Vehicle Safety

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European Commission

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Contents

Please note: This web text aims to give an overview of the main issues and developments in vehicle safety in Europe. Where there is significant overlap with other ERSO web texts (notably in the Safety Ratings and eSafety texts in coverage of consumer information on vehicle safety and new and integrated technologies) readers are directed as appropriate to these web texts

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1 Overview

Vehicle design and road safety

Improving vehicle safety is a key *Safe System* strategy used in addressing international and national road casualty reduction goals and targets for the long-term and the interim. Vehicle safety is a pillar in the Decade of Action's Global Plan for Road Safety 2011-2020 and in the proposal for the next EU Road Safety Action Programme 2011-2020. In best practice activity, countries actively target improvements in vehicle safety in safety programmes.

Vehicle safety addresses the safety of all road users and comprises measures to help avoid a crash (crash avoidance), mitigate the severity of a crash before it occurs through slowing the vehicle through intelligent speed management or advanced braking (crash mitigation) reduce injury in the event of a crash (crash protection) and reduce the consequences of injury (post-crash response). Increasingly, vehicle systems which integrate these objectives are being pursued and which can integrate vehicle and road network interventions (integrated systems).

Substantial and evidence-based improvements have been made in vehicle safety the last 20 years. Improvements in vehicle safety design over this period have reduced the risk of death and serious injury for car occupants by 50% or more. Improvements in vehicle safety design and equipment for pedestrians and motorcyclists are expected over the next decade, as are further developments in driver support and assistance. Research has identified large scope for enhancing vehicle safety further although the increasing variety in the vehicle fleet is expected to bring new challenges over the next decade.

There is large future promise of casualty reduction from crash avoidance and active safety technologies as long as development is prioritised to maximise casualty reduction. New mechanisms are being put in place to monitor and encourage this. There is significant potential to improve crash protection further. The potential value of developing an *integrated approach* to vehicle safety, linking preventive, crash protection and post-crash approaches into cooperative systems for drivers, passengers and vulnerable road users as well as vehicle and road network safety systems is being increasingly understood.

Effective vehicle safety design results rely upon continuing research and development, understanding of the source and mechanism of injury protection in a range of crash conditions, regular monitoring of performance in real-world conditions, and confirmation that new technologies are used and accepted. Socio-economic appraisal of measures ensure that reasonable societal benefits are derived from new safety designs which cost less at design stage than during subsequent stages of production.

Vehicle safety policy

Improvements to vehicle safety result from legislation (much of which is now agreed in the European Union and within the UN ECE process) consumer information, product liability considerations as well as specific initiatives of the car manufacturing industry. EU legislation aims for a minimum but high level of protection across the product line; consumer information aims to encourage the highest possible levels of safety performance based on state of the art testing and protocols; and car industry policies increasingly promote safety as a marketable commodity.

Further EU action on vehicle safety is essential if new goals and targets are to be met (ETSC, 2008). Priority policy actions for reducing serious and fatal casualties identified by research are a standardized test method for car-to -car compatibility; truck to car compatibility and improved methods for front; side and rear impact protection for car occupants; improved frontal protection for vulnerable road users over and above what is covered in current legislation; implementation of Intelligent Speed Adaptation systems, seat belt reminders in all seating positions, alcolocks for fleet drivers, event and journey data recorders and identification of further systems with large potential for casualty savings.

As noted by Euro NCAP, the presence of (new) international players in European Markets inevitably will lead to a new push for global road safety regulations through the UN ECE process. Care must be taken to ensure that existing safety levels in Europe are not compromised. At the same time careful management should ensure that further measures aimed at preventing serious health loss in crashes are not superseded by the green agenda. Although, as the Volvo Car Corporation has observed, while it is often stated that vehicle design to reduce the environmental footprint of motor vehicles is in conflict with improved road safety, these challenges are likely to be overcome given the advances in new modern technologies.

Countries active in safety typically engage in international legislative development work; carry out national research and monitoring of vehicle safety; support the influential European New Car Assessment Programme (Euro NCAP); ensure that safety helmet and safety restraint usage laws are properly enforced and encourage local car industry to fast track key safety measures through government procurement and in-house travel policies.

Key issues for vehicle safety design

- *Addressing human capacities*: Evidence-based vehicle safety measures need to address human capacities and be designed to prevent crashes, reduce injury severity in the event of a crash and facilitate faster access to the emergency medical system through enhanced post-crash response. The main road traffic crash types which need to be addressed to reduce fatal and serious injury are head-on crashes, run-off-road crashes, intersection crashes and pedestrian and other vulnerable road user crashes. *Safe System* approaches aim to inter-link vehicle safety measures with other system measures e.g. separated facilities in the road network, in-vehicle lane departure systems linked to road markings, crash-protective medians and roadsides and speed management to ensure tolerable kinetic energy in the event of a serious and fatal crash.

Achieving safe compatibility between different types and sizes of motor vehicles and between vehicles and non-motorised vehicles continue to be the overarching issues for vehicle safety design in the next decade

- *Car occupants* comprise over 50% of total EU (27) road traffic deaths. Car-to-car collisions are the most common crash type with frontal impacts followed by side impacts being most common in fatal and serious crashes. Different factors influence crash severity, the most important being speed of travel, seat belt use, vehicle mass and the level of crash protection provided in the vehicle.
- *Pedestrians* comprise around 20% of total EU (27) road traffic deaths and around two-thirds of these occur in urban areas. The survival of pedestrians in traffic depends upon their separation from the high speeds of motor vehicles or, where shared use is common sufficiently low vehicle impact speed to prevent severe crash injury and provision of crash protective car fronts addressing the vulnerabilities of the high-risk user groups.
- *Motorized two-wheeler users* comprise around 17% of total EU (27) road traffic deaths. Fatally injured motorcyclists sustain multiple injuries in crashes to the head, chest and legs. The majority of fatal injuries are to the head, despite helmet use. Lower-leg injuries result either from direct contact with the impacting vehicle or as a result of being crushed between the motorcycle and the ground.
- *Cyclists* comprise around 6% of total EU (27) road traffic deaths but a higher share of total deaths (though often lower injury risks) in countries where cycle use is high e.g. the Netherlands. Single vehicle crashes are most common. Head injuries are the major cause of death in around 75% of cyclist deaths leading some countries to mandate cycle helmet use for different age-groups.
- *Minibus,bus occupant and heavy commercial vehicle users* in crashes are a smaller but treatable part of vehicle problem, though heavy vehicles have disproportionate involvement in fatal crashes.

Against the background of the current knowledge base and a rapidly evolving design context, a range of vehicle safety measures and research needs is outlined in this web text for the protection of car occupants, pedestrians, motorcyclists, cyclists, minibus, bus and heavy commercial users in EU countries. See also ERSO eSafety, Safety Ratings web texts.

2 Vehicle design and road safety

2.1 What can vehicle design contribute?

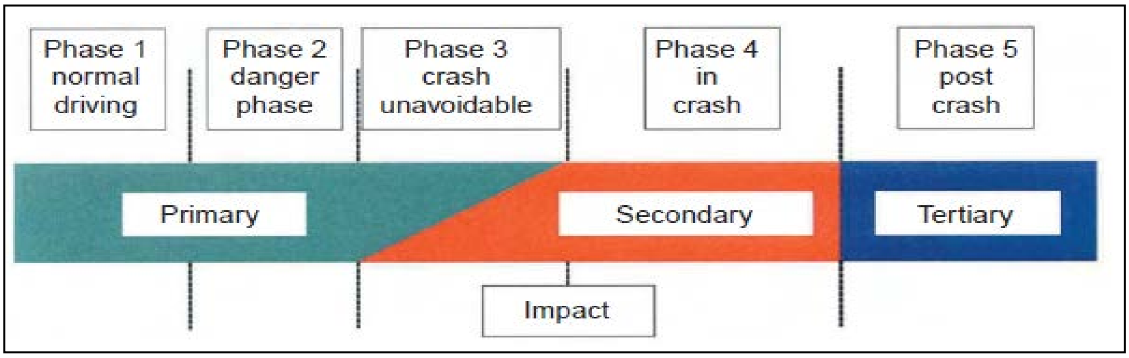
Vehicle design is fundamental to a *Safe System* approach which requires safe interaction between users, vehicles, the road environment and prompt access to the emergency medical system. Vehicle design, which takes account of the behavioural and physical limitations of road users and other system risks, can address a range of risk factors and help to reduce crash involvement, crash injury severity and crash injury consequences. To date, vehicle safety provision in cars on the road has usually been directed towards modifying a vehicle to help the driver avoid a crash, or to protect those inside in the event of a crash. New attention in Europe and globally is being given to ensuring vehicle crash protective design for those outside the vehicle, in-vehicle driver assistance measures which can help to improve safety behaviours and actively mitigate crash severity and post-crash response. The role of vehicle safety intervention for a *Safe System* is summarised in Table 1.

Table 1: The role of vehicle safety measures in Safe System intervention

Key system measures		*System use*	*Vehicles*	*Road*	*Emergency Medical System*
		Examples	Examples	Examples	Examples
Pre-crash	crash occurrence and crash mitigation	Speed management Unimpaired road use	Lighting, braking, handling, driver assistance for speed and impairment management	*Safe System* road design, layout, speed limits and user facilities	
Crash	injury during the crash	Use of safety restraints or helmets	Crash protective design	Crash protective medians and roadsides	Links to vehicle and roadside crash notification
Post-crash	Post-crash injury	Early access to care	Evacuation Crash notification equipment	Safety of post-crash sites for safe recovery	Fast emergency medical response, early diagnosis and efficient trauma care

New attention is also being given to the provision of integrated protection systems aimed at addressing the safety needs of each phase of the crash for those inside and outside of the vehicle shown diagrammatically in Figure 1 in the European Car Manufacturers' Association (ACEA)'s model.

Figure 1: The integrated vehicle safety system ACEA safety model



A review of the effectiveness of casualty reduction measures in the United Kingdom between 1980 and 1996 found that the greatest contribution to casualty reduction was vehicle crash protection (Broughton, 2000). The SUNFlower study of road safety in Sweden, United Kingdom and The Netherlands attributed 20% reduction of fatalities from 1980-2000 (*i.e.* about 1% per year) to vehicle safety improvements (Koornstra et al. SUNFlower, 2002).

Major improvements in vehicle safety design have taken place over the last fifteen years and crash data has confirmed that a 50% reduction in the risk of serious injury has been achieved in new car models. See SARAC II. These results are due to a combination of the effects of new European legislative crash protection standards and the impact of consumer information systems providing objective data on the performance of cars in state of the art crash tests and real crashes. The latest research has concluded that a good correlation exists between Euro NCAP test results and real-world injury outcomes with 5-star rated Euro NCAP cars found to have a 68% lower risk of fatal injury and a 23% lower risk of serious injury compared to 2-star rated cars (Kullgren et al., 2010) See ERSO Safety Ratings web text.

2.2 What role does research play?

Effective vehicle safety design result relies upon continuing research and development, understanding of the sources and mechanisms of injury in a range of crash conditions, regular monitoring of performance in real world conditions, and confirmation that new technologies are used and accepted.

Road crash injury research confirms the importance of designing for the real world (using field trials) rather than for test conditions (in laboratory conditions) which may not reflect conditions found in normal driving or in crashes. Effective design is the result of complex multi-disciplinary scientific research and development which can take up to ten to fifteen years from definition of concept to practical realization.

2.3 What can vehicle safety deliver in future?

Vehicle safety is identified as a key strategy by the EU towards addressing the proposed EU-wide goal to reduce deaths by 50% by the year 2020.

Considerable room for further evidence-based improvements has been identified by European organisations including the International Research Council of the Biomechanics of Injury IRCOBI, the European Transport Safety Council (Hobbs, 2001; ETSC, 2010; ETSC, 2009) the European Enhanced Safety of Vehicles Committee (Cesari, 2005; EEVC 2005, ESV), the Passive Safety Network Roadmap and Euro NCAP's Strategic Map 2009 and its update to 2015 (Euro NCAP 2009) and the European Commission's CARS 21.

Recommendations for a wide range of EU action in the public consultation carried out on the next EU's road safety programme - Technical Assistance in support of the Preparation of the Road Safety Action Programme to 2011- 2020 - are set out in Table 2. (COWI, 2010).

Table 2: Vehicle safety recommendations from the public consultation on developing the EU road safety action programme 2011-2020. (Source: COWI, 2010)

At EU level:

–Amend current EU legislation to include the promotion of clean, safe and energy-efficient road transport vehicles in public procurement.
–Promote effective technologies such as ISA, alcolocks, seat belt reminders in procurement policies to encourage consumer uptake.
–Promote consumer information on the comparative safety of vehicles to encourage rapid changes to vehicle design before 2020.
–Provide a route map for the implementation of Intelligent Speed Adaptation and Event Data Recorder systems
–Extend current legislation on seat belt reminders to include fitment in rear seats as well as front seats.
–Remove the exemption for use of seat belts by taxi drivers.
–Develop and propose standardized test methods for car to car compatibility; truck to car compatibility and improved methods for front, side and rear impacts.
–Legislate for whole vehicle type approval for powered two wheelers such as effective anti-tampering devices, the fitment of front number plates to aid speed enforcement a mandatory ABS for all two wheeled motor vehicles.
–Increase focus on the needs of vulnerable road users in new vehicle safety technologies including pedestrian detection and collision avoidance devices, motorcycle design and equipment.
–Legislate for the construction and use of vans and small lorries (< 3.5 ton) as for heavy good vehicles.
–Require the fitment of alcolocks in heavy goods vehicles and public transport vehicles and promote their use.
–Study the road safety value of a system of continuous compliance to be installed and/or a system for providing technical information for every vehicle
–Study the road safety value of legislating for a PTW roadworthiness test.
–Implement an EC task force to focus Commission work on new vehicle safety technologies in order to identify the systems with expected most effective casualty reduction.
–Develop safety assessment procedures for intelligent systems, human machine interface (HMI) evaluations, identification of systems with greatest casualty potential.
–Develop and implement a systematic programme of evaluation of EU legislation and vehicle technologies including cost-benefit analyses.
–Carry out research into the safety aspects of electric vehicles.

At national and local levels:

–Engage fully in international legislative development work.
–Carry out national research and monitoring of vehicle safety measures.
–Support and join the European New Car Assessment Programme.
–Encourage financial incentives for the use of protective equipment.
–Encourage national car industry to fast- track key safety measures recommended by EuroNCAP through in-house travel policies and public procurement.

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3 Vehicle safety policy

3.1 What are the main policy mechanisms?

The availability and quality of vehicle safety is determined by a combination of international and national regulation, consumer information, car industry policies and product liability considerations. Whilst market forces tend to produce more rapid responses in individual product design, evidence-based legislation can ensure a uniform, acceptable level of safety across the product range.

Over the last 15 years, tests and protocols used by the European New Car Assessment Programme in safety ratings, which promote and reward good and best practice, represent the global state of the art in approaches to provide better protection in car crashes.

3.2 Regulation

3.2.1 Who regulates vehicle safety?

Vehicle safety in Europe is regulated by international standards and regulation devised by the European Union (EU) and the United Nations Economic Commission for Europe (UN ECE). Within Europe, there are two systems of type approval for high-volume vehicles. One is based around EC Directives (and adopted UN ECE Regulations) and provides for the approval of whole vehicles, vehicle systems, and separate components. The other is based around UN ECE Regulations and provides for approval of vehicle systems and separate components, but not whole vehicles.

EC Whole Vehicle Type Approval (ECWVTA)

In 1970, the EU and its Member States developed a new framework for international agreement and co-operation on vehicle safety initiatives culminating in mandatory EC Whole Vehicle Type Approval for cars (which came into full effect in 1998) and for two and three wheeled motor vehicles (into effect in 2003). From April 2009, legislation was extended to cover all new road vehicles such as buses, coaches, trucks, trailers (including caravans) and certain special purpose vehicles such as wheelchair accessible vehicles (WAVs). While the main objective of ECWVTA is removal of barriers to trade, harmonized vehicle standards must provide a high level of consumer protection In accordance with Single Market legislation. An EU Framework Directive lists a series of separate technical Directives that the vehicle must comply with. In order to gain Whole Vehicle Type Approval, the vehicle must meet the requirements of each of the applicable individual Directives. However, the Framework Directive also lists a series of UN ECE Regulations that are considered equivalent to or have superseded certain of the separate technical Directives and proving compliance with these Regulations forms an acceptable alternative to compliance with the relevant Directives.

EU derived standards are mandatory for all the members of the European Union if they fall within ECWVTA. In other circumstances, European countries can adhere to UN ECE either voluntarily or mandatorily if a country decides to incorporate the regulation into national regulation.

EU vehicle classification

EU vehicle standards legislation separates motor vehicles and their trailers into four broad categories.

Table 3: EU vehicle classification

Category L	Mopeds and motorcycles fall into this category, as do all-terrain vehicles (quads) and other small motor vehicles with three or four wheels. Within the L category, motorcycles are split into two groups - those with and without sidecars. There is also a division for mopeds with three wheels, which have smaller engines and lower top speeds than motor tricycles.
Category M	Motor vehicles with at least four wheels that are designed to carry passengers.
Category N	These power-driven vehicles are designed to carry goods. Grouped by size, they include lorries and vans.
Category O	Trailers and semitrailers

Source: Directorate of Enterprise and Industry

Legislative and policy work on vehicle at EU level is led by European Commission's Directorate of Enterprise and Industry. The Directorate of Mobility and Transport – the lead EC agency for road safety – also plays a key role. As part of the Commission's industrial policy, the CARS 21 (Competitive Automotive Regulatory System for the 21st century) process launched in 2005, made recommendations for the short-, medium-, and long-term public policy and regulatory framework of the European automotive industry. This framework aims to enhance global competitiveness and employment, while sustaining further progress in safety and environmental performance at a price affordable to the consumer. The final report was presented in 2006 and encouraged the Commission to come forward with proposals on Electronic Stability Control, seat belt reminders, brake assist systems, improvement of heavy duty vehicles' blind spots and conspicuity, ISOFIX child seats and daytime running lights. The report also noted that several active safety technologies, such as obstacle recognition systems, are at an advanced development stage and encouraged their development and market introduction to be pursued as fast as possible.

The European Commission's new Cars 21 strategy envisages an automotive industry that is leading in technology (clean, fuel-efficient, safe, connected) and where vehicle safety can and should be further improved, for occupants and unpotected road users. Vehicle safety promotion is also pursued by the European Commission through initiatives such as DG Transport's EU road safety action programme and DG Information Society's Intelligent Car initiatives.

Global Technical Regulation (GTR)

The accession of the EC to the UN ECE 1958 and 1998 Agreements as a contracting party is giving further impetus to work on global technical regulations (GTRs). GTRs are administered by the World Forum for Harmonisation of Vehicle Regulations (WP 29), which is a subsidiary body of the UN ECE. The European Commission exercises the right to vote in WP 29 on behalf of the EU and its 27 Member States. At the same time, the EU retains its ability to legislate independently of UN ECE where there is a need for earlier or more stringent action.

The World Forum for Harmonisation of Vehicle Regulations agreed in March 2010 on the need to review and update the 1958 Agreement. Regulation (EC) No 661/2009 on the general safety of motor vehicles (the GSR)6 repealed numerous EU Directives and replaced them with UN ECE Regulations. As of 31 December 2010, the EU had acceded to 106 Regulations under the 1958 Agreement and to all 11 Global Technical Regulations under the 1998 Agreement (see box below). Discussions started in 2010 to develop a new GTR concerning the safety of vehicles with hydrogen propulsion. Also, a working group has been established to develop another new GTR on pole side impact.

Adopted safety GTRs

Global technical regulation No. 9: Pedestrian safety (Adopted 12.11.2008)
Global technical regulation No. 8: Electronic stability control systems (Adopted 26.06.2008)
Global technical regulation No. 7: Head restraints (Adopted 13.03.2008)
Global technical regulation No. 6: Safety glazing materials for motor vehicles (Adopted 12.03.2008)
Global technical regulation No. 5: Technical requirements for on-board diagnostic systems (OBD) for road vehicles (Adopted 15.11.2006)
Global technical regulation No. 3: Motorcycle brake systems (Adopted 15.11.2006)
Global technical regulation No. 1: Door locks and door retention components (Adopted 18.11.2004)

While such global work will increase the convenience of manufacture and removal of barriers to trade, it is clear that decisions concerning new vehicle standards and their implementation are far removed from detailed scrutiny at national level and citizens must rely on Government action to ensure the safety of vehicles (VSRC, 2011). As noted by the World Health Organisation and World Bank in the *World Report on Road Traffic Injury Prevention*. (2004) vehicle safety standardization at regional level can often produce faster action than a similar process at the international level

National type approval schemes

National type approval schemes also exist in different Member States e.g. the National Small Series Type Approval (NSSTA) in the UK but are limited in scope and are for low volume vehicles.

3.2.2 What are the key EU vehicle safety standards?

A list of Directives and global UN ECE regulations can be found on the European Commission DG Enterprise and Industry website. In recent years the most important vehicle safety Directives have been the introduction of crash tests for frontal impact protection and side impact protection to car occupants, sub-system tests for pedestrian protection and a Directive on the General safety of motor vehicles which introduces a range of measures for new cars in 2014, the most important of which identified for safety is electronic stability control.

3.2.3 How are legislative crash tests developed?

European car crash tests and pedestrian sub-system tests have been developed by the European Enhanced Vehicle-safety Committee which brings together national experts and Governmental representative from several countries. Such tests aim to reflect the types and speeds of impact of the most common types of serious crashes and are incorporated in legislation and consumer information programmes after extensive multi-disciplinary research.

The European Motor Vehicle Working Group is an advisory group of EC DG Enterprise and Industry which brings together representatives of the European Commission, Member States and non-governmental and trade associations to discuss proposals for new Directives and standards on vehicle safety. The Committee on Adaptation to Technical Progress is a decision-making group comprising representatives of Member States which advises on specific amendments to EU legislation.

The main scientific conferences for international information exchange on vehicle safety policy and research are ESV, STAPP, IRCOBI and AAAM. More recently global co-operation in research has taken place within IHRA.

3.3 Consumer Information

3.3.1 What is consumer information?

Consumer information provides prospective car buyers with factual information about the safety performance of cars in crashes and encourages manufacturers to introduce evidence-based safety designs beyond those required by legislative norms.

In recent years, safety has been marketed increasingly by car manufacturers and a variety of methods for rating car crash safety are used to provide impartial information which can guide car buyers. These methods fall into one of two broad categories: predictive systems and retrospective systems which are summarised below. For a full outline of the rating systems in use see the ERSO Safety Ratings web text

3.3.2 What are predictive rating systems?

Predictive systems aim to assess a car's safety performance before it is used on the road. The predictions are based on controlled whole car crash tests of individual models; tests of components of the car which have been proven to be important in crashes; and/or visual inspections and rating of the interior of cars.

Since 1997 the European New Car Assessment Programme (Euro NCAP) has provided star ratings of the performance of different cars in dynamic tests which include full-scale frontal and side-impact tests, front-end component tests for pedestrian protection and sled tests for whiplash prevention during rear-end crashes. The presence of seat belt reminders, intelligent speed adaptation (advisory) and electronic stability control and child protection tested to Euro NCAP's protocols also boost a vehicle's rating. The programme also uses visual inspection in addition to crash testing in determining the safety rating assessment.

Launched in July 2011, Euro NCAP Advanced is a complementary reward system to the existing star rating system. It aims to provide advice to car buyers about the potential safety benefits offered by technologies which have a scientifically proven safety benefit. Cars are eligible for a Euro NCAP Advanced reward only if they have achieved a creditable three star rating in the overall rating scheme. In order to encourage further progress in pedestrian protection Euro NCAP will require from 2012 a minimum 60% score in the pedestrian tests for new cars to receive a 5 star rating. A new road map is underway to allow emerging crash avoidance technologies to be included (albeit not supplanting crash protection measures) into the assessment scheme by 2015. With the rapid deployment on to the market of new technologies evaluation of systems with reference to real world crash analysis is essential before wide-scale deployment is anticipated. See www.euroncap.com.

Monitoring shows that Euro NCAP has contributed to marked improvements in crash protective design to protect vehicle occupants with crash tests which are generally representative of the types of crash scenarios found on Europe's roads (Lie and Tingvall, 2000), (Fails and Minton, 2001). SARAC II (Kullgren et al., 2010). The European Commission believes that Euro NCAP has become the single most important mechanism for achieving advances in vehicle safety. Car manufacturers use Euro NCAP star ratings in their advertising. See ERSO Safety Ratings web text for further information.

3.3.3 What are retrospective rating systems?
In retrospective systems, safety ratings are based on the actual performance of cars in real crashes. Such ratings are of particular value for used cars buyers. The frequency and severity of injury to car occupants in individual model cars are determined by examination of police crash statistics and/or insurance injury claim data. The main retrospective system in use at present is Folksam's Safe Car Guide. Although the general principle of this approach is the same for all systems, there are many differences in the exact methodology.

See ERSO Safety Ratings web text for further information.

3.4 Car industry policies
While the car industry tends to speak with through national or regional trade associations in responding to legislative proposals, individual manufacturers have introduced different vehicle safety measures without legislation, in advance of legislation or in response to consumer information programmes, especially in recent years. Examples include the WHIPS system introduced by a Swedish manufacturer to reduce the risk of neck injury or pedestrian protection introduced in advance of legislation by a Japanese manufacturer or in excess of

legislation by a French manufacturer. European frontal airbags fitted to many cars are not regulated in Europe, though are mandatory in the United States. The Volvo Group has set a highly ambitious goal and states that ‘Our ultimate goal is zero accidents with Volvo Group products’.

The European industry associations include the European Car Manufacturers Association ACEA; ACEM (motorcycle industry) and the IRU (truck and bus industry). Like the IRU, ACEM is a signatory to the European Road Safety Charter and has made several road safety pledges. Car companies come together within the European Council for Automotive R&D - EUCAR to co-ordinate proposals for EU funded research.

3.5 Product liability

Globally, there is much variation in the provision of vehicle safety equipment from region to region. Some models may be sold with safety equipment in one country but with a lower specification in others, if the equipment is not required in legislation. Product liability law is based on the level of protection the consumer could reasonably expect.

The EU General Product Safety Directive was introduced in 1985 with strengthened provisions introduced in 1992 and 2001. While European provision for product liability is more limited than the US system, product liability can focus car manufacturing attention on innovative design which goes beyond compliance with current legislation.

3.6 What can EU countries do at national level?

While many decisions on vehicle safety are taken at international rather than national level, EU Member States can play an important role. The best performing countries in road safety typically engage in the following activities towards improving vehicle safety:

<u>Engaging fully in international legislative development work</u> Most European countries are represented in technical committees of the UN ECE and the EU associated with the development of vehicle safety standards and legislation. In addition, several European countries participate actively in the work of international organisations towards the development of legislative tests and standards. For example, France, Germany, Spain, Sweden and the UK contribute to the work of the various working and steering committees of the EEVC and global research co-operation within the International Harmonised Research Activities IHRA.

<u>Carrying out national research and monitoring of vehicle safety measures</u> The monitoring of the performance of European vehicle safety legislation in real crashes to identify progress as well as future priorities for vehicle safety has taken place systematically in few European countries. .A notable example is the Cooperative Crash Injury Research Study in the UK which has run for over 20 years. European protocols for in depth research have been following the EU-wide projects STAIRS and PENDANT. Achieving vehicle safety legislation which reflects real–world conditions necessitates programmes of in-depth crash injury research, crash dummy development and other biomechanical work. During the last 20

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years, countries such as the United Kingdom, Germany, Sweden and France have devoted significant national resource to programmes of work aimed at safety standard development.

Creating a market for vehicle safety Sweden, for example has been pre-eminent in introducing a range of policies which can help to establish a national market for optimal vehicle safety design and vehicle safety equipment. These range from active support for the development of consumer information safety ratings and targeted outcomes in national safety programmes, encouraging national fast-tracking of key safety measures through procurement and organisational in-house safe travel policies and, in several countries, and encouraging financial incentives for the use of protective equipment.

- *Supporting and joining the European New Car Assessment Programme*
  Various national governments have joined the European New Car Assessment programme since its inception in 1996 including the United Kingdom, Sweden, the Netherlands, France and Germany. Some countries actively promote Euro NCAP results. Others target increases in the vehicle fleet with 5 star ratings. In Sweden, the Swedish Transport Administration promotes an in-house travel policy which requires that all cars used in official business have at least a 5* safety rating.

- *Encouraging local car industry to fast-track key safety measures*
  The Swedish Roads (now Transport) Administration has within the *Vision Zero* policy been highly successful in recent years in encouraging rapid voluntary adoption of seat belt reminders in the national car fleet and the voluntary installation of alcohol interlock devices in the national truck fleet. For example, alcohol interlocks are installed in over 1500 vehicles and, since 2002; two major truck suppliers have been offering interlocks as standard equipment on the Swedish market. The majority of new cars sold in Sweden are fitted with seatbelt reminders.

- *Encouraging financial incentives for the use of protective equipment*
  Some countries provide financial incentives for the fitment or use of safety equipment. For example, in the Netherlands there is a tax (called BPM tax) for passenger cars and motorcycles. However, a purchase of a passenger car or a motorcycle fitted with specific safety systems is exempt from BPM tax. The specific safety equipment is side airbags, anti-whiplash head rest system, and navigation devices for passenger cars and ABS and CBS (Combined Brake System) for motorcycles.

Ensuring that national roads and vehicle authorities understand the safety value linkages between in-vehicle technologies and road network treatments Improving the level of protection in the road traffic system requires active partnerships between roads and vehicle authorities in ensuring compatibility of designs which take better account of human tolerance thresholds and available crash protection in speed management. Also in-vehicle interventions such as Lane Departure Warning Systems will be dependent on quality lane road markings for a positive safety effect.

Ensuring that protective equipment usage laws are properly enforced Clearly protective equipment required by law such as seat belts, child restraints and crash helmets are of little value unless they are used. A range of EC funded research reviews have been carried out which have highlighted best practice in enforcing vehicle measures requiring user action e.g. ESCAPE, GADGET, ETSC, SUPREME.

4 Key issues for vehicle safety design

4.1 What forces can be tolerated the human body?

The tolerance of the human body to kinetic forces released in road traffic crashes is limited. Injury is broadly related to the amount of kinetic energy applied to the human frame.

Biomechanical research reported over the years to international scientific conferences (e.g. IRCOBI, STAPP, ESV) indicate that the relationship between crash forces and injury is known for a number of parts of the body and types of injury for different categories of road user as well as for different age groups. For example, a crash load applied to the chest of a young male may result in a bone fracture, but if applied to an elderly female, may produce a life-threatening injury. Whereas current vehicle crash protection is focused on the average-sized male occupant, the driving population is set to become more vulnerable to injury as it ages in line with general demographic trends.

Small differences in speed can have a profound effect on the occurrence and severity of road crashes and injuries. A 1% decrease in average speed corresponds with a 2% decrease in injury crashes, a 3% decrease in serious injury crashes and a 4% decrease in fatal crashes and vice versa. A 5% increase in mean speed will lead to a 20% increase in fatal crashes and vice versa (Nilsson, 2004; Elvik, 2009).

For a collision between a car and a pedestrian, the following relationship between speed and survival chance has been established in in-depth studies (Ashton and McKay 1979). Later research (which includes different types of study) indicates that the threshold for fatalities may have increased since then, although this is not necessarily the case for serious injury. See ERSO Speeding web text.

Table 4: Pedestrian deaths by impact speed

Car speed	% fatally injured pedestrians
32 km/h	5%
48 km/h	45%
64 km/h	85%

Source: Ashton and McKay, 1979

As shown above the probability of a pedestrian being killed rises by a factor of 8 as the impact speed of the car rises from 30km/h to 50km/h (Ashton and McKay 1979). The best-designed vehicle on the road today provides crash protection currently up to 70km/h for car occupants wearing seat belts in frontal impacts and 50 km/h in side impacts (Tingvall & Haworth, 1999).

It has been estimated for the Swedish traffic system (and no doubt the traffic system in most EU countries) that speeds are tolerated on many roads well in excess of the thresholds noted above without separate facilities or protective designs and possibilities of use (by engine capability) to more than 200 km/h (Tingvall, 1987). Against this background, in the Swedish *Vision Zero* strategy (known generically as *Safe System*), the amount of biomechanical energy to which people can be exposed without sustaining serious injury is promoted as the basic road and vehicle design parameter. See ERSO Road Safety Management web text.

4.2 What are the main crash injury problems?

Car occupants: Car occupants are the largest single casualty group comprising over 50% of total EU (27) deaths with the majority of car occupant deaths occurring on non-motorway rural roads (COWI, 2009). The main injury risks for car occupants arise from the way vehicles interact with each other and with the roadside. Car-to-car collisions are the single most frequent category of crash. For both fatally and seriously injured occupants, frontal impacts are the most important crash type followed by side impacts. The head is the body area most frequently involved in life-threatening injury, followed in importance by the chest and then the abdomen. Among disabling injuries, those to the leg and neck are important (Hobbs, 2001). Determinants of injury severity include:

- Speed of travel
- Restraint use
- Contact by occupant with the car 's interior, exacerbated by intrusion into the passenger compartment caused by the colliding vehicle or object
- Mismatch in terms of size and weight between vehicles involved in a crash
- Ejection from the vehicle
- Inadequate vehicle crash protection.

Pedestrians: Pedestrians comprise around 20% of EU (27) road traffic deaths and around two thirds of these occur in urban areas. Research suggests that the majority of all fatally and seriously injured pedestrians in Europe are hit by the fronts of cars. Lower-limb injury is, in general, the most common form of pedestrian injury, while head injury is responsible for most pedestrian fatalities (EEVC 1998, update 2002). The survival of pedestrians in traffic depends upon ensuring either that they are separated from the high speeds of motor vehicles or – in the more common situation of shared use of the road – that the vehicle speed at the point of collision is low enough to prevent serious injury on impact with crash-protective safer car fronts (Peden et al. WHO, 2004).

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Motorised two-wheeler users comprise around 17% of total EU (27) deaths and typically sustain multiple injuries in crashes, including to the head, chest and legs. The majority of the fatal injuries are to the head, despite helmet use. Lower-leg injuries result either from direct contact with the impacting vehicle or as a result of being crushed between the bike and the ground (Peden et al. WHO, 2004). EU-funded EEVC research has shown that a car is involved in a half to two thirds of crashes. A quarter to a third of all motorcycle crashes were single vehicle crashes without collision with another vehicle. Off-road impacts where the motorcyclist leaves the roadway and overturns or strikes a roadside object is the most frequently occurring motorcycle crash type (EEVC, 1994). Research in several European countries indicates that many serious injuries to motorcyclists go unreported to the police which mean that national statistics typically underestimate the size of the problem (IRTAD, 1994).

Cyclists comprise around 6% of road user deaths across EU (27) countries but a larger numerical share in countries where usage is higher than the EU average, though fatality risks lower, e.g. the Netherlands and Denmark. There is evidence that cyclists' crashes are frequently under-reported in national statistics, particularly in non-fatal single vehicle crashes. Single vehicle crashes comprise the most typical crash type. Head injuries are the major cause of death in around 75% of cyclist fatalities. Head or brain injury comprises about 50% of all younger hospitalised crash victims.

Minibus, bus occupants and heavy commercial vehicle users in crashes are a smaller but treatable part of vehicle problem, though heavy vehicles have disproportionate involvement in fatal crashes.

4.3 Crash avoidance and mitigation, crash protection, post-crash care, integrated approaches

Vehicle engineering improvements for safety have been achieved to date by modifying the vehicle to help the driver or rider avoid a crash and by modifying the vehicle to provide protection against injury in the event of a crash for those inside and outside the vehicle. . New attention in Europe and globally is being given to ensuring vehicle crash protective design for those outside the vehicle; driver assistance measures which can help to improve safety behaviours; in-vehicle measures aimed at improving post-crash response and the development of integrated approaches linking communication between vehicles and with the road network.

Table 5: Vehicle safety strategies and measures

Crash avoidance or primary safety	Devices to avoid a crash e.g. daytime running lights, electronic stability control, intelligent speed adaptation, alcolocks. EU level developments in safety are focusing much more around new vehicle based primary safety systems that may prevent collisions occurring. Examples include Electronic Stability Control (ESC) (which are already showing substantial road safety returns), lane keeping systems and pedestrian detection and auto braking systems (OECD, 2003). There are high expectations that these new systems will provide the largest reductions in casualties into the future though the evidence in many cases remains weak (VSRC, 2011).
Crash mitigation systems	Examples are intelligent speed assistance or advanced braking systems which actively aim to lessen crash severity before the crash occurs.
Crash protection or secondary safety or passive safety	Protection in the event of a crash e.g. seat belts, airbags, front and side impact protection. Opportunities exist for further important improvements at EU level such as in vehicle to vehicle compatibility, the protection of side impact occupants on the far side of the vehicle, prevention of whiplash injuries and the protection of more vulnerable car occupants such as elderly drivers and passengers.
Active safety	The term *active safety* is often used to mean crash avoidance but care should be taken in its use since it is also used to denote deployable systems such as crash-protective pop-up bonnets for pedestrian protection or seat belt reminders.
Integrated technologies and co-operative systems	In recent years there has been a move away from traditional approaches towards crash avoidance and crash protection towards holistic in-vehicle approaches. The aim here is to achieve a truly integrated technological vehicle response to the risk of crash and better outcomes before, during and following the crash event. Accordingly, more advanced technologies are under development and testing which support information connectivity between vehicles and with road infrastructure. These are known as co-operative systems (Euro NCAP 2009).

For further discussion on co-operative road-vehicle systems and integrated technologies - See ERSO web text on eSafety.

4.4 Cost-benefit and cost-effectiveness

As in other areas of road safety policy, socio-economic appraisals of vehicle safety measures are usually carried out to ensure that reasonable societal benefits can be derived from any additional manufacturing costs. In general, new safety design can be more easily assimilated into new car manufacturing costs at the original design stage rather than during subsequent stages of production.
However, while the task of evaluating the costs and benefits of relatively simple systems is not difficult, new methodologies need to be devised to help estimate more accurately the cost of more complex systems.

For further information on methodologies for assessing costs and benefits see ERSO web text Cost-Benefit Analysis**.**

5 Safety design needs

5.1 Cars

5.1.1 Crash avoidance and mitigation measures

Speed: Intelligent Speed Adaptation (ISA)
ISA is a system which informs, warns and discourages the driver to exceed the speed limit. The in-vehicle speed limit is set automatically as a function of the speed limits indicated on the road. GPS allied to digital speed limit maps allows ISA technology to continuously update the vehicle speed limit to the road speed limit. There are three types of ISA:

Informative or advisory ISA gives the driver a feedback through a visual or audio signal
Supportive or warning ISA increases the upward pressure on the gas pedal. It is possible to override the supportive system by pressing the accelerator harder.
Intervening or mandatory ISA prevents any speeding, for example, by reducing fuel injection or by requiring a "kick-down" by the driver if he or she wishes to exceed the limit.

Research indicates that the more the system intervenes the more significant are the benefits. Estimates show that if mandatory installation of informative or supportive ISA, injury crashes could be reduced by 20%. The use of a mandatory ISA system, when combined with a dynamic speed limit regime, has the estimated potential to reduce overall injury crashes by up to 36%, fatal and serious crashes by 48% and fatal crashes by 59% (Carsten and Tate 2005). A study in the Netherlands showed that ISA could reduce the number of hospital admissions by 15% and the number of deaths by 21% (Van Loon and Duynstee, 2001). The most recent estimates of savings are presented in Table 6.

Table 6: Expected road safety results from a range of ISA options

	Advisory % reduction	Voluntary % reduction	Mandatory % reduction
Fatal crashes	5%	21%	46%
Serious injury crashes	3%	14%	34%

Source: Carsten O (2012) Personal communication of additional results to study Lai F, Carsten O and Tate F,(2012) *How much benefit does Intelligent Speed Adaptation deliver: An analysis of its potential contribution to safety and environment*, Accident Analysis and Prevention 48 (2012) 63– 72

Different trials using informative and supportive systems across Europe have shown that approximately 60–75% of users would accept ISA in their own cars. An FIA Foundation survey indicates 61% support for physical in-car limiter systems to prevent exceeding speed limits in residential areas, and over 50% support for these systems on main roads and motorways.

The Swedish Transport Administration equips its whole fleet with ISA systems and studies in Europe have been carried out in Norway, the Netherlands and the UK. There have been two major EU-funded projects on ISA. The SRA co-ordinated project PROSPER looked into ways that advanced assisted driving technology and technology relating to speed limitation devices can improve safety, and what are the barriers for the implementation of ISA. SpeedAlert co-ordinated by ERTICO proposed harmonisation of the in-vehicle speed alert concept definition and investigated the priority issues to be addressed at the European level, such as the collection, maintenance and certification of speed (SpeedAlert Project).

See ERSO web text on eSafety.

Event data recorders

Black boxes or event recorders can be used in cars as a valuable research tool to monitor or validate new safety technology, to establish human tolerance limits and to record impact speeds. Current general practice is to use the onboard computer which now is fitted on most cars, and to adapt the transducers and the data collected. In the US, the car manufacturer GM has been using event data recorders since the 1970s to evaluate the performance of airbags in crashes. In the UK, police fleet cars have been fitted with black boxes. In Germany a special crash recorder called UDS by Mannesmann/VDO has been on the market for more than 20 years. Experience in Germany gained with this recorder shows that it can influence driving behaviour considerably and thus contributes to crash reduction, especially in vehicle fleets, of between 20 – 30%. In Sweden, tens of thousands of vehicles have been equipped with event recorders for research purposes since 1995.

An EC project VERONICA collated information on the feasibility of black boxes in European vehicles. Three important questions related to black boxes are the standardisation of procedure and tools to retrieve the data, the use of the data collected (for crash research, or by the police to check driving conditions, or in legal applications to help in the determination of the responsibilities in a crash) and questions concerning the ownership of the data.

See ERSO web text on eSafety.

Visibility:

Daytime Running Lights (DRL)
(DRL) are multi-purpose or specially designed lights on the front of a vehicle for use in daytime to increase its visibility and avoid multi-party crashes. There are various DRL options all of which have positive benefit-to-cost ratios. The options of mandatory manual operation of dipped lights in existing cars and a compulsory advanced DRL unit fitted to new cars seem most advantageous, according to Dutch reviews (Koornstra, 1997; TNO, 2003).

Meta-analyses of the effects of DRL use in cars show that DRL contributes substantially to reducing road crashes, car occupant and vulnerable road user injuries whatever the country's latitude. A reduction in multi-party crashes of between 8%-15% was found as a result of introducing mandatory laws on daytime use (Elvik et al., 2009 Handbook). A Norwegian meta-analysis of 25 studies that have evaluated DRL for cars and 16 studies that have evaluated DRL for motorcycles found that DRL reduces the number of multi-party daytime crashes by 5–10 per cent (Elvik et al., 2003). A Dutch review found that DRL reduced multi-party daytime crashes by around 12% and deaths and injured victims by 25% and 20% respectively (Koornstra, 1997). Motorised two-wheeler users have expressed concerns that daytime running lights on cars could reduce the visibility of motorcyclists. While there is no empirical evidence to indicate this is the case, such an effect would be likely to be offset by the benefits to motorcyclists of increased car visibility (Koornstra, 1997), (PROMISING, 2001).

It has been estimated that the fitment of DRL to cars in EU countries could lead to an annual reduction of 2,800 deaths. The calculation of the cost/benefit ratio (CBR) illustrates that the costs of DRL are considerably lower than the benefits (value 1:4.4). With even more favourable if special DRL-lamps equipped with economical bulbs were installed increasing the CBR to 1:6.4 (ETSC, 2003).

EU Directive 2008/89/EC requires the mandatory fitment of DRL in all new EU cars from February 2011 and for trucks and buses from August 2012.

Braking and handling measures:
In general most of the devices described for improvement of braking and handling interfere with driver behaviour, and the questions of driver acceptance, risk compensation and driver reaction when the system is activated (especially old drivers) are important.

- Anti-lock Braking Systems (ABS)

The main purpose of ABS is to prevent skidding where loss of steering and control result from locked wheels when braking hard. Such systems are now fitted to many new cars. A meta-analysis of research studies shows that ABS give a relatively small, but statistically significant reduction in the number of crashes, when all levels of severity and types of crashes are taken together. However, while injury crashes decrease (-5%), fatal crashes increase (+6%) (Elvik et al., 2009 Handbook). There are statistically significant increases in rollover, single-vehicle crashes and collisions with fixed objects. There are statistically significant decreases in collisions with pedestrians/cyclists/animals and collisions involving turning vehicles. ABS brakes do not appear to have any effect on rear-end collisions.

A German study found that ABS brakes can lead to changes in behaviour in the form of higher speeds and more aggressive driving (Ashenbrenner, 1987). The results also may also be partly due to lack of knowledge or incorrect assumptions amongst car drivers about how ABS brakes actually function (Elvik et al., 2009 Handbook). A British study, for example, indicated that one reason why ABS was not realising its full potential to reduce crashes was that many drivers had little or no knowledge of ABS (Broughton & Baughan, 2000).

- Brake Assist

Brake Assist in emergency situations is a technology which is fitted as standard on some new cars and will be mandatory for new cars in 2014 as part of a legislative package on pedestrian protection. It aims to address the problem of insufficient pressure being applied to the brake by drivers in emergency situations, so increasing stopping distances. Car manufacturing trials have shown that brake assistance systems could help by providing full braking effect, where the driver does not press hard enough on the pedal. In marketing material, Daimler Chrysler indicate that for a car braking at 100km/h, Brake Assist can reduce the normal stopping distance by 45%. Brake assistance systems can use the ABS capability to allow heavy braking without the risk of wheel locking, but have to distinguish between emergency and normal braking as well as respond appropriately to reduced brake pressure.

While a prospective estimate has been made for Brake Assist to reduce fatal and serious injuries among pedestrians by 10%, the same study noted that the casualty reduction effect of Brake Assist has yet to be scientifically established (Hardy & Lawrence, 2005). A Swedish study of real-world pedestrian crashes found that the effects of Brake Assist on pedestrian safety were not significant (Strandroth, 2011).

- Autonomous Emergency Braking

Autonomous Emergency Braking (AEB) systems can help to avoid crashes or to mitigate their severity by warning the drivers and supporting their braking response and/or by applying the brakes independently. All EU heavy commercial vehicles have to be fitted with autonomous emergency braking (AEB) technology by November 2013, though a requirement is not in place for other vehicle types. According to Euro NCAP, real world performance data suggests that these systems can reduce car crashes by up to 27% and some car models are attracting Euro NCAP Advanced rewards. Euro NCAP has grouped systems into three main categories: City, Inter-Urban and Pedestrian. Systems may fall into more than one category, or may meet the requirements of all three. One manufacturer has developed a pedestrian detection system that automatically brings a car to a halt at speeds of up to 35 km/h whenever a person steps out in front of it. It should be noted that this form of autonomous emergency braking differs from Brake Assist which requires action from the driver and alongside crash protective requirements forms part of the EU legislative package on pedestrian protection.

- Electronic Stability Control (ESC)
Electronic stability control (ESC) addresses the problem of skidding and crashes due to loss of control on wet or icy roads. Such devices are now being fitted increasingly into new cars and fitment is rewarded by points towards a star rating in the European New Car Assessment Programme which has developed a protocol for ESC testing. A mandatory requirement for fitting ESC to EU cars from 2011 (new types) and 2014 (all new vehicles) has been introduced. Sweden has been foremost in encouraging the take up of ESC nationally and in December 2010, 99% of all new passenger cars were equipped with ESC (Swedish Government, 2011).

Evaluation studies have shown that ESC has led to substantial reductions in crashes involving large cars at the top end of the market. A Swedish study in 2003 showed that cars fitted with ESC were 22% less likely to be involved in crashes than those without with 32% and 38% fewer crashes in wet and snowy conditions respectively (Tingvall, 2003). In Japan, a study showed that electronic stability reduced crash involvement by 30-35% (Aga and Okada, 2003). In Germany, one study indicated a similar reduction while another showed a reduction in “loss-of-control” crashes from 21% to 12% (Breuer, 2002). A recent US study indicated a 5% overall reduction in all impacts and a 23% reduction in fatalities in passenger car crashes reported to the police (Sivinski, 2011).

Impairment detection systems:
Several systems exist for detecting driver impairment caused by excess alcohol, drowsiness, illness, or drug abuse, which prevent the vehicle from starting or warn the driver or perform an emergency control function that will stop the vehicle. While many systems are at different stages of development with, in some cases, their feasibility being unknown, one particularly promising application is the alcohol interlock system.

- Alcolock systems are automatic control systems which are designed to prevent driving with excess alcohol by requiring the driver to blow into an in-car breathalyzer before starting the ignition. The alcohol interlock can be set at different levels. Alcolocks have been used widely in North America in repeat drink-drive offender programmes and, when used as part of a comprehensive scheme, have led to reductions of between 40% and 95% in the rate of repeated offending. See ICADTS Working Group Report 1 (ICADTS, 2001).

Alcohol interlock systems are also widely used in Sweden in rehabilitation schemes for offenders driving with blood alcohol content over the legal limit and in government and company fleet cars. In 2004 the Swedish government decided that all vehicles purchased or leased in 2005 or later, and intended to be used by the government should be fitted with alcohol interlocks. Some 70 000 alcolocks are now used in Sweden in trucks, buses and taxis on a voluntary basis (Swedish Government, 2011). A transport company in Sweden decided to equip all their 4000 vehicles with alcohol interlock systems before the end of 2006. The Swedish Driving Schools Association has fitted all their 800 vehicles with alcohol inter-locks (Kullgren, 2005).

A major US initiative is entering its second phase in an attempt to develop an in-car detection system that can be more widely used. The US Driver Alcohol Detection System for Safety Program is exploring the feasibility, the potential benefits of, and the public policy challenges associated with a more widespread use of noninvasive technology to prevent alcohol-impaired driving. Two specific approaches have been chosen for further investigation; tissue spectrometry, or touch based, and distant/offset spectrometry, or breath based sensors. Two of the sensors are designed to remotely measure alcohol concentration in drivers' breath from the ambient air in the vehicle cabin, and the third is designed to measure alcohol in the drivers' finger tissue through placement of a finger on the sensor. Prototype testing has indicated that there are potential technologies that ultimately could function non-invasively in a vehicle environment to measure a driver's BAC. Research vehicles will demonstrate the technologies by the second half of 2013 (Ferguson, 2011).

Collision Avoidance Systems

Research and development of collision warning and collision avoidance systems has taken place in Japan, the United States and in the European Union over the last decade and some car models now offer such devices. Large estimates of the safety potential of such systems have been claimed following laboratory studies, but the range of technical and behavioral issues involved in many of the concepts require full on-road assessment. To be practicable, most of the proposed systems require a well-controlled traffic situation, such as that found on motorways, but where the casualty reduction potential is relatively low. Most existing systems are warning only systems. Examples of such systems are:

- Forward Collision Warning is a system which comprises a visual and audible warning that the driver is too close to the vehicle in front. The warning depends on how long the distance is between the vehicle and the vehicle ahead. The level of warning changes from "safe" to "critical" as the following distance decreases.
- The Reverse Collision Warning System is a visual and audible system which warns drivers about the likelihood of collision with an object behind the vehicle by means of sensors in the rear bumper. The warning intensifies when the distance between the vehicle's rear and the object decreases.
- Adaptive Cruise Control enhances automatic cruise control found in many new vehicles by automatically maintaining a set following distance to the vehicle in front. The distance to the preceding vehicle is measured by radar either with laser radar or millimetre wave radar. When the speed of the vehicle in front is slower than the adjusted speed, the ACC system adjusts vehicle speed to allow a safe distance the lead vehicle at a safe distance.

- Lane-Keeping Devices are electronic warning systems that are activated if the vehicle is about to veer off the lane or the road. Times to collision in safety-critical lane changes are normally much less than one second. Since mean driver reaction time is about one second, there is not sufficient time for a driver to respond to a warning before crashing. Because there is insufficient time for reaction to a warning, lane change and merging crashes can probably only be avoided by intervening systems. But these have their own problems: how to detect driver intentions and how to intervene. This may be by taking over the steering from the driver or by providing feedback through the steering wheel.

Implementing intelligent transport systems for road safety
Intelligent transport systems (ITS) require a detailed international framework for implementation which currently does not exist. Such a framework includes work on standardisation, the development of functional specifications for ITS measures and Memoranda of Understanding on their fitment and use. Digital maps, sensors, ensuring appropriate human machine interface, as well as developing communication protocols all form part of the implementation process. Establishing public acceptance as well as legal liability for ITS measures are also fundamental issues (OECD, 2003; Rumar, 1999).

Does car colour influence road safety?
Brightly coloured or light coloured vehicles are sometimes regarded as safer because they seem to be more visible but is this the case? While a small number of studies have started to explore this question (Furness et al., 2003; Lardelli-Claret, 2002) the association between the colour of cars and their safety should be treated with some caution. For instance, if yellow cars were proven to be safer than other colours, it does not mean that safety would improve if all cars were yellow. It is the variation in colour, just as much as the colour itself that generates differences in safety.

5.1.2 Crash protection measures

Fundamental issues of structures, compatibility and restraint

What happens in a typical crash?
Newton's Third Law, states that "For every action there is an equal and opposite reaction." In a frontal crash, the most common impact type, an unrestrained occupant continues to move forward at the pre-crash speed and hits the car structures with an impact speed approaching the pre-crash speed. Use of a seat belt or restraint helps to slow the occupant down in a crash by applying forces to the strong skeletal structures of the pelvis and rib cage; reducing the risk of major contact with the car structure and preventing ejection.

How does crash protection work?
Vehicle crash protection aims to keep the consequence of a crash to a minimum. For car occupants, this means:

- Keeping the occupant in the vehicle during the crash
- Ensuring that the passenger compartment does not collapse

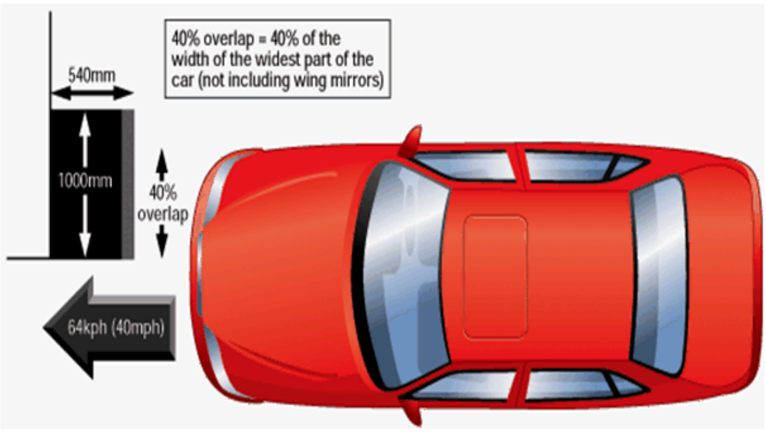
- Reducing the crash forces upon the occupants by slowing down the occupant or pedestrian over as long a distance as possible and spreading the loads as broadly as possible to reduce the effect of the impact forces
- Controlling the deceleration of the car

So reducing the risk of:
- An unrestrained occupant being ejected from a car so increasing the risk of fatal injury;
- A poorly designed passenger compartment which reduces the occupant's survival space;
- Occupant contact with a poorly designed car interior or intruding object

The vehicle's structure, its compatibility with other vehicles or objects on the road and the design and use of the vehicle's restraint system are all key elements for crash protective design. The type of crash protection countermeasure used is dependent on the nature of the crash configuration, i.e. the direction of the impact (using clock direction) and the type of collision partner.

Structures
Crash protection needs to be provided for different parts of the car structure which are struck in different types of crashes. The most common injury-producing crash types are frontal crashes, followed by side impacts, rear impacts and rollovers. Legislative tests cover the crash performance of new cars in front and side impacts. Euro NCAP consumer tests provide a star rating for crash performance in front and side impact tests based on legislative tests, a pole test, sub-system pedestrian tests, and inspection of aspects of the vehicle interior and restraint systems.

Figure 2: Frontal impact test



Frontal impact The current EU legislative test (which is same as UN ECE Regulation 94) is a 40% offset deformable barrier test conducted at 56km/h. The current Euro NCAP test is conducted at 64km/h to represent the majority of severe I jury producing frontal crashes.

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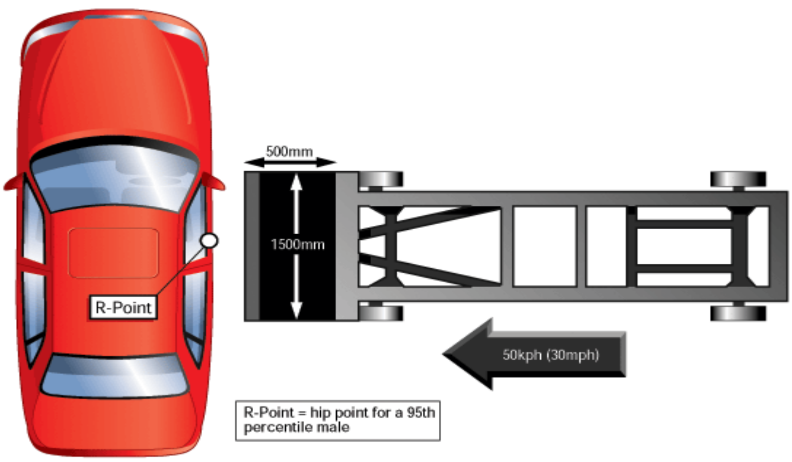
Various suggestions have been made for improvements in the legislative test by the EEVC and others (EEVC, 2000; TRL, 2009).

For car occupants, contact with the car's interior, exacerbated by the presence of intrusion, is the greatest source of fatal and serious injury. The recent priority in frontal impact protection has been to improve the car structure to endure severe offset impacts with little or no intrusion. Without intrusion, the seat belts and airbags have the space to decelerate the occupant with minimum injury risk.

A full width frontal barrier test is used in other regions of the world to test occupant restraint systems. Both tests are needed to ensure crash protection for car occupants (Peden et al. WHO, 2004).

Side impact French, Swedish and UK national data has been analysed and shown that around one quarter of car occupant casualties is injured as a result of a side impact. However, this rises to between 29% and 38% for those fatally injured, illustrating their more injurious nature. In side impacts 60% of casualties are 'struck side' (SS) occupants and 40% are 'non-struck side' (NSS). The proportion of fatal casualties in simple car to car or car to pole impacts is substantial, 50% and 67% for the UK and France (EEVC, 2010). In side impacts the struck side occupant is directly involved in the impact. Contact with the car interior is difficult to prevent so the aim is to improve the nature of the intrusion and provide padding and side-airbags.

Figure 3: Side impact test



Head protection is a priority in side impact which is not yet addressed in the current EU legislative test. In addition to a side impact test, Euro NCAP has a pole test which is encouraging improved crash protection for the head in side impacts.

Various suggestions have been made for improvements in the legislative side impact test The EEVC notes that a regulatory pole test (to current Euro NCAP specification with full dummy assessment) into the existing UN ECE Regulation 95 would deliver significant benefits to society in terms of fatal and serious injuries saved. EEVC recommends the development of a more representative (mass and stiffness distribution) barrier than the one used currently in regulation and work towards protecting non-struck side occupants who are not covered by existing regulatory test procedures (EEVC, 2010). The case for a Global Technical Regulation on Pole Side Impact (PSI GTR) is being discussed in UN ECE's WP 29 following a proposal from Australia.

Rollover crashes

- Most rollovers occur off the carriageway. Providing the occupant is not ejected from the vehicle and the car does not strike any rigid objects, then rollovers are the least injurious of the different impact types;
- If occupants remain completely inside the car (i.e. no partial ejection) they have a low injury rate as they decelerate over a relatively long period;
- The risk of rollover varies with different vehicles depending on e.g. the height of the centre of gravity, suspension characteristics and loads carried;
- The severity of injury depends on the presence of crash-protective roadsides and the speed of impact.
- Electronic Stability Programmes can reduce some single vehicle crashes and loss of control crashes including rollovers.

Rear impacts

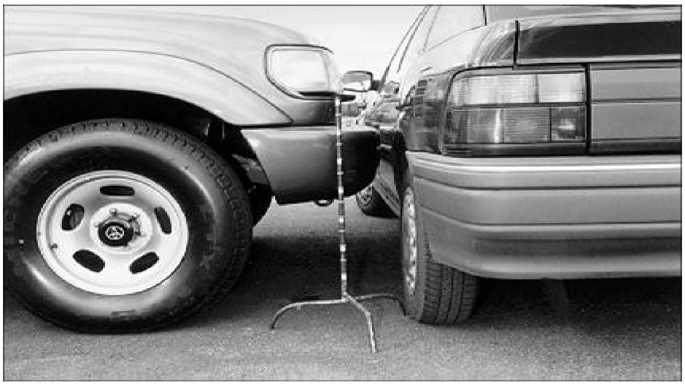
- Rear impact and whiplash type injury is a serious problem in terms of both injury and cost to society. Around 50% of neck injuries leading to disability following crashes occur in rear impacts (Krafft, 1998).
- The risk of whiplash injury is not simply related to head restraint position, but is dependent on a combination of factors related to both head restraint and seatback design (Kleinberger, 2003). Traditionally, attempts have been made to prevent injury by changes in the headrest geometry. A headrest located less than 10cm from the head has proved more beneficial than a distance of more than 10cm (Olsson, 1990; Jacobsson, 2004). Research into the injury mechanisms of neck injury has shown that the dynamic behaviour of seat backs is one of the parameters most influencing neck injury risks (Krafft, 1998).
- Several special test dummies and test devices have been developed to date for the assessment of whiplash injury and several static and dynamic test procedures have been developed (EEVC, 2005 WG20) . A Euro NCAP test protocol also addresses whiplash injury.
- Systems aimed at preventing neck injuries in rear impacts have been presented in recent years and used in several car models (Lundell, 1998; Wiklund & Larsson, 1998). Evaluation in real crashes has shown that an anti-whiplash system can reduce average whiplash injury risk by 50%; that energy absorption in the seat back reduced occupant acceleration and the risk of sustaining a whiplash injury; and further reductions in injury

risk could be achieved by improved head restraint geometry (Krafft, 2004). A Norwegian meta-analysis indicated that the effects of WHIPS systems differ with respect to injury severity. Slight injuries are reduced by about 20%, serious injuries by about 50% (Eriksen et al., 2004).

Compatibility

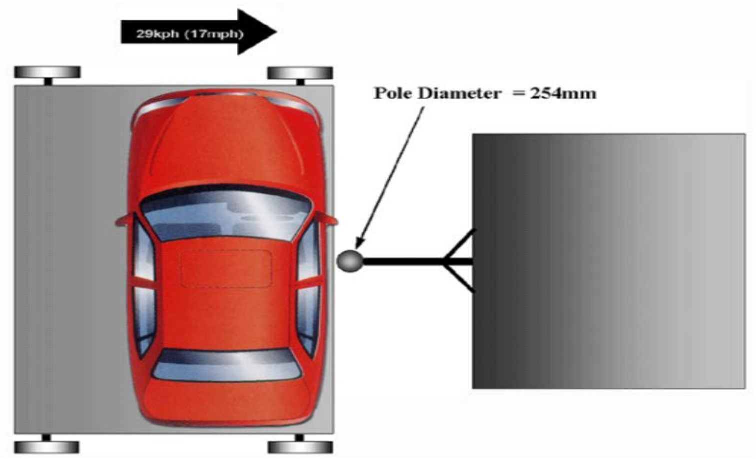
The varying mass of different cars and the different crash types make achieving compatible protection in car crashes quite complex. While cars mostly hit other cars either on the front or sides, they also hit roadside objects, pedestrians and commercial vehicles. Compatibility is seen by vehicle safety experts as next major step forward in improving car occupant safety (Faeber, 2005; Hobbs, 2001; Passive Safety Network).

Figure 4: Car-to-car compatibility



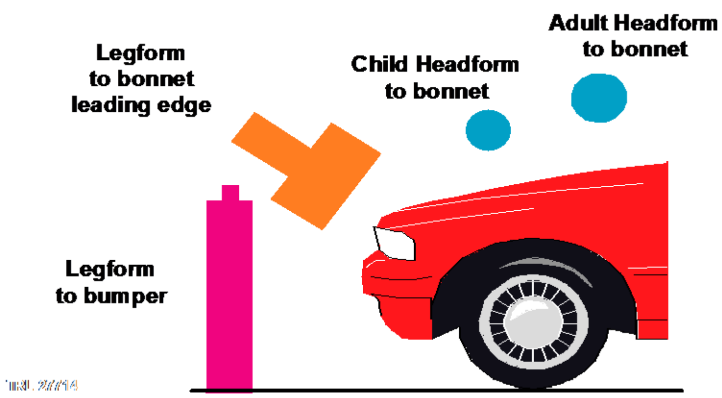
Many new cars can absorb their own kinetic energy in their frontal structures in crashes, so avoiding significant passenger compartment intrusion. But when cars of different stiffness hit each other, the stiffer car overloads and crushes the weaker car. When a car impacts with another, the stiff structures need to interact to minimise injury. There is currently no control of the relative stiffness of the fronts of different models of car. For example, there’s a need to reconcile sports utility vehicles with smaller passenger cars, which form the majority of vehicles on Europe’s roads. The question of geometry and matching of structures is also important to provide better compatibility, and avoid override/underride of different vehicles and objects. The EEVC is developing test procedures to improve car-to-car compatibility for both front-to-front and front-to-side crashes and an EU-funded research programme is coordinating international research.

Figure 5: Car to roadside objects



Impacts with roadside objects such as poles cause between 18%- 50% of car occupant deaths in EU countries. Current legislation only requires the use of crash tests with barriers representing car-to-car impacts. A side car-to-pole test protocol is used in Euro NCAP Coordination is required between the design of cars and crash protective or 'forgiving' safety barriers.

Figure 6: Car to pedestrian tests



Most fatally injured pedestrians are hit by the fronts of cars.

Project co-financed by the European Commission Directorate General for Mobility & Transport

Four sub system tests have been devised by the EEVC to test areas of the car front which are a source of serious and fatal pedestrian injury in impacts. The tests at 40 km/h comprise:

- A bumper test to prevent serious knee and leg fractures;
- A bonnet leading-edge test to prevent femur and hip fractures in adults and head injuries in children;
- Two tests involving the bonnet top to prevent life-threatening head injuries.

Minor amendments to the EEVC tests were proposed following an EC funded feasibility study (Lawrence, 2003). The European Commission stated in 2003 that take up of these challenging tests could avoid 20% of deaths and serious injuries to vulnerable road users in EU countries annually, although rejected inclusion of all in a legislation on the grounds of feasibility in existing car designs (EC, 2003).

Euro NCAP rewards the provision of pedestrian protection in new cars. A pedestrian protocol comprising sub-system tests based on those devised by the EEVC are carried out to replicate crashes involving child and adult pedestrians where impacts occur at 40km/h (25mph). A leg form test assesses the protection afforded to the lower leg by the bumper, an upper Leg form assesses the leading edge of the bonnet and child and adult Head forms are used to assess the bonnet top area. Impact sites are then assessed and rated fair, weak and poor. Euro NCAP released a separate star rating for pedestrian valid from 1997 to 2009. The pedestrian protection rating was based on the adult and child head form tests and the two leg form tests. As of 2009, the pedestrian score has become integral part of the overall rating scheme but the technical assessment has remained the same. In general, the car industry has still to respond well to these tests in their designs. In order to encourage further progress Euro NCAP will require from 2012 that a minimum 60% score in the pedestrian tests will be required for new cars to receive a 5 star rating.

Research has indicated a significant correlation between Euro NCAP pedestrian score and injury outcome in real-life car to pedestrian crashes. One study found a 20% reduction in permanently disabling injuries for two star pedestrian protection compared to one star cars with increasing injury reduction grows with higher levels of impairment and in crashes with lower impact speeds (Strandroth, 2011). Another indicated that there is a correlation between the number of Euro NCAP points and the reduction of MAIS2+ injured pedestrians although even achieving 36 Euro NCAP points will not necessarily reduce the number of seriously injured pedestrians to an acceptable extent (Liers et al., 2009).

EU legislation (aligned with the new Global Technical Regulation 9's passive safety sub-system tests for Phase 2) requires a mixture of crash protection tests (offering a lesser level of protection than the EEVC-based Euro NCAP tests) and crash avoidance measures and comes into force for all new type approvals in 2015 and for new registrations in 2019.

Figure 7: Car to HGV

Front and rear under-run protection on trucks is a well-established means of preventing “under-running” by cars (whereby cars go underneath trucks with disastrous results for the occupants, because of a mismatch between the heights of car fronts and truck sides and fronts). Similarly, side protection on trucks prevents cyclists from being run over.

Legislative requirements for front rigid guards exist. Energy-absorbing front, rear and side under-run protection could reduce deaths in car to lorry impacts by about 12% (Knight, 2001). Research shows that the benefits of a mandatory specification would exceed the costs, even if the safety effect of these measures was as low as 5% (Elvik, 1999).

Figure 8: Frontal underrun test

Restraint systems:
Occupant restraint is the single most important safety feature in the car and most crash protective design is based on the premise that a seat belt will be used.
Over the last 20 years restraint systems fitted in many new cars feature seat belts, frontal air bags, as well as seat belt pre-tensioning systems and belt force limiters – all of which have done much to enhance seat belt protection. Measures to increase the use of restraints by means of legislation, information, enforcement and smart audible seat-belt reminders are central to improving the safety of car occupants. For overview see *World Report on Road Traffic Injury Prevention* (Peden et al., WHO 2004).

Seat belts when used, reduce the risk of serious and fatal injury by between 40% and 65%. Typically, seat belts provide the best protection in frontal impacts, rollovers and in side impacts for the non struck side occupants. While front seat belt use is generally high in normal traffic in many parts of Europe, usage in fatal crashes has been shown to be as low as 30-50%. Seat belt use is also much lower in the rear than on the front seat. Seat belts, their anchorages and their use are covered by European legislation and standards. See European Commission.

Seat-belt reminders are intelligent, visual and audible devices that detect whether seat-belts are in use in various seating positions and give out increasingly urgent warning signals until the belts are used. Research shows that occupants are much more likely to wear their belts in cars equipped with a seatbelt reminder than in those without. It is estimated in Sweden that reminders in all cars could contribute to a reduction of some 20% in car occupant deaths Of all the new cars tested in Euro NCAP in December 2010 almost 95% of the new car sales had a seat belt reminder specification for the driver. 75% had a reminder for the passenger and 35% a system to monitor seat belt use in the rear seat (Swedish Government, 2011). Seat belt reminders are highly cost-beneficial with a benefit to cost ratio of 6:1 (ETSC, 2003). Euro NCAP assesses seat belt reminder systems in tests and rewards their installation See ERSO eSafety web text for further information.

Frontal airbags are fitted voluntarily by car manufacturers in most new European cars, although their use is required mandatorily in other regions such as the US. Driver and front-seat passenger airbags reduce the risk of fatal injury by 68% when combined with seat-belt use (Cummings, 2002). Airbags do not offer protection in all types of impact and do not reduce the risk of ejection. Airbags are no substitutes for seat belts, but are designed to work with them. Estimates of the general effectiveness of frontal air bags in reducing deaths in all types of crashes range from 8% to 14% (Ferguson, 1995).

However, some of the protective measures provided by airbags designed for adults in a normal seating position pose a serious threat to children sitting rearward facing child seats and out-of-position (OOP) adults. Small drivers sitting close to the steering wheel are also at risk of being injured by the deploying airbag. The injury risk increases the closer the driver sits to the steering wheel and research shows that this reduces if the distance is 25 cms or over. Warning labels now have to be fitted in cars to avoid the installation of rearward facing child restraints and in some cars there is now provision for automatic detection of child restraints and out of position occupants or a manual switch to disconnect the passenger airbag system.

Head protecting airbags Head protecting airbags are now increasingly common and help to provide protection for the head against impacts with the car's interior and particularly with structures outside the car. Their introduction, in combination with torso protecting airbags, offers the possibility of providing protection against the stiff B pillar (the stiff pillars in the middle of the passenger compartment). Monitoring of the effectiveness of head curtains in reducing injury is being carried out.

Side airbags Research to date is inconclusive about the performance of side air bags in crashes which are designed to protect occupants in side impacts. No studies to date show convincing evidence of major injury reductions and there are some indications of airbag induced injuries (Morris, 2005; Yoganandan, 2005).

Smart restraint systems Smart restraint systems are vehicle restraint components or systems that adapt their geometry, performance or behavior to suit varying impact types and/or occupants and occupant positions. Few of the systems today attempt to adapt its characteristics to those of the person to be protected, and this is a key issue for the future with more biomechanical research needed. To date, most of the current smart restraint systems are intended to reduce the inflation power and aggressivity of frontal airbag systems. The future holds much promise for intelligent systems which can identify variables such as occupant physique and positioning, so providing more tailored crash protection. The EC PRISM project aimed to facilitate the efficient and effective development of "smart restraint systems".

Child restraints Children in cars need appropriate child restraints for their age and size. Several types of child restraint systems are in use within the EU. These include: infant carriers, child seats, booster seats and booster cushions. Infant carriers are used rearward-facing up to the age of 9 months. Both forward and rearward-facing child seats are used for children between 6 months and 3 years old. Booster seats and cushions are used forward facing up to approximately 10 years of age. All types are covered by European standards. See Euro NCAP protocols.

Research shows that the use of rearward facing restraints provides the best protection and should be used up to as high an age as possible (although not used adjacent to frontal passenger airbags). Rearward-facing systems have been shown to reduce injuries between 90% and 95%, while forward-facing systems have been shown to have an injury reducing effect of approximately 60% (Tingvall, 1987; Volvo, 1997). The use of child safety seats has been shown to reduce infant deaths in cars by approximately 71% and deaths to small children by 54% (National Highway, 2002).

Increasing the use of child restraint systems is the most important action in countries where the usage rate is low. Misuse of child restraints has in many EU Member States been identified as a major problem since most child restraints are not manufactured by car manufacturers and are not integrated into the original design of the car. Another problematic area for all child restraint systems is side impacts. Euro NCAP has shown the limited ability of current restraints to constrain the movement of the child's head and prevent contact with the car's interior. A side impact test procedure for child restraints is under the development within ISO TC22/SC12/WG1.

Euro NCAP has developed a child protection protocol to encourage improved design. Points are awarded if universal child restraint anchorages ISOFIX are provided' for different types of child restraint provision and the quality of the warning labels or presence of de-activation systems for frontal passenger airbags.

Rear restraints The rear seats of cars are occupied much less frequently that the front seats and the severity of injury is generally lower, where seat belts are worn. Occupants seated in the rear of cars are less exposed to intrusion problems so that improving the intrusion resistance of passenger compartments is likely to provide less benefit to rear seat occupants, particularly children. There are no legislative or crash tests which cover the crash protection of rear occupants or the performance of occupant restraints.

Head restraints The risk of whiplash injury is related to both head restraint and seatback design and dynamic seat back tests (Kleinberger, 2003). Evaluation in real crashes has shown that an effective anti-whiplash system can reduce average whiplash injury risk by 50%; that energy absorption in the seat back reduced occupant acceleration and the risk of sustaining a whiplash injury; and further reductions in injury risk could be achieved by improved head restraint geometry (Krafft, 2004).

A headrest located less than 10cm from the head has proved more beneficial than a distance of more than 10cm (Olsson, 1990; Jacobsson, 2004). The greatest protection is provided by:

- Correct vertical adjustment. The top of the head rest must, if possible, be at the same height as the top of the head. The minimum is just above the ears.
- Correct horizontal distance between head and head rest. This must be as small as possible: in any case less than 10 cm and preferably less than 4 cm.

Head restraint ratings based on static measurements of head restraint geometry using the Head Restraint Measuring Device (Gane & Pedder, 1999) are used by the insurance industry around the world (Thatcham).

A Euro NCAP test protocol assesses the geometry of the restraint in relation to the head and tests the seats in three severities of impact – high, medium and low – using a dummy specially designed for rear impacts. Seats at the top of the table are likely to offer better protection than those at the bottom. Rating categories are good, medium and poor.
Phase 1 of a Global Technical Regulation 7 on head restraints was adopted in 2008.

Car occupant interior head, knee and lower leg protection

Head injury The head is the highest priority for protection in road crashes. Although seat belts and frontal airbags offer protection, they do not prevent contact with the car's interior in all crash scenarios. For example, angled frontal impacts present considerable head injury risk as current restraint and airbag systems may not prevent contact with parts of the car such as the windscreen pillar. Interior surfaces that can be impacted by the head need to be padded and the idea of an interior head form test has been proposed as a potential tool by European vehicle safety experts (Hobbs, 2001). Partial ejection of the head in side impacts and contact with the striking object is also a key determinant of survivability The Euro NCAP pole test is encouraging increasing provision of head air bags in new cars.

Knee injury Currently, there is no dummy instrumentation or biomechanical data in legislative tests to cover knee damage from direct impact against the knee. Furthermore, there is no test procedure for testing the whole of the potential knee impact area of the facia. Sources of knee injury are included in the Euro NCAP inspection procedure which forms part of the safety rating analysis.

Lower legs, feet and ankles Lower leg injuries can result from direct impact against the fascia, parcel shelf or foot pedals or from loads applied to the foot or leg. Offset frontal collisions present a high risk for lower extremity injuries with long impairment and high societal costs. Crashworthiness optimisation to alleviate serious injury risk to some body regions leads to changes in injury distribution patterns and shifts the focus to other areas of the body. Injuries to the lower legs have been neglected until recently and the introduction of an improved dummy leg is awaited. Sources of injury to lower legs, feet and ankles are included in the Euro NCAP inspection procedure which forms part of the safety rating analysis.

Other issues - rescue systems

Emergency Notification Systems or 'Mayday' systems aim to reduce the time between when the crash occurs and when medical services are provided. By improving information transfer between the trauma care physician and emergency medical service personnel, they aim for faster and more appropriate treatment. In 2000, Autoliv and Volvo introduced one of the world's first post-crash safety systems (Volvo Club).

Automatic Crash Notification (eCall) takes the safety benefits of Mayday systems further by providing emergency responders with data that indicates the severity of the crash and the nature of injuries sustained. A Finnish study has estimated that such a system might reduce between 4-8% of road deaths and 5-10% of motor vehicle occupant deaths in Finland (Virtanen, 2006). See ERSO eSafety and Post Impact Care web texts for further information.

Electric vehicles

Fully electric vehicles are increasingly being introduced to the passenger car market. Hybrid and full electric vehicles potentially have new safety concerns that will need to be addressed which will become an increasingly important area of vehicle safety.

Standards relating to performance for protecting occupants from electric shock after the collision of an electric vehicle or hybrid vehicle were established in UN ECE's WP.29 in 2010.. A new safety regulation for a Rechargeable Energy Storage System (RESS) is now being discussed at WP29.

New Car Assessment Programs (NCAPs) have subjected several petrol-electric hybrid vehicles to the 64km/h frontal offset crash test, 50km/h barrier side impact test and the 29km/h side pole test. No problems with the electrical systems or batteries were encountered.

A review of the potential hazards afforded by electric vehicles has recommended that further research should be conducted into the robustness of Li-ion batteries in a crash scenario, investigation should consider the types and severities of crash that can be expected to place severe demands on in the in-built safety systems of electric vehicles and their batteries. Further research is also needed to develop appropriate and consistent post-crash procedures for dealing with electric vehicles, including fires (Paine et al., 2011)

5.2 Motorcycles

Motorcycle use is the most dangerous mode of road travel. Around 7000 motorised two wheeler users die each year in the EU (27), comprising 17% of total deaths. In line with rising use, motorcyclist deaths have risen annually as a percentage of all road deaths in the EU. The numbers of moped deaths have, however, declined from 1,670 to 1,456 (between 2005 and 2008), although the proportion of moped deaths in relation to all deaths has remained about the same. Two thirds of motorcyclist deaths are in the 25-49 age group, and 19% are aged 18-24 and deaths have increased annually in line with increasing use. The risk of death for motorcyclists has been estimated at around 18 times that of car occupants (ETSC, 2007).

Motorcycles tend to have much higher power-to-weight ratios than cars, and increasing numbers of motorcycles are capable of very high speeds and accelerations. Apart from their inherent instability, compared with other motorised vehicles, motorised two-wheelers, because of their size and shape, are less easy to see than other motor vehicles and have poor visibility in daytime. Various attempts have been made to improve the general stability of motorcycle through concepts such as the BMW C1.

In the World Report on Road Traffic Injury Prevention (Peden et al., 2004 WHO) the World Health Organisation and World Bank have advised that care should be taken to avoid the adoption of policies which could encourage the growth of motorised two-wheeler traffic by giving advantages to motorised two-wheeler users. Research shows that in addition to managing exposure to risk, vehicle engineering and protective equipment measures play a particularly important role in reducing injuries and crashes amongst motorised two wheeler users.

Notwithstanding the high risks associated with motorcycle use, relatively little research on motorcycle safety design has been carried out. However, with the increasing popularity of this transport mode and increased casualty levels, new EU and national attention is currently being given to this area.

5.2.1 Exposure measures

Restricting engine capacity for novice motorcyclists from 250cc to 125cc, accompanied by a limitation on the maximum power output (to 9 kW) proved to be a successful measure in the United Kingdom in the early 1980s. Many inexperienced motorcyclists transferred to less powerful vehicles, leading to an estimated 25% reduction in casualties among young motorcyclists. Significantly greater crash risk is associated with larger motorcycles, even when these machines are ridden by more experienced riders (Broughton, 1987).

However, many studies of the relationship between engine size and crash risk have failed to control for confounding variables which has had a major influence on the results of studies (Ruijs, 1997; Elvik et al., 2009 Handbook). For example, a study by Ingebrigtsen (1990), showed only weak effects of engine size once a host of other variables influencing the crash rate had been taken into account.

Japan imposes limits, for safety reasons, on the engine size and performance of large motorcycles used domestically. For most exported motorcycles, outputs of 75–90 brake horse power (56 –67 kW) or even 130 brake horse power (97 kW) are common with top speeds reaching almost 322 km/h (RoSPA, 2001).

5.2.2 Crash avoidance and mitigation measures

Daytime Running Lights

The objective of mandatory use of daytime running lights for motorcycles is to reduce the number of crashes by making it easier for other road users to see motorcycles in traffic. The use of daytime running lights (generally low beam) is compulsory in several EU Member States (e.g. Austria, Germany, Belgium, France, Spain and Portugal). Some of these require action on the part of users to switch on headlamps.

The effects of headlights have been studied in a case control study in New Zealand (Wells et al, 2004) and the crash rate was found to be 27% lower for motorcycles with headlights on during daytime. A meta-analysis of mainly US studies concluded that the average effect of making the use of running lights on mopeds and motorcycles mandatory is a reduction of around 7% (± 3%) in the number of multi-party accidents in daylight (Elvik et al., 2009 Handbook). In Europe the use of daytime running lights by motorized two-wheelers has reduced visibility-related crashes in several countries by between 10% and 16%. In Europe, motorcyclists who use daytime running lights have a crash rate that is about 10% lower than that of motorcyclists who do not. In Austria, automatic DRL reduced the number of injured motorcyclists in daytime multiple crashes by about 16% (Bijleveld, 1997). One estimate of the cost–benefit ratio of using running lights in daytime is put at around 1:5.4 for mopeds and 1:7.2 for motorcycles (Elvik et al., 2009 Handbook).

EU-registered motorcycles are not required to be fitted with DRL although manufacturers are fitting new motorcycles increasingly with headlights which come on automatically with ignition. Research indicates that two lamps and lamps over 180mm diameter have greater influence than single or smaller lamps (Donne & Fulton, 1985).

Anti-lock Braking Systems

Research shows that riders often fall off machines while braking before impacts with cars. Improved braking systems such as ABS, combined braking and enhanced braking are likely to make a contribution in single vehicle crashes and crashes where the rider falls Until recently the potential casualty reduction information on ABS has been prospective and positive (Sporner & Kramlich, 2000). A Swedish study (Rizzi et al., 2009) has evaluated the effectiveness of antilock brake system (ABS) technology on motorcycles in reducing real life injury crashes and to mitigate injury severity. Induced exposure analysis showed that the overall effectiveness of ABS was 38% for all injury crashes and 48% for severe and fatal crashes, with a minimum effectiveness of 11 and 17% respectively. Since the launch of the Swedish Transport Administration's study results in June 2009, Swedish importers increased the number of motorcycle models with ABS as standard and the share of new motorcycles with ABS has gone from 15% in 2009 to 60% in 2010 (Swedish Government, 2011).

Typically, these systems are available on more expensive models of motorcycle. In 2004, the Association des Constructeurs Européens de Motorcycles (ACEM) made a commitment to offer the majority of PTW street models to be equipped with advanced braking systems. An Advanced Braking System is a braking system in which either an antilock brake system and/or a combined brake system is present by 2010 and has set a further objective of 75% of new models to equipped with ABS or offered as an option by 2015. As a result of the 2004 commitment, ACEM reports that 35% of the motorcycles sold by the ACEM manufacturers and registered in Europe in 2008 were equipped with advanced braking systems.

5.2.3 Crash protection measures

Mandatory crash helmet use

Approximately 80% of motorcyclists killed on European roads sustained head impacts and in half of these cases, the head injury was the most serious. Motorcycle helmets aim protect against head injuries in the event of a crash and to reduce the severity of such injuries. Full face helmets provide better protection than open face helmets (EEVC, 1994). Helmets can reduce fatal injury by around 44% (Elvik et al., 2009).

Table 7: Injury-reducing effects of helmets for moped-riders and motorcyclists

	Percentage change in number of injuries		
Injury severity	Type of injury affected	Best estimate	95% confidence interval
Fatal injury (3%)	Head injury	-44	(-55; -32)
Serious injury (17%)	Head injury	-49	(-58; -39)
Slight injury (80%)	Head injury	-33	(-41; -25)
All injuries (100%)	Head injury	-44	(-22; -41)
All levels of severity	Injuries other than head injuries	-8	(-22; +8)
All levels of severity	All types of injury	-25	(-30; -20)

Source: Elvik et al., 2009

Research shows that only mandatory use legislation can achieve high levels of use and injury reduction. A meta-analysis of studies – mainly from the United States, where many laws on helmets were introduced in the period 1967 –1970 (and about half of which were repealed between 1976 and 1978) found that the compulsory helmet wearing reduced the number of injuries to moped riders and motorcyclists by 20 –30%. Analysis of the effects of repealing helmet wearing laws showed that withdrawing them resulted in 30% more deaths, a 5 –10% increase injuries to moped riders and motorcyclists (Elvik et al., 2009 Handbook). In Europe, an evaluation of helmet use and traumatic brain injury, before and after the introduction of legislation, in the region of Romagna, Italy, found that helmet use increased from an average of less than 20% in 1999 to over 96% in 2001, and was an effective measure for preventing traumatic brain injury at all age (Servadei, 2003).

Research has found that present helmets are too stiff and too resilient, with the maximum energy absorption of the liner occurring at high impact velocities where the probability of death is high. Research shows that helmet shells and liners should be less stiff in order to provide maximum energy absorption at lower, more prevalent, impact velocities where the benefit of a wearing a helmet can be more effectively realised (Elliott, 2003). The COST 327 European Research Action on motorcycle helmets reported that improvements in helmet design could save up to 1,000 lives per year across the EU. A UN ECE regulation exists but has superseded the British Standard 6658 which included tests for rotation and the chin guard deemed necessary following in depth crash injury research (Elliott, 2003). A new UK consumer information programme provides comparative safety assessment of over 30 different new helmets. *See* SHARP.

Chest air bags

In head on collisions, the rider continues to move forward in a seated position and hits the opposing object at close to pre-impact velocity. These crashes often result in fatal or serious injury to the head and upper body of the motorcyclist.

While the provision of air bags on motorcycles is more complex than installation in cars, because the dynamics of a motorcycle crash are more difficult to predict, early crash tests with airbags on motorcycles (1973) indicated that an airbag system could be beneficial in frontal impacts. In the early 1990s tests were completed in the UK in which three different types of motorcycle were fitted with an airbag (Happian-Smith & Chinn, 1990). The results showed that full restraint was not possible above a speed of 30 mile/h, though reducing speed and controlling rider trajectory could still be beneficial. Further work was carried out by the Transport Research Laboratory and Honda during the 1990s (Chinn et al., 1997).

In 2004, Honda announced that it had developed the world's first production motorcycle airbag system to be made available in 2006 on new Gold Wing motorcycles. The airbag module, containing the airbag and inflator, is positioned in front of the rider. A unit in the airbag positioned to the right of the module analyses signals from the crash sensors to determine whether or not to inflate the airbag. Four crash sensors attached on both sides of the front fork detect changes in acceleration caused by frontal impacts.

Figure 9: Honda air bag system

Leg protection

Injuries to the legs of motorcyclists occur in approximately 80% of all crashes. In all collisions in which the motorcyclist is hit in the side by a car or other party, the forces involved impact the legs directly.

A large amount of research has been conducted in this area which shows that leg protectors could help reduce those injuries which result from direct crushing of the rider's leg against the side of the motorcycle during impact (Huang and Preston, 2004). Studies show different possibilities for optimising leg protection (Chinn & Hopes, 1985; Chinn & Macaulay, 1986). Studies with leg protective airbags have also been carried out (Sporner, 1990; Sporner, 2000). It has been estimated that the severity of leg injuries would be reduced in approximately 50% of the crashes which involved serious leg injury if leg protection were to be fitted (Nairn, 1993). Further work in this area has been recommended to ensure that leg protection does not change rider trajectory to result in negative side effects (Hobbs, 2001).

Protective clothing

Many riders sustain soft tissue injuries from road impact, and suitable protective clothing systems have been developed. A European CEN standard now exists to promote higher levels of effectiveness in clothing (EN 13594 gloves; EN 13595-1 bis - 4 jackets, trousers and combi-units;EN 13634 shoes). A drop-test is used to measure shock absorption. Special protector systems are used on the shoulders, elbows, arms and thorax, and special back protectors are used to protect the spine.

A review of the literature found that improved design and wider use of protective clothing could make a significant contribution to lessening the severity of motorcycle injuries. Protective clothing can:

- Prevent most laceration and abrasion injuries that occur when a rider slides on the road surface after falling off.
- Prevent contamination of open fractures by road dirt.
- Reduce the severity of contusions and fractures, with the prevention of some fractures and joint damage.
- Reduce the severity (or prevention) of muscle stripping and de-gloving injuries, particularly to the lower leg and hands.
- Prevent crashes by maximising the conspicuity of the rider.
- Prevent crashes by maintaining the rider in good physiological and psychological condition by keeping the rider dry, warm, comfortable and alert (Elliot, 2003).

The selection of single items of clothing and their combined use should be based on the following considerations:

- Clothing must be able to protect against, wet, cold and heat even when these occur for long periods.
- Falls and impacts are common in all types of riding (including off-road) except on motorways. Collision severity is dependent on the surface impacted. However because it is not possible to control where a rider will travel at any one time, the clothing must satisfy all requirements.
- A set of clothing may be bought by a rider from different sources. It is therefore important that advice should be given on compatible items. For example there should not be a gap between boots and trousers.
- The outermost layer should always be of high conspicuity even in wet weather.

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Clothing should be designed to ensure that all tasks required of a motorcyclist are easily accomplished and in particular movement must not be restricted.

5.3 Heavy commercial vehicles

Heavy commercial vehicles are those with a total weight above 3,500 kg. (vehicle + load). Heavy goods vehicles are over-involved in fatal crashes, since their high mass leads to severe consequences for other road users in crashes. In view of this and the growth in heavy good vehicle traffic internationally over the last twenty five years, the safety of heavy goods vehicles continues to be strictly regulated in the best performing countries in road safety and work-related road safety action encouraged. See ERSO Work-related road safety web text. EU Whole Vehicle Type Approval was introduced for heavy commercial vehicles in 2009.

5.3.1 Crash avoidance and mitigation measures

Speed limitation

It has been estimated that automatic speed limitation through the installation of speed governors to heavy goods vehicles could contribute to a reduction in 2% of all injury crashes (Elvik & Vaa, 1997).

In European Union countries in-vehicle speed limitation is required Initially applying a 90 km/h limit to commercial vehicles over 12 tonnes in 1992, the provision was extended in 2002 to all commercial vehicles over 3.5 tonnes (by 1st January 2005 for all new vehicles and 1st January 2006 for existing vehicles) by EC Directive 2002/85.

Vision and conspicuity:

Blind spot mirrors Every year, around 400 road users are killed in crashes where truck drivers fail to notice them when taking a right turn (or a left turn in the UK, Ireland, Malta or Cyprus). Both new and old heavy duty vehicles are now required by EU legislation to be equipped with blind spot mirrors. In-depth crash investigation has shown that restricted driver vision to see pedestrians and bicycle riders is a factor in crashes with particularly high risks whilst manoeuvring or reversing.

In 2003, the European Parliament and Council adopted Directive 2003/97/EC on rear view mirrors and supplementary indirect vision systems for motor vehicles. This Directive aims to improve road user safety by upgrading the performance of rear view mirrors and accelerating the introduction of new technologies that increase the field of indirect vision for drivers of passenger cars, buses and trucks. The Directive was further amended by Directive 2005/27/EC to extend the installation of wide angle mirrors to more vehicle types and in 2007 to require retrofit.

Retro-reflective markings: In depth crash investigations show that nearly 5% of severe truck crashes involve the poor conspicuity of the truck or its trailer at night where car drivers failed to see truck or truck combinations turning off the road, turning around or driving ahead of them. Different studies have shown that trucks can be rendered much more conspicuous by marking the sides and rear of commercial vehicles using retro reflective markings

(Langewieder, 2000). Currently, the European standard ECE-Regulation 104 (January 1998) which refers to the conspicuity of long and heavy vehicles and their trailers is optional.

Braking and handling:
Electronic stability devices In loss of control crashes due to speed or steering behaviour and driving through narrow bends or during evasive movements, the truck or trailer can slide or jack-knife. Prospective research indicated that Electronic Stability devices for trucks could improve the safety during the driving through bends by about 40% (VDI, 2000).

EU legislation on Electronic Stability Control (ESC) for heavy commercial vehicles is being phased in from 2012. Mandatory Advance Emergency Braking (AEBS) on large vehicles employing sensors to alert the driver when a vehicle is too close to the vehicle in front and, in certain situations, apply emergency braking to prevent or reduce the consequences of a collision is being phased in from 2013. According to the European Commission, preliminary estimates suggest that the new measures for fitting advanced systems to heavy vehicles could ultimately save around 2500 lives per year (around 500 for ESC and 1000 each for AEBS and LDW) and many more lives outside the EU since the legislation will encourage manufacturers to fit ESC as standard for a wider range of markets.

*Rollover stability**:*** By continuously monitoring the vehicle's movement and its relationship to the road surface, the rollover stability system automatically applies brakes and/or reduces engine power when a potential rollover situation is identified. This system has been introduced on various truck models. In depth research shows that since HGV rollovers do not usually result in serious injury, any benefit derived may be more to reduce congestion than road safety.

Impairment by alcohol and fatigue:
Alcolock systems are automatic control systems which are designed to prevent driving with excess alcohol by requiring the driver to blow into an in-car breathalyzer before starting the ignition. Since the late 1990s Sweden has experimented widely with alcolocks in commercial vehicles and manufacturers have been offering fitment as an option. The technology used is a simplified version of the Alcolocks used in car offender programmes in order to allow companies to have more than one driver able to use the interlocks (ETSC, 2005).
Since 2007 all trucks of 3.5 tons and over, which are contracted by the Swedish Road Administration (SRA) for more than 100 hours per year have to be fitted with alcohol interlocks. Several EU countries are introducing alcolocks into their high risk-offender drink drover programmes. See ERSO eSafety, Alcohol web texts.

Compliance with drivers' hours Driving fatigue has been identified as a special problem for commercial transport, given the long distances which need to be covered and irregular shift patterns which affect sleep. Research indicates that fatigue is most prevalent in long distance lorry driving (Maycock, 1995) and a factor in 20-30% of commercial road transport crashes in Europe and the United States (ESC, 2001; NHTSA Expert Panel, 1996). The Commission has moved to strengthen driving and working time rules and enforcement in recent years. EU legislation regulates the driving time of professional drivers in cross-border transport where part or all of the journey is in EU territory. Driving hours should not exceed nine hours per day or 56 hours per week. After driving for four and a half hours, a break of at least 45 minutes is mandatory. See Regulation (EC) No 561/2006 on the harmonisation of certain social legislation relating to road transport. See also ERSO web text on Fatigue for detailed discussion.

Digital tachographs Council Regulation (EC) 2135/98, which amends Regulation (EEC) 3821/85, introduced a new generation of fully digital tachographs to assure compliance with drivers' hours legislation. The digital tachograph is a more secure and accurate recording and storage device than the present equipment. The device records all the vehicle's activities, for example distance, speed and driving times and rest periods of the driver. The system includes a printer, for use in road side inspections and a personal driver card incorporating a microchip, which drivers must insert into the tachograph on taking control of the vehicle. The technical specifications for the digital tachograph have been laid down in Commission Regulation (EC) 1360/2002, to be mandatorily fitted in new vehicles from August 2004.

5.3.2 Crash protection measures

Seat belts and seats

The restraint rate of truck drivers and also of passengers of trucks is very low in Europe. For example in 2001 in Germany seat belt use ranged between 5% and 10%. The installation and use of seat belts in heavy goods vehicles has recently been covered by European legislation. EEC Directive 2003/20/EC amending 91/671/EEC, mandates the use of safety belts where fitted by 2006 in all forward facing front and exposed rear seats in new HGVs. No mandatory EU-wide installation requirement exists for seat belts in heavy goods vehicles, though national regulations in some countries apply. For example the UK regulation states that every heavy goods vehicle first used on or after 1 October 2001, and having a maximum gross weight exceeding 3.5 tonnes, shall be fitted as respects the driver's seat belt with a three-point "lap and diagonal" belt or two-point lap belt, and as respects every other forward-facing front seat with a three-point "lap and diagonal" belt or two-point lap belt. Research indicates that to improve restraint use, 3-point belts should be integrated directly into the seat of the driver and passenger.

Driver cabin structure

Ongoing crash investigation indicates that the stiffness of the driver cabin, especially for truck/truck collisions or single-truck collisions is not sufficient. Currently in Europe two (optional) regulations exist relating to the stiffness of driver cabins (ECE-Regulation 29, VVFS or "Sweden-Test"). Enhanced cabin structure together with restraint use would improve the survivability for HGV occupants in severe HGV crashes (Langwieder, 2000).

Front underrun protection Due to the size and mass of heavy vehicles, the problem of compatibility with other road users in crashes is a significant safety issue. Trucks are stiff, heavy and high and pose a serious threat to occupants of other vehicles in the event of an impact. Frontal car-to-truck collisions are the most common impact type in crashes where trucks are involved. It has been estimated that energy-absorbing front, rear and side under-run protection could reduce deaths in car to lorry impacts by about 12% (Knigt, 2001).

An EU requirement was introduced in 2000 based on ECE Regulation 93 requiring mandatory rigid front underrun protection defining a rigid front underrun protection system for trucks with a gross weight over 3.5 tonnes Directive 2000/40/EEC. Studies performed by EEVC WG 14 have shown that passenger cars can 'survive' a frontal truck collision with a relative speed of 75 km/h if the truck is equipped with an energy absorbing underrun protection system. Furthermore, these systems could reduce about 1,176 deaths and 23,660 seriously injured car occupants in Europe per year. Research shows that the benefits of a mandatory specification for energy absorbing front underrun protection would exceed the costs, even if the safety effect of these measures was as low as 5% (Elvik, 1999). Energy absorbing systems are available from all truck manufacturers as an optional device but not there is no mandatory fitment requirement for these at EU level.

Rear underrun protection Council Directive 70/221/EEC and amendments mandate a rear underrun protection system for trucks and trailers with a gross weight of more than 3.5 tonnes. The regulation describes for example a ground clearance of 550 mm and test forces of maximum 25 km/h, respectively 100 kN, depending on the test point.

Research, however, indicates that the ground clearance of rear underrun protection systems is insufficient and that the systems are insufficiently strong. Research indicates that the ground clearance needs to be reduced to 400mm, the cross-member height and the test forces need to be increased (Minton & Robinson, 2010). The first conservative estimates of EEVC WG14 on underrun protection devices have indicated that improved rear underrun protection systems with a lower ground clearance as well as higher test forces would reduce fatally and severely injured car occupants by a third in rear underrun impacts in Europe. In addition, Working Group 14 has found that the costs for fatalities and severe injuries could be reduced by 69 -78 Million Euro.

Side underrun protection Council Directive 89/297/EEC mandates side underrun protection on heavy goods vehicles to prevent pedestrians, bicycle riders and motorcyclists from falling under the wheels of the heavy good vehicle when it turns.

In the Netherlands research indicates that the existing legislative requirement is limited and that an improved side underrun protection system could reduce pedestrian and cyclist deaths in such situations by about 10% (Kampen & Schoon, 1999; Langeveld & Schoon, 2004). In addition, protection needs to be provided in side collisions with cars and motorcycles.

5.4 Light vans and minibuses

There is relatively limited data in Europe on lights good vehicle crashes and these vehicles are yet to be covered by EU Whole Vehicle Type Approval legislation. In-depth work has been carried out in Britain (Lenard, 2000) and Germany (Niewohner, 2000) which forms the basis of information in this section.

- *Casualties*: Research in the UK indicates that LGV casualties comprise around 4% of total fatal or seriously injured vehicle occupant casualties, with over 80% comprising drivers. The majority of crashes involved a car (46%). German research indicates what while vehicles do not necessarily have a higher crash rate than other motor vehicles, crashes tend to occur in predominantly urban environments.
- *Crash types*: UK and German studies both found that respectively around 59% and 60% of the crashes with passenger cars were frontal impacts and 14% and 26% were side impacts. In the British study around 22% were rollovers and 16% in Germany were rear impacts as opposed to 4% of cases in Britain. Evidence for belt use by drivers in such vehicles was relatively low, in the order of 20% in Germany and 47% in Britain.
- *Key issues*: The UK in-depth study of around 500 light goods vehicle (up to 3500 kg GVM) crashes indicates three key issues for LGV design:

Poor crash compatibility between LGVs and passenger cars in car-to-LGV crashes in Britain, car drivers bear greatest risk of injury at every level of severity. LGVs tend to have greater size and mass and usually have their stiff structures at a greater height than those of passenger cars. This misalignment of stiff structures can result in the large vehicle over-riding the smaller vehicle. This in turn has the effect of penalising the occupants of the smaller collision partner, since there is an inherent risk of greater intrusion in the smaller vehicles that are already at a mass disadvantage. Any regulatory crash-testing option needs to take strong account of LGV to car compatibility needs.

Low restraint use amongst LGV occupants compared with car occupants in fatal crashes in Britain, 77% were not wearing seat belts and around one-third of drivers and almost half of passengers were found not to have been wearing the seat belt at the time of the crash. Possibilities for increasing seat belt use include the use of in-vehicle seat belt reminder systems; higher profile awareness and education programmes; stricter policing and enforcement actions; and a review of the categories of occupants who are currently exempted from the mandatory wearing of seat belts.

5.5 Buses and coaches

Transport by bus and coach is the safest mode of road travel. However every year, around 20,000 European buses and coaches are involved in crashes causing injury or death producing 30,000 casualties, 150 of whom die. As identified by the major European ECBOS project (Mayrhofer, 2005) vehicle safety design can address a range of identifiable problems. Currently, the vehicle safety performance of buses is regulated by seven ECE (Economic Commission for Europe) regulations and 5 corresponding EC directives. Various research-based improvements have been identified within ECBOS to inform current policymaking, particularly crash protection measures.

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5.5.1. Crash avoidance and mitigation

See section on heavy commercial vehicles re alcolocks, driving hours and digital tachographs.

5.5.2 Crash protection

Crash analysis shows that the occupants in the first row (driver, guide) can be ejected through the front window, or affected by the intrusion. Coupled to the seat, restraints can control better the occupant movement during a crash such that the driver remains conscious, allows driver control of the vehicle until it comes to rest and to facilitate evacuation. While the use of seat belts prevents ejection and reduces the risk of severe injury, there remains the problem of the energy absorbing capacity of the frontal area and intruding objects through the windscreen.

Frontal crash protection

In-depth research shows that special protection devices need to be designed for the driver protection in the front of the coach since driver safety is not adequately considered in current regulations. Research is needed to define the requirements for front structures, a suitable test for buses and to modify the actual designs to preserve the integrity of drivers in frontal of front-lateral impacts (Mayrhofer, 2005).

Restraint systems

Analysis of real world crashes shows that the partial or total ejection is a mechanism for severe injury. The injury severity of the casualties is less if the bus is equipped with a seat restraint system and with laminated glasses. A side airbag especially developed for rollover movement could also prevent occupant ejection. Research has also shown that seats and their anchorages are often unable to resist the forces to which they are exposed in large coach crashes (Mayrhofer, 2005). The risk of being injured by failing seat and anchorages can be reduced by integrated systems and improved standards to control the strength of seats and their anchorages.

- Rollover protection In cases of rollover where the side windows get broken, the risk of passenger ejection and injury increases. The most common body regions injured in a rollover, when no ejection occurs, are the head, the neck and the shoulder. Crash analysis indicated that injury in rollover crashes can be caused by the impact of the occupants on the side panel, on the luggage rack and also by the effects of occupant interaction. The development of new test dummies and rollover tests has been proposed (Mayrhofer, 2005).

- Evacuation Crash injury research shows that in serious crashes bus passengers are hindered from using the emergency doors either because they are severely injured or the doors are locked due to the impact. ECE-Regulation 107 currently sets out the technical rules with respect to emergency doors. An effective measure would be a side window which, even broken, would remain in position and would act as a safety net keeping passengers in the bus interior. At the same time the design of coach corridors should enable rapid

evacuation of bus occupants. This would require the possibility of ejecting windows easily after the coach comes to rest by pyrotechnic charges (Hobbs, 2001).

- Safety of wheelchair users in coaches A study assessing the safety of wheelchair users in coaches in comparison with travellers seated in conventional seats (fitted with headrests) has made various suggestions for modifications (Le Claire, 2003). The work found that the heads and necks of wheelchair users were particularly vulnerable but that this could be addressed through the use of a head and back restraint. However, such a restraint should meet the requirements of ECE Regulation 17 for strength and energy absorption and the wheelchair should fit well up against the head and back restraint for maximum benefit. Further recommendations from the work were that an upper anchorage location for diagonal restraints is preferable to a floor mounted location and that the restraint anchorages should meet more rigorous strength requirements than are required at present. A protected space envelope for forward facing wheelchair passengers is also recommended. Under normal transit conditions a vertical stanchion is preferable to a horizontal bar in terms of preventing excessive movement of the wheelchair.

5.6 Bicycles

5.6.1 Crash avoidance

Bicycles are typically viewed as consumer products rather than road vehicles with much less attention to design and maintenance issues than received by other road vehicles. As yet, there is no EU-wide whole vehicle type approval system for bicycle design which is covered largely by national regulation.

Reflectors and lighting: In many countries it is mandatory for the cycle to be fitted with a rear reflector, and reflectors on the wheels. A Dutch study estimated that more than 30% of bicycle crashes in the Netherlands occurring at night or in twilight could have been avoided if bicycle lighting had been used (Schoon, 1996). In Denmark, requires the fitment of lamps and requires their visibility at a distance of 200m. The quality and use of lights can be improved by enabling the storage of separate light systems or by designing the lighting into the cycle frame (Allsop, 1999).

Braking: Studies of bicycle impacts indicate that there are large differences in component strength and the reliability of bicycle brakes and lighting. In the Netherlands, for example, the failure of components such a sudden crash or brake failure causes 10% of all cycle collisions (Schoon, 1996).

5.6.2 Crash protection

Bicycle helmets can reduce the risk of head and brain injuries by between 63% and 88% (Thomas, 1994), (Thompson, 1996; Sosin, 1996). A meta-analysis of studies on the benefits of bicycle helmets indicated that wearing a helmet had an odds-ratio efficacy of 0.40, 0.42, 0.53 and 0.27 for head, brain, facial and fatal injuries, respectively (Attewell, 2001).

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Legislation requiring the use of bicycle helmets has been introduced in several countries, including Australia, New Zealand, Sweden and the United States.

Safer car structures for cyclists Research and development to date in Europe has been aimed primarily at improving vehicle design to protect pedestrians in the event of a crash. There is an urgent need for research into how cars can be made more forgiving for cyclists.

Heavy commercial vehicle side guards: When trucks and cyclists are side by side and the truck turns into the direction of the cyclists, the cyclist is at risk of being run over by the motor vehicle. Side guards close off the open space between the wheels of the truck. While fitment is common in several European countries and there is national regulation, no EU-wide requirement yet exists.

6 Knowledge gaps

As the Swedish government has observed “A *safe system* is achieved when user capabilities, vehicle safety, road design and speed limits all are in harmony. A holistic perspective on road safety is under development and is important when prioritizing research efforts.” (Swedish Government, 2011).

Relatively recent international overviews of research needs for vehicle safety have been carried out. A progress report of recent research undertaken by the EEVC was presented in 2011 (Swedish Government , 2011). A decade earlier, the priorities for EU-wide research in vehicle safety design were identified by the European Transport Safety Council (Hobbs, 2001; ETSC, 2001) and many of these recommendations remain relevant. The International Research Council on the Biomechanics of Impact as conducting a comprehensive review. The Advanced European Passive Safety Network provides a forum for co-operation in vehicle safety research and has produced a roadmap for vehicle safety research.

Current issues include the need for better understanding about the epidemiology of traffic injury in crashes involving vehicles, research into areas of biomechanics, such as the biomechanics of children, soft tissue injury and tolerance limits of different body regions. How can design protect occupants of different shapes and sizes and in different crash conditions? How can crash protection design take account of real world needs rather than meet specific test conditions? How far can crash avoidance approaches contribute to vehicle safety? How does the driver adapt to different vehicle measures? What are the implications of a mixed vehicle fleet with differing capabilities and technologies? How can the vehicle deliver truly integrated approaches to each stage of the crash phase? How can an effective interface between vehicles and between vehicles and roadsides maximise the opportunities for road safety?

A brief general summary of research needs as identified by the international organisations is presented below:

6.1 The epidemiology of road traffic injury

Effective vehicle crash protection depends upon understanding of the distribution, nature and mechanisms of road traffic injury. In particular:

- Better knowledge of the population differences in injury tolerance especially for the head, chest, and abdominal regions is required.
- Analytical research is needed to optimise crashworthiness design across the ranges of crash types, crash severities and populations.
- More realistic test requirements that reflect population variations in injury tolerance must be developed to recognise the tradeoffs between the strong and the vulnerable.
- Better, quantitative assessment measures of the long-term consequences of traffic injury are needed.
- The safety needs of elderly road users need to be evaluated more thoroughly to take account of changing demographics. Baseline information on the physiological changes of the elderly and the identification of injuries of special interest is required. Issues of optimisation will need to be addressed to ensure that protective systems optimised for a younger population are as effective with older groups.
- The slight/serious/fatal categories currently used for injury severity scaling in large databases are inadequate. A simple injury scale is needed that is usable by police and first responders and that is compatible with the AIS currently used in in-depth and hospital-based studies.

6.2 Biomechanical research

Biomechanical research improves understanding of the human body so that better tools can be built to assess the risk of injury. These tools can be physical – crash test dummies –or numerical – computer simulations. The further development of dummies and humanoid models depends upon improving the characterisation of human biomechanical properties at tissue level and at structural level. Future development of injury assessment functions is expected to depend on experimental approaches using dummies to measure the forces to which the body is exposed and simulations to assess the human responses and the specific nature and locations of injury. In particular:

- Better description of the biophysical characteristics of the variety of human structures, components and subsystems that can be injured are needed.
- Better characterization of the dynamic response of these components and structures to external insult are needed as is better characterization of the mechanisms by which these structures undergo mechanical failure
- Better definition and measurement of the limits at which these structures begin to fail is necessary
- Better account needs to be taken of the variability of human beings in terms of age, sex, race, etc. New biomechanical (biofidelity) data especially for the elderly population and for children are fundamental.
- Materials able to simulate the human body in a more realistic way are needed.
- The applicability of current dummies to advanced restraints needs investigation

- The interaction of crash dummies with sensors (occupant monitoring) is a fertile field for research.
- Knowledge of human body response in pre-crash conditions and how that response can be simulated must be developed.

Various proposals have been made for areas of biomechanical research covering child biomechanics, head and brain injury, neck injury, chest and abdominal injury and injury to the upper and lower extremities International Research Council on the Biomechanics of Impact.

6.3 Crash avoidance

A range of promising new crash prevention technologies offer high potential for future casualty reduction, are being applied and require close monitoring to assess their effectiveness in real world crashes. Their success is highly dependent upon proven feasibility, practicability and acceptance and use by road users. Important factors needing further research concern limitations of human adaptation to new systems and the acceptability of the driver to relinquish control over the vehicle. In general, there are no analytical strategies available to ensure that passive and active safety systems are optimised together to maximise the potential casualty reduction. In collision avoidance research, assessment methodology needs to be developed for pre-crash sensing systems in passenger cars for occupant and pedestrian protection and in trucks.

6.4 Crash mitigation and protection

Real-world crashes show a wide variability in terms of the people involved, the characteristics of the vehicles and the crash configuration. To protect all road users systems should not be optimised for one specific crash test, instead they should have versatile and robust designs that together provide the optimum protection for the full crash population. The current use of a small range of crash conditions to specify the performance of cars in crashes opens the possibility that vehicles will be optimised for these tests rather than for the full range of real-world conditions. Research is needed to develop methodologies to engineer systems for maximum benefit, particularly for side-impact protection where safety systems are less developed and where current standards do not offer protection for non-struck-side occupants. Additionally, a wider range of crash types needs to be incorporated into the development process of new cars, and methodologies based on physical or virtual testing are needed to support this. These methods should take account of the natural bio-mechanical variations between individuals as well as the range of vehicle types within national fleets.

6.5 Advanced and integrated technologies

Research programs are underway in several countries towards the further development of in-vehicle car to car and car to roadside communication.

Vehicle to roadside interface Here the challenge is to see how rules, standards and strategies for line markings and road signs could be aligned with modern vehicle system devices to achieve good functionality and safety. Strategies for speed signs have been highlighted as being important for vehicle mounted cameras which provide the driver with information about the speed limit. High quality, consistent lane markings are essential for modern lane departure assistance/warning systems. For example, for vehicle systems depending on lane markings for their performance several issues have been identified as being important. These include the contrast to the road surface, the spacing between the dashed lines, the link up between lanes and exits. All these will have an impact on whether the lane departure system provides efficient driver support aid or will be unavailable for the majority of the road usage. A working partnership between the Swedish Transport Administration and Volvo Car Corporation was established in 2008 towards defining the interfaces and division of responsibilities between vehicles and infrastructure in Sweden (Eugensson et al., 2011).

Pre-crash to post-crash assistance A further key area for research is how a vehicle can restrict and guide the driver into a safe driving envelope through improved speed management, more advanced braking systems and through enhanced crash protection and post crash response.

6.6 Hybrid and electric Vehicles

Electric hybrid and, increasingly, fully electric vehicles are appearing in the vehicle fleet bringing new potential hazards to vehicle occupants and rescue workers such as exposure to corrosive chemicals and toxic fumes and fire following crashes. A number of NCAPs are conducting specific tests into these new risks and hazards and a paper offering recommendations for pre and post -impact procedures has been published in Australia with the cooperation of ANCAP (Paine et al., ESV paper 107).

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