APROSYS Final Report

D9.1.1 I

Project no. **FP6-PLT-506503**

APROSYS
Advanced Protection Systems

Instrument: **Integrated Project**

Thematic Priority 1.6. Sustainable Development
Global Change and Ecosystems

Leading contractor: **TNO**
Issuing date: 26 October 2009

Authors
Margriet van Schijndel-de Nooij, TNO
Jac Wismans, TUG
Mervyn Edwards, TRL
Jürgen Gugler, TUG
Roger Hardy, CIC
Aquilino Molinero, CIDAUT
Jean-Pierre Verriest, INRETS
Joachim Tandler, Continental
Franck Delcroix, Altair

IP Coordinator
Margriet van Schijndel-de Nooij
TNO
Steenovenweg 1
5708 HN Helmond, the Netherlands
Phone: +31 40 2652639
Mobile: +31 653846379
Fax: + 31 40 2652601
Email: Margriet.vanschijndel@tno.nl

Start date of project: **1 April 2004** Duration: **60 months**

European funded project

APROSYS SP 9

Final APROSYS Report

Deliverable report; public

D9.1.1 I

AP-SP90-0008

Confidential level: Public

Executive summary

Background and vision

In spite of the significant improvements in vehicle safety achieved in the past 25 years, the current number of deaths and injuries plus all the associated social and economical costs, must be regarded as unacceptably high.

The European Vehicle Passive[1] Safety Network [1], a EU-funded Thematic Network provided the basis of the development of the Integrated Project (IP) Advanced Protection Systems (APROSYS). The road map [2] presented by the Network concluded that to achieve further advances and breakthroughs in the field of passive safety, future RTD work should focus on the development and introduction of critical technologies, i.e. integrated solutions, that improve passive safety for all European road users in all relevant accident types and accident severities. The research should extend from the design practice, which focuses on protection in a single or limited set of accident conditions, in particular a mid-sized male occupant in a standard accident at medium impact speed, to all road users in all accident types.

The European Union belongs to the largest car producing areas and car markets in the world. Research and Technological Development (R&TD) is essential for improving the impact motorized transport has on our society. Safety is one of the key issues in this respect. In the European Union, there are about 39.000 reported deaths (2008) [28] and 1.3 millions casualties as a result of road traffic accidents. The annual costs to the European Society due to these accidents are more than 160 billion Euro, which is twice the entire budget of the European Union [5]. Significant growth in the demand for transport of people and goods is foreseen in the next decades.

Passive safety (also called secondary safety) is one of the most important and effective strategies to reduce the number of road traffic victims. This strategy protects traffic participants in case an accident is happening by reducing the loads on the human body during the accident by technological measures like for instance restraint systems and vehicle designs. Passive safety has proven to be a very effective strategy to reduce the number of casualties among road users. For example, a study in the UK [3] demonstrated that the greatest contribution to casualty reduction was from passive safety improvements to vehicles in the period 1980-1996. These measures accounted for 15% reduction in casualties compared to 6.5% for road safety engineering measures.

The **vision** of the APROSYS project is that also in the next 30 years not all accidents can and will be prevented, in spite of very impressive developments in accident avoidance (accident-free traffic) and that in case of an accident is happening a significant higher level of protection can be offered though new secondary safety technologies. In particular technologies that combine active safety and passive safety strategies and more specifically also strategies that use information from the pre-crash phase to affect the crash phase are seen as very promising to reduce to the number of fatalies and the number and severity of injuries. This area is often identified as **integrated safety**. So APROSYS focussed on the scientific and technology development in this area. The field of passive and integrated safety concerns in particular human biomechanics (injury mechanisms and criteria), vehicle and infrastructure crashworthiness, sensing and control and occupant and road user protection systems.

---

[1] Primary, or active, safety: systems aiming at preventing an accident from happening
Secondary, or passive, safety: systems aiming at largely decreasing the effect of an impact

Goal and Objectives

APROSYS's **goal** is to offer a significant contribution to the reduction of road victims in Europe and in this way contribute to the road safety goals of the European Commission as defined for instance in the White Paper for transport. The **general objective** of APROSYS is the development and introduction of critical technologies that improve passive safety for all European road users in all relevant accident types and accident severities. Furthermore, APROSYS aims to increase the level of competitiveness of the European industry by developing new safety technologies (safety is a proven selling point) and by developing design tools (CAD) and evaluation methods that will increase the efficiency of the development process of the involved industries.

To reach these goals the emphasis in APROSYS has been placed on R&D topics with the greatest fatalities / injuries reduction potential. The choice for these topics was based among others on the PSN roadmap [2], state-of-the-art of technology reviews and extensive discussions with stakeholders. This resulted in the following 7 **scientific and technological objectives**:

1. **New injury criteria and injury tolerances**
2. **New mathematical models of the human body**
3. **New world-wide harmonized crash dummy**
4. **New knowledge and tools for intelligent safety systems**
5. **Enhancement of virtual testing technology**
6. **New test methods (for advanced safety systems)**
7. **Advanced protection systems for injury reduction in most relevant accident types**

These 7 project objectives have been evaluated on a regular basis. They remained valid until the end of the project.

Project Structure and external links

The APROSYS Integrated Project (IP) on Advanced Protective Systems which is started in 2004, is a European co-operation project co-funded by the European Commission. The project has 50 partners including a number of OEM's (Volkswagen, Fiat, Daimler, Fiat, Renault, Toyota and Nissan). The total duration of APROSYS is 5 years. In order to meet above objectives, the APROSYS project was structured in 7 strongly inter-connected sub-projects (SP's). Four of these subprojects concern 4 different accident types: SP1 car accidents, SP2 heavy vehicle accidents, SP3 pedestrian-pedal cyclist accidents and SP4 motorcycle accidents; the three other subprojects concern common technology area's: SP5 injury biomechanics, SP6 intelligent safety systems and SP7 virtual testing. The APROSYS project started with an accident investigation study delivering basic information to the vertical accident type subprojects.

The project is developed in the framework of e.g. the Integrated Safety (IS) Program of EUCAR [4], and in this way linked to other projects in both passive or primary and active or secondary safety. The EUCAR IS Programme has the objective to create a steady trend of decreasing number of traffic accidents and fatalities. Figure 1 shows how APROSYS is related to the EUCAR IS Program and its links to some other European projects. The time line, from left to right, shows the time to/after impact. In the minutes and seconds before a impact, a relatively long response time is available to avoid an accident; here vehicle-to-vehicle or vehicle-to-infrastructure communication is an important (future) technology. Projects like CVIS and Safespot focus on this "time frame".

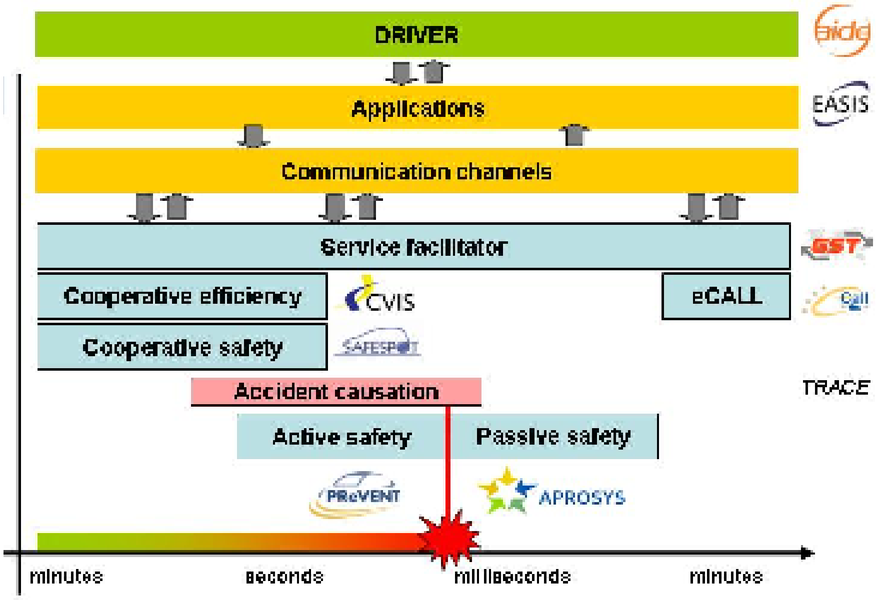


Figure 1: European research on Integrated Safety; courtesy of EUCAR

In the last second before the impact, active safety plays an important role (covered by the project PReVent). During the last milliseconds before an impact, passive safety plays the major role (as covered in APROSYS). After the impact, emergency calls can be made to increase speed and effectiveness of first aid (eCall). While the lower part of the graph focusses directly on impact prevention and impact mitigation, the upper part works more on the long term, largely decreasing the risk of an impact.

Other, strong relations have been established with stakeholders like EEVC, EuroNCAP and ISO, as shown in Figure 2, as well as with 5th, 6th and 7th Framework projects and proposals. These contacts are necessary to have valuable input to the project, but also to have a proper way of disseminating project results and have the stakeholders aware of the results, in an early stage. Furthermore, through the partnership there are strong links with industrial parties which will help in introducing project results in the automotive market.

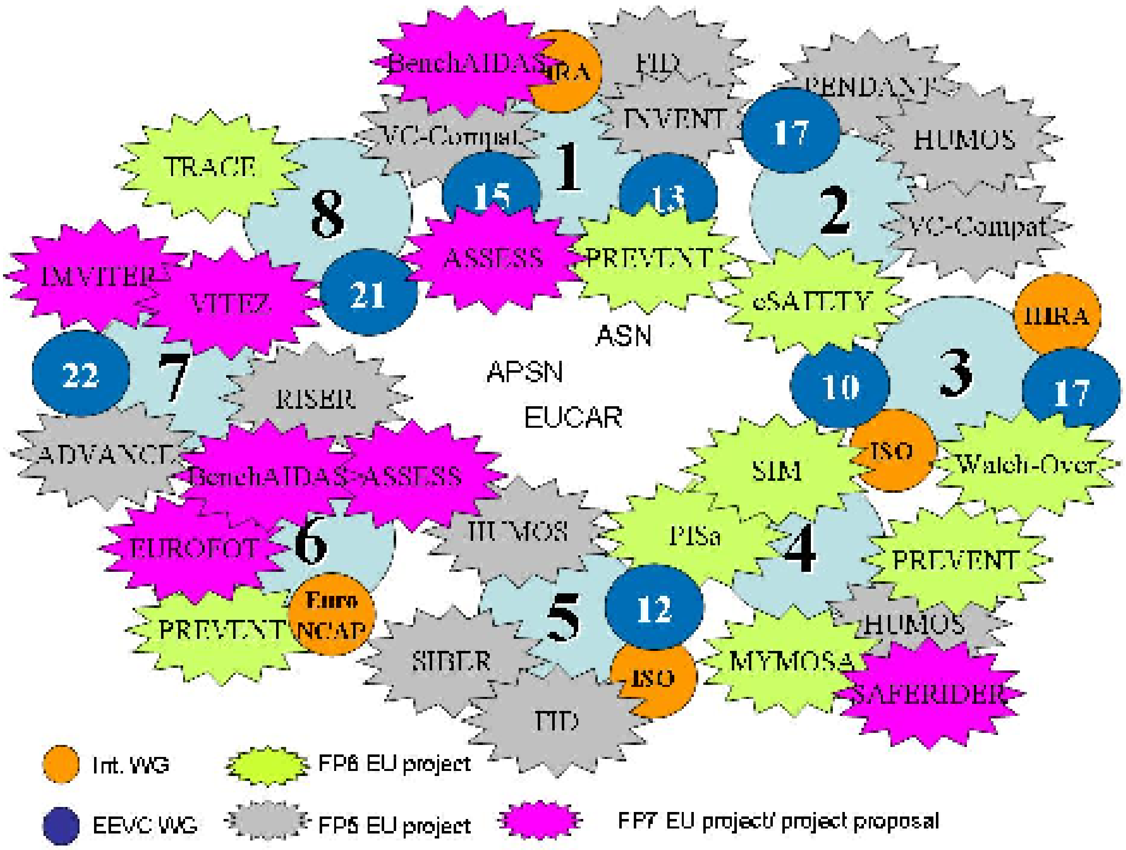


Figure 2: Graphical overview of the relations between APROSYS and other European projects and stakeholders.

Achievements

Within the project, many detailed results were delivered, varying from new protection methods, design tools (CAD) tools to new test and evaluation methods. In order to structure the various results they were integrated into the socalled 10 Main Results, all having a large impact on the safety problem. These 10 Main Results (MR) that together fully address the seven project objectives, are:

MR 1: New human body mathematical models

MR 2: WorldSID 5th percentile female dummy for side impacts

MR 3: Side impact protection system for car occupants,using pre-crash sensing

MR 4: Generic assessment methodology for advanced pre-crash safety systems,

MR 5: Generic car mathematical models,

MR 6: Virtual testing methodology

MR 7: Test methods for vulnerable road users,

MR 8: Full width frontal impact test for Europe

MR 9: New side impact test methods

MR 10: New protection systems for vulnerable road users.

The links between the project objectives and the 10 Main Results are illustrated in Figure 3. Note that these links are only the major ones due to the strong integration within the APROSYS project.

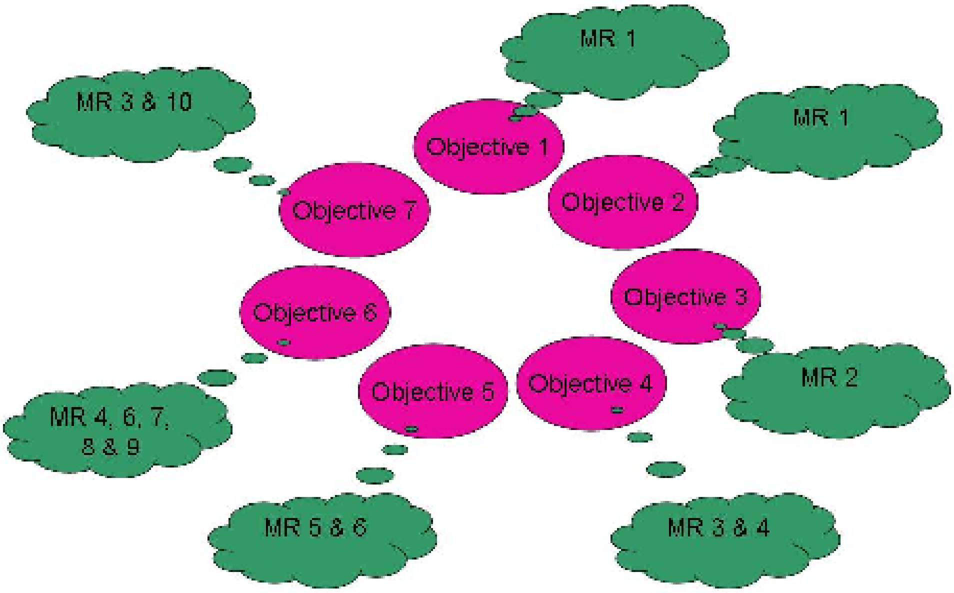


Figure 3: All objectives are covered by one ore more Main Results

A summary of the 10 Main results is given below.

MR 1. <u>New human body mathematical models</u>

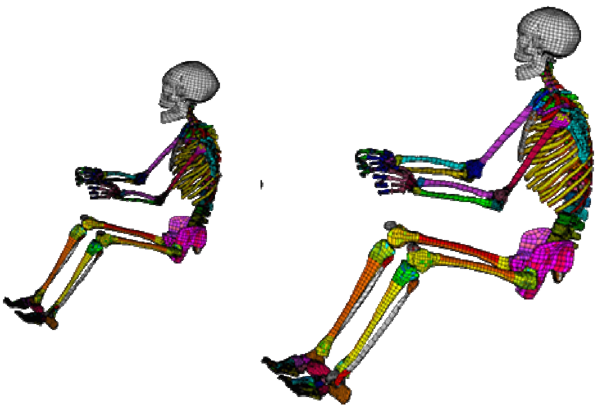


Figure 4: Effects of age and gender in new mathematical models of the human body

A number of human body mathematical modelling activities has been performed, dealing among others with active human body models for studying the pre-crash phase and the effect of age and gender on the structural behaviour of the human body, combined with related injury risks for several body parts. Figure 4 highlights these issues showing anthropometric differences between models due to age. The thorax, shoulder, abdomen, neck and leg have been addressed, also for the head, these relations were established. Concerning the brain, based on new animal tests, improved constitutive models were implemented, as shown in Figure 5, and detailed accident reconstructions were carried out in order to gain a better understanding of the injury mechanisms and to define injury criteria for the brain.

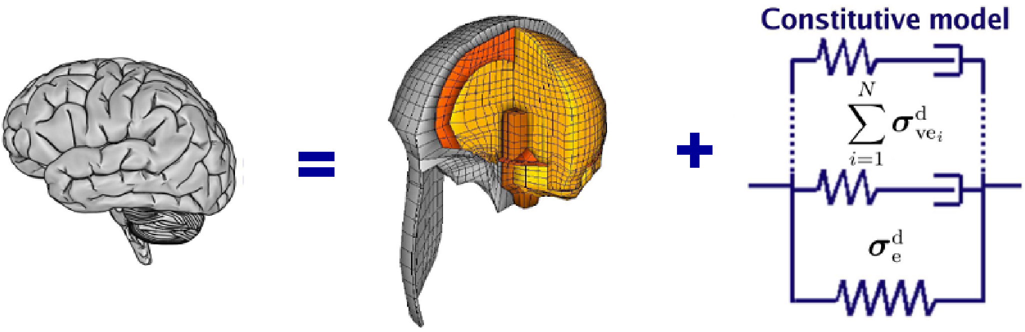


Figure 5: Brain material, head model and constitutive model

MR 2. WorldSID 5th percentile female dummy for side impacts

A new world-wide harmonised crash dummy has been developed in the framework of APROSYS. This has been deemed as the WorldSID 5th, a small female dummy for side impacts based on the 50th percentile version of this dummy. In 2006, the first prototype was released. After an extended series of evaluation tests and international discussions about harmonisation, a second prototype has been realised recently. This prototype is being under final evaluation now (outside of the APROSYS framework). The schematics of this new dummy are shown in Figure 6.

MR 3. Side impact protection system for car occupants

A new side impact protection system for car occupants was developed. Basically, it consists of a sensing and an acting part, linked through a decision logic unit. The sensor system is built around fusion of the data of radar and stereo vision, covering the side of a car. Based on the input from this sensor system, the decision logic can until a minimum of 200ms ahead of a side crash, release an actuator mechanism based on shape memory alloy in the side structure. This system supports mitigating the severity of the side impact by reducing the door velocity and intrusion. The side impact protection system has extensively been tested also in full scale test environment.

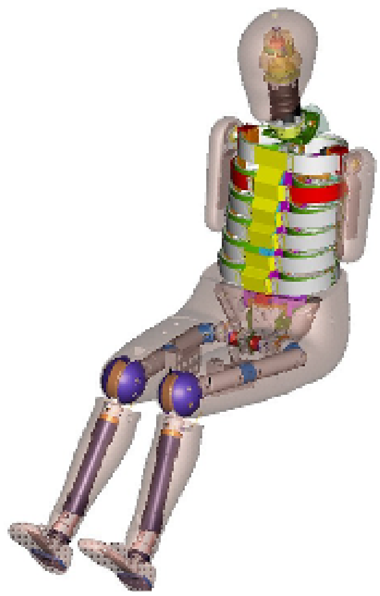


Figure 6: Schematics of the WorldSID 5th

MR 4. Generic assessment methodology for advanced safety systems

A clear trend in automotive safety is towards integrated safety, and towards application of adaptive safety systems. However, there is not yet a well-established test procedure for evaluation of such systems available. To cover this need, APROSYS has developed a generic assessment methodology for adaptive safety systems, taking into account the accident scenarios the system is intended for, the types of sensors used, etc. Using this assessment methodology gives a clear and independent insight in the effectiveness and efficiency of the system under evaluation. The set-up of this generic methodology is shown in Figure 7.

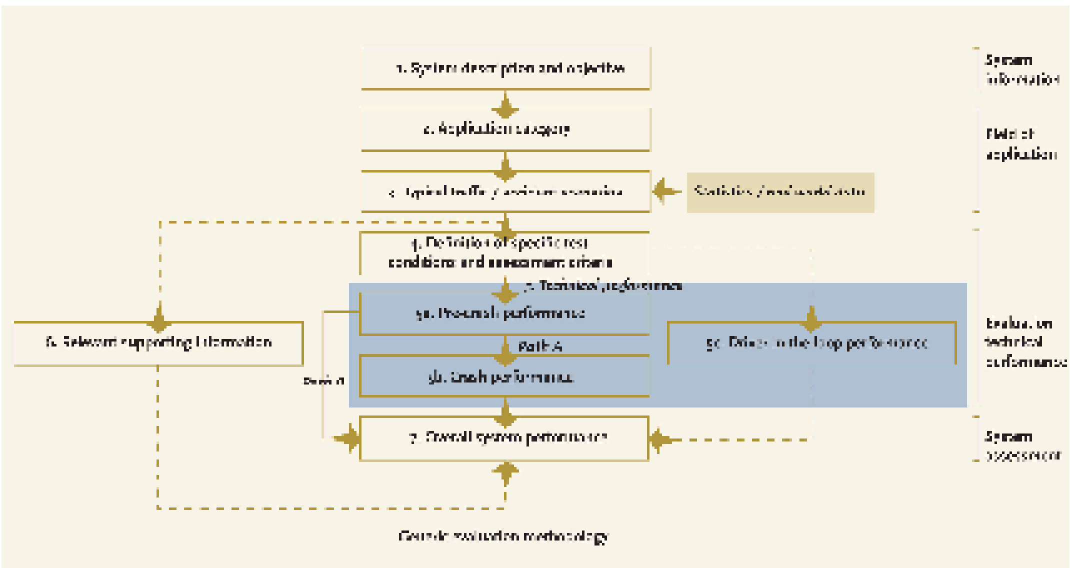


Figure 7: Generic assessment methodology for advanced safety systems

MR 5. Generic car mathematical models

In developing new safety measures for all road users, application of computer modelling for analyzing the crash has become common practice in many companies and institutes. However vehicle models used for such studies are usually in-house developed models representing a specific single vehicle type. There is a clear need for a set of generic vehicles models representing various vehicle classes that can be applied in a range of accident conditions and scenario's, including vehicle to vehicle, truck to vehicle, vehicle to pedestrian and vehicle to motor cyclist impacts. Such a set of models has been successfully developed within the framework of APROSYS for different types of techniques, such as finite elements and multibody models.

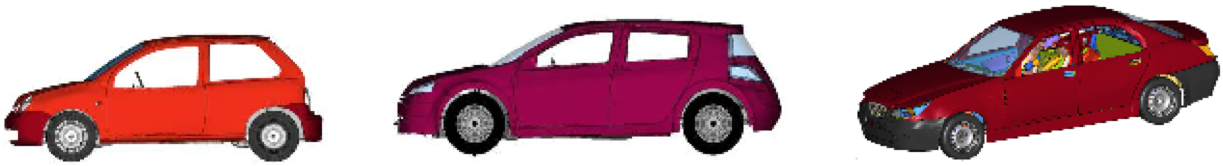


Figure 8: some examples of Generic Car Models

MR 6. Virtual testing methodology

Certainly, the future of vehicle and component testing for regulatory purposes will include virtual testing. The enhancement of the actual virtual testing technology for passive safety and the discussion and preparation of virtual testing tools for future regulatory purposes, have been major objectives for APROSYS. Virtual testing in vehicle safety is nowadays used very extensively in the vehicle design process, including the development of safety features. APROSYS has developed guidelines how to implement virtual testing in the regulatory environment and which analysis criteria to be used. This has been done, using demonstrators for analyzing pedestrian safety based on a hybrid approach using a multibody model for overall kinematics and a FE modelling approach for detailed local injury prediction. In a virtual testing roadmap, the path to implement virtual testing in current and new regulations has been described.
Figure 9 shows two examples on the use of virtual testing, developed in APROSYS, a truck impacting a pedestrian and a side impacted car.

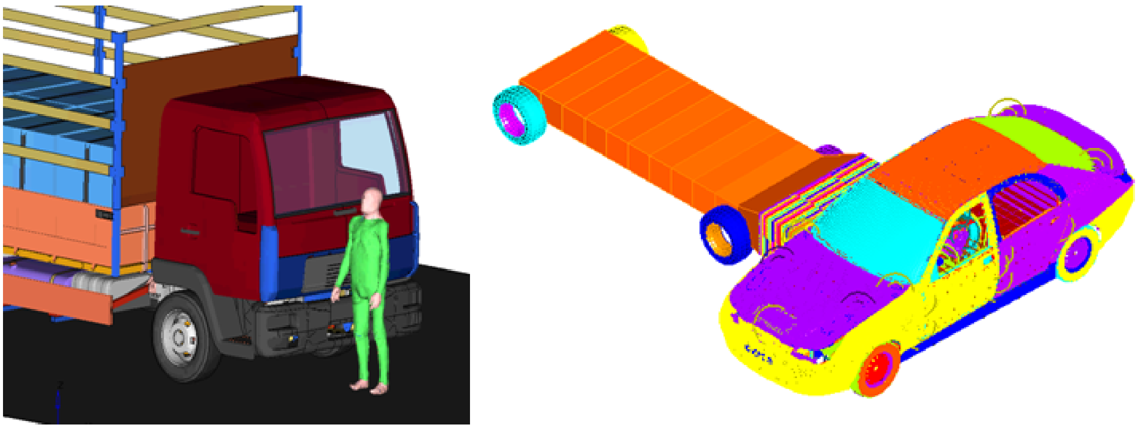


Figure 9: Use of GCMs to support (biomechanical) investigations

MR 7. Test methods for vulnerable road users

For vulnerable road users, i.e. pedestrians and (motor)cyclists, the main focus was on new evaluation methods. These evaluation methods include:

(1) Vulnerable road users impacted by heavy vehicles. For this, a Heavy Vehicle Aggressivity Index (HVAI, see Figure 10) has been developed. This index gives an indication of the risks of a heavy vehicle truck in case of an impact with other road users. There are three subjects in this index: a run-over factor, a vehicle structural factor and a field of view factor,

(2) vulnerable road users impacted by passenger

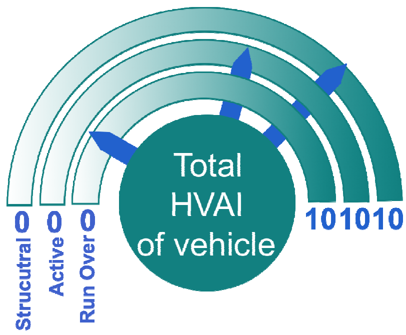


Figure 10: HVAI score for a test vehicle

cars. This includes new test procedures for pedestrian safety, including virtual and experimental testing and new impactors for head impact testing. In the work done here, it has become apparent that cyclist cannot be seen as a subgroup of pedestrians.

(3) motorcyclists. This includes the development of a reviewed standard for helmet testing, a road and misuse test standard for the deployment of active safety systems and a proposal for test procedures to evaluate road infrastructure in terms of motorcyclist safety.

MR 8. More realistic frontal impact tests

To assess the car's frontal impact crashworthiness, including its compatibility, an integrated set of test procedures is required. The European Enhanced Vehicle-safety Committee (EEVC) compatibility and frontal impact working group has recommended that this set of test procedures should contain both a full overlap test and an offset (partial overlap) test. Currently in Europe, only an offset test exists in regulation and consumer test programmes (EuroNCAP). Within APROSYS a full overlap test protocol appropriate for be used within Europe has been developed and evaluated. The evaluation considered issues such as the effect of having a deformable element in the test compared to a rigid wall and potentional assessment of the rear seat positions.

MR 9. New side impact test methods

In 2005 the International Harmonisation of Research Activities (IHRA) side impact working group proposed a 4 part suite of test procedures, to form the basis of harmonisation of side impact regulation world-wide and to help advances in car occupant protection. The 4 parts of the proposed procedures were: a Mobile Deformable Barrier test, an oblique car to pole side impact test, an interior headform tests and a series of side out-of-position tests. APROSYS has evaluated and developed this procedure further focus on a European perspective. One of the main achievements of the APROSYS work was the development of a new Advanced European Mobile Deformable Barrier (AE-MDB), a test including a new deformable barrier and the use of the WorldSID dummy.

MR 10. New protection systems for vulnerable road users

A large number of new protection systems for vulnerable road users have been developed within the framework of APROSYS. Examples are a safety bar add-on for trucks, active bumper strategies and pedestrian airbags on the windshield, an improved helmet design for motorcyclists and a thorax protector for motorcyclists, as shown in Figure 11. The commercial version of this thorax protector is planned to enter the market mid 2009. It therefore is a very good example of how international cooperation in EU projects leads to new, innovative products.

Figure 11: The new thorax protector

Discussion and future outlook

This report gives an overview of the project APROSYS, being the largest project in Europe in the field of passive and integrated vehicle safety. The project has run for 5 years and has resulted in a number of significant resulst as presented here.

The impact of the results and the research carried out in APROSYS on the European safety problem will become visible only to a small extent before 2010. The long lead time for the introduction of safety systems normally applicable in the automotive market and the slow renewal of the vehicle fleet, makes accordingly the impact of APROSYS largely to be expected in the period after 2010. General estimates on the future effect of passive safety measures have been made in the roadmap of future automotive passive safety technology development [2]. Estimates made by vehicle safety experts here are dependent on the collision type. The largest effects are predicted for frontal impacts namely a 50% fatality reduction due to new passive and integrated safety measures. For frontal impacts this is due to, among others, compatibility measures and the large scale introduction of intelligent safety systems. For side impacts a fatality reduction due to passive safety measures of 40% is predicted and for motorcycles and pedestrians, respectively 25 and 30% in this roadmap.

The APROSYS project has adressed a number of important technology development needs like presented by EEVC, EUCAR and ERTRACC.The work carried out within APROSYS has identified a number of further detailed research recommendations in the various area's covered by APROSYS. These recommmendations are included in the final SP reports (public documents) for each of the 7 APROSYS subprojects (see www.aprosys.com for download). [18]-[24]

For the new and improved test protocols and tools for side impact, frontal impact and pedestrian testing, discussions on its use and implementation in formal procedures are taking place with regulative bodies as well as industrial partners. Discussions with stakeholders like EEVC, EuroNCAP and ISO have contributed to the leap forward that the new developed protocols offer, as well as to their chance of being implemented in existing test and assessment programs.

Table of contents

1 Vision and objectives

1.1 Vision

The European Union belongs to the largest car producing areas and car markets in the world. Research and Technological Development (R&TD) is essential for improving the impact motorized transport has on our society. Safety is one of the key issues in this respect. In the European Union, there are about 39.000 reported deaths [9] (2008, EU 27) and 1.3 millions casualties as a result of road traffic accidents. The annual costs to the European Society due to these accidents are more than 160 billion Euro, which is twice the entire budget of the European Union. Significant growth in the demand for transport of people and goods is foreseen in the next decades.

Passive safety is one of the most important and effective strategies to reduce the number of road traffic victims. This strategy protects traffic participants in case an accident is happening by reducing the loads on the human body during the accident by technological measures like for instance restraint systems and vehicle designs. Passive safety has proven to be a very effective strategy to reduce the number of casualties among road users. For example, a study in the UK [3] demonstrated that the greatest contribution to casualty reduction was from passive safety improvements to vehicles in the period 1980-1996. These measures accounted for 15% reduction in casualties compared to 6.5% for road safety engineering measures.

The **vision** of the APROSYS project is that also in the next 30 years not all accidents can and will be prevented, in spite of very impressive developments in accident avoidance (accident-free traffic) and that in case of an accident is happening a significant higher level of protection can be offered though new secondary safety technologies. In particular technologies that combine active safety and passive safety strategies and more specifically also strategies that use information from the pre-crash phase to affect the crash phase are seen as very promising to reduce to the number of fatalies and the number and severity of injuries. This area is often identified as **integrated safety**. So APROSYS focussed on the scientific and technology development in this area. The field of passive and integrated safety concerns in particular human biomechanics (injury mechanisms and criteria), vehicle and infrastructure crashworthiness, sensing and control and occupant and road user protection systems.

APROSYS aims to contribute in a significant way to the future reduction of the number of fatalities and injuries as well as of the severity of injuries on European Roads. This challenge is in line with the ambition of the European Commission as defined in the White Paper that calls for a reduction in the numbers of deaths on the road by half in 2010 [5].

1.2 Objectives

APROSYS' **goal** is to offer a significant contribution to the reduction of road victims in Europe and in this way contribute to the road safety goals of the European Commission as defined for instance in the White Paper for transport. The **general objective** of APROSYS is the development and introduction of critical technologies that improve passive safety for all European road users in all relevant accident types and accident severities. Furthermore, APROSYS aims to increase the level of competitiveness of the European industry by developing new safety technologies (safety is a proven selling point) and by developing design tools (CAD) and evaluation methods that will increase the efficiency of the development process of the involved industries.

To reach these goals the emphasis in APROSYS has been placed on R&D topics with the greatest fatalities / injuries reduction potential. The choice for these topics was based among others on the PSN roadmap, state-of-the-art of technology reviews and extensive discussions with stakeholders. This resulted in the following 7 **scientific and technological objectives**:

1. New injury criteria and injury tolerances
2. New mathematical models of the human body
3. New world-wide harmonized crash dummy
4. New knowledge and tools for intelligent safety systems
5. Enhancement of virtual testing technology
6. New test methods (for advanced safety systems)
7. Advanced protection systems for injury reduction in most relevant accident types

In case of accidents with pedestrians and pedal cyclists the focus is on impacts with the front of passenger cars with special emphasis on injuries to children and elderly.
Concerning car to car accidents the focus is on the protection of car occupants in front and side impacts.
In case of heavy trucks accidents involving vulnerable road users and passenger cars striking the side of a truck will be considered and for motorcycle accidents the focus is on collisions with passenger cars and the infrastructure.

2 Background

2.1 Accident data

Accident data show that car occupants represent the majority of fatalities in Europe. In 1998, there was a total of 42.699 transport related fatalities, of which 24.218 car occupants [6]. In 2008, the number of fatalities still was 39.000. The distribution for different classes of road users is shown in Figure 12. Expected trends are shown in Figure 13. Next to car occupants the most important categories are the vulnerable road users: motorcyclists, pedestrians and cyclists. Included in the category “others” are, among others, truck occupants, drivers of agricultural vehicles and bus and coach occupants. This last category is estimated at about 150 fatalities a year [7]. The total number of registered non-fatal casualties is estimated to 1.3 million per year in Europe [8] and around 3.5 million if the non-routinely reported casualties are included. No equivalent distribution data of injuries for the various classes of road users are available but, it will be assumed here that injury frequency is roughly similarly distributed, although the type of injuries significantly varies among the different road user classes. The total annual costs of traffic related trauma in Europe is estimated to be 160 billion Euros [10].

The risk of being fatally injured varies significantly per road user class. For car occupants, this is 0.8 fatalities per 100.000.000 km travelled, for pedestrians and cyclists about 9 times higher (respectively 7.5 and 6.3 fatalities per 100.000.000 km) and for motorcyclist even 20 times higher.

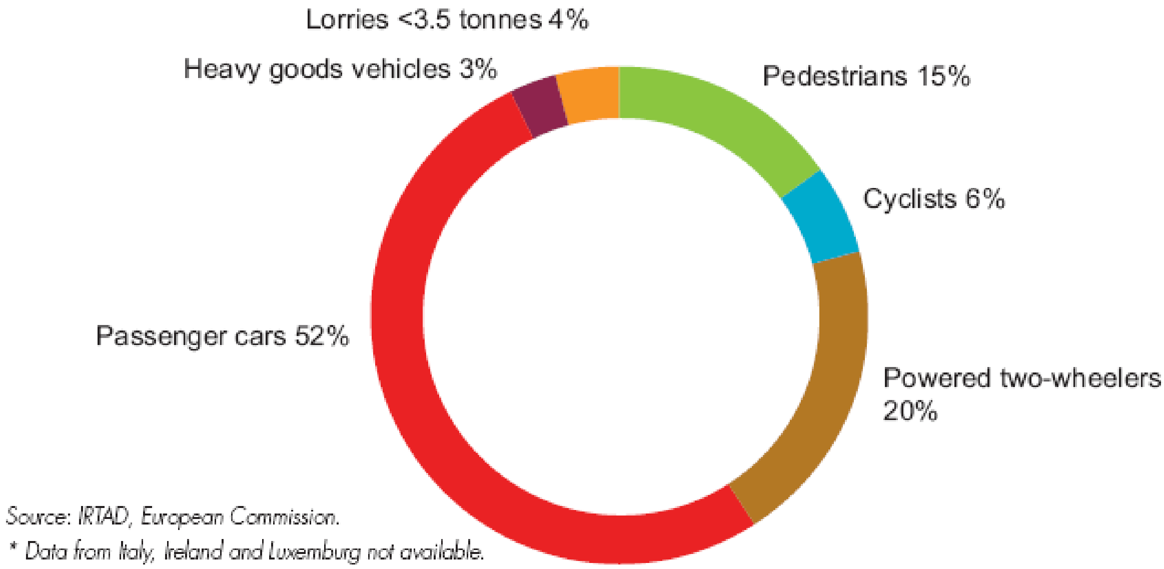


Figure 12: Distribution of road user fatalities in Europe among different classes of road user (2006, source: RTAD European Commission)[11]

More detailed accident data indicate that within the above mentioned classes of road users the following accident types are of particular importance (with the highest injury reduction potential):

- Car to car front and side impacts, taking into account compatibility issues,
- Cars to trucks collisions,
- Pedestrians and cyclists impacted by the front of a passenger car,
- Pedestrian and cyclists impacted by trucks,
- Motor cycle accidents with cars and with the road infrastructure.

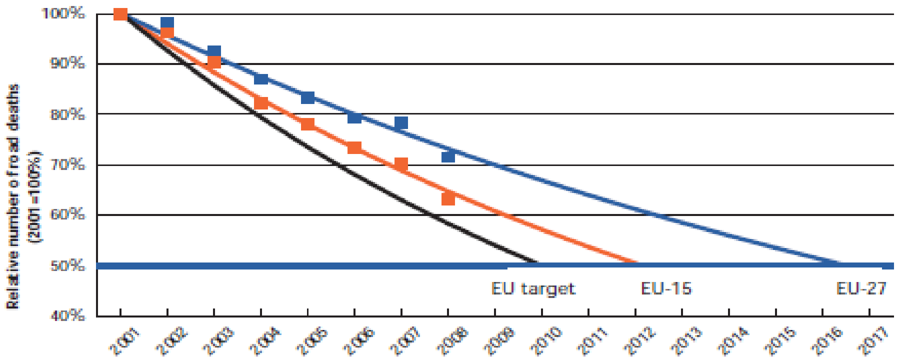


Figure 13: Estimated trends in road deaths in the EU15 and EU27, based on developments in 2001-2008 [12]

Based on accident data like this, available at the project start, it was decided to focus the work in APROSYS primarily on the major classes of road users indicated above: car occupants, motorcyclists, pedestrians and cyclists impacted by cars and trucks.

2.2 Roadmaps and stakeholder views

A summary of important future passive safety items, as identified in various roadmaps and as expressed by several stakeholders, is given in Table 1. These priority items have been taken as much as possible into account in the formulation of the APROSYS project and more specifically in the definition of the scientific and technological project objectives.

The **Roadmap of the PSN network** [2] concludes that to achieve further advances and breakthroughs in the field of passive safety, future RTD work should focus on the development and introduction of critical technologies (integrated solutions) that improve passive safety for all European road users in all relevant accident types and accident severities. In other words, the research should extend from the current design practice, which focuses on a single or limited set of conditions like a mid-sized male occupant in a standard accident at medium impact speed, to all road users in all accidents. Important topics of future RTD are in this respect:

1) Assessment of injury frequencies and types of accidents causing casualties.
2) Evaluation of regulations and countermeasures by accident investigations, generating new knowledge on injury mechanisms for relevant body parts like the head and lower legs.
3) Development of world-wide harmonised crash dummies for relevant impact conditions and body sizes.
4) Development of new harmonised test methods that also account for compatibility issues.
5) Development of reliable human body mathematical models for all body sizes.
6) Further enhancement of well validated virtual testing technologies and introduction of pre-crash sensing based technologies for new and optimised vehicle safety functions.

The **EUCAR Masterplan 2000** [4] clearly illustrates the relevance and appropriateness of passive safety R&TD with respect to the automotive industry needs and related societal priorities: *"Safety in road traffic stays a top priority for the automotive industry, authorities and the public. Progress in vehicle safety can be achieved by … passive safety, offering protection in the case of an accident. Important are design and development of new impact absorbing vehicle structures and materials, advanced restraint systems, pedestrian protection and emergency support."*

The **European Enhanced Vehicle-safety Committee (EEVC)** [13] indicated the following items as important for future research in the 6th Framework Programme: dummy development, side impact protection compatibility between vehicles, pedestrian safety, safety of children in cars and improvement of protection in rear impacts.

Euro NCAP indicated in 2003, among others, the following items as relevant for the next 2-6 years: a rollover test, harmonisation of world-wide NCAP's, internal head protection testing and smart systems and for the period from 6-10 years: compatibility, a additional full width frontal impact test and front and rear underrun protection.

Table 1: Important secondary safety topics as stated by stakeholders

PSN roadmap	**EUCAR Masterplan 2000**	**EEVC**
• Accident analyses • Improved injury criteria • New crash dummies • Test methods e.g. for compatibility • Virtual test methodology • Pre-crash sensing methodology	• New energy absorbing vehicle structures and materials • Advanced restraint systems • Pedestrian protection • Emergency support	• Dummy development • Side impact protection • Compatibility between vehicles pedestrian safety • Safety of children in cars • Improvement of protection in rear impacts
EuroNCAP • Rollover test • Harmonisation of world-wide NCAP's • Internal head protection testing smart systems • Compatibility • 2nd frontal impact test • Front and rear underrun protection (trucks)	**ETSC** • accident and injury causation • compatibility • protection in side • whiplash • motorcycle protection • intelligent restraints • front underrun protection (trucks) • injury criteria and crash dummies pedestrian head protection	

The **European Transport Safety Council (ETSC)** indicates as top priorities in the field of Passive Safety RTD: EU in-depth accident and injury causation, car frontal and side impact compatibility and advanced protection systems, protection in side impacts at higher severities and for non-struck side occupants, greater understanding of "whiplash" injuries and measures to improve motorcycle leg and upper torso protection. Other priority items for RTD include among others: development of advanced intelligent restraints, energy-absorbing front underrun protection, more comprehensive biomechanical data, injury criteria and improved crash dummies and pedestrian head protection measures for the windscreen surround.

2.3 European and National projects in the field of Passive Safety

Table 2 summarises the most important outputs from various European and National projects as used in APROSYS. For the description of the various sub-projects (SP's) in APROSYS see Paragraph 3.3.
Examples of results used are the harmonised adult (average male) crash dummies resulting from the FID (frontal impact) and SIBER (side impact) projects, the human body computer models resulting from the HUMOS 1 and 2 projects, results from the projects ADVANCE and VITES in the field of virtual testing (aimed at a wider acceptance of virtual testing methodology).
In Figure 2 the relations between APROSYS and other projects as well as international stakeholders like ISO and EEVC are shown.

Table 2: Summary of input from various EU projects used in APROSYS

SP no.	Link related to	Project name	Description
SP1	FP5	SIBER	WorldSID dummy test device
		ROLLOVER	Data to help define scenarios for OOP side airbag OOP test
		PENDANT	Date to help define the injury mechanisms for the non-struck side occupant in side impacts
		FID	New advanced frontal impact dummy test device (probably THOR)
		VC-COMPAT	Suite of fully developed test procedures to assess frontal impact compatibility
		PRISM	Information to give starting point for guidelines to evaluate the performance of adaptive systems
	FP6	GST	Critical accident data
		Prevent	APALACI sensor tech
SP2	FP5	Protector	Planned legilative rules
		Chameleon	Pre-crash sensing State of the art
		PENDANT	Real world accident information
		Prevent	Compose and APALACI sensor tech
SP3	FP5	SAVE-U	Sensor and active systems technology
		PENDANT	Available pedestrian and cyclist data
	FP6	Prevent	Compose and Apalaci sensor tech
	National	Programme input	UK On-The-Spot accident data project
			UK CCIS accident data project
			German GIDAS accident data project
			UK Pedestrian Protection study ref. DfT-S222C/VF
SP4	FP6	Prevent	Compose and APALACI sensor tech
		GST	Critical accident data
	National	Programme input	Spanish project in relation to motorcyclist safety problem, speciallyroad infrastructure accidents
SP5	FP5	SIBER	WorldSID dummy test device
		HUMOS2	General output from HUMOS
SP6	FP6	Prevent	Sub-Project COMPOSE: Radar and FIR front sensing subsystem
			Sub-Project COMPOSE, APALACI and USIRCEMS: Workshop side system
			Sub-Project COMPOSE, APALACI and USIRCEMS: Workshop crash sensing
SP7	FP5	VITES / ADVANCE	General output from VITES and ADVANCE including Adviser-tool.

Concerning accident data at the start of APROSYS important input was achieved through the projects MAIDS and PENDANT.

2.4 Relevance to EC Transport Policy

The need for a strategy and action plan on a European level to reduce the road casualty problem is well recognised by the European Commission. In 1997, the European Commission presented its Programme for 1997-2001: **"Promoting Road Safety in the European Union"**. In this document, the European Commission advocates a cost-benefit approach in the formulation of future road safety policy: there is economic justification for taking measures costing up to one million Euros in order to save a single life.

The more recent European Commission "**White Paper for Transport**", calls for a reduction in the numbers of deaths on the road by half in the current decade. The White Paper specifies the responsibility of the European Union and the role of new technologies to achieve this ambitious goal as follows: *"Though responsibility for taking measures to halve the number of road deaths by 2010 will fall chiefly to the national and local authorities, the European Union too needs to contribute to this objective, not just through the exchange of good practice, but also through action at two levels: harmonisation of penalties, and promotion of new technologies to improve road safety"*[10].

Reduction of the risk and severity of injuries in case an accident is taking place by means of vehicle and other safety technologies, being the scope of APROSYS, is one of the most effective strategies to reduce the road safety problem. Above described input and priorities from various projects and stakeholders, including the European Commission, has helped shaping the APROSYS RTD project, resulting in the specific project objectives described in Chapter 1 and the project approach outlined in the next Chapter 3.

3 Approach

3.1 The Integrated Safety Programme

APROSYS is part of the Integrated Safety Programme (ISP), a EUCAR initiative. This was composed at its start of five projects (Figure 14). The co-coordinating organization for every project is included in this Figure. Such ISP integrates through various projects a complementary set of relevant and innovative road safety strategies. Such co-operation between active safety research, passive safety and post crash research (rescue) is important to get a holistic safety concept. For APROSYS in particular the co-operation with PReVENT [14] appeared to be important in view of technologies for new types of pre-crash triggered protection systems. PReVENT deals with e-safety based technologies to prevent accidents happening (zero accident vision). The AIDE project [15] focus was on new methodologies concerning human machine interface (HMI) technologies required for a safe and efficient integration of in-vehicle information systems. The EASIS project [16] dealt with methodologies for increasing the safety and reliability of vehicle electronic driver assistance functions (dependability of electronic architecture in a vehicle). The GST project [17] focus was on technologies and services for a heterogeneous wireless vehicle network environment, supporting the establishment of safety-related functions.

At the start of the ISP a 6th project was proposed as well: ISAAC. This project dealing with accident data research was considered important as input for the other projects within ISP but it was not accepted by the EC. As a consequence within APROSYS some changes in the project objectives were introduced in order to obtain the required data directly within the project through a separate subtask (within subproject 8) and closer links to other European projects like TRACEand SafetyNet.

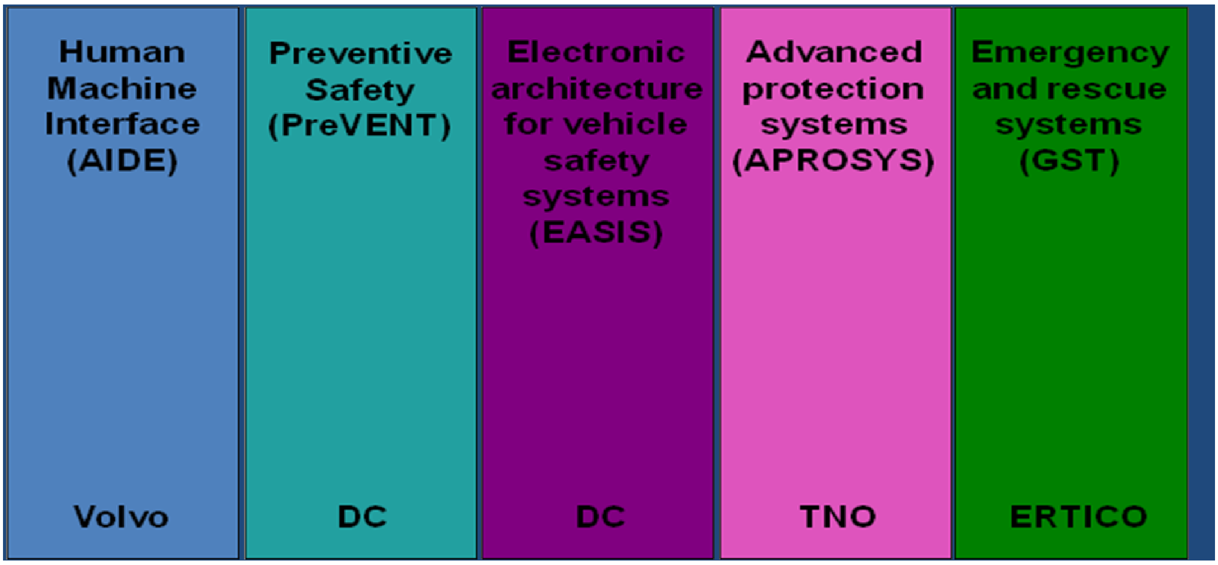


Figure 14: The EUCAR Integrated Safety Programme (ISP)

Under the implementation of ISP the involved projects were regularly monitored and assisted for a harmonised and consistent direction of research. In further calls within FP6 and more recently within FP7 a number of new R&TD projects have been initiated dealing with various methodologies contributing to the reduction of the road safety problem. For a recent overview of projects see the latest EUCAR project overview [4].

3.2 APROSYS structure

Based on general European accident data (see Chapter 2) in APROSYS the following accident types have been selected as the most relevant ones for developing new advanced passive and related integrated safety strategies (see also Figure 15):

- SP1: **car accidents** concerning the protection of car occupants including improved protection in car to roadside obstacle accidents and improved compatibility in car to car accidents;
- SP2: **heavy truck accidents** concerning accidents with pedestrians and accidents with passenger cars;
- SP3: **pedestrian and cyclist accidents** due to impact by a passenger car;
- SP4: **motorcycle accidents** with infrastructure and passenger cars.

These 4 accident types have been selected as separate “application” oriented sub-projects (SP’s) (vertical activities) within APROSYS These sub-projects are intended to result in significant reduction in fatality and injury numbers after implementation of the project results. Project deliverables within these accident scenario projects are aimed to directly contribute to the main objectives 6 and 7 of APROSYS (see Chapter 1) and in particular to new protection methodologies as well as new design and evaluation methods for these iaccident categories.

The starting point of the RTD activities in these accident scenario sub-projects are detailed accident data studies, specifying the most relevant accident conditions within each accident type. The next phase in the methodology generally consists of virtual and experimental evaluations of the most relevant accident scenarios as a basis for the development of countermeasures and evaluation methods. The last phase is devoted to the development and evaluation/validation of new advanced protection methods.

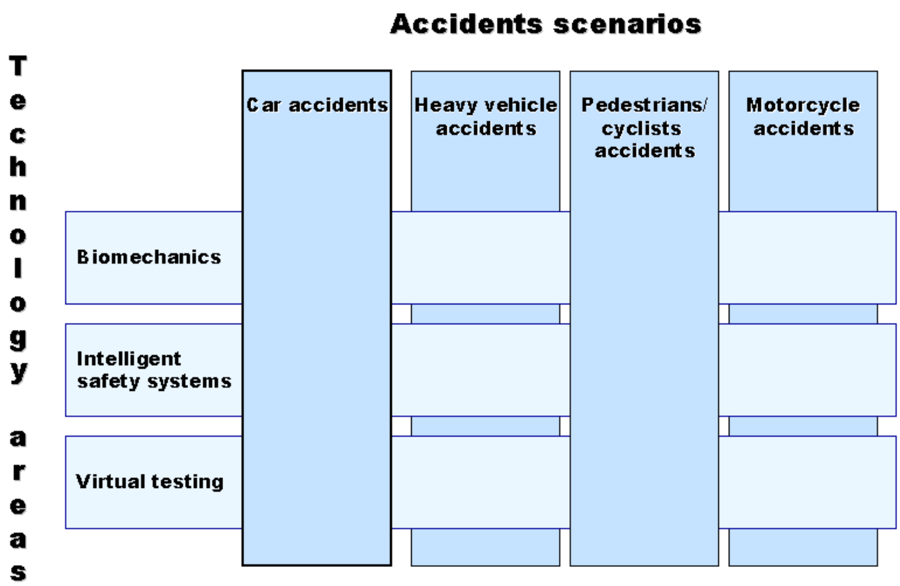


Figure 15: Accident scenarios and technology areas

In addition to the 4 accident type sub-projects, three technology focussed sub-projects have been defined (horizontal activities):

- SP5: **injury biomechanics**, dealing with new knowledge on injury mechanisms, injury criteria and human substitutes.
- SP6: **intelligent safety systems**, dealing with advanced sensor (pre-crash sensing) and actuator technologies.
- SP7: **virtual testing**, dealing new computer simulation technologies.

The primary focus in these technology sub-projects is on deliverables that will be used directly in the 4 accident scenario sub-projects such as new injury criteria or new tools like a crash dummy. But in addition these projects will lead to new technologies that will be implemented outside APROSYS and as such will directly contribute to the reduction of the road safety problem. Moreover a number of the results from these technology sub-projects will lead to significant advancements in the design process within the automotive industry as regards the design of future new safety systems.

In addition to these 7 R&TD sub-projects, two more sub-projects have been defined, one dealing with “training and innovation-related activities” (SP8) and one with the “integrated project management” (SP9). SP 8 includes a separate supportive work package on accidentology. All sub-projects are organized in a number of work-packages (WPs). An overview of the project structure is given in Figure 16. A brief description of SP 1-7 is given in Paragraph 3.3.

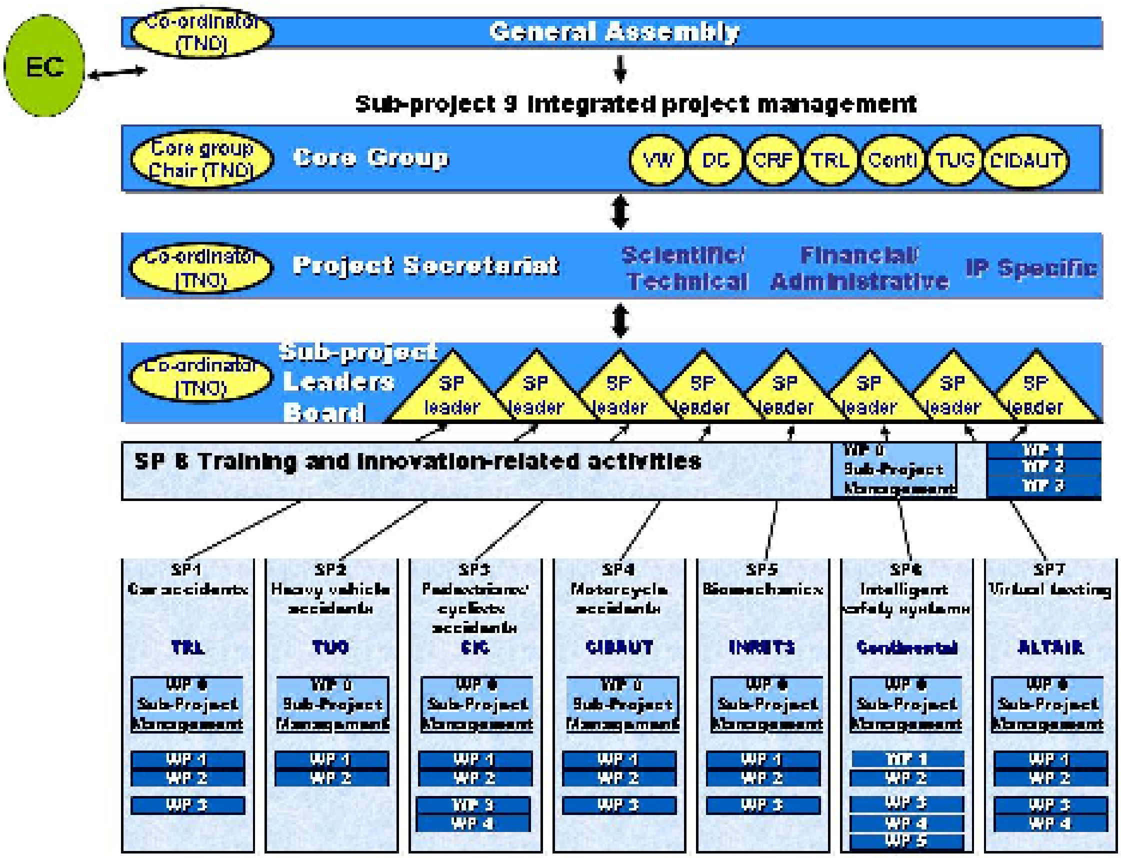


Figure 16: APROSYS Project structure

3.3 Overview of sub-projects

3.3.1 Sub-project 1: Car accidents

The main objective of the sub-project car accidents is to reduce the number of fatalities and serious injuries in car accidents. More specifically side impacts, frontal impacts and adaptive safety systems will be addressed. Results include:

- The development and evaluation of the draft suite of test procedures as proposed by the International Harmonization of Research Activities (IHRA) side impact working group. An MDB test, an oblique pole test, a free motion headform test and occupant Out of Position (OOP) testing.
- A high deceleration Full Width impact test. Issues that will be considered include, what dummies (THOR dummy vs. HYBRIDIII) to be used, whether or not the barrier should have a deformable face so that compatibility measures can be taken and whether or not the rear seated position should be assessed.
- Methodologies for evaluating adaptive safety systems. The implications of intelligent vehicle safety systems for regulation will be identified and methodologies to evaluate the sensor and actuator parts of these systems will be developed and demonstrated.

3.3.2 Sub-project 2: Heavy vehicle accidents

The objective of the sub-project heavy trucks is to reduce the number of both fatal and serious injuries in Europe due to accidents where heavy vehicles are involved. More specifically advanced protection systems including compatibility strategies will be developed dealing with the protection of pedestrian/cyclists in accidents with trucks and the protection of occupants of cars impacting the sides of trucks. Results include:

- Development strategies for enhanced pedestrian and cyclist friendly truck front design.
- Active protection system for the front structure with speed dependant and/or pre-crash sensing based activation.
- Development strategies for enhanced truck and trailer design including all-side under-run prevention systems for new truck and trailer concepts.

3.3.3 Sub-project 3: Pedestrian/pedal cyclist accidents

The overall objective of the sub-project pedestrian/cyclists is to pave the way for the introduction of advanced protection systems for the reduction of the number and severity of injuries to pedestrians and pedal cyclists in all relevant accident scenarios involving cars, MPVs and SUV’ s. The aim is to reduce fatalities and severe and moderate injuries, in particular for the priority vulnerable user groups of children and elderly. Results include:

- Detailled statistics for pedestrian and cyclists accidents.

- Geometric and stiffness corridors for the European vehicle fleet.
- New material models for laminated glass and fibre reinforced plastics (FRP).
- New and improved vehicle test methods to assess vehicle – vulnerable road user impact safety; in particular to ensure that there are the same benefits for cyclists as for pedestrians.
- New techniques for building vehicle front ends to improve compatibility with vulnerable road users, like airbag deployment technologies and redesigned front-end geometry..

3.3.4 Sub-project 4: Motorcycle accidents

The main objective of sub-project motorcycle accidents is to reduce the number of motorcyclists killed or seriously injured in the main motorcycle accident scenarios focusing on developing forgiving road infrastructure and the improvement of helmets and other protective clothing. Results include:

- Identification of the main accident scenarios for motorcyclists.
- Injury characterization for motorcyclists in the identified accident scenarios.
- A new draft test procedure for rider-infrastructure interaction.
- Guidelines to design motorcyclist friendly roadside infrastructure based on this draft test procedure.
- Design concepts and prototypes for innovative motorcyclist protective equipment and clothing.

3.3.5 Sub-project 5: Biomechanics

The objective of the sub-project biomechanics is to develop new biomechanical knowledge and tools in particular in support of the application oriented subprojects. Results include:

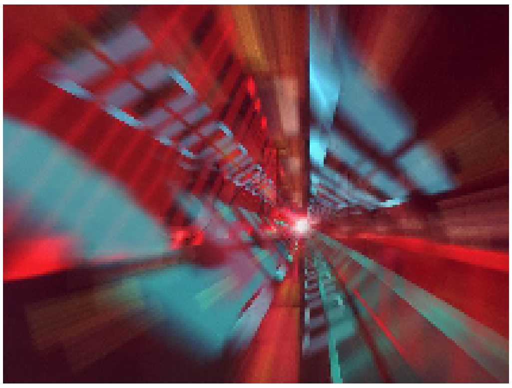
- Injury criteria for the next generation of frontal and lateral cash test dummies i.e. the THOR and the WORLDSID dummy.
- A new numerical model for the prediction of head injuries in various accident scenarios.
- The development of a small female version of the WORLDSID side impact crash test dummy along with its finite element numerical counterpart.
- The development and validation of a set of finite element human body models based on the HUMOS 2 project. Their capability to reproduce the behaviour of real humans, including muscular reactions and pre-crash emergency manoeuvres, and to predict the risk of injury will be enhanced.

3.3.6 Sub-project 6: Intelligent safety systems

The objective of this sub-project is the development of knowledge and tools enabling the design, implementation and evaluation of intelligent pre-crash safety systems. Pre-crash safety systems consist of anticipatory crash sensors with related scene modelling algorithms coupled to active safety devices via decision algorithms embedded in control units. The research focus is on development of (pre-competitive) technologies for each of these parts as well as the development of methodologies and related numerical and experimental tools for the design and evaluation of systems. The project is intended as a technology showcase demonstrating the potential of a combination of different advanced technologies for improvement of the crashworthiness behaviour. Whilst front and side crashes occur with comparable frequency, the risk of an injury from a side crash is much higher. This is due to the short distance between an occupant and the incoming object. For the same reason, existing in-crash sensing technology does not allow for timely deployment of collision mitigation measures. This SP addresses technology gaps and develops a suitable integrated side pre-crash sensor and actuator system. Knowledge of state-of-the-art technologies and advanced methods and design tools is applied to implement and evaluate these intelligent safety systems.

3.3.7 Sub-project 7: Virtual testing

The main objective of this sub-project is to provide a solid theoretical and industrial background to issues related to virtual testing procedures and applications. Various models, methodologies and tools are developed and pioneer procedures are investigated and proposed. Results include:



- Numerical car models to be used as bullet cars and prototypes for studies to the introduction of new passive safety devices.
- Numerical deformable barrier models (experimental or regulation based).
- Material models and identification procedures.
- Procedures for rating and evaluation of numerical models compared to experimental counterparts.
- A virtual testing demonstrator for regulatory applications and corresponding procedures.

3.3.8 Accident analysis Task, part of SP8

The main objective of the accident analysis Task is to collect and analyze supporting accident data to be used in the other sub-projects. Results include:

- Input for the benefit part of the SP1 cost benefit analyses for the introduction of each part of the test procedures to improve side impact protection proposed by IHRA.
- Input for the benefit part of the SP1 cost benefit analysis for the introduction of a full width high deceleration frontal impact test in Europe, including the relevant information for the assessment of rear seated occupants.
- Characteristics of accidents of heavy trucks versus pedestrians and cyclists, only front and side impacts are investigated. Statistical distributions of main collision parameters and specifications of typical crash types.
- Characteristics of accidenst of heavy trucks versus passenger cars, only oblique and side impacts are investigated. Statistical distributions of main collision parameters and specifications of typical crash types.

3.4 Project integration and co-operation within APROSYS

Various types of project integration and co-operation aspects can be distinguished **within** APROSYS. Concerning **external** cooperation and integration in particular the integration through the Integrated Safety Program is already decribed in Chapter 3.1.

Integration within APROSYS concerns in particular:

- the contributions from the various sub-projects to the 7 main objectives of APROSYS, see Chapter 1 for a description of the main objectives.
- the use of deliverables from sub-projects (output) as input in other sub-projects.

The contributions of the sub-projects to the main APROSYS objectives are summarized in Table 3. In this Table the sub-project contributions are split in direct contributions (A), marked ‘green’ and indirect contributions (B), marked ‘orange’. In case of indirect contributions, the results of the sub-project have been used by other sub-projects to meet the main APROSYS objectives.

Table 3: Sub-project contributions to the APROSYS objectives

Sub-project \ Objective	1: Injury criteria	2: Human models	3: Dummy	4: Intelligent systems	5: Virtual testing	6: Test methods	7: Protection Systems
Cars SP1	B	-	B	A	B	A	A
Trucks SP2	B	B	-	-	B	A	A
Pedestrians and cyclists SP3	B	B	-	-	B	A	A
Motorcycles SP4	B	B	-	-	B	A	A
Biomechanics SP5	A	A	A	-	B	B	B
Intelligent vehicles SP6	-	-	-	A	-	B	B
Virtual testing SP7	B	B	B	-	A	B	B

As can be seen, for each of the objectives at least two sub-projects have delivered a contribution, but in most cases addressing the objectives is done based on results of four or even more SPs. The co-operation between the APROSYS sub-projects is illustrated in Table 4. This table shows which sub-projects have used the results of other sub-projects in order to meet together the main APROSYS objectives. Green (+) indicates input from the sub-projects in the left column to the sub-projects in the upper row.

Table 4: Relations between APROSYS sub-projects; use of results of other SPs

from \ by	SP1	SP2	SP3	SP4	SP5	SP6	SP7
SP1	X	-	-	-	+	+	-
SP2	-	X	-	-	-	-	+
SP3	-	-	X	-	+	-	+
SP4	-	-	-	X	-	-	-
SP5	+	+	+	+	X	-	+
SP6	+	-	-	-	-	X	-
SP7	+	+	+	+	+	-	X

The following observations can be made:

- The four accident scenario based sub-projects have their own field of operation, which explains that there are direct links between these sub-projects. But of course there were many indirect links and exchange of information between these sub-projects.

- Results from sub-projects "Injury biomechanics" and "Virtual testing" have been used by all accident scenarios related sub-projects.

As shown in Table 4, the "Intelligent vehicle" activities have less interactions with the other sub-projects than the other activities. However there was a closed co-operation between sub-project 6 and sub-project 1 concerning assessment methods for integrated safety systems.
Examples of close interactions amongst SPs are summarised in Table 5. It shows some important examples of inputs and outputs exchanged between SPs, which were only fully possible in the framework of an Integrated Project.

Table 5: Examples of cooperation between sub projects

SP1	▪ A numerical study was carried out to the effect of different test parameters on the outcome of a car to pole side impact test. The study has been carried out using the generic vehicle model (GM3) as developed by SP7. ▪ Two full scale side impact tests, using an AE-MDB as developed by SP1, were carried out using the WorldSID5th dummy as developed by SP5. The injury risk curves for this dummy, as defined by SP5, will be used to analyze the results. ▪ The Generic Assessment methodology for advanced safety systems was built on input from SP 6, and their concept test methods.
SP2	▪ Human body models were used from SP5 to study the accident scenarios and to derive protection strategies. ▪ The generic truck and trailer models from SP7 were the basis of the virtual studies and demonstrator designs. ▪ SP8 supported with relevant accident statistics as basis towards the scenario definition. ▪ The aggressivety of front end of trucks has been evaluated with current dummies but also with the full body human model as developed in SP5.
SP3	▪ The stiffness and shape of car fronts (bumper and bonnet leading edge) have been evaluated through computer simulations using Generic Car Models (GCMs) from SP7 to identify parameters that can be adjusted to improve vulnerable road user safety. ▪ The Human leg model LLMS updated in SP5 was used to evaluate the aggressivety of car front end geometries. ▪ The Head FE model as developed within SP5 is used to evaluate the consequences of an impact on the bonnet. ▪ Simulations of pedestrian full-scale tests and subsystem tests have been carried out using the computer models as developed by SP7.
SP4	▪ A new helmet design has been developed and its performance was assessed on the basis of new biomechanical criteria developed under SP5. ▪ The information from SP5 was used to define the parameters for performance of crash tests dummy against infrastructure. ▪ Generic Car models as developed in SP7 have been used in the simulations of motorcycles against car impacts for the development of innovative passive safety systems.
SP5	▪ Demonstrators of usability of human models have been tested in accident simulations using generic car models provided by SP7. ▪ The SP 4 helmet models were used for coupling to the updated human head model, in order to perform simulations for model validation.
SP6	▪ Concept test methods of SP6 have served as a starting point for the development of a generic test methodology in SP1. The draft methodology has been used to evaluate the SP6 side impact protection system. Feedback is given back from SP6 to SP1 in order to enhance the draft generic test methodology.
SP7	▪ Input from SP 3 has been used for the development of models for the performance of full scale pedestrian simulations. ▪ Human body models from SP 5 were used in the simulations that finally results in the road map for virtual testing.

3.5 Project management

The overall organisation and structure of the APROSYS IP-management is illustrated in Figure 16. The general assembly consists of representatives of each partner of the IP. This group monitored the progress of the IP, consolidated its activities and has proposed decisions to the Core Group.
The Core group consists of high level representatives of the key project partners. The Core Group was responsible for strategic issues of the project and its role was of particular importance in the initial stage of the project. They were involved in the project reviews and the approval of work programs.

Day-to-day management of project on the consortium level was carried out by TNO, as the coordinator of the project. This involves technical / scientific as well as financial / administrative management. Specific tasks of the day-to-day management included:

- Monitoring scientific progress and project finances;
- Reporting of the project status, submission of deliverables and other reports, discussions on the project contents and next steps as well as workplans with the European Commission;
- Organisation of meetings of the general assembly, Core Group meetings and sub-project Leaders Board Meetings.
- Receiving, compiling and distributing of documents; technical reports, financial statements, meetings' minutes as well as other information to the partners and other relevant parties;
- Organisation of training activities and workshops.

The management of the sub-projects is carried out by the sub-project leaders. This involves:

- managing the technical and financial progress of the sub-project;
- reporting to IP management and sub-project Leaders Board Meetings with respect to financial and scientific progress;
- organisation of dissemination activities;
- chairing of sub-project meetings, with WP leaders and project partners.

4 Project achievements

From the project start on, work was performed in several technical sub-projects. These activities led to a lot of results, ranging from test procedures and test objectives to prototype protective devices and safety systems demonstrators.
Although a lot of cooperation amongst the SPs was found, from the results were for a long time mostly related to a certain SP. After some years of work in the project, an integration phase was started to incorporate SP results into clusters of results, consequently showing better the main outcomes of the project and its leap forward in the field of road safety.
In this integration phase of the project, many of the project results were combined into the 10 Main Results. The general objectives and the Main Results are summed in Table 6.

Table 6: APROSYS general objectives and the Main Results

General project objectives	APROSYS Main Results
1. New injury criteria and injury tolerances 2. New mathematical models of the human body 3. New world-wide harmonized crash dummy 4. New knowledge and tools for intelligent safety systems 5. Enhancement of virtual testing technology 6. New test methods (for advanced safety systems) 7. Advanced protection systems for injury reduction in most relevant accident types	1. New human body mathematical models 2. WorldSID 5th percentile female dummy for side impact 3. Side impact protection system for car occupants 4. Generic assessment methodology for advanced safety systems, 5. Generic car mathematical models, 6. Virtual testing methodology 7. Test methods for vulnerable road users 8. Full width frontal test for Europe 9. New side impact test methods 10. New protection systems for vulnerable road users

Figure 17 shows the relations between the general project objectives (outer circle) and the Main Results (inner circle). The area in the middle shows an image representative for the Main Result. It thus can be seen that with these project results, all general project objectives are addressed. Furthermore, it becomes clear that some Main Results address more then one objective, and on the other hand, that some objectives are addressed by more then one Main Result.
First, section 4.1 shows the relation between the Main Results and the project objectives, per MR, including some information on the ownership and exploitation.

In this chapter, a description is given of the 10 Main Results, giving a good overview of the overall achievement of the project APROSYS.
More in-depth information can be found in the dedicated Final SP reports, each describing the main achievements of an SP within the framework of APROSYS [18], [19], [20], [21], [22], [23] and [24]; all available through www.aprosys.com.

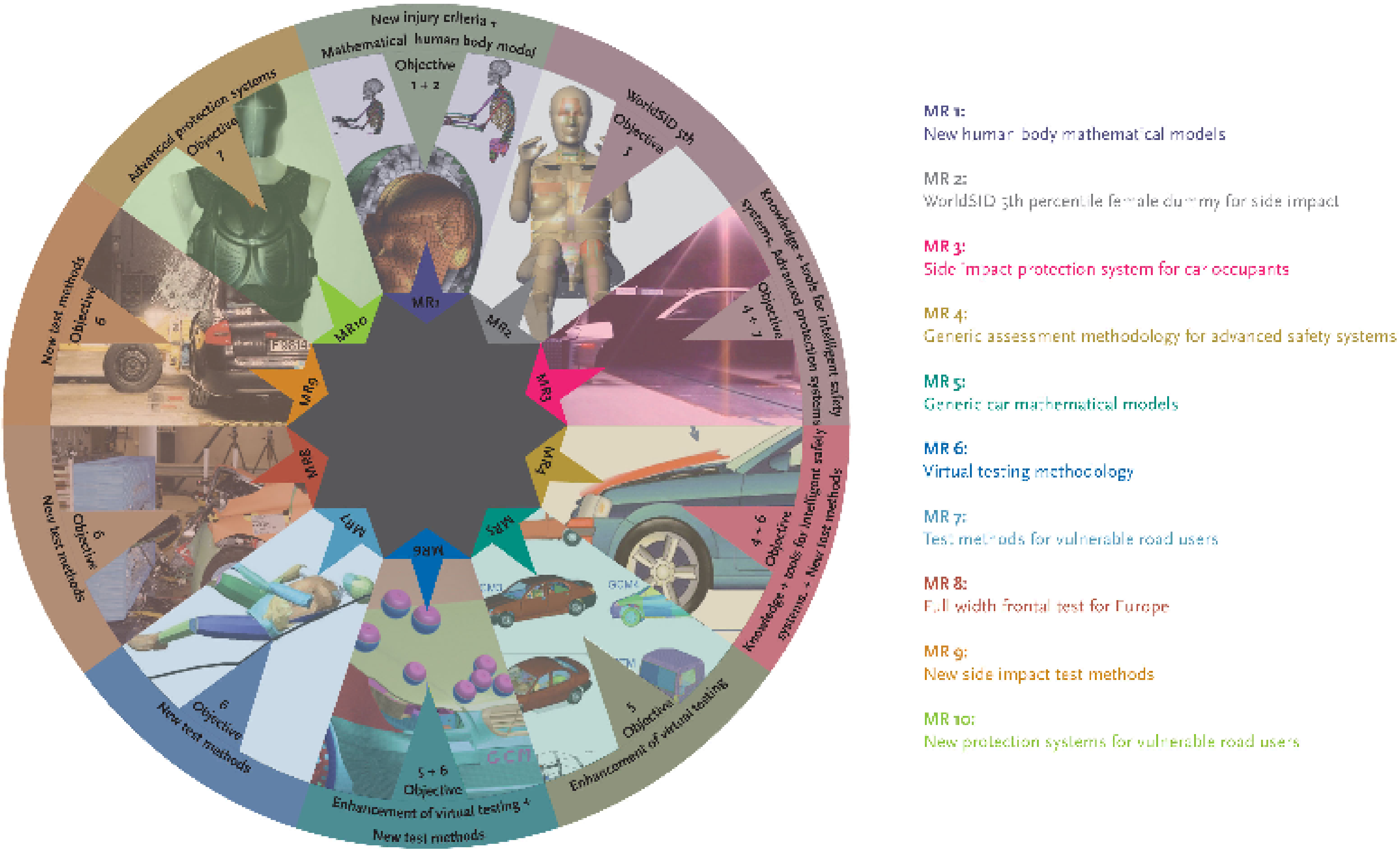


Figure 17: Relations between Main Results and objectives

4.1 Link between the Main Results and the project objectives

This paragraph reflects the link between each of the Main Results and the project objectives. It shows how these Main Results cover the original objectives, see also Figure 3. Here, it can be easily seen that all seven original project objectives have been met. To show the relations between the objectives and the MR in more detail, slices from Figure 17 are used and illustrated.

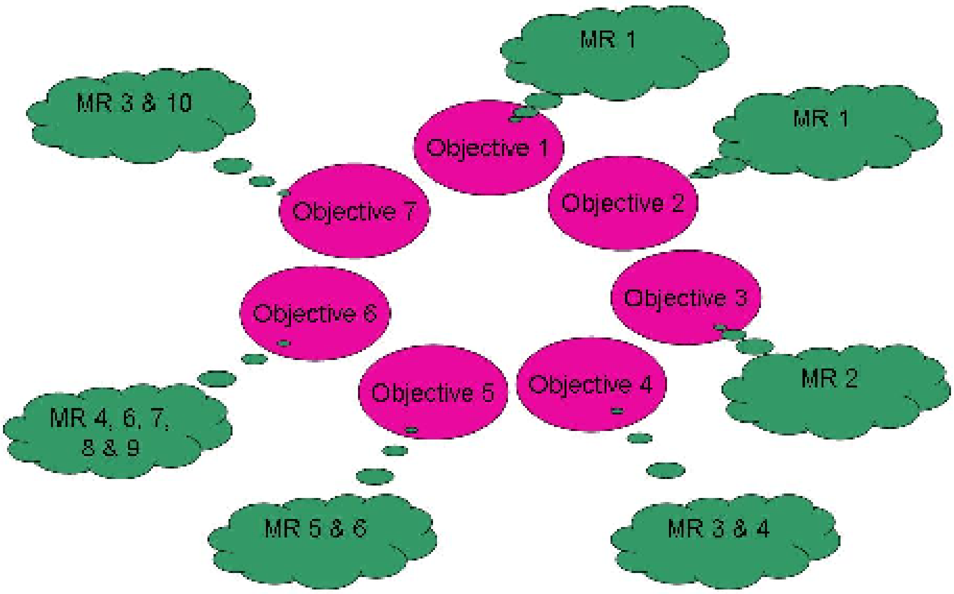


Figure 18: All objectives are covered by one ore more Main Results

Main Result 1
Main Result 1 (New human body mathematical models) is linked to the first two project objectives, as shown in Figure 19.

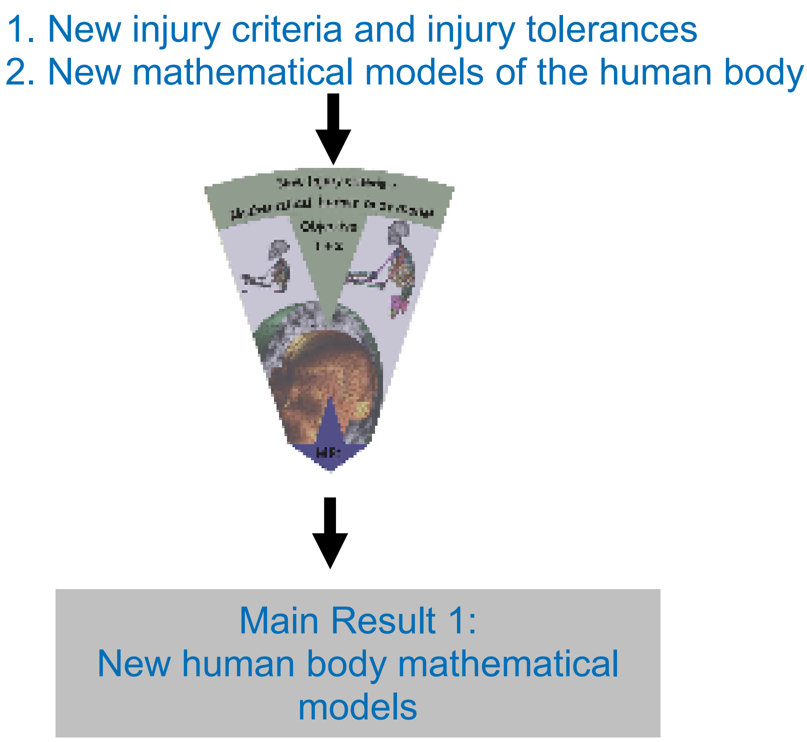


Figure 19: MR 1 covering objectives 1 and 2

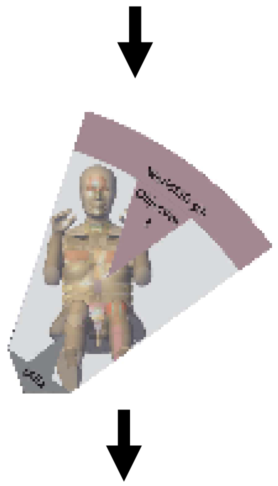
Some more information on this Main Result:

- Built on 4 Exploitable results
- Owners:
  - ESI (software license)
  - TNO (software license)
  - TNO, WUT, LMU (software under development)
  - ULP, TRL (software license)
- Future: support acceptance of use of human body models in virtual testing of car crash safety features. Guidelines to be developed for validation and use of the models similar to that of crash test dummies.

Main Result 2

Main Result 2 (WorldSID 5th percentile female dummy for side impacts) fully covers the third objective, seeFigure 20.

3. New world-wide harmonized crash dummy



Main Result 2:
WorldSID 5th harmonised dummy for side impact

Figure 20: MR 2 fully covering project objective 3

Some more information on this Main Result:

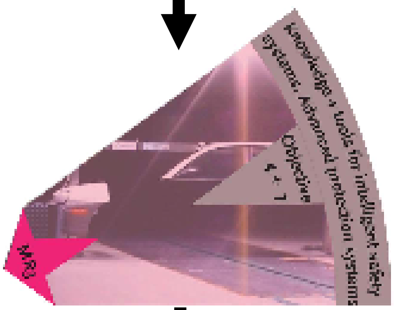
- Built on 5 Exploitable results
- Owners:
  - FTSS (sales of dummies & instrumentation of dummies)
  - TRL, BASt, UPM, FTSS, INRETS (use of injury criteria, computer models)
  - TRL, BASt, UPM, FTSS (consumer rating of vehicles)
  - TNO, FTSS (new dummies and new models, sales)
- Future: world-wide harmonisation of dummy, implementation in e.g. consumer tests (Euro NCAP) and regulatory tests. Responsible: FTSS.

The world-wide harmonisation is currently running, outside of APROSYS. It is done in parallel with the WorldSID 50th; combining this means the WorldSID 5th can be accepted much faster than would be the case otherwise.

Main Result 3

Main Result 3 (Side impact protection system for car occupants) addresses 2 of the project objectives, number 4 and number 7. This is shown in Figure 21.

4. New knowledge and tools for intelligent safety systems
7. Advanced protection systems



Main Result 3:
Advanced side impact system for crash mitigation

Figure 21: MR 3 covering parts of both objective no 4 and no 7

Further information on this Main Result:

- Built on 11 Exploitable results
- Owners:
  - Continental (commercial product, patents pending)
  - Continental, FhG (commercial product)
  - FhG, Faurecia (commercial product, patents pending and approved)
  - WUT (long term commercial, further input needed)
  - FhG (consultancy for industry and government)
  - Cidaut, IST, Faurecia, FhG (further developments needed)
  - Daimler, TNO, Conti, FhG, Cidaut (consumer testing)
- Future: introduction in the fast growing market for intelligent safety systems, by owners.

Main Result 4
This result (Generic assessment methodology for advanced safety systems) is closely linked to objectives 4 and 6, as shown in Figure 22.

This Main Result is based on one project result, which was an important focus area for a large group of partners throughout the project duration.

- Owners:
  - VW, Daimler, TRL, TNO, Conti, BASt (implementation in consumer testing)
- Future: further refinement in FP7 ASSESS. The methodology was used as starting point to set up a protocol for Beyond NCAP (objective assessment of new safety features by Euro NCAP)

4. New knowledge and tools for intelligent safety systems
6. New test methods

Main Result 4:
Generic Assessment methodology for advanced safety systems

Figure 22: Relation between MR 4 and objectives 4 and 6

Main Result 5

Main Result 5 (Generic car mathematical models) together with MR 6 fully covers objective number 5, the enhancement of virtual testing Figure 23.

5. Enhancement of Virtual Testing

Main Result 5:
Generic Car Models

Figure 23: MR 5 covers - together with MR 6- project objective no 5

Some more details regarding this Main Result:

- Built on 7 Exploitable results
- Owners:
  - Polito, CRF, Cidaut, Altair, TUG, TNO, IST
  - Free use in RTD projects/restricted use/licences/consultancy/commercial product

- Future: use in safety RTD projects, Virtual Testing procedures/protocols

Several requests came from industry and universities are registered, requesting for the use of these models.

Main Results 6

The 6th Main Result is closely liked to the 5th Main Result. Together, they fully cover objective 5. Furthermore, MR 6 covers project objective 6, as shown in Figure 24.

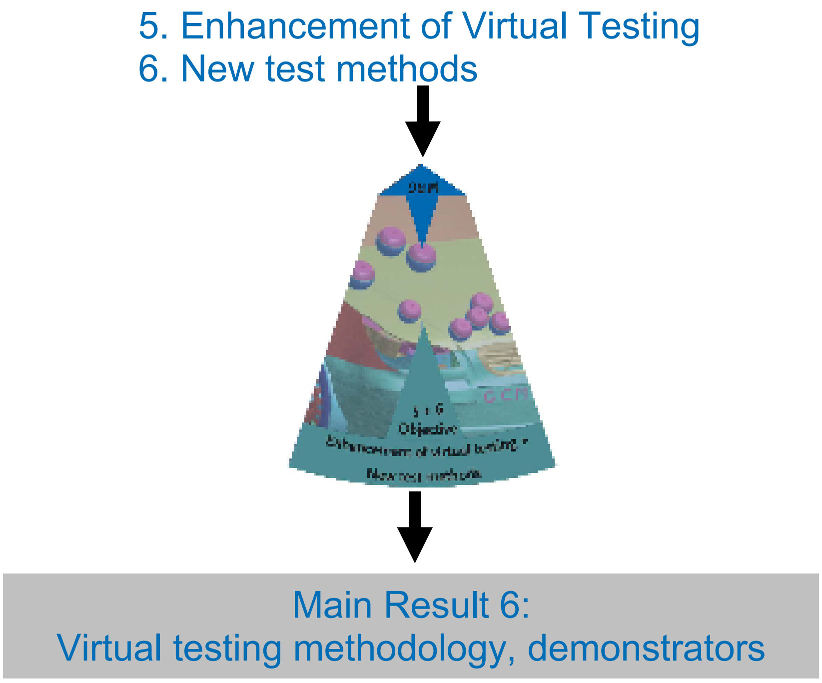


Figure 24: Main Result 6 covers objective 6. Furthermore, together with MR 5 it covers project objective 5

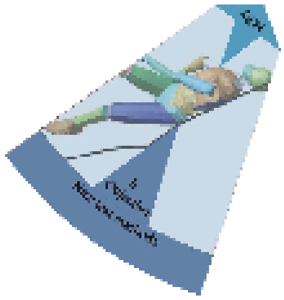
For this Main Results, many Exploitable results were used as building blocks. This involved an important part of integration of results.

- Built on 32 Exploitable results
- Owners:
  - Altair, TNO, CRF, Polito, FhG, Cidaut, CIC, IFTR, IST
  - Licensed software (commercial product, some of them already available), further internal research & use of know-how, consultancy
- Future: VT will be part of future component/car testing. Demonstrators and guidelines for future use are given.

Main Result 7

This MR (Test methods for vulnerable road users), together with Main Results 6, 8 and 9 covers the 6th project objective (see Figure 25). This part focusses on the vulnerable road users, a group amongst whom still a large portion of the severely injured and fatal victims can be found.

6. New test methods



Main Result 7:
Test Methods for VRU

Figure 25: MR 7 covers objective 6

This Main Result involved also a lot of intergration work, as several of the projects Sub Projects were involved.

- Built on 14 Exploitable results
- Owners:
  - Cidaut, Dekra, Hiasa, LMU, Altair, Fema, TNO, Dianese, Piaggio (introduction of new standards, updating of standards)
  - TRL, RWTH, TK-P, UPM, Toyota, CIC, TNO, ULP, BASt (consumer testing, licences, commercial products)
  - TUG, RWTH, Dekra, IDIADA (public information, spread knowledge broadly)
  - TRL, RWTH, TK-P, UPM, Toyota, CIC, TNO, ULP, BASt (introduction into consumer testing & type approval, licences, commercial products
- Future: Integration of the new and improved test methods with the current vehicle assessment test procedures to enhance the safety benefits for vulnerable road users – as a first step by EuroNCAP and subsequently in European legislation.

Main Result 8

Main Result 8 (More realistic frontal impact tests) together with MR 6, 7 and 9 covers objective 6, as shown in Figure 26.

This Main Result is based on one project result, which was an important focus area for a large group of partners with intensive cooperation with external parties.
Some further information on this Main Result:

- Owners:
  - TRL, TNO, VW, CRF, Toyota, IDIADA, BASt, TUG, Nissan (regulation/consumer testing)
- Future: Improve Reg 94 and Euro NCAP testing, improved car frontal impact protection will lead to reduction in accident casualties.

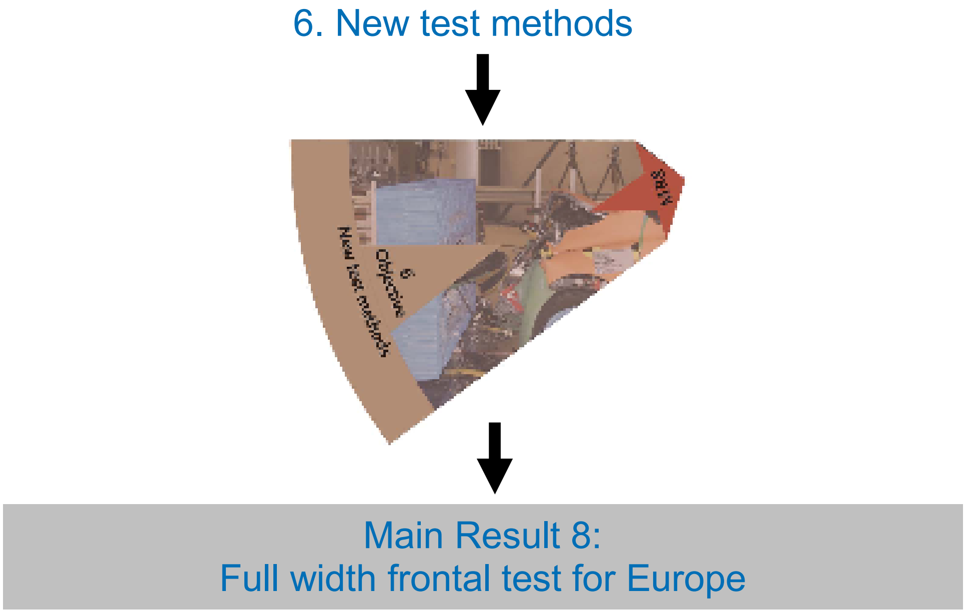


Figure 26: Relation between objective 6 and Main Result 8

Main Result 9
This Main Result (New side impact test methods) closes the coverage of objective 6, see also Figure 27.

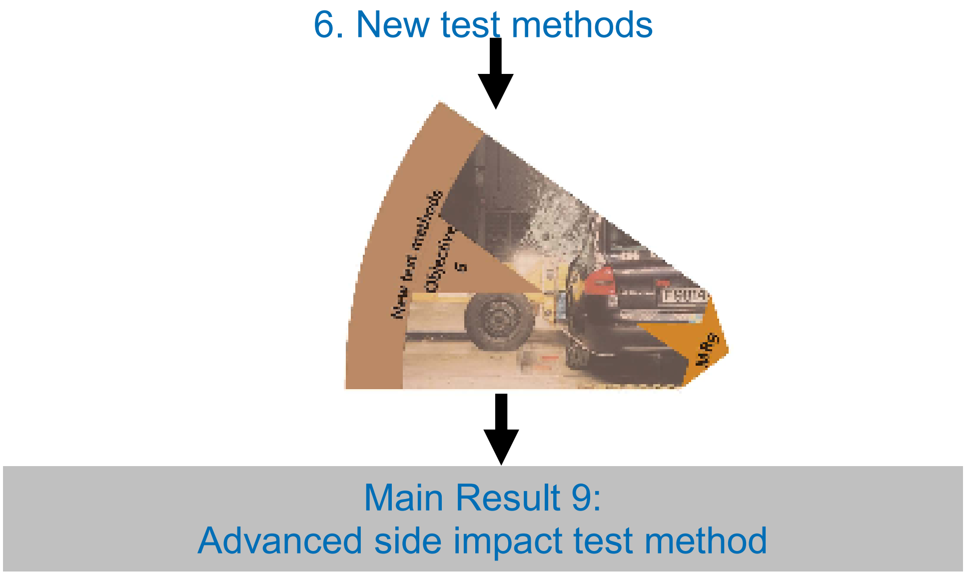


Figure 27: Link between MR 9 and objective 6

Furthermore, this MR is:

- Built on 6 Exploitable results
- Owners:
  - TRL, TNO, Toyota, VW, UPM, IDIADA, BASt, Cellbond, TK-P, CRF (introduction in consumer testing and regulatory testing, also input for further research projects)
- Future: being used by EEVC WG13 (Side impact); recommendations for improved side impact regulations

Main Result 10
This Main Result (New protection systems for vulnerable road users) fully addresses objective 7 on Advanced protection systems. This MR focusses on the vulnerable road users; new protection systems for other road users are covered within MR 3 (see above).

7. Advanced protection systems

Main Result 10:
New protection systems for VRU

Figure 28: Relation between Main Result 10 and objective 7

Some more information on this Main Result:

- Built on 10 Exploitable results
- Owners:
  - Hiasa, Cidaut, Dekra, LMU, Altair, Fema, Unifi, TNO (new products, licences)
  - Dianese (commercial product)
  - Cellbond (commercial product)
  - CIC (product, licenses)
  - TK-P, CRF (commercial product, licenses)
  - TUG, Dekra, CRF, GDV, Altair, IFAM, IDIADA, Schmitz, TNO, TRL, RWTH, Bolton, Polito, Daimler (guidelines, demonstrators, workshops (public available information)
  - CRF, Altair, Chalmers (product, licenses)
- Future: in many cases, commercial application. First items to enter the market are the thorax protector and the improved helmet (both planned for end 2009).

4.2 MR 1: New human body mathematical models

4.2.1 Objective/goals

To develop advanced human body numerical models using:

- existing models of whole human body and detailed models of body segments.
- state-of-the-art knowledge in the field of human tolerances to impacts and criteria used to quantify it.
- new tools to adapt models to individual characteristics such as age, gender, posture, muscular activation status [22].

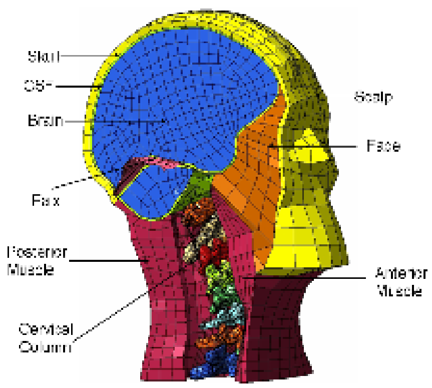


Figure 29: State of the art head-neck model

4.2.2 Approach

The model produced by the EC funded FP5 project HUMOS2 provided the base of the present work. Several research actions were undertaken to improve the capabilities of this base model in different ways.

First, statistical methods were developed which were required to predict injury probability for a given severity of impact. Also, methods were developed for scaling to occupants other than the 50th percentile adult male (e.g. small females and the elderly). The effect of age on geometry and material properties were documented in order to produce scaled models to representing children or elderly people.

Furthermore, methods were developed to interface more detailed body segment models or internal organ models with the whole body in order to produce hybrid models. This allows the inclusion of state-of-the-art modelling contributions from various origins.
For example, a numerical head model was developed by evaluating and combining the best of the currently available models. The model incorporates the latest understanding of injury mechanisms, skull and brain mechanical properties and boundary conditions. Injury criteria for different injury mechanisms were derived through extensive accident reconstructions. Thereby, this head model is coupled to a neck model that can simulate active behaviour.

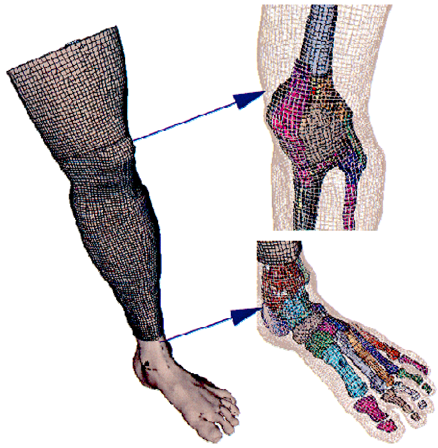


Figure 30: Detailed lowe limb model

Several other detailed models of body parts (lower limbs, knee, arm, see Figure 30) were developed or updated from the available finite element whole body human model HUMOS-2 (ribs, abdomen, lower limbs) to predict injuries based on injury mechanisms and/or to simulate active behaviour. Such models consist of high level of detail, e.g. internal liver vein system. It was shown that the separate body part models can be interfaced with whole human body models such as the whole finite element human body model which was developed in the European projects HUMOS and HUMOS2.

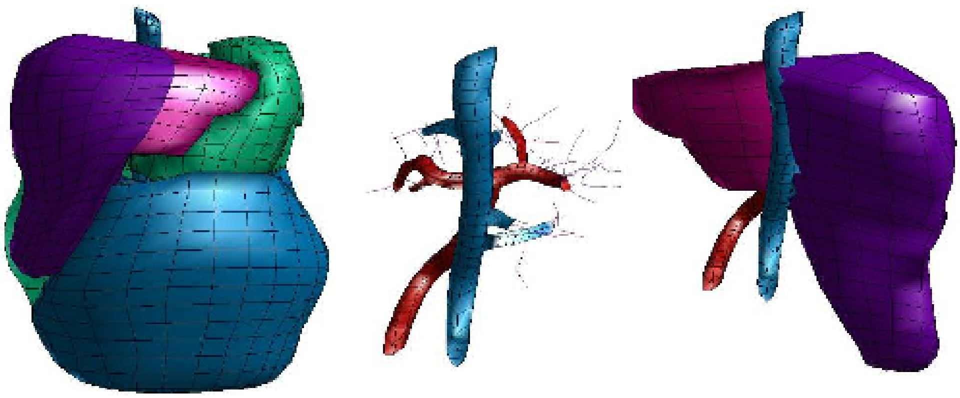


Figure 31: Detailed abdomen model including internal liver vein system

Experiments were performed with human volunteers in order to collect data on the effects of the muscular activation on mechanical properties of muscular tissue and also on posture and movements adopted in pre-crash situations. Kinematics sequences of pre-crash movements performed by volunteer subjects submitted to accidental situations on a driving simulator have been collected. They constitute a reference for the simulation of the reactions of a driver in a crash situation.

An arm model including active muscles has been developed and tested. It allows to reproduce arm movements when it is activated with electromyographic signals recorded on human volunteers, as shown in Figure 32.

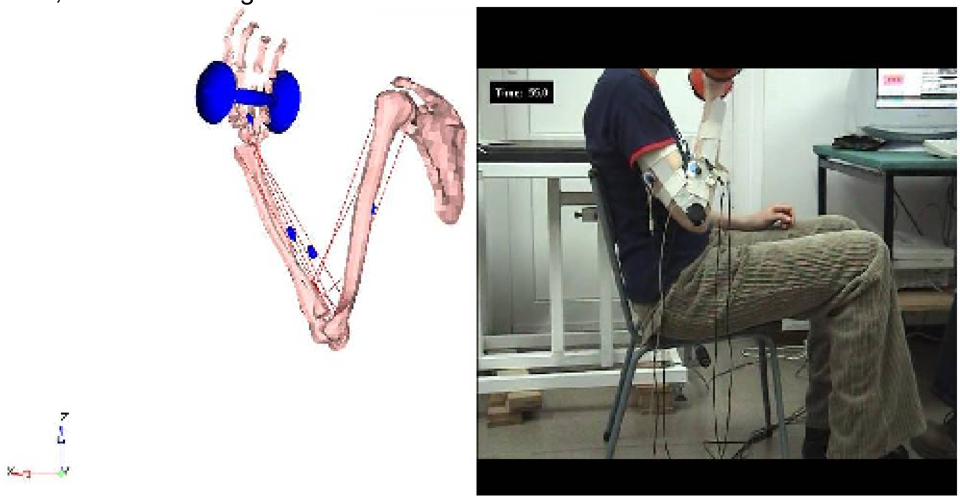


Figure 32: Detailed arm model with active muscles, versus volunteer experiment

4.2.3 Contribution to the safety problem/achievement

Simulation based methodologies are currently among the most promising technologies in order to study different injury mechanisms as well as prediction of real world accident injuries. Since any reduction of fatal injuries requires primarily an in-depth understanding of the sources of excessive loading on the occupants, the newly developed human body (part) models are essential for car manufacturers and researchers. This technology is now becoming more accessible due to the availability of sufficient computing power as well as better knowledge on detailed human body geometrical and mechanical properties.

To prove such new technology, frontal and struck side lateral car crash demonstrators (see Figure 33 and Figure 35) were developed and simulated. It deals with two car models (Neon and generic car models) equipped with standard safety systems (three-point belt and airbag). A real crash scenario was performed with these vehicles. Updated human body model underwent this scenario as a driver protected by safety restraint systems like belts and/or airbag. Standard and new injury measures proved correspondence to the real cases.

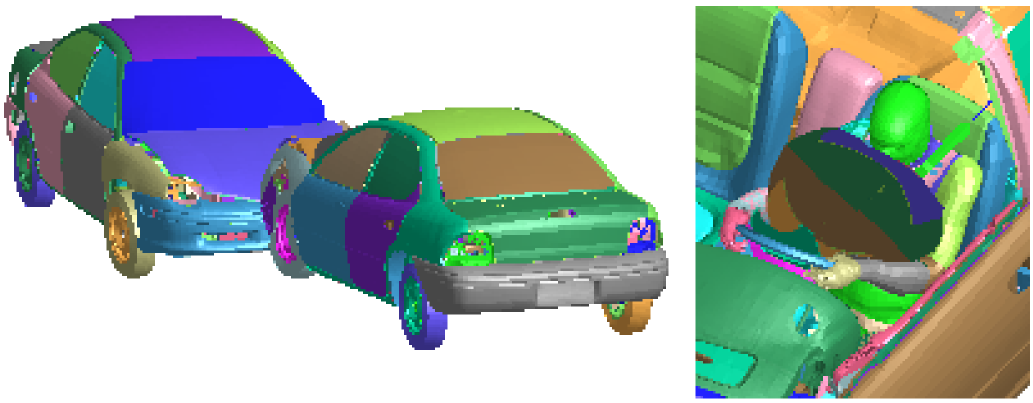


Figure 33: Human body model in frontal impact, with airbag

In simulations of various non-struck side side lateral impact situations in which the human reaction was based on volunteer tests, it was shown that the dummy model response was considerably different from that of the active human model. These simulations demonstrated that in cases in which there is time to react (e.g. non-struck side impact, low severity impacts) the human reaction can affect the severity of the injuries sustained during the crash event.

The developed statistical methods for injury prediction were used to generate injury risk curves for dummies and dummy or human body mathematical models. These can be used within regulatory and consumer test programmes to assess the safety of current and future vehicles and to guide the optimalisation of vehicle design to protect all occupants and in more than the standard accident cases.

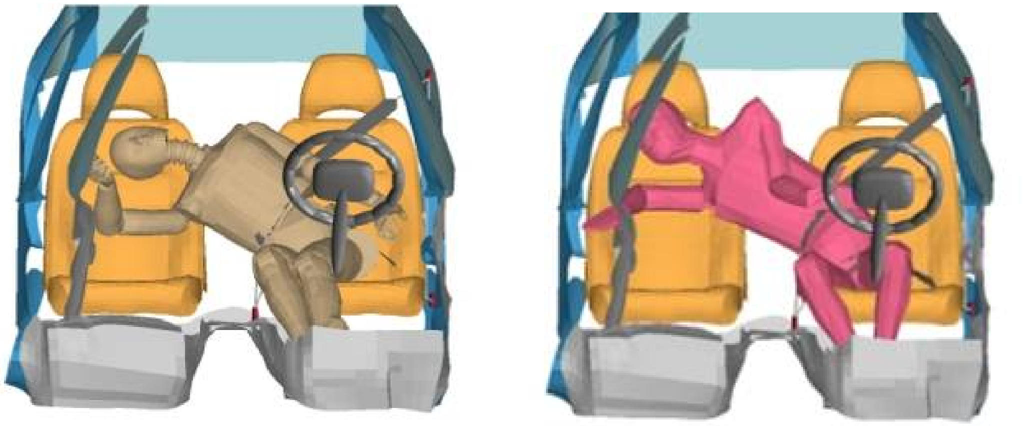


Figure 34: Dummy model (left) and active human model (right) in non-struck side lateral impact. The human model's head impacts the passenger's window, the dummy model does not

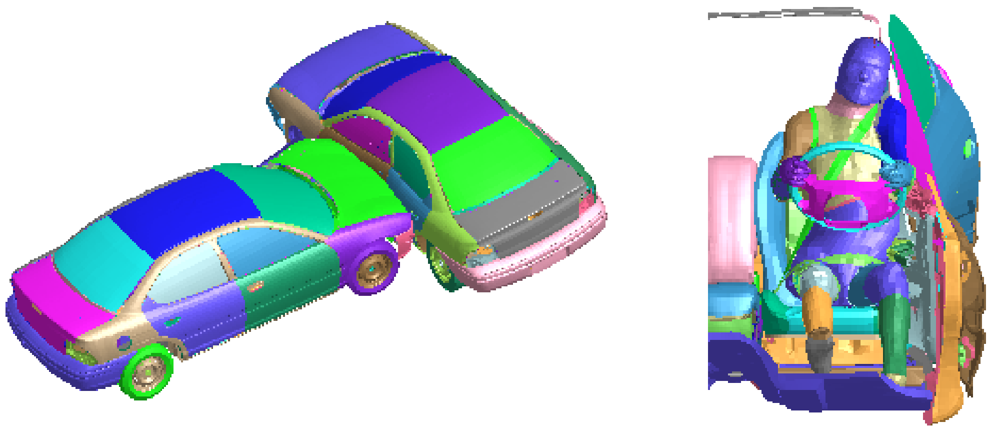


Figure 35: Human body model in lateral struck side impact

4.2.4 Application

The newly developed human body (part) mathematical models and scaling tools can be used in combination with dummy tests in order to provide more detailed information on:

- effect of size,
- effect of age and gender,
- injury mechanisms,
- effect of active behaviour.

4.2.5 Future

To support the general acceptance of the use of the human body models in virtual testing of car crash safety features , guidelines should be developed for the validation and use of the models similar to that of crash test dummies.

4.2.6 Special case: Injury criteria for motor cyclists

This work is related to the impacts of sliding motorcyclists against roadside barriers. The HUMOS_2 model has been successfully used in simulations focussing on injury mechanisms associated to impacts of sliding motorcyclists on roadside barriers.

Data from reconstructed real-world accidents served as input for these simulations. Mechanisms of injury to upper extremities, neck and thorax were numerically simulated. Analysis of the selected impact scenario showed that new measurements and dummy modifications are necessary for the development of a future standard.

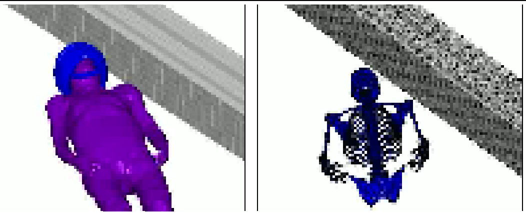


Figure 36: Human model (motorcyclist) in sliding impact to road side barrier

Two series of simulations of motorcyclists in a sliding impact on roadside barriers (with a modified Hybrid III 50th percentile dummy and a 'standing' HUMOS 2 model) were performed. To perform the simulations a helmet model and a steel roadside barrier model have been developed. These simulations have been analysed to compare the human and the dummy models outputs and results. Kinematics and injuries of the two models in the two selected configurations were analysed and compared. Guidelines on new injury criteria for motor cyclists in this typical impact situation were formulated.

Contribution to safety problem/achievement
The main contribution to safety problems is the new possibility of applying new mathematical models of the human body to motorcyclists in specific type of accidents (sliding impacts against roadside barriers). Achievements also exist of completely new knowledge of the injury criteria to be used for motorcyclists' impacts.

Application
The application of this result is in the motorcycle industry and the protective equipment industry, as well as in standard development.

4.3 MR 2: WorldSID 5th percentile female dummy for side impact

4.3.1 Objective/goals

The objective of this APROSYS activity is to develop an instrument that enables vehicle manufacturers and restraint suppliers to develop restraint systems and legislative bodies to enforce countermeasures to protect the category of car occupants that are now at highest risk in road traffic [22].

4.3.2 Approach

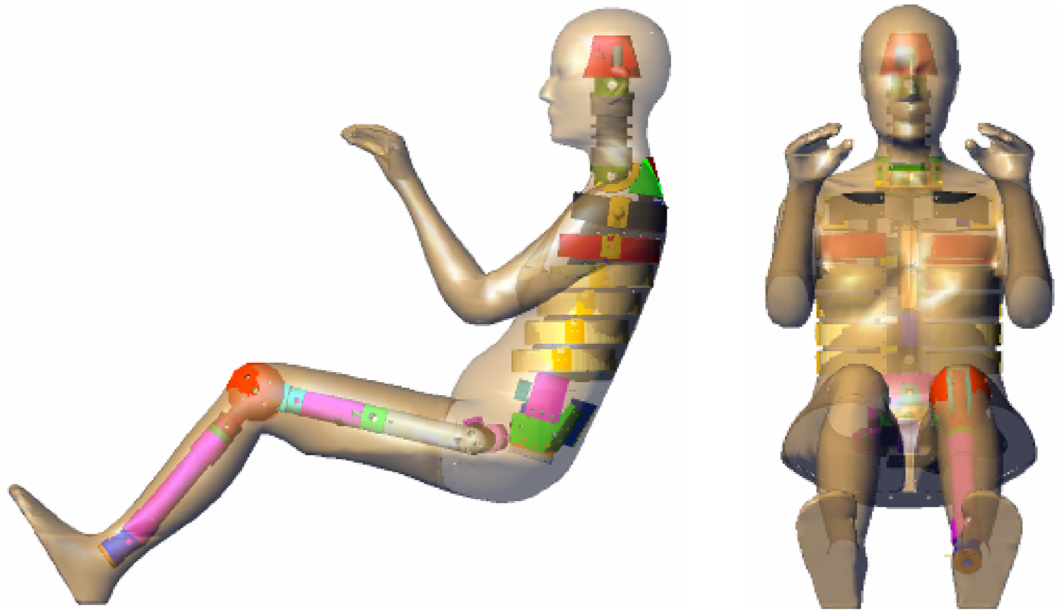


Figure 37: WorldSID small female CAD design model

1. Development of requirements and specifications for a globally harmonised biofidelic side impact dummy of small female anthropometry and small female biomechanical response, including measurement capabilities and handling-maintenance aspects. A detailed design specification was developed, based on the WorldSID 50%-ile male dummy, with small female anthropometry, coherent biomechanical response requirements based on accepted scaling methodologies. The design requirements were discussed in various globally active platforms, such as the WorldSID Task Group and ISO/TC22/SC12/WG, to ensure acceptance of the design not just within the circle of APROSYS partners, but also by potential future users around the globe.

2. Design and build prototype. A prototype dummy was designed and built according to the specifications and made operational for testing and evaluation.

Figure 38: WorldSID small female dummy first prototype

3. Evaluation of the prototype. The prototype was evaluated against its requirements to find how well it meets the design specifications and to identify potential problems. The WorldSID 5th percentile female prototype dummy was extensively tested by APROSYS partners and also by stakeholders outside the consortium. The key aspects to assess were the anthropometry and biomechanical responses under various impact test conditions. The overall results obtained during the evaluation process are considered encouraging for a prototype dummy. The biofidelity assessment according to ISO TR9790 is based on a sub set of high weighted test conditions. The prototype overall biofidelity rating is just exceeding the requirement of Biofidelity Rating (Scale 1-10) > 6.5 which is considered as “GOOD”. However, not all body segments met this target. Some of the responses, particularly for the thorax, are close to scoring 10. The neck test conditions are conflicting and provide no direction for neck response improvement. All results were compiled and recommendations for necessary and desired dummy updates were listed. The outcome of the prototype tests were published at ESV 2007 [18].

4. Design and build revised prototype. Two prototypes were built to address the recommended updates. Improvements were made in mass distribution according anthropometry;

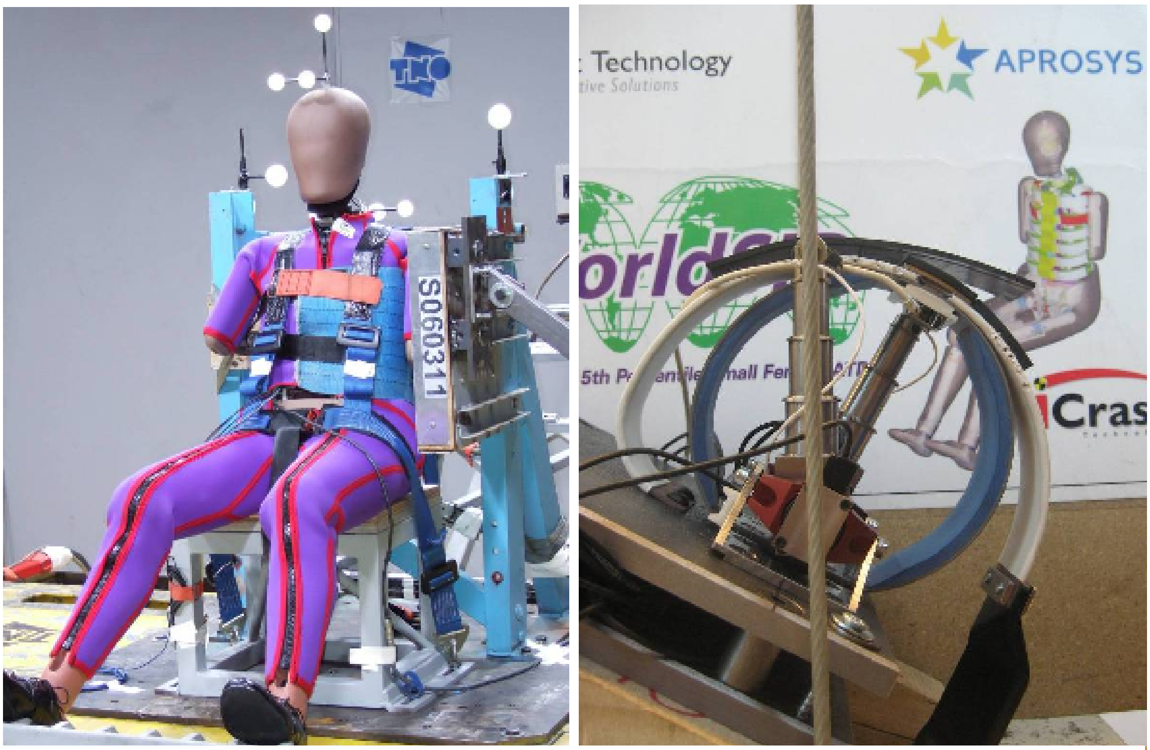


Figure 39: left: WorldSID small female dummy in testing, right: Oblique isolated rib unit test on drop tower, with new 2D-IR-tracc deflection sensors

- the ribs were changed to improve biomechanical response and the durability;
- 2-dimensional rib deflection sensors were developed to improve the performance of the thorax and the abdomen in oblique loading conditions;
- the dummy arms were updated to achieve more human like anthropometry and bone bending characteristics;
- a lower leg and foot were developed to align with the WorldSID style moulded shoe/foot and to improve anthropometry;
- and finally an on-board data acquisition-cabling system was developed to address concerns of handling and durability with the existing system.

In parallel, a study was conducted to the appropriateness of the scaling rules for the head neck complex. New head neck response scaling rules were derived, based on neck length as dominant factor, rather than neck circumference. Based on the new rules, small female head-neck response requirements were derived providing new targets for evaluation. The neck response scaling research was published in the I-Crash Journal 2008 [19].

5. Evaluation of the improved prototypes: The revised prototypes were subjected to basically the similar set of reference test conditions to find if the improvements worked out as intended. Also isolated single rib unit tests were conducted to assess the sensitivity of the new 2-dimensional rib deflection measurement systems to various conditions of impact angles. A complete revised prototype dummy was subjected to oblique thorax pendulum tests and static deployment airbag tests under various impact angles and impact severities. Arm impact and bending tests were conducted according the biomechanical reference tests. Additionally two real world side impact

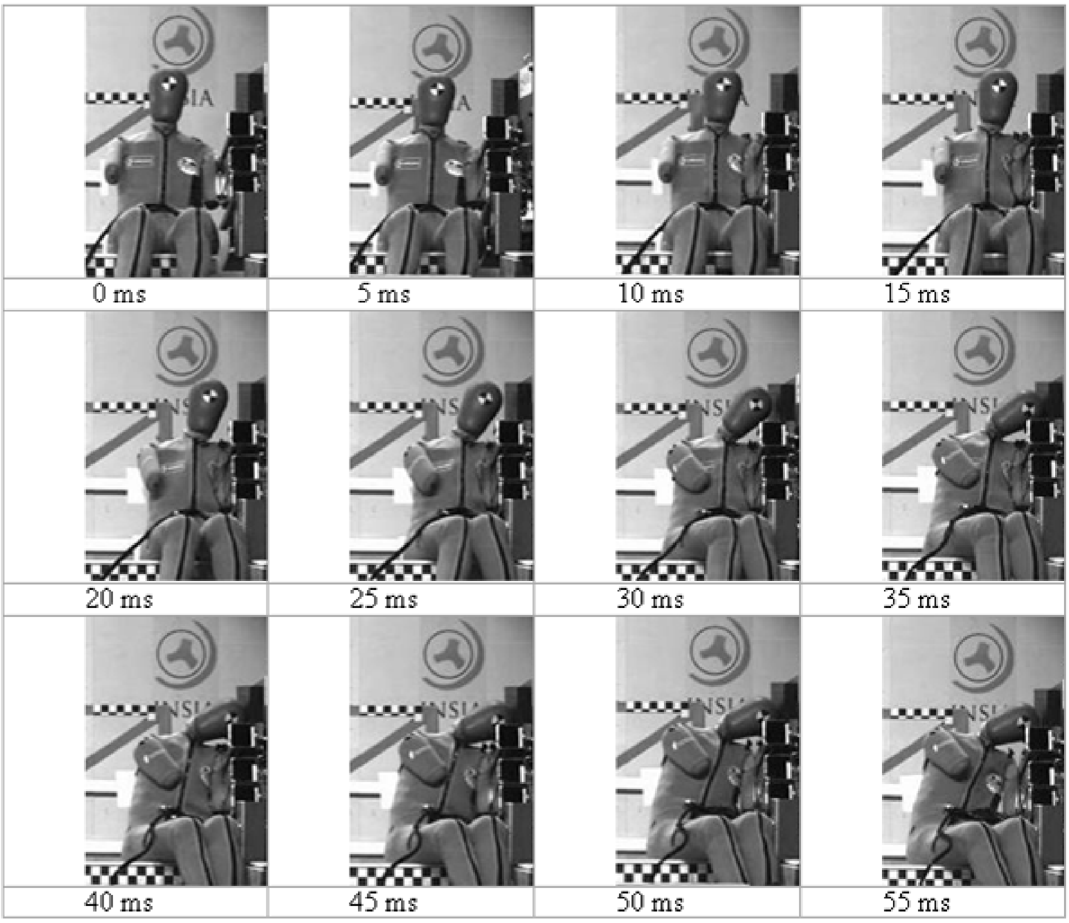


Figure 40: WorldSID small female in a sled test sequence of high speed video images

accidents involving small female occupants were reconstructed in a laboratory environment with the WorldSID 5th, to see whether the injuries sustained in a real world crash would be predicted correctly by the dummy. Finally, two revised prototype dummies were used in current and future application regulatory tests for the small female dummy in side impact: full scale vehicle mobile deformable barrier tests under the conditions of IIHS and FMVSS214 and the future Advanced European Mobile Deformable Barrier test (AE-MDB) that was developed by APROSYS, see MR 9 and [18]. The results of the biomechanical tests were used to construct preliminary injury risk curves for the thorax, abdomen and pelvis. Injury risk curves are ultimately necessary to use the dummy as regulatory tool and give meaning to the dummy test results in terms of risk at injury to a certain body segment at a certain loading level. The initial results are promising. Now, further test results will be analysed to come to final conclusions.

4.3.3 Contribution to the safety problem/achievement

The side impact crash is now the key contributor to fatal and serious injuries in road accidents in Europe. Also in other industrialised countries, such as the USA, Canada and Japan the side impact crash is a significant contributor to road accident serious injuries and fatalities. Various studies reveal similar trends in occupants at risk and type of collisions. The majority of fatalities and serious injuries are sustained in vehicle to vehicle impacts. Chest and head injuries are the most frequent generally. Males and younger occupants are over-represented in single vehicle collisions to narrow fixed road side objects, and females and elderly are over-represented in vehicle to vehicle crashes. Two factors appear to be contributing to higher risk for smaller and older occupants. Current side impact protection systems are optimized for taller and more tolerant occupants by using the ES2 mid size male crash dummy in development and testing. The vehicle fleet is changing towards higher ground clearance/high bonnet vehicles growing. The smaller and weaker occupants are facing a higher risk at direct contact with the colliding vehicle bonnet because of closer proximity of the head and chest to hazardous structures. Restraint systems appear not to be optimized for this category of occupants.

4.3.4 Application, future

Future application for WorldSID small female dummy will be as a globally harmonised side impact next to the WorldSID midsize Male side impact dummy in tests like the IIHS mobile deformable barrier test, the FMVSS214 crabbed barrier test, the FMVSS214 pole test and the Advanced European Mobile Deformable Barrier Test. Another possible application for the small female WorldSID dummy is consumer rating test programs like Euro NCAP and J-NCAP. It is highly likely that the small female WorldSID family member will be used in mobile deformable barrier tests and that the WorldSID mid size male will be used in the Car to Pole tests, to align with size and age groups at highest risk under these respective accident scenarios.

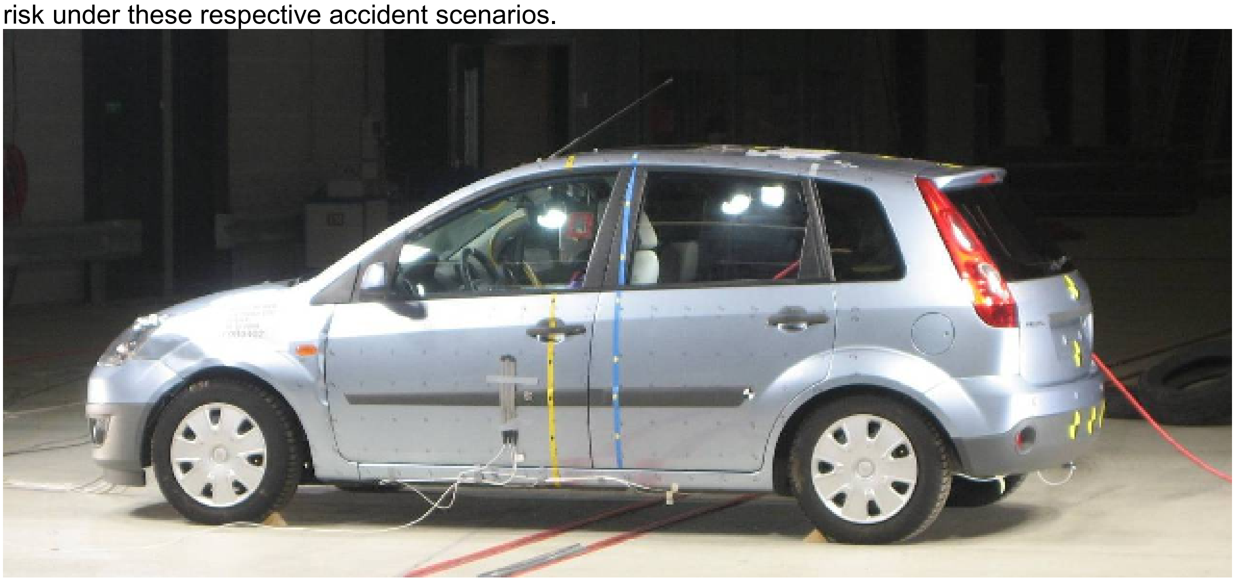


Figure 41: WorldSID revision 1 prototype first time in full scale car crash

4.4 MR 3: Advanced side impact system for crash mitigation

4.4.1 Objective/goals

The general objective addressed here is the development of knowledge and tools enabling the design and implementation of intelligent safety systems with special emphasis on new sensor and actuator technologies for pre-crash safety systems [23].

Pre-crash sensing systems consist of anticipatory crash sensors with related scene modelling algorithms. These are coupled to safety devices via decision algorithms embedded in control units. These devices offer the potential to react adaptively on the specific accident situation. The research focused on development of (pre-competitive) technologies for each of these parts as well as the development of methodologies and related numerical and experimental tools for the design of such systems.

4.4.2 Approach

A pre-crash side impact protection system for car occupants (main items are shown in Figure 43) was developed applying different innovative technologies:

- a shape memory alloy based reversible actuator device.
- an environmental sensing system observing the side of a vehicle
- a decision logic for integration into a pre-crash system taking action before a crash happens.

As a technology showcase, these have been put together into an integrated system for side impact protection. The sensing system detects an imminent collision (active safety) and activates the actuator before the crash occurs in order to mitigate injuries (passive safety).

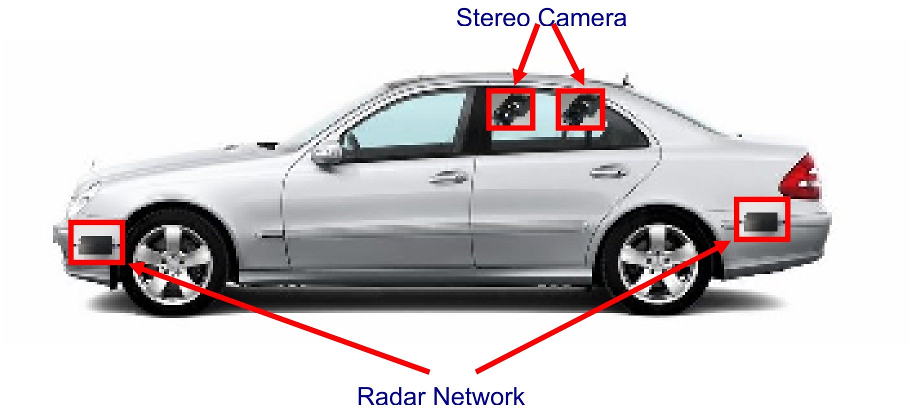


Figure 42: The sensing system projected on the test vehicle

A well-defined development process was followed. First, accident statistics were analysed in detail. Based on this, various concepts for side impact protection were studied using multi-body and finite elements simulations. Also human behaviour in side crashes was examined using driver simulation tests. Accordingly, the sensor and actuator subsystems were defined, developed and integrated into several vehicles. A thorough evaluation programme has been carried out both on the sensor and on the actuator subsystem.
The sensing system (see Figure 42) consists of the combination of 24 GHz radar sensors and a stereo video camera. The actuator uses shape memory alloys to realise a fast but reversible action. The system was kept generic, so that it can be built into different vehicles.

4.4.3 Contribution to the safety problem/achievement

In order to achieve the next significant step in traffic safety, intelligent safety systems and especially pre-crash systems have to be brought into the vehicle fleet, as these systems have a very high potential to reduce accident injuries.

Here, in particular side crashes are a major threat to traffic safety. While front and side crashes occur with comparable frequency, the risk of an injury from a side crash is much higher. This is due to the short distance between an occupant and the incoming object. For the same reason, existing in-crash sensing technology does not allow for timely deployment of collision mitigation measures.

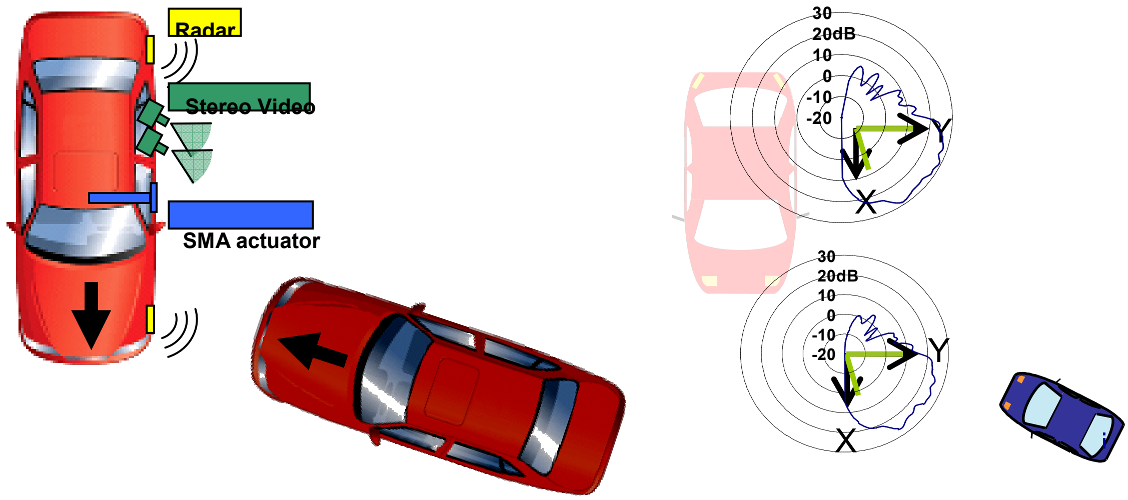


Figure 43: Main items in the advanced side impact system

By the successful realisation of the technology showcase application it was shown:

- Environmental sensors combined with fast actuators offer new protection strategies (adaptivity).
- Although side impact detection with vehicle mounted sensors is inherently more difficult than e.g. frontal impact detection: side pre-crash impact detection was proven to be feasible.
- Pre-crash systems taking action at the latest 200 ms before a crash are feasible. Already at this time it is possible to determine that a collision cannot be avoided.
- Fusion of stereo video and radar provides good results; detection efficiency for true alarms combined false alarm discrimination.
- Shape Memory Alloys can be used to realise fast but reversible safety actions to reduce intrusions and redirect impact loads.
- Novel actuators, such as the developed door-seat coupling (see Figure 44), did prove their crashworthiness in component and vehicle crash tests.

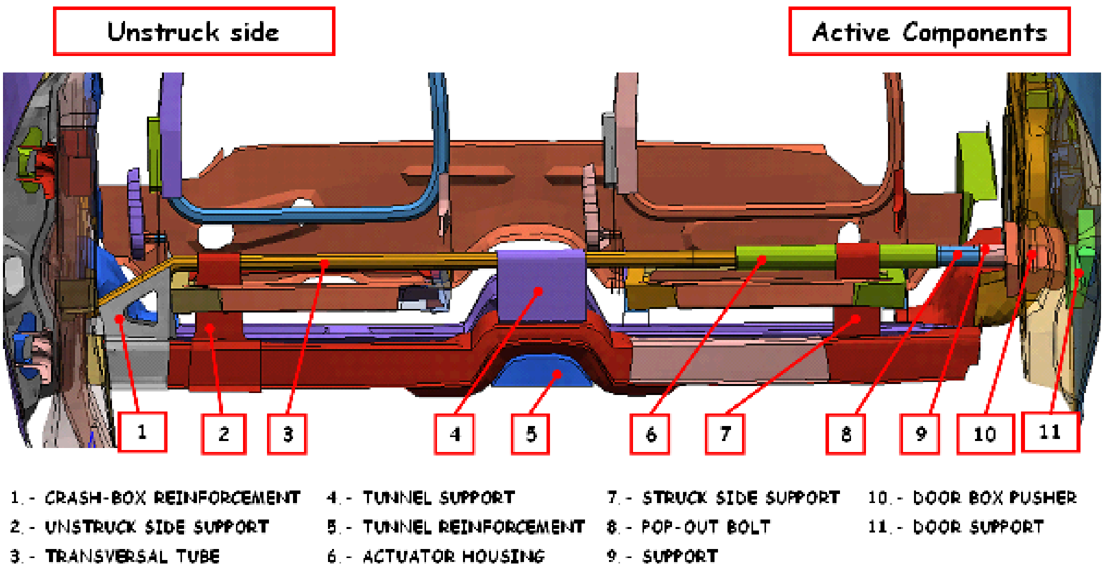


Figure 44: Actuator layout; Cross section of vehicle floor (transversal direction)

Apart from these results showing the feasibility of the involved technologies also the concrete implementation of a prototype of the side impact protection system has proven to bring a significant benefit to car occupants:

- Intrusion into the passenger compartment is significantly reduced and it is reduced exactly where the occupant sits.
- Restraint systems (e.g. airbags) have more space and time to deploy more efficiently.
- Contact time is delayed and with this contact forces as well as the other biomechanical values are reduced.
- Survival space and time are gained.

4.4.4 Application

This result will be used by the involved partners in various ways in their individual activities. Here, only a small selection of the most relevant applications can be given.

- Continental offers the developed near distance pre-crash radar sensors to car manufacturers and uses the gained knowledge in other pre-crash applications.
- Fraunhofer IITB offers the stereo video system and uses the knowledge in engineering consulting activities.
- Faurecia and Fraunhofer LBF will progress with the development, qualification and marketing SMA based safety devices as well as with technology transfer issues.
- TNO and CIDAUT, as suppliers of testing services, offer enhanced pre-crash tests and engineering services.
- Daimler uses the knowledge about the challenging side impact application to find the best way to make their future vehicle models safer. Furthermore, they have gained experience in evaluating pre-crash systems, in particular in field tests.
- WUT and IST profit from the industry cooperation in their scientific programs.

In the coming years there will be more and more vehicles equipped with intelligent safety systems. Last but not least, other funded projects will build on the gained knowledge, which was made public in large parts.

4.4.5 Future

In general, modern vehicles will implement an increasing number of active and passive safety features. Hence, there will be a growing demand for an intelligent integration of both. Although the market of intelligent safety systems is in an early phase, it is rapidly growing and will soon contribute substantially to traffic safety. The new technology is also especially promising for alternatively driven, very lightweight cars.

4.5 MR 4: Generic assessment methodology for advanced safety systems

4.5.1 Objective/goals

A generic evaluation methodology suitable to assess advanced pre-crash safety systems consisting of

- remote sensing systems
- adaptive actuator systems.

This generic methodology [18] should cover the wide range of existing and future adaptive safety applications. It should also be ready for use by different stakeholders, e.g. industry, consumer testing and regulatory bodies.

4.5.2 Approach

Initially, an inventory study was performed to investigate assessment methodologies defined by previous research projects to evaluate advanced safety systems and to identify issues preventing a vehicle fitted with advanced safety systems from complying with the existing European legislation. Using this knowledge, a draft evaluation method was developed. To verify this methodology it was applied to two pre-crash systems. Based on the results and the experience gained the method was updated to its final version, as shown in Figure 45.

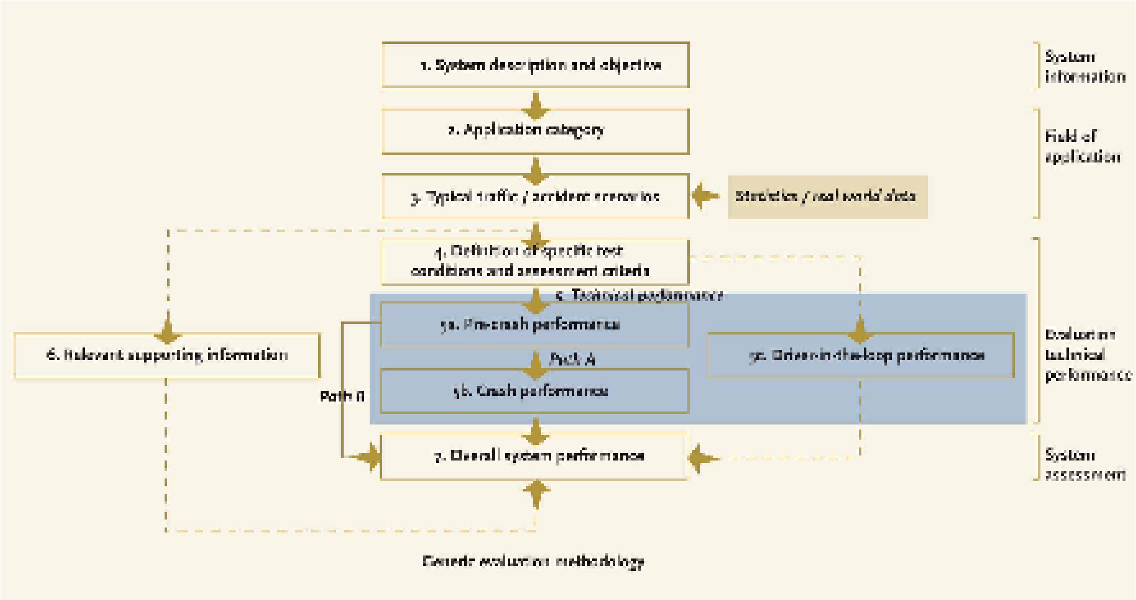


Figure 45: Generic assessment methodology for advanced safety systems

4.5.3 Contribution to the safety problem/achievement

A clear trend in automotive safety is towards integrated safety, and towards application of adaptive safety systems. However, there is not yet a well-established test procedure for evaluation of such systems. To cover this need, APROSYS has developed a generic assessment methodology for adaptive safety systems, taking into account the accident scenarios the system is intended for, the types of sensors used, etc. Using this assessment methodology gives a clear and independent insight in the effectiveness and efficiency of the system under evaluation.

This generic methodology is suitable to assess complete safety applications. The system specific test conditions and assessment criteria are defined using relevant accident and traffic scenarios. The evaluation of the technical performance is split in the three parts:

- pre-crash performance
- crash performance
- driver-in-the-loop performance

The test results, together with optional supporting information of the system, are combined to provide the overall system performance; this can be related to the target population to estimate the safety benefit of the system.

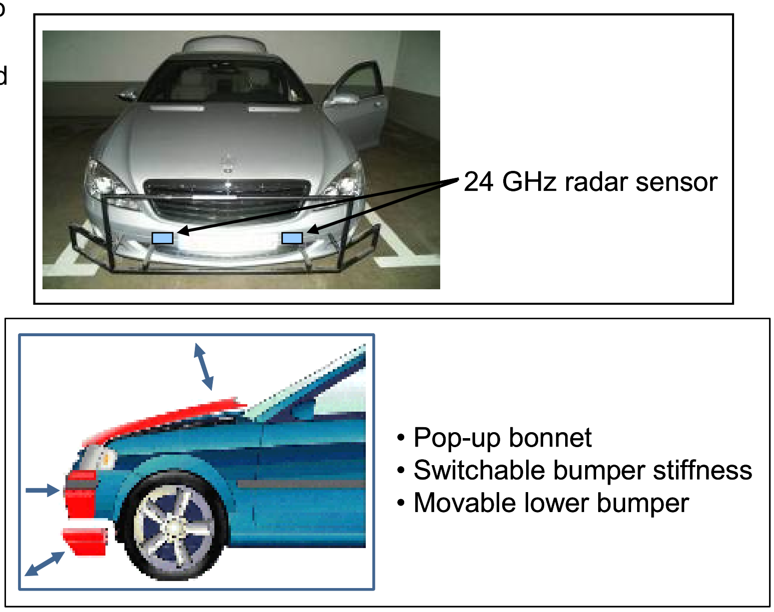


Figure 46: Sensing system and pedestrian protection system

4.5.4 Application

To verify the proposed evaluation methodology, the method was applied to two different pre-crash safety systems:

- a pre-crash pedestrian protection system
- a pre-crash side protection system (MR 3) [22].

The verification using the pre-crash pedestrian protection system is described below.

Pre-crash pedestrian protection system
The relevant accident scenarios for the pedestrian system were derived from the GIDAS accident database. These accident scenarios were transformed into test scenarios with specific test parameters. The assessment criteria were defined based on the functionality of the three different actuators, see Figure 46.

The pre-crash performance of the sensor system was tested at three different test labs using rope-ways and a guided platform to move the test object, see Figure 47.
The crash performance was tested using the head and leg impactor tests defined in Part 1 of EC Directive 2003/102. For the driver-in-the-loop tests a dynamic driving simulator was used to examine, if this could be an appropriate tool for the driver performance evaluation.

In general, the developed evaluation methodology could be applied quite well to the pre-crash protection systems tested. However, some open issues were identified and further refinements of the method itself and of the test conditions and methods are necessary, e.g. how to identify relevant scenarios and agreed standardized test objects for pre-crash testing.

4.5.5 Future

The methodology needs realistic accident scenarios. As was shown in the verification of the methodology, there is a clear need for a detailed European accident database and detailed test specifications and requirements. In addition the proposed evaluation methodology also should be applied to other pre-crash safety systems. Further refinements of the method will be done in follow-up projects like ASSESS within FP7.
The developed methodology was used as a starting point to set up a protocol for Beyond NCAP, an objective assessment of new safety features by the Euro NCAP organisation.

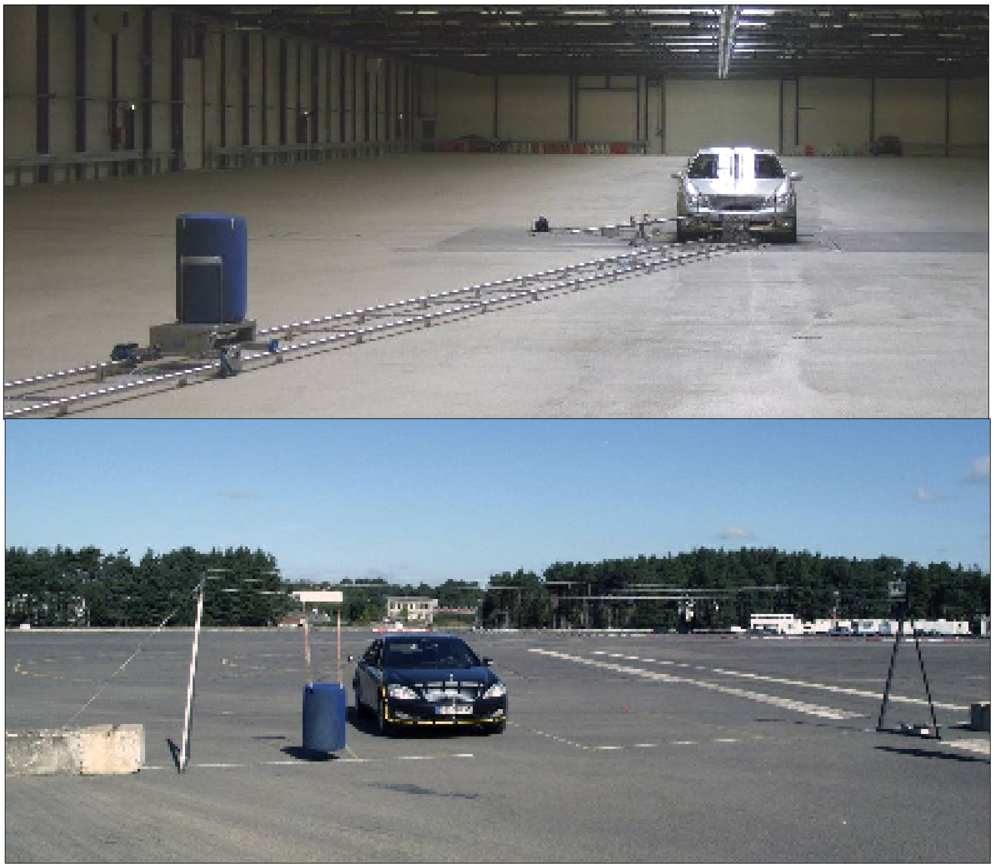


Figure 47: upper: moving platform with test object; in-door-testing. Lower: rope-way with foam block as test object

4.6 MR 5: Generic car mathematical models

4.6.1 Objective/goals

To support Virtual Testing related activities within APROSYS and beyond, a full fleet of numerical models representing current vehicles is needed. The main objective was to create:

- Virtual vehicle prototypes having a realistic crash behaviour, reflecting the crash performance of modern vehicles
- Realistic behaviour equivalent to similar state-of-the-art real vehicles (Euro NCAP public test results)
- Finite element detailed models inspired by real vehicles marketed nowadays (in terms of structural solutions, size, weight, internal lay-out, etc.)
- Simplified Multi-Body / Mass Spring versions derived from detailed finite element models for efficient numerical studies. [24]

In addition, the absence of a physical counterpart allows for the sharing of the same mathematical car models amongst different research partners, avoiding confidentiality problems and related constraints.

4.6.2 Approach

The first series of Generic Car Models (or, GCM) are detailed finite element models, inspired by real vehicles marketed nowadays, in terms of structural solutions, size, weight, internal lay-out, etc., and that are built on the basis of available material by interpreting the reference architectural concept. The resulting virtual vehicles are generic cars that have a high level of detail (similar to the mathematical models used in the car industry), that behave in a realistic manner; this realistic behaviour is the target that guided all the development work and that represents, when achieved, its "validation".

The GCM generation process can be summarized in the following steps:

1) Selection of a "reference" real car; design, size, geometry, specifications, etc.
2) Analysis of vehicle generic characteristics and structural lay-outs on the basis of available data
3) Development of the corresponding general purpose FE vehicle model having these characteristics and structural lay-outs. This step can have two variants:
    a) external shape generation first, followed by the internal structural architecture and lay-out generation;
    b) internal structural architecture and lay-out generation first, followed by the external shape;

In both variants, the initial geometrical reference starting point is an available existing FE model of the same class (weight and dimensions) as the GCM to be generated: within such reference volume, the new shapes and architectural lay-outs are built according to the contents of the selected "reference" car.

4) Virtual testing campaign towards a proper range of crash configurations (mainly front and side impacts) in order to achieve the proper realistic behaviour representing the "validation" of the GCM.
   It has to be highlighted that in pursuing a realistic behaviour, a proper amount of typical crash engineering activities is put within the GCM realisation: then, a GCM can be considered a product that is comparable to the ones originated by industrial "on the shelf" projects.

The GCM FE model fleet is made of GCM1 (supermini), GCM2 (small family), GCM3 (large/executive), GCM4 (MPV), GCM5 (Chrysler Neon) and GTM (truck), see Figure 48.

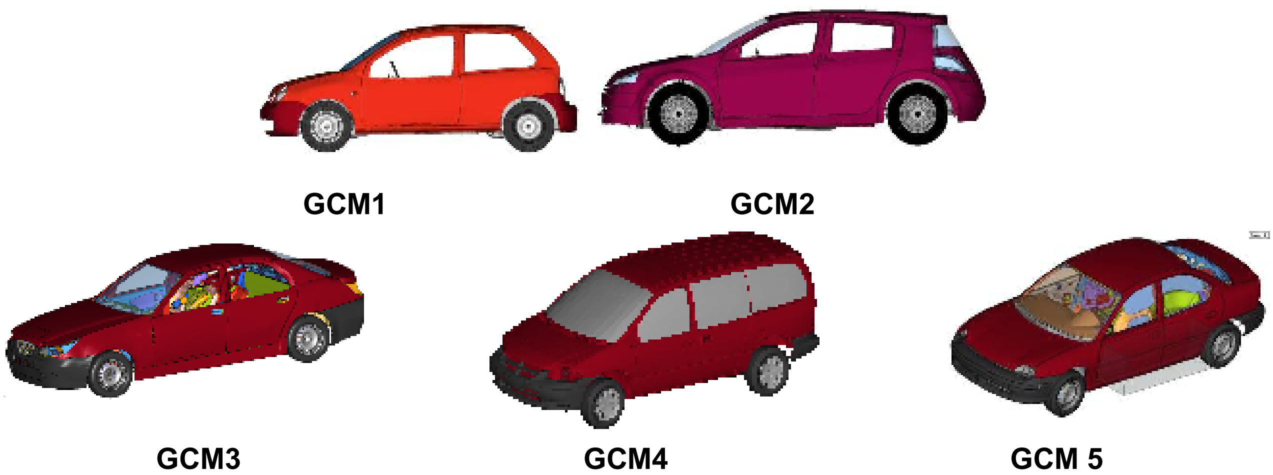


Figure 48 Generic car models

A second fleet of GCM was developed. These are multibody or simplified models developed from the finite element GCM models. The approach to develop them required use of optimization techniques. Existing multibody or simplified models were used, mapped (in terms of constitutive parts and overall dimensions) on the finite elements GCM models and their properties were then tuned so that they give, in selected cases, the same results as the FE models. The GCM multibody and simplified model fleet is made of GCM1 (supermini), GCM2 (small family), GCM3 (large/executive), see also Figure 49.

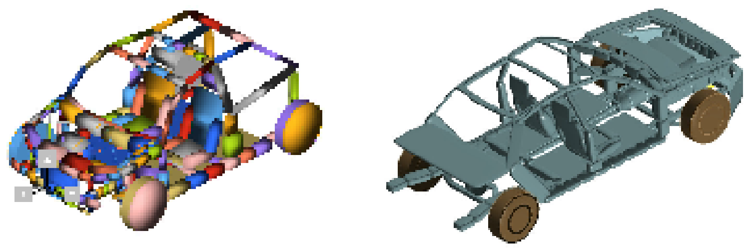


Figure 49: GCM multibody and simplified model fleet: GCM 1 Multibody and GCM3 Multibody

4.6.3 Contribution to the safety problem/achievement

The development of this complete fleet of numerical vehicles has provided reference models that have been widely used within APROSYS for the various research activities. This enabled the consortium to come with solutions valid for large groups of vehicle (types), rather than vehicle specific solutions. This largely increases the potential effect of the work performed, as well as the potential level of penetration of new safety systems in the future vehicle fleet.

4.6.4 Application

The generic car models have been used in a large variety within APROSYS itself. Furthermore, several of the models are available for use outside APROSYS. Thus, also new developments can be virtually tested with generic cars, so new safety devices or safety systems can be more widely usable. Especially in the development stage of new products, this is a very useful toolkit.

4.6.5 Future

The Generic Car Model fleet developed here has been extensively used to support APROSYS activities. Beyond APROSYS, they may be used in other research projects and there is a potential for future development and implementation as a part of new safety procedures/protocols involving Virtual Testing (e.g. car compatibility).

4.7 MR 6: Virtual testing methodology

4.7.1 Objective/goals

Tools and methods to boost the use of Virtual Testing and provision of elements towards a future use in vehicle regulations. This includes the development of knowledge and tools to facilitate the design and evaluation of advanced crash protection systems in a virtual environment. This result is closely embedded with the other technology areas of APROSYS to provide the required knowledge and tools to develop advanced protection systems for the various accident scenarios [24].

4.7.2 Approach

The main area of application here is road user safety assessment and injury evaluation or prediction via the provision. The result is actually the outcome of a four step approach where the following items were addressed:

1. Virtual Testing models
2. Virtual Testing methods
3. Virtual Testing Tools
4. Virtual Testing Demonstrator and Roadmap

1. Virtual Testing Models; Improvement of the predictive capabilities of numerical models (creating models for comparative and rated crash simulations)

- Development of material and assembly of models and procedures to include the effects of "ageing" in vehicle crash performance evaluation, see Figure 50
- Improvement of predictive capabilities of vehicle numerical models such that virtual testing can become an integrated part in safety system design as well as in future regulations
- Provision of generic vehicle models for safety analysis
- Conducting reference experimental work for validation of models

This resulted in experimental data and in models including airbags, material models, barriers, dummies, and a full fleet of vehicle models (FE or MB), shown in Figure 48 and Figure 49.

-

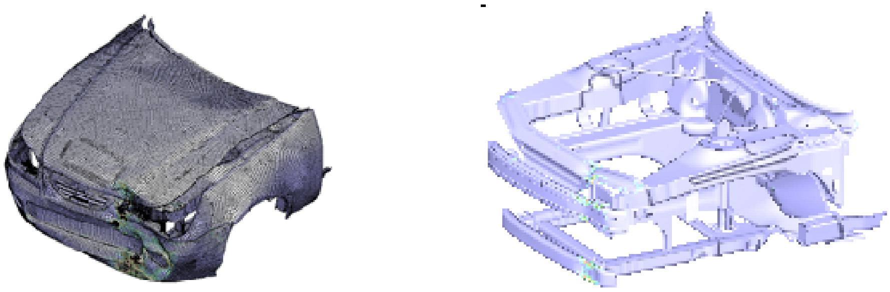


Figure 50: Ageing via repeated crash

2. Virtual Testing methods; Analysis of real world scenarios via exploratory techniques and dispersion analysis (building up methods for real life analysis)

This part was on the use and evaluation of exploratory methods (e.g. stochastic analysis, DOE, response surface methods, reliability based approach and robust optimisation) in order to simulate responses corresponding to real world accident scenarios. These scenarios often are not taken into account by standard normative procedures and physical crash tests. Additionally, flow charts for regulatory virtual testing applications have been developed. In order to achieve these objectives:

- Innovative exploratory analysis and simulation methods are employed and adapted to the special case of passenger safety simulations taking into account possible sources of dispersion.

- The robustness and predictive capabilities of simulations are assessed using advanced analysis methods.
- Demonstrators are provided in order to evaluate the feasibility of application of crash simulation codes in conjunction with exploratory methods for virtual real world accident scenario reconstruction.
- Methods for the analysis of sources of dispersion of input data and their consequences on evaluation and rating criteria were investigated in order to enhance the quality and level of predictability of numerical simulations.

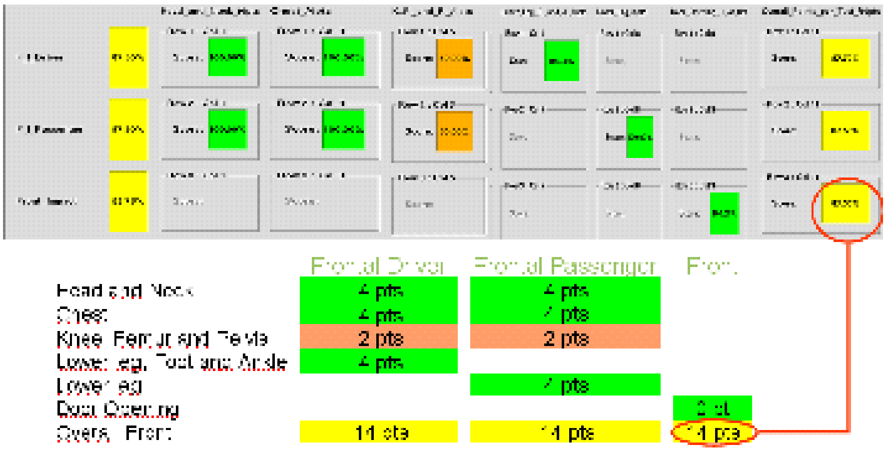


Figure 51: Example of rating proceedure

3. Virtual Testing Tools; Development of new simulation related technologies and user-friendly tools.

In order to implement and promote intensive and structured use of virtual testing for the prediction of occupant loading and injury mechanisms, it is essential to provide new technologies issued from computer implementations and user-friendly simulation, analysis and rating tools. Thus, the primary objective of this step was to provide a solid CAE support via:

- Improvements, templates, extensions and user interface developments of the Virtual Testing rating tool;
- Provision of new evaluation technologies such as 2/3-D image recognition and analysis tool;
- Development of evaluation criteria and rating procedures;
- Development of specific tools needed for enhancing the simulation activities

4. Virtual Testing Demonstrators and Roadmap; Towards the integration of Virtual Testing in regulatory test procedures

As a summary and illustration of the possible enhancements of the Virtual Testing methodology this step investigated the implementation and dissemination of virtual testing in traffic safety regulations and procedures, an example is shown in Figure 52. To deploy VT procedures in current or future regulations, the following steps were executed:

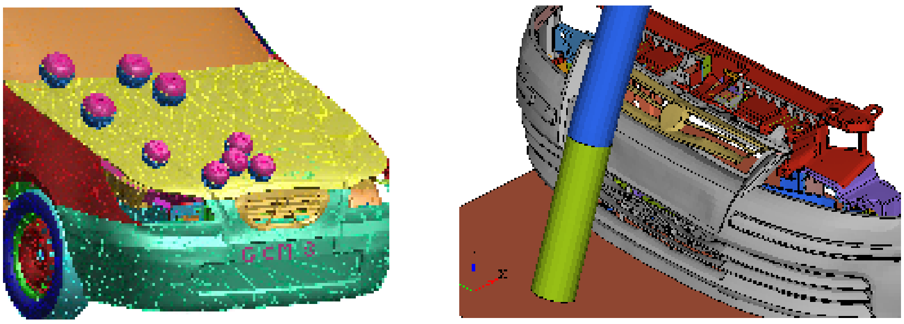


Figure 52: Pedestrian head form and leg form testing: two VT demonstrators

- Define what virtual testing procedures are required for selected existing regulations.

- Develop demonstrators that clearly show the enhancements in traffic safety by the incorporation of virtual testing procedures in existing regulations;
- Discuss and develop (inside and outside APROSYS, e.g. with regulatory bodies) a roadmap defining recommendations to have the proposed virtual testing procedures implemented in regulations;
- Support regulatory bodies with the implementation of the virtual testing procedures by providing draft procedures and introduction guidelines.

4.7.3 Contribution to the safety problem/achievements

The development of tools, methods and procedures helps in increasing the quality of the simulation activities leading to improved designs for protection devices and vehicles. As shown in the pedestrian demonstrators (both leg form and head form), the proposed Virtual Testing approach allows to cover a much wider range of impact conditions and hence increases the in-depth investigations of other scenarios. Important contributions in the regulatory domain with particular cost-effectiveness as well as exploratory (real-life) applications are envisaged.

4.7.4 Application

The results demonstrate potential applications of Virtual Testing in the pedestrian testing configurations. Tools and methods developed along the project were also applied in other areas such as motorcyclist safety and injury biomechanics.

4.7.5 Future

The future of vehicle and component testing for regulatory purposes will include virtual testing activities. The enhancement of the actual virtual testing technology for passive safety and the discussion and preparation of virtual testing tools for future regulatory purpose has been a major challenge. APROSYS has developed guidelines how to implement virtual testing and what analysis criteria to be used. This has been illustrated using demonstrators for analyzing pedestrian safety. Having developed a dedicated virtual testing roadmap, the path to implement virtual testing in current and new regulations and innovative “real-life designs” has been described.
From the results, and starting with the roadmap proposed, the range of the Virtual Testing applications is very large. A joint work with regulatory boards and the full support of all actors of the passive safety world will be a key factor for success.

4.8 MR 7: Test methods for vulnerable road users

This main result is built around three types of vulnerable road users accidents, described below:

1. pedestrians and pedal cyclists impacted by passenger cars
2. vulnerable road users in contact with heavy good vehicles
3. various motorcyclists accidents.

4.8.1 Objectives/goals for pedestrians and pedal cyclists

To develop new and/or improved vehicle test methods to assess and improve vehicle to vulnerable road user impact safety and taking advantage of:

- accident statistics to address the priority accident scenarios
- accident statistics to address real world injury mechanisms
- reconstructions identifying the sequence of events in an accident [20].

4.8.2 Approach for pedestrians and pedal cyclists

The first step in improving vulnerable road user (VRU) safety was to understand the nature of real world accidents. Analysis of accident statistics and of the accidents compiled into the In Depth Accident Database revealed that for VRUs two body regions sustained the most injuries; the legs and the head. In the first case the injuries ranged from slight to serious, whereas in the second case the injuries ranged from slight to fatal. In fact head injuries were identified as the single most likely cause of VRU fatalities. In addition, the locations of primary head impacts with vehicles were identified and these points lay mainly on the windscreen, scuttle and A-pillar of cars. Child head impacts were also identified in these regions. These two regions were targeted for the development of new and improved test methods.

Real world head injuries were identified as been caused by linear and angular acceleration inputs that resulted in both hard tissue (skull) and soft tissue (brain) injuries. However, the current head impact test procedure does not consider angular/rotational impact characteristics and in nearly all tests the headform tumbles uncontrollably after impact. Using virtual testing techniques the significance of neck loadings were established with a human body model. The differences in the head impact characteristics of the human body model and the current head impactor were quantified for three vehicle classes (roadster, family car and sports utility vehicle).

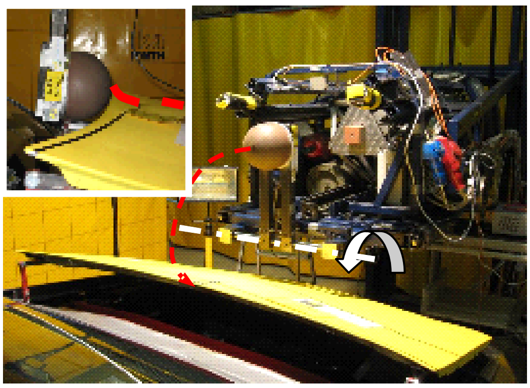


Figure 53: New assessment technique for head impact to sharp bonnet edges

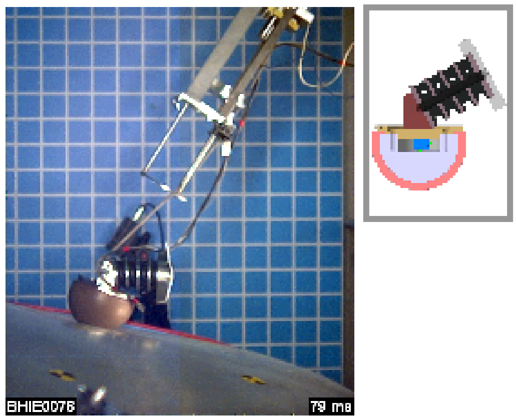


Figure 54: Newly developed combined head and neck impactor

The design parameters of a combined **head and neck impactor** (shown in Figure 54) that was capable of measuring both linear and angular accelerations were established for the three vehicle classes. The design was realised in hardware using the current headform with the addition of a neck element that constraints head motion in a manner comparable to that of a human being. Test equipment for the new impactor was developed and tested. Analysis of the effect of the linear and angular rotations can be assessed using the finite element model of the head (skull and brain) to predict likely injuries to the hard and soft tissues.

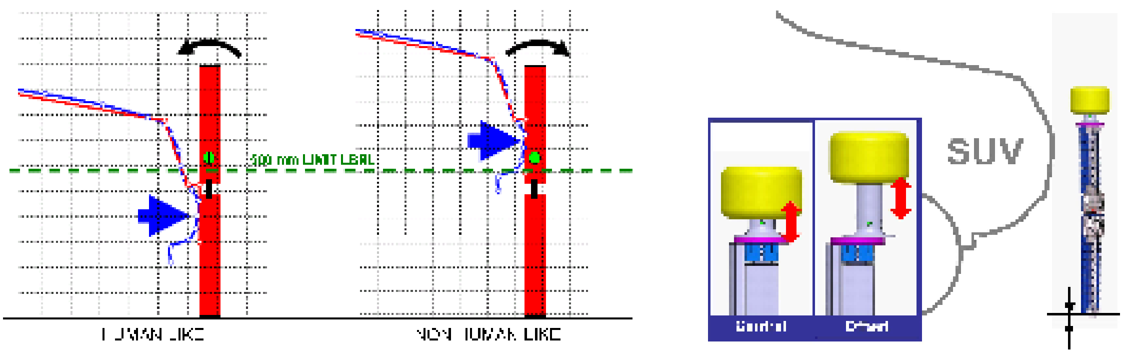


Figure 55: Legform impactor for SUV front testing

Where active/deployable bonnet systems are used in cars to achieve the necessary under-bonnet clearance during head impacts. This exposes the rear and side edges of the bonnet. To assess the severity of head impacts to these edges a new assessment technique has been developed (see Figure 53 for the developed and tested hardware) that uses force based criteria to investigate the highly localised loading of the skull.
The kinematics of the current **legform impactor** is representative of human behaviour during impacts with most cars except those with high bumpers. In these cases the vehicles (most often sports utility vehicles – SUVs) strike the impactor above its centre of gravity and cause kinematics that are unconstrained by the mass of the upper body as they would be by a vulnerable road user.

Virtual testing techniques were employed to examine how the impactor kinematics can be made more realistic both for the EEVC legform impactor and the Flex PLI. The investigations established that a 6 kg mass added to the top of both impactors can provide the necessary constraint to correct the kinematics and allow a realistic assessment of the risk for leg and knee injuries.

Cyclists have different impact characteristics (see Figure 57 and Figure 56) compared to pedestrians due to the difference in centre of gravity heights, legs orientations and their higher relative speed with respect to the vehicle. The forces experienced by cyclists' leg loadings can be significantly different to those of pedestrians' legs and in particular the knee bending moments can be in the reverse direction. This suggests the potential for a different knee injury mechanism for cyclists in some accident scenarios that is not addressed by the current pedestrian impactor tests. Cyclists' heads are more likely to strike the car further rearward and higher than pedestrians' heads, often beyond the pedestrian 2100mm wrap around distance limit. For the most cars (except SUVs) this impact position is more likely to be on the windscreen and A-pillars.

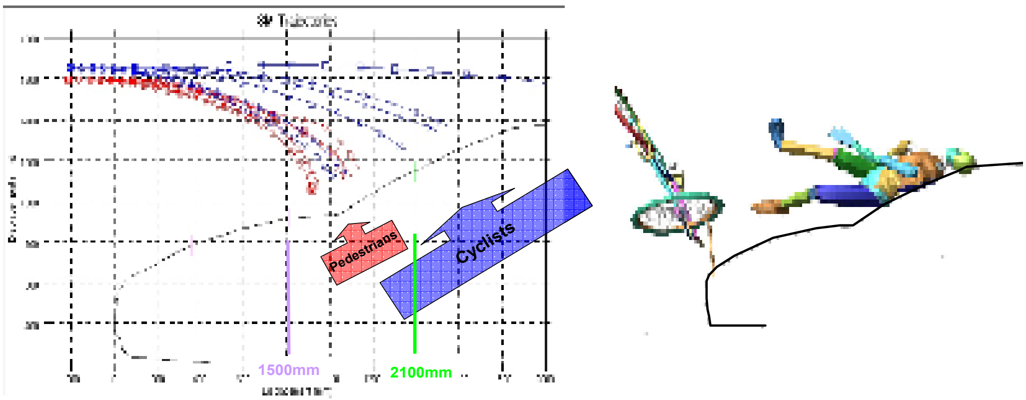


Figure 57: Trajectories of cyclist head impact against vehicle front

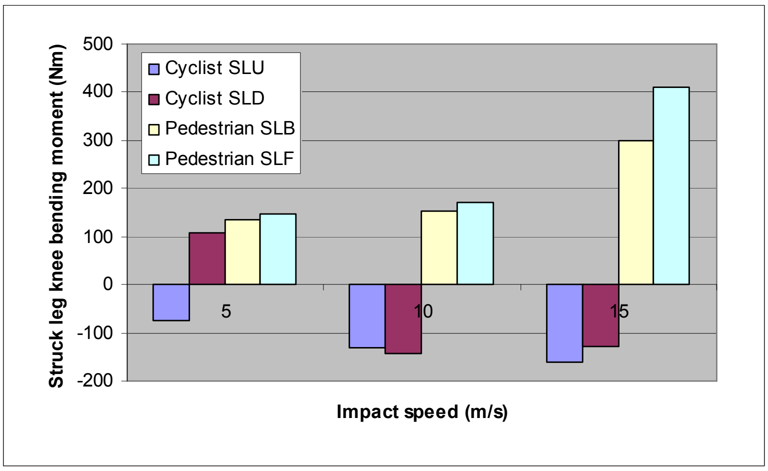


Figure 56: Cyclist struck leg knee bending moment (Nm).
SLU = Struck leg up, SLD = Struck leg down, SLB = Struck leg back, SLF = Struck leg forward

Adjusted test procedures are necessary to evaluate cyclist safety during impacts with cars that reflect the different positioning of cyclists' bodies with respect to the car frontal geometries and the subsequent impact locations of cyclists' limbs on cars.

4.8.3 Contribution to the safety problem for pedestrians and pedal cyclists/achievements

The new head impact test methods, hardware developments and test procedures address a wider range of head injuries in accidents as a basis to improve the vulnerable road user safety performance of vehicle fronts.
The ability to more accurately assess lower leg and knee injuries for vehicles with high bumpers will offer the prospect of improvements in the design of these vehicles that will result in greater safety benefits for vulnerable road users.
Recognition of the different impact conditions of cyclists with cars and the development of adjusted test procedures to reflect these differences, will directly improve the safety benefits for around one-third of all vulnerable road users.

4.8.4 Application towards pedestrians and pedal cyclists

The new or improved test methods can be used either on their own or in a hybrid test procedure ,a combination of virtual and experimental testing, to better examine the levels of safety provided by cars during impacts with vulnerable road users (pedestrians and pedal cyclists) that reflect real world conditions.

4.8.5 Future

Integration of the new and improved test methods with the current vehicle assessment test procedures to enhance the safety benefits for vulnerable road users – as a first step by EuroNCAP and subsequently in European legislation.

4.8.6 Objectives/goals for vulnerable road users in contact with heavy good vehicles

To develop test methodology and a rating system for assessing the aggressivity of heavy good vehicles to vulnerable road users [19].

4.8.7 Approach towards vulnerable road users in contact with heavy good vehicles

APROSYS developed an aggressivtiy index – the so called Heavy Goods Vehicle Aggressivity Index (HVAI) -, for the assessment of protection afforded by trucks to vulnerable road users. The proposed index consists of three parts, assessing the performance of the vehicle design in relation to the following areas:

- Direct contact between the person and the vehicle structure – structural index;
- Risk of the casualty being run over by the HGV – run-over index;
- The ability for the accident to be avoided though good visibility and/or active safety systems – active index.

A combination of experimental testing and numerical simulation is proposed. Where appropriate, proven methods accepted by the automotive industry have been adopted and modified to make them appropriate for assessment of HGVs.

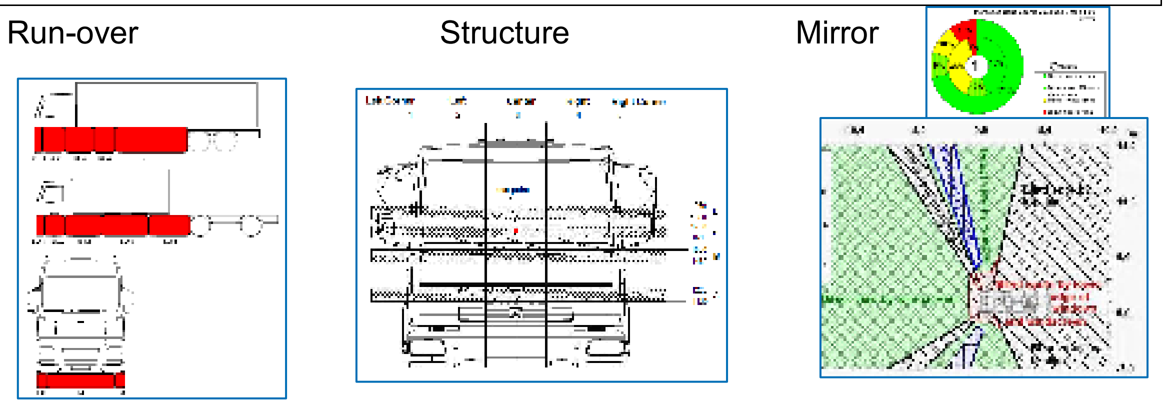


Figure 58: Basic parts of the HVAI

Physical measurements have been selected for assessing the structural impact. The structural aggressivity index defines two impact zones (adult, child) with 6 areas per zone and 4 regions per area. A WG 17 adult and child headform is propelled horizontally at 11m/s towards one region per area. Up to 15 tests per truck are required to assess the structural response.

Numerical simulations are proposed to assess the risk of run-over. A pedestrian model with and without bicycle is used. In total 21 simulations are required, covering two accident scenarios (turning, going straight), two road users (bicyclist, pedestrian) and seven impact areas depending on the scenario (two on the front and five on side). Run over in the numerical simulation is defined by the torso, the pelvis and/or the head contacting the tire and/or by the head and/or pelvis coming to rest within a predefined “critical area”.

The driver field of view has been assessed (see Figure 58) using a combination of physical measurements and geometry calculations. The index evaluates the field of view of a 50th percentile driver, separating in a primary area of interest,in the close surroundings of the vehicle, and a secondary area of interest , >5m away from the right front edge of the HGV.

4.8.8 Contribution to the safety problem

By introducing low aggressivity designs, annually 300-500 lives can be saved in Europe.

4.8.9 Application towards vulnerable road users in contact with heavy good vehicles

The Heavy Vehicle Aggressivity Index (HVAI) aims to encourage heavy goods vehicle (HGV) manufacturers /designers to develop vehicles that reduce the current number or severity of vulnerable road user (VRU) casualties from accidents involving HGVs. It can also be applied by regulatory bodies to set standards (index levels).

4.8.10 Future

It is recommended that the proposal is disseminated across Europe and that further development/discussions be taken up by an expert working group, such as EEVC WG14 or ISO. Attention should be paid to active driver assistance systems and appropriate assessment should be implemented in an updated HVAI.

4.8.11 Objective/goals for motorcyclists

For motorcyclists, three proposals for new test procedures were made:

- To give technical indications that help in the development of a reviewed standard for helmet testing

- Road and misuse tests standard for the development of active safety systems in the motorcycle industry.
- To develop a draft test procedures to evaluate road infrastructure in terms of motorcyclists' safety [21].

4.8.12 Approach towards motorcyclists

1. Helmets

Accident analysis performed in APROSYS has shown that head injuries caused by motorcyclists' accidents are quite frequent, even in the case that the rider is wearing a helmet. Protection given by current helmets needs to be improved.
At present, helmets need to withstand a series of impact tests according to the regulations currently in force, namely ECE Regulation 22/05 (R22). This current standard is limited in what concerns the prevention of specific injuries, like the ones related with the rotational acceleration effects, or the directional dependence of injury criteria.

The aim of the work performed is to propose amendments to the R22 regulation after comparing the real impact conditions taking place in real accidents (COST 327 report) with the impact conditions included in the R22. Then, some modifications in the R22 have been suggested with the purpose of making the Regulation closer to true conditions. These modifications have been given in two ways. From one side, a first approach has been developed, based on slight modifications in the R22 which can be easily put into practice in the mid term. From other side, a more innovative way of testing the helmets behaviour has been proposed for the long term.

2. Road and misuse tests

Reliable detection of accidents and prompt firing of safety devices in the vehicle can save lives. However, this requires exact adjustment of the sensors system to the individual crash behaviour of the relevant vehicle.

In order to develop advanced protection equipment for motorcycle riders "misuse" tests (see Figure 59 and Figure 60) are necessary to adjust the sensors system of the motorcycle to prevent the unintended deployment of the protective device.

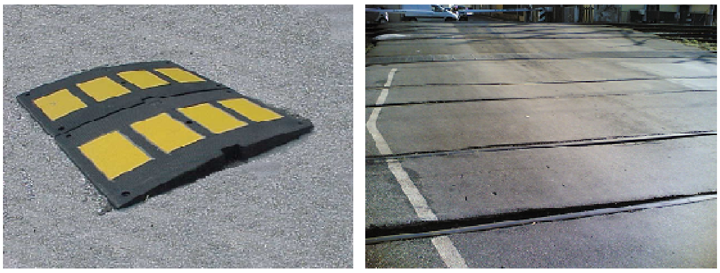


Figure 59: Different configurations of misuse tests: bumpers and railway segment

The measurement of decelerations by the sensor system occurring when tested under a variety of running misuse and handling conditions was used as the base data for creating the lower limit for collision judgement and threshold value.

Figure 60: Piaggio MP3 250 and Gilera Nexus 500 showing sensor positions

3. Road infrastructure
Prior work showed the most representative configurations of accidents involving motorcyclist impacts against infrastructure. Aspects such as impact angles, trajectories, distance of sliding on the carriageway, injuries, etc, have been investigated to define the better impact conditions for the standard proposed.

Though most of the information used comes from MAIDS project database ('In-depth investigation of motorcyclist accidents'), DEKRA (in-depth accidents database) and DIANA (in-depth accidents database developed by CIDAUT), also a literature review has been done to obtain some data related to other accident studies and related to motorcyclist tests which are being performed in different countries. From the database analysis, no conclusive results have been obtained. A theoretical study and computer simulations led to the selected set of parameters (incidence angle, impact speed etc.) recommended for the standard proposal.

An impact angle was chosen and a minimum impact speed has been recommended, after having demonstrated that the injury severity provoked in that configuration is close to the injury level provoked in real accident conditions.

4.8.13 Contribution to the safety problem of motorcyclists/achievements

These results help improving standards to make better products for the motorcyclists' protection. They deliver better knowledge about the performance of physical sensors implemented (related to future passive safety systems) in the motorcycle during normal and anomalous driving conditions as well as on needs towards protection by helmets. Also, the implementation of the standard for testing road furniture can lead to a largely increase safety in sliding impacts.
The socio-economic impact of this work will be important due to the high severity of the impacts of motorcyclists in case of accidents.

4.8.14 Application towards motorcyclists

The results presented here can on relatively short term be applied by:

- Helmet industry
- Motorcycle industry
- Passive and active safety Tier1
- Road safety (infrastructure) on a pan-European level.

4.8.15 Future

The results should be applied to update standards related to helmets. Furthermore, they can boost the development of active safety systems in motorcycles. For the road furniture, additional work by Road Authorities is needed to lift results to the level of harmonisation with EN-1317.

4.9 MR 8: Full width frontal test for Europe

4.9.1 Objective/goals

To assess a car's frontal impact crashworthiness, including its compatibility, an integrated set of test procedures is required. The European Enhanced Vehicle-safety Committee (EEVC) WG15 has recommended that this set of test procedures should contain both a full overlap test and an offset test. Currently in Europe, only an offset test is used in regulation and consumer (Euro NCAP) tests. The objective was to develop a full width test for Europe and perform a cost benefit analysis for its introduction into regulation [18].

4.9.2 Approach

The approach consisted of the following three tasks:

- Define a draft test protocol using accident analysis and review of similar procedures, e.g. FMVSS208.
- Evaluate the draft test protocol using full scale crash testing
- Perform an associated cost benefit analysis.

4.9.3 Contribution to the safety problem/achievements

Definition of draft protocol

The draft protocol was defined using accident analysis and review of similar procedures, e.g. FMVSS208 and the Full Width Deformable (FWDB) test.

Analysis of the CCIS (Co-operative Crash Injury Study, some results are shonw in Figure 61) and GIDAS (German In-Depth Accident Study) databases was used to establish the main aspects of the test procedure including the test configuration (overlap and impact direction), test speed, injury criteria, dummy specifications and rear seat occupant protection. The analysis showed that distributed damage is the most frequent type of damage for all injury levels and also has the highest risk of injury, indicating the need for a full width test. Also, the analysis showed that a 56km/h test speed would cover over 80% of MAIS3+ injuries in frontal impacts.

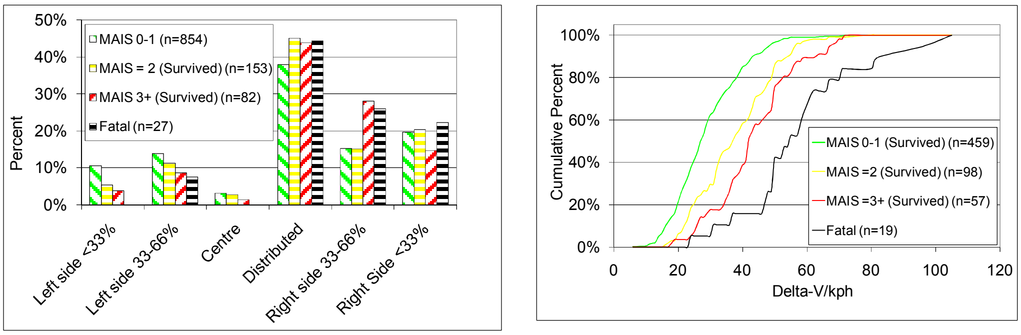


Figure 61: Analysis of CCIS database showing damage distribution by occupant injury severity (left) and cumulative frequency of occupant injury against Delta V (right)

Evaluation of draft protocol

Twelve full crash tests were performed as detailed in the matrix in Figure 62. These were performed to evaluate the draft protocol and investigate the following issues:

- Effect of deformable face compared to rigid wall
- Effect of the introduction of rear seated occupants
- Repeatability and reproducibility
- Practicality and robustness

Vehicle	**Test Configuration**	
	Rigid Wall	**Deformable Face**
	Test Objective	**Test Objective**
Supermini 1	Baseline	Baseline
		Reproducibility
Supermini 2	Baseline	Baseline
		Rear occupants
Small Family 1	Baseline	Baseline
	Rear occupants	Rear occupants
		Repeatability
		Reproducibility

Figure 62: Overview of the twelve crash tests performed

Effect of deformable face

The purpose of the deformable face is to make the test more representative of a vehicle to vehicle impact and to enable measures to be taken on a high resolution load cell wall (LCW, see Figure 63) to assess a vehicle's compatibility, i.e. its partner protection. The deformable face was designed such that a vehicle's crossbeam structures are loaded in the test as they would be in a vehicle to vehicle impact and that the unrealistic high engine deceleration loads seen in a test with a rigid wall are attenuated, so structural loads can be assessed more easily. Hence, vehicle deformation was different in the tests with and without the deformable face, especially for the front of the lower rails and bumper crossbeam. The LCW results also showed significant differences with the deformable face attenuating the engine inertial 'dump' loading seen in the rigid wall test, as expected.

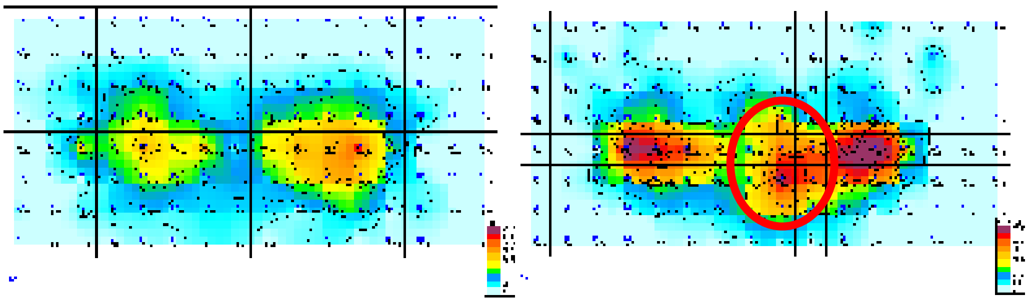
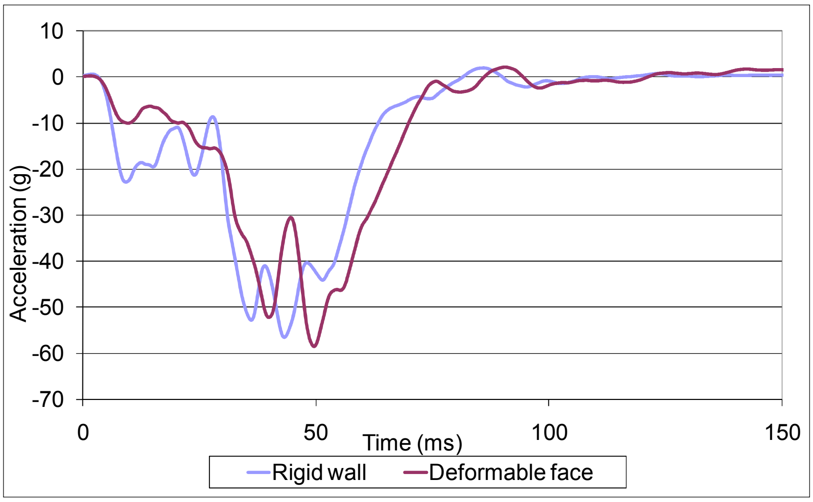


Figure 63: LCW force distribution for tests with (left) and without (right) deformable face showing attenuation of engine dump

The vehicle's compartment deceleration at the start of the impact was slightly lower in the tests with the deformable element compared those with the rigid wall. This resulted in a later airbag firing time for the tests with Supermini 2 (

Figure 64), but made little difference for the other cars tested. This shows that a deformable element may be needed in a full width test to ensure a more realistic assessment of a vehicle's crash sensing capability.



	Driver	Passenger
Rigid wall	12 ms	12 ms
Deformable element	33 ms	33 ms

Figure 64: Compartment deceleration and airbag firing time for tests with Supermini 2

The dummy injury criteria values were generally comparable for the test with the deformable face and the rigid wall test, indicating that the deformable element had little effect on the overall severity of the test. The exception was for Supermini 2, where the later airbag firing time resulted in different dummy injury values.

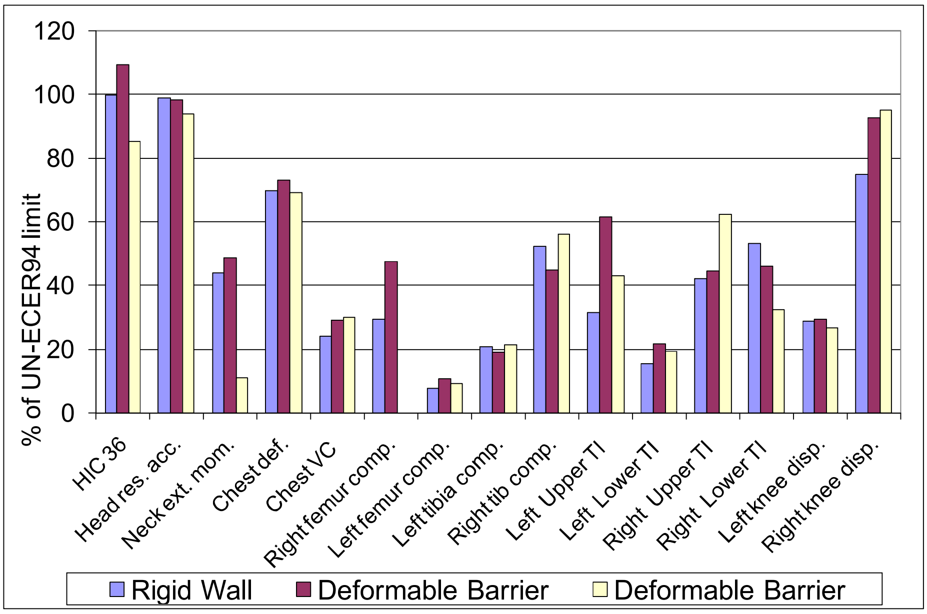
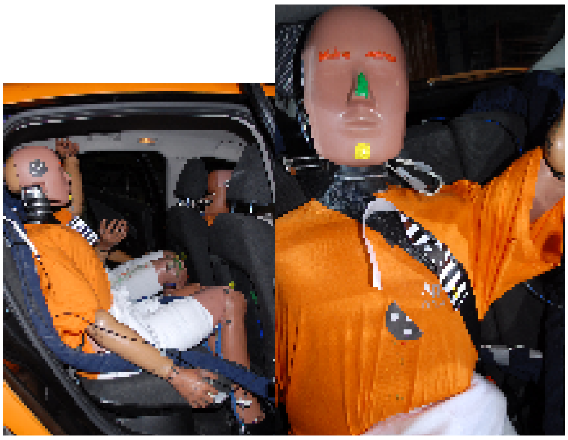


Figure 65: Dummy injury values for tests with small family 1 car.



Effect of rear seated occupants

The performance of the front seated dummies did not vary significantly in the tests with and without the rear seated dummies. There were significant differences for the performance of the rear seated dummies compared to the front seated dummies. The main differences were to the head, neck and tibia body regions. There was some evidence of the rear occupant submarining in the Small Family 1 car, see Figure 66.

Figure 66: Rear occupant submarining in test with small family 1 car.

Repeatability / reproducibility

The repeatability and reproducibility of the test with the deformable face was assessed as the repeatability of the test with the rigid face is already well known. Considering self protection measures, such as dummy injury criteria, it was found that the repeatability and reproducibility were at least as good as current R94 procedures. Considering compatibility (partner protection) measures, it was found that the global load cell wall force was repeatable. However, although the vertical component of the Structural Interaction (VSI) metric to assess a car's compatibility was repeatable, the horizontal component (HSI) was not. This was because of its high sensitivity to small variations in individual cell loads. Further development of the SI metric will be necessary to resolve this problem.

Table 7: HSI and VSI for Supermini

Supermini 1	VSI	HSI
Test 1	0.0	4.93
Test 2	0.0	3.26

Practicality / robustness

The introduction of rear seated dummies into the test protocol may create difficulties when testing vehicles with limited access (such as 3 door cars) when taking measurements such as pelvic angle.

Cost benefit analysis

An analysis to estimate the benefit for the introduction of a full width test into European regulation was performed based on the assumption that a full width test would encourage improved restraint systems, which would in turn reduce restraint induced thorax and abdomen injury. A potential benefit of up to about €2,000 million per year was estimated for EU15.

Table 8: Cost benefit overview

EU15	Fatal	Serious
Casualties prevented	430	6,017
Financial benefit per casualty (€)	1,787,340	200,832
Financial Benefit (€ Million)	769	1,208
Total	**€ 1,976 Million**	

The cost of restraint system modifications to enable current vehicles to meet FMVSS208 or R94 equivalent limits in a full width test were calculated; €242 million for FMVSS208 and €455 million for R94.
This results in a benefit-cost ratio of approximately 4:1 for R94 equivalent limits. However, it should be noted that the test performance limits may need to be raised to deliver all of the potential benefit, which would inevitably increase the costs, and hence reduce the benefit-cost ratio.

4.9.4 Application

It is expected that the full width test will be used in regulatory and / or consumer (Euro NCAP) testing.

4.9.5 Future

Further research is required to help set appropriate performance limits for the possible introduction of the full width test into regulation taking into consideration the costs and benefits. Also, further work, as part of the future EEVC WG15 activities, is required to determine whether a deformable face is required and whether rear seated dummies should be included in the test.

4.10 MR 9: Advanced side impact test method

4.10.1 Objective/goals

The main objective [18] was to complete the development and evaluate the suite of side impact test methods proposed by the International Harmonisation of Research Activities (IHRA) side impact working group.
The 4 parts of the proposed suite of procedures were:

- A Mobile Deformable Barrier test
- An oblique pole side impact test
- Interior headform tests
- Side Out of Position (OOP) tests

4.10.2 Approach

Mobile Deformable Barrier test

Because tests with the Advanced European Mobile Deformable barrier (AE-MDB) v2, developed by EEVC WG13, did not give a realistic vehicle deformations, two improved AE-MDB barriers with bumper beam elements, v3.1 and v3.9, were developed. Prototypes of these barriers were evaluated by comparing barrier tests with baseline car to car tests, load cell wall calibration tests and robustness tests. Simulations were used to support these development and evaluation activities. Most of the tests were carried out with the ES-2 dummy. A limited number of tests were repeated with 50th and 5th percentile WorldSID dummies.

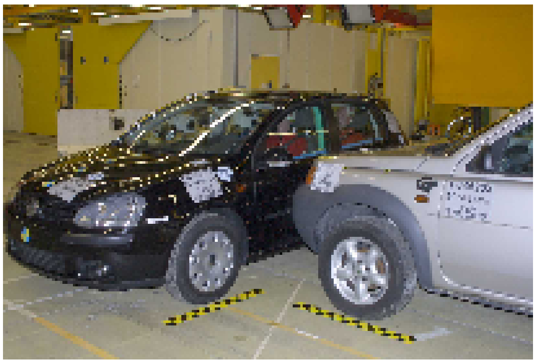
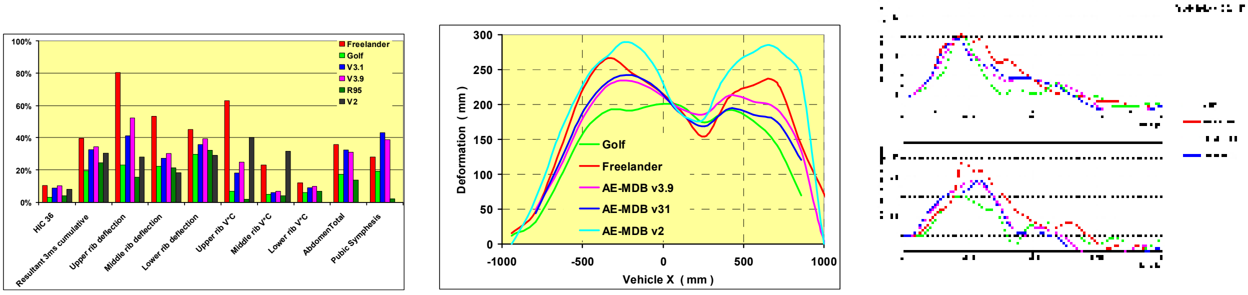


Figure 67: Baseline car to car test

Both v3 barriers (see Figure 68) gave more comparable dummy injury values and final deformation measures compared to the baseline car to car tests than the v2 and R95 barriers. There were only slight differences in the dummy injury values, door velocities and deformations for the v3.1 and v3.9 barrier tests.
However, the driver dummy pubic symphysis values for the v3.9 barrier compared better to the baseline test values.



Dummy results **Deformation** **Door velocity**

Figure 68: Test results, comparing different barrier designs

Tests with the v3.9 barrier using WorldSID dummies were carried out successfully. Head results of the WorldSID and ES-2 dummies were comparable. The thorax, abdomen and pelvic results showed differences mainly caused by the dummy design. As soon as injury criteria are available for the WorldSID, a more detailed comparison of the results can be performed to select the best dummy for a future AE-MDB test procedure.

Pole side impact test

Various car to pole test specifications, as used by Euro NCAP in Europe and proposed by IHRA, were evaluated using a series of full scale tests and two numerical studies.
Full scale tests with Toyota Avensis and Subaru Legacy vehicles were carried out with impact speeds of 29 and 32 km/h, different angles of impact (0° and 15°) and different impact locations. The influence of speed, angle, impact location and pole diameter were also investigated by numerical simulation.
Analysis of the results showed that a perpendicular car to pole test would be preferable but an oblique test would also be suitable. A literature study carried out within APROSYS showed that a significant decrease of about 40% of the number of car to pole accidents is predicted in the future, as a result of the introduction of electronic stability control (ESC). Combined with the new car to pole test procedure, road safety will be largely improved.

Free motion headform test

An evaluation of the draft EEVC WG13 protocols was carried out. Alignment tests to check the different flow-charts to define the impact locations and impact tests to check repeatability and reproducibility were performed using Fiat Stilo and VW Golf vehicles. Significant modifications to improve the EEVC WG13 draft protocol were proposed from this study, like a better definition of the head impact zone and an improved flow chart of points to be tested.

Side OOP tests

The IHRA draft protocol was evaluated from tests at 4 test laboratories using typical OOP scenarios suitable for Europe. Three and 6 year old child dummies and the SID2s dummy were used. As the use of child restraint systems is mandatory in Europe, additional tests with CRS were also performed.

Analysis of accident data showed there is no need for side OOP tests in Europe at present. However, should OOP tests be required in the future, a sub set of the IHRA scenarios could be used, but an update of the protocol is needed for regulatory tests in Europe.

Figure 69: OOP test with CRS

4.10.3 Contribution to the safety problem/achievement

In Europe (EU27) around 10,000 car occupants are killed annually in side impact accidents. Introduction of the new test procedures into regulatory and / or consumer testing will help reduce these fatalities.

4.10.4 Application

It is expected that the new and updated side impact test procedures will be used in regulatory and / or consumer (Euro NCAP) testing.

4.10.5 Future

The results of this work are being used by EEVC WG13 “Side impact”. The aim of this group is to provide recommendations to improve side impact regulation (UNECE Regulation 95).

4.11 MR 10: New protection systems for vulnerable road users

This main result is built around four types of vulnerable road users, all described below:

1. pedestrians and pedal cyclists impacted by passenger cars
2. vulnerable road users in contact with heavy good vehicles
3. motorcyclists.

4.11.1 Objective/goals for pedestrians and pedal cyclists

Develop new vehicle based concepts for improved pedestrian and cyclist protection and taking advantage of:

- real world accident statistics and injury mechanisms sustained by vulnerable road users
- ‘add-on’ systems to be integrated into vehicles and ‘build-in’ systems enhancing VRU safety
- knowledge of the constraints on vehicle front-end design

4.11.2 Approach towards pedestrians and pedal cyclists

The first step in improving vulnerable road user (VRU) safety was to understand the nature of real world accidents. This step was also necessary for Main Result 7. Also here, focus needs to be on the head and legs impacts. On the vehicle side, for the location of primary head impacts, focus is on the windscreen, scuttle and A-pillar.

To improve the leg area, an adaptive bumper concept was developed through the use of virtual testing techniques to investigate the likelihood of different bumper configurations causing injuries to vulnerable road users during an impact. The **adaptive bumper concept** as shown in Figure 70 has the following functional characteristics:

- bumper that moves forward in order to enlarge the available deformation space to soften the leg impact;
- extraction operated through gas-spring units which also act as energy absorbers;
- retraction via four Bowden cables connected to an electric motor that recalls the four gas springs;
- adaptive control, based essentially on the vehicle speed;
- only simple sensors needed, slow actuation.

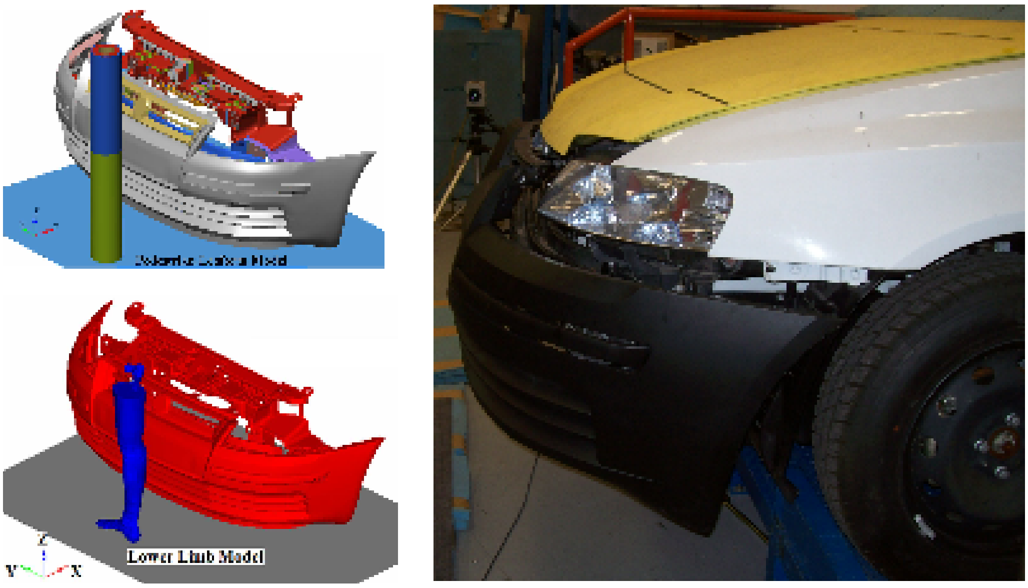


Figure 70: Adaptive bumper concept

In the case of the head impact area several systems have been designed to address head impacts at different locations on the front of a car. An Integrated Head Protection Airbag (IHPA) system has been developed to protect the head of a vulnerable road user during impacts on the bonnet and on the lower regions of the windscreen and A-pillars.

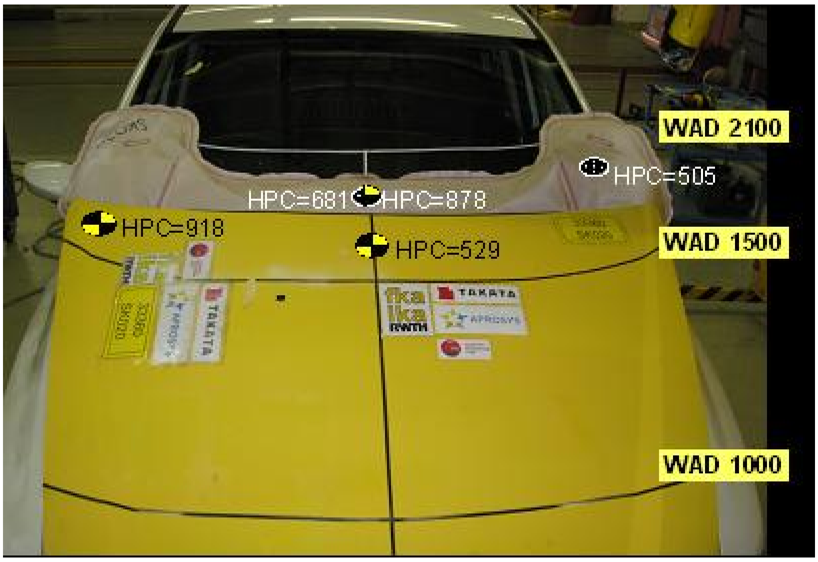
The airbag system is triggered based on a pedestrian detection system (contact sensor/ pre-crash sensor) and performs 3 main functions:

- lifting the rear end of the hood;
- closing the gap between the lifted hood and the windscreen with the airbag;
- covering the lower A-pillar with the airbag.

The deployment sequence is illustrated in Figure 71.

Figure 71: Deployment of the Integrated Head Protection Airbag

Following the development of the system a series of impact tests were conducted to confirm the performance of the system. During the impacts, using WG17 and ACEA head impactors the tests results from a vehicle originally not designed for pedestrian protection were all acceptable, as illustrated below.



WG17 Impactor (m=4.8 kg) *ACEA Impactor (m=3.5 kg)*

Figure 72: Head impact results, all acceptable

The IHPA system has shown the potential for implementation of a new protection device in existing vehicle models, and the realisation of improved head protection in all relevant test areas.

A **passive safety bonnet** (see Figure 73) was developed with limited under-bonnet clearance. It has the following features/characteristics:

- the existing bonnet framework below the outer skin was reduced significantly;
- the outer skin has an etched ‘gridload’ pattern on the inner surface;
- a ‘pressload’ energy absorber panel is located beneath the outer skin;
- an inner panel retains the ‘pressload’ panel and is attached to the edges of the remaining framework.

Based on the use of virtual testing techniques, the design parameters of the component parts have been choseen. Complete bonnet systems have been developed and physically tested, leading to promising results.

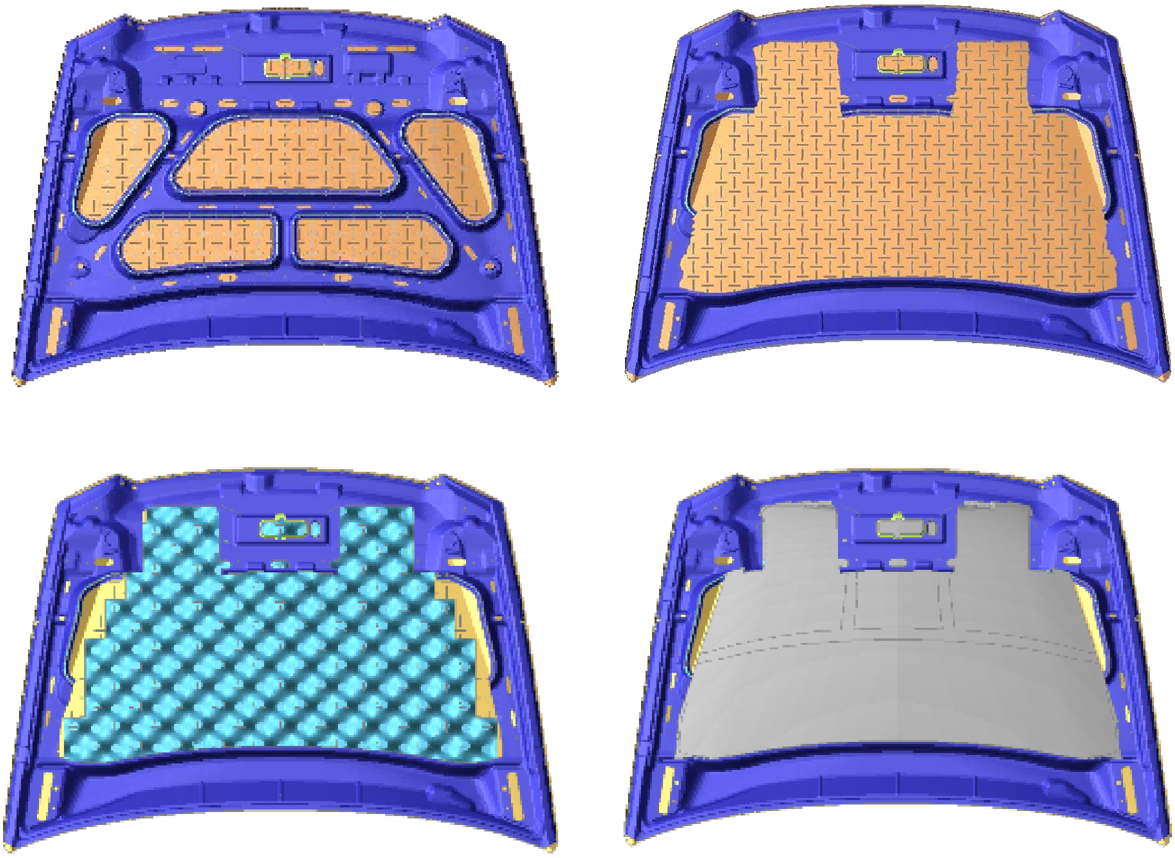


Figure 73: upper left: original under bonnet framework, upper right: reduced under bonnet framework and gridload etched outer skin. Lower left: pressload panel, lower right: inner panel

To address real world impacts at all allocations on the windscreen, including beyond the current test positions, a new **energy absorbing system** (Figure 74) for mounting the windscreen to the car body has been developed. Virtual testing techniques have been used to identify favourable parameters for improved head impact performance.

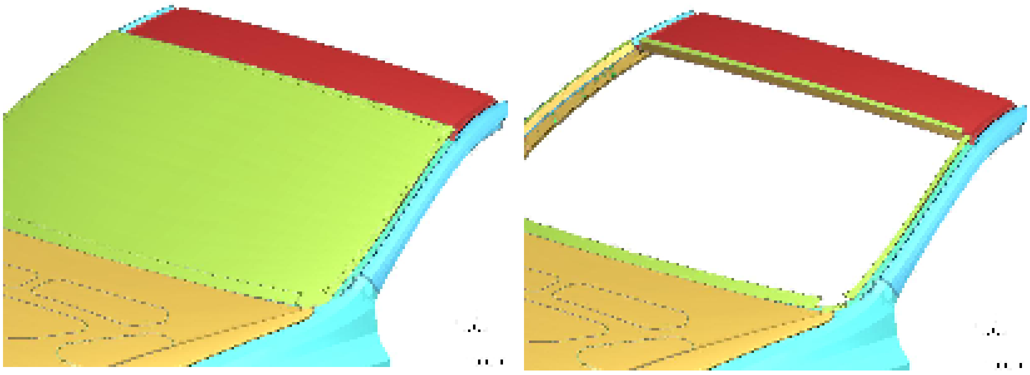


Figure 74: Left: windscreen located by new mounting system. Right: new mounting system beneath windscreen

The system has the following characteristics:

- enables the current technology for mounting windscreens in cars to be retained;
- fits between the windscreen and the current windscreen aperture flanges;
- constructed to form a folded cross-section that absorbs energy during deformation;
- assembled with corner joining pieces;
- improves head impact performance at all locations on the windscreen but specifically at the edges of the windscreen;

- the parameters of the energy absorbing windscreen mounting system can be tuned for individual vehicles and impact scenarios.

Predicted head injury criterion (HIC) values at impact locations at the edges of the windscreen ranged from 30% to 50% of the HIC of a windshield with a standard mounting (HIC nearly 1700), depending on the design parameters and construction of the energy absorbing component. The principles of the energy absorbing windscreen mounting system are now the subject of a patent.

4.11.3 Contribution to the safety problem of pedestrians and pedal cyclists/achievements

The benefits of the bumper adaptive concept, the integrated head protection airbag system, the passive safety bonnet and the energy absorbing windscreen mounting system are:

- a reduction in the number of killed and injured pedestrians and cyclists;
- a reduction in the severity of injuries sustained by pedestrians and cyclists.

4.11.4 Application for pedestrians and pedal cyclists

The new safety systems and construction techniques developed can be used to provide enhanced levels of safety for vulnerable road users during impacts with cars. The design parameters of each can be tuned for individual car models and impact scenarios to achieve the optimum levels of protection that can be provided for vulnerable road users during impacts.

4.11.5 Future

Full integration during the design stages of vehicle development of the technical advances identified and demonstrated in APROSYS will provide the greatest improvements in safety and bring about a further contribution to the reduction in accident fatalities and injuries.

4.11.6 Objective towards vulnerable road users in contact with heavy good vehicles/goals

To develop and demonstrate advanced protections systems for heavy goods vehicles in case of impacts with vulnerable road users [19].

4.11.7 Approach for vulnerable road users in contact with heavy good vehicles

Based on findings in statistical and in-depth accident analyses numerous safety concepts were suggested. Concepts were reviewed towards cases in the APROSYS accident collection and their potentional benefit for individual cases was rated by an expert panel. Based on this information, two concepts were selected for further investigations and for being built up as a demonstrator: the Nose-cone and the Safety bar.

The **nose cone** concept (Figure 75) deflects the vulnerable road user and avoids an over-run by the heavy goods vehicle. This is an integrated concept that needs a redesign of the truck cabin front.The **safety bar** (Figure 76) is an add-on part for trucks, which aims to reduce the aggressivity of the front structure of the cabin by reducing the severity of the primary impact.

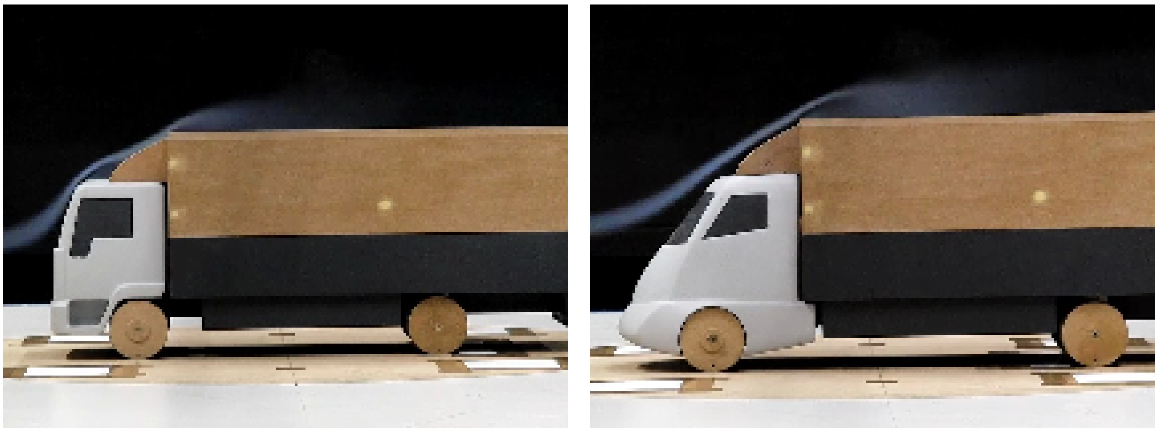


Figure 75: Vehicle front, original (left) and with nose cone. Lab models for windtunnel testing

Passive safety measures in the field of heavy good vehicles are not the first topic for OEMs and the haulier; primary interest is reduction of fuel consumption and emissions. A future streamline truck design can address both, enhanced passive safety and decreased fuel consumption. These benefits were shown by wind tunnel tests, comparing a conventional truck with a truck having the nose cone integrated.

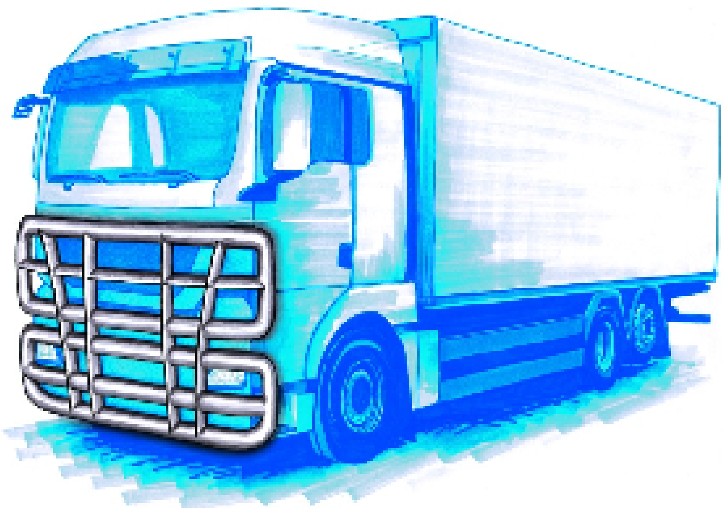


Figure 76: SafetyBar as styling feature and vulnerable road user protection device

4.11.8 Contribution to the safety problem of vulnerable road users in contact with heavy good vehicles/achievement

Depending on the impact velocity, three mechanisms for enhanced vulnerable road user safety were identified:

1. Lower impact velocity range: Enhanced field of view will reduce accidents with vulnerable road users.
2. Middle impact velocity range: At impact velocities below 30kph, approx. 80% of the vulnerable road users end up under the heavy goods vehicle. Deflecting the pedestrian to the side prevents this type of run-over. The nose-cone concept is a promising concept reducing fatalities due to run-over. Numerical simulations indicated also a less severe secondary contact with the road, when hit by a nose-cone goods vehicle.
3. Upper impact velocity range: At impact velocities exceeding 30kph, the severity of the primary impact is to be reduced. The safety bar is reducing the load on the vulnerable road user during impacts with the cabin. This results in a reduced injury risk to the head and to other body regions.

4.11.9 Application for vulnerable road users in contact with heavy good vehicle

The nose cone design offers benefits going far beyond enhanced vulnerable road user protection: reduced fuel consumption, enlarged drivers working place, additional space for font-underrun protection devices (FUPD) and improved direct view for the truck driver. Experimental testing suggested that the nose-cone design can reduce the drag coefficient by 10-20%. These additional benefits will promote the integration of safety features.
The safety bar as add-on device is addressed of the after-market and the individual needs of truck drivers to style their vehicles.

4.11.10 Future

The introduction of a nose-cone concept is in Europe conflicting with the current truck-length regulation. A revision of weight and dimension regulations is essential for enhanced partner-protection in HGV. It is suggested to allow for extra length and weight when the vehicle is equipped with safety features for improved partner-protection. The decision for a safer truck has also to be promoted by tax-benefits and/or regulation enforcements. The introduction of a nose-cone design will also be driven by hauliers and fleetowners asking for reduced fuel consumption. The safety-bar can be taken on board by after-market suppliers, provide low-cost style combined with improved safety for vulnerable road users.

4.11.11 Objective towards passenger cars to heavy good vehicles/goals

To develop and demonstrate advanced protections systems for heavy goods vehicles for accidents where a passenger car is running into the side of a heavy goods vehicle.

4.11.12 Approach towards passenger cars to heavy good vehicles

Among heavy goods vehicle side impact accidents, two scenarios for European roads were identified:

- Accidents with the passenger car impacting the side of a trailer at a velocity of 65kph (75th percentile value) perpendicularly
- Sliding/swiping collisions with closing speeds of 120kph (75th percentile value)

In a first step several concepts of side underrun protection devices (SUPD) were roughly developed and evaluated. Bearing in mind the above mentioned scenarios, the final cost-benefit estimation of concepts resulted in three main candidates for a demonstrator:

- Front underrun protective device adapted to the side of the HGV
- Deflection device: Guard-rail-like device around the truck/trailer
- Crashworthy pallet box for trailers (see Figure 77).

The performance of these concepts with respect to side underrun prevention and deflection capabilities was analysed in a numerical environment, using the generic car models developed within APROSYS SP7. In parallel a quasi-static testing procedure for side-underrun protection devices was developed.
All three concepts provided the necessary protection and met the requirements set by the quasi-static testing procedure.

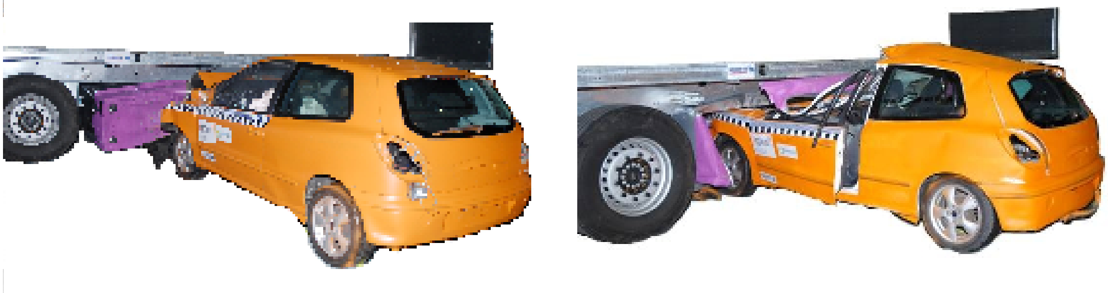


Figure 77: Full scale testing of crashworthy pallet box, versus full scale testing of conventional pallet box

In the testing procedure three rectangular rams are loading the side underrun protection device with a total force of 270 kN. The maximum intrusion must not exceed 400mm. For the final demonstration the crashworthy pallet box was designed and tested under real world conditions. All devices were designed as add-ons or adaptations for conventional trucks or trailers. Therefore additional weight (reducing the payload) and/or additional costs are arising and influencing the cost-benefit ratio negatively. A substantial change of the truck/trailer body design towards an advanced frame concept will lead to a costefficient integration of an (all-around) underrun protection and other benefits, like a decreased drag coefficient.

4.11.13 Contribution to the safety problem

The developed side underrun protection devices and the testing procedure can contribute to safe about 100 lives of fatally injured car occupants impacting the side of a truck or trailer annually in the EU.

4.11.14 Application for passenger cars to heavy good vehicles

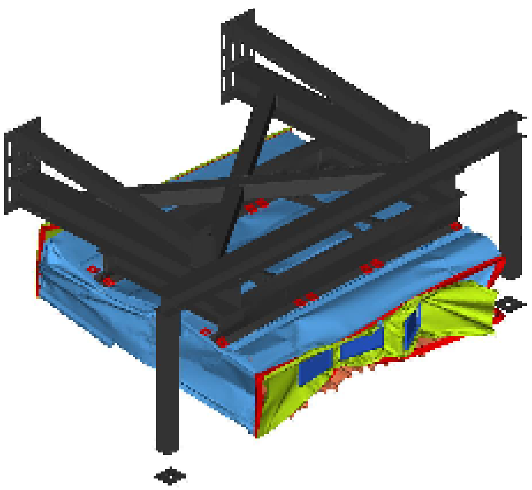


Figure 78: Virtual testing of crashworthy palletbox (3 impactors loaded at 90kN each)

The design of side underrun protection devices (also virtual tested as in Figure 78) showed the possibilities and challenges for side underrun protection. It showed also the application of virtual testing and use of computer aided engineering for the truck/trailer development.

4.11.15 Future

For the integration of an (all-around) underrun protection for cars and vulnerable road users a complete and comprehensive redesign of the truck/trailer frame is required. The reliability of computer aided engineering and a joint development of new truck/trailer concepts in Europe will bring a cost-efficient passive safe truck/trailer. Also the development of active safety devices and driver assistant systems has to be taken into account. The developments achieved so far will be very helpful in this process.

4.11.16 Objective towards motorcyclists/goals

For motorcyclists, two different protection systems were developed:
1. A helmet prototype with improved safety on chin part and better head protection in impacts.
2. A thorax protector (male and female version and in different garments) to reduce the risk of suffering injuries in the thoracic body region in case of accidents [21].

4.11.17 Approach towards motorcyclists

Helmet

1. Selection of materials for the new prototype: polypropylene foam for the liner and aluminium honeycomb for the chin guard.
2. Shape optimisations aiming at minimising the overall head accelerations (HIC) and head rotational accelerations.
3. Development of a chin element capable to absorb impact energy.
4. Development of a helmet prototype FE model.
5. Prototype according to the best designs obtained in the simulation phase.
6- Test the prototype according to the suggested procedure to improve the R22/05 regulation (see MR 7).
7. Comparison of the behaviour of the prototype and a commercial helmet through several tests, analyzing parameters as the HIC value, linear acceleration and rotational acceleration.
8. Validation on the new helmet prototype model.
9. Assessment the model performance regarding biomechanical criteria.
10.- Final assessment; ergonomics and comfort by motorcycles users.

Figure 79: Prototype helmet

Figure 80: Male & female thorax protector prototype

Thorax protector

Motorcyclists often suffer injuries on the thoracic body region; the level of these injuries is very severe. In consequence, it has been decided to develop a new protector for the thoracic area. Starting from the in depth accidents data collected, the impact conditions were defined and tests to be performed in order to verify the effective protection offered by this new safety device.

Materials selected for the prototype manufacturing are: polypropylene for the rigid shell, aluminium honeycomb for the shock absorption. All materials were characterised and a series of simulations with HUMOS model were conducted. The protector reduces the injury risk.

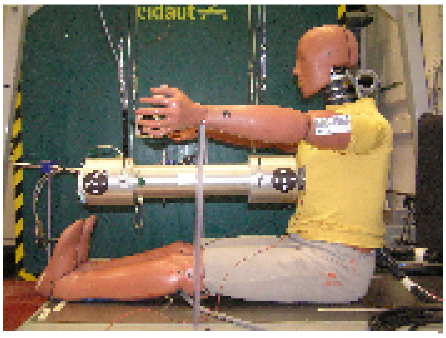


Figure 81: Validation test done over the thorax protector

After the simulations, a series of thorax protector prototypes were manufactured and tested in terms of comfort (ergonomic tests) and protection against impact.

Ergonomic test confirmed the good quality of the design, showing that the protector doesn't interfere with the normal rider's movements. A series of real tests impacts using HYBRID confirm that the protector increases the level of rider's safety protecting its thorax.
Finally, different garments have been manufactured showing the flexibility of this new protective device.

Figure 82: Different garments for the male thorax protector

4.11.18 Contribution to the safety problem of motorcyclists

These results help to minimize the risk of severe injuries and casualties amongst motorcyclists. Head and thoracic region become better protected.

4.11.19 Application for motorcyclists

The results obtained can on the short term be used by:

- Motorcycle industry
- Helmet industry
- Protective equipment industry
- Further research

4.11.20 Future

Commercial exploitation by the industry. The thorax protector is planned to enter the market at the end of 2009.

4.12 Combining Main Results; some examples

In several cases, Main Results have been combined to gain best possible project results. The main striking example is the combination of Main Results 3 and 4, which will be described in some more detail below. Futhermore, another important combination to mention here, is the use that was made in the final development stage of MR 9 (Advanced side impact test method) of the WorldSID 5^{th}, MR 2. This was especially the case in the MR 9 part focussing on the AE-MDB testing.

4.12.1 MR 3 and MR 4: Evaluation of the advanced side impact system using the Generic assessment methodology

The generic methodology (MR 4) was used to evaluate the advanced side impact system for crash mitigation. Accident scenarios were selected based on accident analysis studies on side collisions. According to their relevance, these accident scenarios were transferred into test scenarios.

- Assessment of real world performance (“false alarm rate” and comfort issues) by track tests and a field test. This test cluster represents the area: “supporting information”, primarily focusing on the sensing and decision system.
- Assessment of the pre-crash performance. The test conditions are based on the accident scenarios taking into account also the system- and test lab limitations. Focus on pre-crash sensing system (Radar / Stereo camera).
- Assessment of the crash performance. For this, the EuroNCAP side impact test protocol was selected. Focus of the crash performance test is the reversible crash actuator application.

A false alarm analysis in real traffic has been carried out in a Field Test on European roads (F, I, A, D - approx. 2000 km), see Figure 83. Several alarm situations were recorded and now clustered whether they are real false alarms (comfort issue) or acceptable with regard to the triggered safety application. Such field tests can be recommended as essential within the evaluation of a pre-crash system supplemented by Track Tests to evaluate the sensor performance in specific traffic situations. These situations are non-accidents, but are considered as challenging for the sensor and decision system in terms of distinguishing an accident from a non-accident situation.

The Pre-Crash performance Test cluster proceed with non-destructive tests, representing accident scenarios. The tests are performed with “critical” objects in a controlled environment. The results serve the purpose of the extended “technical performance” evaluation cluster of advanced safety systems. The Crash Test, showing the potential of the reversible actuator by means of a reduction of intrusion and intrusion velocity, finally allows an overall assessment of the complete pre-crash side protection system.

The above described results and experiences are used for the finalization of the final proposal for future methods to evaluate advanced safety systems. This will facilitate the development and market introduction of advanced safety systems and thus the potential to improve the primary and secondary safety of vehicles.

Figure 83: Route used during the field study, and a view from the study

5 Deliverables and other output

This chapter describes the deliverables and other types of output including dissemination activities, resulting from the APROSYS work.

5.1 Deliverables

Within the project, there are more than 200 deliverables. Most of these are technical deliverables, belonging to specific technical work performed in one of the SPs. Though, APROSYS delivered also several other reports, of a more general character, e.g. those summarising the results of each SP. The final reports –one per technical SP and an overall final report- are characterised in Table 9. All these final reports are public available, and therefore freely to be downloaded from the project website www.aprosys.com.

Table 9: Final deliverables, together thoroughly summarising the projects achievements. All reports are public

Report number	Name	SP	Description
AP-90-0001	Final report for the work on “Car Accidents” (SP1)	1	This report summarises the main outcomes of SP 1. The main aim of the APROSYS ‘Car Accidents’ subproject (SP1) was to develop new test methods. The subproject was divided into three work packages which focused on side impact, frontal impact and advanced safety systems with pre-crash sensing. The following three main results were the outcome of the work performed: • Advanced side impact test methods. • A full width frontal impact test for Europe. • Generic assessment methodology for advanced safety systems.
AP-90-0002	Final report for the work on “Heavy Vehciles” (SP 2)	2	This report summarizes the work of APROSYS SP2. This subproject addressed accidents in-volving heavy goods vehicles. Accidentology studies indicate that the rate for killed or seriouly injured casualties in HGV-VRU (Heavy Goods Vehicle against Vulnerable Road User (pedestrians and cyclists)) accidents is extremley high and 7 to 10 times more frequent than in PC-VRU (Passenger Car against Heavy Goods Vehicle) accidents. In APROSYS SP2 “Heavy vehicles” specifically two scenarios have been addressed: Pedestrians and cyclists hit by trucks and Cars hitting the side of a truck.
AP-90-0003	Final report for the work on “Pedestrian and Pedal Cyclist Accidents” (SP3)	3	This report gives an overview of the outcomes of SP 3. The overall objective of sub-project (SP) 3, ‘Pedestrian and Pedal Cyclist Accidents’ was to pave the way for the introduction of advanced protection systems for the reduction of the number and severity of injuries to pedestrians and pedal cyclists (commonly referred to as vulnerable road users) in all relevant accident scenarios involving cars,

			MPVs and SUV's. The aim was to reduce fatalities in addition to severe and moderate injuries generally, but in particular for the priority vulnerable user groups of children and the elderly. The results from SP3 fall into two categories: • Those that were instrumental in defining the priorities of the sub-project and provided the tools needed to achieve the objectives; • Those that were the main/exploitable results from the sub-project, which were shown at the Final Event Conference and Exhibition, and which are contributing to the APROSYS project's ten Main Results.
AP-90-0004	Final report for the work on "Motorcyclist Accidents" (SP4)	4	Motorcycling is an important and popular way of transport in many of the EU countries, as well as in several other countries around the world. It is undeniable that motorcycling has some important advantages over other forms of transport: flexibility in the journeys, more efficient use of roads and parking spaces, better environmental care. The risk of sustained injuries or being involved in an accident associated with these vehicles is also extremely high: in EU roads during 2001, 6,000 fatalities out of 40,000 are related to Powered Two Wheelers (PTWs) [27]. Riding a motorcycle is 20 times more dangerous than driving a passenger car: 16 fatalities per million–person km vs. 0.8 fatalities per million–person km. The aim of APROSYS Subproject 4 'Motorcyclist Accidents' is to reduce the number of fatalities and the number and severity of motorcyclist injuries on EU roads, focusing on: • Forgiving road infrastructure behaviour. • Motorcyclists advanced protection systems.
AP-90-0005	Final report for the work package on "Biomechanics" (SP 5)	5	The sub-project (SP) on Biomechanics is one of the three technological APROSYS SPs providing knowledge and tools to other SPs. Those other SPs are in charge of the various accident scenarios considered in APROSYS in order to develop advanced protection solutions for all road users in all accidental situations. The main aim of this SP was to fill these gaps and support other sub-projects by providing knowledge and evaluation tools to assess the safety performance of vehicles and safety devices. The focus was on the development of two specific tools. The first one is the small female version of the WorldSID side impact dummy. The second one is the numerical model of the human body.
AP-90-0006	Final report for the work on "Intelligent Safety Systems" (SP6)	6	In the APROSYS Sub-Project 6 (SP6), "Intelligent Safety Systems" further progress in car safety technology was envisioned from the use

			of, so called, pre-crash systems. Such systems make use of sensing which looks around or inside a vehicle, so information about an imminent crash can be available prior to the impact. The actuator can thus react to the situation on the road, i.e. it is adaptive. This additional possibility has a large safety potential. The focus of the project was on system definition, specification and validation of such a system with sensors, algorithms and actuators. It was decided that the proposed system should be adaptive, generic (adaptable to virtually any car) and reversible. Specific research objectives were: o Outline specification for an advanced adaptive safety system, including an estimation of the pre-crash system potential for injury reduction o Design and construction of an experimental car equipped with a sensor system, decision algorithms and HMI for evaluation in real traffic o Set up of test und evaluation methods for pre-crash sensing systems This report shows the SP 6 main achievements.
AP-90-0007	Final report for the work on "Virtual Testing" (SP7)	7	Subproject SP7 "Virtual Testing" was primarily aimed at investigating how Virtual Testing can be incorporated into present and future regulations. During the life of APROSYS, it turned out to be also a valuable transversal project, providing tools such as car models, rating and stochastic software or methods, to other technology areas. This report can only summarise the results of 5 years of intensive activities to develop (and promote when feasible)) the use of VT. The objectives of this subproject were essentially focused first on providing tools, models and methods to support the other technology area (this was achieved through a variety of models provided) and aimed to establish and demonstrate use of Virtual Testing.
AP-90-0008	Final APROSYS report	9	This is the currently underlying report, summarising the results and efforts of the APROSYS consortium. It shows the main results obtained during the project lifetime from April 2004 until March 2009. It also shows e.g. synergies amongst the technical SPs, thus showing the integrated approach within the project works quite well. The close cooperation between the SPs and the vivid exchanges of data, test procedures, information and experiences was only possible within the framework of an Integrated Project.

5.2 Prototypes and models

Though most deliverables were technical reports, several other types of results were obtained. These contain prototypes, demonstrators and models, all accompanied by a report describing the work performed to come to the end results. The prototypes and models are listed in Table 10.

Table 10: Prototypes and models developed within APROSYS

No	SP	Title	Purpose	Main responsible partner(s)
D4.3.2B	SP4	Improved helmet	Showing the new helmet, including new material, chin part and geometry. The helmet prototype also was used in testing.	Cidaut, Dianese
D4.3.2D	SP4	Prototype validated helmet model	Helmet model for use in simulations, using new materials and geometry (closely liked to the prototype improved helmet).	Cidaut
D4.3.3	SP4	New thorax protector	Showing geometry and material of the concept of the newly developed thorax protector for motor cyclists, discussion material and dissemination material	Dianese
D4.3.3A	SP4	Female thorax protector	Geometry and design of the female version of the thorax protector	Dianese
D4.3.3B	SP4	Different female and male thorax protector size	The concept of the thorax protector applied in wearable protective clothing, almost ready for production and marketing.	Dianese
D5.2.6	SP5	Six prototype units 2D rib deflection sensors	Prototype rib deflection sensors, based on new principles of work, to be used within the WorldSID 5th dummy, showing more realistic rib deflection measurements than available so far.	FTSS
D5.2.7	SP5	Updated prototype dummy fully operational for testing	WorldSID 5th dummy, ready for testing both insided APROSYS and by third parties. The dummy was updated based on input from previous testing and input regarding the harmonisation process.	FTSS
D6.2.1	SP6	Functional radar side sensing system	Radar sensing system to be implemented in the test vehicle for the side impact mitigation system	Conti
D5.3.16-19	SP5	Human FE model	Simulation of Human body reponse in virtually reconstructed accidents	ALTAIR, ESI, TNO
D6.2.2	SP6	Functional camera side sensing system	Camera sensing system to be implemented in the test vehicle for the side impact mitigation system, in conjunction with the radar sensing system	FhG
D6.3.2	SP6	Prototype of actuator	Actuator on component level, for implementation in and triggering of the side impact mitigation system	Faurecia, FhG
D6.4.4	SP6	Functional side pre crash system implemented in test car torso	The side pre crash system fully built into a test vehicle, ready for further (development) testing and demonstration	Conti
D7.1.4A	SP7	Generic Car Models	Generic Car Models (both FE and MB) for the following categories: supermini, small family car, large family car or executive, MPV, heavy vehicle	

5.3 Dissemination and other outputs

An efficient and effective dissemination of results and knowledge is a large challenge for large multi-partner projects like APROSYS. Overall aims of the dissemination activities were:

- Increase collaboration both between partners, either working within the same SP, as over the SP borders. Furthermore, increase the cooperation of partners with third parties, e.g. representing other European projects, international working groups (EEVC, ISO) and international organisations (Euro NCAP).
- Enhance and obtain a full implementation of research results in automotive industry.
- Promotion, by publications and presentations, of the project findings, spreading knowledge to a broad audience. This included both automotive audience as well as a more general public.
- Creating a better understanding of the road safety issue amongst the general public, policy makers and industry.

A special dissemination strategy for APROSYS has been formulated in Sub Project 8, WP8.2 “Innovation-related activities” co-ordinated by TNO. The aim of this Work Package was:

- to facilitate technology to accelerate dissemination of APROSYS on-going activities;
- to maximize the dissemination of the results towards decision makers, the industry, suppliers, research actors and the general public
- to monitor and relay relevant information generated in the SPs to be disseminated.

In addition, in parallel to the main dissemination tasks, a large target audience database was set up for the project in order to ensure that the appropriate public was well informed and to allow the dissemination work to be done efficiently.
The various tasks envisioned regarding the general APROSYS dissemination have been structured as follows:

- task 1: image
- task 2: dissemination database
- task 3: general documentation
- task 4: website
- task 5: presentations
- task 6: final event

These six key components of the APROSYS dissemination are highlighted below.

Figure 84: APROSYS logo

5.3.1 Task 1: Style

In order to well-disseminate the results an image was created for APROSYS that was used along the project. This includes a logo, templates for reports to be published; templates for workshops and flyers. The logo (see Figure 84) has several arrows pointing to the middle-star to show the committed teamwork. The stars are based on the EC logo stars. To intensify the image and the visibility of the project in view of the final event, an illustration (see Figure 85) was designed to complete the foundation for the corporate style. This style was implemented throughout the final year, and applied in the electronic newsletter, APROSYS magazine and all the publicity for the final event and other dissemination activities.

5.3.2 Task 2: Dissemination database

To efficiently distribute information within the consortium, a database of contact details was created. As it is vital for the project that the information reaches the appropriate people, the details were regularly updated. The database has been further developed and implemented within the electronic newsletter module, in which a segmented database is saved for further use. For the invitations to the Final Event, this database but also partner contact databases were used.

5.3.3 Task 3: General documentation

A general flyer was widely disseminated. This flyer was complemented with flyers per sub-project. General newsletters (internal: six, external: three) were published with updates of the project progress for a targeted public.
A special electronic newsletter for direct mailing purposes has been developed The electronic newsletter was mainly used for announcing workshops and the Final Event.

The first edition of the APROSYS magazine was issued at the PReVENT final event in September 2007 in Versailles, Paris. More than 500 magazines were distributed at this occasion to a targeted public, more magazines were spread through other means.
The second edition of the APROSYS magazine was distributed in February 2009 during the Final Event and onwards. This magazine focussed on the project Main Results. This magazine is available both in hardcopy and on the APROSYS website.

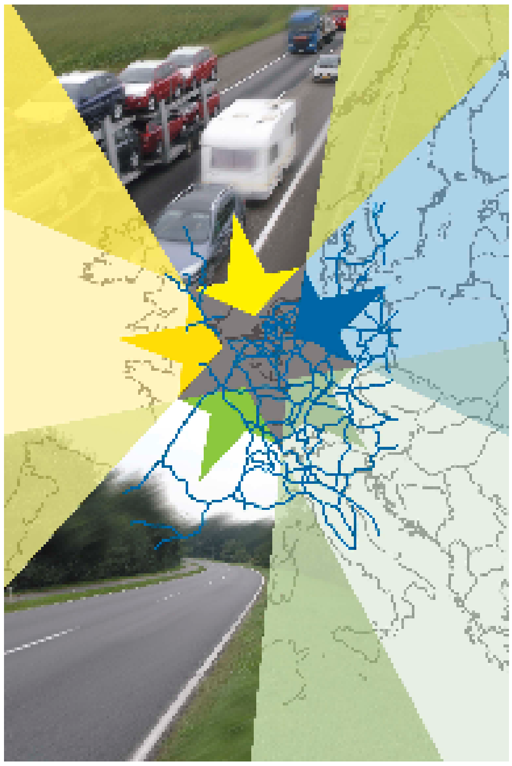


Figure 85: visualisation of APROSYS, part of the APROSYS style

Figure 86: Welcome page to the APROSYS website

5.3.4 Task 4: Website

In addition to the “project server” for management purposes by the project coordinator, a website was designed, maintained, updated and devoted to the activities of the project and other relevant topics, events and documents of interest placed on it. The address is www.APROSYS.com, see the welcome page in Figure 86.

The website contains:

- a summary of the project;
- a presentation of the project objectives (possible to download in power point format) and the possibility to use the logo;
- an explanation of the structure of the IP and a summary of the work per sub project;
- links to APROSYS related projects and interesting sites;
- The APROSYS participants’ details and links to the participants’ websites;
- a list of deliverables. The public deliverables can be downloaded directly from the sites, the non-public will be summarized with the details of the sub-project-leaders details for further inquiries;
- all proceedings and posters from the final event.

5.3.5 Task 5: Presentations

The objective of Task 5 of SP8 was to promote APROSYS at international events. The project results were presented regularly to the general public, dedicated conferences and several other events. Presentations were given on a high project level, showing an overview of the work

running and results achieved, but also on a dedicated technical level, going into the details of the work performed. This was supported by the many papers published by the consortium.
Partners have continuously used new possibilities to participate in congresses and other events in order to develop the promotion of APROSYS. TNO has coordinated partners' efforts to this end.

5.3.6 Task 6: Final Event

At the end of the project, a final event was organized on 17 and 18 February 2009 in Amsterdam, 170 people participated in this event. The event aims were:

- stimulating interest in APROSYS project and the Main Results achieved;
- ensuring dissemination towards a wide and varied target audience from different backgrounds;
- stimulating discussion and feedback on the project results and further use of the knowledge, information and materials.

The Main Results of the project have been demonstrated and presented. On the first day the main conclusions of the project have been shown. A panel (see Figure 87) discussed how the APROSYS results can be implemented to address the challenges articulated by industry and EC.

Figure 87: Panel during the Final Event

On the second day two parallel interactive workshops were organized focusing on how the new technologies and methods developed in the APROSYS project can be used to influence and improve the protection of all road users. Attention has been given to the regulatory, infrastructural and technical and commercial aspects. Also, the process after the White Paper on European transport policy for 2010 has been addressed..

Part of the APROSYS Final Event was an exhibition, where a selection of the APROSYS results and demonstrators were shown. An impression of the exhibition is shown below.

Figure 88: Impressions from the APROSYS Final Event exhibition

5.3.7 Other dissemination activities

APROSYS organised a large number of workshops, starting in month 8. The workshops were organised for a broad audience, in many cases also showing demonstrations and tests. Input from the workshops was used to adjust the directions of the technical work and to improve options for implementation of results. A list of workshops is shown in Table 11.

Table 11: Workshops organised by APROSYS

Deliverable number	Title	Main responsible partner	Project month (planned)
D8.1.0	Workshop on Injury Criteria	ULP/INRETS	M8
D8.1.1	Workshop on the development of the "Aggressivity Index" of heavy vehicles	TUG	M12
D8.1.2	Workshop on software program ADVISER	ALTAIR	M12
D8.1.3	Training organised by SP6	Conti	M12
D8.1.4	Presentation on Gender issues in research	TNO	M12
D8.1.5	Workshop for SP1 members as a result of SP5.2 dummy development (m20)	FTSS	M20
D8.1.6	Workshop on the development demonstrators (SP7) (m22) (7.2.3B)	TNO	M22
D8.1.7	Workshop on Pedestrian and Cyclist Accidentology and collision partner characteristics (SP3) (m30)	CIC/BASC	M30
D8.1.10	2nd Virtual Testing Workshop	TNO	M39
D8.1.11	Workshop on HVAI and design concepts	TUG	M35
D8.1.12	Contribution to PReVENT Conference	Conti	M42
D8.1.13	Workshop on impacts of motorcyclists into road infrastructure	CIDAUT	M38
D8.1.14	Workshop on Test Methods for Pre-Crash Testing	CIC	M44
D8.1.15	Workshop on initial concepts for new or improved VRU test methods	CIC	M44
D8.1.16	Technical Workshop "Test Methods for Pre-Crash – Side Crash Test	Conti	M46
D8.1.17	Technical Workshop “Virtual Testing in Crash”	CIC	M50
D8.1.18	Technical Workshop “Passive Safety Systems for Motorcycles”	DEKRA	M51
D8.1.19	Technical Workshop on improved truck/trailer side protection	TUG	M51

Apart from these workshops, APROSYS partners were very active in writing journal papers and conference papers, as well as in giving lectures and e.g. broadcasts on national tv items.

6 Synergy and complementaries

This chapter describes important synergies and complementaries, which all together have paved the way for the final achievement of the 10 Main Results. It shortly shows how e.g. SPs had to cooperate to obtain overall targets aimed for. The synergies and complementaries are described per Main Result. The synergies and cooperation described here, were in many cases only possible within the framework of an Integrated Project.

6.1 Main Result 1: New human body mathematical models

Human body models are tools that will be used more and more in the future for the evaluation of the safety performance of vehicles and devices. A significant step forward has been achieved in APROSYS showing that this technology is mature enough to be used for product development. But their use for regulatory purposes is still far away. The confidence in simulation technology must be established first with non-human models (dummies) for which validation is an easier challenge then for human models.

Several basic studies were undertaken to produce fundamental data such as soft tissue material properties and knowledge on injury mechanisms that could not yet be included in the models within the project. But they will be used in future studies conducted after the end of this project. Other developments could be directly implemented, providing up-to-date human models on the three crash software codes represented in the consortium. The work on human body mathematical models (SP 5), while partially relatively fundamental, on the other hand was used in other fields for test evaluation of e.g. new test procedures, impact effects with car side impact and others (SP 1, 3, 4). These activities sent their feedback on the use of the models and the results to SP 5, for further updating or consolidation.
The whole body model was used by another team inside the consortium to evaluate the injury risk sustained by motorcyclists in impact against road barriers. Improved model based head injury criteria have been used for a new pedestrian head impact proposal and also for longer term helmet standard evolution. Possible applications have also been demonstrated in pedestrian safety against truck. Virtual testing applications have also considered the use of human body models for future applications.

6.2 Main Result 2: WorldSID 5th percentile female dummy for side impact

Scaling methodologies developed in WP5.1 were used for development of injury risk functions to be used with the WorldSID 5th small female dummy. The risk functions were also used in the new side impact test method MR9 for comparison of injury risk between different dummy types and occupant sizes. The injury risk functions were used in vehicle tests according the existing test methods and for comparison the results with the first generation small female side impact crash dummy, the SIDIIs.
The 2D-IR-Tracc rib deflection sensor was used in the small female side impact dummy in biomechanical tests. The results were used to assess the dummy responses under oblique testing conditions and to assess improvement of the performance of the dummy. The results of the testing were used to develop preliminary injury risk functions for the small female WorldSID 5th dummy. Risk functions were developed based on the compression of the IR-Tracc alone (conventional) and based on the calculated displacement from the 2D IR-Tracc measurement. The risk functions based on testing were compared with those based on scaling form WorldSID 50th midsize male dummy (WP5.1). Both the direct method (which uses scaled impact test conditions) and the scaling of the 50th male injury risk functions use a variety of assumptions in the scaling process. It was found that this leads to different risk functions in some instances, but further work will be required to determine which approach is to be preferred.

The most important complementary for this main result is the contribution as test tool in the side impact regulation (Main Result 9).

The WorldSID 5th has been used within the testing schedule of SP 1. The development and evaluation of the dummy was delayed, endangering the progress of the SP 1 work. Clear communication and collaboration over SP borders was essential to be able to finish both tasks before the end of the project. The results obtained in the SP 1 testing are taken further by the WorldSID task group in the evaluation of this new dummy. Furthermore, the dummy is now in a worldwide harmonisation process. SP 5, as main responsible for the achievement of the Main Result, has always been in close contact with external groups, ensuring the dummy could be in the harmonisation process on such a short term. Input from external parties was used to update the dummy according to the latest scientific insights.

6.3 Main Result 3: Side impact protection system for car occupants

The side impact protection system for car occupants employs pre-crash technology in order to offer an optimal protection potential i.e. environmental sensors survey the side/front of the host vehicle to detect impacting objects. Collaboration with PReVENT, an FP6 project studying advanced sensing technologies, was very fruitful. A common workshop at the start of APROSYS identified possible synergies. Especially in the fields of sensor fusion techniques, tracking algorithms and accidentology, there were work results that were shared.

For the development of the actuator of the side impact protection system one main development tool was the finite elements simulation of a side crash. Here, inside APROSYS, the intelligent safety systems sub project (SP 6) and the virtual testing sub project (SP 7) worked together to provide a suitable FE model. For validation of this model, test data and knowledged were exchanged awith the car accidents sub project (SP1).
Last but not least, for the evaluation of the side impact protection system, Main Result 4, the generic assessment methodology for advanced safety systems, was applied and feedback was given back in terms of the feasibility and applicability of the generic method. This meant a close contact on work between partners from both SP 6 and SP 1. Information also was given to other projects like eVALUE and PReVAL.

6.4 Main Result 4: Generic assessment methodology for advanced safety systems

The generic evaluation methodology, mainly developed by SP 1, with important feedback from SP 6, is intended to be applicable to a wide range of advanced safety systems and describes the different steps that should be taken in the development of a performance evaluation protocol for a specific advanced safety system. The generic methodology is designed to be suitably flexible such that it can be used by a wide variety of stakeholders, from consumer organizations, legal authorities and industry. .
The two main exploitation routes for the 'Generic Methodology' are via Euro NCAP and industry. Euro NCAP has used the generic methodology to help develop its Beyond NCAP protocols, which aims to encourage the implementation of advanced safety systems to improve a car's crashworthiness. These systems include the side impact system (MR3) developed by APROSYS SP6. Industry is using the generic methodology to help assess and evaluate advanced systems to introduce them in the vehicle fleet more quickly.

To assess a particular advanced safety system a specific methodology to assess that system has to be developed using the generic methodology. Hence, the development of a generic methodology is just the first step of the work to develop methodologies to assess all advanced safety systems. Therefore many of the links for the exploitation of the 'Generic Methodology' Main Result involve its further development and application to assess specific systems in future EC framework projects such as ASSESS, eVALUE and interactIVe.

6.5 Main Result 5: Generic Car mathematical Models

The Generic Car Models developed within SP7 have been extensively used throughout all the technology areas of APROSYS:

- in SP1, to various car to car and car to pole impacts;
- in SP2 to perform nose cone simulations and to develop the side underrun protection system, to analyse VRU protective devices;
- in SP3 to perform leg impacts analysis, using different car classes;
- in SP4 as target vehicle in an impact with a scooter;
- in SP5 to perform various simulation scenarios while working on the human body models and in validating them.

These SPs gave their feedback on the use and the results of the GCMs, for updating and consolidation of the models.

6.6 Main Result 6: Virtual testing methodology

The Main Result “VT methodology” comprises most of the activities performed within SP7 and covers then:

- creation of models to support VT application;
- creation/application of methods for VT, such as stochastics or robustness;
- creation of tools to support these methods;
- proposal and demonstration of VT methodologies.

Those four items have been widely used across the various technology areas. For example:

- the models such as the AE-MDB barrier used in SP1 (see also GCM above);
- the methods such as the parametric analysis made in the motorcycle rider impact against a road barrier in SP4;
- the tools, since ADVISER software was used for example by various partners in SP2 (nose cone evaluation, Aggressivity index), SP3 (legform parametric analysis) and SP4 (parametric analysis).

The work on this Main Result will partially be taken further by the FP7 project IMVITER. Therefore it’s important to have an active link with that project, transferring the public knowledge gained.

6.7 Main Result 7: Test methods for vulnerable road users

The vulnerable road user (VRU) protection activities addressed a number of different aspects of VRU safety issues. First a number of questions need to be answered. These included: What were the accident statistics? At what road locations were casualties injured? What types of vehicles were involved in collisions with VRUs? Which vehicles caused injuries? Which vehicles caused fatalities? Which age groups were the most at risk? Was there a gender difference in the casualties? The answers to these questions enabled priority targeting of resources for maximum benefit and helped define the activities that would be needed across the different SPs in APROSYS. Therefore, the issues to be addressed by SP2 Heavy vehicle accidents, SP3 Pedestrian and pedal cyclist accidents, SP 4 Motorcycle accidents and SP5 Biomechanics became clear. Focus is here on SP 3 and SP 4.

For SP2 there were no relevant test methods available and they had to consider how to develop test methods for addressing the safety of vulnerable road users in collisions with heavy vehicles. The SP3 activities started from a consideration of the existing pedestrian test methods developed by EEVC WG10 and 17 during the 1990s, the version of these methods adopted by Euro NCAP and similarly those adopted for use in European legislation (EC Directive). The need then was to address how vehicles (shape, size, weight and class), casualties and injury patterns had changed in the intervening period. In each case, there was the need to assess the best injury risk criteria that should be used in new or amended test methods. Here input from SP5 was necessary to consider whether existing criteria were still relevant, whether amended criteria or updated criteria were necessary or in some cases whether entirely new criteria were needed.
Within SP4, for Motorcyclists, three different proposals for new test procedures are made:

- proposal of a new standard for impacts of sliding motorcyclists against metal barriers;

- revision of current helmets testing standards;
- development of road and misuse tests.

In addressing the safety needs of pedestrians and cyclists, and where deployable systems such as pop-up bonnets or deployable bumpers were employed, the activities in SP1, Car accidents, in evaluating how to assess the safety performance of such systems were considered.
In the SP3 activities the Generic Car Models developed in SP7 were used. Virtual Testing, in order to assess the interaction between a vehicle and a pedestrian and so evaluating the range of injury mechanisms that should be considered in new or amended test methods.
Head and leg impacts were the focus of the activities. These resulted in:

- a new head edge testing method to address concerns with deployable bonnet systems;
- a new head and neck impactor and test process to measure both linear and rotational accelerations an more fully assess head injury risk;
- upper body mass elements for connection to the EEVC legform and Flex PLI to enhance kinematics during testing of SUV and other high bumper vehicles;
- proposals for cyclist test methods to address their unique impact scenarios.

Also SP 2 and SP 4 used the Generic Car Models developed in SP 7 to ensure safety solutions found were generic, and thus applicable for large portions of vehicle fleet.

6.8 Main Result 8: Full width frontal test for Europe

Most research work to improve frontal impact protection in Europe has been co-ordinated by the EEVC WG15. The work has focused on the development of an integrated set of test procedures to assess and control a vehicle’s frontal impact crashworthiness, including its self and partner (compatibility) protection. The VC-COMPAT FP5 EU project contributed to this work. EEVC WG15 has recommended that a set of test procedures for frontal impact should contain both a full overlap test and an offset (partial overlap) test. IHRA have also made this recommendation. Currently in Europe only an offset test is used for frontal impact.

In response to this APROSYS developed a full width frontal impact test suitable for Europe and performed an associated cost benefit analysis for its introduction into the regulatory arena. It is expected that these results will be used by GRSP Frontal Impact Informal Working Group, EEVC WG15, Euro NCAP and industry to improve car occupant safety in frontal impact. It is planned that this work will be taken forward in the EC 7th framework project FIMCAR.

6.9 Main Result 9: Advanced side impact test methods

The draft side impact test procedure proposed by IHRA was evaluated and developed further from a European perspective by APROSYS leading to main result of ‘Advanced Side Impact Test Methods’. The four parts of the procedure were:

- a revised Mobile Deformable Barrier (MDB) test;
- an oblique pole side impact test;
- a Free Motion Headform (FMH) test;
- side Out of Position (OOP) tests.

The WorldSID small female dummy (MR 2) developed by APROSYS SP5 is intended to be used in either the AE-MDB test or the pole impact test. It is planned that these results will be used by EEVC WG13, Euro NCAP and industry to improve car occupant safety in side impact. EEVC WG13 will use the results to help enhance UNECE Regulation 95. The results have been presented to them through presentations at EEVC WG13 meetings and a joint APROSYS / EEVC WG13 workshop in 2006. At present, EEVC WG13 are performing a cost benefit analysis to decide the best route for the enhancement of Regulation 95 and reviewing the work performed by APROSYS. Euro NCAP will use the results to help improve their side impact test and assessment protocols. Euro NCAP have identified in their road map that they require improved methods to assess occupant protection in side impact in the short term (2010 to 2012). Industry will improve car design to meet the enhanced regulatory requirements and Euro NCAP assessment.

6.10 Main Result 10: New protection systems for vulnerable road users

In SP 3 the new protection systems for VRUs were developed, in part, as a consequence of the accident data, the accident reconstruction activities and the development of new or amended test methods. Knowledge of the priority VRU groups, the type of injuries sustained and the impact locations on cars that contributed to these injuries were all investigated, with special focus to the parts of vehicles were improvements were necessary. As the systems were new developed; assessments of their contribution to reducing injuries were made by reference to the current injury risk criteria and the new or adjusted injury risk criteria from SP 5, Biomechanics.

In these assessments human body models (SP 5) and the Generic Car Models (SP 7) were used , in order to assess the interaction between a vehicle and a pedestrian and so evaluating the possible counter-measures that could be developed to reduce the risk of injury.
Head and leg impacts were the focus of the activities. These resulted in:

- a deployable bumper system to enhance the energy absorption potential during leg impacts;
- a passive safety bonnet to reduce the severity of head impacts without requiring greater under-bonnet clearance;
- an airbag system that raised the rear edge of a vehicle bonnet and provided protection for head impacts at the base of the windscreen and the lower parts of the A-pillars
- an energy absorbing windscreen mounting system to attenuate the severity of head impacts at all locations on the windscreen.

For motorcyclists (SP 4), three different protection systems were developed, which suppose then the complementation for the all vulnerable road users studied in APROSYS (pedestrians and pedal cyclists, vulnerable users in contact with heavy good vehicles, relatively vulnerable passenger cars against heavy good vehicles and of course, motorcyclist) concerning new protection systems:

- motorcyclist protective system; motorcyclist friendly barriers, roadside infrastructure;
- development of thorax protector prototypes, male and female versions;
- development of a helmet prototype with improved performance.

7 Conclusions and outlook to the future

7.1 Integration

APROSYS is a so-called Integrated Project. During the first couple of years of the project, a lot of links between the sub projects were established and vividly used. During the last 1,5 year of the project, integration of results was given a high priority. On instigation of the IP Management, the SP leader board together with the Core Group proposed the definition of the 10 Main Results. This proposal was accepted and completed by the General Assembly, June 2008.
Since then on, the 10 Main Results have been used broadly in the dissemination of the project results. This structure also was one of the basics behind the organisation of the APROSYS Final Event, in February 2009.
While dissemination was running according to this integrated structure, links between SPs were tightened to truly integrate results into the 10 Main Results. This took a lot of effort from especially the SP leaders, but in the end, it worked out perfectly.
Many of the good results that APROSYS has achieved could only be obtained by a full and true cooperation beyond SP borders. Therefore, the given framework of an Integrated Project was ideal for the objectives and aims that APROSYS worked with.

The APROSYS partners were not only looking for cooperation within the SPs and the consortium itself. As Figure 2 has shown, many active links were obtained with, other EC projects (FP 5, FP 6 as well as FP 7), legislatory bodies and consumer organisations. This turned out to be very effective in gaining the right input for the APROSYS work, especially at the start-up phase of the project, but also in getting critical feedback on directions of development chosen and especially in the dissemination, exploitation and implementation of project results.

7.2 Project management

APROSYS, with its 50 partners and €30 mln budget, was one of the biggest Integrated Projects within the 6th Framework Programme. Beside the technical challenges in the project, this brought along challenges in the field of project management.
The IP coordinator (TNO, Margriet van Schijndel-de Nooij; predecessors Gijs Kellendonk and Michiel van Ratingen) has been strongly supported by the SP leaders. The SP leader board is shown in Table 12.

Table 12: APROSYS SP leaders board

SP	Sub project title	SP Leader organisation	SP leader
1	Car Accidents	TRL	Dr Mervyn Edwards
2	Heavy Vehicle Accidents	TUG	Dr Jürgen Gugler
3	Pedestrians / Cyclists Accidents	CIC	Mr Roger Hardy
4	Motorcyclists Accidents	CIDAUT	Mr Aquilino Molinero
5	Biomechanics	INRETS	Mr Jean-Pierre Verriest
6	Intelligent Safety Systems	SVDO	Dr Joachim Tandler
7	Virtual Testing	Altair	Dr Franck Delcroix
8	Training & innovation related activities	TNO	Ms Annemarie Mahieu
9	Integrated project management	TNO	Ms Margriet van Schijndel-de Nooij

Meetings of the SP leaders board were at least twice a year. In many cases, the Core Group members joined these meetings, as most issues discussed in the SPL board were very relevant for the Core Group. Thus, there was hardly any need anymore for separate meetings of the Core Group. The transfer of knowledge, progress and results from the SP leaders to the Core Group thus was done very efficient.

Within TNO, the IP coordinator always has been supported by the SP 8 Dissemination manager. She also acted as Project Administrator, taking care of administrative issues and reporting activities. Furthermore, an IP Controller was dedicated to take care of the financial issues of the

project. Many other colleagues and partners formed an active support to ensure the IP kept running smoothly. Also the chair of the Core Group, Jac Wismans on behalf of TNO, was very helpful in this respect.
This IP had a lot of deliverables planned. Along the way, it turned out better to combine some of the deliverables, as contents would partially be duplicated. In future projects, this issue should be handled with care. It's not good to combine too many issues into one report, but delivering many reports generates a lot of work for the project management team in handling, chasing and review deliverables and updated deliverables.

7.3 Project results

Summarising the work and efforts made within the framework of APROSYS, it can be said that the project was very successful in achieving its original objectives. As was shown already in Figure 3, the combined Main Results fully address the seven project objectives. The results obtained were all submitted to the EC before the official end of the project. The IP management judges the level of the results as satisfactory and good, also opening further work and application of the APROSYS results by industry, regulatory bodies, consumer organisations and (clusters of) project partners.
A lot of important work has been performed to achieve the APROSYS Main Goal, as shown in Figure 89. The 10 Main Results are a very good answer to this. Besides these 10 MR, many other results are contributing to this goal. APROSYS has achieved what it aimed at.

Figure 89: The APROSYS Main Goal as it was stated at the beginning of the project. It was maintained throughout the entire lifetime of the project.

7.4 Future

Several of the APROSYS results are taken further by the partners. In some cases, APROSYS results will be brought onto the market on the short term by an industrial partner. The updated helmet (improved geometry and chin part) and the thorax protector, both for motor cyclists, are good examples. Another example is the small female dummy for side impact, the WorldSID 5th. This dummy currently is in a worldwide harmonisation process, and will afterwards be put on the market. The speed with which this is happening is extremely high for a process like this. The fact that a consortium like this is behind the dummy development, makes it's case very strong, as well as the urge to get it truly harmonised.

Other results, such as knowledge and experience gained in the development of the advanced side impact system (e.g. on the actuator and the vision system) are taken further by partners in new, customer related projects.

Many other issues will be further addressed by Euro NCAP, EEVC working groups and other international bodies. To make this possible, many of the APROSYS partners but especially the SP leaders and the IP management have strongly invested in the relationship with these bodies, and have been actively feeding them with valuable information throughout the running time of the project. Discussions on several specific topics will run for a longer period of time after the official end date of the project, so-called dedicated champions will represent APROSYS in these discussions. Topics one can think of are the Generic Assessment methodology, the Advanced side impact test method, the Full width frontal test for Europe, the specific test methods for pedestrians, cyclist and motor cyclist, application of the Aggresivity Index for heavy vehicles and the implementation of virtual testing in regulation.

New FP 7 project are also taking further many of the APROSYS results. Examples are IMVITER for the SP 7 virtual testing results, EuroFOT using amongst others SP 6 test results, ASSESS fully focussing on the Generic Assessment methodology (SP 1, SP 6) and SAFERIDER, taking along the SP 4 results.

References

[1] EVPSN2 Contract number: G3RT-CT2001-05074. For more, see http://www.passivesafety.com

[2] Roadmap of future automotive passive safety technology development, PSN, June 2004

[3] Broughton & al., "The numerical context for setting national casualty reduction targets", TRL report 382, 2000, TRL Ltd, Crowthorne, UK. For full report, see http://www.trl.co.uk

[4] EUCAR Integrated Safety Programme, see www.eucar.be

[5] EC White Paper "European transport policy for 2010: time to decide", 2001.

[6] ETSC, Priorities for EU Motor Vehicle Safety Design, 2001. For more information, see: http://www.etsc.be

[7] ECBOS project. For more, see http://www.dsd.at/ecbos.htm

[8] Data for 2000 in European Commission, Statistical pocketbook 2002, "EU Energy and Transport in Figures", 2001

[9] ETSC, EU GAINS MOMENTUM IN ROAD SAFETY, June 2009, see http://www.etsc.be

[10] EC White Paper, "European transport policy for 2010: time to decide", 2001

[11] RTAD, European Commission, publications on road fatality statistics in Europe

[12] ETSC, 2010 on the horizon, 3rd Road Safety PIN report, available through www.etsc.be

[13] EEVC Status report, 17th ESV conference - 2001, www.eevc.org

[14] PReVENT Final report, available through http://www.prevent-ip.org/download/deliverables/IP_Level/PR-04000-IPD-080222-v15_PReVENT_Final_Report_Amendments%206%20May%202008.pdf

[15] AIDE final report, available through http://www.aide-eu.org/pdf/sp4_deliv_new/aide_d4_1_6_far.pdf

[16] EASIS project information and deliverables, to be found on www.easis.org

[17] GST: Global System for Telematics, FP6 Integrated Project, more information available at http://www.gstforum.org/

[18] Final report for the work on "Car Accidents" (SP1), M. Edwards, AP-90-0001, 2009

[19] Final report for the work on "Heavy Vehciles" (SP 2), J. Gugler, AP-90-0002, 2009

[20] Final report for the work on "Pedestrian and Pedal Cyclist Accidents" (SP3), R. Hardy, AP-90-0003, 2009.

[21] Final report for the work on "Motorcyclist Accidents" (SP4), A. Molinero, AP-90-0004, 2009

[22] Final report for the work package on "Biomechanics" (SP 5), J.P. Verriest, AP-90-0005, 2009

[23] Final report for the work on “Intelligent Safety Systems” (SP6), C. Mayer, J. Tandler, SP-90-0006, 2009

[24] Final report for the work on “Virtual Testing” (SP7), F. Delcroix, AP-90-0007, 2009

[25] WorldSID Small Female Side Impact Dummy Specifications And Prototype Evaluation, Bernard Been, Riske Meijer, Francois Bermond, Klaus Bortenschlager, David Hynd, Luis Martinez, Gustavo Ferichola, Paper Number 07-0311

[26] Scaling Head-Neck Response Data and Derivation of 5th Percentile Female Side-Impact Dummy Head-Neck Response Requirements in NBDL Test Conditions’, Riske Meijer, Robbert Wisgerhof, Jac Wismans, Bernard Been, papernr 305, IJcrash Journal 2008

[27] http://ec.europa.eu/transport/road_safety/observatory/statistics/reports_graphics_en.htm

[28] Countdown to 2010, Only two more years to act! 2nd Road Safety PIN Report, ETSC 2008.

Keywords

Active safety	Also called Primary safety. Systems aiming at preventing an accident from happening. Crash avoidance.
EEVC	European Enhanced Vehicle-safety Committee, founded in 1970. The EEVC steering committee, consisting of representatives from several European Nations, initiates research work in a number of automotive working areas. These research tasks are carried out by a number of specialist Working Groups who operate for over a period of several years giving advice to the Steering Committee who then, in collaboration with other governmental bodies, recommends future courses of action that would lead to improved vehicles with respect to safety.
ES2	EuroSID2; European Side Impact Dummy, developed to evaluate occupant protection in lateral impacts. The dummy represents a 50th percentile adult man.
EUCAR	European Counsil for Automotive R&D. EUCAR is the European body for collaborative automotive and road transport R&D. EUCAR is an industrial association owned by its members, which are the 12 major European manufacturers of cars, trucks and buses.
EuroNCAP	European New Car Assessment Protocol; organization for (consumer) testing of new vehicles. Euro NCAP provides motoring consumers with a realistic and independent assessment of the safety performance of some of the most popular cars sold in Europe.
Human biomechanics	Application of mechanical principles to the human body, in the field of automotive used to determine possible risks in accident scenarios. Done by computer simulations or by the use of test dummies in experiments.
HVAI	Heavy (Goods) Vehicle Aggressivity Index
Injury criteria	Mechanical parameters (e.g., force, acceleration, or deformation) that correlate with injury risk. Used in the studies of human biomechanics in impacts.
IP	Integrated Project
IS	Integrated Safety
ISP (EUCAR)	Integrated Safety Programme by EUCAR
OEM	Original Equipment Manufacturer; used for car manufacturers
Passive safety	Also called Secondary safety. Systems aiming at largely decreasing the effect of an impact. Crashworthiness.
Primary safety	Also called Active safety. Systems aiming at preventing an accident from happening. Crash avoidance.
Secondary safety	Also called Passive safety. Systems aiming at largely decreasing the effect of an impact. Crashworthiness.