



# Vehicle Safety

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## 1. Vehicle Safety

### Vehicle design and road safety

Improving vehicle safety is a key strategy used in addressing international and national road casualty reduction targets and in achieving a safer road traffic system. Vehicle safety addresses the safety of all road users and currently comprises measures to help avoid a crash (crash avoidance) or reduce injury in the event of a crash (crash protection).

Substantial and evidence-based improvements have been made in the last 15 years and research has identified large scope for enhancing vehicle safety further. The European Commission has stated that If all cars were designed to provide crash protection equivalent to that of the best cars in their class, half of all fatal and disabling injuries could be avoided. There is large future promise of casualty reduction from crash avoidance and active safety technologies if technology development is prioritised to give maximum casualty reduction.

### Vehicle safety policy

Improvements to vehicle safety results from legislation (much of which is now agreed in the European Union and internationally) consumer information, the initiatives of individual manufacturers and product liability considerations. 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; and car industry policies increasingly promote safety as a marketable commodity. Countries active in safety engage in international legislative development work; carry out national research and monitoring of vehicle safety; support the European New Car Assessment Programme; ensure that helmet and restraint usage laws are properly enforced and encourage local car industry to fast track key safety measures

### Key issues for vehicle safety design

- Addressing human limitations: Evidence-based vehicle safety measures need to address human limitations to prevent crashes and reduce injury severity in the event of a crash.
- Car occupants: Car occupants comprise 56% of total EU (15) 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.
- Pedestrians: The survival of pedestrians in traffic depends upon their separation from the high speeds of motor vehicles or, where shared use is common – ensuring that the vehicle impact speed is low enough to prevent severe injury on impact and providing safer car fronts.
- Motorized two-wheeler users 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 bike and the ground. A car is involved in most crashes.
- Cyclists comprise around 5% of road user deaths across EU countries, but as much as 18% in countries where there is a lot of cycling e.g. the Netherlands. Single vehicle crashes are most common. Head injuries are the major cause of death in around 75% of cyclist deaths.
- Minibus and bus occupant injury is a smaller but also a treatable vehicle safety problem.
- Cost benefits and cost-effectiveness: Socio-economic appraisal of vehicle safety measures ensure that reasonable benefits can be derived from new costs. New safety design costs less at the new car design stage than during subsequent stages of production.



## Safety design needs

A range of crash avoidance and crash protection measures is outlined for the protection of cars occupants, pedestrians, motorcyclists, minibuses and bus users

## Knowledge gaps

Effective vehicle safety design result relies 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. A range of research needs is outlined.

## 2. Vehicle design and road safety

### 2.1 What can vehicle design contribute?

Vehicle design is fundamental to a safe traffic system which requires safe interaction between users, vehicles and the road environment. Vehicle design, which takes account of the behavioural and physical limitations of road users, can address a range of risk factors and help to reduce exposure to risk, crash involvement and crash injury severity. To date, vehicle engineering for improved safety 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. Recently, attention in Europe has been given to crash protective design for those outside the vehicle.

Key system risk factors		Human	Vehicles and equipments	Road
Exposure	traffic system use	too early access to driving or riding a motor vehicle	availability of high performance motor vehicles	poor land-use planning, user mix
Pre-crash	crash occurrence	speeding, impairment	poor lighting, braking, handling, speed management	poor road design or layout, absence of speed limits and pedestrian facilities
Crash	injury during the crash	non-use of restraints or helmets	poor crash protective design	absence of forgiving roadside (e.g. crash barriers)
Post-crash	post crash injury	poor access to care	poor evacuation	absence of rescue facility

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 secondary safety or crash protection in vehicles. This accounted for around 15% of the reduction, compared with 11% for drink-drive measures and 6.5% for road safety engineering measures [14].

Major improvements in vehicle safety design have taken place over the last decade in Europe leading to a large reduction in fatal and serious injury risk amongst car occupants. These results are due to a combination of the effects of new European legislative crash protection standards and the impact of new consumer information systems providing objective data on the performance of cars in state of the art crash tests and real crashes.

## 2.2 What role does research play?

Effective vehicle safety design result relies 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. It 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 realisation.

## 2.3 What can vehicle safety deliver in future?

Vehicle safety is identified as a key strategy by the EU towards addressing the EU-wide goal to reduce deaths by 50% by the year 2010.

Considerable room for further improvement has been identified. The European Commission has stated that if all cars were designed to provide crash protection equivalent to that of the best cars in the same class, half of all fatal and disabling injuries could be avoided [European Commission, 2003](#). A range of future needs has been identified by European organisations: the International Research Council of the Biomechanics of Injury [IRCOBI](#), the European Transport Safety Council [\[84\]](#) and the European Enhanced Safety of Vehicles Committee [EEVC Status Report 2005](#) and the Passive Safety Network Roadmap.

## 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.

#### 3.1.1 Who regulates vehicle safety?

Vehicle safety in European Union countries is regulated mainly by international standards and regulation devised by the European Union (EU) and the United Nations Economic Commission for Europe (UN ECE).

With the main objective of removing trade barriers, international harmonisation in vehicle standards by the UN ECE started in 1958 supervised by the Inland Transport Committee's Working Party on the Construction of Vehicles [\[149\]](#) in Geneva. This provided the framework for a voluntary type approval system based on UN ECE Regulations.

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 EU 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). The process of introducing such a system for trucks and buses is currently underway. All harmonized vehicle standards are supposed to provide a high level of consumer protection (Treaty Article 75(1) as amended by the Treaty of Amsterdam). European Union derived standards are mandatory for all the members of the European Union if they fall within Whole Vehicle EU Type Approval. In other circumstances, European countries can adhere to Economic Commission for Europe (ECE) of the United



Nations either voluntarily or mandatorily if a country decides to incorporate the regulation into national regulation.

The accession of the EC to the revised 1958 Agreement in 1998 is giving further impetus to work on global technical regulations. While such global work will increase the convenience of manufacture and removal of barriers to trade, it reduces opportunities for current full Parliamentary scrutiny and involvement at regional (EU) and national levels. As noted by the World Health Organisation and World Bank, vehicle safety standardization at the regional and national levels, taking into account as it does local conditions, can often produce faster action than a similar process at the international level [World Report on Road Traffic Injury Prevention](#).

Legislative work at EU level is led by [European Commission's Directorate of Enterprise and Industry](#). 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 and Society's Esafety and Intelligent Car initiatives.

### 3.1.2 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 and sub-system tests for pedestrian protection.

### 3.1.3 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 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 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 is taking place within [IHRA](#).

## 3.2 Consumer information

### 3.2.1 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 legislative norms.

In recent years, safety is increasingly marketed 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.

### 3.2.2 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. For example, the European New Car Assessment Programme ([EuroNCAP](#)) provides star ratings of the performance of different cars in state of the art frontal impact tests using an offset deformable barrier, a side impact test and pedestrian protection sub-system tests based on those devised by the European Enhanced Safety of Vehicles Committee. The European programme also uses visual inspection in addition to crash testing in determining the safety rating assessment. Monitoring shows that EuroNCAP 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 [110] [76]. The European Commission believes that EuroNCAP has become the single most important mechanism for achieving advances in vehicle safety. Car manufacturers use EuroNCAP star ratings in their advertising e.g. Renault. [Example of a EuroNCAP crashtest](#)

### 3.2.3 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. Examples of retrospective systems are the Folksam Safety Rating System (Sweden); The VALT Safety Rating System (Finland); The Department for Transport Rating System (UK). Although the general principle of this approach is the same for all systems, there are many differences in the exact methodology.

## 3.3 Car industry policies

While the car industry tends to speak with one voice 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 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 pledging to supply progressively more powered two-wheelers equipped with advanced braking systems to the market. Car companies come together within the European Council for Automotive R&D - EUCAR to coordinate proposals for EU funded research.

### 3.4 Product liability

Globally, there is much variation in the provision of vehicle safety equipment from region to region. 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.

### 3.5 What can European countries do?

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

- Engaging fully in international legislative development work
- Carrying out national research and monitoring of vehicle safety measures
- Supporting and joining the European New Car Assessment Programme
- Encouraging financial incentives for the use of protective equipment
- Ensuring that protective equipment usage laws are properly enforced
- Encouraging local car industry to fast track key safety measures

## 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.

The energy of a crash is related to the square of the velocity, so small increases in speed produce major increases in the risk of injury. The human tolerance to injury of a pedestrian hit by even the best-designed car will be exceeded if the vehicle is travelling at over 30km/h [145]. Studies show that pedestrians have a 90% chance of surviving a car crash at 30km/h or below, but less than a 50% chance of surviving an impact at 45 km/h [120]. Research shows that 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 [5]. 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 [145].





It has been estimated that the Swedish traffic system as a whole probably tolerates speeds of between 30 and 60 km/h, allows use on most roads between 50 and 100km/h (through road speed limits) and possibilities of use (by engine capability) to more than 200 km/h [147]. Against this background, in the Swedish Vision Zero strategy, the amount of biomechanical energy to which people can be exposed without sustaining serious injury is now promoted as the basic road and vehicle design parameter. Sweden is re-shaping its road infrastructure and encouraging appropriate vehicle crash protection accordingly. A similar process is also underway in the Netherlands within the Dutch Sustainable Safety policy.

## 4.2 What are main crash injury problems?

**Car occupants** looking at fatality numbers, car occupants are the largest single casualty group. They comprise 56% of total EU (15) deaths with the majority of car occupant deaths occurring on non-motorway rural roads. 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 [84]. Determinants of injury severity include:

- 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 safety standards

**Pedestrians:** Research in Europe suggests that the majority of all fatally and seriously injured pedestrians are hit by the front of a car. Lower-limb injury is, in general, the most common form of pedestrian injury, while head injury is responsible for most pedestrian fatalities [32]. 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 World Report on Road Traffic Injury Prevention.

**Motorized two-wheeler users** tend to 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 World Report on Road Traffic Injury Prevention, 2004. The European Enhanced Vehicle-safety Committee EEVC, 1994 showed 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. 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 [93].

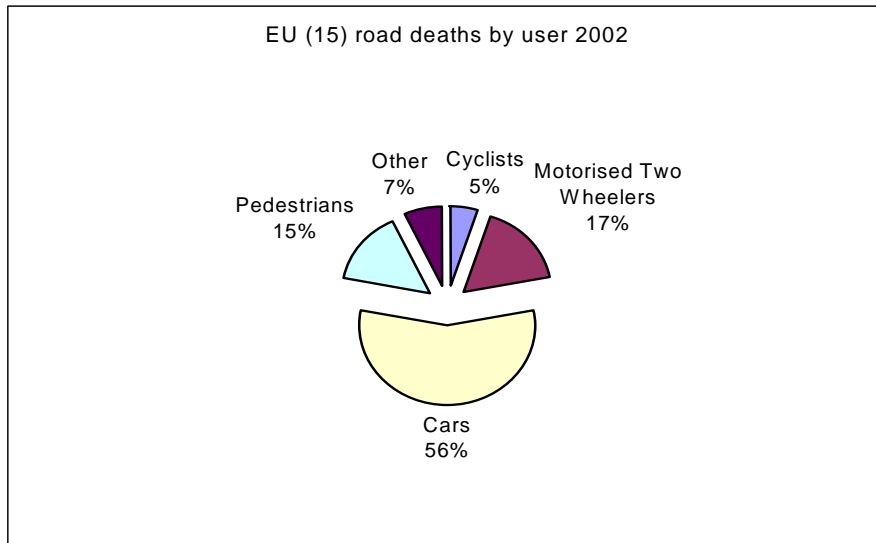


Figure 1: Source: Care 2002

**Cyclists** comprise around 5% of road user deaths across EU countries, but as much as 18% in the Netherlands where, with the exception of Denmark, use is substantially higher than in other countries.

Country	kms/year
Denmark	893
Netherlands	853
Germany	287
Ireland	181
United Kingdom	76
Spain	20

Table 1: source RAI, 1998

There is much 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. Typically, these result from rider stunts (27%), or feet caught between the vehicle spokes (18%), as a result of a defect in bicycle design or maintenance (13%) or due to poor road surface (8%). 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 and bus occupant** injury is a smaller but also a treatable vehicle safety problem.

### 4.3 Crash avoidance and crash protection

Vehicle engineering improvements for safety have been achieved 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.



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

Crash avoidance or primary safety

Devices to avoid a crash e.g. daytime running lights, electronic stability control, intelligent speed adaptation, alcolocks

The term active safety is often used to mean crash avoidance but care should be taken in its use since it can also mean deployable systems such as crash-protective pop-up bonnets for pedestrian protection

New technologies are emerging which can help the vehicle to play its part in crash prevention. Some technologies such as electronic stability control, while not yet universally fitted, are already showing substantial road safety returns. Other effective and available road safety technologies e.g. intelligent speed adaptation will require public and political support before universal adoption. Much work is being carried out on promising technologies such as collision avoidance systems but their usefulness in addressing high-risk crash scenarios typical of most European roads is yet to be determined [118].

For the short to medium term, therefore, preventing or reducing death and serious injury in the event of a crash continues to be the major role for vehicle safety improvements. As stated in the World Report on Road Traffic Injury Prevention “a traffic system better adapted to the physical vulnerabilities of its users needs to be created with the use of more crash protective vehicles and roadsides”.

#### 4.4 Cost-benefit and cost-effectiveness

As in other areas of road safety policy, socio-economic appraisals of vehicle safety measures need to be 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

Two examples of vehicle safety measures where the benefits exceed the costs are the mandatory installation of seat belt reminders and daytime running lights (DRL) to cars. One analysis shows that the introduction of DRL 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. An audible seat belt reminder is a device that gives an audible warning whenever a seat is occupied by an unrestrained occupant. Taking into account the injury and fatality reducing potential injuries, it was estimated that the value of benefits of mandating audible seat belt reminders for the front seats of cars in the EU amounts to 66,043 million Euro. The value of the costs amounts to 11,146 million Euro, giving a cost benefit ratio of 1:6 [74].

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 complicated systems.



## 5. Safety design needs

### 5.1 Cars

#### 5.1.1 Crash avoidance measures

While crash avoidance is the logical first objective for vehicle engineering for safety, vehicle crash avoidance measures are, in general, in their infancy in terms of development and practical application. In several cases, they hold much future promise. In other cases, technological solutions either address relatively minor road safety problems, are of unknown effectiveness or the technological application has still to be proven practicable. The focus of this section is on the former, although some coverage is given to measures in the latter category which may be of current interest.

#### 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.

The more the system intervenes, the more significant are the benefits. Estimates by the Institute for Transport Studies at the University of Leeds 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% [17]. A study in the Netherlands showed that ISA could reduce the number of hospital admissions by 15% and the number of deaths by 21% [151].

Different trials using informative and supportive systems across Europe have shown that approximately 60–75% of users would accept ISA in their own cars. A 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 Road Administration (SRA) plans to equip its whole fleet with ISA systems and experimental studies are underway or have been carried out in Norway, the Netherlands and the UK. There have been two major European-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 harmonises the in-vehicle speed alert concept definition and investigates the first priority issues to be



addressed at the European level, such as the collection, maintenance and certification of speed.

### **Black boxes**

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 15 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, approximately 60,000 vehicles have been equipped with event recorders for research purposes since 1995.

An EC project [VERONICA](#) is collating information to assist the European Commission on the feasibility of black boxes in European vehicles. Three important questions related to black box are the standardisation of procedure and tool 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.

### **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. At present nine European countries have compulsory DRL for cars and the European Commission is considering proposals for an EU-wide requirement. There are various options for DRL introduction, 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 a Dutch review [\[98\]](#).

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 [\[36\]](#). 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. A Dutch review found that DRL reduced multi-party daytime crashes by around 12% and deaths and injured victims by 25% and 20% respectively [\[98\]](#). Motorized 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 is likely to be offset by the benefits to motorcyclists of increased car visibility [\[98\]](#) [\[124\]](#) For further information, see SWOV Fact sheet.

#### **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 [\[106\]](#) 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.

### **Braking and handling measures**

#### **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%) [36]. 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 [4]. The results also may also be partly due to lack of knowledge or incorrect assumptions amongst car drivers about how ABS brakes actually function [36]. 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 [16].

#### **Brake Assist**

Brake Assist in emergency situations is a technology which comes as standard on some new cars and is being proposed by the car industry as part of an EU 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, BrakeAssist 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 various prospective estimates have been made, the casualty reduction effect of Brake Assist has yet to be scientifically established [82]. 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. Unlike for passive safety there is no standard method to assess the safety performances of these devices, which makes it difficult to estimate their potential benefits; moreover, under the same name very different systems can be found, as each manufacturer has its own specification.

#### **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 introduced onto the luxury large car market and are recommended by the European New Car Assessment Programme EuroNCAP ESP.

Evaluation studies have shown that ESC can lead to substantial reductions in crashes involving large, luxury cars. 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 [146]. In Japan, a study showed that electronic stability reduced crash involvement by 30-35% [2]. In Germany, one study indicated a similar reduction while another showed a reduction in “loss-of-control” crashes from 21% to 12% [13]. Whether or not the same benefits from ESC will be derived from smaller cars will need to be studied.

### **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.

Alcohol interlock systems are automatic control systems which are designed to prevent driving with excess alcohol by requiring the driver to blow into an in-car breathalyser before starting the ignition. The alcohol interlock can be set at different levels. These 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. 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. More than 5000 company cars in Sweden are today equipped with alcohol interlocks and the number is rapidly growing. 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 interlocks [103].

### **Collision Avoidance Systems**

Research on collision warning and collision avoidance systems is taking place in Japan, the United States and in the European Union within the European Commission’s an Esafety programme. Very large estimates of the safety potential of such systems have been claimed following laboratory studies, but the range of technical and behavioural 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. Various systems are under development:

- Forward Collision Warning
- Reverse Collision Warning System
- Adaptive Cruise Control
- Lane-Keeping Devices

### **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 [118] [129].



## 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.



Frontal impact

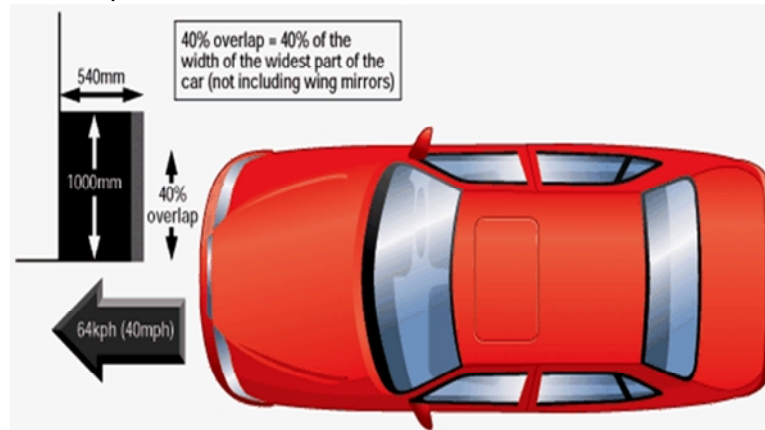


Figure 2

The current EU legislative test is a 40% offset deformable barrier test conducted at 56km/h. The current EuroNCAP test is conducted at 64km/h. Various suggestions have been made for improvements in the legislative test EEVC. 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 (see World Report on Road Traffic Injury Prevention).

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.

Side impact

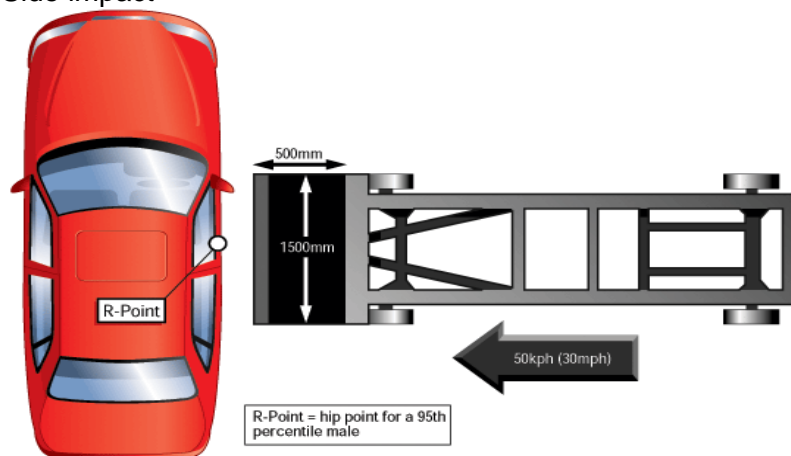


Figure 3



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, EuroNCAP 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 EEVC.

### 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;
- 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 [102].
- 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 [99]. 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 [119] [96]. Research into the injury mechanisms of neck injury have shown that the dynamic behaviour of seat backs is one of the parameters most influencing neck injury risks [102].
- 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 but not mandated [30].

Systems aimed at preventing neck injuries in rear impacts have been presented in recent years and used in several car models [111] [158]. 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 [101]. 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%. [40].

### 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 EEVC [84] [121].

Car to car compatibility

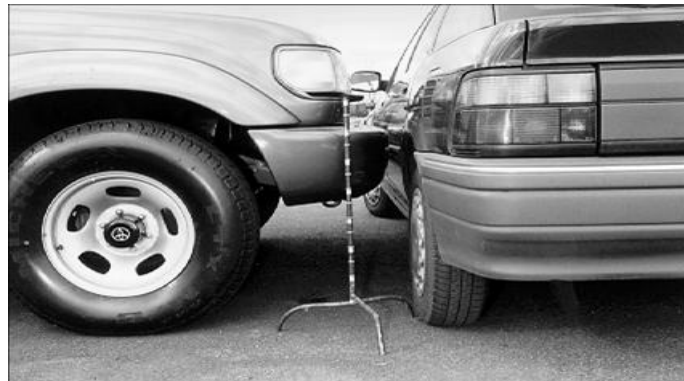


Figure 4

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/underide 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 VC Compat is coordinating international research.

Car to roadside objects

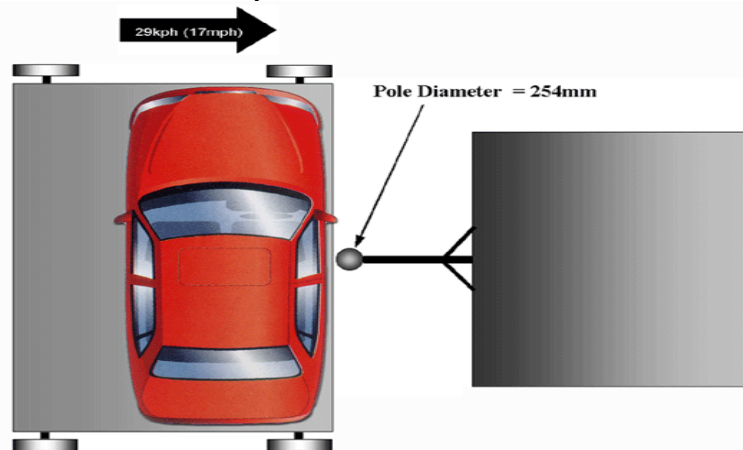


Figure 5

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 is practised in [EuroNCAP](#). Coordination is required between the design of cars and crash protective or 'forgiving' safety barriers.

Car to pedestrian

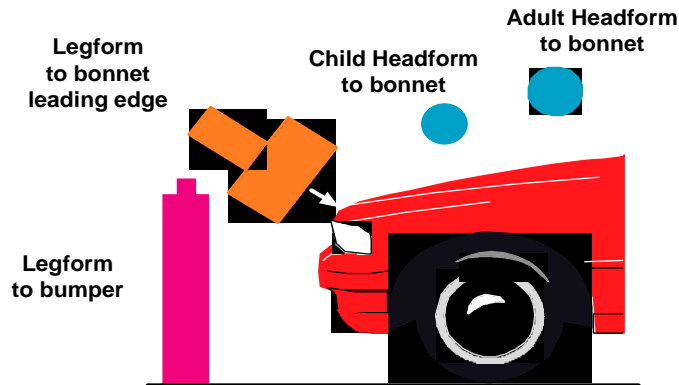


Figure 6

Most fatally injured pedestrians are hit by the fronts of cars. Four sub system tests have been devised by [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.

Take up of these challenging tests could avoid 20% of deaths and serious injuries to vulnerable road users in EU countries annually [European Commission, 2003](#). Recent minor amendments to the EEVC tests have been proposed following a EC funded feasibility study [107].

**Bullbars:** The European Commission has proposed action to prevent the installation of aggressive bull bars on car fronts.

Car to HGV



Figure 7

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 lorries 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% [37].



Figure 8

### Restraint

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 10 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 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. See World Report on Road Traffic Injury Prevention

### Seat belts, seat belt reminders, smart restraint systems

Seat belts When used, seat-belts reduce the risk of serious and fatal injury by between 40% and 65% (For overview of studies see World Report on Road Traffic Injury Prevention). 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 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. EuroNCAP has developed a seat belt reminder specification and encourages their installation. Of all vehicles tested by EuroNCAP since 2003, 72% have seat-belt reminders. It is estimated in Sweden that reminders in all cars could contribute to a



reduction of some 20% in car occupant deaths. They provide a cheap alternative to police enforcement with benefit to cost ratio of 6:1

### Frontal airbags

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 USA.

Effectiveness: Driver and front-seat passenger airbags reduce the risk of fatal injury by 68% when combined with seat-belt use [23]. 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% [77].

Problems: Some of the protective measures provided by airbags that have been designed for adults in a normal seating position will 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 [114] [160].

### Smart restraint systems

Smart restraint systems are vehicle restraint components or systems that adapt their geometry, performance or behaviour to suit varying impact types and/or occupants and occupant positions. None of the systems today adapts 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 objective of EC PRISM project is 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.

**Effectiveness:** 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% [148] [156]. 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% [116].

**Problems:** 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. EuroNCAP 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.

EuroNCAP has developed a child safety protection rating to encourage improve 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 [99]. 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 [101].

A headrest located less than 10cm from the head has proved more beneficial than a distance of more than 10cm [119] [96]. 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 [80] are used by the insurance industry around the world [142]

## Car occupant interior head, knee and lower leg protection

### Head injury

The head is the highest priority for protection. 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 headform test has been proposed as a potential tool by European vehicle safety experts [84]. The EuroNCAP pole test, however, 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 fascia. Sources of knee injury are included in the EuroNCAP 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 EuroNCAP 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.

Automatic Crash Notification (eCall) which is under development 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 [155].

## 5.2 Motorcycles

Motorcycle use is the most dangerous mode of road travel. More than 6500 motorised two wheeler users die each year in the EU (15) and the risk of death for motorcyclists is 20 times that of car occupants. 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, 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 motorized two-wheeler traffic by giving advantages to motorized 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) has 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, despite even when these machines are ridden by more experienced riders [15].

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 [129] [36]. 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 [128].



## 5.2.2 Crash avoidance 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 to see motorcycles in traffic. The use of daytime running lights (generally lowbeam) 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.

European standards for day time running lamps for motorcycles have been developed. New motorcycles are fitted 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 [25].

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% [12]. 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 [36].

### Anti-lock Braking Systems

The aggressive front wheel brake systems in use today are important to keep the enhanced driving performance in check. However, in the case of emergency braking, they can cause the front wheel to block and the driver to fall off the motorcycle. Anti-lock braking can prevent the front wheels of a motorcycle from locking and help to maintain stability. One prospective estimate suggests that ABS might reduce the number of crash victims by at least 10% [137]. Typically, these systems are available on more expensive models of motorcycle.

As part of its commitment to the European Road Safety Charter Honda has pledged to increase the installation of advanced braking systems (Advanced braking systems are brake systems in which either an Anti-lock Brake System (ABS) and/or a Combined (or Linked) Brake System (CBS) are present) so that by 2007, the majority of its powered two wheeler models will be equipped (either as standard equipment or as optional equipment, depending on the model) with Honda's 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. See EEVC Motorcycle Safety Review. Helmets can reduce fatal injury by around 44%.

Injury severity	Percentage change in number of injuries		
	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)

Table 2: Injury-reducing effects of helmets for moped-riders and motorcyclists  
Elvik and Vaa, 2004)

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 [36]. 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 [132].

Economic evaluations of a mandatory helmet wearing law indicate that the use of helmets for moped riders and motorcyclists has a benefit-cost ratio of around 17 (□ 6) (Norway), a result confirmed by American cost-benefit analyses [36].

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. 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 [33]. 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 [33].

#### 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 [81]. 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.

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. See Honda Motorcycle Airbag System. 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

### 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 [87]. Studies show different possibilities for optimising leg protection [21] [20]. Studies with leg protective airbags have also been carried out [136] [135]. Nairn [115] 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. Further work in this area has been recommended to ensure that leg protection does not change rider trajectory to result in negative side effects [84].

### 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 (Elliot et al, 2003). 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 degloving 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 [33].

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.

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 goods vehicles

Heavy 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 years, the safety of heavy goods vehicles continues to be strictly regulated in the best performing countries in road safety and action by HGV companies encouraged. Mandatory regulation at EU level has been limited to date and though technical standards exist they tend to be optional. However, discussion is underway to bring trucks and buses into the EU Whole Vehicle Type Approval System alongside cars and motorcycles.

### 5.3.1 Crash avoidance 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 [35].

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) EC Directive 2002/85.

### **Vision and conspicuity**

#### **Blind spot mirrors**

Every year a large number of people, mostly vulnerable road users, are killed or severely injured in road traffic because of trucks turning right. 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. The European Commission estimates that around 500 deaths are caused annually on EU roads.

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 lorries. The Directive was further amended Directive 2005/27/EC to extend the installation of wide angle mirrors to more vehicle types.

A legal obligation already exists in Belgium and the Netherlands for retrofitting existing trucks with blind spot mirrors or cameras. In its Road Safety Action Programme the European Commission announced that, in connection with the directive on blind spot mirrors for new vehicles, it would also assess the benefits and cost from a directive for the retrofitting of such systems to existing vehicles. This study has been finished. It estimates the benefits to be approximately four times higher than the costs for the retrofitting of lateral blind spot mirrors to existing heavy goods vehicles. See an update of European Union activity in this area.

**Retro-reflective markings:** In depth crash investigations show that nearly 5% of severe truck accidents can be traced back to 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 [105]. Currently, the European standard ECE-Regulation 104 (January 1998) which refers to the conspicuity of long and heavy vehicles and their trailers is optional.

### **5.3.2 Braking and handling**

Electronic stability devices in loss of control crashes due to speed or steering behaviour and driving through narrow curves or during evasive movements, the truck or trailer can slide or jack-knife. Research has indicated that Electronic Stability devices for trucks could improve the safety during the driving through curves by about 40 % [153]. Some newer full-size trucks offer electronic stability control but no European standard yet exists.

**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. Europe is working on the drawing up of requirements for the rollover stability and a dynamic rollover test for new lorries.



### 5.3.3 Impairment by alcohol and fatigue

Alcohol interlock systems are automatic control systems which are designed to prevent driving with excess alcohol by requiring the driver to blow into an in-car breathalyser before starting the ignition. Sweden has experimented widely with Alcolocks and commercial vehicles. In a trial running from 1999 to 2002 in Sweden, 300 Alcolocks were installed in commercial passenger and goods transport. Manufacturers such as Volvo and Toyota have also started offering installation of alcohol interlocks in trucks as a dealership option. See From 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 will have to be fitted with alcohol interlocks. This requirement is already part of the procurement criteria.

There has been no evaluation of the impact that alcohol interlocks used in commercial transport have on road safety, but experience shows that most companies were successful in stopping drivers who attempted to drive while over the limit. In Sweden rehabilitation programmes using alcohol interlocks are also used in commercial vehicles and the number of alcohol interlocks installed in such vehicles is higher than the number of interlocks installed in drink driving offenders' cars. 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 [41].

Digital tachographs 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 [112] and a factor in 20-30% of commercial road transport crashes in Europe and the United States [42] [27]. The Commission has moved to strengthen driving and working time rules and enforcement in recent years.

Council Regulation (EC) 2135/98, which amends Regulation (EEC) 3821/85, introduces a new generation of fully digital tachographs. The digital tachograph is a more secure and accurate recording and storage device than the present equipment. The new device will record all the vehicle's activities, for example distance, speed and driving times and rest periods of the driver. The system will include a printer, for use in road side inspections and the driver will be given a card incorporating a microchip, which he must insert into the tachograph when he takes control of the vehicle. This personal driver card will ensure that inspections remain simple. 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 See European Commission overview.

### 5.3.4 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. 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 [105].

### **Front underrun protection**

Due to the size and mass of heavy vehicles, the problem of compatibility with other road users is a serious 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% [100]. 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% [37]. Energy absorbing systems are available from all truck manufacturers as an optional device but almost none are sold. A test procedure for legislative action is under development VC Compat.

### **Rear underrun protection**

Council Directive 70/221/EEC mandates 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 kph, 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 and the test forces need to be increased. 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% [97] [104]. 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 light goods vehicle crashes. In-depth work has been carried out in Britain [109] and Germany [117] 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 that 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. Further research is required to derive a 'best outcome' scenario to guide future design.

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.

The implications of introducing a regulatory compliance crash test for LGVs.

The available data do not appear to support a particular case for either an offset or fully distributed frontal crash-test requirement since both crash types occur with roughly equal frequencies (36% and 37%) and with similar injury outcomes. Any regulatory crash-testing option needs to take strong account of LGV to car compatibility needs.

## 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 [113] 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.



## 5.5.1 Crash avoidance

### Digital tachographs

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 [112] and a factor in 20-30% of commercial road transport crashes in Europe and the United States [42] [27]. The Commission has moved to strengthen driving and working time rules and enforcement in recent years.

Council Regulation (EC) 2135/98, which amends Regulation (EEC) 3821/85, introduces a new generation of fully digital tachographs. The digital tachograph is a more secure and accurate recording and storage device than the present equipment. The new device will record all the vehicle's activities, for example distance, speed and driving times and rest periods of the driver. The system will include a printer, for use in road side inspections and the driver will be given a card incorporating a microchip, which he must insert into the tachograph when he takes control of the vehicle. This personal driver card will ensure that inspections remain simple. 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 European Commission overview.

## 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 [113].

### 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 [113]. 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 have been proposed [113].

### 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 [84].

### 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 [108]. 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

Cycles 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 vehicle design which is covered largely by national regulation.

The role of reflectors and better 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 [131]. 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 [3].

The role of better 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 as a sudden crash or brake failure causes 10% of all cycle collisions [131].

### 5.6.2 Crash protection

Can bicycle helmets save lives?

Bicycle helmets can reduce the risk of head and brain injuries by between 63% and 88% [143] [144] [133]. 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 [9].

Legislation requiring the use of bicycle helmets has been introduced in several countries, including Australia, New Zealand, Sweden and the United States. In countries which do not require the use of helmets by law, the wearing rate is normally less than 10%. Monitoring shows that rates of helmet use tend to be higher among younger children, as opposed to teenagers and adults.

Can cars be made more forgiving?

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.

Can side guards on trucks help?

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

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 2005 and by the EU. In 2001 the priorities for EU-wide research in vehicle safety design were identified by the European Transport Safety Council [84] [42]. The International Research Council on the Biomechanics of Impact is 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? A brief summary of research needs as identified by the international organisations is presented below:



## 6.1 The epidemiology of traffic injury

Effective vehicle crash protection depends upon understanding of the distribution, nature and mechanisms of 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 and are being applied. Their success however, are 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 promising areas, such as alcohol interlock devices, seat belt reminders and intelligent speed adaptation, research is needed to develop international specifications. 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. Specifications need to be developed for on-board crash recorders for all motor vehicles as well as for GPS based warning of crashes.

### 6.4 Crash 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. 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.

- Car occupants
- Motorcyclists
- Cyclists
- Other road users

## 7. Appendix

### 7.1 What can European countries do?

#### 7.1.1 Engage fully in international legislative development work

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.

#### 7.1.2 Provide technical support

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 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.

#### 7.1.3 Carry out national research and monitoring of vehicle safety measures

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. European protocols for in depth research have been following the EU-wide projects STAIRS and PENDANT.

#### 7.1.4 Support and join the European New Car Assessment Programme

Various 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 Europe NCAP results. In Sweden, the National Road Administration promotes an in-house travel policy which requires that all cars used in official business have at least a 4\* safety rating.

[Example of a EuroNCAP crashtest](#)

#### 7.1.5 Encourage 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:  
Passenger cars: side airbags, anti-whiplash head rest system, navigation devices and for Motorcycles, ABS and CBS (Combined Brake System).

#### 7.1.6 Ensure that protective equipment usage laws are properly enforced

Clearly protective equipment such as seat belts and child restraints are of little value unless they are used. The European Commission proposed on 6th April 2004 a package of



measures aiming at improving road safety through a better enforcement of road safety rules. In addition to recommending the setting up a national enforcement plan, the Commission recommended in relation to seat belts to:

Ensure that intensive enforcement actions concerning the non-use of seat belts with a duration of at least two weeks take place at least three times a year, in places where non-use occurs regularly and where there is an increased risk of accidents, and ensure that the use of seat belts is enforced in every individual case where non-use is observed and the car is being stopped; these enforcement actions may take place in combination with other traffic enforcement actions, such as those concerning speeding and drink-driving.

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.

Encourage local car industry to fast track key safety measures

The Swedish National Roads Administration has within the Vision Zero policy been 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 now 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.

### 7.1.7 Crash avoidance: collision avoidance systems

- 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. The technical and operational feasibility of such systems has still to be demonstrated. Most existing systems are warning only systems.





## 8. Knowledge gaps

### 8.1 Car occupants

#### Frontal and oblique impact

- How can versatile structures for the range of real-world conditions be designed?
- How can new structures be designed to respond to low mass and improved fuel economy from environmental demands?
- Criteria and instrumentation for frontal impact injury to the abdomen and knees
- How can front and side-impact compatibility for car-to-vehicle (all sizes) and car-to-roadside object impacts (e.g., trees, poles, guardrails, median dividers) be improved?
- How can adaptive and deployable structures to improve energy management be developed?
- How can intrusion in real-world crashes, particularly in the footwell region, be reduced further?

#### Side impact

- How can protection in side impacts at higher severities and for non-struck side occupants be achieved?
- How can the sensing of side impacts be improved to permit side airbags to be deployed more effectively?
- Are current restraint systems such as side-curtain airbags effective in preventing head injury to occupants of a car when struck by an SUV or pole?
- What are the causes of far-side occupant injuries, how well are they represented by existing dummies and how can the injuries be prevented?
- How do current front bumper standards and low speed crash repair cost tests affect bullet car aggressivity in side impacts?
- How can structures be improved to benefit compatibility in car-to-car or car-to-SUV side impacts?

#### Restraint systems

- Methods need to be developed to provide interior restraint systems which are sensitive to impact severity, occupant sitting posture, occupant size and susceptibility to injury;
- Development of a legislative specification for smart audible seat belt warning devices
- A reduction in “whiplash” associated disorder injury should be sought through improvements in seat belts and airbags;
- assessment of the potentials of pre-crash sensing technology.
- development of integrated child seats
- new technologies to encourage seat belt usage, particularly in rear seats, by improving comfort, spool in and convenience
- improved seat belt and airbag performance in oblique crashes

#### Rear impacts

- Major research questions on rear impact safety concern the nature and biomechanics of “whiplash” injury.
- Additional research is needed on the relationship between rear structure design, rear impact crash pulses and “whiplash” injury risk.



- Monitoring of the effectiveness of existing head restraints is needed to support further design improvements.
- The integrity of fuel systems in rear crashes should be monitored and improved.

## Rollovers

The primary means of improving rollover protection is increased levels of seat belt use. Improved restraints that reduce partial ejection and interior head contact would also be beneficial. Further research into improved roof strength and the application of laminated glass in side windows and sunroofs is needed.

## 8.2 Motorcyclists

- Further research on the relative benefits of leg protectors should be conducted.
- Further improvements in helmet design are needed to ensure that protection is optimised for the full range of real-world crash conditions and that tropical designs still offer the maximum protection in all European countries and worldwide.
- The importance of rotational loading and helmet design needs to be further clarified although there are strong suspicions that they play an important role in injuries to helmeted riders. Moped and scooter riders may be subject to different head impact conditions and there is a need to ensure that helmets offer optimised protection for the full range of crash conditions of these special types of cycle as well.
- Further improvements in rider protection are dependent on a satisfactory dummy being available. The rider dummy is only partially validated and requires further development before it can be used to assess the effectiveness of modern technologies in mitigating injuries. Field accident data and biomechanical studies are required to properly validate these dummies and finite element models are needed to improve injury prevention technologies. These dummies also require improved biomechanical knowledge concerning the relevance of car occupant-derived injury parameters to the injuries sustained by motorcycle riders.
- The changing distribution of rider age groups in many motorised countries may have implications for rider protection. Further field accident data are needed to clarify these issues.

## 8.3 Cyclists

- A fuller assessment of the protection offered by helmets in real-world collisions is needed to determine how helmet design could be improved.
- A better understanding of cyclist kinematics and interaction with all vehicle fronts, aided by improved modelling techniques, is needed to properly evaluate front-end aggressivity.
- Further accident data analysis is needed to evaluate the travel speed of the cycle, especially the influence on head trajectory and the role of injuries sustained from interaction with Conflicts and synergy with pedestrian impact standards need investigation.

## 8.4 Pedestrians

Although improvements in pedestrian protection are expected to derive from the recent directive in Europe, there are still several areas where further research is needed.

- Detailed accident studies are required to monitor the introduction of the EC Directive and to develop an understanding of pre-crash and crash events.



- There is still the need to understand the interaction between vulnerable road users and the front structures of vehicles with regard to secondary road impacts. More knowledge is required on the effect of modern front-end shape and on the biomechanics of the event so as to support developments in methods to control the impact with the road.
- Biomechanics of pedestrian impacts with trucks and buses needs much greater attention. This work should aim at developing bus/truck-pedestrian impact standards by 2010
- There is a need for an improved understanding of the relation between bumper height and knee-joint injuries. The implications for injuries in one body region, when loads are applied to another region, need to be assessed, particularly in relation to subsystem tests. Improved finite element dummy models will enable new research to be conducted that may address these issues.

There is still the need to improve knowledge on the biomechanics of pedestrian protection. Issues concerning long-term head injury sequelae (chronic headaches, behavioural effects) from impacts at <1,000 HIC need to be addressed.

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