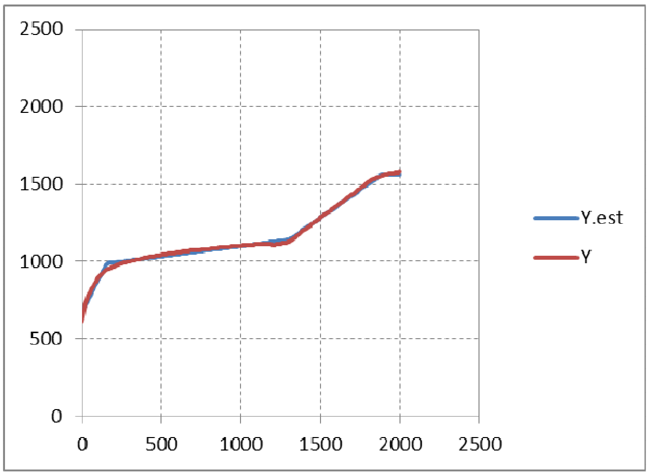


Opel Movano

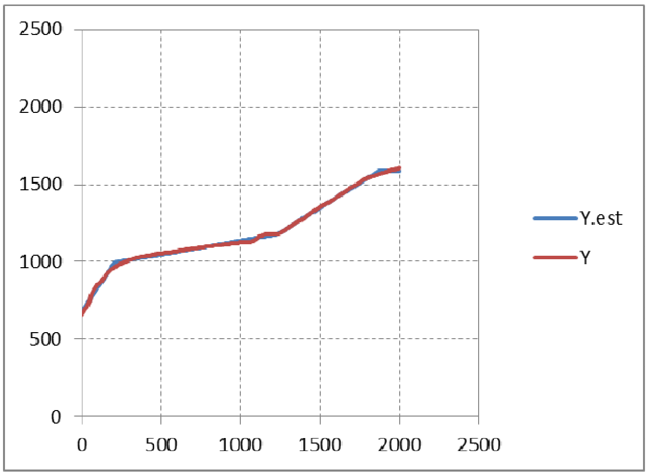
Figure 5-12: Front profile identification (intermediate and large van type)



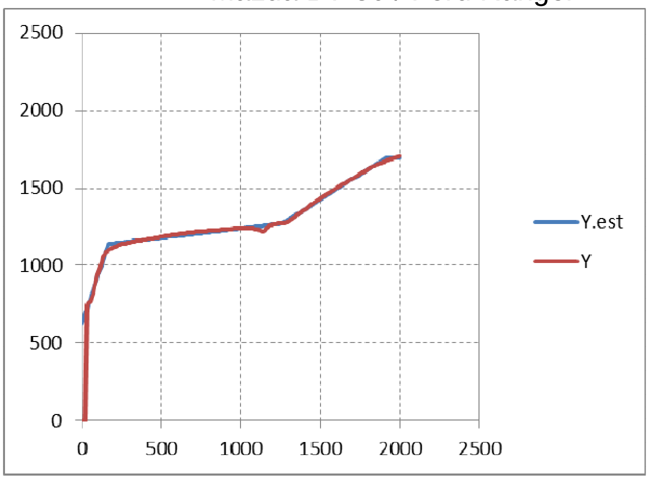
Isuzu D-Max



Mazda BT-50 / Ford Ranger



Mitsubishi L200

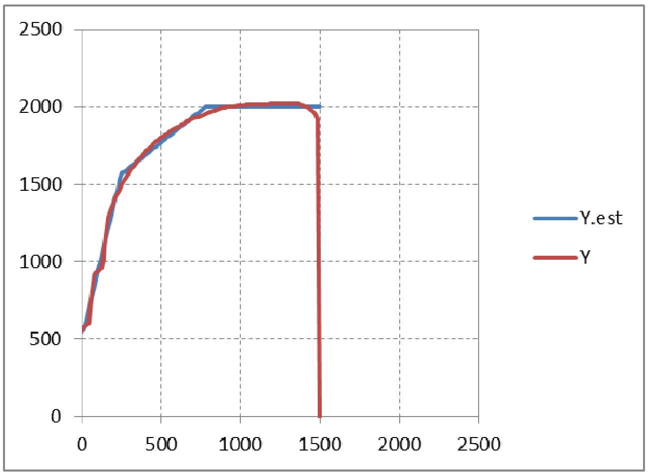


Nissan Navara

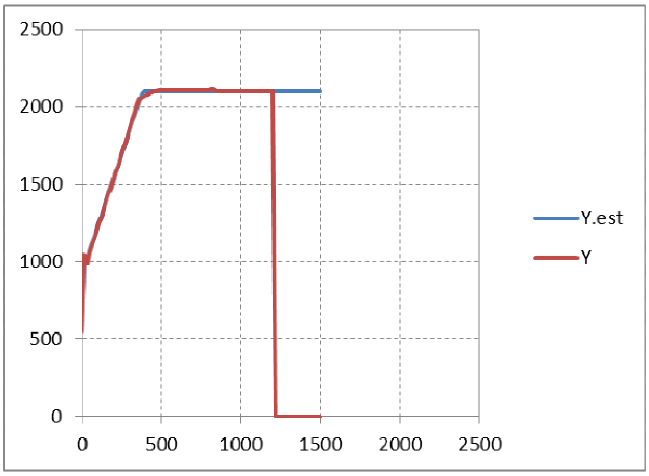
Figure 5-13: Front profile identification (pick-up)

MAKE / MODEL	Type	y_3	α_{34}	l_{34}	α_{45}	l_{45}	α_{56}	l_{56}
Citroën Berlingo / Peugeot Partner	Multispace	611	61	383	14	820	31	1040
Fiat Doblò	Multispace	602	65	395	11	856	43	893
Opel Combo	Multispace	512	66	258	14	902	32	830
Peugeot Partner	Multispace	678	59	305	12	854	38	996
Renault Kangoo	Multispace	670	57	401	10	616	36	950
Skoda Roomster	Multispace	700	28	316	11	674	28	945
Volkswagen Caddy	Multispace	474	54	234	15	581	32	800
	Average	**607**	**56**	**327**	**12**	**757**	**34**	**922**
	Deviation	**14%**	**23%**	**21%**	**16%**	**17%**	**15%**	**9%**
Citroën Nemo / Fiat Fiorino - Qubo / Peugeot Bipper	Small van	721	44	422	14	606	36	750
Dacia Logan	Small van	597	60	312	11	871	33	875
Citroën Jumpy / Fiat Scudo / Peugeot Expert	Intermediate	707	51	576	17	618	33	1100
Ford Tourneo	Intermediate	514	76	431	30	596	43	1081
Hyunday H-1	Intermediate	536	75	530	20	704	32	1081
Nissan Primastar / Renault Traffic / Opel Vivaro	Intermediate	659	62	554	21	555	36	1030
Volkswagen Caravelle	Intermediate	728	69	397	21	716	35	1050
Volkswagen Multivan	Intermediate	705	64	488	20	450	35	1070
Volkswagen Transporter	Intermediate	617	72	602	22	759	36	1100
	Average	**643**	**64**	**479**	**20**	**653**	**35**	**1015**
	Deviation	**13%**	**17%**	**20%**	**28%**	**19%**	**9%**	**12%**
Citroën Jumper / Fiat Ducato / Peugeot Boxer	Large	709	57	557	26	397	43	1155
Ford Transit	Large	694	71	410	26	737	43	800
Iveco Daily	Large	804	67	354	24	756	47	1500
Mercedes Sprinter / Dodge Sprinter	Large	726	76	478	25	879	43	1600
Mercedes Vito	Large							
Nissan Interstar / Renault Master	Large	652	76	457	34	705	44	750
Opel Movano	Large	716	78	434	24	726	44	1050
	Average	**717**	**71**	**448**	**26**	**700**	**44**	**1142**
	Deviation	**7%**	**11%**	**15%**	**14%**	**23%**	**4%**	**31%**
Isuzu D max	Pickup	648	68	418	8	1002	33	986
Mazda BT-50 / Ford Ranger	Pickup	682	63	343	8	1158	36	720
Mitsubishi L200	Pickup	678	57	377	10	1039	32	766
Nissan Navara	Pickup	626	72	537	7	1105	33	769
Nissan NP300	Pickup	755	56	464	7	1043	37	712
	Average	**678**	**63**	**428**	**8**	**1069**	**34**	**791**
	Deviation	**7%**	**11%**	**18%**	**17%**	**6%**	**6%**	**14%**

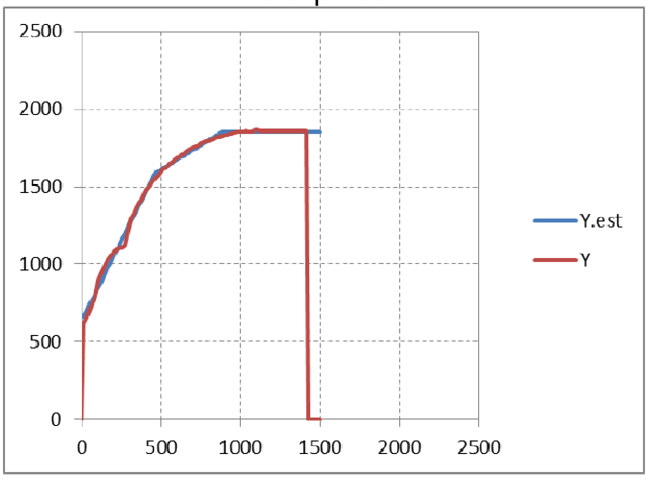
Table 5.4: Profile analysis N1 class



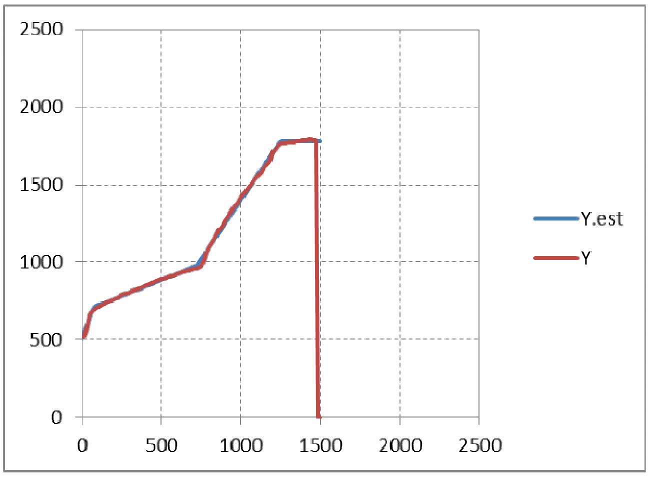
Goupil G3



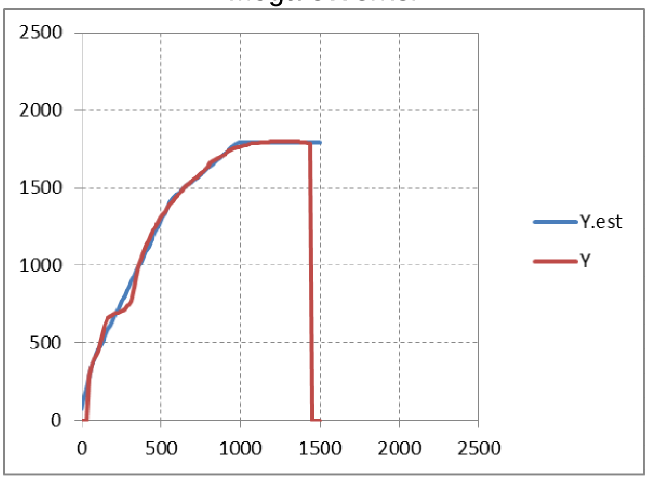
Blucar Golia



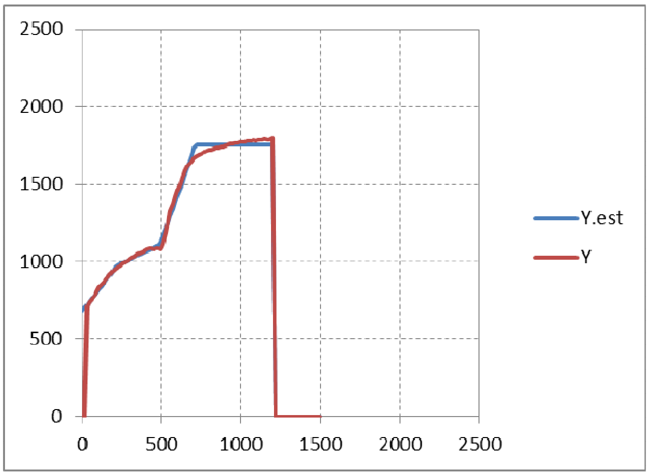
Mega eWorker



Comarth Cross 4



FAAM Smile



Mega Van

Figure 5-14: Front profile identification of L7e vehicles

MAKE / MODEL	Type	y_3	α_{34}	l_{34}	α_{45}	l_{45}	α_{56}	l_{56}
GOUPIL G3	Large	551	10	13	77	1038	39	691
Blucar Golia	Large	549	0	0	88	412	72	1199
Mega eWorker	Large	663	10	13	64	1024	32	509
	Average	**588**	**7**	**9**	**76**	**825**	**48**	**800**
	Deviation	**11%**	**87%**	**87%**	**16%**	**43%**	**45%**	**45%**
Aixam Mega City	Small	0	86	626	52	223	27	1401
COMARTH cross 4	Small	503	71	216	22	704	57	961
FAAM Smile	Small	74	77	319	65	1155	41	553
MEGA Van	Small	682	53	365	26	303	71	683
	Average	**315**	**72**	**382**	**41**	**596**	**49**	**900**
	Deviation	**105%**	**19%**	**46%**	**49%**	**72%**	**38%**	**42%**

Table 5.5: Profile analysis L7e vehicles

In Figure 5-14 the shape and analysis of the L7e vehicles is shown. In Table 5.5 are collected the results from the L7e vehicles' analysis.

In general the following consideration can be drawn:

- Among the N1 category, the different groups are quite homogeneous: the various parameters, especially the angles do not vary more than 20%
- For the large vans the scatter is even more reduced with angles varying less than 10% and length varying around 15%
- The pickups are quite homogeneous: some parameters have variations about 5% and most are around 15%
- For the L7e category there is much difference; in the larger vans there is more uniformity, even if the single parameters seems quite different: there is a much rounded shape like GOUPIL G3 and Mega eWorker, and a simpler two-flat-surfaces like Blucar Golia
- For the smaller van there is a rounded shape similar to the previous ones, like in FAAM smile and a "pickup-style" with an almost horizontal bonnet (hood) and a more sloped windscreen (like in Comarth Cross 4 and Mega Van). This, in our opinion will not affect or is even disadvantageous for pedestrians

Finally, it is possible to derive a “typical” shape for all the categories from the average shape parameters. This is shown in Figure 5-15.

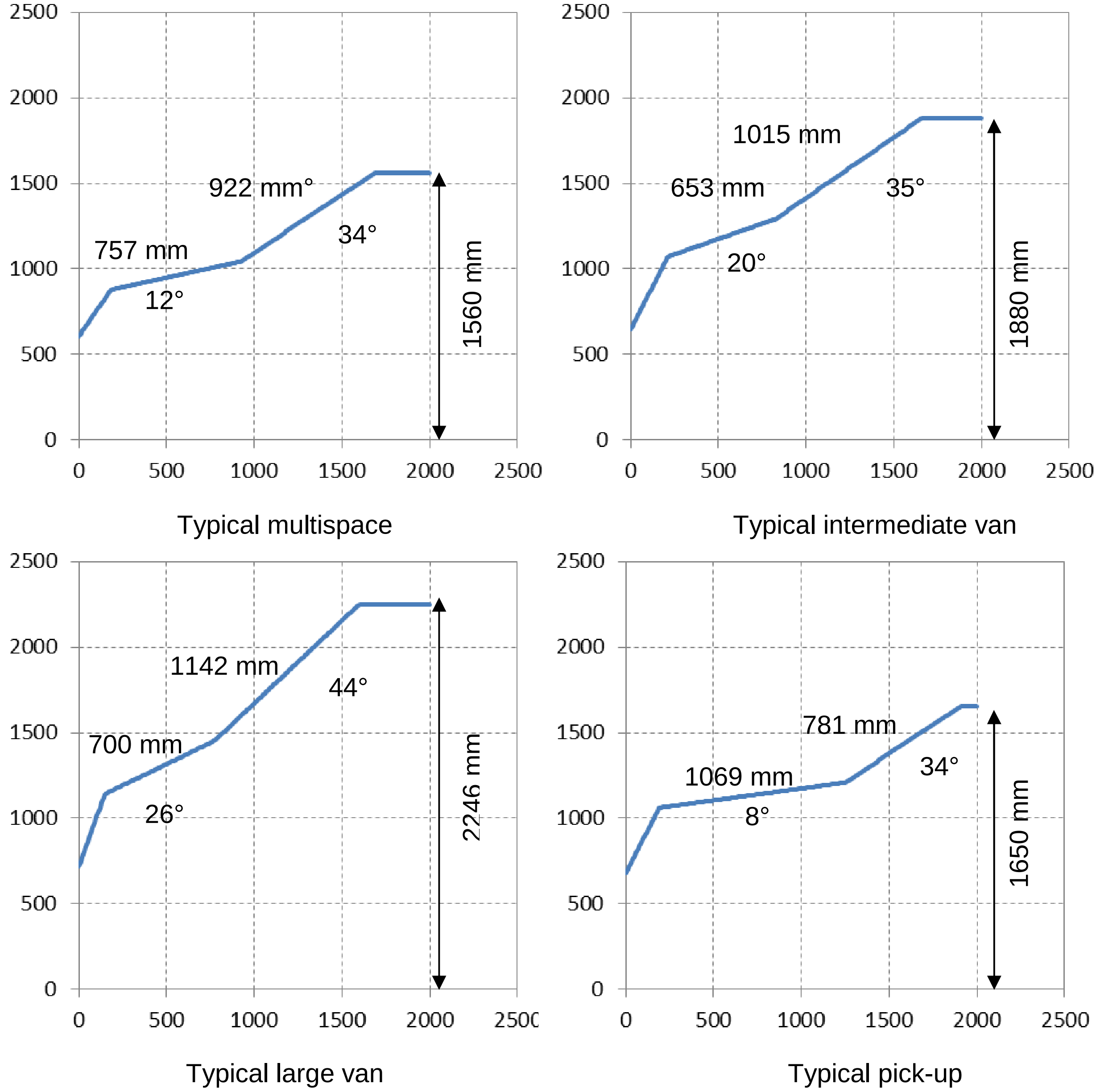


Figure 5-15: Front profile identification of L7e vehicles

5.5. Compartment strength

The strength of the passenger compartment is crucial for occupant safety in severe car-to-car frontal collisions. Occupants of lower mass vehicles often have higher injury risk due to both lower vehicle mass and stiffness. Ignoring crashworthiness, heavier cars are stiffer for other reasons, with structures often being stronger to take the higher engine and suspension loads. There is clear evidence, however, that during last years the stiffness of smaller cars is increasing as a consequence of new crash test requirements.

There is virtually universal agreement amongst independent accident investigators that passenger compartment intrusion is a major cause of fatal and serious injuries to restrained car occupants. For instance, in [13], when an occupant sustains a “contact with intrusion” injury, this injury is the most severe in most of the cases. This view is also supported by many accident investigators. In order to limit and manage occupant compartment intrusion in car-to-car frontal impacts, the crush zones of the cars involved must be capable of absorbing the full energy of the impact.

One of the suggestions is to design a ‘semi-rigid’ passenger compartment. It involves designing the vehicle in such a manner that the occupant compartment is sufficiently stiff so that it can resist the deformation force putt on it by any colliding car. This ensures that the impact energy is absorbed by the front structures of both cars.

Another suggestion has been made in which a limit is placed on the maximum crush force that must not be exceeded in a given impact. This concept has been extended with suggestions being made that both maximum and minimum force requirements are needed or that force corridors should be defined. These proposals are effectively equivalent to controlling the vehicle’s stiffness.

5.6. Summary of the VC-COMPAT project

In car to car accidents incompatibility is constituted by:

- Structural incompatibility, meaning
    - Low overlap,
    - Underrun & Overrun, due to misalignment of the main load paths,
- Stiffness incompatibility, meaning
    - Inadequate frontal stiffness,
    - Insufficiently stiff compartment cell

In crash tests, a car's front structure must manage the kinetic energy of the impact, which is proportional to the vehicle mass when hitting a barrier or a rigid wall. Because of that, the frontal stiffness is highly related to the mass of the car. If the mass ratios are different than "1" it is considered as an indication of stiffness incompatibility.

Compatibility could be improved providing a more homogenous front part of the vehicle and this could be achieved by connecting the multiple load paths. At the time of the project, no solution was considered valid to solve the problem for the low overlap due to missing load paths in the outer frontal areas. If an overlap of at least 20% is not achieved, the longitudinal rails won't be able to account for any reasonable structural interaction. Another limitation is the "principal direction of force". To adequate strain the load paths, the range of degrees around the frontal direction is limited.

Based on a study of the GIDAS database, improving car compatibility could affect 14 to 21% of all belted front occupants in passenger cars being killed due to a traffic accident, as well as 29 to 39% of those being seriously injured (based on averaged injury numbers from 1998 to 2002). 611 to 916 car fatally injured occupants might be saved by taking compatibility measures and 15,328 to 20,614 seriously injured car occupants might get less severely injured or even not injured.

On average, improving car compatibility would affect more than 20% of all car occupant fatalities and almost 40% of severe injured occupants.

5.6.1. Cost benefit

In the project "Improvement of Vehicle Crash Compatibility through the Development of Crash Test Procedures" (VC-COMPAT) the benefits for improved frontal impact car to car compatibility in EU15 were estimated. The benefit estimated of the improved compatibility was between 721 and 1,332 lives saved (of approximately 33,000 fatalities in EU15 roads, 54% of them were car occupants) and between 5,128 and 15,383 seriously injured casualties mitigated per year.

Another argument was that a more compatible vehicle would benefit reducing seat belt loads and therefore, the risk of thoracic injuries. This is a very important note due to the fatal consequences of especially head and thoracic injuries.

5.6.2. Test procedures

In the project, the following characteristics were identified as beneficial influencing car's compatibility in car to car testing:

- Improved vertical load spreading capability (It is possible to achieve using additional load paths)
- Strong vertical connections between load paths
- Strong lateral connections able to distribute rail loads
- Adequate compartment strength and frontal force levels, especially for light cars

In addition, the width of the front structure had an effect on crash compatibility, but they suggested further work in order to determine the relevance of this characteristic.

The project focused on the development and evaluation of two approaches for assessing compatibility:

- Full Width Deformable Barrier (FWDB)
- Progressive Deformable Barrier (PDB)

A set of test procedures could be based on the combination of both:

- Set 1:
  - Full Width Deformable Barrier (FWDB) test
    - Structural interaction
    - High deceleration pulse
  - ODB test with EEVC barrier
    - Frontal forces levels
    - Compartment integrity
- Set 2:
  - Full Width Rigid Barrier (FWRB) test
    - High deceleration pulse
  - Progressive Deformable Barrier (PDB) test
    - Structural integration
    - Frontal forces matching
    - Compartment integrity
- Set 3:
  - Combination of FWDB and PDB

Finally, the recommended work needed to reach the position to make a proposal for a set of test procedures to be implemented in order to improve compatibility in regulation and consumer testing is outlined.

5.6.3. Car to truck impact

In order to study the accidents involving trucks a lack of harmonized accident data was found due to the differences in definition, quality of reporting and compilation of statistical data. These differences make the comparison difficult between the different countries.

The available in depth investigation data indicated:

- 60% to 90% of collisions causing serious and fatal injuries occurred with a relative speed higher than 80 km/h.
- Car collisions into the rear part of trucks or trailers at only 30 km/h caused severe and fatal injuries (passenger compartment intrusion due to underrun), especially in cases with small overlap.

Benefits were predicted in terms of annual reduction in the number of fatally and seriously injured car occupants in car-to-truck frontal and rear end collisions when appropriate underrun devices were installed (FUP: Front underrun protection, RUP: Rear underrun protection):

- Having energy absorbing FUP instead existing rigid FUP:
  - Reduction of fatalities ~160; benefit 160 M€ - 300 M€
  - Reduction of severe injuries ~1200; benefit 100 M€ - 250 M€
- Having improved RUP instead existing rigid RUP:
  - Reduction of fatalities ~150; benefit 165 M€ - 300 M€
  - Reduction of severe injuries ~1800; 150 M€ - 400 M€

For frontal tests it was not possible to recommend a specific test procedure because of a lack of baseline test data from the full scale testing.

The amount of energy absorbed underneath the truck without causing too much underride is limited and the energy absorbing capability and capacity of passenger car front structures has improved to the extent that impact speeds up to 64 – 75 km/h may well be survivable in collision with rigid FUPs. Due to this fact, the additional structural deformation in the front of trucks may be necessary to achieve the benefits originally expected from energy absorbing FUPs to increase the energy absorbing capacity without permitting too much underrun.

In the rear collision cases accident data and crash tests showed that collisions of modern passenger cars into the rear end of trucks or trailer at speeds higher than 50 km/h are catastrophic due to the fact that current RUP devices are not able to prevent underrun in those conditions, although it does not seem to be a problem in front underrun protection devices when the same speed is considered. A full scale test was performed and showed load increase and improved compatibility through cross member height and decreased ground clearance. It was proposed as a possible basis for an improved directive regarding rear underrun protection.

They recommended some amendments to be implemented in regulation ECER-58 to prevent cars under-riding trailer and trucks:

- Ground clearance of the RUP max. 400 mm
- RUP beam height min. 200 mm
- Horizontal forces applied successively at P1 = 110 kN, at P2 = 180 kN and at P3 = 150 kN (Points on the RUP according to ECE R-58 procedure)
- The current requirement regarding the reduction of these forces depending on the maximum technically permissible mass of the vehicle may be considered to maintain.
- Vehicles now exempted from the current legislation may be included in future legislation in some way.

Lighter trucks are permitted to have reduced test load requirements and the validity of these lower test loads was not assessed.

In side impacts the design of the front of a vehicle influences the injury risk of the passengers in the struck vehicle. The average Height of Door Force (AHoDF) was shown to correlate with the dummy measurements. Thus the vertical force distribution of vehicle fronts should be monitored for any potential problems in side impacts.

The results and conclusions of the cost benefit, test procedures and amendments to the existing regulations are detailed for frontal, rear and side impacts.

5.7. Summary of the FIMCAR project

FIMCAR is a research project co-funded by the European Commission which started in October 2009 and is still ongoing. The main target of the project is to identify open questions to overcome existing obstacles for finding a good compromise how to assess compatibility, focused on car-to-car frontal impacts. The FIMCAR project is harmonizing its activities with the GRSP informal group on frontal impact and is cooperating with EUCAR due to its large industry representation.

The main goal of the project is to propose an assessment approach for frontal impact integrating self and partner protection. The FIMCAR project is developing a verification procedure to guide the final selection of test procedures. The program will specify the tests, simulations and analysis that confirm the test procedures address specific compatibility issues.

In this part final part of the deliverable, some of the results of the project will be showed as well as an overview of the project, its methodology and some preliminary results.

5.7.1. Accident research

The first part of the project consisted in an accident analysis to determine if compatibility issues identified in previous studies are still relevant in the current vehicle fleet. This issues included structural interaction, frontal force matching and compartment strength. The second objective of the analysis was to determine the nature of the injuries and injury mechanisms of vehicle occupants. The analysis was performed in two parts: an overall analysis (compartment strength issues) and a detail case analysis (structural interaction and frontal force/compartment strength matching issues).

The databases used for the analysis were the UK Cooperative Crash Injury Study (CCIS) and the German In-Depth Accident Survey (GIDAS). The criteria used to select the cases for the study was:

- Car involved in frontal impact
- UNECE R94 or an equivalent safety level required
- Only adult front seat occupants were considered
- Occupant belted
- Occupant sustaining MAIS2+ injuries

A total of 1785 occupants from the CCIS database (83 fatal, 466 MAIS2+ survived and 1236 MAIS1) and 872 cases from the GIDAS database (16 fatal, 155 MAIS2+ survived and 701 MAIS1) were finally considered in the study.

The results of the accident analysis showed a high proportion of fatal and MAIS2+ survived injuries in accidents with high overlap (between 75% and 100%), more in detail, 30% of fatalities and 40% of MAIS2+ survived injuries.

To investigate compartment strength issues, injury patterns and mechanisms were examined in the accident analysis. Six categories were created to assign to each injury a causation code:

- Restraint. Seatbelts and airbags, mainly due to acceleration loads
- Contact no intrusion. Contact with an interior component of the occupant compartment when there was no intrusion (determined by the investigators)
- Contact with intrusion: Same as previous one but with intrusion
- Non-contact. For instance, whiplash. Injuries without contacting any component
- Other object. Contact with object inside or outside the vehicle
- Unknown.

To give an indication of compartment strength problems, the category “contact with intrusion” is used because the reduction of the intrusion would help to mitigate these injuries. In this category, the MAIS2+ occupants that had an AIS2+ injury were 25% for CCIS and 12% for GIDAS. The CCIS data reduced to 16% when intrusion of 10cm or less was considered as “no intrusion”.

In CCIS, 25% of occupants were found to have the most severe injury in the “contact with intrusion” category, so in most of the cases where an occupant suffers an AIS2+ injury, it is related to “contact with intrusion”. When injury patterns are considered, it was found that most of the “contact with intrusion” injuries were located in lower extremities and thorax. Injuries associated to “restraint” were located in thorax (mainly clavicle fractures). In the “contact without intrusion” category the injuries were mainly located in lower extremities, upper extremities and thorax.

The most commonly injured body region (AIS2+) was the thorax both in CCIS and GIDAS, followed by upper and lower extremities (CCIS) and head, lower and upper extremities (GIDAS). Considering fatal injuries, the most frequent injury body region was the head.

Other analysis found that the higher overlap, the higher proportion of restraint system associated injuries and the less contact with intrusion injuries. In addition, most of the drivers suffering fatal and MAIS2+ survived injuries were over 60 years old.

Finally, accidents related with collisions with heavy goods vehicle (HGVs) and objects had a higher proportion of fatal and MAIS2+ survived injuries than vehicle-vehicle collisions. This shows the more severe nature of objects and HGV collisions.

The second part of the accident analysis was a detail case analysis to understand whether compatibility issues are still present in the vehicle fleet. The analysis was performed using the CCIS database.

For fatal cases, structural interaction problems were found in 19 of 48 cases although only 33% had intrusion. In 4 cases frontal force/compartment strength problems were identified. The main structural interaction problems were override and low overlap.

Summarizing, the structural interaction is still considered an issue, especially the over/underriding and small overlap. The compartment strength is another issue, especially in crashes against heavy good vehicles (HGV) and objects, and seems to be independent of the vehicle size.

A really high proportion of fatalities and severe injuries are related to large overlap accident, even when they occur at relatively low speed. There is also a higher injury risk for occupants of lighter cars in car-to-car accidents.

5.7.2. Project strategies

The main objective of the FIMCAR project is to develop a frontal test procedure to assess frontal impact protection considering self and partner protection. This assessment can consist of one or several procedures. The FIMCAR project has reviewed previous projects related to crash compatibility and updated the results with newer analysis. The priorities of the project after this review have been:

- Structural interaction
- High overlap collisions
- Risk of injuries arising from acceleration loadings

For the structural interaction by “under/overriding”, the structural alignment is considered as a key parameter.

The procedures that the FIMCAR project will finally propose for the assessment should be able to provide:

- A common interaction zone for the vehicles that is defined between 406 and 508 mm
- The initial loading of the barrier evaluated above and below the 457mm (centreline of the common interaction zone)
- The vertical load spreading is evaluated in the *Part 581 Zone* and between 180 and 406, and the horizontal load spreading is evaluated between the longitudinal members
- The current compartment strength requirements should be maintained
- Consider appropriate severity levels for occupant protection
- Relevant pulses for all test configurations obtained from reconstructions, car-to-car tests, etc.
- Repeatability and reproducibility performance
- Pass/fail thresholds
- Good cars as rated good and poor cars as rated poor

5.7.3. Analyzed test procedures

Several test procedures were analyzed within the FIMCAR project to evaluate their compatibility assessment potential. The test procedures analyzed were:

- Off-set test procedures
  - Current Off-set Deformable Barrier (ODB)
  - Progressive Deformable Barrier (PDB)
  - Mobile Progressive Deformable Barrier (MPDB)
- Full width procedures
  - Full Width Rigid Barrier (FWRB)
  - Full Width Deformable Barrier (FWDB)

5.7.3.1. Off-set procedures

In the current ODB procedure there is no compatibility assessment metric known up to now and the FIMCAR members do not believe that is possible to finish the development of this assessment metric before the end of the project.

In the PDB case, a subjective analysis of the barrier face deformation is possible using 3-D images. The FIMCAR project believes that the PDB has the potential for compatibility assessment in the future, but further research and work in the development of the metric is needed.

The same subjective compatibility assessment as for the PDB can be performed for the MPDB, but up to now there is no robust objective compatibility metric developed. The MPDB has identical assessment procedures as the PDB, with the different of impact severity related to the mass of the vehicles. A heavy vehicle experienced a R94 severity level crash test while a lighter vehicle experienced a Euro NCAP severity level crash, so these procedure addresses higher injury risk for lighter cars.

5.7.3.2. Full width procedures

The FWRB is the worldwide used standard procedure. The advantage over FWDB is that load cells wall measures the vehicle forces directly instead of being filtered by a deformable element.

The FWRB has a high acceleration pulse, especially in the first phase of the collision. The FWDB has an acceleration pulse more comparable with car accident pulses and is less sensitive to protruding parts than FWRB.

5.7.4. FIMCAR test approach

The current proposal from FIMCAR is a combination of an off-set and a full width procedure. The FIMCAR project has considered the current ODB and the FWDB to be included in the frontal impact assessment.

This combination addresses the different issues regarding compatibility such as:

- The alignment of structures
- Compartment strength
- Injuries related to acceleration loading

However, some issues like vertical and horizontal load spreading are not addressed in the optimal way and future improvements are needed. Moreover, the FIMCAR partners believe in the PDB potential to be considered in the compatibility assessment in the future.

The final assessment will be published in autumn 2012.

6. Conclusions

The data analyzed showed that the trend was to reduce the number of fatalities in road accidents. During the last decade (2000 - 2009), IRTAD data showed a general decrease on all countries, except in countries like Cambodia (+17.5) or Malaysia (+1.2). In Europe, the number of accidents has been reduced in most countries, except Romania, where the number has increased. Germany remains the country with greater number of accidents followed by Italy, UK, Spain and France.

A review of the Piemonte Region database, in Italy, showed that only one person died in accidents involving quadricycles. The small number of fatalities and injuries in accidents involving this category of vehicles might me due to: safety measurements integrated in the vehicles, small mass, low speed, they mostly circulate in urban areas and/or the number of vehicles in this category is very small. Frontal-side impact (Frontal with offset) and rear impact are by far the most frequent types of accidents. However, frontal impact and pedestrian accidents are much more severe causing more casualties and injuries than the other types of prevailing accidents.

The number truck accidents and the number of fatalities associated with those accidents are significantly higher than for quadricycles. Especial effort need to be done to reduce the number of pedestrian accidents in both quadricycle and truck cases.

Analyzing the CARE database, in 2009 a total of 19,910 people were killed in the countries of the EU14 group. Italy was the country with greater number of deaths in traffic accidents, a total of 4,731 deaths. Accidents in urban areas represent a high number of deaths and they require especial attention due to the urban use that the OPTIBODY vehicle will have. Into the EU19 group 153,780 people died during the period between 2000 from 2009. According to CARE database, the number of deaths in lorries under 3.5 tons, was of 893 for the EU19 in 2009, 5.2% less compared to 2008. A total of 155 of those deaths occurred in urban areas.

Accidents trends in U. S. showed a decrease in the number of deaths over the last years (2000-2007). In 2007, 41,059 people died in the U.S. roadways and the total number of accidents exceeds 6 million. The number of injured people was 2,491,000. In the U.S., 3.6 times as many passenger car occupants were killed as LTV occupants in car-to-LTV collisions. When LTVs were struck in the side by a passenger car, 1.6 times as many LTV occupants were killed as passenger car occupants. On the other hand, when passenger cars were struck in the side by LTVs they were killed 18 times more than LTV occupants.

Japan has more than 90 million registered vehicles, of which more than 16 million are trucks. The number of accident documented in the Traffic Bureau and the National Police Agency database was 832,000, in which a total of 5744 died during 2007. If only trucks are considered, there were 153,746 accidents and 1650 of them were fatal. The higher number of accidents occurred in drivers with 10 or more years of experience.

A review of the VC/ COMPAT and FIMCAR projects as well as a review of the existing literature was performed to evaluate the state of the art of the accidentology and the existing and future test procedures to evaluate car-car and car-truck crash compatibility.

Based on the results of task 1.2 and task 1.3 and considering the fact that the OPTIBODY vehicle category does not require any mandatory crash test for certification, it is necessary for the project to establish a minimum of safety requirements for the OPTIBODY vehicle that ensure the safety of its passengers. These crash tests do not need to be as demanding as for conventional vehicles due to the nature of the L7e and low speed vehicles. These crash tests should incorporate, at least:

- Frontal impact tests:
    - ODB at lower speed than Regulatory tests for passenger vehicles for self-protection

  - Full Width test: for crash compatibility and to provide a second pulse for self-protection.

- Side impact test
- Rear impact test to
- Pedestrian tests (using head and leg form impactors)

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