Powered Two Wheelers

Please refer to this document as: DaCoTA (2012) Powered Two Wheelers, Deliverable 4.8n of the EC FP7 project DaCoTA

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

Contents

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

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

1 Overview

There are two different types of powered two wheelers (PTWs):

- mopeds with 50cc and restricted top speed;
- motorcycles.

Use and safety of PTWs

With two wheels in line, minimal bodywork and high power to weight ratio, PTWs are an economical means of transport. Riding a PTW gives a sensation which is attractive to some groups of riders. However, riding a PTW is much more dangerous than using another motor vehicle.

PTWs are more popular in southern European countries. Greece has the highest ownership rate with 150 mopeds and 100 motorcycles per 1000 inhabitants. In most countries the number of mopeds and fatalities is decreasing, although at different rates, or has stabilised. The majority of moped fatalities occur at age groups under 25 years in some countries, and at age groups 25 years in other countries. Trends for numbers of motorcycles are quite different. With the exception of middle European countries, almost all countries have experienced an increase in number of motorcycles, again at various rates. The increase is greater for older motorcycle riders. Middle European countries show a continuing downward trend in the number of motorcycles registered. In most countries the proportion of motorcycle fatalities among riders aged 25 years and older is greater.

Motorcycle and moped fatalities accounted for 16% of the total number of road deaths in 2009 in the EU-24 countries. More specifically, in 2009, 1,209 riders (drivers and passengers) of mopeds and 4,905 riders of motorcycles were killed in the EU-18 countries in traffic crashes, 15% less than the number in 2008 in the same countries for mopeds and 1% less 2008 for motorcycles. Motorcycles are the only mode of transport for which the number of fatalities has increased over the period 2000-2008 and for the last two years there was only a slight decrease compared to 2000.

PTW collision characteristics and injury mechanisms

Studies of moped and motorcycle crashes find a large proportion of collisions occurring when a car driver pulls out unexpectedly, indicating problems with the perception of PTWs. These problems are both physical, due to the small size of the PTW, and psychological: the presence and behaviour of PTWs is not expected by car drivers and sometimes not given enough attention by them. Some PTW riders contribute to the problems by speeding. A partial solution to the perceptual problems for both moped and motorcycle is the use of headlights during daytime, the wearing of fluorescent/retroflective clothing, as well as better speed management.

Contributory factors in crashes

Age and experience are the main risk factors relating to the PTW rider. Young PTW riders have much higher crash rates than older ones, even if corrected for lack of experience. The injury crash rates of middle-aged PTW riders are still many times higher than for car drivers of the same age. Different types of experience with a PTW (years of riding, recent or frequent riding, familiarity with a specific motorcycle and familiarity with specific conditions) all contribute to a lower crash rate to some extent. Riding conditions, rider motivation and riding style contribute to crashes as well.

Mopeds, with their small engine and low top speed, have lower fatality rates than motorcycles but higher crash rates when less severe injuries are included. Little is known about the crash rates for 125cc motorcycles , which is unfortunate because some countries have a low minimum age limit of 16 years for these vehicles and/or allow access with only a car licence. Sports motorcycles have been found to have higher crash rates than other types of motorcycle. This is possibly the consequence of the riding style of the riders who choose this type of motorcycle, a riding style which includes speeding. Power to weight ratio is probably a greater influence on crash rates than cubic capacity.

Overall, motorcyclists ride at higher speeds than cars and PTW crashes usually occur at higher speeds than cars. Speeding appears to be a bigger problem for PTW crashes, compared to other modes. PTWs may be difficult to control under certain conditions such as poor road surface or where small objects are found in the road.

Crash prevention and injury protection

There are a number of measures that can make riding a PTW safer. These can focus on reducing the number of crashes occurring or improving injury protection when crashes do occur. However, even if these measures were used to their full potential the crash rates of PTWs would still be much higher than for driving a car. Further reductions in number of PTW crashes could be made by restricting access to the licensing system to a higher age limit, improvement of training and testing, lower power to weight ratios and restricting top speed. These measures are unlikely to be popular with present user groups or the PTW industry. Discouraging or restricting the use of PTWs may be more acceptable if alternatives are made more attractive. The bicycle, public transport or cars do not seem to be alternatives to the present use of PTWs. (Electric) power assisted bicycles and tilting three wheelers could become acceptable alternatives in the near future for some existing groups of PTW users.

PTWs provide little protection against injuries in the case of a crash. Injuries to the legs are frequent, but injuries to the head are more severe even when wearing a helmet. Crash studies show that head injuries would have been much more frequent if helmets had not been worn. From the point of view of preventing injuries, there is no reason to exclude any group of PTW users from compulsory wearing a helmet. Wearing protective clothing would prevent many minor injuries. Collisions between the front of the PTW and the side of a car are frequent, with many riders falling before the collision as well as many riders separating from the PTW during the collision. Devices, like airbags and leg protectors, to prevent injury in these circumstances are still experimental. Braking on a PTW is difficult and loss of control in an emergency situation is often found in crash studies. Some crashes can be prevented with ABS/CBS brake systems on motorcycles but they are expensive and unlikely to be fitted to all PTWs. Injuries from single vehicle crashes are often more severe when hitting a fixed object such as a guard rail. Devices have been designed to be retrofitted to existing guard rails to prevent injuries to motorcyclists.

Licensing requirements
Given the characteristics of a PTW and their high crash rate it is obvious that riders need a high level of competency. A graduated licensing system will reduce the number of motorcycle crashes because:

- Young riders are not allowed to ride a motorcycle
- Learning and gaining experience is restricted to low risk conditions
- Licensed riders are more competent (when compared with other systems)
- Some potential riders are discouraged from obtaining a motorcycle licence

The (proposed) European directive on licensing is not a graduated system in the strict sense. From age 18, riders have direct access to a 35kW motorcycle and from 24 years to an unrestricted motorcycle. The adverse effects of immaturity may be minimised with these age limits but not with the age limit of 16 for 125cc motorcycles and 16 (or even 14) for mopeds. In terms of crash prevention, a potentially better licensing system would have:

- The same minimum age limit as for a car licence
- At least two stages of riding under low risk conditions on a low performance motorcycle with a combination of compulsory training and unsupervised practice
- Testing before and at the end of each stage
- No direct access to high performance motorcycles
- Moped riders start with compulsory training followed by a period with a provisional licence and ending with practical training/test

However, an improved licensing system may not prevent the higher crash rates caused by rider motivation and riding style. The effects of voluntary, advanced training programs will depend on the motivation of the participants. With riders who are safety minded these programs can be expected to improve their behaviour and prevent crashes. With performance oriented riders the result may be the opposite.

Legal violations & enforcement
Certain types of legal violations by PTW riders (speeding, drinking, tampering with the engine, and not wearing a helmet) contribute to accidents/injuries. Depending on the proportion of riders violating the law, increased enforcement effort may be needed.

Road design & maintenance
In road design and in road maintenance more attention is needed to prevent PTW crashes particularly in the provision of all kinds of speed inhibitors and lane markers.

2 Use and safety of PTWs

In most EU countries a moped is defined as a PTW with an engine size below 50cc and design speed up to 50 km/h, and is prohibited on motorways. The minimum age for the driver varies between 14 and 16 years old. The use of a helmet is required in most countries, a compulsory theoretical test is often required and in most countries a practical test too. Licence plates and vehicle registration are increasingly required.

A motorcycle is a PTW with an engine size above 50cc and is allowed on motorways. A driving licence is compulsory. A minimum age of between 16 and 18 years old is required for engine sizes up to 125cc or power up to 11kW (A1). Larger engine sizes (A2, A) can be accessed after 2 years driving experience. A helmet is required. Motor scooters are assigned to one of these categories depending on engine size.

Mopeds are used for shorter trips compared to motorcycles. The minimum age requirements in most European Countries are 16 years for the A1 licence category (mopeds and motorcycles <125cc) and 18 or 21 for other motorcycles. However, there are many differences in the details of countries' legal requirements. For example, Portugal, Spain, Italy, France and Switzerland have a minimum age for mopeds as low as 14 years. Denmark, Sweden, Germany, the Netherlands and Belgium also have a light moped with lower maximum speed. Apart from in Sweden the riders of this light moped do not have to wear helmets. Most European countries recognise a separate category light motorcycle with 125cc engines and a minimum age of 16. However, in Denmark, Austria, Switzerland, Belgium and Greece this minimum age is 18. Italy, France, Belgium, Germany and Austria allow the use of a 125cc motorcycle with only a car licence – however, from 2010 in France a 7 hour compulsory training for riding is required in addition to a car licence. The Netherlands has no 125cc category. In most countries motorcyclists start with motorcycles with restricted engine power and access an unrestricted motorcycle at a later age. Some of these details will be discussed in following sections.

The requirements for training and testing are not as strict for moped riders as for motorcycle riders. Since 2011, helmet use has been obligatory for drivers of both mopeds and motorcycles and their passengers in all European Countries. Furthermore, technical inspections of motorcycles are obligatory every 12 months (Belgium, Ireland, Latvia, Netherlands, Austria and United Kingdom) or 24 months (Germany, Greece, Spain, Italy and Sweden) with only in a few countries including Finland, Denmark, France and Portugal not requiring inspections.

PTWs have a number of characteristics which are relevant to their use and their safety. Compared to cars, mopeds are an economical means of transport and for younger road users they provide the only means of powered transport.

Mopeds and motorcycles are also relatively small, which makes them attractive in areas with dense or congested traffic where they can drive between car lanes (lane filtering) and be parked more easily. Their small size and the practice of lane filtering make them less detectable and predictable for car drivers, which can cause conflicts or crashes.

PTWs may be unstable and require body coordination and careful control by the rider at low speeds, when cornering and in emergency situations. Moreover, PTWs are more likely to lose friction between their tyres and the road surface and are therefore more vulnerable on poor road surfaces. Braking is further complicated by most PTWs having separate controls for front and rear wheel brakes.

In the absence of much bodywork, PTWs give little protection to the rider against adverse weather and against injuries in the case of a crash.

Motorcycles have powerful engines (even if restricted by law) and in combination with their low weight are capable of higher acceleration and a higher top speed than many cars.

Together, these characteristics make riding a PTW, in particular a motorcycle, potentially more dangerous. At the same time, riding a motorcycle gives a completely different sensation to driving a car, which is attractive to some groups of riders.

The above considerations suggest that the motives for riding a PTW can be different to those for driving a car and can vary between groups of PTW users. They also suggest that riding a PTW is, by its nature, potentially more dangerous than driving a car. The level of danger again can vary between groups of PTW users. Definitive conclusions have to be based on actual crash data and empirical research and care has to be taken when applying the results of studies of one group of riders to other groups of riders in other regions or in different time periods.

The use of PTWs varies between countries. PTWs are more popular in southern European countries. Greece is at the top with 150 mopeds and 100 motorcycles per 1000 inhabitants. In most countries the number of mopeds is decreasing although at different rates or has stabilised. The trends for numbers of motorcycles are quite different. Almost all countries have experienced an increase in number of motorcycles, again at various rates. The increase is greater amongst older motorcycle riders. Middle European countries show a continuing downward trend in number of motorcycles.

2.1 Use of PTWs

The rate of PTWs per 1000 inhabitants varies between countries and shows the popularity (or lack of it) of the PTW. Southern European countries (Greece, Italy and Spain) have in general high ownership rates for motorcycles and even higher for mopeds (Figure 1). Greece is at the top with 136 mopeds and 126 motorcycles per 1000 inhabitants. Figures for Finland lie between those for southern and other countries with a rate of 49 for mopeds and 41 for motorcycles. For the other countries the rates are between 7 and 53 for mopeds (with Luxembourg highest at 53 and Bulgaria lowest at 7) and between 14 and 45 for motorcycles (with Germany and Austria higher at 45 and 43 respectively and Bulgaria and Hungary lower with 9 and 14).

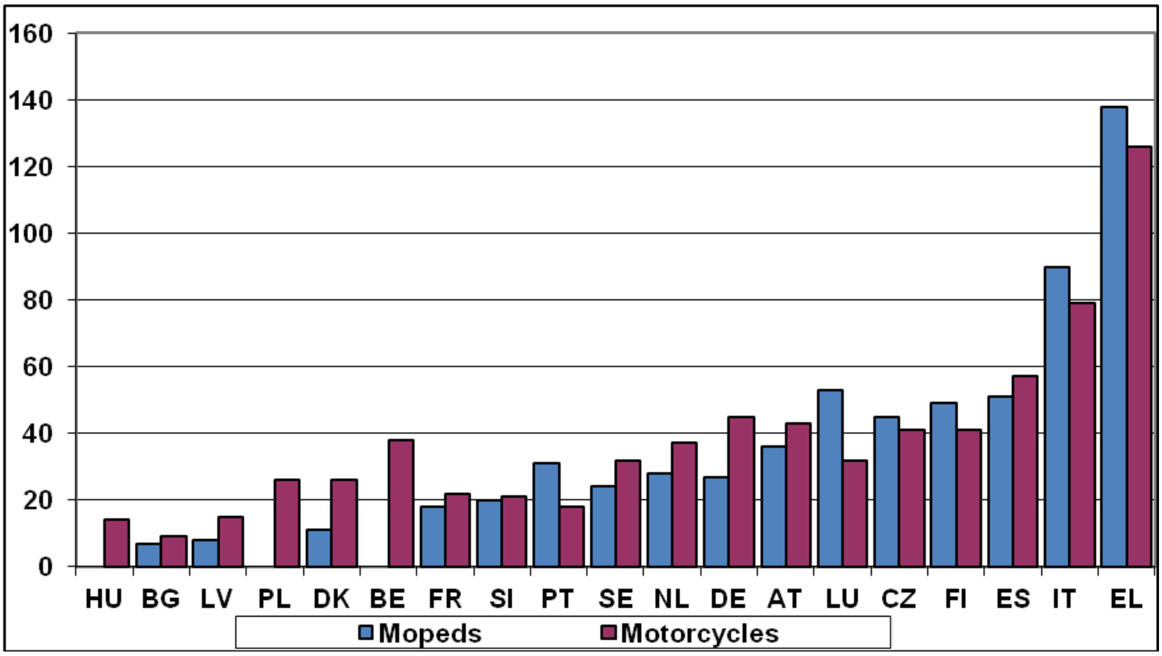


Figure 1 Rate of PTWs per 1000 inhabitants, 2009. Countries ordered by the total PTW use. Source: CARE Database / EC

The rates in *Figure 1* refer to the year 2009, but there have been remarkable changes in recent decades. In southern countries the rate of mopeds per 1000 inhabitants increased relatively slowly over the last 20 years with the exception of Portugal which showed a decrease over the last 10 years. Most western and northern countries saw a marked decrease between 1980 and 1995, followed by a relatively stable period.

The trends for motorcycles are quite different. Almost all countries experienced an increase in motorcycle ownership rates between 1990 and 1995, some with a marked increase (e.g. Austria, Germany and Greece), and some less so (e.g. France and Portugal). In contrast the available information from middle European countries indicates a continuing downward trend in motorcycle ownership rates. Information on ownership per age group per country is not generally available, but it is likely that the age distribution of moped and motorcycle owners varies between countries.

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

2.2 The safety of PTWs

The safety of PTWs is generally expressed in terms of numbers of crashes and casualties. Since the number of crashes and casualties depends upon the amount of use of or exposure to PTWs, these numbers should be corrected with some measure to reflect exposure. One such measure is the number of PTWs, which is of limited use because the amount of actual riding is likely to vary between groups of PTWs and groups of PTW riders. A better measure is the number of kilometres travelled on the road. Unfortunately, many countries have no reliable and detailed data on this measure.

2.2.1 PTW fatalities in Europe

Overall, PTW rider fatalities account for 17% of all traffic fatalities.

Figure 2 shows that the trend for motorcycle user fatalities differs clearly from the trend for mopeds and all other modes of transport. Motorcycles are the only mode of transport for which the number of fatalities has increased over the period 2000-2008 and for the last two years there was only a slight decrease compared to 2000.

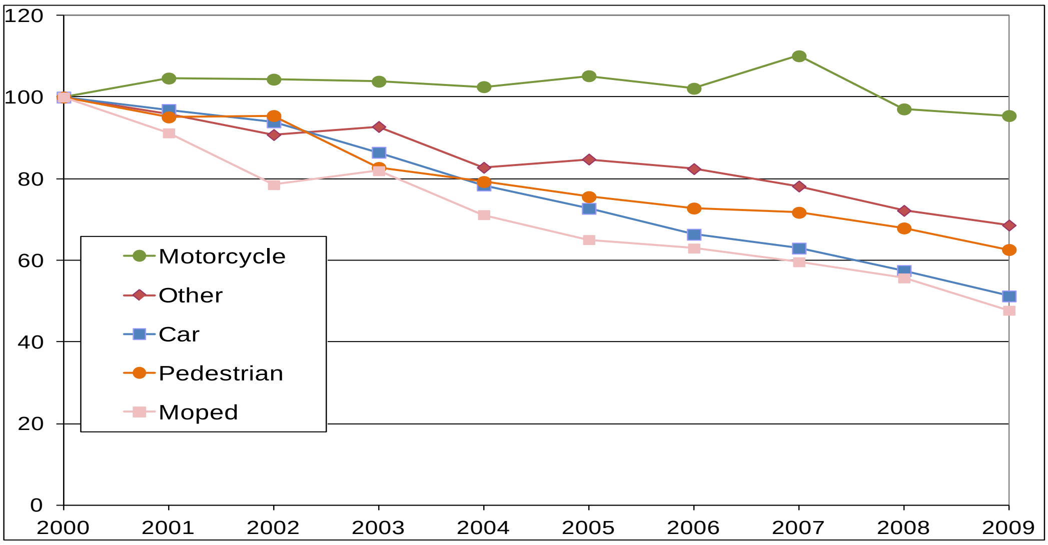


Figure 2: Index (2000=100) of motorcycle and moped fatalities compared with other modes EU-19

2.2.2 Moped fatalities

In 2009, 1,209 riders (drivers and passengers) of mopeds were killed in the EU-18 in traffic accidents, 15% less than the number in 2008 in the same countries. The total decrease during the decade for these countries was more than 50% with the average decrease being 7% per year. The most significant reductions occurred in Slovakia (86%) and Portugal (74%) while the reduction in Belgium, Italy, Spain, Denmark and Greece was more than 60%.

On the other hand, only in Finland, Sweden, Poland and United Kingdom have the number of moped rider fatalities increased during the last decade. Most northern and western countries had rapidly decreasing numbers of moped fatalities between 1990 and 1995, after which the number decreased more slowly (e.g. Germany, Switzerland and the Netherlands), remained more or less the stable (e.g. Sweden, Norway, Finland, Austria, France) or even increased somewhat (e.g. Denmark and the UK). Belgium is the exception with a continuous decrease since 1980.

Among the southern countries, Portugal and Italy show a continuous decline although it is more marked in Portugal. The number of moped fatalities in Greece peaked between 1990 and 1995 and then decreased to a much lower level. Spain experienced a similar peak in 1990. Of the central European countries, Poland and Hungary have similar decreasing trends which levelled out in very recent years. However, moped fatalities in the Czech Republic in recent years are lower than before. These trends in moped fatalities roughly correspond with the trends in ownership.

The age range in which moped fatalities occurs varies significantly between the countries. In Germany and the Netherlands, a large proportion of moped fatalities were aged 25 years and above in 2005. This was different in 1980 when the proportion of under-25 years was larger. This indicates a strong decline of moped fatalities over the years, in particular for young moped riders. Some northern and western countries show a majority of moped fatalities under 25 years in 2005. France is one of these but used to have more fatalities 25 years and older in 1980, whereas Great Britain always had more young moped fatalities.

Of the southern countries Greece, Italy and Portugal have a large proportion of older moped fatalities, which for Greece and Italy has always been the case. Portugal used to have about equal numbers of young and old moped fatalities in 1980. Spain had equal proportions young and old moped fatalities in 2005 as well as in 1980.

The central European countries always had more moped fatalities in the older age group.

2.2.3 Motorcycle fatalities

In 2009, 4.905 riders (drivers and passengers) of motorcycles were killed in the EU-18 countries in traffic crashes, only 1% less than the number reported in 2008 for the same countries. A similarly low annual total decrease for these countries by 2% is recorded during the decade, an average of 0.1% a year. As there is no reliable data available about the exposure of PTWs (vehicle kilometres or fleet numbers) in each of the above countries, it is difficult to interpret the numbers of fatalities in the group of PTW or the difference in the distribution over mopeds and motorcycles. In some countries, like Greece and Czech Republic, the majority of PTW fatalities are motorcyclists. By definition in Ireland and the United Kingdom there are hardly any moped fatalities

The most significant reduction occurred in Portugal (46%) and Germany (31%) while the reduction in Ireland, Netherlands, United Kingdom and Austria exceeded 20%. On the other hand the highest decrease in motorcycles fatalities during the last decade occurred in Romania, Finland and Poland.

The most consistent finding with regard to motorcycle fatalities is the larger proportion of riders aged 25 years and older in northern and western countries in 2005 compared to 1980 when the proportion under 25 years was much higher. The trends in number of fatalities for the two age groups combined is less consistent with the northern countries showing little change and other countries (e.g. Germany, Austria, Switzerland, Great Britain) showing a decline until 1990-1995.

The southern countries are similar to the western and northern countries with many more motorcycle fatalities 25 years or older in 2005 and the younger age group higher in 1980. Of the central European countries Czech Republic and Slovenia show a strong increase in older motorcycle fatalities in recent years and a decrease in younger fatalities, with a slowly decreasing overall number as a result. Hungary forms an exception with a rather strong fall between 1990 and 1995, which was even stronger for motorcycle fatalities 25 years and older.

2.2.4 Moped and motorcycle fatality rates

Fatality rate per inhabitant reflects both the number of vehicles per inhabitant and the fatality rate per vehicle. All southern European countries have high moped fatality rates per inhabitant, but rate per vehicle is highest in Denmark and Austria. Similarly, the motorcycle fatality rate per inhabitant is extremely high in Greece, but mainly due to the high rate of motorcycles per inhabitant.

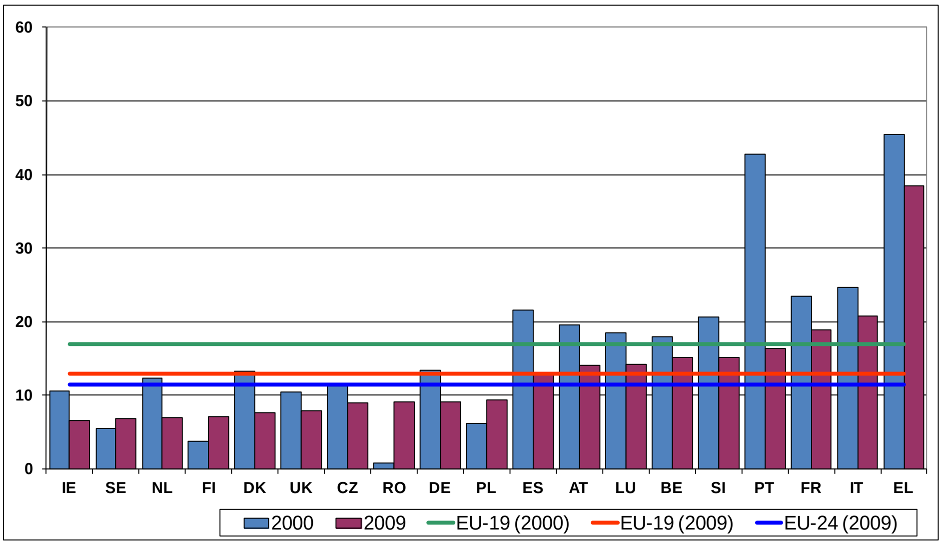


Figure 3 Motorcycle and moped rider fatalities per million inhabitants, 2000 versus 2009. Source: CARE Database / EC

The fatality rate in 2009 is much higher in Southern European countries than in the other countries (Figure 3). More specifically, the rate for PTW rider fatalities per million inhabitants is extremely high for Greece and to a lesser extent for Italy, France and Portugal. Furthermore, the fatality rate in 2009 has decreased compared to 2000 in the vast majority of the 24 European countries except Sweden, Finland, Romania and Poland. The most significant reduction occurred in Portugal (62%).

Most countries have a large proportion of motorcycle fatalities aged 25 years and older, other countries show a majority under 25. This is different from the situation in 1980 when the proportion under 25 years was much higher. The number of moped rider fatalities fell between 2000 and 2009 for almost all ages. Furthermore almost 39% of the moped rider fatalities are aged between 15 and 24 years old in 2009. The number of motorcycle rider fatalities aged 40-60 year old doubled between 2000 and 2009.

Figure 4 shows the fatality rate by age group in the EU-24 countries. The rates for moped riders aged 15-19 and motorcycle riders aged 20-29 are particularly high.

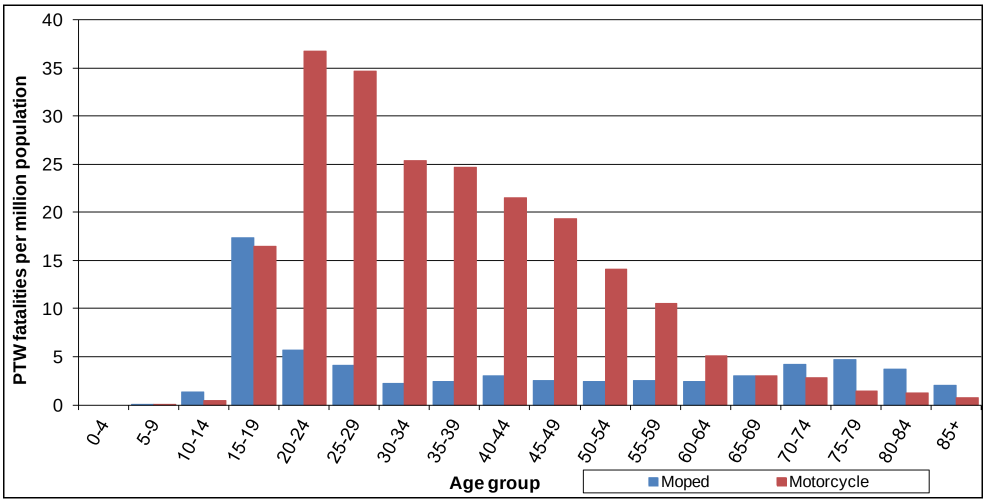


Figure 4 Motorcycle and moped fatalities per million inhabitants by age group - EU-24, 2009. Source: CARE Database / EC

2.2.5 Severity of crashes

The rates in figures 2, 3 and 4 are for fatalities only. Including crashes with less serious injuries might affect some of the observations. Based on fatalities plus hospital admissions, the rates for moped occupants for all age groups are much higher than for motorcycle occupants. This is because moped occupants are more likely to become involved in a crash (corrected for kilometres travelled) but with less serious injuries than motorcycle occupants. This finding illustrates the importance of the method of sampling crash in a study on the safety of PTWs. A sample with less severe injuries can lead to different conclusions than a sample with fatalities only.

2.2.6 Crash characteristics and scenarios

Effective countermeasures are based on a thorough understanding of the crash causes and the circumstances under which these crashes occur. Crash reports provide valuable information in this respect which provides information on:

- Type of PTW (moped vs. motorcycle)
- Type of situation (built up vs. non built up and intersection vs. between intersections)
- Road users involved (single, PTW+car, other)
- Movements of PTW and car relative to situation and to each other
- Severity of damage/injuries
- A combination of these variables is needed to describe the character of PTW crashes.

Some studies include reports of both moped and motorcycle crashes while others deal with the latter only.

Although different studies are likely to use different sampling methods or different ways to characterise the crash three frequent crash scenarios occur.

- Scenario 1: motorcycle/moped rider having a single vehicle crash, riding between intersections, losing control in a curve.
- Scenario 2: motorcycle/moped rider approaching an intersection, being hit by a car driver coming from a side road who did not notice the motorcycle in time.
- Scenario 3: a car driver turning left and not noticing the motorcycle coming from the opposite direction.

In the scenarios 2 and 3 a large majority of car drivers should have given right of way to the PTW, indicating problems with the perception of the PTW. Overall, there is an over-representation of detection problems in two-wheelers vehicle crashes, which suggests a specific problem of conspicuity, ranging from 36% (Motorcycle Accident In-Depth Study MAIDS, 2004) to potentially 60% (Eslande, Van, 2002) of all PTW crashes – excluding loss of control single vehicle crashes. In all three scenarios the motorcyclist may have been speeding which presents a further problem to be addressed. These scenarios give a description of the situation and events before the actual crash. This is followed by a sequence of events resulting in injuries of the PTW rider.

2.2.7 National studies on moped and motorcycle crashes

Only for France and the Netherlands are there studies on both moped and motorcycle crashes. The French study on moped crashes used all *moped* fatalities for 1994-1995 (Carré & Filou, 1996). They found:

- Equal number of moped fatalities on built-up and non built-up roads
- Twice as many fatalities between intersections (as at intersections) on both built-up and non built-up roads, of which almost one in three in a curve
- 32% fatalities in single vehicle crashes on built-up roads, compared to 15% on non built-up roads.

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

The French study is more recent and based on all *motorcycle* fatalities for 2002-2003 (Filou, Lagace & Chapelon, 2005), with the following results:

- 60% motorcycle fatalities on non built-up roads, of which 25% at intersections, against 50% at intersections on built-up roads
- 30% fatalities in single vehicle crashes and 40% in collision with a passenger car

The collisions with a passenger car can be further divided into:

- 50% at intersection, 32% of the cars making a left turn with the motorcyclist on the same road, 20% with car coming from side road
- 12% between intersections with car and motorcycle in the same direction, with 7% motorcycle hitting the back of the car
- 33% between intersections with car and motorcycle from opposite directions, with 10% motorcycle on left side of road
- 5% dangerous manoeuvres by car driver such as turning, backing etc.

A comparison of the two studies shows more fatal crashes on non built-up roads for motorcyclists than for moped riders; large proportions of crashes between intersections, particularly for mopeds on built-up roads. Furthermore it is interesting to see the higher proportion of single vehicle crashes on built–up roads than on non built-up roads for moped fatalities.

The Dutch moped study is based on a sample of 1054 moped crashes resulting in hospital admissions in 1993 (Noordzij, 1998). In summary:

- Twice as many crashes on built-up roads
- 20% single vehicle crashes, most of them in between intersections
- 60% collisions with a car of which more than two third at intersections
- At intersections about 50% of the car drivers (coming from a side road or turning left or right) should have waited for the moped rider.

A similar study was reported for motorcycle crashes: 926 motorcycle crashes resulting in hospital admissions in the Netherlands in 1993 (Noordzij & Vis, 1998). In summary:

- Equal numbers of crashes on built-up and non built-up roads
- 27% single vehicle crashes on non built-up areas as compared to 17% built-up
- 60% collisions with a car, on non built-up roads about equally often at intersections and road sections but on built-up roads more often at intersections
- At intersections about 50% of the car drivers coming from a side road should have waited for the motorcyclist and another 20% turned left in front of an oncoming motorcycle
- In 80% of all collisions with a car at intersections the car driver had seen the motorcycle too late or not at all; on road sections this was the case in 60% of the collisions with a car
- On built-up roads about 40% of the motorcyclists were exceeding the speed limit before colliding with a car, in other situations this percentage was much lower.

Again the proportion of crashes on non built-up roads is higher for motorcyclists than for moped riders. Compared to France there were relatively more crashes on built-up roads for both moped and motorcycle. It should be noted that the French figures are based on fatalities and thus on more severe injuries than the Dutch studies. Apart from this, there are striking similarities in results for all four studies.

2.2.8 National studies on motorcycle crashes only

The following studies from other European countries deal with motorcycle crashes only.
A German study based on a sample of 500 crashes in the year 2000 involving motorcycles and resulting in injuries (Kramlich, 2000) gave the following distribution of collisions between a motorcycle and a car:

- 45% at intersections with priority for the motorcyclist
- 22% at intersections with the car turning left against an oncoming motorcyclist
- 10% on road section with the motorcyclist passing a car which turns left
- 6% on road section with the car making a full turn and the motorcyclist from behind or opposite direction
- 8% on road section with car overtaking in front of oncoming motorcyclist.

The conclusion from these results is that in nine out of ten of these collisions the car driver should have given right of way to the motorcyclist.

Broughton (2005) reports on a study based on police reports of fatal motorcycle crashes in Great Britain between 1994 and 2003. In summary:

- 60% of crashes on non built-up roads
- 28% single vehicle crashes
- On built-up roads 60% at intersections, against 40% on non built-up roads
- 35% of crashes at bends, 20% at left hand bend (with left moving traffic), 15% at right hand bend
- 13% of motorcyclists were overtaking
- 72% of motorcyclists were found by the police to be principally responsible, of whom 64% were reported to have lost control, with loss of control by reason of excessive speed in 37%
- Of drivers of other vehicle found to be responsible, 40% failed to give way.

The 64% loss of control is quite high. Loss of control is expected in single vehicle crashes. But with 28% such crashes, more than half of the lost control cases must have been collisions with another vehicle, either because of loss of control due to inappropriate speed, or when loosing control during an emergency action, or when driving too fast to be reasonably seen by other vehicles in time.

A recent questionnaire study in Norway (Bjørnskau et al., 2012) suggested that:

- Riders of sport bikes are much more at risk of being involved in crashes than other riders.
- Young riders exhibit more risky behaviour and less safe attitudes than older riders.
- Motorcycle riders of 16–17 years are at particularly high risk of being involved in crashes.
- Riders in fatal crashes are often inexperienced riders in general and/or with the motor cycle they were riding

A national study in Slovenia (Sraml et al., 2012), showed that:

- the risk of being killed in a traffic crash is 40 times higher for PTW riders than that for car occupants;
- PTW crashes concern only 6.5% of injury crashes, but result in 71% of all injuries;
- crashes where PTW riders were involved mainly occur on the main and regional state roads and in urban areas;
- more than 90% of crashes involving PTW riders occurred on the so-called “open roads”, on dry road surface; the main cause of crashes is inappropriate speed (53%);
- in most cases the riders hold their driving licence for less than 3 years.

2.3 Injury mechanisms

The Safe System approach has as its prime objective the prevention of fatal and serious injury in case of an accident.

To be able to design effective counter measures one has to know what parts of the body are injured and what injury mechanism is responsible for the injury.

The events before and during a crash can be very complex. The rider of the PTW may take action to avoid the crash. This may change the trajectory and speed of the PTW and its rider. A collision with a car or other object will again change these and eventually parts of the body of the rider may hit some parts of his own PTW, of another vehicle or of another object. The nature and severity of the injuries depend on how these parts hit each other (which speed and angle).

Standard crash reports contain little information on injuries. Detailed information on the events before and during the crash can only come from in-depth studies at the scene of the accident and from inspection of vehicles and objects involved in the crash as well as from medical examination of the casualties. As a consequence the sample of an in-depth study is usually small, includes few severe injury cases and is regional rather than national; relatively few such studies exist.

In-depth studies show that injuries to the legs are frequent, but injuries to the head are more severe even though wearing a helmet. Head injuries would have been much more frequent if helmets had not been worn. Collisions between the front of the PTW and the side of a car are frequent, with many riders falling before the collision as well as many riders departing from the PTW during the collision. Injuries from single vehicle collisions are more severe when hitting a fixed object.

Special attention is paid to the injuries as a result of a rider colliding with a guard rail. The injuries as a result of a collision with a guard rail are influenced by the design of the guard rail. More injuries result from hitting the rail post than from impact with the rail itself (2BESAFE, 2009). Little is known about differences in injury mechanisms between types of PTW, between different traffic conditions or about crashes with more severe injuries.

2.3.1 In-depth studies

There is a recent in-depth study with samples from mostly urban areas in five European countries: France, Germany, the Netherlands, Spain and Italy (Motorcycle Accident In-Depth Study MAIDS, 2004).The accident sample for 1999-2000 contained 398 moped and 523 motorcycle accidents. About 70% of the PTW riders took action to avoid the crashes, mostly by braking. However, about half of these (i.e. one third of all 921 riders) lost control doing this.

The parts of the PTW that were hit first:

- 63% at the front (29% centre front)
- 26% at either side
- The other vehicles were first hit:
- 32% at the front (7% centre front)
- 40% at either side

The report contains lots of information e.g. on the angle at which the vehicles hit each other, on the speed of both vehicles before and at the time of collision. However there is no combination of these elements or separate figures for motorcycles and mopeds in the report. A report of a German study (Otte, 1998) provides a combination of elements. The sample contains 1029 crashes with injured motorcyclists (excluding scooter types) from 1985-1995. Many riders suffered multiple injuries to different parts of the body. The parts of the body that were injured:

- 20% of the riders had injuries to the head
- 21% of the riders had injuries to the upper torso
- 21% of the riders had injuries to the lower torso
- 44% of the riders had injuries to the arms
- 71% of the riders had injuries to the legs

The part of the motorcycle and the part of a car that were hit first, together with the angle are combined as types of collision:

- 36% no car involved
- 13% both frontal
- 7% front of car against side of motorcycle
- 27% front of motorcycle against side of car (5% at right angle)
- 4% front of car against rear of motorcycle

European Commission

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

Injuries to the leg were more frequent and more severe with frontal collisions. Severe injuries to the head were more frequent with the motorcycle against the side of the car at a right angle.

Otte (1998) also showed the trajectory of the motorcycle rider during the crash:
- 8% thrown from motorcycle without hitting car
- 20% fell from motorcycle before hitting car/object
- 18% remained on motorcycle and hit car
- 50% departed from motorcycle and hit car (6% after being thrown)

More and more severe head injuries as well as leg injuries resulted from being thrown and landing on the car. Injuries to the upper torso were more frequent and severe when the rider fell before hitting car/object.

22% of the crashes were single vehicle collisions. In most of these cases (75%) the rider was injured by hitting the road surface. However, injuries from hitting fixed objects were more severe.

Otte also presented results of a sample of 89 crashes with scooters most of which were mopeds. The results showed more single vehicle crashes than with motorcycles (33% against 22%) and some differences in injury patterns. Since on the average the speed of scooters was lower it is not possible to decide if the two PTW designs result in different injury patterns.

3 Contributory factors

Contributing factors are traditionally categorized in three groups.
- Factors related to road users. In the case of PTW crashes it is useful to distinguish between factors related to the PTW rider (such as age, experience and behaviour) and factors related to other road users, including the perceptual problems which may also rise from environment factors (obstacle to visibility) and vehicle factors (size of the PTW).
- Factors related to the vehicle. Examples of such factors are engine performance and type of PTW etc
- Factors related to the road. Examples of such factors are quality of road surface and obstacles.

3.1 Factors related to road users

Riders or rider groups who ride more kilometres are more exposed to the dangers of road traffic and will usually have more crashes. Therefore, when studying other factors that may contribute to crashes, the crash figures have to be corrected for kilometres travelled. Such a study can be based on national statistics. However, reliable and detailed data on kilometres are scarce. Other designs to study rider factors that may contribute to crashes are case control and questionnaires.

There is a problem when the results of all these studies are compared: the more information on rider characteristics in the study, the more crashes with no or less severe injury.

In all studies the age of the rider has been found to be important. Young riders have much higher crash rates, even if corrected for (lack of) experience. This has to be explained as a result of age related psychological factors. Unfortunately there is no information on crash rates for the very young ages at which mopeds or motorcycles are allowed in some countries. Trends in risk by age have been different for different modes over the last 20 years.

Rider experience is also found to be related to the crash rates of motorcycle riders, although not in all studies. There are different types of experience: years of riding, recent or frequent riding, familiarity with a specific motorcycle and familiarity with specific conditions. All types of experience to some extent contribute to a lower crash rate. Riding experience may not be sufficient to overcome the extra problems created by adverse weather conditions during winter.

Several studies emphasise the high crash rate of riders of a sports motorcycle. Some studies indicated a higher crash rate for recreational riding which may have to do with a combination of different conditions and a different riding style. Other groups of riders with a relatively high crash rate were only found in single studies: winter riders in Great Britain, urban riders in New Zealand, inexperienced riders of custom bikes in the Netherlands.

Other factors influencing PTW safety are psychological factors, influencing rider motivation and riding style, and the increasing numbers of older motorcyclists.

There are several violations of the law which are common to PTW riders and may contribute to accidents such as speeding, drinking, riding without a valid licence, tampering of the engine. The proportions of riders with such violations vary from country to country.
Rider safety is also influenced by the perceptions of other road users. Other road users appear often to fail to perceive PTW riders and to some extent this lack of perception is made worse by the behaviour of the PTW riders.

3.1.1 Age, comparing transport modes

As an example using national statistics in Figure 5 shows crash rates per billion kilometres per vehicle type and per age group for two 10 year periods. The crash figures are actually vehicle occupants fatalities (i.e. riders/drivers as well as passengers) in the Netherlands and driver fatalities in Greece. Kilometre data are from national travel surveys. There are several interesting observations to be made.

For the most recent 10 year period, car occupants of all ages have a much lower fatality rate than moped or motorcycle occupants. For example, between 40 and 50 years of age (which is the age group with the lowest rates for all three vehicle types) the rate is 2 for car occupants and 37 and 52 respectively for moped and motorcycles. There is a strong relation between these fatality rates and age.

3.1.1.1 Mopeds

The moped fatality rates show a U-shaped curve in the Netherlands, with equally high rates for young (15-17) and old (60-65) occupants and the lowest rate between 25 and 50 years of age. In Greece, on the other hand, moped fatality risk presents a sharp increasing trend with age, with the elderly being at almost 10 times higher risk than the average, and the young presenting a very slightly increased risk.

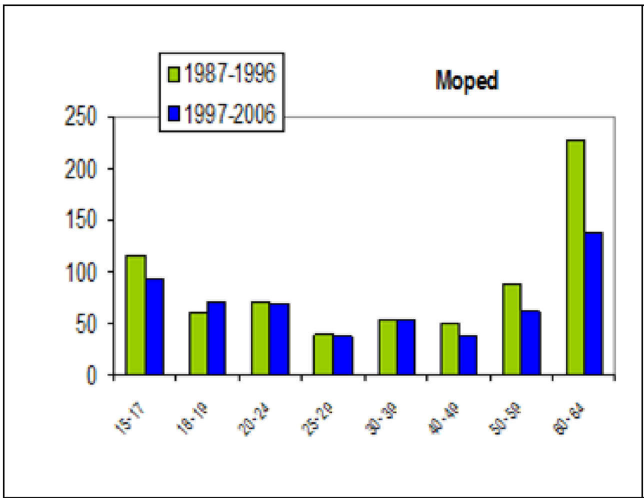
3.1.1.2 Motorcyclists

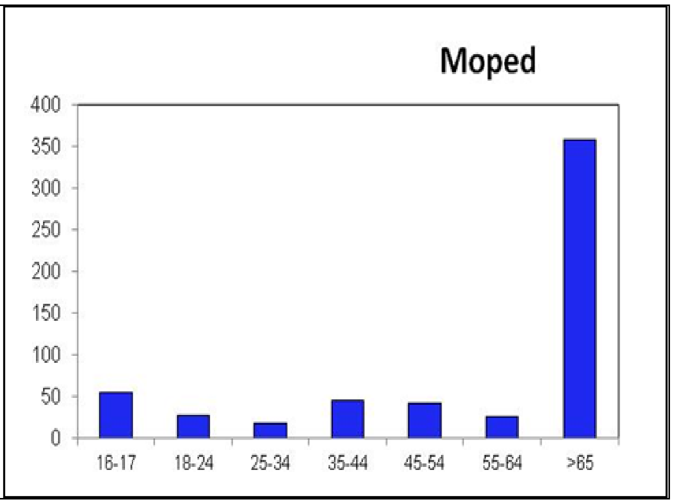
The trend for motorcyclists age in the Netherlands is different with fatality rates falling from age 20-25 and a lower rate for 18-19 years than for the next youngest group. In Greece, both young and older riders are at higher fatality risk

In both countries, the fatality rates for car occupants show a U-shape too, with the highest rate for young car occupants (18-19) and the very old (75+) and the lowest level between 40 and 60 years of age.

In general, the higher fatality rates for young riders/drivers as compared to middle aged ones has to do with both inexperience as a rider/driver and a difference in age-related (psychological) factors, whereas the higher rates for old riders/drivers are influenced by their poorer physical condition, resulting in more serious injuries from crashes.

Disregarding the age differences gives crash rates of 4 for car occupants, 68 for moped and 73 for motorcycle in the Netherlands. The respective average values in Greece are 8 for car drivers, 45 for moped and 78 for motorcyclists.





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

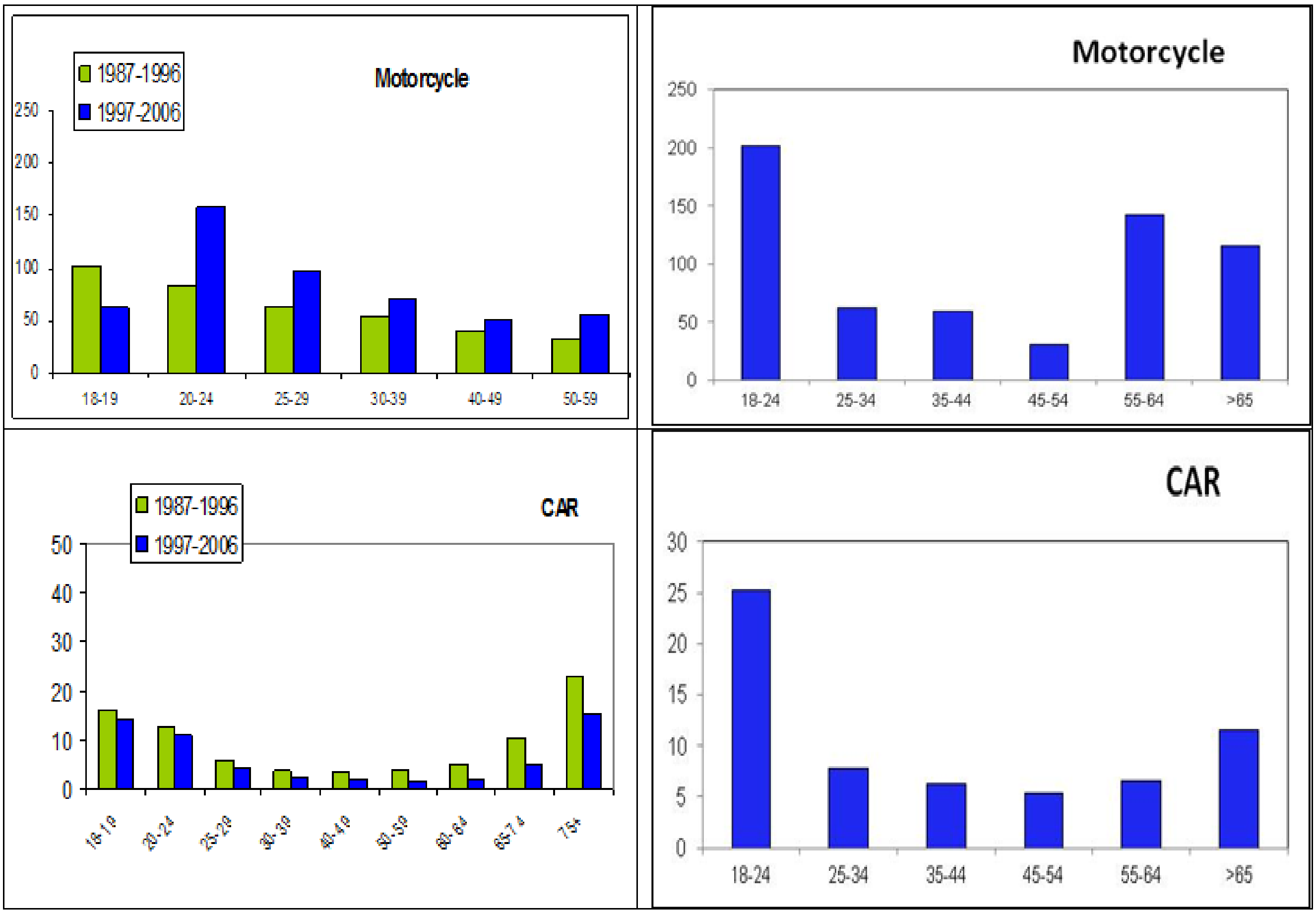


*Figure 5 Fatalities per 10*9 kilometres for different modes of transport by age of driver (or rider) in the Netherlands (1987-1996 and 1997-2006, Source: SWOV) and in Greece (2004, Source: NTUA)*

3.1.2 Trend in risk by age over the last 20 years

3.1.2.1 Mopeds

A comparison between the two 10 year periods shows in the Netherlands that for moped and car occupants the fatality rates are lower for the most recent years, but only for older age groups. For moped occupants the lower rates start from age 40 and car occupants already have lower rates at 30 years. A partial explanation for the difference in trend for young and old rider/drivers could be that older riders/drivers in the recent 10 year period are on average more experienced than riders/drivers of the same age in the earlier period; younger riders/drivers are relatively inexperienced in both periods.

3.1.2.2 Motorcyclists

There is a striking difference in fatality rates in the Netherlands between the two periods for motorcycle occupants. For the early 10 year period there was a continuously falling rate with age, starting with the youngest age group. For this age group only the fatality rate has decreased. But from age 20 there was a substantial increase in fatality rates from the first period to the most recent 10 years. There are two possible explanations. Firstly, many riders of the older age groups in the recent period are starting riders and thus are less experienced than riders of the same age in the earlier 10 year period. In addition, the motorcycles they ride tend to be heavier and more powerful. Secondly, the Netherlands have introduced a graduated licensing system in 1996. From then on riders of 18-20 years could only ride motorcycles with restricted engine power. A more definitive explanation would require more detailed information which is not available.

3.1.3 Age and experience

Although the crash statistics show a clear effect of age, the question whether this effect is a result of the actual age of the rider, rather than his level of experience remains unanswered. To tease out the effects of the two factors, extra information is needed about actual driving experience, or by comparing accident involved rivers with crash-free riders (case-control studies). Overall, studies which assess crash risk with the number of years of license showed that crash risk diminishes with the number of years and the total number of kilometres travelled.

However, a distinction should be made between young drivers and novice drivers, in the sense that a novice driver is not necessarily young. Crash risk depends on both age and experience; however younger riders are expected to have a longer novice period. There are some studies showing that the age of driver is a more important contributing factor than the lack of experience (Mullin et al., 2000; Rutter et al., 1998).

3.1.3.1 Case control studies

A slightly different study design to examine the effects of contributory factors is the "case-control study". With this design crash facts are recorded in detail as soon as possible after the event. As a consequence of this method the sample of crash cases is usually small, includes few severe injury cases and is regional rather than national. The sample of riders serving as controls is more or less similar to the crash sample in terms of times and places of sampling and in any way consists of riders not involved in an accident at the time of sampling. By comparing crash and control samples it is possible to calculate relative crash rates i.e. the crash rate corrected for exposure of a subgroup of riders relative to that of all other groups of riders (or one specific other group).

Such studies have been carried out in Australia and New Zealand. In the New Zealand study 463 crash cases in 1993-1995 were compared to 1233 control cases. The results show a strong relation between relative crash rate and age as well as with familiarity with the specific motorcycle. There was no evidence of an effect of experience in terms of years riding a motorcycle after adjusting for age (Langley et al., 2000). The same data were used in a study on the effect of engine size on crash rate (Langley et al., 2000) and another study on motorcycle conspicuity (Wells et al., 2004).

The Australian study comprised 205 crash cases and 1225 controls (Haworth & Smith, 1998). Relative crash rates were again found to be strongly related to age and in this instance a weak relation with years of riding was found. The results also indicated a higher relative crash rate for infrequent riding (less than three days a week) and for non work related riding. A sub group of riders without valid license had a high relative crash rate.

3.1.3.2 Questionnaire studies

Another Australian study was designed as a survey in which both crash data and exposure data are obtained from 790 questionnaires completed by motorcyclists (Harrison & Christie, 2005). The weakness of such a design is the response rate which usually is around 40%. This implies that the results found in the study do not necessarily apply to the whole group of PTW riders at which the study was originally aimed. Another point of concern is that crashes reported by the respondents are without injury or slight injury only. The advantage of such a study is that many questions can be asked on riding habits and psychological variables that seem to be relevant for crash involvement.

Among the results of this study is a relation between crash rate corrected for kilometres and kilometres per year, with lower rates for more kilometres per year. Three groups of riders were found with a high crash rate, all three with a pattern of recreational riding, either as off-road riding or as long-distance riding on a sports motorcycle, or weekend riding in urban areas with a low number of kilometres travelled per year.

A large scale study was done in Great Britain in 2002 (Sexton et al., 2005) based on 11265 questionnaires from registered motorcyclists. These riders reported 1495 crashes of which over half occurred during commuting or work-related riding. A statistical model was used to calculate the expected number of crashes per rider based on kilometres per year and other factors. This model showed that the age of the rider is the most important predictor, closely followed by kilometres travelled per year. The experience of the rider was the next most important factor, followed by riding conditions. Riders travelling more kilometres per year had lower crash rates when corrected for kilometres per year. The effect of riding conditions was such that those who rode on a regular basis during the year irrespective of weather had the highest crash rate corrected for kilometres, age and experience. Riding experience may not be sufficient to overcome the extra problems created by adverse weather conditions during winter. Engine capacity was related to crash rate with riders of motorcycles with an engine of more than 125cc having a 15% lower rate (corrected for other factors) than riders of 125cc motorcycles. The authors found no evidence that riders who returned to riding after a long break had higher crash rates compared to other riders of the same age.

3.1.3.3 Other studies

To separate the effects of age and experience information is needed on experience of riders involved in crashes and of riders not involved. This requires a special study design to obtain this information. Noordzij & Vis (1998) obtained extra information on 926 motorcyclists involved in crashes resulting in hospital admission in the Netherlands in 1993 as well as from a special national survey of 3000 motorcyclists. Motorcyclists were divided in young (under 25 years of age) and inexperienced (less than five years riding a motorcycle), old and inexperienced and old with (five or more years) experience. The extra information also included type of motorcycle as touring, sports or custom. The crash rate per million kilometres show:

- Crash rate for young motorcyclists is one and a half times higher than for older riders with equally limited experience
- For older motorcyclists the crash rate is lower with more experience
- The rates for sports motorcycles is approximately double that of touring motorcycles and the rate for custom motorcycles is also higher than for touring motorcycles but only for inexperienced riders.

3.1.4 Psychological factors

The questionnaire in the Sexton study included a part on rider behaviour and a part on rider motivation. The latter part was based on several studies in Germany by Schulz and partners. Schulz (1991) distinguished between twelve different aspects of motorcycle rider motivation which were found to be closely related to age of the rider and type of motorcycle. In later work Schulz (1998) used a questionnaire aimed at riding style. Analyses of the Great Britain questionnaire showed

- Three aspects to describe motivation: pleasure from riding, liking for speed, economic aspects
- Three aspects to describe riding style: careful vs. careless, tolerant vs. intolerant and slow vs. fast
- Five aspects describing behaviour: traffic errors, speeding, stunting, use of safety equipment, control errors

Rider motivation and riding style were found to be related to rider errors and violations, which were related to crashes. To be more precise: a proportion of self-reported crashes were the result of behaviour such as speeding, traffic errors and control errors, which were the result of riding style such as confident, fast and careless and/or the result of rider motivation such as a liking for speed. These authors conclude that an important part of the motorcycle safety problems stems from motivations for choosing to ride motorcycles.

It might be expected that PTW riders differ from car drivers or the general population with regard to some psychological factors. There has not been much recent interest from researchers in this subject. A recent study with an interesting design compared motorcyclists and car drivers in Great Britain (Horswill & Helman, 2003). Three groups of subjects were tested in a simulator with traffic situations and completed a questionnaire on behaviour and some psychological variables including social motives and sensation seeking. A first group of 47 motorcyclists had to react as a motorcycle rider but a second group of 47 riders were asked to react as if driving their car. The third group was 48 car drivers. The three groups were carefully matched with regard to age, sex and experience. The results of the car drivers and of the motorcyclists acting as car drivers were very similar except that the motorcyclists were better at detecting potentially dangerous situations. The group of motorcyclists reacting as riders travelled faster, pulled out into smaller gaps, overtook more often, but did not follow closer to a vehicle in front. These results do not necessarily apply to all motorcycle riders. The samples were not representative since the subjects volunteered themselves and all motorcyclists also held a car driving license. But it is clear that at least a group of motorcyclist is equally (or even more) competent and careful as a group of car drivers with similar demographics, except for the fact that the riders choose to ride a motorcycle in order to profit from the properties of the motorcycle such as being small and powerful.

3.1.5 Speeding, drink-driving and other violations

Overall, motorcyclists ride at higher speeds than cars and PTW crashes usually occur at higher speeds than cars (Horswill & Helman, 2003). Speeding appears to be a bigger problem for PTW crashes, compared to other modes. Excessive speed is responsible for up to half of PTW crashes and up to 2/3 of single vehicle PTW fatal crashes, and young riders are over-represented in speeding risk (Lardelli-Claret et al., 2005; Mullin et al, 2000).

Apart from speeding there are other examples of PTW rider behaviour in violation of the law, which may contribute to PTW accidents. Broughton (2005) found that 12% of the motorcyclist fatalities died in a drink/drive accident in 1994-2001, compared with 22% for car drivers. The situation in Great Britain seems to be different from that in France. Filou (2005) report 23% of motorcyclists and 32% of moped riders in a fatal accident as positive for alcohol, compared to 19% for drivers of a passenger car. The French authors also mention that 18% of the riders of a light motorcycle and 8% of the riders of heavier motorcycles who died in an accident did not have a valid rider license.

Results from the DRUID European project (DRUID, 2010), the French case study, suggest that, among drivers involved in fatal crashes, drivers of motorised two-wheel vehicles and especially moped drivers, have higher prevalence of alcohol and cannabis than other road users.

Tampering with a moped or 125cc motorcycle engine to make it go faster seems to be a problem in Germany. Raithel (1998) obtained questionnaires from 137 young riders of PTWs, half of whom admitted tampering. It is very likely that tampering is related to a higher accident rate. The “Handbook of road safety measures “(Elvik et al. 2009 refer to a Norwegian study in which the relative rate for injury crashes was found to be about 50% higher for tampered mopeds.

The most extreme example of violations is from Greece in 1994, where only 15% of the injured motorcyclists had been wearing a helmet when this was compulsory (Petridou et al, 1998). In more recent years the Greek wearing rates seem to be higher. In other countries where helmet wearing is compulsory the wearing rates of helmets by moped and motorcycle riders is usually reported to be between 90 and 100%.

3.1.6 Perception by other road users

Crash studies show that the perception of PTWs is problematic and a contributory factor to collisions with cars. Wulf et.al. (1989) present a review of studies on these problems and discuss several explanations for them. The first explanation has to do with the physical properties of the PTW: the small size of the PTW compared to cars makes it less conspicuous and judging of distance and speed with a small frontal area or with only one headlight is difficult. Other explanations are of a psychological nature. Because of the small number of PTWs in traffic, car drivers do not expect to meet a PTW and are therefore less prepared to notice or recognise a PTW. PTWs seem to lack relevance to most car drivers. Wulf even suggests that a car driver is inclined to ignore the presence of a PTW since the impact of a collision with a PTW is less threatening than with a car.

To a certain extent these problems are made worse by the behaviour of the PTW riders such as overtaking in situations where cars cannot do this and high speeds. Other road users may not look for PTWs in places where they do not look for cars and they do not anticipate higher speeds and shorter approach times than for cars. A recent study (Clabaux et al., 2012) showed that, in urban environments, motorcyclists' speeds involved in 'looked-but-failed-to-see' accidents are significantly higher than in other crashes.

More fundamental research on the perception of objects has shown that attention may be drawn through physical properties and or through the relevance these objects have for the observer. The lack of relevance of PTWs for car drivers has not been studied directly, but is illustrated in a study by Magazzu et al. (2006). The results of the MAIDS case control study were used to obtain 740 cases of a collision between a car and a PTW, together with an expert judgement if the rider or car driver was at fault. After correction for other factors such as age and experience of the car driver it was found that car drivers who also held a motorcycle licence were less likely to be at fault than car drivers without this licence. The possession of a motorcycle licence is an indication of interest in and experience with riding a motorcycle, which may have helped in the detection of an oncoming PTW and the prediction of its manoeuvre.

3.2 Factors related to the vehicle

The effect of engine performance on safety is not fully understood; the relation between engine power and crash rate is not a simple one. Engine cubic capacity is not a very good indication of motorcycle performance and its associated crash rate. In practice the relation is further complicated since different groups of PTWs are used by different groups of riders with different accident rates.

Crash rates differ between different types of PTW.

Mopeds with their small engine and restricted top speed have crashes with less severe injuries than motorcycles, which results in lower fatality rates. Including less severe injuries results in rates that are not much different from or even higher than for motorcycles.

There is little known about the crash rate of 125cc motorcycles. Broughton (1988) reported that in the UK, 126-250 cc motorcycles have lower casualty rates than the 51-125 cc machines, a finding that was attributed to the fact that learner riders were restricted by law to machines of at most 125 cc capacity.

Sports motorcycles have been found to have higher crash rates than other types of motorcycle. Power to weight ratio is probably a better indication of performance and more strongly related to the accident rate of sports motorcycles than cubic capacity. A higher crash rate for these motorcycles, even if corrected for age and experience of the rider, does not automatically mean that the type of motorcycle is more difficult to control and therefore less safe. It is quite possible that they are used by riders with a different style of riding. There is no knowledge on the crash rate of scooters either as mopeds or as motorcycles. This is unfortunate because their number on European roads is increasing.

PTW braking a is difficult and loss of control in emergency situations often occurs.

3.2.1 Engine performance

At first sight the engine power seems to be the most important of all PTW properties in relation to safety. There are several studies on this subject with mixed results. The idea is that a heavy and powerful PTW is difficult to control even at low speeds and may invite riders to test the potential acceleration and/or top speed, which brings them in situations which are difficult to control. This means that it is not necessarily the character of the PTW itself, but the experience and motivation of the rider which determine the safety of the rider-PTW combination. In addition, heavy or powerful PTWs may be used more in conditions which differ from smaller PTWs and these conditions themselves may be related to the safety of PTW use.

3.2.2 Cubic capacity

A study with crash data from 1984-1986 in Great Britain covers the whole range of engine (cubic) capacity. The kilometre data came from a travel survey of 372 riders (Broughton, 1988). Crash rates per million kilometres were found to be related to the age of the rider and traffic conditions as well as to engine capacity. Riders of 16-18 years had fatality rates which were about four times higher than for riders of 30 years and older, after correction for conditions (built-up or non built-up) and engine size. The age difference was even stronger for less severe injuries. The fatality rate for non built-up roads was about one third higher but the rate for less severe injury about half that for built-up roads. This is an indication of more crashes on built up roads (corrected for kilometres) but with much less severe injuries. After correction for age of the rider and traffic conditions, the fatality rate for the 50cc PTW was lowest and highest for PTWs with engines of more than 250cc, with the fatality rate for 125cc in between. Including injuries resulting in hospital admission produced a rate which is a little higher for 125cc machines with little or no difference between the other engine capacities, i.e. both 50cc and over 125cc. It must be noted that in this study most riders of 125cc PTWs had a provisional license. Problems with the interpretation of these results are the small sample of the travel survey and the absence of information on the experience of the PTW riders. The study is rather dated and to day's motorcycles in general have bigger and more powerful engines.

The "Handbook of road safety measures" (Elvik & Vaa, 2004) refers to a Norwegian study by Ingebrigtsen (1990) which corrects for age, experience and other factors, including a measure to take risk. The study found no substantial increase in crash rate with increasing cubic capacity.

A more recent New Zealand study used 463 crash cases from 1993-1995 and 1233 controls in a case control design (Langley et al., 2000). The relative crash rate was corrected for age and experience of the rider and other factors and was found to be somewhat lower for motorcycles under 250cc, with no clear relation between cubic capacity and relative crash rate for motorcycles over 250cc. The authors conclude that if cubic capacity is used as basis to restrict motorcycles of novice riders the limit should be substantially lower than 250cc and power to weight ratio or motorcycle type may be a better basis.

3.2.3 Power to weight ratio

The cubic capacity of the engine may not be the best indication of the potential acceleration and top speed. An Australian study used power to (laden) weight ratio for the motorcycle and focussed on novice riders (Rogerson, Lambert & Allen, 1992). There were 2247 novice riders involved in injury crashes in 1987-1990 (learners: 1356 and first year license holders: 891). The age limit to obtain a licence was 18 years. The sample of motorcycles was compared with registered motorcycles. The crash rate (corrected for estimated kilometres) shows a strong relation with power to weight ratio, with four times higher rates for the most powerful motorcycles compared to the least powerful. The study did not correct for age of the rider, but many of the novices must have been young. It has to be remembered that learner riders were restricted to motorcycles with engines up to 250cc.

3.2.4 Type of PTW

There is a recent study with a case control design with samples from mostly urban areas in five European countries: France, Germany, the Netherlands, Spain and Italy (Motorcycle Accident In-Depth Study MAIDS, 2004. The crash sample for 1999-2000 contained 398 mopeds and 523 motorcycles, which were compared with 923 control cases; it should be kept in mind thought that a bias of minor injuries may be involved in that study. The report states that there is no difference between the crash and control cases with regard to age of the PTW rider, moped versus motorcycle and scooter versus other PTW. Young moped riders and scooters with mostly young riders are compared with mostly older motorcycle riders. Unfortunately, this does not allow conclusions to be drawn for these factors separately.

3.2.4.1 Mopeds

Mopeds with their small engine and restricted top speed can be expected to have a lower crash rate than motorcycles. But this is not evident from the actual figures. They have crashes with less severe injuries than motorcycles, which results in lower fatality rates. Including less severe injuries results in rates that are not much different from or even higher than for motorcycles. There are some remarkable differences between countries. A report comparing the traffic safety in the United kingdom, Sweden and the Netherlands discusses the difference in moped crash rates (Lynam et al., 2005).This rate (over all ages) for the Netherlands is almost double that for the other two countries. In the United Kingdom the moped is much less popular than in the Netherlands but the average kilometres per moped per year in the United Kingdom is about double that in the Netherlands. Therefore the use of the moped must be quite different. In the United Kingdom the moped is mainly used for commuting, in the Netherlands more for social or recreational purposes and in Sweden the moped is mainly used in the summer. In Great Britain moped riders have to obtain a license after taking a basic training course and passing a test (car drivers only have to take the training course and motorcyclists are already qualified). There is also a difference in traffic conditions, which are much less dense in Sweden. All these differences may affect the overall moped crash rates. In addition, the majority of mopeds in Sweden are light mopeds with a lower maximum speed. The Netherlands have the same type of moped, but without helmet. According to Noordzij (1998) the crash rate per million kilometres (and corrected for age) for the light moped without helmet is about the same as for the faster moped.

3.2.4.2 125 cc

There is little known about the crash rate of riders of 125cc motorcycles. At least in Great Britain they were shown to have a slightly higher rate than riders other motorcycles, which was largely due to the fact that learner riders were restricted to 125 cc (Broughton, 1988). This does not necessarily mean that this also holds for other countries. A German study presents fatality rates per 100000 motorcycles for 1994-1999 (Assing, 2002). For all age classes these rates are lower for 125cc vehicles only than for all motorcycles. For 125 motorcycles the age 16-19 has a fatality rate five to ten times higher than riders 25 years and older. There is no information on kilometres and the pattern of crash rates corrected for kilometres may be quite different. It is unfortunate that these rates are not known especially for the age group 16-18 and for the older drivers who are allowed to ride these motorcycles with only a car license since there are differences in legislation between countries for these groups.

3.2.4.3 Sports motorcycles

The type of motorcycle has been studied in surveys in Germany (Schultz, 1995, 1998).The samples were attendants of motorcycle shows. The questionnaires included questions on riding style and type of motorcycle. Only for sports motorcycles and only for riders with a sporting style the number of self-reported single vehicle crashes was higher for very powerful engines. There was no such relation for collisions with other road users.

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

With a different type of study design Noordzij & Vis (1998) calculated crash rates per million kilometres for three groups of riders and three types of motorcycle. 926 motorcycles involved in crashes resulting in hospital admission in the Netherlands in 1993 were combined with kilometre data from a national travel survey with 3000 motorcyclists. The crash rate per million kilometres for sports motorcycles was about double that for touring motorcycles regardless of age and experience of the rider. Custom motorcycles also had higher crash rates than touring motorcycles, but only for inexperienced riders. This last finding is surprising because this has not been found in other studies.

3.2.5 Other design elements

Other design elements of PTWs are relevant for their safety such as frame, suspension, wheels, brakes, tyres. But with current progress in PTWs design, their contribution to accidents is low. The MAIDS study found that 5% of crashes involved vehicle failure as a contributing factor, mostly tyre or wheel problems.

3.2.6 Braking

Braking a PTW is difficult for several reasons. With only two wheels in line the PTW may easily loose friction between tyres and road surface resulting in a fall. This is more likely during braking or cornering and even more likely during braking in a curve. The rider has to carefully apply braking force taking account of the quality of the road surface and the leaning angle of the PTW. Modern high performance motorcycles have high performance braking systems with which locking of the wheels is easy. In addition, the PTW rider has to divide the braking capacity between front and rear wheel. Most PTWs have separate controls for the front and rear wheel brakes; therefore they have to cope with with the downturn in the front fork during strong braking. As a result the total braking capacity will seldom be fully used or, when braking suddenly, the rider may lose control.

Loss of control in an emergency situation is often found in crash studies (Broughton, 1995). In a special study on the role of braking in crashes, Sporner (2002) used a sample of 502 injury accidents in 2001-2002 in Germany. 279 of the motorcyclists took action to avoid the crash, of which 54 lost control.

3.3 Factors relating to the road environment

In an Australian in-depth study with 205 crash cases as reported by Haworth et al. (2005) 15% of the cases were found in which the road surface had contributed to the collision. In more than half of all cases some site factor (of various kinds, including lack of vision) was involved. The role of road design and maintenance in PTW collisions may vary from country to country.

3.3.1 Road design

Several design and operational elements of the road network may be contributory factors to crashes. According to the MAIDS project, 30% of all PTW road crashes have a curve in the pre-crash path. For other vehicles this is 21%. Curves with a small radius, or with a changing (decreasing) radius, are more difficult to handle and require more anticipation from the rider

(ACEM, 2006 & MAG, 2008). Inappropriate crossfall / superelevation may be equally difficult to handle (2-BE-SAFE, 2009).

Obstacles (constructions, road signs, road equipment etc.), especially at inner curves or at intersections, may not also compromise the rider's visibility but also increase severity in case of crash occurrence (2BESAFE, 2009; MAG, 2008).

Traffic calming installations (e.g. speed humps), road kerbs and delineation posts, roundabout installations etc. rarely represent a risk for car users; however, when hit by PTW when riding at in inappropriate speed, there is a risk of loss of stability (BIVV, 2005).

3.3.2 Road surface

The MAIDS study (2004) with 921 PTW crash reports roadway defects in 30% of all cases. This does not necessarily mean that the defect contributed to the crashes. In a report by the European Motorcycle Industry (2006) some more results are presented. In 25 of all 921 cases a roadway maintenance defect was judged to have contributed to the crash. The total number of cases in which the road environment contributed was 72, including road design defects as well as temporary obstacles.

Both studies were based on officially reported crashes. It could well be that the role of poor road surface is more prominent in crashes which are not reported because no other road user was involved or the damage and or injuries were minor.

Brendicke et al. (1995) presents an overview of the problems of PTW riders with different road surfaces. They show the considerable, adverse consequences of poor road surface on skid resistance and thus on braking and cornering of PTWs.

3.3.3 Guard rails and barriers

A French study (Brailly, 1998) was concerned with collisions with guard rails. In 1993-1995 there were 63 fatal collisions of motorcyclists with a guard rail in France per year representing 8% of all motorcycle fatalities. Records of injury crashes were used to reconstruct the crashes, which was only possible with 157 out of 239 records:

- In 21 cases the motorcycle hit the rail but the rail did not affect the injuries of the rider
- In 43 cases the motorcycle hit the rail and the rider was thrown away and injured (42 of them without hitting the rail)
- In 50 cases the motorcycle and rider hit the rail (in 29 cases with the rail post)
- In 43 cases the rider fell and slid under the rail

The number of such cases is dependent on both the frequency of motorcycles leaving the road following an impact and the presence of guard rails at such places. What would be the outcome of these crashes if the guard rail had not been there is difficult to decipher since the guard rail was there to prevent collisions with other objects. On the basis of the records Brailly suggests that in about half these cases the injuries would have been less severe with a different design of the rail. For instance, cable barrier guard rails are suggested as Safe System treatments.

4 Prevention of injuries

PTWs provide little protection against injuries in the case of a crash. Injuries to the legs are frequent, but injuries to the head are more severe even though wearing a helmet.
Based on knowledge of injury mechanisms there are several ways to prevent injuries

- Helmets and clothing are devices worn by the PTW rider to provide protection in case of a collision with an object, be it the own PTW, other vehicle, road surface or fixed object. The main purpose of the helmet is to absorb energy from a direct collision of the head, whereas clothing cannot be expected to absorb much energy, but prevents direct contact of body parts.

  Studies show that head injuries would have been much more frequent if helmets had not been worn. From the point of view of preventing injuries there is no reason to exclude any group of PTW users from compulsory wearing a helmet. Wearing protective clothing would prevent many minor injuries.

  Other devices such as neck and knee braces or back protectors are specially designed for riders on a race track or off road.

- Other devices may be integrated into the design of the PTW. Crash studies show that collisions between the front of the PTW and the side of a car are frequent, with many riders falling before the collision as well as many riders departing from the PTW during the collision. Most attention to devices to prevent injuries in these cases has been given to leg protection and air bags. The purpose of such devices may be quite different: from preventing direct contact with collision objects to controlling speed and trajectory of the rider when departing the PTW during a collision. These devices are still experimental.

- Another means of preventing injuries is to equip the collision objects with energy absorbing devices or smoothening their surface. Crash studies have shown that injuries from single vehicle accidents are more severe when hitting a fixed object like a guard rail. Devices have been designed to be retrofitted to existing guard rails to prevent injuries to motorcyclists. So far the design of cars has had little attention in respect to reducing injuries of PTW riders.

4.1 Helmets

It is well known that helmets are very effective in preventing or reducing the severity of injuries to the head. A review of all (Petridou et al., 1998) available studies on helmets (Liu et al., 2004) concludes that helmets are effective in reducing head injuries to motorcyclists who crash by 72%. To study this effect requires a sample of impacts with large numbers of riders with and without helmets. A recent study is from Greece where helmet wearing rates are still low (Petridou et al., 1997). This sample consisted of 143 motorcycle riders with helmet and

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

1764 without killed or injured in crashes. The fatality rate of riders with helmet was 44% lower than for riders without a helmet.

The main purpose of helmets is to reduce the peak and duration of acceleration of the head by absorbing energy in case of a collision. There are two types of helmet: open face and full face. The full face helmet provides better protection to the face and chin area but is usually a little heavier. On the basis of research it is not possible to decide which type is better.

Tests at TRL with different energy absorbing liners and shells have shown that standard helmets have liners that are too stiff and shells that are too stiff and resilient (Hopes & Chinn, 1989). A more recent study showed that this may be correct when helmets are tested with existing standard tests. Tested with a more demanding test (which is recommended in that report) required an even stiffer shell. The design of helmets for PTW riders can be much improved. Eventually the motorcycle helmet may have a different design from a moped helmet. So far helmets for motorcycle riders and moped riders are the same and the standards for (testing) helmets do not differentiate between the two. A new UK consumer information programme provides comparative safety assessment of over 30 different new helmets (SHARP http://sharp.direct.gov.uk/).

From the point of view of preventing injuries there is no reason why any group of PTW users should be exempted from compulsory wearing of a helmet.

4.2 Protective clothing

Protective clothing has two objectives: The first one concerns high visible clothing aiming to improve conspicuity during daytime (fluorescent or bright clothing, vest, helmet, etc.) or during night time (reflective parts incorporated in the jacket or vest). The results of related studies on the conspicuity effect of PTW rider clothing are somewhat ambiguous, as their effectiveness appears to depend on the brightness of the environment (Hole et al., 1996; Gershon et al, 2011).

The second concerns clothing aiming protect all body parts against injuries when sliding over a surface. Other requirements depending on the climate and weather conditions are protection against cold, wet or heat. Clothing should not restrict the movements of the rider. On the basis of four studies, Elvik & Vaa (2004) estimated the effectiveness of protective clothing in reducing injuries. They concluded that the use of protective clothing reduces the probability of minor injury in a crash by 33-50%. This applies to the use of gloves, boots and clothing (see also Vehicle Safety text).

4.3 Leg protection and air bags

Leg protection in the form of crash bars may only prevent injuries from direct contact in collisions of the side of the PTW with a car/object. Other forms of leg protection have been studied to prevent injuries in frontal collisions by absorbing energy and directing the trajectory of the legs. Unfortunately, these devices may change the directory of the rider in such a way that the upper parts of the body are more likely to be injured.

Experiments with air bags show that the speed of the PTW rider who departs from the PTW during a frontal collision can be considerably reduced. Such devices are tested in full scale collision tests in which a moving PTW with a dummy rider collides with a moving or stationary car. The accelerations and loads on parts of the dummy are recorded and translated into injury patterns. The resulting injuries will depend on the speed of the PTW, the type of PTW, the seating position of the rider, the angle and point of collision with the of car and the type of car. Only a limited number of these variables have been included in such tests. For this reason it is difficult to decide how effective devices such as airbags or leg protectors are in practice. It seems that a combination of such devices will be needed to prevent injuries in a number of types of collision and to avoid that devices are beneficial in one type of collision but have adverse effects in others, or are effective in preventing one type of injury but introduce others. These devices are not likely to have much effect on loss of control accidents.

Most tests have been done with a motorcycle at a speed of about 60 km/h. It would be interesting to know the results of tests with scooter or step through types of moped.

The experiments with air bags are based on the idea that reducing the speed and controlling the trajectory of the PTW rider during a collision is preferable to fixing the rider to the PTW. A departure from this idea is made in the design of one particular type of PTW (Kompass, Osendorfer & Rauscher, 1998). In this case the PTW is designed as a safety cell which largely protects the rider from direct contact with collision objects among other things by means of a roof frame and seat belts. Tests showed positive effects with several types of collision (see also Vehicle Safety text).

4.4 Guard rails

Guard rails have been designed to prevent cars from colliding with obstacles behind the rail. They absorb energy and control the trajectory of the vehicle in collision with the rail. Existing rails have not been designed for collisions by PTWs and may cause severe injuries to their riders.

The first studies on collisions of PTWs with guard rails have concentrated on the design of the rail post as a short-term, low-cost solution. A recent German study tested several guard rail designs intended to reduce injuries to motorcycle riders (Gärtner, Rücker & Berg, 2006). The full scale collision tests showed two problems: a motorcycle sliding against the rail with the rider hitting the rail post and/or sliding under the rail and an upright motorcycle with the rider hitting or being trapped by the upper part of the rail. The experimental devices were designed to be retrofitted to existing rail designs. The test results showed the devices to be effective in preventing injuries to the rider and in controlling the trajectory of the motorcycle. They have not been tested yet in collisions by a car.

The costs of fitting these devices can be reduced by selecting road sections where collisions by motorcycles are more frequent, i.e. in tight curves in rural areas (Domhan, 1987).

European Commission

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

5 Prevention of crashes

Measures to prevent PTW crashes are based on knowledge of the crash characteristics and of factors contributing to crashes. Measures to prevent crashes are directly or indirectly aimed at the riders, the vehicles, other road users, the road environment or a combination of these.

Licensing, testing and training are related measures directed at the riders as well as defining access to categories of PTW. Little evidence exists of the effect of current licensing systems in improving safety. One future option is to introduce a more graduated system.

PTW braking a may be difficult and loss of control in an emergency situation is often found in accident studies. Some of these can be prevented with ABS/CBS brake systems on motorcycles but they are still to expensive to be fitted to all PTWs and depend on their effective use by riders. A Swedish study (Rizzi et al., 2009) has estimated positive safety effects of antilock brake system (ABS) technology on motorcycles in reducing real life injury crashes and to mitigate injury severity.

Conspicuity devices are worn by riders or are part of the vehicle. Most research has focused on the potential role of daylight running lights.

Enforcement and promotional campaigns may be directed at PTW riders as well as at other road users.

Measures aimed at the road environment may directly prevent crashes or act through their influence on the behaviour of road users. Variations in road surface can cause particular problems for PTW riders.

Work on eSafety systems has mainly been directed at cars and Lorries but the potential to improve motorcycle safety through ITS is now being explored.

A detailed overview of PTW safety measures and recommendations is available via the 2-BE-SAFE project (2012).

5.1 Learning, testing and licensing

Learning, testing and licensing of PTW riders are related subjects. Together they form a system to make sure that all riders have an acceptable level of competency. This competency requires sufficient mental maturity and has to be learned by training and experience. Although there is no concrete results to support a crash reduction effect for rider training (not within a graduated licensing system with other restrictions), given the characteristics of a PTW and their high crash rate, it is obvious that riders need a high level of competence both in terms of vehicle control and in terms of safe interaction with other road users.

European Commission

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

During training and practising riders have to learn where and when to take action to avoid a situation in which there is little or no time left to avoid a crash. In most situations riders will react in time with a gradual change in speed and/or direction, but sometimes more extreme changes are needed and in an emergency situation only a change at the limit of losing control is needed to prevent a crash.

During learning riders will improve their control of the PTW when accelerating, braking, changing direction at different speeds and on different sorts of road surface. As a result, situations that are close to resulting in a crash at an early stage of learning may not be so later on. The aim of training programs is to improve the competency of riders in order to reduce their crash rate. But a program may have adverse effects depending on the motivation of the applicants. More experienced riders may willingly start actions (like overtaking, cornering at high speed) which are close to their limit of losing control.

A recent review on licensing and training of motorcycle riders from Australia (Haworth & Mulvihill, 2005) emphasises that there is no convincing evidence of the effect of traditional licensing systems and very little of elements of such systems. The review presents an optimal motorcycle licensing and training model. The model is based on the concept of gaining experience in low-risk situations before graduating to higher-risk situations. According to the review this requires that potential riders should gain experience driving a car before they start learning to ride a motorcycle. The model specifies a learner stage, a provisional stage and a full license stage with both a minimum and maximum period for a learner license and a minimum period for holding a provisional license. Off road training and testing is needed to obtain a learner license aimed at acquiring skills for unsupervised riding. On road training and testing is needed for a provisional license aimed at improving ability to detect and respond to physical hazards as well as hazards associated with other road users. Both stages also have restrictions on power to weight ratio of the motorcycle, on carrying of passengers and a zero alcohol level. Fully licensed riders are retested on road each ten years.

Such a system of graduated licensing is expected to reduce the number of motorcycle crashes because:

- Young riders are not allowed to ride a motorcycle, or are not allowed to ride a motorcycle exceeding a given engine size.
- Learning and gaining experience is restricted to low risk conditions
- Licensed riders are more competent (as compared with other systems)
- Some potential riders are discouraged to obtain a motorcycle license

The Australian review does not address the licensing of moped riders or the voluntary advanced training of fully licensed riders.

There are current proposals to change the European Directive on licensing (Directive 2006/126/EC of the European Parliament, 2006. This increases the age access for some types of PTW but generally does not apply graduated licensing principles, and includes some aspects which may increase the likelihood of motorcycle accidents.

The potential to introduce hazard perception as part of the motorcycle test is also the subject of recent research. Such training might also be achieved through voluntary advanced training programmes. Specific training programmes for moped riders might also be considered.

5.1.1 European Directive on licensing

Most European countries follow the EU Directive on licensing (Directive 1991/439/EEC). There is a proposal to change this Directive with the following categories (Directive 2006/126/EC):

- Moped, with design speed of max. 45 km/h (excluding those with design speed of max. 25 km/h), minimum age of 16 years (countries may vary between 14 and 18), compulsory theoretical test or motorcycle/car license instead (countries may require practical test or motorcycle license instead)
- 125 cc motorcycle, with max. 11 kW and 0,1 kW/kg, minimum age 16 years (countries may vary to 18 years), compulsory theory and practical testing or other motorcycle license instead (countries may allow car license instead)
- 35 kW motorcycle, with max. 0,2 kW/kg, age limit two years more than for 125 cc (i.e. at least 18), compulsory theory and practical test or two years 125 cc license plus practical training/test instead
- Unrestricted motorcycle, with age limit of 24 years and compulsory theoretical and practical test, or two years 35 kW license plus practical training/test instead

The proposed Directive also contains minimum requirements for testing with specific requirements for motorcycle tests.

The main differences with the existing Directive are less freedom to countries for moped licensing, direct access to an unrestricted motorcycle at age 24 instead of 21 and the 35 kW motorcycle replaces the 24 kW categories. The first two differences may help to reduce the number of PTW crashes. The third (35 kW motorcycle) is more likely to do the opposite although it is hard to predict to what extent.

The most striking differences with the model proposed in the Australian review are that no car license is required, low age limit for a 125 cc license, absence of unsupervised and restricted riding to gain experience, possibility of direct access to 35 kW and to unrestricted motorcycles. The requirement of a car license has several effects on crashes. Experience in real traffic is gained in a car which is safer than on a motorcycle and motorcycle riding is delayed or possibly given up. There is no question that a higher age limit will result in less crashes and in this respect an age limit for moped riders of 18 is much better than 16 or 14 and an age limit of 18 years for 125 cc motorcycles is better than 16. The European system is not a graduated system in the strict sense. It may be hoped that potential riders will start riding on a moped or 125 cc motorcycle but from 18 years they have direct access to a 35 kW motorcycle and from age 24 to an unrestricted motorcycle. The adverse effects of immaturity may be minimised with these age limits. But a system with direct access to high powered motorcycles is more likely to lead to crashes during the first years of riding than a truly graduated system unless the quality of training for direct access is at an exceptionally high level.

In western European countries it is common to allow on-road training only if supervised by a qualified instructor. Great Britain differs with compulsory training at 17 years, followed by maximum period of two years of unsupervised riding on a 125 cc motorcycle. After passing a theoretical and practical test the rider is then licensed to ride a 25 kW motorcycle and after two more years to ride an unrestricted motorcycle. Again this system is not strictly graduated since it also has the option of direct access from age 21.

There is no evidence or indication which of the presently existing systems is better, supervised training by a qualified instructor or unsupervised practising on a low performance PTW. There is little doubt, however, that a better system in terms of crash prevention is a graduated system with:

- High minimum age limit (at least as high as for a car license)
- At least two stages of riding under low risk conditions on a low performance motorcycle with a combination of compulsory training and unsupervised practising
- Testing before and at the end of each stage
- No option of direct access

5.1.2 Hazard perception and responding

According to the Australian review (Haworth & Mulvihill, 2005) the present tests and training programs do not adequately address rider motivation and riding style or hazard perception and response. A traffic hazard is an element of a traffic situation with the potential of initiating a collision and therefore requiring special attention. It may be related to the road (a change in road surface, a curve) or related to the presence and behaviour of other road users. Hazard perception and responding is the behaviour in between normal and timely actions (to avoid a situation with little or no time to avoid a crash) and emergency actions (with little or no time left).

Hazard perception has been the subject of recent research, mostly in relation to car driving. Studies have shown that hazard perception can be improved by training but as yet there is no proof that this will result in safer behaviour or a lower crash rate.

Great Britain has introduced a hazard perception test as part of the compulsory testing for a license. The test consists of video presentations of traffic situations containing an indication that a risky situation might result. There is no separate test for motorcycle riders. Haworth et. al. (2005) argue that hazard perception in relation to motorcycling is different because motorcyclists have to deal with additional hazards which are road-based as well as related to the behaviour of other road users in the presence of a motorcycle. Responding to a hazard is also more crucial because other road users may not respond to the motorcyclist and controlling the motorcycle trying to avoid the risky situation is difficult. The subject of hazard perception and responding is complicated because whether the situation becomes risky also depends on the behaviour of the rider. Motorcyclists may start actions like overtaking and accepting small gaps in situations where car drivers would not do so.

5.1.3 Voluntary, advanced training programs

Many private organisations offer voluntary, advanced training programs. Their aim may differ e.g. improving the detection and avoidance of (potential) emergency situations or improving vehicle control in difficult situations. The effects will depend on the motivation of the participants. With riders who are safety minded these programs can be expected to improve their behaviour and prevent accidents. With performance-oriented riders the result may be the opposite.

5.1.4 Moped riders

There is very little research on the licensing of moped riders. In the Netherlands the effect of an experimental practical training program has been studied (Goldenbeld et al., 2004). Participants had just passed the compulsory theoretical test at age 16 and were randomly assigned to the training program and to a control group. The program consisted of 16 hours off and on road training over a period of four weeks. During a 30 minute standard test ride in real traffic the riders were scored by a qualified (motorcycle) examiner who did not know which riders were trained. The training group scored better in the test ride two weeks after training. After 11 month the control group had improved as well to about the same level of competency, but the trained riders had slightly lower scores then before. Based on the results of this study a licensing system for moped riders could start with a compulsory training programme, followed by a period with a provisional license and ending with a practical training programme/test.

5.1.5 PTW Braking

In a special study on the role of braking in crashes, Sporner (2002) used a sample of 502 injury crashes in 2001-2002 in Germany. 279 of the motorcyclists took action to avoid the accident, of which 54 lost control. Based on the crash records an estimate was made of cases that might have been prevented if the rider had been able to use an anti locking brake system (ABS).10-15 crashes would have been avoided and another 30 would have had less severe consequences since the system would have prevented loss of control and would have reduced the collision speed.

More recently, Rizzi et al. (2009) show that head-on collisions were the least ABS-affected crash types and collisions at intersections the most influenced, while the overall effectiveness of ABS was 38 % on all crashes with injuries and 48% on all severe and fatal crashes, with a minimum effectiveness of 11 and 17%, respectively.

Today ABS is available for many large motorcycles and scooters, but is still too expensive to be fitted to all PTWs. There are various systems with ABS on front wheel only or on both wheels with separate or combined control of both wheels. A combined braking system (CBS) automatically distributes the braking force between front and rear wheel. These systems are also available without ABS, but these will not prevent locking of the wheels when braking too hard.

Even ABS is no guarantee for successful braking in an emergency. Braking in a curve produces forces on the steering system which have to be corrected by the rider. For this reason the full potential of ABS cannot be used at the same time. Also riders have to learn to use the full potential of ABS when riding in a straight line. Moreover, while the implementation of ABS on motorcycles may improve stability during critical situations, further development of integrated leg protectors might still be needed, especially in collisions with barriers (Rizzi et al., 2012).

Electronic Stability Control (ESC) is another mature vehicle technology incorporated as a standard or as extra equipment in several PTW vehicle models, aiming to prevent the rear wheel from spinning uncontrolled when accelerating. However, there are no specific research results on the effectiveness of ESC to reduce motorcycle crashes.

5.2 Conspicuity devices

Research has mainly focussed on the potential benefit of daytime running lights. Although it is clear that the perception of a PTW is much improved by the use of a PTW headlight during the daytime this is only a partial solution; many crashes still occur where the driver had not seen the motorcycle in spite of the headlight being on.

Research studies show that the use of daytime running lights by cars has no adverse effect on the benefits of headlight use by PTWs in most situations.

5.2.1 Daytime running lights for PTWs

Several experiments have been done on potential solutions to the problems of perception of PTWs by other road users. The effect of headlights during daytime and of clothing have been studied by Hole et al. (1996) using slide pictures and by Langham (1995) using video presentations in a similar study. At short viewing distance it did not matter whether the motorcycle headlight was on or against which sort of background the motorcycle was shown. At longer viewing distance the motorcycle was noticed better with headlight on against a complex background. The effect of bright clothing also depended on the type of background. In another experiment Hole and Tyrrell (1995) found that the more pictures were shown in which other motorcycles had headlights on, the less likely a motorcycle without headlight was to be noticed.

These experiments will never fully reproduce the natural behaviour of car drivers in real traffic i.e. their strategy to scan the road for other road users who may be relevant to them. But the assumption is made that if one condition (e.g. headlight on) is found to be better than another (e.g. dark clothing) this will be the same in real traffic.

The effects of headlights and clothing in practise have been studied in a case control study in New Zealand (Wells et al., 2004) with 463 crash cases from 1993-1995 and 1233 controls. The relative crash rate was corrected for other factors such as age and experience of the rider and found to be 27% lower for motorcycles with headlight on during daytime and 37% lower for riders with reflective or fluorescent clothing.

Bijleveld (1997) used crash statistics from Austria and calculated a saving of 35% of collisions between car and motorcycle during daylight after the introduction of compulsory use of headlights by motorcyclists (compared to a situation with 0% use). Elvik and Vaa (2004) included 12 primarily studies from the United States in a meta-analysis on the effects of a mandatory use of running lights. This meta-analysis showed a reduction of around 7% (+/- 3%) in the number of multiparty crashes in daylight.

Although it is clear that the perception of a PTW is much improved by the use of a headlight during daytime, Noordzij & Vis (1998) still found many crashes in which the car driver had not seen the motorcycle in time in spite of its headlight being on.

5.2.2 Daytime running lights for cars

The benefits of motorcycle headlights may be less if cars also have their headlights on. There are some experimental studies on this subject. Brendicke et al.(1994) showed pictures of traffic situations and observers had to report which vehicles they had seen. The pictures contained motorcycles with headlights on and cars with or without headlights on urban as well as rural intersections and road sections. A closer examination of their results shows that only on rural intersections were motorcycles less often noticed than cars and even less so in combination with cars with headlights.

In an experiment by Brouwer et al. (2004) observers had to report if and which other road user was present. The slides always showed a car with or without headlight. The experiment also varied the distance between car and other road user, the background, the proportion of slides with a car with headlight on and the proportion of slides with another road user. It took more time to detect a pedestrian than a pedal cyclist or motorcyclist and the detection of a motorcycle with headlight was even faster than without headlight. However, the headlight of the car had no negative effect in all situations studied.

In a field experiment (Cobb, 1992) observers in a moving car had to report which road user they had seen at an intersection. There was always a car alone or together with a pedal cyclist or a motorcycle with headlight on. Observers always noticed the pedal cyclist and motorcycle except when the car used very bright headlights.

The conclusion from these experiments is that the use of headlights during daytime by cars has no adverse effect on the benefits of headlight use by PTWs in most situations, except when the car headlights cause glare. This conclusion is confirmed by Koornstra et al. (1997) with accident statistics from Norway and Denmark where compulsory use of headlights was introduced for cars some years later then for motorcycles. An increase in collisions between car and motorcycles during daylight was insignificant.

All studies were concerned with motorcycles rather than mopeds, but the perceptual problems are likely to be the same and the use of headlights during daytime by mopeds and the wearing of fluorescent/reflective clothing is a partial solution to them as well.

On the other hand, a recent study (Cavallo & Pinot, 2012) suggests that car DRLs may hamper motorcycle perception compared to conditions where car lights are not on, especially when the motorcycle is at a greater distance from the observer. Although the globally positive safety effect of car DRLs is generally acknowledged, the study suggests that more attention should be paid to motorcyclists and other vulnerable road users when introducing car DRLs.

Another contribution to solve the problems of perception of PTWs may be found in more attention to these problems in the training of car drivers.

5.3 Enforcement of legislation

A licence system needs enforcement to prevent the use of PTWs by unlicensed riders. Haworth and Smith (1998) found a group of Australian riders without valid licence with a relatively high crash rate. Other subjects that may need enforcement are speed limits, drinking, tampering of the engine and helmet wearing, inappropriate acceleration or overtaking, mobile phone use.

The actual need for enforcement programs will depend on the proportion of riders in violation of the law. This may vary between countries.

5.4 Promotional campaigns

Several subjects are eligible for promotional campaigns to prevent PTW crashes and injuries:

- Wearing helmets (properly locked) and protective clothing
- Headlights on and wearing fluorescent/ retroflective clothing
- Avoiding risky behaviour and situations (speeding, alcohol, red light violation)
- Attention from car drivers to the presence and behaviour of PTW riders (using turning lights, using mirrors as well as head checks to make sure blind spots are clear etc.)

5.5 Road environment and traffic management

In general, the principles of self-explaining and forgiving road environments should be applied to all road users, with special care for PTW safety issues.

The quality of the road surface is much more important for the safety of PTWs than for cars. Poor condition of the road surface or small objects on the road are likely to cause loss of control of a two-wheeled vehicle.

The European Motorcycle Industry has prepared “Guidelines for PTW safe road design in Europe” (2006). This is an inventory of aspects that are relevant for (the safety of) PTWs with attention to road design, road maintenance, traffic engineering and traffic management. Particular problems in view of PTW safety are:

- All kinds of speed inhibitors in urban areas with different types of road surface, speed humps, lane narrowing's etc. Traffic calming schemes, although beneficial for all road users, may raise motorcycle safety concerns due to the road surface interventions involved.
- Use of raised lane markings and lane dividers, as well as barriers and guardrails; these are designed to increase protection of passenger cars, but may have detrimental effects on PTW safety.
- Poor maintenance and temporary road repairs

5.5.1 Lane splitting and filtering

Lane filtering by motorcyclists is defined as moving between traffic when other surrounding traffic is stationary. Lane splitting is defined as moving through traffic when other traffic is in motion. The first case is standard motorcycle practice and necessary for efficient motorcycle travel, however there are safety concerns on which the existing literature is not conclusive. The second case, however, is not allowed in most European countries.

5.6 eSafety

Technical developments have sparked off a complete new field of potential countermeasures, which aim to assist the rider, to control the vehicles, to regulate the access to vehicles, and to monitor behaviour. These so-called ITS systems are mainly developed for implementation in passenger cars and lorries. Bayly et al. (2006) reviewed the literature on the availability and effects of ITS systems on motor cycle safety. They concluded that almost no systems are available for motorcyclists, and that very little evaluative studies exist.
To fill this gap in knowledge, the EU project PISa aims to develop and implement "reliable and fail-safe" integrated safety systems for a range of PTWs, to improve the performance and primary safety (handling and stability) and that can link to secondary safety devices. Within the project PTWs will be fitted with integrated safety systems with the ambition to demonstrate the potential of such systems to reduce the incidence and severity of up to 50% of PTW crashes. The specification of components of such safety systems will be defined from relevant accident mechanisms and rider assistance functions identified and from identification of existing technologies and safety systems in cars. The systems will take human reaction to information, warning and support systems in to account. More information can be found on http://www.pisa-project.eu/site/en/about.php

References

2-BE-SAFE (2009) Risk factors of powered-two-wheelers safety: state of the art.

2-BE-SAFE (2012) Powered Two Wheelers - Safety Measures: Guidelines, Recommendations and Research Priorities.

Assing, K.(2002) Schwerpunkte des Unfallgeschehens von Motorradfahrern. Bericht zum Forschungsprojekt 99 420 der Bundesanstalt für Strassenwesen BASt. Bergisch Gladbach, Bundesanstalt für Strassenwesen BASt, 2002, 83 p., 9 ref.; Berichte der Bundesanstalt für Strassenwesen : Mensch und Sicherheit ; Heft M 137.

Bayly, M., Regan, M., & Hosking, S. (2006) Intelligent transport systems and motorcycle safety. [Report No. 260]. Melbourne, Australia: Monash University, Accident Research Centre.

Bijleveld, F.D (1997) Effectiveness of daytime motorcycle headlights in the European Union. On behalf of KeyMed Medican and Industrial Equipment Ltd. Leidschendam, SWOV Institute for Road Safety Research, 1997, 43 p., 16 ref.; R-97-9.

BIVV (2005) Aandacht voor Motorrijders in de Weginfrastructuur, brochure voor de Wegbeheerders nr. 3, 35p.

Bjørnskau, T., Nævestad T-O., Akhtar J. (2012) Traffic safety among motorcyclists in Norway: A study of subgroups and risk factors. Accident Analysis and Prevention 49 (2012) 50– 57.

Brailly, M.C (1998) Studie von Motorradunfällen mit Stahlleitplankenanprall. In: Safety environment future II : proceedings of the 1998 International Motorcycle Conference, IfZ Forschungshefte Zweiradsicherheit No. 8, p. 387-401.

Brendicke, R. Forke, E. & Gajewski, R (1995) Motorradfreundlicher Strassenbau: Motorradspezifische Anforderungen und Planung, Bau und Betrieb von Ausserortsstrassen. Essen, Institut für Zweiradsicherheit IfZ, 1995, 71 p, 72 ref.; 2., aktualisierte Auflage; Praxishefte Zweiradsicherheit.

Brendicke, R. Forke, E. & Schäfer, D (1994) Auswirkungen einer allgemeinen Tageslichtpflicht auf die Sicherheit motorisierter Zweiräder. In: Motorrad : 6. Fachtagung der VDI-Gesellschaft Fahrzeug- und Verkehrstechnik Gemeinschaftskonferenz, Köln, 4. und 5. Oktober 1994, p. 283-318, 43 ref.

Broughton, J. (1988) The relation between motorcycle size and accident risk. Crowthorne, Berkshire, Transport and Road Research Laboratory (TRRL), 1988, TRRL Research Report.

Broughton, J. (2005) Car occupant and motorcyclist deaths, 1994-2002. Prepared for the Department for Transport, Road Safety Division. Crowthorne, Berkshire, Transport Research Laboratory TRL, 2005, TRL Report.

Brouwer, R.F.T. Janssen, W.H. Theeuwes, J. Duistermaat, M. & Alferdinck, J.W.A.M (2004) Do other road users suffer from the presence of cars that have their daytime running lights on? Soesterberg, TNO Human Factors Research Institute TM, 2004, 28 p., 26 ref.; Report TNO TM-04-C001.

Carré, J.-R. Filou, C (1996) l'Insécurité des cyclomotoristes: situation francaise et internationale. Arcueil, Institut National de Recherche sur les Transports et leur Sécurité INRETS, Rapport INRETS.

Cavallo V., Pinot M. (2012) Are car daytime running lights detrimental to motorcycle conspicuity? Accident Analysis and Prevention 49 (2012) 78– 85.

Clabaux, N., Brenac T., Perrin C., Magnin J., Canu B., Van Elslande P. (2012) Motorcyclists' speed and "looked-but-failed-to-see" accidents. Accident Analysis and Prevention 49 (2012) 73– 77.

Cobb, J.(1992) Daytime conspicuity lights. Prepared for Department of Transport DOT, Vehicle Standards and Engineering VSE. Crowthorne, Berkshire, Transport Research Laboratory TRL, 1992, 29 p., 17 ref.; Working Paper ; WP/RUB/14.

Directive 2006/126/EC Of the European Parliament and of the Council, 20 dec. 2006.

Domhan, M.(1987) Passive Sicherheit von Schutzplanken beim Anprall von Motorradfahrern. In: Forschungshefte Zweiradsicherheit No. 5, Institut für Zweiradsicherheit IfZ, Bochum.

DRUID (2010) Prevalence study: Main illicit psychoactive substances among all drivers involved in fatal road crashes in France, Deliverable 2.2.4 of DRUID, available on-line at: http://www.druid-project.eu/cln_031/nn_107548/Druid/EN/deliverales-list/downloads/Deliverable__2__2__4,templateId=raw,property=publicationFile.pdf/Deliverable_2_2_4.pdf.

Elslande, P. van (2002) Specificity of error-generating scenarios involving motorized two-wheel riders. In: Wang, K., Xiao, G., Nie, L. & Yang, H. (Eds.). Traffic and transportation Studies ICCTS'2002 (Vol. 2, pp. 1132-1139). Reston : ASCE.

Elvik, R., Hoye A., Vaa, T., & Sorensen M. (2009) The handbook of road safety measures. 2nd Edition: Emerald Publishing Group UK.

Filou, C. Lagache, M. & Chapelon, J. (2005) Les motocyclettes et la sécurité routière en France en 2003. Paris, la Documentation Francaise.

Gärtner, M. Rücker, P. & Berg, F.A. (2006) Entwicklung und Prüfung der Anforderungen an Schutzeinrichtungen zur Verbesserung der Sicherheit von Motorradfahrern. Bonn-Bad Godesberg, Bundesminister für Verkehr, Bau- und Wohnungswesen, Abteilung Strassenbau, Strassenverkehr, 2006, 137 p., 11 ref.; Forschung Strassenbau und Strassenverkehrstechnik ; Heft 940 - ISSN 0344-0788 / ISBN 3-86509-477-5.

Gershon, P., Ben-Asher, N. & Shinar, D. (2011) Attention and search conspicuity of motorcycles as a function of their visual context. In: Accident Analysis & Prevention, Vol. In Press, Corrected Proof, nr.

Goldenbeld, C. Twisk, D.A.M. & Craen, S. de (2004) Short and long term effects of moped rider training: a field experiment. Transportation Research Part F. 2004 /01 7f (1) Pp1-16 (25 Refs.).

Guidelines for PTW-safer road design in Europe (2006) Brussels, ACEM - Association des Constructeurs Européens de Motocycle (The Motorcycle Industry in Europe).

Harrison, W.A. & Christie, R. (2005) Exposure survey of motorcyclists in New South Wales. Accident Analysis & Prevention. 2005 /05. 37(3).

Haworth, N.L. & Smith, R. (1998) Estimating risk factors for motorcycle crashes. In: Safety environment future II : proceedings of the 1998 International Motorcycle Conference, IfZ Forschungshefte Zweiradsicherheit No. 8, p. 205-220.

Haworth, N. Mulvihill, C. & Symmons, M (2002) Motorcycling after 30. Clayton, Victoria, Monash University, Accident Research Centre MUARC, 2002, XII + 88 p., 4 ref.; MUARC Report ; No. 192 - ISBN 0-7326-1491-0.

Haworth, N. & Mulvihill, C. (2005) Review of motorcycle licensing and training. Clayton, Victoria, Monash University, Accident Research Centre MUARC, 2005, XII + 84 p., 77 ref.; MUARC Report ; No. 240 - ISBN 0-7326-2310-3.

Haworth, N. Mulvihill, C. & Symmons, M. (2005) Hazard perception and responding by motorcyclists: background and literature review. Clayton, Victoria, Monash University, Accident Research Centre MUARC, 2005,; MUARC Report ; No. 235.

Hole, G.J. & Tyrrell, L (1995) The influence of perceptual `set' on the detection of motorcyclists using daytime headlights. Ergonomics, Vol. 38 (1995), No. 7 (July), p. 1326-1341, 19 ref.

Hole, G.J. Tyrrell, L. & Langham, M (1996) Some factors affecting motorcyclists' conspicuity. Ergonomics, Vol. 39 (1996), No. 7 (July), p. 946-965, 16 ref.

Hopes, P.D. & Chinn, B.P.(1989) Helmets: A new look at design and possible prevention. In: Proceedings of the 1989 International IRCOBI Conference on the Biomechanics of Impacts, Stockholm (Sweden), September 13- 14- 15, 1989, p.39- 54, 18 ref.

Horswill, M.S. & Helman, S. (2003) A behavioral comparison between motorcyclists and a matched group of non-motorcycling car drivers: factors influencing accident risk. Accident Analysis & Prevention. 2003 /07 35(4) Pp589-97 (32 Refs).

Ingebrigtsen, S. (1990) Risikofactorer ved verdsel med moped og motorsykkel. TøI –report 66. Transportøkonomisk institutt Oslo.

Kompass, K. Osendorfer, H. & Rauscher, S.(1998) The safety concept of BMW C1. In: Safety environment future II : proceedings of the 1998 International Motorcycle Conference, IfZ Forschungshefte Zweiradsicherheit No. 8, p. 223-241, 2 ref.

Koornstra, M.J. Bijleveld, F.D. & Hagenzieker, M.P.(1997) The safety effects of daytime running lights : a perspective on day daytime running lights (DRL) in the European Union EU : the statistical re-analysis and a meta-analysis of 24 independent DRL-evaluations as well as an investigation of possible policies on a DRL-regulation in the EU. On behalf of the Commission of the European Communities CEC, Directorate-General for Transport VII. Leidschendam, SWOV Institute for Road Safety Research, 175 p., 130 ref.; R-97-36.

Kramlich, T. (2002) Noch immer gefährliche Begegnungen: die häufigsten Gefahrensituationen für Motorradfahrer und die resultierenden Verletzungen. In: Safety environment future IV : proceedings of the 4th International Motorcycle Conference, München, 16-17 September 2002, IfZ Forschungshefte Zweiradsicherheit No. 10, p. 55-84.

Langham, M.P (1995) The effects of cognitive style in a laboratory investigation of motorcycle conspicuity. In: Vision in vehicles VI : proceedings of the Sixth International Conference on Vision in Vehicles VIV6, Derby, England, 13-16 September 1995, p. 191-199, 23 ref.

Langley, J. Mullin, B. Jackson, R. & Norton, R.(2000) Motorcycle engine size and risk of moderate to fatal injury from a motorcycle crash. Accident Analysis & Prevention. 2000 /09. 32(5).

Lardelli-Claret, P., Jimenez-Moleon, J. J., Luna-del- Castillo, J. D., Garcia-Martin, M, Bueno-Cavanillas, A. and Galvez-Vargas, R. (2005). Driver dependent factors and the risk of causing a collision for two wheeled motor vehicles, Injury Prevention, 11, 225-231.

Liu, B. Ivers, R. Norton, R. Blows, S. & Lo, S.K. (2004) Helmets for preventing injury in motorcycle riders. The Cochrane Library, (2004), No. 3.

Lynam, D. Nilsson, G. Morsink, P. Sexton, B. Twisk, D.A.M. Goldenbeld, C. & Wegman, F.C.M. (2005) SUNflower +6 : further comparative study of the development of road safety in Sweden, United Kingdom, and the Netherlands. [Title on cover: An extended study of the development of road safety in Sweden, United Kingdom, and the Netherlands.]. Leidschendam, SWOV Institute for Road Safety Research / Crowthorne, Berkshire, Transport Research Laboratory TRL / Linköping, Swedish National Road and Transport Research Institute VTI.

MAG – Motorcycle Action group (2008), Vademecum motorrijdersvoorzieningen, Belgium, March 2008.

Magazzu, D. Comelli, M. & Marinoni, A. (2006) Are car drivers holding a motorcycle licence less responsible for motorcycle - Car crash occurrence? A non-parametric approach. Accident Analysis & Prevention. 2006 /03. 38(2) P 365-70.

Mellor, A.N. StClair, V.J.M. & Chinn, B.P.(2007) Motorcyclists' helmets and visors : test methods and new technologies. Crowthorne, Berkshire, Transport Research Laboratory TRL, 2007, 349 p., 22 ref.; Published Project Report ; PPR 186 - ISSN 0968-4093 / ISBN 978-1-84608-853-7.

Motorcycle Accident In-Depth Study MAIDS (2004) In-depth investigations of accidents involving powered two wheelers : final report. Brussels, ACEM - Association des Constructeurs Européens de Motocycle (The Motorcycle Industry in Europe).

Mullin, B., R. Jackson, J. Langley, and R. Norton (2000) Increasing age and experience: are both protective against motorcycle injury? a case-control study. Injury Prevention 6, 32 { 35.

Noordzij, P.C. (1998) Safety of mopedriding in The Netherlands. In: Safety environment future II : proceedings of the 1998 International Motorcycle Conference, IfZ Forschungshefte Zweiradsicherheit No. 8, p. 135-145.

Noordzij, P.C. & Vis, A.A (1998) Safety of motorcycling in The Netherlands. In: Safety environment future II : proceedings of the 1998 International Motorcycle Conference, IfZ Forschungshefte Zweiradsicherheit No. 8, p. 123-132.

Otte, D. (1998) Unfall- und Verletzungssituation bei Motorrollern. In: Safety environment future II : proceedings of the 1998 International Motorcycle Conference, IfZ Forschungshefte Zweiradsicherheit No. 8, p. 147-172.

Petridou, E. Skalkidou, A. Ioannou, N. & Trichopoulos, D. (1998) Fatalities from non-use of seat belts and helmets in Greece: a nationwide appraisal. accident analysis & prevention. 1998 /01. 30(1) PP87-91.

Raithel, J.(1998) riskantes verkehrsverhalten jugendlicher motorzweiradfahrer : befunde einer pilotstudie. Zeitschrift Fuer Verkehrssicherheit. 1998. 44(4) Pp146-50.

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

Rizzi, M., Strandroth, J. and Tingvall, C. (2009) 'The Effectiveness of Antilock Brake Systems on Motorcycles in Reducing Real-Life Crashes and Injuries', Traffic Injury Prevention, 10: 5, 479 — 487.

Rizzi M., Strandroth J., Sternlund S., Tingvall C., Fildes B. (2012) Motorcycle Crashes into Road Barriers: the Role of Stability and Different Types of Barriers for Injury Outcome. IRCOBI Conference 2012.

Rogerson, P. Lambert, J. & Allen, P.(1992) Motorcycle accident involvement by power to weight ratio for novice and experienced riders. Hawthorn, Vic., VIC Roads, Road Safety Division RSD, 1992, VIC Report ; No. GR 92-11.

Rutter, D., Quine, L and Albery, I.(1998) Perceptions of risk in motorcyclists: unrealistic optimism, relative realism and predictions of behaviour. British Journal of Psychology 89, 681696.

Schulz, U. Gresch, H. & Kerwien, H.(1991) Motorbiking: motives and emotions. In: Safety environment future : proceedings of the 1991 International Motorcycle Conference, Bochum, 1991, IfZ Forschungshefte Zweiradsicherheit No. 7, p. 465-483.

Schulz, U. (1995) Gibt es einen Zusammenhang zwischen Motorradleistung und Unfallverwicklung ? : Oder: sind leistungsstärkere Motorräder gefährlicher ? Verkehrsunfall und Fahrzeugtechnik, Vol. 33 (1995), No. 9 (September), p. 239-244.

Schulz, U (1998) Riding style, engine power and accident involvement of motorcyclists. In: Safety environment future II : proceedings of the 1998 International Motorcycle Conference, IfZ Forschungshefte Zweiradsicherheit No. 8, p. 263-277.

Sexton, B. Baughan, C. Elliott, M. & Maycock, G. (2004) The accident risk of motorcyclists. Prepared for the Department for Transport, Road Safety Division. Crowthorne, Berkshire, Transport Research Laboratory TRL, 2004, TRL Report ; No. 607 - ISSN 0968-4107.

Sporner, A.(2002) Neueste Ergebnisse der Unfallforschung der deutschen Autoversicherer mit speziellem Schwerpunkt : Bremsen mit Motorrädern. In: Safety environment future IV : proceedings of the 4th International Motorcycle Conference, München, 16-17 September 2002, IfZ Forschungshefte Zweiradsicherheit No. 10, p. 151-178, 3.

Sraml M., Tollazzi T., Rencelj M. (2012) Traffic safety analysis of powered two-wheelers (PTWs) in Slovenia. Accident Analysis and Prevention 49 (2012) 36– 43.

Vries, de, Y.W.R. Margaritis, D. & Mooi, H.G.(2003) Moped and mofa accidents in The Netherlands from 1999-2001: accident and injury causation. In: Proceedings of the 18th International Technical Conference on Enhanced Safety of Vehicles ESV, Nagoya, Japan, May 19-22, 2003, 9 p., 2 ref.

Wells, S. Mullin, B. Norton, R. Langley, J. Connor, J. Lay-Yee, R. & Jackson, R. (2004) Motorcycle rider conspicuity and crash related injury case-control study. British Medical Journal, (23 January 2004) doi:10.1136/bmj.37984.574757.EE, 6 p., 24 ref.

Wulf, G., Hancock, P.A. & Rahimi, M. (1989) Motorcycle conspicuity: an evaluation and synthesis of influential factors. In: Journal of Safety Research, Vol. 20/4.