D8 - Harmonised analytic methods to predict casualty reductions of both accident and injury reduction measures – Part 2

Contract No: GMA2-2001-52066 S07.17215
Acronym: PENDANT
Title: Pan-European Co-ordinated Accident and Injury Databases

Project Co-ordinator:
Professor Pete Thomas
Vehicle Safety Research Centre
Ergonomics and Safety Research Institute
Loughborough University
Holywell Building
Holywell Way
Loughborough
LE11 3UZ

Organisation name of lead contractor for this deliverable:
Graz University of Technology

Due Date of Deliverable: 30/06/2006

Submission Date: 15/06/2006

Author (s): **P.A.J. Ruijs (TNO)**
W. Weimin (TNO)
G. Griotto (TNO)
R.B.J. Hoogevelt (TNO)

Project Start Date: 1st January 2003 **Duration: 3,5 years**

Project funded by the European Community under the 'Competitive and Sustainable Growth' Programme (1998-2002)

Contents

Summary

The goal of Task 1.3 is to develop tools/methods to simulate real world accidents with validated vehicle crash models and to predict the injuries and/or the effect of engineering countermeasures like improved restraint systems on the injury risk of the occupants.

In general we can conclude from this investigation that generic vehicle crash models, which are validated with crash test data, can be used to predict injuries of the occupants and also the effects of improved restraint systems.
The conclusions of each phase of the investigation are:

1. Out of the PENDANT accident database the accident case UK8033 has been selected in which the two cars (Vauxhall Astra & Ford Fiesta) are involved in a frontal impact, both cars have been tested by Euro NCAP and represent different (mass) generic vehicle crash models. Despite the fact that the PENDANT cases contain at least one car newer than 1998, the selected cases with Euro NCAP cars do not represent very new cars (2002 and older).
2. The two generic vehicle models are validated with respect to the corresponding Euro NCAP front impact test data. The Vauxhall Astra is modeled with the Chrysler Neon generic model and the Ford Fiesta is simulated by the Geo Metro generic model. The corresponding stiffness functions of the longitudinals, shotguns and the connector are scaled and the crash pulses are fitted with Euro NCAP front crash tests.
3. The PENDANT accident case UK8033 is simulated and investigated. It is observed that the Vauxhall Astra has more damage than the Ford Fiesta as observed in the real accident. Although the air bag of the Vauxhall Astra was not deployed, the maximum acceleration is similar as that of the Ford Fiesta which had the air bag deployed. However, the combined thorax index, the cumulative 3 ms maximum and the HIC values of the driver of the Vauxhall Astra are higher than those of the Ford Fiesta. These may explain a severer head and neck injury of the driver of Vauxhall Astra.
4. The influence of an improved restraint system, namely a pre-crash pretensioning of the safety belt of the driver of the Vauxhall Astra, has been investigated. The pre-crash pretensioning has a beneficial effect on the driver response, providing lower loads during the crash event and thus resulting in lower levels of injuries. This can be explained by the fact that, as result of pretensioning, the driver is pushed backwards in the seat thus gaining additional space for energy absorption and dissipation during the crash.

1 Introduction

1.1 Goal of Pendant Task 1.3

Policy decisions over the relative benefits and costs of different casualty reduction methods rely on comparable estimates of injury and casualty reductions in the crash population. Pendant Task 1.3 will develop and validate a harmonised analytic procedure that has general applicability to both injury and accident causation countermeasures. The methods will utilise the data collected in WP 2 and WP 3 as well as available accident data to predict casualty reductions for the EU based on the prevailing accident and injury distributions. The methods will include engineering assessment of the effectiveness of the technologies under well defined conditions which will then be expanded to the full range of crash circumstances seen in the real world.

In this report the influence of engineering countermeasures and in particular improved restraint systems will be investigated using a general simplified multi-body car model for the collision phase which will be used to predict the acceleration, deformation and intrusion behaviour of the involved cars during a real world accident. The validation of these models will be based on available crash test data of comparable Euro NCAP tests.
The validated model is used to simulate a real world accident and to predict the injuries and/or the effect of engineering countermeasures like improved restraint systems on the injury risk of the occupants.

1.2 Strategy

The original strategy of the effect of improved restraint systems on the injury of occupants was defined as follows:

1. Selection of VC-Compat/PRISON multi-body vehicle crash models;
2. Creation of a passenger car lists which are representative to the vehicle crash models;
3. Validation of the vehicle crash models with data of Euro NCAP test;
4. Selection of a real accidents of cars of which the accident type is comparable with Euro NCAP tests;
5. Simulation of a real accident with the vehicle crash models using the Euro NCAP parameter values and prediction of the injuries of the occupants;
6. Comparison of the injuries of the occupants with the real world accident;
7. Determination of the effect of improved restraint systems on the injuries of the occupants with new simulations;
8. Final report of the findings.

There have been decided to apply a new strategy which is more efficient to select the vehicle crash models and accidents cases to investigate the influence of an improved restraint system:

1. Selection of two VC-Compat/PRISON multi-body vehicle crash models which represent the majority of the passenger car population;
2. Selection of real accidents between two cars from the PENDANT accident database with conditions comparable to the Euro NCAP frontal impact tests and both cars involved are tested by Euro NCAP. Only Euro NCAP frontal impact tests are chosen because the VC-Compat/PRISON vehicle crash models are not validated for other impacts;
3. Selection of one real accident case in which both vehicles are represented by a different vehicle crash model;
4. Validation of the two vehicle crash models with Euro NCAP frontal impact test data;

5. Simulation of the real accident with both vehicle crash models using the Euro NCAP parameter values and prediction of the injuries of the occupants;
6. Comparison of the injuries of the occupants with the real world accident;
7. Determination of the effect of improved restraint systems on the injuries of the occupants with new simulations;
8. Final report of the findings.

The selection of the two vehicle crash models and the final PENDANT accident case is discussed in Chapter 2. The distribution and relation (if applicable) of the most important and interesting crash parameters of the selected and all PENDANT frontal car-car accidents has been analysed and described in Chapter 3. Chapter 4 gives the results of the validation of the generic vehicle crash models and Chapter 5 describes the simulation of the real accident with a prediction of the injuries of the drivers. In Chapter 6 the benefit of an improved restraint system, namely a pre-crash pretensioning of the safety belt of the driver, on basis of the biomechanical responses and injuries is described.

2 Selection vehicle crash models and PENDANT accident case

The selection of the vehicle crash models for the simulation of the real accident is given in paragraph 2.1. In paragraph 2.2 the selection criteria and the final result of a real accident case with conditions comparable to a Euro NCAP frontal impact test are described.

2.1 Selection of vehicle crash models

For the benefit assessment of improved restraint systems two generic MADYMO vehicle crash models for car-car frontal accidents were chosen on basis of their vehicle mass:

1) Chrysler Neon with an original mass of 1371 kg;
2) Geo Metro with an original mass of 1191 kg.

These vehicle models will be validated with Euro NCAP frontal impact test data of the cars involved in a real accident. For the validation of the vehicle models the displacement of the B-pillar among others shall be used. The B-pillar displacement is not measured in the Euro NCAP frontal tests, but can be constructed from the B-pillar acceleration. For the oldest Euro NCAP cars, this acceleration is not always present in the signal list and those cars shall be omitted in the selection.
The PENDANT database has been used as a data source to select frontal car-car accident cases and from this selection only those cases will be chosen in which both cars have been tested by Euro NCAP and the necessary signals are available in the Euro NCAP frontal test data.

2.2 Selection of the PENDANT accident cases

For the selection of the accident cases, the PENDANT database (downloaded 12th October 2005) has been used and the following criteria has been applied for acquiring the necessary cases and crash information:

1) <u>Frontal accident</u>
   Only frontal accidents with an impact location the front of the vehicle and an impact direction is within ±60 degrees. The applied selection criteria for the query are:
   a. The general location of the impact is at the front of the car (parameter CD3=”F”);
   b. The direction of the impact force is between 10 and 02 o’clock (parameter CD12=01,02,10,11 or 12);
   c. The type of accidents which also includes frontal crashes, see Table 1.
2) <u>Car-car accident</u>
   In the PENDANT database no description of the vehicle/object itself is available and also not the actual collision partner. The only information available about the collision partner is the type of vehicle/object. To ensure that the query only produce car-car accidents, those accidents are selected in which exactly two cars are involved. This however eliminates multiple car accidents and consequently lowers the number of possible accident cases.
   The applied selection criteria for the query are:
   a. The number of vehicles involved in the accident is two (parameter No of involved cars=”2”);
   b. The other vehicle is a car (parameter Collision partner=”1”).
3) <u>Cars tested by Euro NCAP</u>
   The car list from the PENDANT frontal car-car accidents are manually compared to the Euro NCAP list of tested cars and only those accidents cases are selected in which both cars are tested by Euro NCAP.

Table 1 Selected accident type codes which also includes frontal crashes

Accident Type Code	Description Accident Type
D2	At least two vehicles - opposite direction no turning
D21	At least two vehicles - head on collision in general
D22L	At least two vehicles - U-turn in front of other vehicle
D22R	At least two vehicles - U-turn in front of other vehicle
D29	At least two vehicles - opposite direction no turning - others
E21L	At least two vehicles - same road - opposite direction - turning right in front of other vehicle
E21R	At least two vehicles - same road - opposite direction - turning left in front of other vehicle
E22L	At least two vehicles - same road - opposite direction - turning into same road
E22R	At least two vehicles - same road - opposite direction - turning into same road
E24L	At least two vehicles - same road - opposite direction - turning left in front of other vehicle
E24R	At least two vehicles - same road - opposite direction - turning right in front of other vehicle
E2L	At least two vehicles - turning or crossing - same road - opposite direction
E2R	At least two vehicles - turning or crossing - same road - opposite direction
E41L	At least two vehicles - different roads - turning left in front of vehicle from the right
E41R	At least two vehicles - different roads - turning right in front of vehicle from the left
E42L	At least two vehicles - different roads - turning right - head on collision
E42R	At least two vehicles - different roads - turning left - head on collision
E43L	At least two vehicles - different roads - turning right - both vehicles turning
E43R	At least two vehicles - different roads - turning right - both vehicles turning

From the selected accident cases the following information has been gathered:

1) General vehicle data
    a. Model;
    b. Make;
    c. Variant;
    d. Year;
    e. Kerb weight;
    f. Weight at crash.
2) Crash data
    a. Delta-V;
    b. EES;
    c. ETS;
    d. Offset;
    e. CDC1 – CDC8.
3) Occupant data
    a. Age;

b. Gender;
c. Height;
d. Weight;
e. Seat and row position;
f. PENDANT severity level;
g. Presence and use of restraint system(s);
h. Presence and use of airbag(s).

The PENDANT database (downloaded 12th October 2005) with in total 958 accident cases consists of 40 cases (4.2%) with frontal car-car crash accidents. Combining this selection with the Euro NCAP vehicle list gives eight accident cases with 16 cars and 31 occupants. The general specifications of the involved cars (make, model, variant & year) can be seen in Table 2 below. It is remarkable that no very new cars are involved in the selected accident cases, the year of manufacturing ranges from 1996 to 2002!

Table 2: Selected PENDANT accident cases and specifications of the cars involved in frontal car-car crashes

PENDANT AccID	PENDANT VehID	Make	Model	Variant	Year of manufacturing
FR3050	FR3050-V1	Peugeot	406		1999
	FR3050-V2	Volkswagen	Polo	3	1997
GE4089	GE4089-V1	Opel	Corsa		2001
	GE4089-V2	Ford	Ka		1998
SW7001	SW7001-V1	Peugeot	206	XS	2001
	SW7001-V2	Toyota	Corolla	Linea Luna	1999
UK8009	UK8009-V1	BMW	330	SE	2001
	UK8009-V2	Ford	Fiesta	Encore	2001
UK8033	UK8033-V1	Vauxhall	Astra	LS	1999
	UK8033-V2	Ford	Fiesta	Flight	2001
UK8045	UK8045-V1	Mitsubishi	Carisma	Gdi equip	2001
	UK8045-V2	Ford	Mondeo	TD	1996
UK8127	UK8127-V1	Fiat	Punto	Active sport	2002
	UK8127-V2	Volkswagen	Polo	GL	1996
UK8169	UK8169-V1	Ford	Escort	Finnese	2000
	UK8169-V2	Renault	Clio	MTV	2000

The desired accident information has been extracted from the PENDANT database by two different queries. The difference between both queries is the information about the presence and use of airbag(s). Airbags are commonly not present for rear seated occupants, thus these (seven) occupants are not present in the query with airbags information.
The gathered accident information can be seen in Table 3 to Table 5. The description of the PENDANT severity codes can be found in Table 6.

Table 3: Vehicles specifications and crash data of selected frontal car-car crash accidents

Accident	Vehicle data							Crash data								
AccID	VehID	Make	Model	Variant	Year	Kerb weight	Weight at crash	Delta-V	EES	ETS	Offset	CDC12	CDC45	CDC6	CDC7	CDC8
FR3050	FR3050-V1	Peugeot	406		1999	1275	1410	25	32	31	-29	12	Y1	E	W	3
FR3050	FR3050-V2	Volkswagen	Polo	3	1997	965	1085	33	29	27	-13	11	Y1	A	W	3
GE4089	GE4089-V1	Opel	Corsa		2001	1010	1010	13	14	0	0	11	Y1	E	W	2
GE4089	GE4089-V2	Ford	Ka		1998	946	936	14	22	0	0	11	L1	E	E	1
SW7001	SW7001-V1	Peugeot	206	XS	2001	1120	1120	47	32	31	11	11	Y0	E	W	3
SW7001	SW7001-V2	Toyota	Corolla	Linea Luna	1999	1260	1300	41	59	49	-15	2	Z0	E	W	3
UK8009	UK8009-V1	BMW	330	SE	2001	1470	1674	999	999	999	43	12	R0	E	E	3
UK8009	UK8009-V2	Ford	Fiesta	Encore	2001	958	1021	999	43	42	0	12	R1	E	E	3
UK8033	UK8033-V1	Vauxhall	Astra	LS	1999	1121	1257	20	20	20	22	12	R0	E	E	2
UK8033	UK8033-V2	Ford	Fiesta	Flight	2001	954	1167	21	22	21	0	12	R1	E	W	2
UK8045	UK8045-V1	Mitsubishi	Carisma	Gdi equip	2001	1235	1339	43	47	42	0	11	D0	E	W	4
UK8045	UK8045-V2	Ford	Mondeo	TD	1996	1305	1443	40	50	40	0	1	D0	E	W	3
UK8127	UK8127-V1	Fiat	Punto	Active sport	2002	920	1070	55	68	55	0	1	D0	E	W	4
UK8127	UK8127-V2	Volkswagen	Polo	GL	1996	990	1128	53	60	53	0	11	Y0	E	W	4
UK8169	UK8169-V1	Ford	Escort	Finnese	2000	1077	1292	16	20	18	27	1	D0	E	W	1
UK8169	UK8169-V2	Renault	Clio	MTV	2000	910	973	22	23	20	-27	11	Y1	E	W	1

Table 4: Occupant data, injury levels and restraint systems of selected frontal car-car crash accidents

Accident	Occupant data								Injury level	Restraint systems		
AccID	OccID	SeatID	Seat Row	Seat position	Age	Male	Height	Weight	PENDANT severity	Head restrained type	Seat belt	Child restrained fitted
FR3050	FR3050-V1-1/1-O1	FR3050-V1-1/1	1	1	62	Yes	0	75	3	1	1	2
FR3050	FR3050-V1-1/3-O2	FR3050-V1-1/3	1	3	56	No	0	60	3	1	1	2
FR3050	FR3050-V2-1/1-O3	FR3050-V2-1/1	1	1	64	No	0	60	2	0	2	2
FR3050	FR3050-V2-1/3-O4	FR3050-V2-1/3	1	3	90	No	0	60	1	2	2	0
GE4089	GE4089-V1-1/1-O1	GE4089-V1-1/1	1	1	20	No	178	75	3	1	1	0
GE4089	GE4089-V2-1/1-O1	GE4089-V2-1/1	1	1	43	No	160	65	3	1	1	0
SW7001	SW7001-V1-1/1-O1	SW7001-V1-1/1	1	1	23	Yes	999	999	3	2	3	2
SW7001	SW7001-V2-1/1-O2	SW7001-V2-1/1	1	1	58	Yes	999	999	2	1	1	2
UK8009	UK8009-V1-1/1-O1	UK8009-V1-1/1	1	1	58	Yes	180	92	2	1	1	0
UK8009	UK8009-V1-1/3-O2	UK8009-V1-1/3	1	3	58	No	163	67	3	1	1	0
UK8009	UK8009-V1-2/1-O3	UK8009-V1-2/1	2	1	3	No	91	999	4	1	1	1
UK8009	UK8009-V1-2/3-O4	UK8009-V1-2/3	2	3	1	No	60	999	4	1	0	1
UK8009	UK8009-V2-1/1-O1	UK8009-V2-1/1	1	1	51	No	999	999	3	1	1	0
UK8033	UK8033-V1-1/1-O1	UK8033-V1-1/1	1	1	69	Yes	171	73	1	1	1	0
UK8033	UK8033-V1-1/3-O2	UK8033-V1-1/3	1	3	999	No	999	999	4	1	0	0
UK8033	UK8033-V2-1/1-O1	UK8033-V2-1/1	1	1	19	Yes	999	999	4	1	1	0
UK8033	UK8033-V2-1/3-O2	UK8033-V2-1/3	1	3	19	Yes	999	999	4	1	1	0
UK8033	UK8033-V2-2/1-O3	UK8033-V2-2/1	2	1	999	No	999	999	4	0	9	0
UK8045	UK8045-V1-1/1-O1	UK8045-V1-1/1	1	1	26	Yes	182	104	3	2	1	0
UK8045	UK8045-V2-1/1-O1	UK8045-V2-1/1	1	1	42	Yes	999	999	2	1	3	0
UK8045	UK8045-V2-1/3-O2	UK8045-V2-1/3	1	3	25	No	999	999	2	1	3	0
UK8127	UK8127-V1-1/1-O	UK8127-V1-1/1	0	0	0	No	0	0	0	1	1	0
UK8127	UK8127-V1-1/1-O1	UK8127-V1-1/1	1	1	23	Yes	999	999	2	1	1	0
UK8127	UK8127-V1-1/3-O2	UK8127-V1-1/3	1	3	29	Yes	999	999	2	1	1	0
UK8127	UK8127-V2-1/1-O1	UK8127-V2-1/1	1	1	23	Yes	999	999	2	1	1	0
UK8127	UK8127-V2-1/3-O2	UK8127-V2-1/3	1	3	27	No	999	999	2	1	1	0
UK8169	UK8169-V1-1/1-O1	UK8169-V1-1/1	0	0	48	Yes	999	999	4	1	1	0
UK8169	UK8169-V1-1/3-O2	UK8169-V1-1/3	0	0	37	No	999	999	4	1	1	0
UK8169	UK8169-V1-2/1-O3	UK8169-V1-2/1	0	0	7	Yes	999	999	4	1	1	0
UK8169	UK8169-V1-2/3-O4	UK8169-V1-2/3	0	0	14	No	999	999	4	1	1	0
UK8169	UK8169-V2-1/1-O1	UK8169-V2-1/1	0	0	23	No	999	999	3	1	9	0

Table 5: Occupant data, injury levels, airbag data and restraint systems of selected frontal car-car crash accidents

Occupant data								Injury level	Airbag				Restraint systems		
OccID	SeatID	Seat Row	Seat position	Age	Gender	Height	Weight	PENDANT severity	No	Location front row	Location	Activated and deployed	Head restrained type	Seat belt	Child restrained fitted
FR3050-V1-1/1-O1	FR3050-V1-1/1	1	1	62	Male	0	75	3	1	1	0	1	1	1	2
FR3050-V1-1/3-O2	FR3050-V1-1/3	1	3	56	Female	0	60	3	1	2	0	1	1	1	2
FR3050-V2-1/1-O3	FR3050-V2-1/1	1	1	64	Female	0	60	2	1	1	0	1	0	2	2
FR3050-V2-1/3-O4	FR3050-V2-1/3	1	3	90	Female	0	60	1	1	2	0	1	2	2	0
GE4089-V1-1/1-O1	GE4089-V1-1/1	1	1	20	Female	178	75	3	2	4	0	0	1	1	0
GE4089-V2-1/1-O1	GE4089-V2-1/1	1	1	43	Female	160	65	3	1	1	0	0	1	1	0
SW7001-V1-1/1-O1	SW7001-V1-1/1	1	1	23	Male	999	999	3	1	1	0	1	2	3	2
SW7001-V2-1/1-O2	SW7001-V2-1/1	1	1	58	Male	999	999	2	1	1	0	1	1	1	2
UK8009-V1-1/1-O1	UK8009-V1-1/1	1	1	58	Male	180	92	2	1	1	0	1	1	1	0
UK8009-V1-1/3-O2	UK8009-V1-1/3	1	3	58	Female	163	67	3	5	3	0	0	1	1	0
UK8009-V1-2/1-O3	UK8009-V1-2/1	2	1	3	Female	91	999	4	7	3	0	0	1	1	1
UK8009-V1-2/3-O4	UK8009-V1-2/3	2	3	1	Female	60	999	4	8	3	0	0	1	0	1
UK8009-V2-1/1-O1	UK8009-V2-1/1	1	1	51	Female	999	999	3	1	1	0	1	1	1	0
UK8033-V1-1/1-O1	UK8033-V1-1/1	1	1	69	Male	171	73	1	1	1	0	0	1	1	0
UK8033-V1-1/3-O2	UK8033-V1-1/3	1	3	999	Female	999	999	4	2	2	0	0	1	0	0
UK8033-V2-1/1-O1	UK8033-V2-1/1	1	1	19	Male	999	999	4	1	1	0	1	1	1	0
UK8045-V1-1/1-O1	UK8045-V1-1/1	1	1	26	Male	182	104	3	1	1	0	1	2	1	0
UK8045-V2-1/1-O1	UK8045-V2-1/1	1	1	42	Male	999	999	2	1	1	0	1	1	3	0
UK8127-V1-1/1-O1	UK8127-V1-1/1	1	1	23	Male	999	999	2	1	1	0	1	1	1	0
UK8127-V1-1/1-O	UK8127-V1-1/1	0	0	0	Female	0	0	0	1	1	0	1	1	1	0
UK8127-V1-1/3-O2	UK8127-V1-1/3	1	3	29	Male	999	999	2	2	2	0	1	1	1	0
UK8127-V2-1/1-O1	UK8127-V2-1/1	1	1	23	Male	999	999	2	1	1	0	0	1	1	0
UK8169-V1-1/1-O1	UK8169-V1-1/1	0	0	48	Male	999	999	4	1	1	0	0	1	1	0
UK8169-V2-1/1-O1	UK8169-V2-1/1	0	0	23	Female	999	999	3	1	1	0	0	1	9	0

Table 6: PENDANT crash severity description

PENDANT Crash Severity Code	PENDANT Crash Severity
1	Fatal
2	Serious
3	Slight
4	Not Injured

The final accident case has been chosen from the selected eight cases with the extra condition that both cars are represented by a different vehicle crash model. The end result is accident case UK8033 (see Table 7) and shall be used for the benefit assesment of an improved restraint system. Before continuing with the validation of the vehicle crash models, the crash parameters of the selected 16 cars are compared with all PENDANT cars involved in a frontal crash.

Table 7: Final accident case UK8033

PENDANT AccID	PENDANT VehID	Make	Model	Variant	Year of manufacturing	PENDANT Injury severity	Injury location
UK8033	UK8033-V1	Vauxhall	Astra	LS	1999	1	Head & neck
	UK8033-V2	Ford	Fiesta	Flight	2001	4	Head & neck

3 Analysis PENDANT crash parameters

To investigate if the eight accident cases represent the car-car frontal crashes, the distributions of several crash parameters are determined. For this purpose the query has been repeated without the condition of only reconstructed accident cases and resulted in 57 cases (5.9%). In Figure 1 below, the distribution of car-car frontal and other crash types is given per country. It has to be mentioned that no information about the accident damage was available for the Spanish cases, thus Spain does not appear in the results.

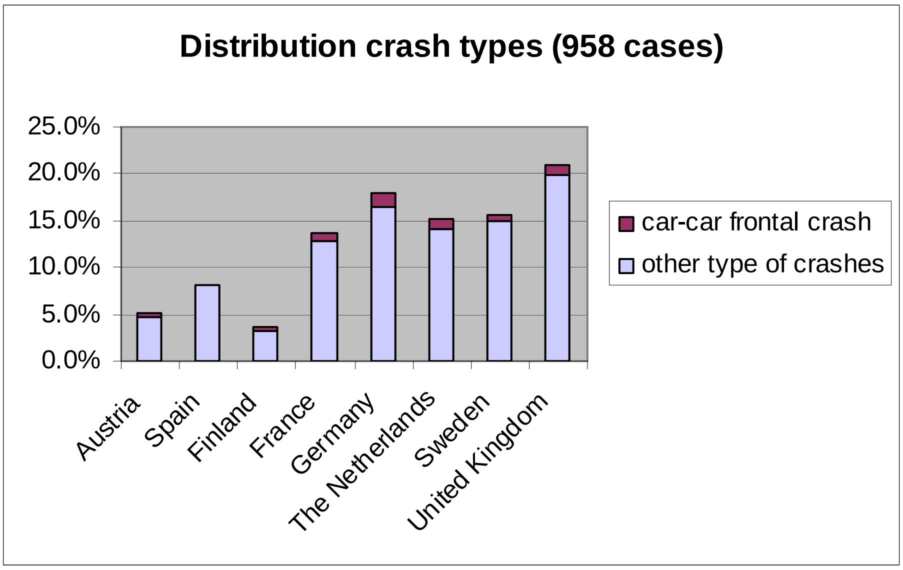

Figure 1 - Car-car frontal crash type

The selected eight car-car frontal accidents are not similar distributed over the countries as all car-car frontal accidents, see Table 8. The UK accidents are overrepresented. All other countries except Sweden and Spain are underrepresented.

Table 8 Distribution car-car frontal accidents

Country	**ALL car-car frontal**		**Selected car-car frontal**	
	Counts	**Percentage**	**Counts**	**Percentage**
Austria	3	5%	0	0%
Spain	0	0%	0	0%
Finland	4	7%	0	0%
France	10	18%	1	13%
Germany	14	25%	1	13%
The Netherlands	10	18%	0	0%
Sweden	6	11%	1	13%
United Kingdom	10	18%	5	63%
Total	*57*	*100%*	*8*	*100%*

In the following part the distribution of the following crash parameters of the selected car-car frontal crash cases are given:

1. Delta-V;
2. EES;

3. ETS;
4. Offset of damage;
5. Angle of impact force.

Because the first three crash parameters are not independent of each other, their relation has also been investigated.
UK accidents are overrepresented and due to left-side driving the offset of the damage and angle of impact force shall be opposite (mirrored) to the accidents of the other countries.

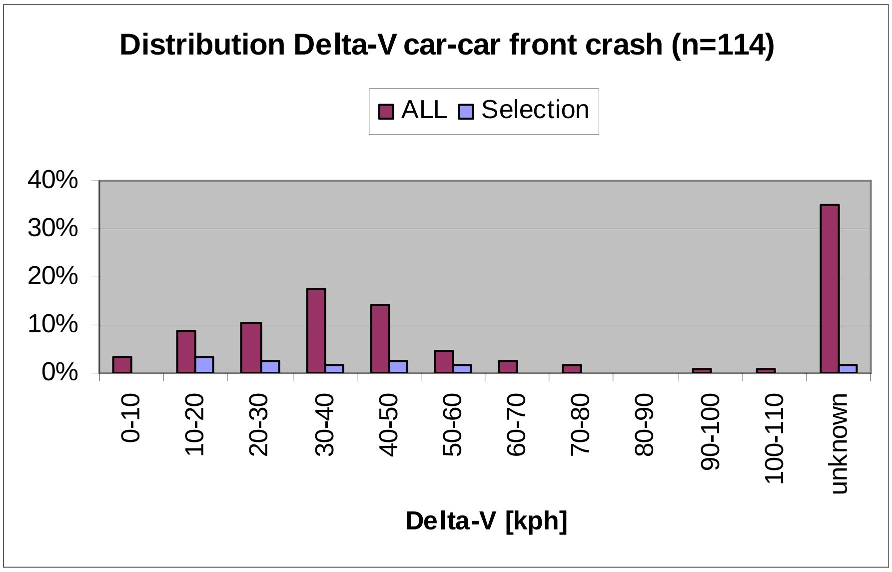

Figure 2 - Delta-V of PENDANT car-car frontal crash accidents (114 cars)

The distribution of Delta-V is given in classes of 10 km/h, see Figure 2. The distribution of Delta-V has a clear peak around 30 – 40 km/h and high Delta-V values do not appear frequently. No information about the Delta-V value is available for 34% of the cars. This high number of unknowns' originates mainly from the accident cases without reconstruction.
In all figures with distribution of crash parameters also the values of the eight selected accident cases are plotted to show if they represent the car-car frontal accidents. Figure 2 shows that the selected accidents cover the most important range (10-60 km/h). However they exclude very low and high (> 60 km/h) Delta-V values.

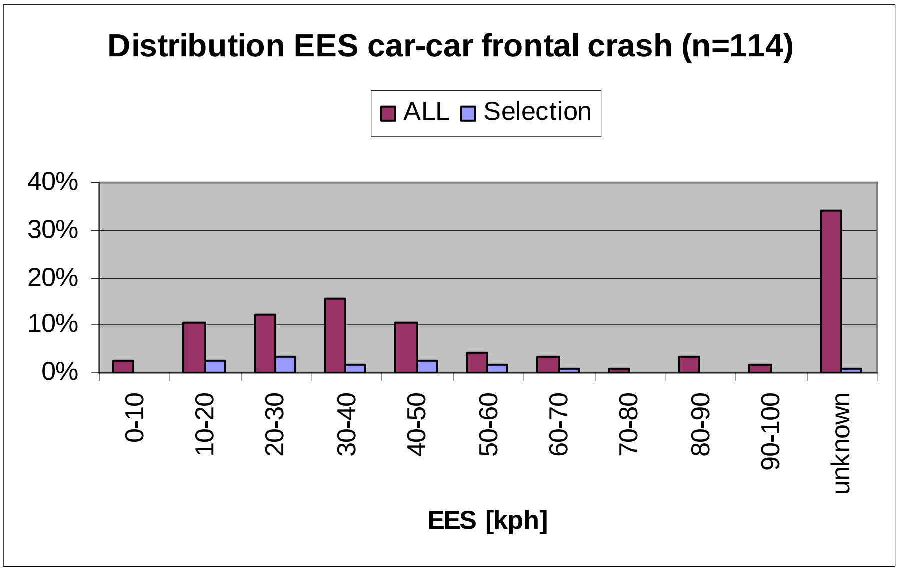

Figure 3 - EES of PENDANT car-car frontal crash accidents (114 cars)

The distribution of EES (see Figure 3) is similar with Delta-V. This is expected for frontal accidents with low impact angle and low velocity after the crash. Under these conditions the crash parameter Delta-V and EES are almost equal, see equation below. In Figure 4 the EES and Delta-V values are plotted against each other. The relation can be regarded as reasonable linear with a Pearson correlation coefficient of 0.91.

$$EES = \sqrt{DeltaV^2 + DeltaV * V_b} \quad \textbf{(1)}$$

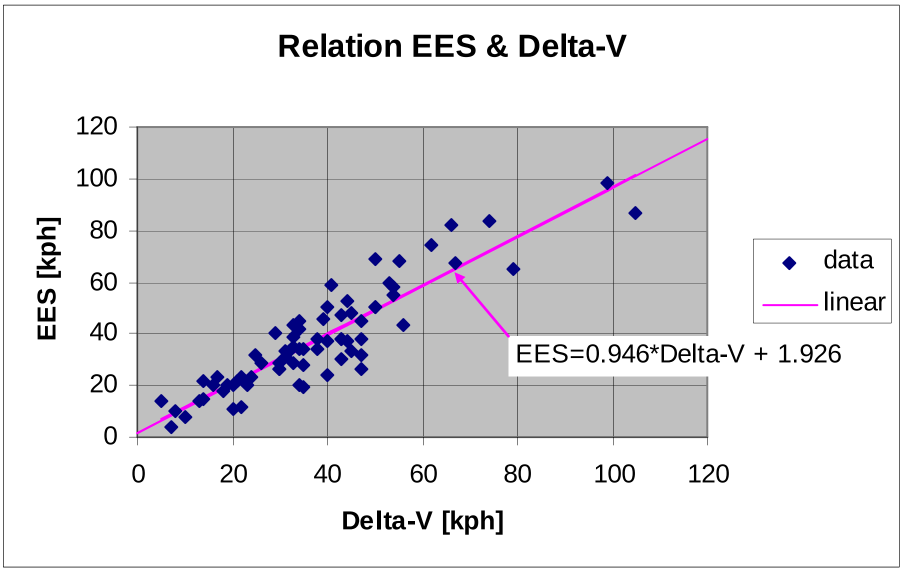

Figure 4 - Relation between EES and Delta-V (Pearson correlation coefficient = 0.91)

Figure 5 shows that for nearly 50% of the cars information about ETS is available. Nevertheless, the shape of the distribution of ETS of these vehicles is very quite similar with EES. Therefore, it is expected that EES and ETS are almost identical. This can be seen in Figure 6 which shows a good linear relation with a Pearson correlation coefficient of 0.97. The relation between ETS and Delta-V is less compared to EES (Pearson correlation coefficient 0.89), see Figure 7.

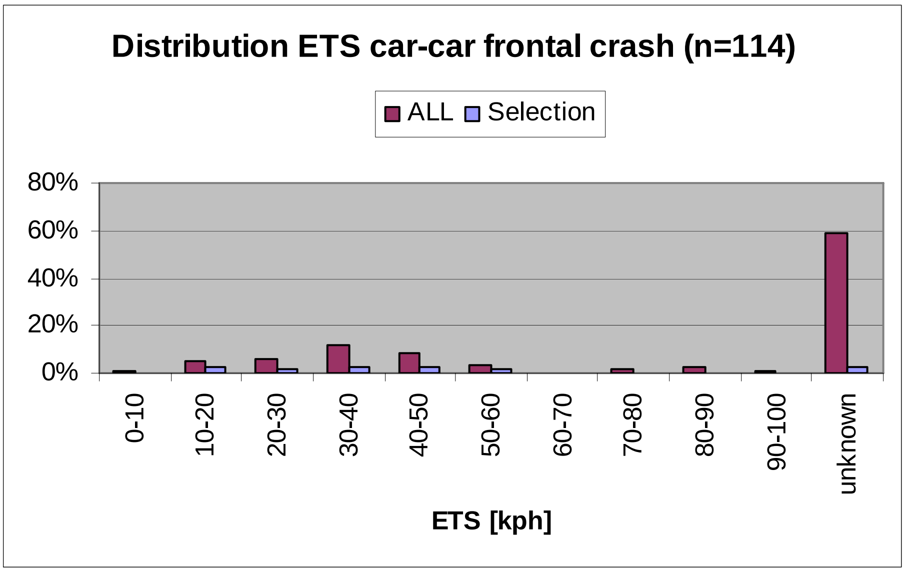

Figure 5 - ETS of PENDANT car-car frontal crash accidents (114 cars)

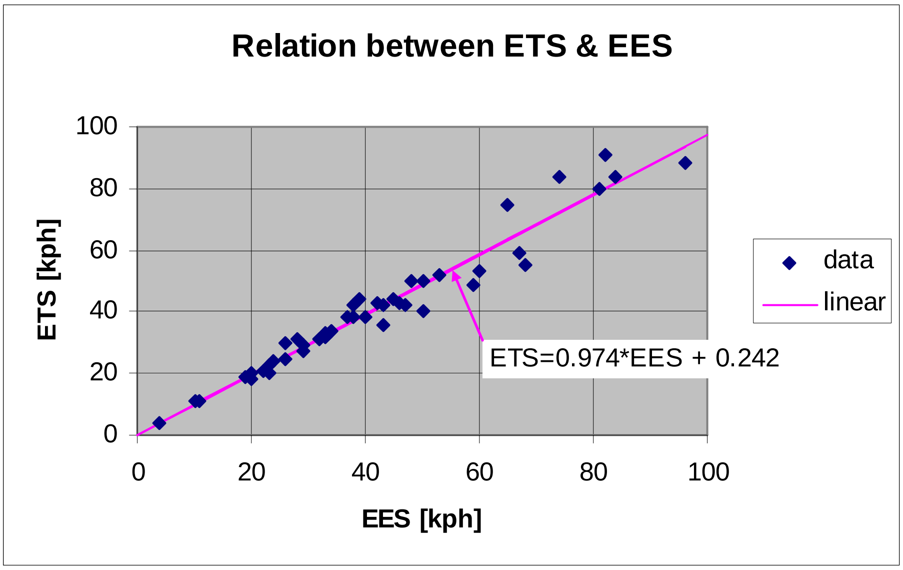

Figure 6 - Relation between ETS and EES (Pearson correlation coefficient = 0.97)

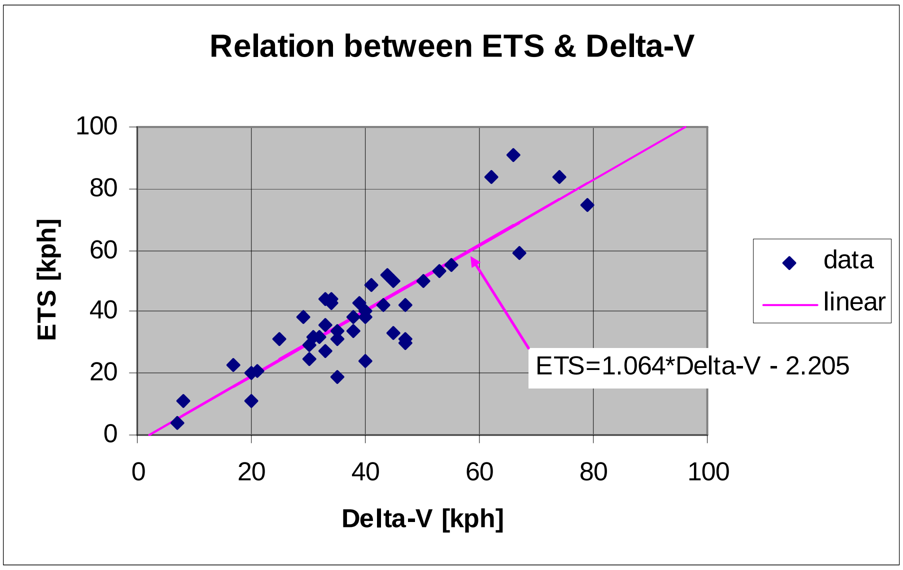

Figure 7 - Relation between ETS and Delta-V (Pearson correlation coefficient = 0.89)

The distribution of the value of the damage offset is given in classes of 10 cm, see Figure 8. The data of the damage offset on the front part of the car consists of a considerable amount of zero values, which indicates that the centre of the damage is located in the centerline of the vehicle. After checking the CDC45 code, which give the horizontal location of the damaged zone, it appeared that for 29 of the 58 cars with zero damage offset (=50%) the centreline of the vehicle is not in the given zone. A check of another parameter, the damage width, gives a complete different result, namely that for 11 cars (=19%) the centreline of the vehicle is not likely to be in the damaged area. Due to the conflicting data, all cases with zero damage offset have been regarded as a special class. Figure 8 shows that the damage offset is spread over the whole front side of passenger cars, see. For the selected accidents, the range of the damage offset is in the centre of the front (±30cm). Another method of presenting the distribution is using a cumulative distribution. Figure 9 shows the cumulative distribution of the damage offset excluding the cases with zero and unknown values.

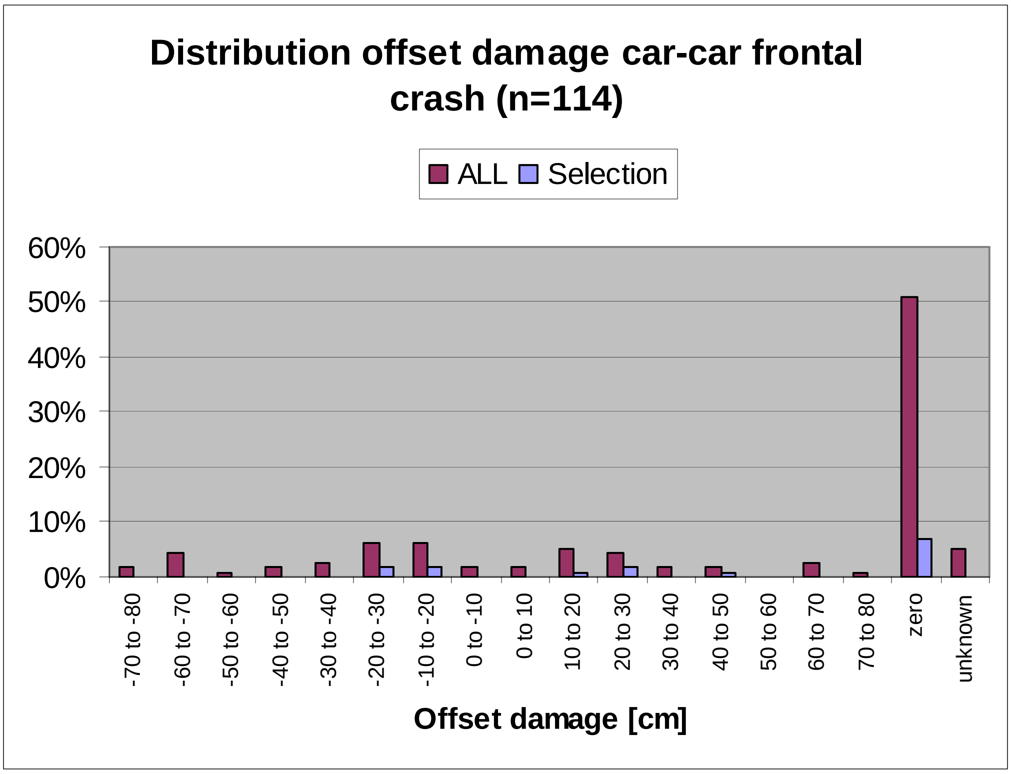

Figure 8 - Offset damage of PENDANT car-car frontal crash accidents (114 cars)

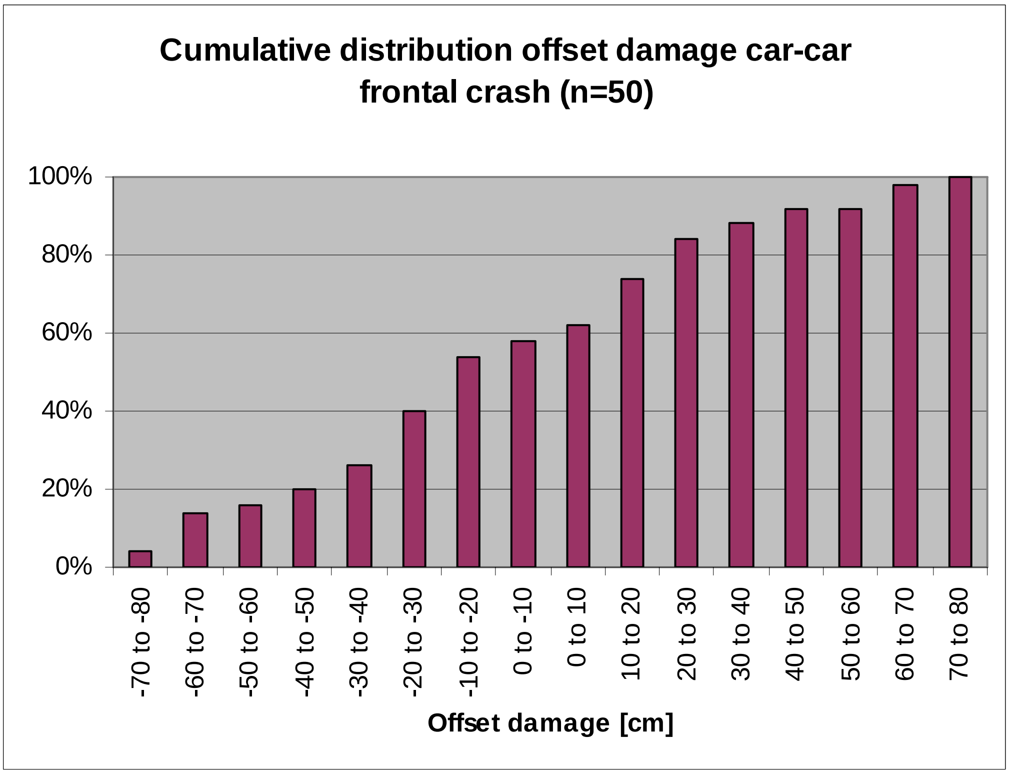

Figure 9 - Offset damage of PENDANT car-car frontal crash accidents (50 cars)

Figure 10 shows that the angle or direction of the impact force is in most cases between ±30 degrees (11 to 1 hour) with a maximum around zero degrees (12 hour).

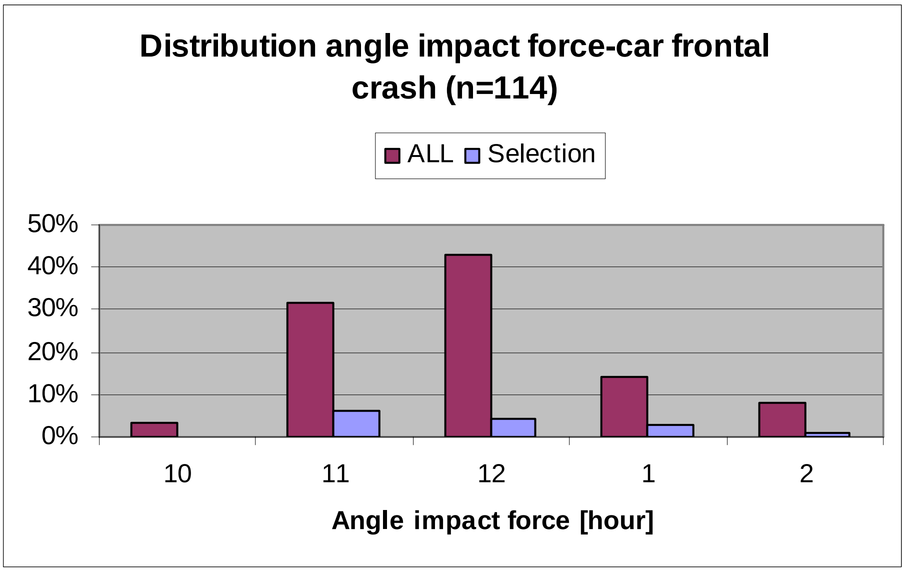

Figure 10 - Angle impact force of PENDANT car-car frontal crash accidents (80 cars)

For the selection of the accident cases for the crash simulation it is important to look also at distributions and relations of other crash parameters/conditions, like:

1. relation/ratio mass of both cars;
2. relation between EES or Delta-V and the angle of the impact force;
3. relation between EES or Delta-V and the damage offset;
4. Relation between EES and mass of the car.

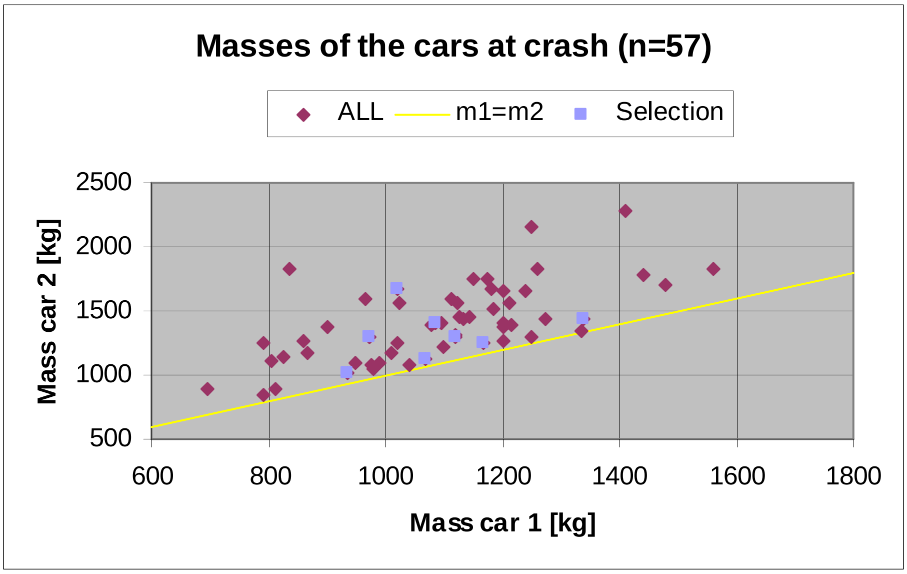

Figure 11 - Distribution of both car masses at crash

Figure 11 and Figure 12 show the relation between the masses of both cars involved in the car-car frontal accident. The mass ratio between the "heavy" and "light" car varies from 1.0 to 1.6. The selected accidents represent the full ratio range, but not the full range of the masses. The really light and heavy cars are not present in the selection.

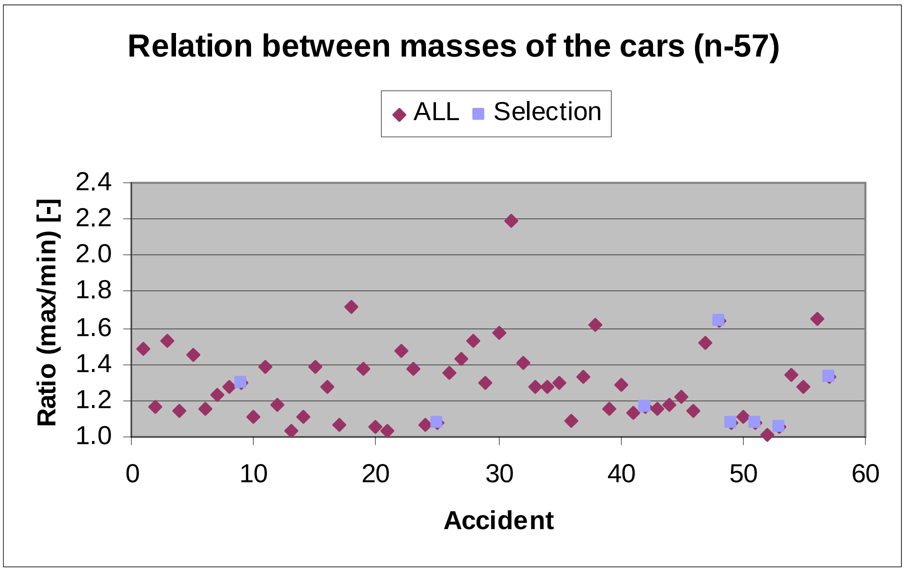

Figure 12 - Distribution of car mass ratio

Figure 13 and Figure 14 show that the angle of the impact force is reasonable spread over respectively the Delta-V and EES range. Extreme values of Delta-V and EES only appear for zero impact force angle.
The selected accidents do not represent all combinations. For zero impact force angle no medium and high Delta-V values are present.

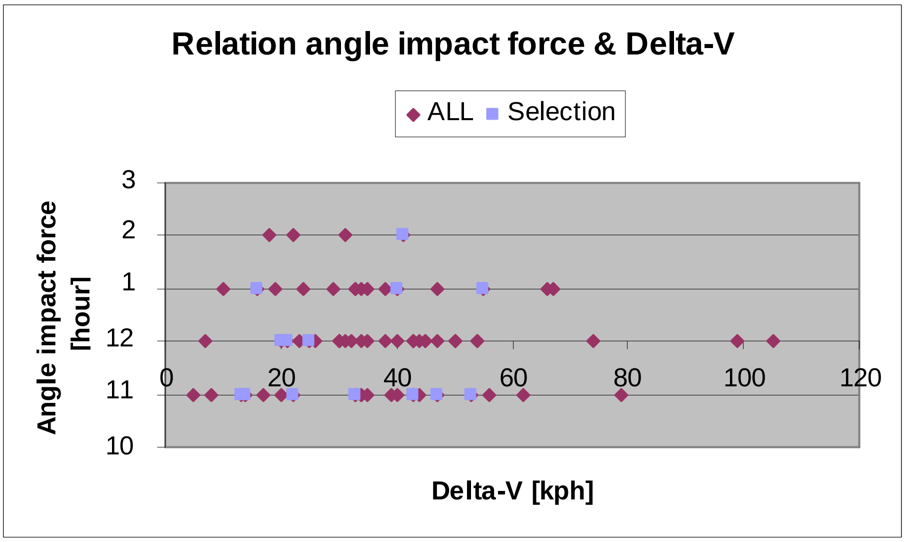

Figure 13 - Relation between the angle of the impact force and Delta-V (clockwise is positive direction)

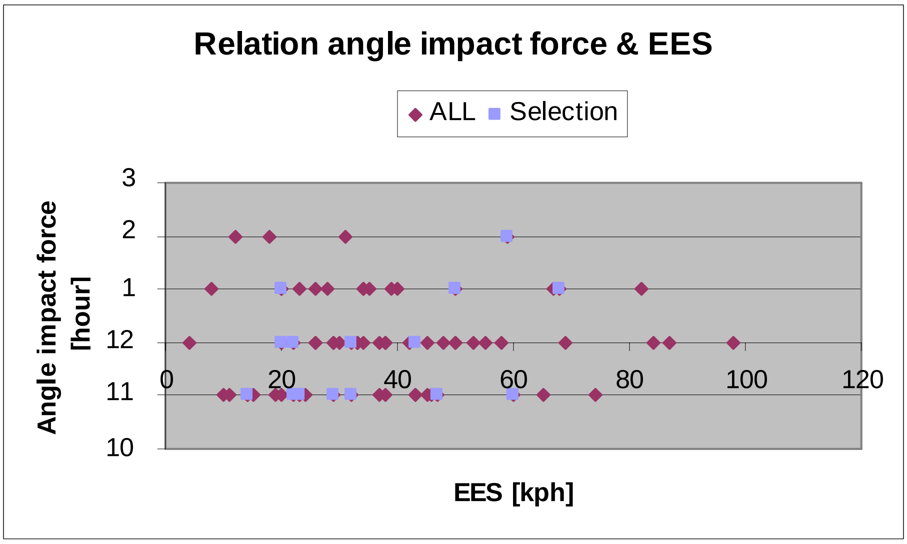

Figure 14 - Relation between the angle of the impact force and EES (clockwise is positive direction)

In Figure 15 and Figure 16 the relation between the damage offset and Delta-V respectively and EES is given. There is no uniform distribution of the damage offset over Delta-V or EES. Care has to be taken when interpreting the difference or similarity between the positive and negative damage offset values. The UK represents 17.5% of the car-car frontal cases and due to driving on the left side of the road several crash parameters have opposite signs. The UK data has not been mirrored to get comparable values.
The selected accidents only represent small damage offsets: ±30 cm.

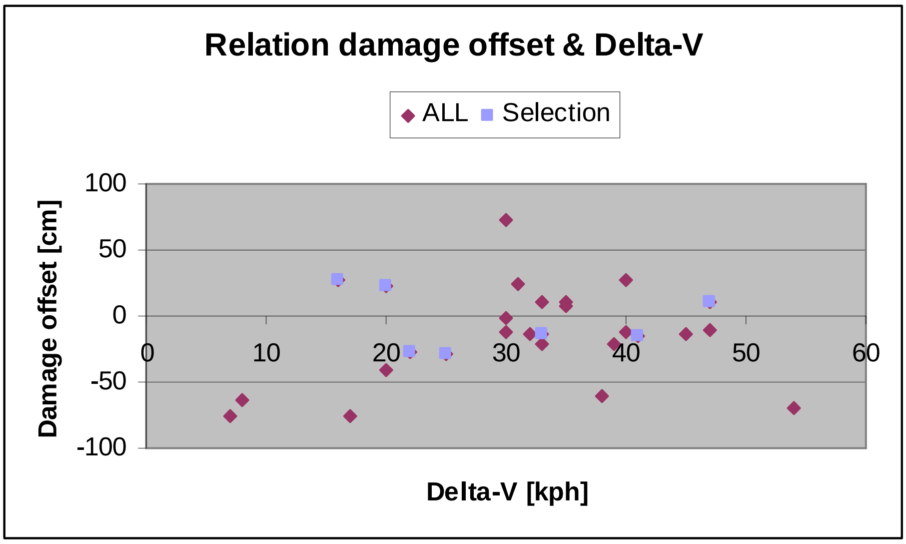

Figure 15 - Relation damage offset and Delta-V

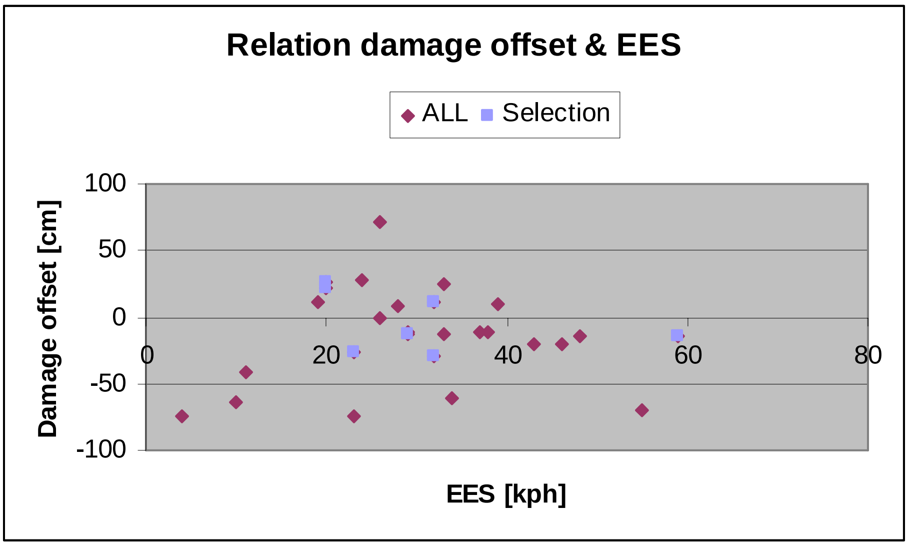

Figure 16 - Relation damage offset and EES

The relation between EES and the mass of the car at crash can be seen in Figure 17. The selected cars represent the EES range up to 70 km/h.

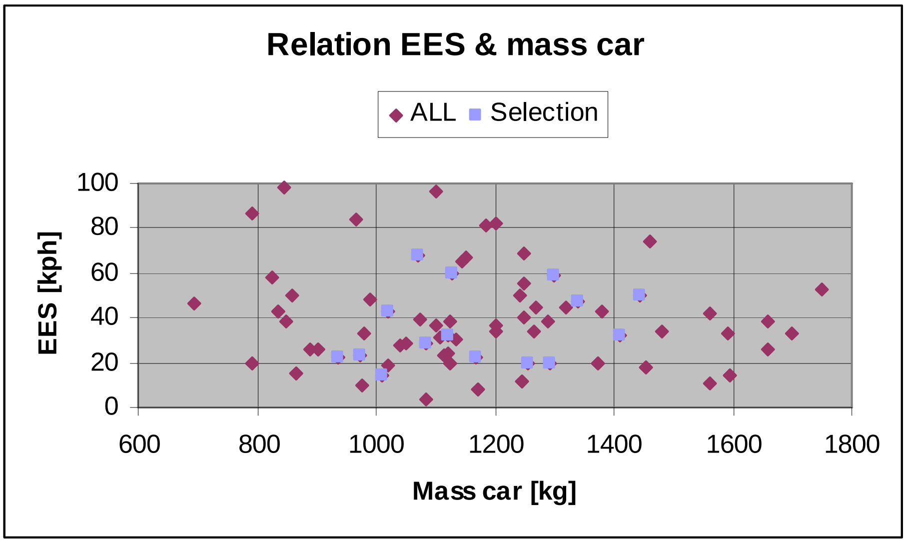

Figure 17 - Relation EES and mass of the car at crash

4 Validation generic vehicle models with Euro NCAP test data

Based on the existing Madymo Multi Body vehicle models, two generic vehicle models are selected and validated with the corresponding Euro NCAP test data. The Vauxhall Astra is modeled with the Chrysler Neon generic model and the Ford Fiesta is simulated by the Geo Metro generic model [1].

The generic vehicle model is an optimized multi-body vehicle model by removing of the joints that are not substantially deformed during the crash [2]. In the development of a generic vehicle model two steps are distinguished:

1) The frontal car structure is modeled and optimized based on the required crash scenarios;
2) The car interiors with respect to restraint systems are modeled.

Figure 18 shows the identified important loading paths based on the accident analysis and Figure 19 outlines the main strictures (bodies and joints) that involved in the energy management in a generic vehicle.

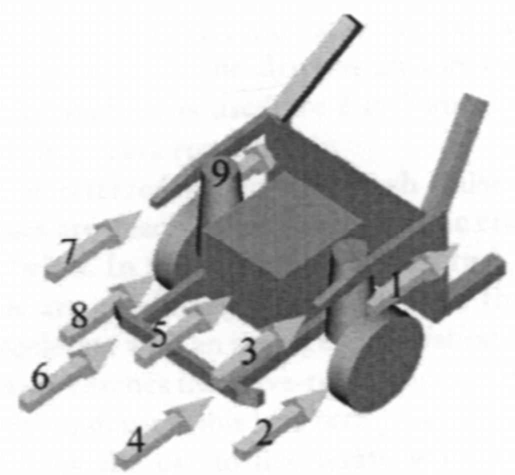

Figure 18 - Identification of important load paths (see also Table 9) based on the accident analyses

Table 9 Load path description

Load path	Description
1	Direct load to left side structure
2	Load on left front wheel transmitted to hinge pillar and front sill
3	Load on left shotgun/ shocktower
4	Load on left longitudinal
5	Load on engine transmitted to compartment
6	Load on right longitudinal
7	Load on right shotgun/ shocktower
8	Load on right front wheel transmitted to hinge pillar and front sill
9	Direct load to right side structure

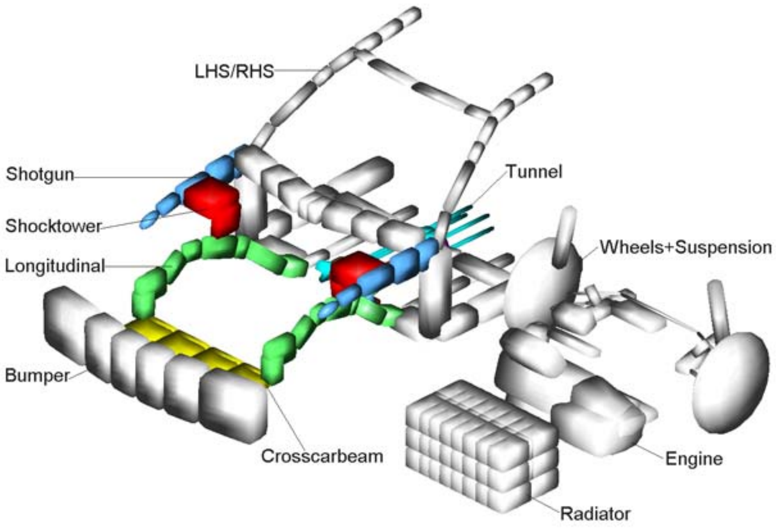

Figure 19 - Main structures involved in energy management in a generic vehicle

According to previous study on energy absorption for different vehicle [1], the roles of the longitudinals, the shotguns, the subframe and the bumper are always significant for energy absorption during different crash scenarios. Furthermore, the large energy dissipation by the connection between front suspension and the longitudinal is observed. Therefore, only the stiffness functions of the longitudinals, shotguns and the connector are scaled and the crash pulses are fitted with Euro NCAP front crash tests. The Euro NCAP front tests are performed with a 64 km/h collision speed and an overlap of 40% (see Figure 20).

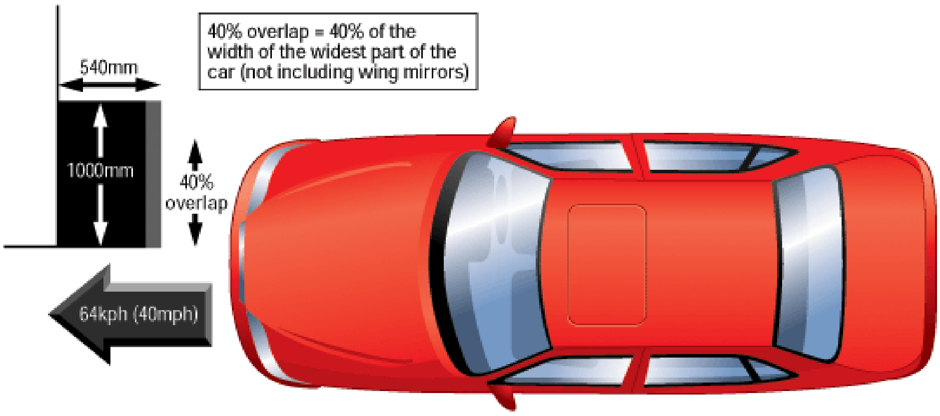

Figure 20 - Euro NCAP frontal impact takes place at 64 km/h (40 mph, 17.78 m/s), car strikes deformable barrier that is offset

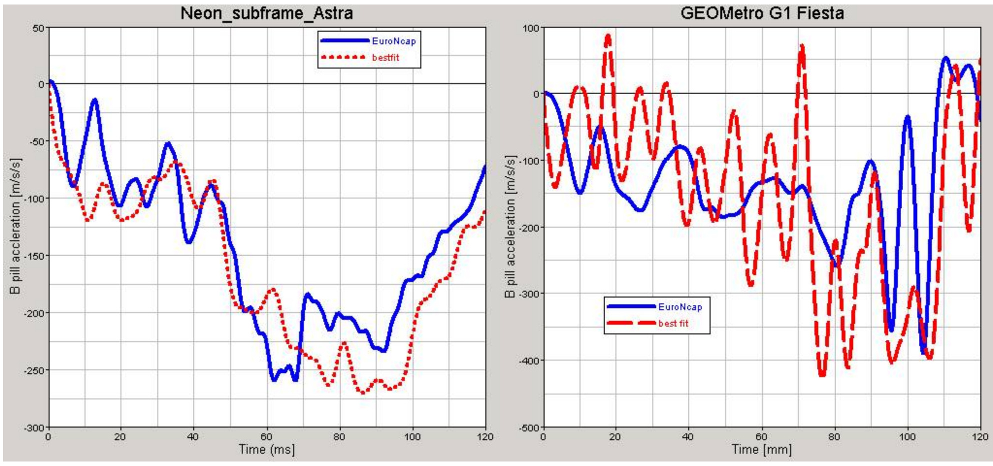

Figure 21 - The validated crash pulses of the generic models with respect to the corresponding Euro NCAP front test pulses

Table 10 The best fitted stiffness scalar parameters

Vehicle	longitudinals	shotguns	connector
Vauxhall Astra	9.3372	0.63195	1.125
Ford Fiesta	11.442	18.781	14.102

Figure 21 shows the validated crash pulses of the generic models with respect to the corresponding Euro NCAP front test pulses. The validation is performed by using Mode Frontier. It is a design optimization program that calibrates the best fit parameters. Table 10 outlines the calibrated data. Note these parameters are relative scalar factors that are used to scale the joint stiffness functions that calibrated for the corresponding reference vehicles.

It should be mentioned that the Vauxhall Astra generic model correlates with the Euro NCAP test well while the Ford Fiesta generic model shows some discrepancy.

5 Real accident analysis: accident case UK8033

To investigate the real accident, the accident case UK8033 is selected from the PENDANT data base. The accident specifications are outlined in Table 11.

Table 11 Accident specifications

Vehicle	variant	Kerb weight Kg	Weight at crash Kg	Delta-V	EES
Vauxhall Astra	LS, 1999	1121	1257	20	20
Ford Fiesta	Flight, 2001	954	1167	21	22
	ETS	**Offset**	**CDC12**	**CDC45**	**CDC6**
Vauxhall Astra	20	22	12	R0	E
Ford Fiesta	21	0	12	R1	E
	CDC7	**CDC8**	**Injury severity**	**Air bag**	
Vauxhall Astra	E	2	1(head, neck)	0	
Ford Fiesta	W	2	4 (head, neck)	1	

Figure 22 - Vauxhall Astra LS, 1999 (left) and Ford Fiesta, 2001 (right)

Note that in the accident specification only the Delta-V, not the initial impact speed, is specified. Therefore, the initial impact speeds of the Ford Fiesta and the Vauxhall Astra are estimated and validated. Figure 23 shows the impact consequences with an impact speed of 25 km/h. The Vauxhall Astra has more damage than the Ford Fiesta as observed in the real accident. In Figure 24 the front deformation of impacted vehicles are plotted and the velocity history is plot in Figure 25, respectively. The maximum left-front (contact area) deformation of the Vauxhall Astra is 0.33 m while the maximum left-front (contact area) deformation of the Ford Fiesta reads 0.05 m. The Delta-V of the Ford Fiesta is 20 km/h and the Delta-V of the Vauxhall Astra is 22 km/h, correlate well with the accident data.

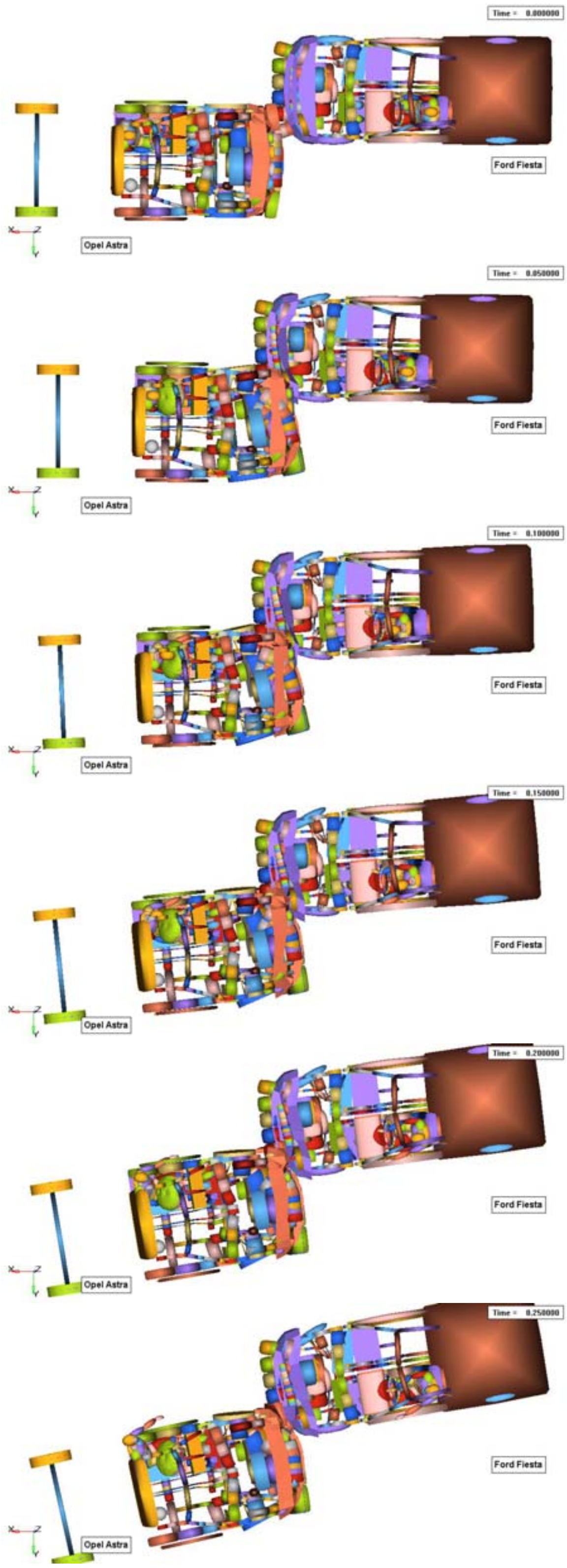

Figure 23 - Madymo simulations (t=0, 50, 100, 150, 200 and 250 ms)

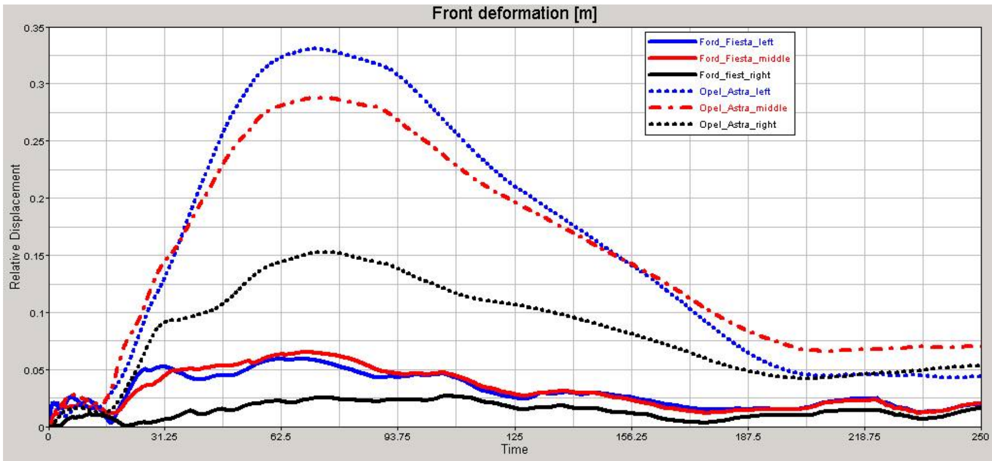

Figure 24 - The front deformation of vehicles

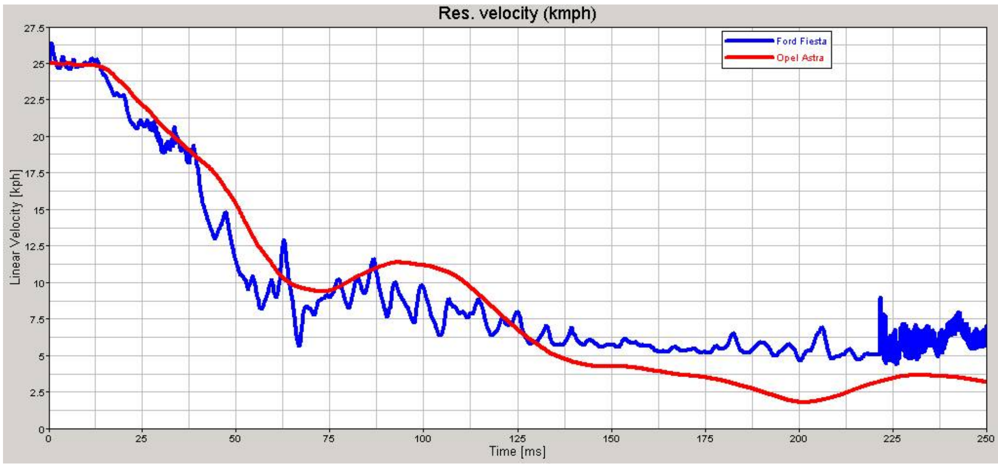

Figure 25 - Time- velocity plot

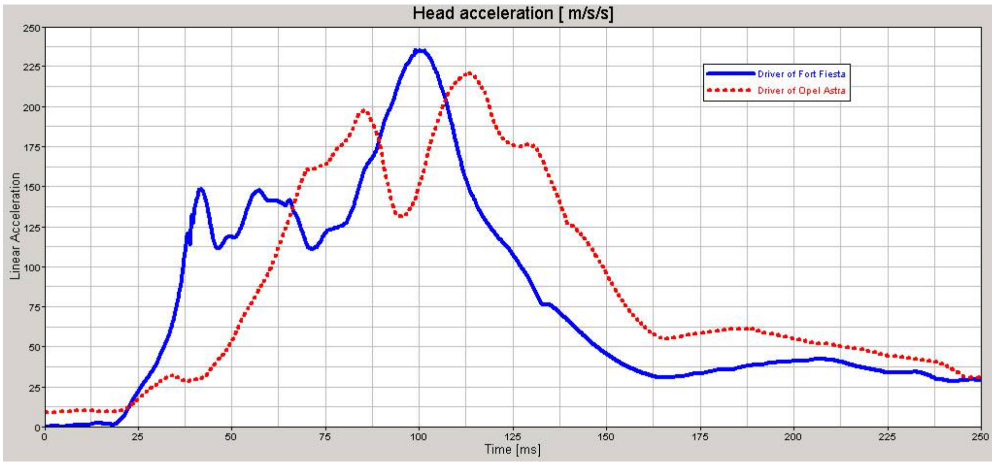

Figure 26 - The driver head acceleration

Table 12 Injury parameters

driver	Combined thorax index	Cumulative 3ms maximum	HIC36_inj
Ford Fiesta	0.543	229	57.7
Vauxhall Astra	0.635	271	58.3

In Figure 26 the head accelerations of the drives are plotted. Although the air bag of the Vauxhall Astra was not deployed, the maximum acceleration is smaller than that of the Ford Fiesta which had the air bag deployed. However, the combined thorax index, the cumulative 3 ms maximum and the HIC values of the driver of the Vauxhall Astra are higher than those of the Ford Fiesta. These may explain a severer head and neck injury of the driver of the Vauxhall Astra.

6 Influence of an improved restraint system

As improved restraint system a pre-crash pretensioning of the safety belt of the driver of the Vauxhall Astra (NEON simulation model) has been applied. The real accident has been simulated again, but now with this pre-crash pretensioning system. The results are compared to the results without pretensioning.

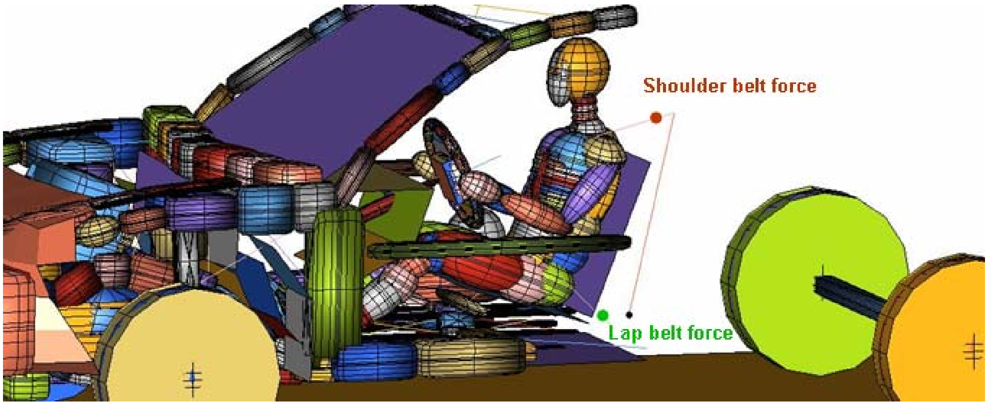

Figure 27 - Bullet car (NEON) Belt forces measurement

Pretensioning in the pre-crash phase is applied 150 [ms] prior to impact (impact occurs at time 0 [ms]). This value of 150 ms has been based of the presence of a pre-crash sensing device and engineering judgement. The pretensioning is applied at the retractor; the amount of belt inlet in the pretensioning phase is 5 [cm].

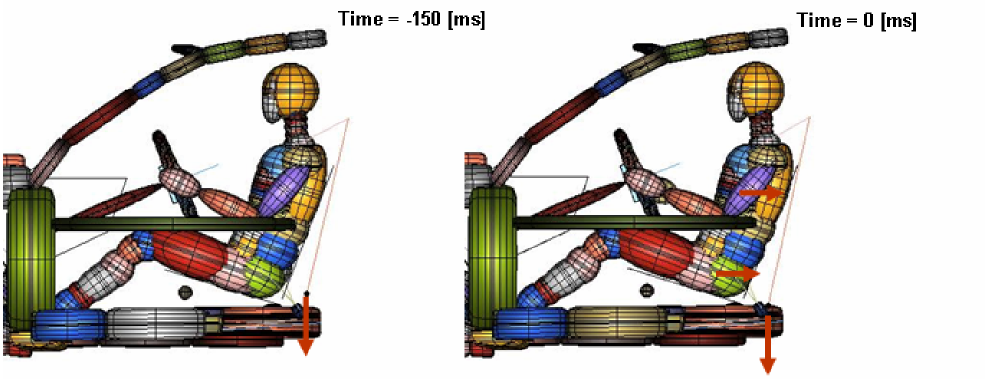

Figure 28 - Bullet car (NEON) Pretensioning phase

During pretensioning, the following phases are observed:

1. A first phase (between 150 and 110 [ms] prior to impact) in which the belt forces increase due to pretensioning; in this phase the shoulder belt starts to compress the chest of the driver (see Figure 31); at the same time, the occupant is accelerated in the longitudinal direction towards the seatback;
2. A second phase (between 110 and 10 [ms] prior to impact) in which the driver starts to move backwards. The belt forces and acceleration levels on the occupant decrease and a new dynamic equilibrium configuration is reached;

3. A third phase (between 10 and o [ms] prior to impact) in which the driver cannot be pushed any further into the seat, the slack in the belt system has been completely removed and the belt forces, occupant accelerations and chest deflection start to increase again.

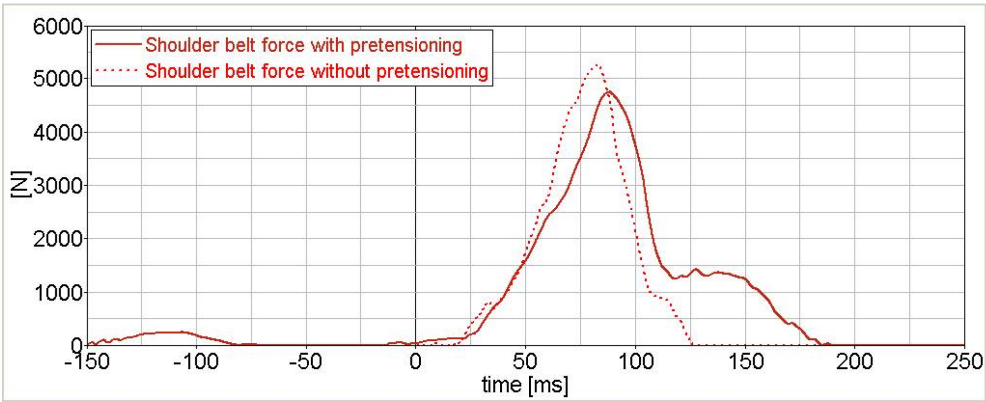

Figure 29 - Comparison of NEON occupant shoulder belt force with and without pretensioning

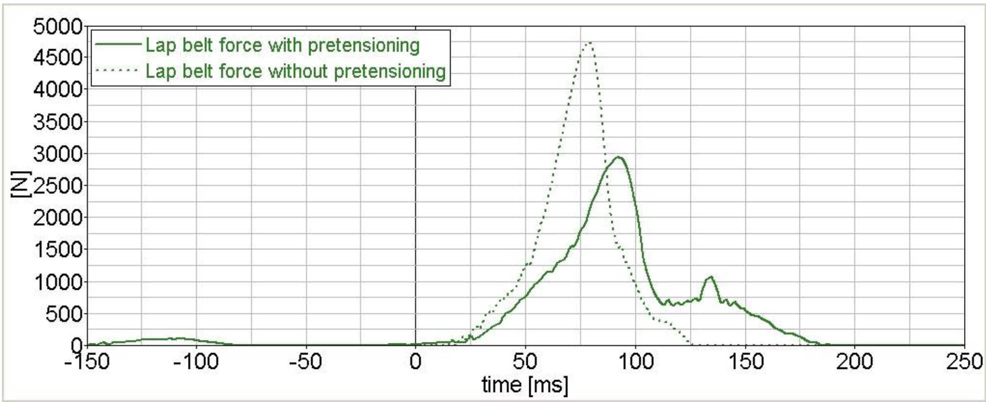

Figure 30 - Comparison of NEON occupant lap belt force with and without pretensioning

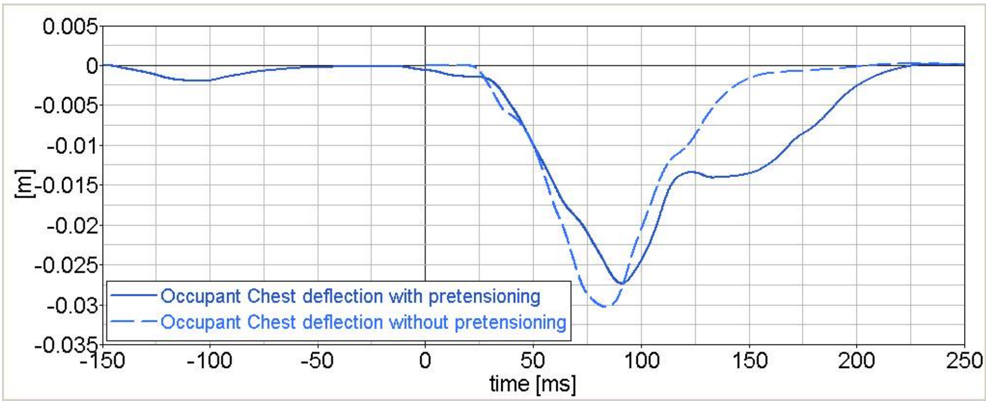

Figure 31 - Comparison of NEON occupant chest deflection with and without pretensioning

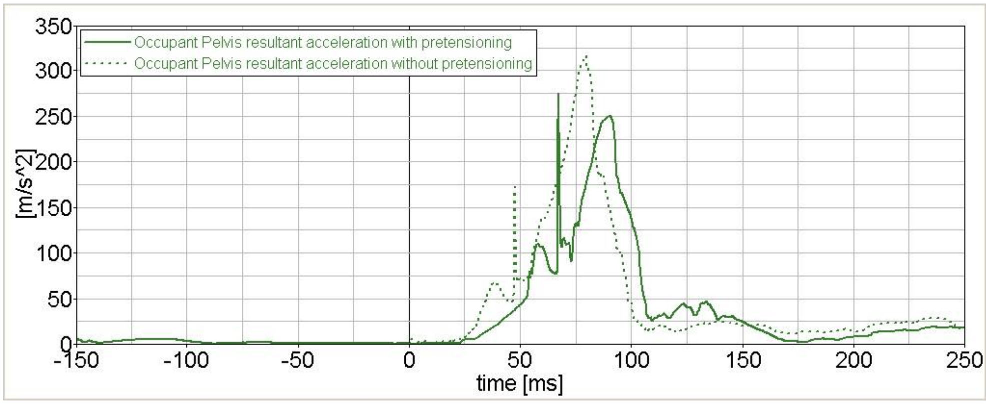

Figure 32 - Comparison of NEON occupant pelvis resultant acceleration with and without pretensioning

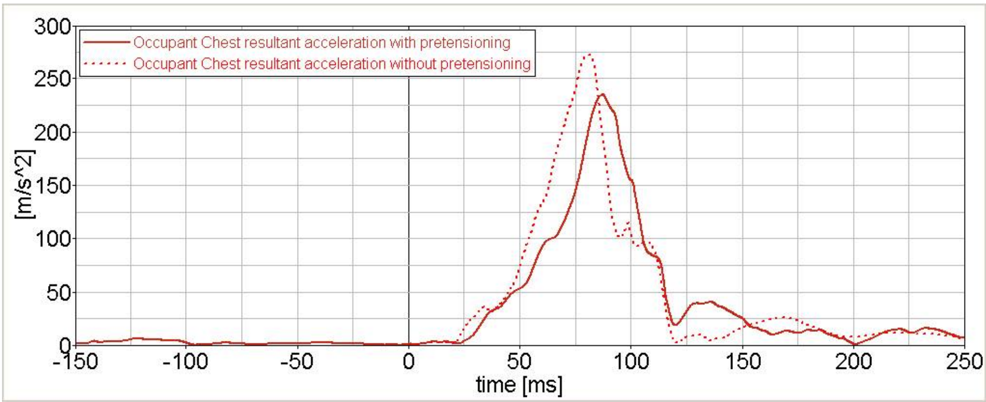

Figure 33 - Comparison of NEON occupant chest resultant acceleration with and without pretensioning

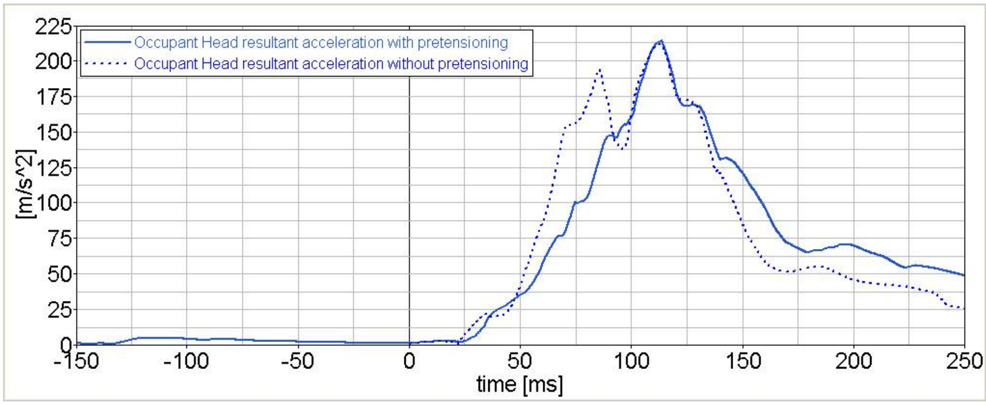

Figure 34 - Comparison of NEON occupant head resultant acceleration with and without pretensioning

Table 13 Comparison of biomechanical responses (peak values) of NEON occupant with and without pretensioning

Variable/parameter	pretensioning	no pretensioning
Shoulder belt force [N]	4746	5271

Lap belt force [N]	2943	4733
Head res. Accel. [m/s^2]	214	212
Chest res. Accel. [m/s^2]	235	273
Pelvis res. Accel. [m/s^2]	275	317
Chest deflection [m]	0.029	0.032
Combined thorax index	0.559	0.633

The results of this investigation indicate that pre-crash pretensioning has a beneficial effect on the driver response, providing lower loads during the crash event and thus resulting in lower levels of injuries. This can be explained by the fact that, as result of pretensioning, the driver is pushed backwards in the seat thus gaining additional space for energy absorption and dissipation during the crash.

7 Conclusions and discussions

The goal of Task 1.3 is to develop tools/methods to simulate real world accidents with validated vehicle crash models and to predict the injuries and/or the effect of engineering countermeasures like improved restraint systems on the injury risk of the occupants.

In general we can conclude from this investigation that generic vehicle crash models, which are validated with crash test data, can be used to predict injuries of the occupants and also the effects of improved restraint systems.
The conclusions of each phase of the investigation are:

1. Out of the PENDANT accident database the accident case UK8033 has been selected in which the two cars (Vauxhall Astra & Ford Fiesta) are involved in a frontal impact, both cars have been tested by Euro NCAP and represent different (mass) generic vehicle crash models. Despite the fact that the PENDANT cases contain at least one car newer than 1998, the selected cases with Euro NCAP cars do not represent very new cars (2002 and older).
2. The two generic vehicle models are validated with respect to the corresponding Euro NCAP front impact test data. The Vauxhall Astra is modeled with the Chrysler Neon generic model and the Ford Fiesta is simulated by the Geo Metro generic model. The corresponding stiffness functions of the longitudinals, shotguns and the connector are scaled and the crash pulses are fitted with Euro NCAP front crash tests.
3. The PENDANT accident case UK8033 is simulated and investigated. It is observed that the Vauxhall Astra has more damage than the Ford Fiesta as observed in the real accident. Although the air bag of the Vauxhall Astra was not deployed, the maximum acceleration is similar as that of the Ford Fiesta which had the air bag deployed. However, the combined thorax index, the cumulative 3 ms maximum and the HIC values of the driver of the Vauxhall Astra are higher than those of the Ford Fiesta. These may explain a severer head and neck injury of the driver of Vauxhall Astra.
4. The influence of an improved restraint system, namely a pre-crash pretensioning of the safety belt of the driver of the Vauxhall Astra, has been investigated. The pre-crash pretensioning has a beneficial effect on the driver response, providing lower loads during the crash event and thus resulting in lower levels of injuries. This can be explained by the fact that, as result of pretensioning, the driver is pushed backwards in the seat thus gaining additional space for energy absorption and dissipation during the crash.

8 References

[1] R.R.P. Rodenburg, *"Development of a Generic Vehicle Modelling Procedure for Compatibility Research"*, TNO Report 05.OR.SA.023.1/GKE, TNO Automotive, Delft, The Netherlands, June 2005.
[2] M. Lindquist, *"Real world car crash investigations, A new approach"*, IJCrash 2003 vol. 8 No 4 pp 375-384, Saab Automobile AB and Disaster Medical Centre, Sweden, 2003.