Integration of needs of moped and motorcycle riders into safety measures

P.C. Noordzij (SWOV), E. Forke (IfZ), R. Brendicke (IfZ)
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Review and statistical analysis in the framework of the European research project PROMISING, Workpackage 3

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P R O M I S I N G

Promotion of Measures for Vulnerable Road Users
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TRL - Transport Research Laboratory, Great Britain

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Notice to the reader

This volume is one of the six deliverables of the European research project PROMISING, on the promotion of mobility and safety of vulnerable road users. The research was carried out by a consortium of European partners, which was co-ordinated by the SWOV Institute for Road Safety Research.

The main report of the PROMISING project is written and edited by SWOV, based on the contributions of the various authors of the six deliverables. These deliverables were not re-edited, but are published in the form in which they were furnished by the authors. SWOV is not responsible for the contents of deliverables that were produced by authors outside SWOV.

Copies of the PROMISING publications can be obtained by contacting the respective author, or by downloading them from the SWOV website www.swov.nl. The full publication consists of the following volumes:

Final report; SWOV publication D-2001-3
Promotion of mobility and safety of vulnerable road users. Final report of the European research project PROMISING.
SWOV Institute for Road Safety Research, Leidschendam, the Netherlands.

Deliverable 1
Measures for pedestrian safety and mobility problems. Final report of workpackage 1.
NTUA National Technical University of Athens, Greece.

Deliverable 2
Measures to promote cyclist safety and mobility. Final report of workpackage 2.
VTT Technical Research Centre of Finland, Espoo, Finland.

Deliverable 3; SWOV publication D-2001-5
Integration of needs of moped and motorcycle riders into safety measures; Review and statistical analysis in the framework of the European research project PROMISING, Workpackage 3.
SWOV Institute for Road Safety Research, Leidschendam, the Netherlands.

Deliverable 4
Safety of young car drivers in relation to their mobility. Final report of workpackage 4.
BASt Bundesanstalt für Straßenwesen, Bergisch-Gladbach, Germany.

Deliverable 5
Cost-benefit analysis of measures for vulnerable road users. Final report of workpackage 5.
TRL Transport Research Laboratory, Crowthorne, United Kingdom.

Deliverable 6; SWOV publication D-2001-6
National and international forums to discuss the approach and the results of PROMISING. Discussion in the framework of the European research project PROMISING, Workpackage 7
SWOV Institute for Road Safety Research, Leidschendam, the Netherlands.

Leaflet
Integrated planning for mobility and safety is promising. Leaflet on the European research project PROMISING.
SWOV Institute for Road Safety Research, Leidschendam, the Netherlands.

Summary

The PROMISING project for DG VII of EU is aimed at the development and promotion of measures to improve the safety of vulnerable road users and inexperienced drivers and riders. This report is part of PROMISING and is concerned with riders of motorised two-wheelers. The report gives a review of statistical information on the use and safety, and of legislation, concerning mopeds and motorcycles for Western European countries. Also a review of the literature on safety problems and measures is given. The report concludes with a list of recommendations. The work for the report has been a cooperation between SWOV, IfZ, TRL, and INRETS.

In Western Europe the *absolute number of mopeds* is 13-14 million. This number did not change much over the last ten years, but used to be higher before that. The *absolute number of motorcycles* in Western Europe is lower than the number of mopeds, at almost 10 million. This number is slowly, but constantly increasing. There is a clear regional pattern, there are many more mopeds/motorcycles in southern European countries in comparison with northern Europe. The number of *vehicles per 1000 inhabitants* is c.50 mopeds for southern countries and 30-40 motorcycles. For northern countries the rates are c.20 for mopeds and 10 for motorcycles. Because of the low minimum age for moped riding, many of the riders are young. Motorcycle riders used to be young as well, but there is a long term trend with fewer young riders and many more older drivers. Today about 75% of motorcyclists are older than 25 years.
As a result of European regulations, the legislation concerning mopeds and motorcycles has become more uniform in recent years. But there are still many differences in detail.
The number of *motorcycle fatalities* in Western European countries is more than 4000 per year. For *moped fatalities* the number is about 2500. Together they represent 10-15% of all traffic fatalities. These numbers are high in relation to the numbers of vehicles. Since there are more mopeds than motorcycles, the *rate of fatalities per 10^5 vehicles* is even worse for motorcycles. However, the use of motorcycles in terms of kilometrage is probably higher. In most European countries, the absolute number of moped fatalities under 25 years of age is about the same as for older riders. For both moped and motorcycle the rate of fatalities per 10^5 vehicles is much higher for young than for older riders. Nevertheless, there are more motorcycle fatalities over 25 years old than younger. This does not apply to southern European countries, where the numbers are about equal in both age groups. Ten to fifteen years ago, most countries used to have many more young rider fatalities, but the age distribution of the motorcycle rider population has changed to more older riders. For both moped and motorcycle more than two-thirds of the serious accidents are collisions with a car, many of these at intersections with the car driver coming from a side road or turning in front of the rider.
Both mopeds and motorcycles have some special characteristics which directly or indirectly contribute to their relatively high number of accidents. The fact that they are *single track vehicles* means that the rider has difficulty controlling the vehicle, in particular when cornering or braking, and even more so in emergency situations. A *small frontal area* contributes to the

problems of the perception of mopeds/motorcycles by other road users. Small numbers of mopeds/motorcycles on the road also contribute to this problem. The *small size* of a moped/motorcycle and their *low weight in relation to their engine performance* provide opportunities to their riders for behaviour which is different from car drivers. *Age and experience* are important for the safety of riding a moped or motorcycle. A statistical relationship may be found between moped/motorcycle characteristics and accident rate. But it is the *rider motivation* or *riding style*, rather than the vehicle characteristics which can explain this relation. The *absence of a bodywork* means that riders of a moped/motorcycle have little or no protection against collision impact. Until now, there has been little attention to the characteristics of both moped/motorcycle and collision object/vehicle in contributing to the injury consequences to the rider of a moped/motorcycle.

Training and experience of riders are important to control the moped/ motorcycle in all kinds of situations; to cope with imperfect road surfaces and obstacles on the road; to recognise situations in which other road users may not react adequately to their presence; and to learn the consequences of behaviour which is different from that of car drivers, and how to cope with these consequences. This is all in addition to what all road users or car drivers have to learn about safe behaviour. In other words, learning to ride a motorcycle safely may take longer, and to a certain extent is different from learning to drive a car. Since mopeds have a lower speed, this is only partly true for learning to ride a moped. An effort could be made to obtain international agreement on the minimum content and form of basic training programs, based on the present knowledge on safety problems of riding a motorcycle/moped. *Legislation* concerning mopeds and motorcycles shows differences in minimum age and training/testing requirements for different categories of moped and motorcycle. Countries with a relatively low minimum age for riding a moped, or without compulsory training or licensing, should reconsider this. This is either with or without the option of a low speed moped with lower requirements. Countries should promote the availability and participation in voluntary training programs. Over the years the *handling, braking, lighting etc.* of mopeds/motorcycles has much improved. But there is continuous need for more development and research into improved control of brakes. Tampering with mopeds to make them go faster is known to be a problem in some countries. All countries are advised to provide information on this subject and to exchange the information on the effectiveness of anti-tampering measures. The present road network has primarily been designed for the use by cars. Road authorities have to become aware of the special needs of riders of mopeds/motorcycles in terms of the *design and maintenance of the roads*. Special requirements have to be developed based on these needs for road markings, road surface repairs, longitudinal grooves, drainage, timing of traffic lights (for longer braking distances on wet surface) etc. Speed reducing measures may pose special problems for mopeds/motorcycles and should be tested to prevent these. The same applies to the design and location of guard rails which may add to the injuries of riders of motorcycles/mopeds in the case of collision with them. Special *traffic rules* for motorcycles/mopeds to separate them from cars, or to give them privileges compared to car drivers, have been tried in several places in Europe. Countries are recommended to evaluate such rules where they already exist and to promote demonstration projects to gain more experience with them. The *perception of mopeds/motorcycles* is a special

problem for other road users. This can only be partly solved by the use of daytime headlights by riders of mopeds/motorcycles. This measure is estimated to reduce (daytime) collisions with cars by 30-40%. Countries which do not have compulsory daytime use of headlights for motorcycles/ mopeds are advised to introduce this. Another part of the problem is that other road users are not prepared to search for mopeds/motorcycles and to take action to avoid a collision. All countries are suggested to promote campaigns to improve the behaviour of car drivers in relation to motorcycles/ mopeds and campaigns to improve the behaviour of riders to prevent collisions with cars. The lack of *protection of riders* of mopeds/motorcycles can only partly be compensated by wearing a helmet (which reduce the risk of a fatality by half) or other protective clothing. Some countries make exceptions to the compulsory helmet wearing by moped riders or have low wearing rates despite a compulsion and helmets are not always worn correctly. These countries are encouraged to reconsider the reasons for making these exceptions, resp. to enforce the compulsory wearing of helmets more strictly. *Data collection and research* are not safety measures in themselves, but serve to study the need for and the effects of such measures. In the case of mopeds and motorcycles there is a strong need for more reliable data and more and better research. All countries should provide the necessary statistical information on the safety and use of motorcycles/mopeds.

Contents

1. Introduction

This report is part of the PROMISING project for the DG VII of EU. Promising stands for the development and PROmotion of measures for vulnerable road users with regard to Mobility Integrated with Safety, taking into account the INexperience of the different Groups. The objective of the project is to capitalise on technical developments and to show the potential for problem solving through non-restrictive measures.

Four groups of road users were specified: pedestrians, cyclists, riders of motorised two-wheelers and young car drivers. This report is concerned with the riders of motorised two-wheelers, which can be divided in mopeds and motorcycles (including scooters).

The planning for the report has been to start with the collection and presentation of statistical information on the use and safety of mopeds and motorcycles, followed by a review of the special safety problems of riding a moped or motorcycle and a review of measures to solve these problems. It soon appeared that the necessary information on the use and safety of mopeds and motorcycles was very difficult to obtain, particularly in the case of mopeds. One of the problems was that many countries had only recently changed their legislation concerning mopeds and motorcycles or were in the process of doing so. The same difficulty was found with research literature on the safety problems and measures, with the only exception of the protection of motorcyclists, for which a recent review could be used as a start.
A first consequence has been that the report does not include information on Eastern European countries. Another consequence was that considerable time and effort has been spent on the collection of statistical and legal information and on research literature. Having made this effort, it seems useful to present the result in some detail in this report, so that future international projects on the safety and use of mopeds and motorcycles can profit from the work.

One of the findings from all the information is that the population of riders of mopeds and motorcycles has changed over time and that, contrary to the popular image, a large proportion of riders is over 25 years of age. The report also gives an up to date review of the present legislation in Western European countries concerning mopeds and motorcycles. Another finding is that there is a range of safety problems of which the behaviour of the riders of mopeds and motorcycles is only one. Although the safety of riding a moped or motorcycles has improved over the years, the accident rate is still relatively high compared to cars. For that reason the report contains the whole range of potential safety measures, rather than concentrating on technical and non-restrictive measures.

The work for this report has been a cooperation between SWOV, IfZ, TRL and INRETS. IfZ has been responsible for all or most of the texts in chapter 2 (target groups), chapter 3 (legislation), chapter 4 (accident statistics), chapter 5 (safety problems) and parts of chapter 7 (measures) concerned with legislation and measures related to the rider, to the vehicle and to the infrastructure. TRL has prepared the texts for chapter 6 (rider protection) and the part of chapter 7 on rider protection. SWOV has

contributed to the texts of chapter 5 and 7 on other road users and was responsible for chapter 8 (summary and conclusions) and chapter 9 (recommendations).

Since chapters 2-7 contain much detail, readers who are not interested in this could start with chapter 8 (summary and conclusions) and return to the earlier chapters for background information on subjects of their interest.

2. Target groups of moped and motorcycle riders

2.1. **Definition of powered two-wheelers (PTWs) in Europe**

Powered two-wheelers (PTWs) are defined as smaller capacity one-track vehicles with lower 50 cc (mopeds) and higher capacity vehicles with more than 50 cc (motorcycles). Although this definition is used for statistical purpose of different international sources the EU has defined the following motorcycle classes according to the Council Directive 92/61 EC:

European definitions of Powered two-wheelers
Class A: Small vehicles not exceeding 50 cc and ≤ 45 km/h
Class B: Powered Two-Wheelers ≤ 125 cc /11 kW
Class C: Powered Two-Wheelers ≤ 25 kW / 0.16 kW/kg Power to Weight Ratio
Class D: Other powered two-wheelers than class B and C

In the future a Class L bicycles with electric motor (EPAC-Electric Power Assisted Cycle) will be defined by the EC.

But there are many different national definitions existing in Europe for example in Germany, where "Mopeds," "Mokicks", "Kleinkrafträder", "Mofas" and "Leichtmofas" are existing as categories of small capacity vehicles. These classes can once again be distinguished between scooters and other small motorcycles. In the Netherlands the terms "bromfiets" and "snorfiets" are used for small powered two wheelers. These definitions often include low capacity one track vehicles with a speed limit of 25 km/h (*Table 2.1*).
In addition to these capacity or power orientated definitions there is as well a distinction between motorcycles, mopeds and scooters and moreover between different motorcycle categories like touring, sport, street, off-road or custom versions etcetera.

In the year 1980 22.9 Mill. PTWs were in use in Europe. Between 1980 and 1990 this figure fell to 19.8 Mill. (1985), but raised to 20.6 Mill. in 1990 and over 23.6 Mill. vehicles in the year 1995. Motorcycles had a continuously rising trend in these 15 years from 5.4 Mill. to 9.4 Mill. vehicles in Europe. A different development can be found for mopeds between 1980 and 1995. The number of mopeds dropped from 17.5 Mill. to 13.5 Mill. vehicles (in 1985). In the last ten years this figure went up to 13.5 Mill. (1990) and 14.2 Mill. (1995) vehicles in use in European countries (*Figure 2.1*). But the number of mopeds only increased by 700,000 vehicles in ten years.
In the last ten years until 1995 there was a tendency for a nearly equal share of different one-track vehicle categories (mopeds and motorcycles). In 1995 mopeds had a percentage share of 60 % and motorcycles of 40 % a figure that was 23.6 % in the 1980s for motorcycles and 76.4 % for mopeds.

The European PTW park is not equally distributed between all countries and moreover there is a very different proportion between the national share of motorcycles and mopeds. Looking at PTWs as a total, half of the vehicle fleet

Country	Name	Max. Speed	Capacity / kW / other definitions
EU	Moped	45 km/h	max. 50 cc
A *Sergey Cieca*	Moped	45 km/h	max. 50 cc
B *Sergeys*	Moped	Class A: max.. 25 km/h Class B: max. 45 km/h	
CH *Cieca*	Mofa Moped	30 km/h with 14 45 km/h with 16	max. 50 cc 1 Gear
D	Mofa Mokick	25 km/h 50 km/h	
E *Direccion General de Trafico*	Moped		
F *Inrets*	Cyclomoteur	45 km/h	max. 50 cc
GB *Department of Transport*	Moped	30 mph	max. 50 cc max. 250 kg
Gr *DUMAS*	Moped	50 km/h	max. 50 cc
I	Ciclimotori Velocipedi		
N *Sergey*	Moped	45 km/h	
NL *SWOV*	Bromfiets Snorfiets	45 km/h 25 km/h	
S *Cieca*	Moped	45 km/h	max. 50 cc two classes before Oct. 1st 1998

Table 2.1. *National definitions of mopeds in Europe*

is in use in the southern parts of Europe, e.g. Italy, Greece and Spain with a high portion of mopeds. This north/south distinction can be related to climatic and social conditions in these European nations (*Table 2.2*).

Taking forms of mobility into consideration there was a historical development from the fifties on, when the utilisation of PTWs was predominantly for functional purposes. With the opportunity to afford cars this function of PTWs modified to more or less leisure time use. In the last ten years, under the conditions and problems of the urban traffic dilemma PTWs are more and more used for dual purposes, with a clear impetus for an economic vehicle in urban areas. This new orientation for PTWs can be seen by the kilometres travelled with one-track vehicles 1995 (*Table 2.2*).

The share of PTWs in surface transport in Western Europe is about 3 % (133 bn passenger km a year). This share equals half the transport volume of Europe's railways (Moscato & Sergeys, 1998).

A more detailed view on the PTW fleet in Europe will give additional information about the development of the number of motorcycles and mopeds.

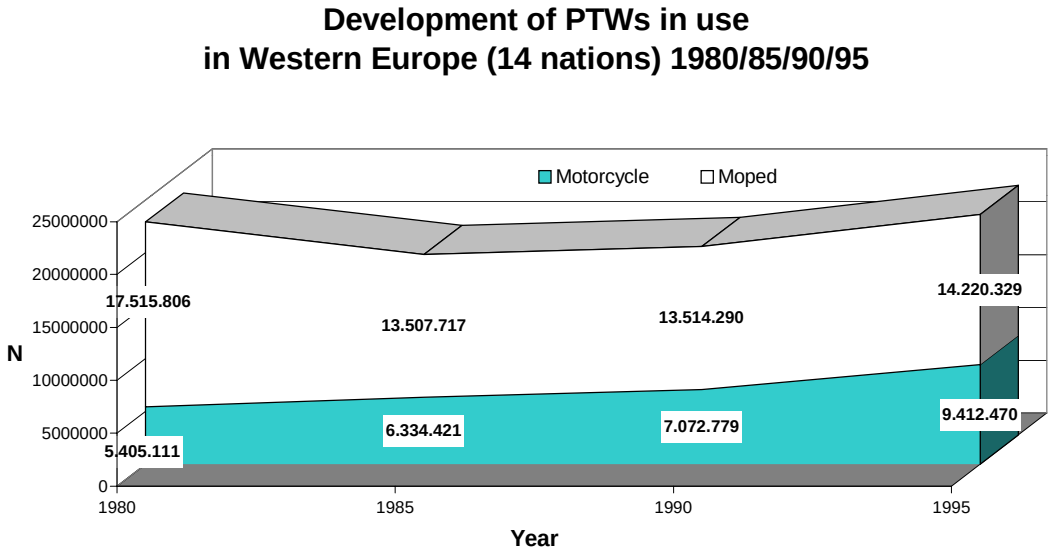


Figure 2.1. *Development of the PTWs in use in Western Europe (14 Nations) 1980/85/90/95 Nations: A, B, CH, D, DK, E, F, FIN, GB, GR, I, N, NL, S;*
Source Motorcycles: Honda (E; I '90;); IRTAD (I '95), rest UN; Mopeds: CEMT (B '90), Honda (D '80, '90, '95; DK '95 (previous year); E; F '85; I; S '80, '85 (previous year), '90, '95 (previous year)); rest UN; 1980-90: without moped data from Greece.

Region	Fleet/vehicles (million)	PTW park (million)	Km travelled (billion)	PTW per 1000 inhabitants	Km per head per year
Mediterranean 1)	116.8	12.7	90.3	109	773
Central Europe 2)	181.0	9.6	39.1	53	216
Northern Europe 3)	85.6	1.5	8.5	17	99
1) Italy, Greece, Portugal, Spain 2) Austria, Belgium, France, Germany, Luxembourg, The Netherlands, Switzerland 3) Denmark, Finland, Norway, Sweden, UK, Ireland					

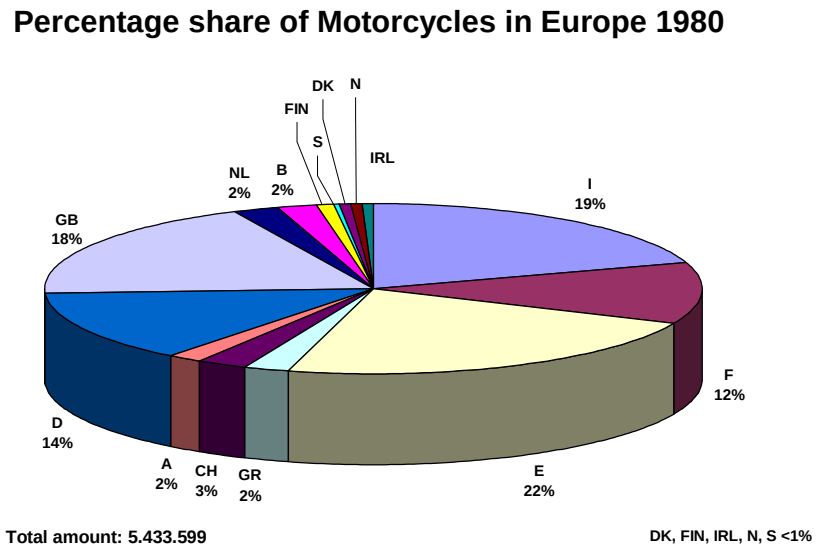
Table 2.2. *Regional PTW utilisation in Europe (Moscato & Sergeys, 1998).*

2.2. Motorcycles (class B, C and D)

The use of motorcycles for dual purpose becomes more and more attractive in Europe and the total number of motorcycles increased between 1990 and 1995 in almost all European countries continuously (*Figure 2.1*).
In the year 1980 5.4 Mill. vehicles were in use. This number increased in the year 1990 to 7.1 Mill. vehicles. From 1990 to 1996 2.7 Mill. additional motorcycles were registered in Europe (9.8 Mill. 1996 / + 38 %).

But there is a large variation between the vehicle population in different European countries. Italy and Germany represent over 50 % of the vehicle population in the year 1995 with more than 9.4 Mill. motorcycles. If we add

Spain and France, a total of 74 % of all registered motorcycles in Europe are used in these four countries (*Figure 2.2*).
Other European nations have a share of less than 1 to 7 % (GB) in 1995. Motorcycles are most intensively used in southern parts of Europe, and only Germany, and in some respect GB, have a high portion of motorcycles in the Northern European nations.
On the other hand, in comparison between the year 1980 and 1995 we find a changing tendency towards motorcycles in some European countries. In the year 1980 Spain had the highest amount of motorcycles with a share of 22 % followed by Italy (19 %) and GB (18 %). Germany only had 14 % of all motorcycles in Europe. For two countries with a former high utilisation of motorcycles (GB/E) a strong decreasing tendency can be found during the fifteen years.



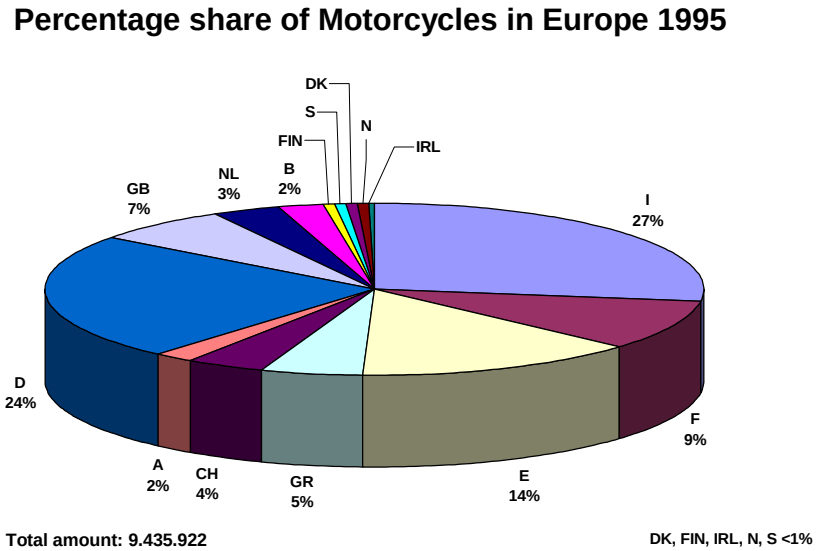


Figure 2.2. *National percentage share of motorcycles in Europe 1980/1995; Source IRL: UN; other nations see Figure 2.1.*

Furthermore GB is the only nation with a decreasing motorcycle population between 1990 and 1995. In all other countries the number of motorcycles increased (*Figure 2.3*). Especially in nations with a high number of motorcycles (D and I) the number increased by about 850,000 and 650,000 vehicles (Italy). Other nations (E,GR,NL) have 140,000 to more than 200,000 additional vehicles registered. In the category of nations with a growth of less than 100,000 motorcycles IRL only shows a growth of 708 vehicles and France 80,000 motorcycles.

In accordance with the absolute numbers the percentage change between 1990 and 1995 increased by up to 60.4 % in D respectively 33.7 % in I. Although there is a nearly doubling of the motorcycles registered in NL (+89.3 %) and in GR (+85.4 %) in the same period of time, the absolute numbers are relatively small (*Figure 2.4*).

Another rate for the utilisation is the number of vehicles per thousand inhabitants, but this ratio doesn't show a relation to the absolute numbers of motorcycles in use. Generally the number of motorcycles per thousand inhabitants in Europe increased from an average of 19.3 per thousand inhabitants in the year 1990 to 21.7 in the year 1994. This means a percentage change of +12.4 % up to the year 1994 (*Figure 2.5*).
In the year 1983, this ratio was 20 per 1,000 inhabitants, which fell to 16 in the year 1985.

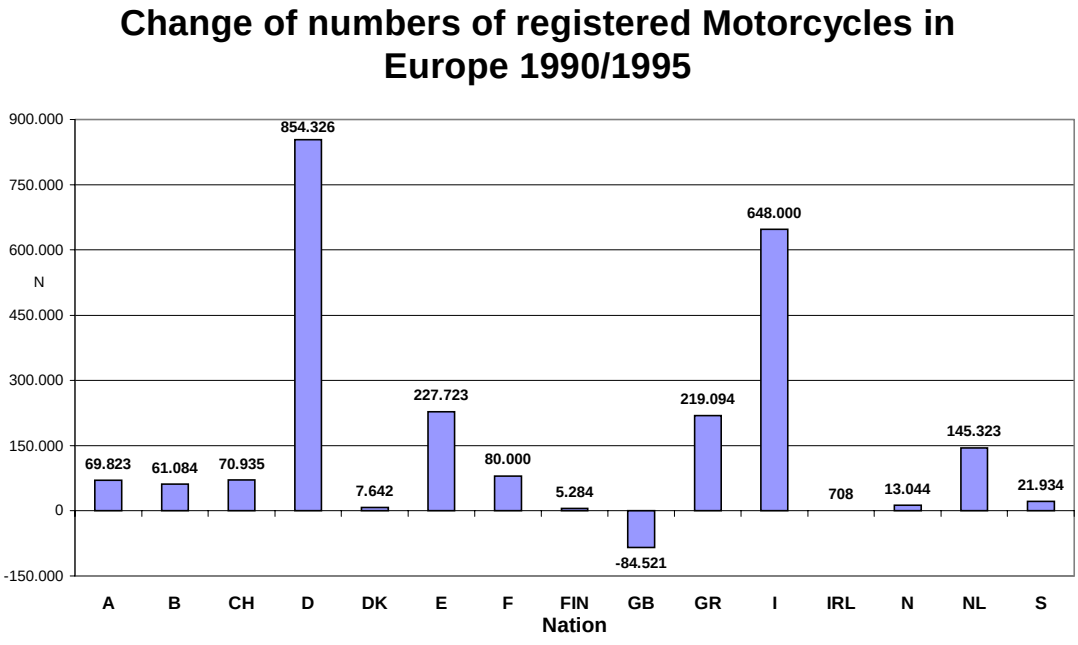


Figure 2.3. *Change in numbers of registered motorcycles in Europe 1990/1995*

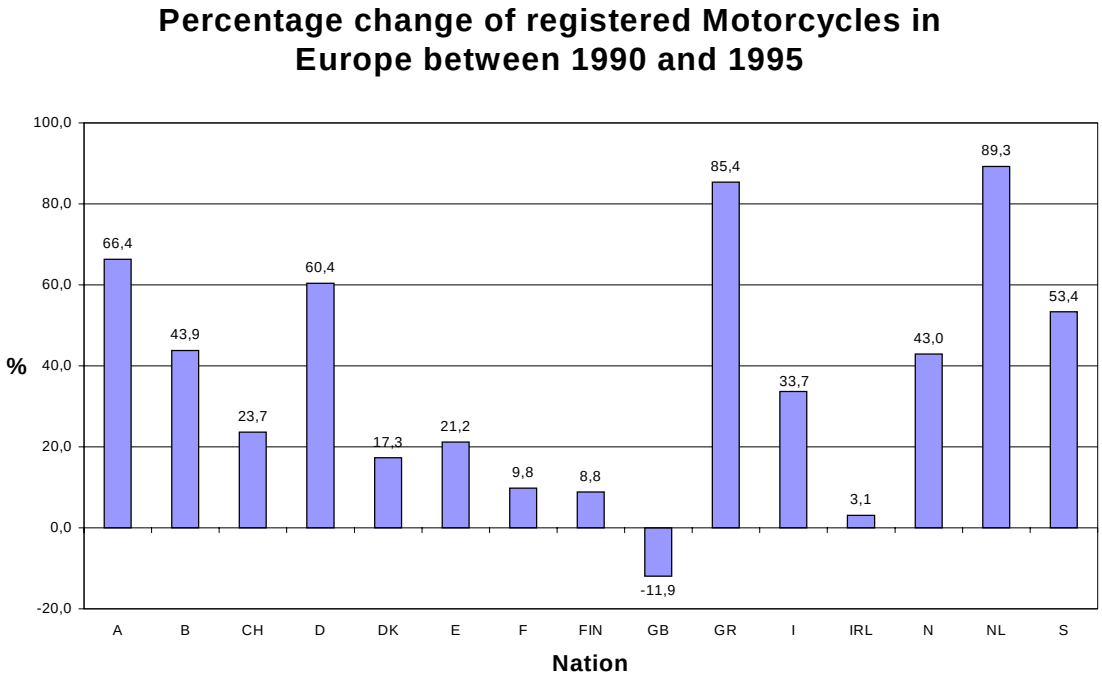


Figure 2.4. *Percentage change of registered motorcycles in Europe*.

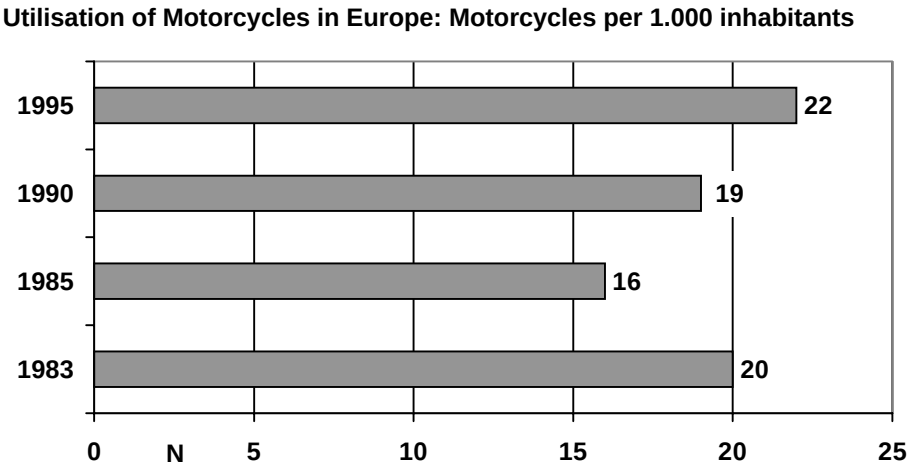


Figure 2.5. *Motorcycles per 1,000 inhabitants 1983/85/90/95 (CEMT)*

Although Switzerland has only a total share of 4 % of all motorcycles in Europe in the year 1994 the Number of motorcycles per 1.000 inhabitants is the highest in Europe 1994 (51), followed by Italy (43), Greece (37) and Spain (33). Germany with one of the highest absolute numbers of vehicles has a figure of only 24 motorcycles per 1,000 inhabitants in the year 1994 (*Figure 2.6*).

For Austria, Italy and Great Britain a negative percentage change of -13.0 % (A), -12.2 % (I) and -9.1 % (GB) is to be seen. In all other European nations the number of motorcycles per 1.000 inhabitants increased by a minimum of +6.3 % (F) and a maximum of +81.8 % (NL) (*Figure 2.7*).

Obviously this utilisation rate does not reflect the absolute numbers and the positive development of vehicles in use. Italy and Germany, with over 50 % of all motorcycles in Europe registered, have low positive or negative figures in relation to this rate.

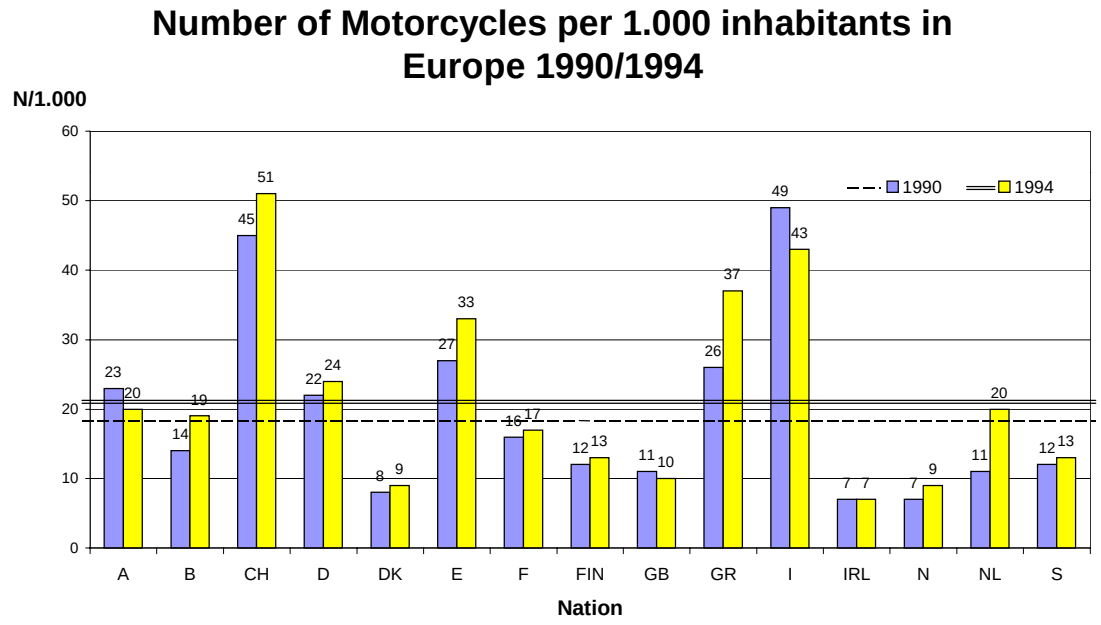


Figure 2.6. *Number of motorcycles per 1,000 inhabitants in Europe (CEMT).*

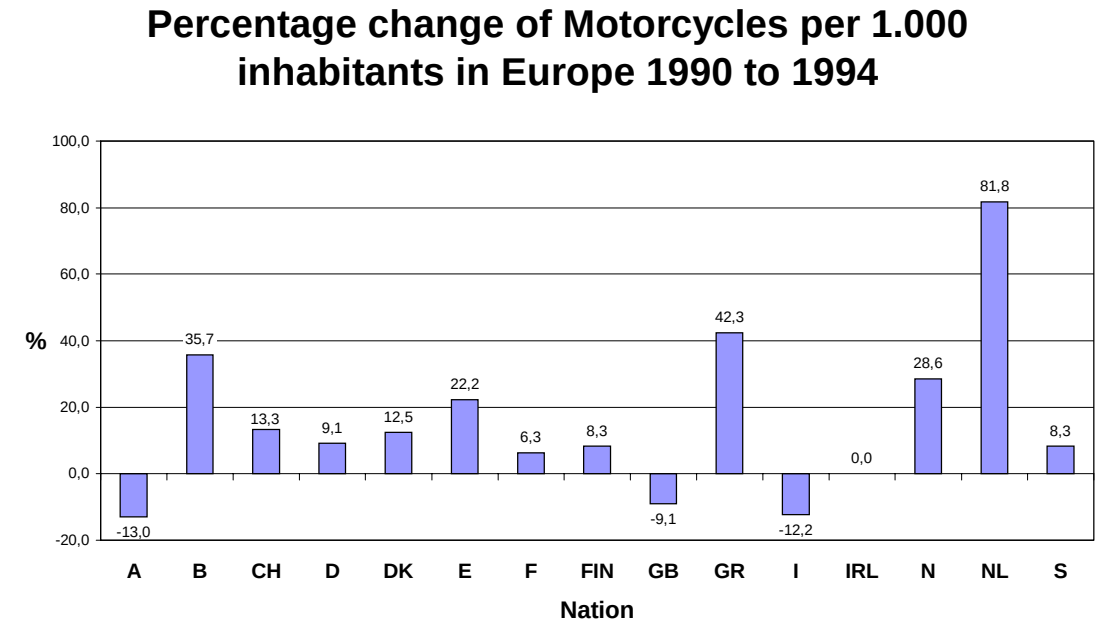


Figure 2.7. *Percentage change of motorcycles per 1,000 inhabitants in Europe (CEMT; CEMT uses different data for Italy, therefore a decrease was to be seen).*

2.3. Mopeds (class A and in future class L)

The development of the number of mopeds in Europe in the last 15 years was not as positive as the development of motorcycles, although mopeds have a slight majority in comparison to motorcycles.
In the year 1980 17,515,806 mopeds were registered in 14 European countries. This number decreased by 22.82% to 13,514,290 vehicles in the year 1990. In the year 1995 there was an increase of 5.2% to 14,220,329 mopeds. This last figure is more or less related to the data of Greece (only 1995) and Germany with increasing moped parks. If Greece would be excluded the number of vehicles would fall to 12,874,329 or -4.7 % for the total of Europe (*Figure 2.8*).

Four Southern European countries have a share of 72% of all mopeds in Europe. These European nations are Italy (35%), Spain (15%), France (12%) and Greece (10 %). If Germany (12 %) is included this would be a total of 84% in Europe in five of the fourteen countries (see *Figure 2.9*).

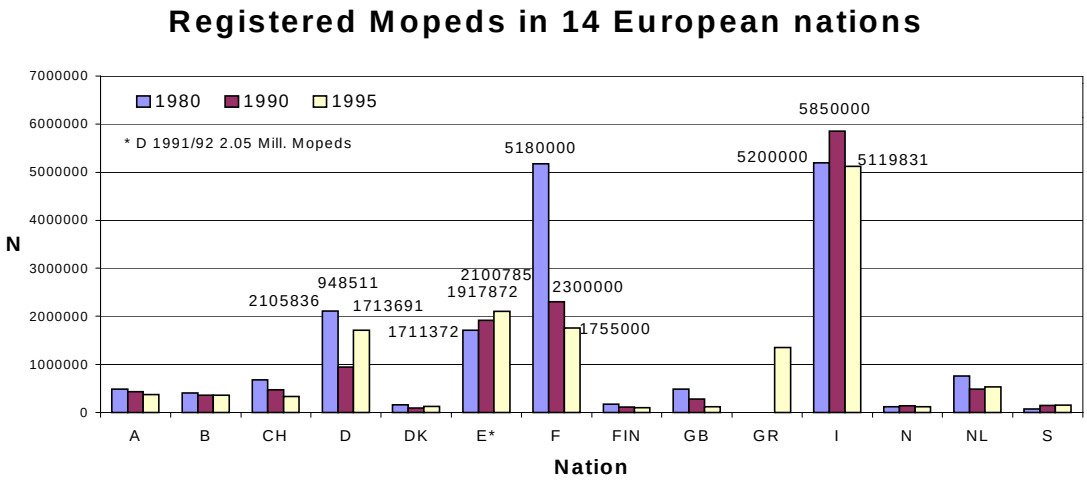
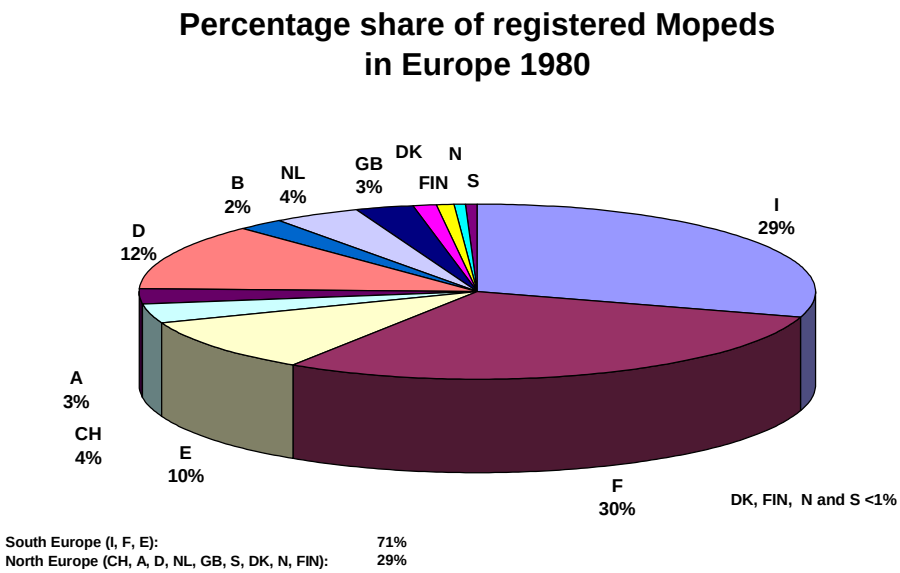


Figure 2.8. *Number of registered mopeds in Europe. (*) Details for Spain in 1980 from 1982. Sources: Honda: D , DK ('95), E, I, S (80, 90); Rest: UN.*

The decreasing number of mopeds in the decade between 1980 to 1990 was caused by an exceptional reduction of the number of mopeds in France by 55.6% (from 5 to 2.3 Mill.) and in Germany from 2.1 Mill. mopeds in the year 1990 to less than 1 Mill. vehicles in the year 1995 (the German situation is very difficult because of the reunion and a different counting of vehicles by insurance companies; in the year 1991/1992 2 Mill mopeds were registered).

From 1990 to 1995 an increase (by including Greece) can be stated. Nevertheless in France the number of mopeds once again decreased by 23.7% to 1.8 Mill. vehicles and in Italy by 12.5 %. An increase could be found in Germany, Denmark and the Netherlands. In Germany this meant a change of 80.7% to 1.7 Mill. (*Figure 2.10*).



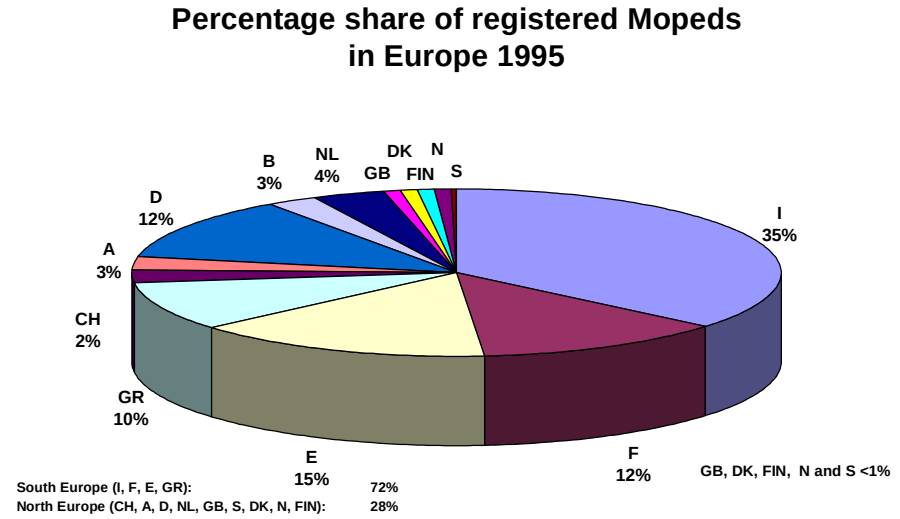


Figure 2.9. *Percentage share of mopeds in Europe 1980/1995; Source: see Figure 2.1*.

The utilisation rate ‘Number of mopeds per thousand inhabitants’ declined in all European countries except D, DK, and E in a comparison of the years 1990 and 1994. An average 34.8 mopeds could be found in the year 1990 per 1,000 inhabitants. This figure decreased in 1994 to 31.8 mopeds per 1,000 inhabitants in Europe (-8.4%). Once more Switzerland has the highest ratio for 1990 with 68 per 1,000 inhabitants, followed by Italy with 60, Austria with 52 and Spain with 51. In the year 1994 Italy had the highest rate with 57 per 1,000 inhabitants (*Figure 2.11*).
As a conclusion, the use of low capacity single track vehicles seems to be more attractive in the beginning of the 90's, which is related in some ways to the renaissance of scooters as a new mobility mode in urban areas, although the number of vehicles per inhabitants fell in comparison with the years 1990/1994.

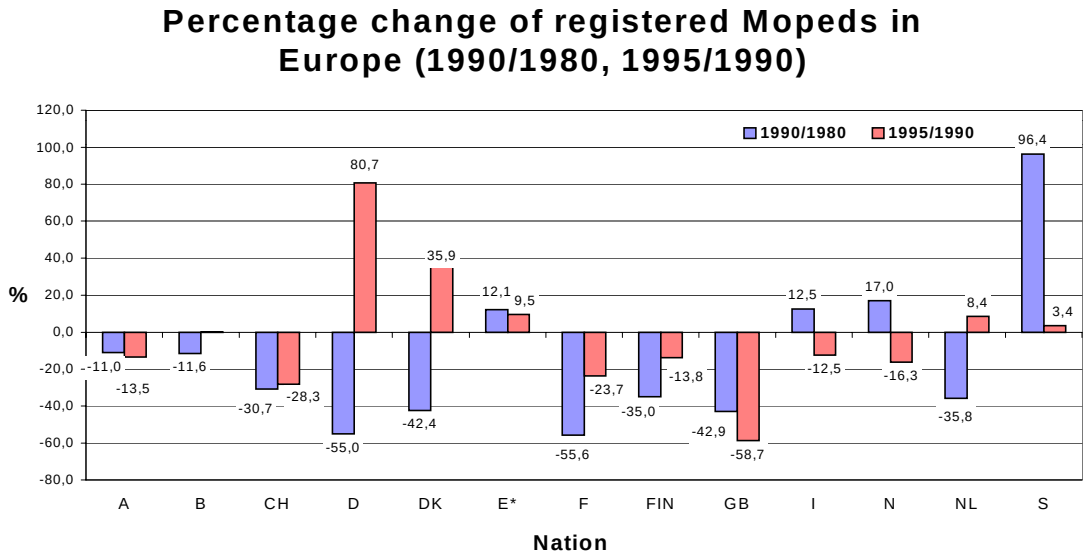


Figure 2.10. *Percentage change of mopeds in Europe 1990/1980 and 1995/1990 (without Greece).*

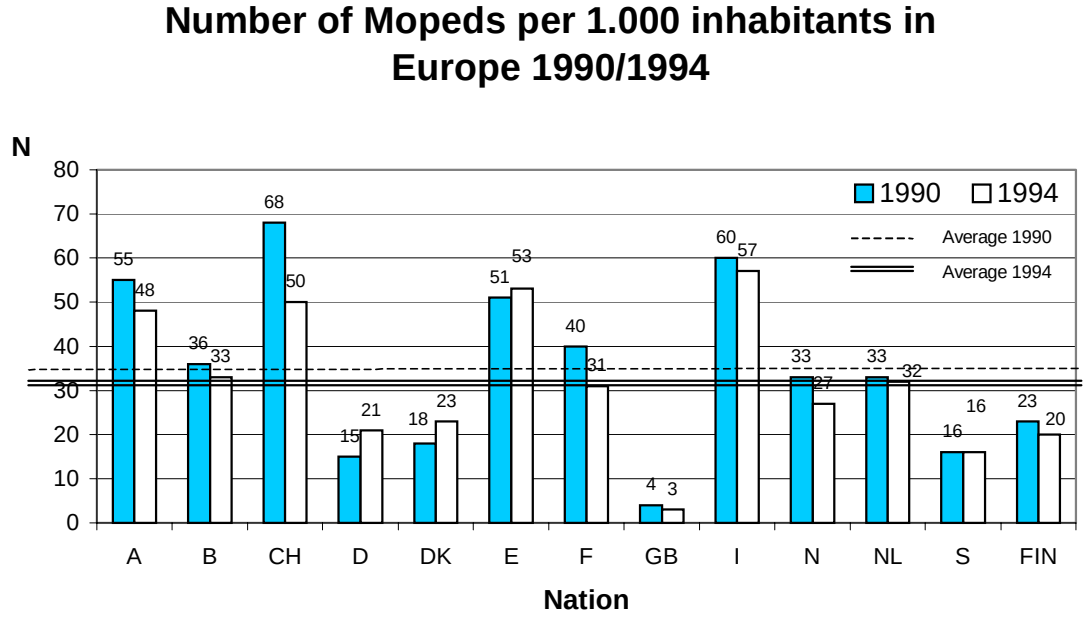


Figure 2.11. *Number of mopeds per 1,000 inhabitants in Europe (CEMT).*

2.4. Description of motorcycle framework

2.4.1. *Motorcycle categories*

In Europe only few and poor data exists. For example in Germany the following development by capacity can be found for new motorcycle registrations (*Figure 2.12*).

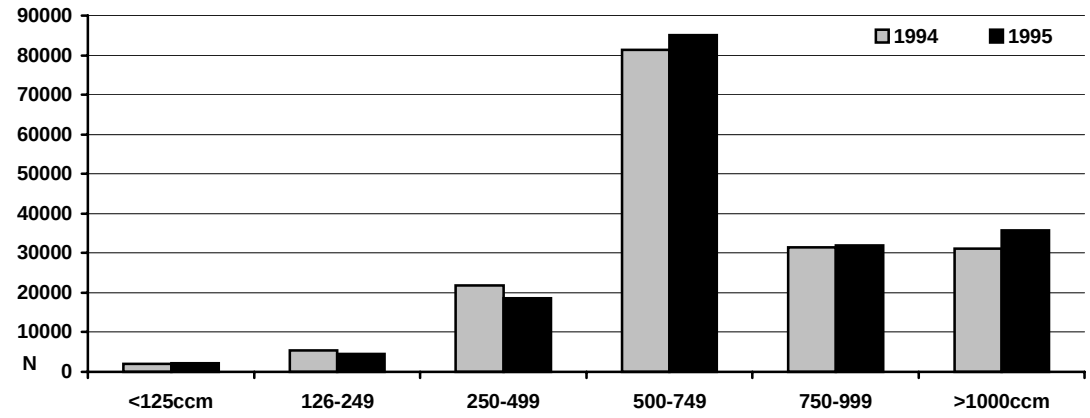


Figure 2.12. *New registrations of motorcycles in Germany 1994/1995 by cc (KBA).*

In Germany the capacity classes 500 to 750 cc and above 1000 cc increased by 15 % to 17 % related to other capacity classes from 1994 to 1995 (*Figure 2.15*). This correlates with the horse power (kW) classes of new registered motorcycles, although the highest change occurred among vehicles with 38 to 57 kW and not for over 72 kW motorcycles (*Figure 2.13*).

Changes of the motorcycle market in Germany can be analysed by categories of motorcycles like street bikes, sport bikes, touring bikes, off-road bikes and custom bikes. Between the compared years 1993 and 1995, there is a changing of motorcycle categories which are purchased (see *Figure 2.14*). From 1993 to 1994 the number of street, touring, sport and hyper-sport motorcycles decreased in relation to custom and off-road bikes. In relation to 1995 sport, touring and off-road bikes fell, and street, custom and hyper-sport bikes increased, with a clear majority of street bikes.

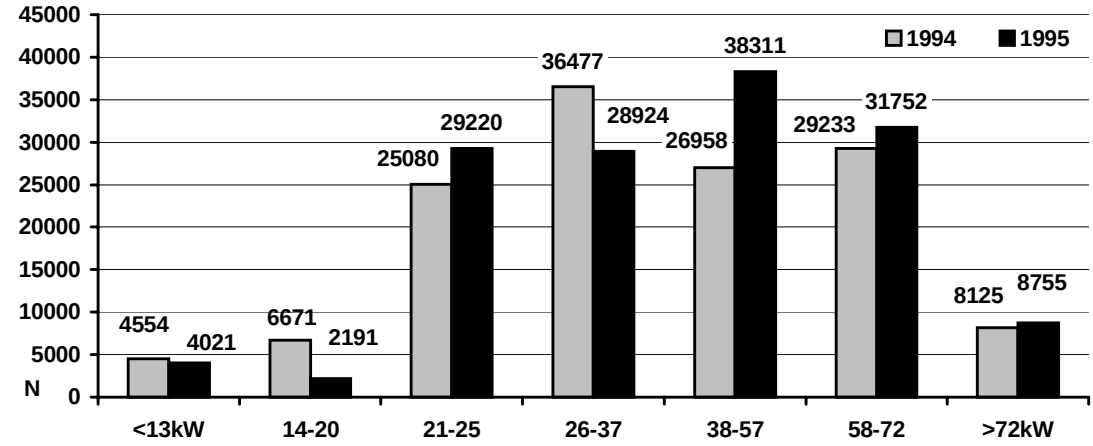


Figure 2.13. *New registrations of motorcycles distinguished by kW 1994/1995 (KBA).*

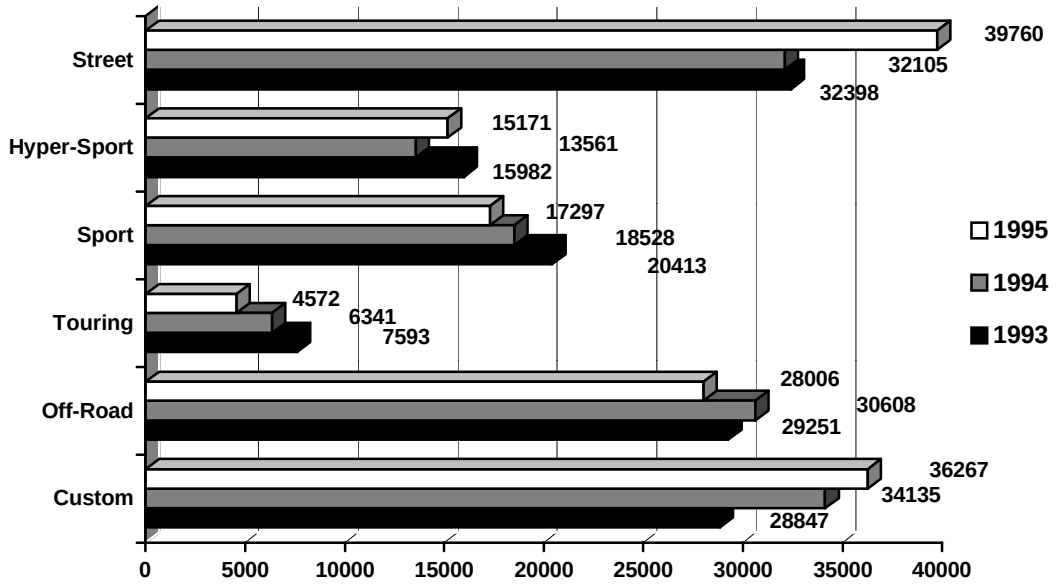


Figure 2.14. *Sold motorcycles in Germany by categories 1993, 1994 and 1995 (IVM).*

Custom bikes had an increase of 25.8 % and street bikes an increase of 22.5 %. Both categories are the most frequently sold vehicles in Germany from 1993 to 1995. Sport motorcycles and hyper-sport motorcycles follow with 15.3 % and 5.1 %. This means a clear tendency towards the "normal" street motorcycle and the classic custom bike (*Figure 2.14*).

A look at the motorcycle fleet in Germany explains a decreasing tendency for motorcycles lower than 500 cc and a higher percentage share for motorcycles above 500 cc (*Table 2.3*), although an increasing number of vehicles can generally be found in all classes. The biggest growth is connected to the class lower 750 cc (49.7 %) and above 750 cc (50.6 %).
The mean age of motorcycles increased from 8.25 years in the year 1992 to 8.83 years in the year 1995. The average capacity of motorcycles increased in this time period from 620 cc to 636 cc, whereas the average kW-power of motorcycles was 38 kW in all this years.

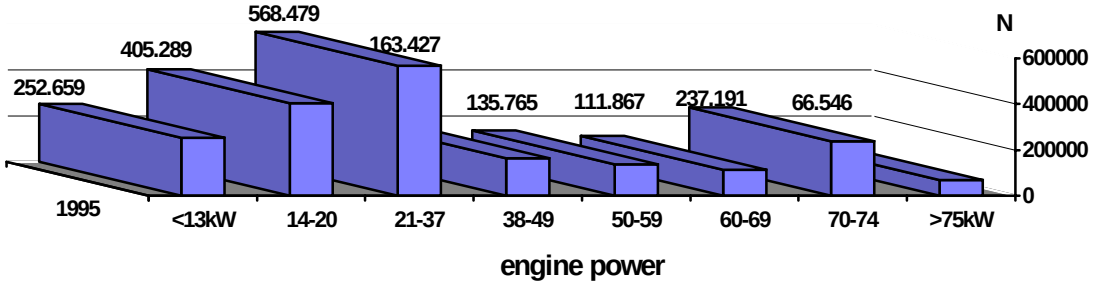


Figure 2.15. *Motorcycle fleet in Germany by kW-power July 1st 1995 (KBA)*

Motorcycle characteristics	July 1st 1995		July 1st 1994		July 1st 1993		July 1st 1992		Change from '92-'95	
cc classes	Number	(%)	Number	(%)	Number	(%)	Number	(%)	Number	(%)
80 and 81-99	28,984	1.5	29,374	1.6	29,539	1.8	28,575	2.0	+409	+1.43
100 - 125	36,569	1.9	35,577	2	33,675	2.1	30,617	2.2	+5,952	+19.4
126 - 174	54,327	2.8	57,374	3.2	55,143	3.4	37,797	2.7	+16,530	+43.7
175 - 199	27,126	1.4	27,091	1.5	26,974	1.7	26,799	1.9	+327	+1.2
200 - 249	164,857	8.5	163,545	9.2	156,599	9.7	135,917	9.6	+28,940	+21.3
250 - 349	45,413	2.3	42,894	2.4	39,932	2.5	36,139	2.5	+9,274	+25.7
350 - 499	336,555	17.3	325,373	18.2	310,502	19.2	294,757	20.7	+41,798	+14.2
500 - 749	688,659	35.5	610,658	34.2	535,137	33	459907	32.4	+228,752	+49.7
>750	558,498	28.8	494,080	27.7	431,550	26.6	370,854	26.1	+187,644	+50.6
Total	1,940,988	100	1,786,200	100	1,619,265	100	1,421,362	100	+519,626	+36.6
Average age (years)	8.83		8.67		8.5		8.25			
Avg. capacity (cc)	636		642		631		620			
Avg. power (kW)	38		38		38		38			

Table 2.3. *Motorcycle fleet in Germany by capacity (KBA).*

Of all capacity classes, 64.3 % are above 500 cc and motorcycles lower 250 cc have a percentage share of 16.1 % in 1995. Although Germany has a high portion of high capacity motorcycles, the relation to kW-power classes results in a clear majority of the <13 kW to 37 kW motorcycles with a total share of 63.2 % of all vehicles (*Figure 2.15).*
The relation between motorcycle capacity and kW power is not linear at all and, for example, motorcycles with <750 cc have a high share of 21-37 kW vehicles (*Figure 2.16*).
As a conclusion in Germany more high capacity vehicles can be found in the last years, although a linear relation to kW power can not be stated in general. The tendency of sport and hyper-sport motorcycles reverses in the last years towards a new orientation to the normal street and custom bikes.

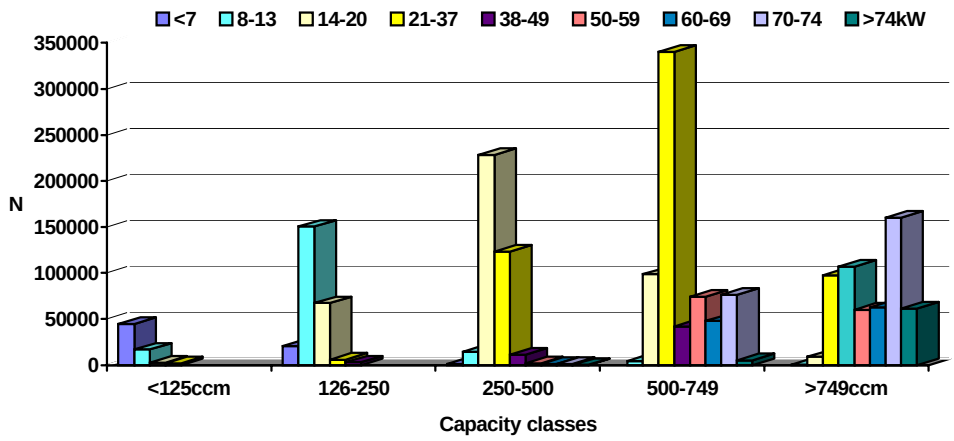


Figure 2.16. *Motorcycle fleet in Germany by capacity and kW-power July 1st 1995 (KBA).*

2.4.2. *Age and motorcycles/mopeds*

From the European point of view it is problematic to obtain reliable data. Only for France, Germany and the Netherlands some information has been given.
Only for France is age- and gender data concerning mopeds available. In France the majority of the moped riders is under 18 years. The share of female moped riders was 13 % in 1993 (Filou et al., 1994). One reason for the poor data is that most mopeds have only an insurance certificate and therefore no official registration are sometimes supported. Concerning other demographic details the share of vehicle licensed women in the southern countries is lower than in the northern parts with an increasing share of female vehicle users in general (Klemenjak, 1997).

In Germany the share of motorcycle owners (> 125 cc) older than 30 years increased strongly during the beginning of the nineties. Compared with data of the year 1990, the number of motorcycle owners older than 35 years increased by more than 250 % in the year 1997. For the same period of time the number of owners between 21 and 25 years decreased by 26.6 % (*Figure 2.17*). The total percentage share of motorcyclists above 35 years grew from 27 % in 1990 to 49 % in 1997.
A similar development of age groups is visible in the Netherlands data (*Figure 2.18*) and in that of many other European nations (personal communication, no data received).

The data for the motorcycle development in France ends by the year 1993 and the situation seems to be slightly different. For the year 1993 the majority of the motorcycle owners in France were between 29 and 35 years (35 %). This age group does not belong to the group of inexperienced motorcyclists. A reliable trend like in other European nations could not be detected for France because of absent data for the years 1994 to 1997.

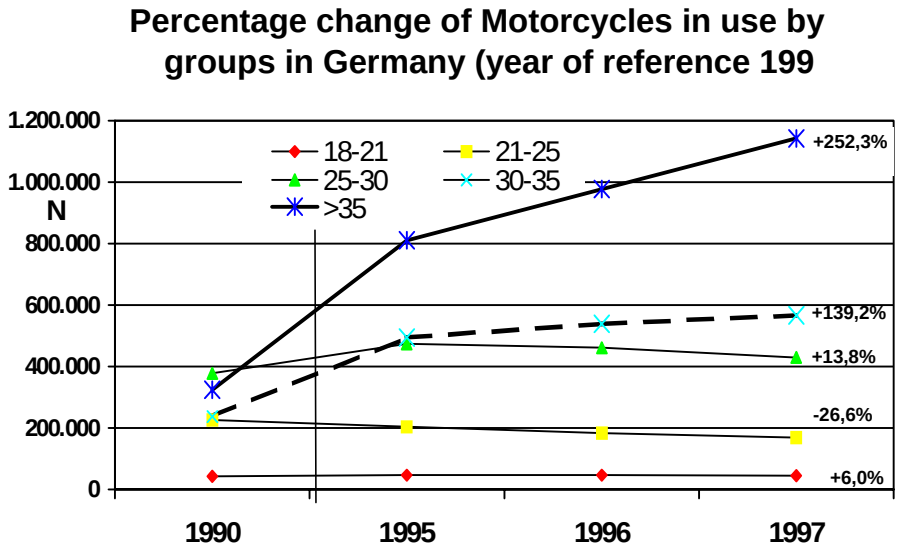


Figure 2.17. *Percentage change of Motorcycles in use by age groups in Germany (KBA).*

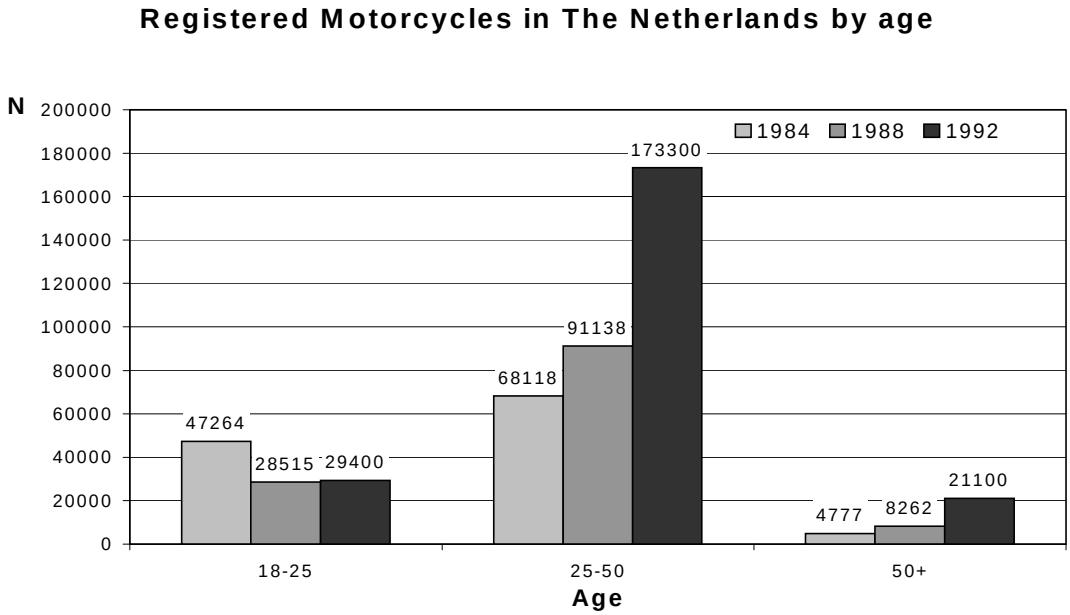


Figure 2.18. *Number of motorcycles by age in the Netherlands (Noordzij & Mulder, 1994).*

For lightweight vehicles the following tendency of age classes is to be found between the years 1996 and 1998 in Germany. This development is closely related to the new European Licensing Scheme. One important aspect for the development is the inclusion of driver licenses made before the April 1st 1980, which means that car drivers can use a 125 cc motorcycle (see *Figure 2.19*).

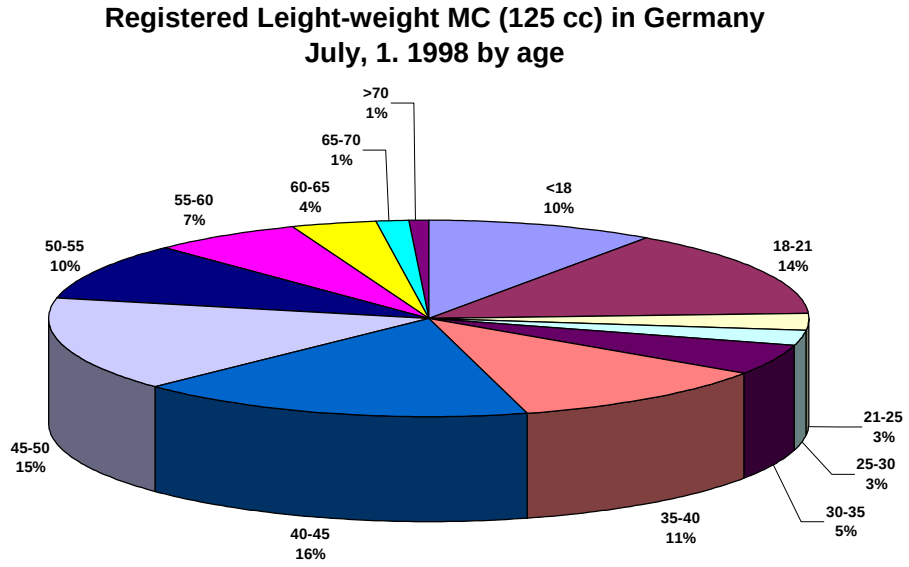


Figure 2.19. *Registered light-weight motorcycles (125 cc) in Germany July 1st,1998 by age (KBA).*

This means that 65 % of all lightweight motorcycles <125 cc are used by riders that are older than 35 years.

As a conclusion, motorcyclists are getting older in comparison with the years before 1990, and motorcycling is nowadays not a solely youth-orientated mobility mode like in former days.

2.4.3. *Gender and motorcycles/mopeds*

There are very small information about gender and motorcycles. Beside the general statement that young women are holding more driving licences in the northern part of Europe (Klemenjak, 1997), only few details can be found.

For instance in France for the year 1990, the distribution between women and men riding motorcycles was 4 to 96 %. This figure dropped to 3 % women and 97 % men in the year 1993. Moped use has a similar development in France, where mopeds are predominantly used by men (75 %) and only 25 % women in the year 1990. This figure changed as well to 87 % men and 13 % women in the year 1993. There seems to be a decreasing trend of number of female riders, although no data for the years 1994 to 1997 is available.

The development in Germany is quite different to France and the share of female motorcyclists increases continuously from 11 % in the year 1990 to 14 % in the year 1998.
For women this means an increase of 220,772 motorcycles between 1989 and 1998 or an increase of 181.5 % in the nine years period (*Figure 2.20*).

A look at the age structure of women in relation to men results in a very similar development for both gender groups although women have a slight majority in the classes between 21 and 35 years. Above 35 years men have a higher portion than women. For both groups the age class 30 to 35 years has the maximum share followed by the age group of 35 to 40 years (see *Figure 2.21*).

In respect to gender groups, motorcycle riding is dominated by male riders in most European states with a higher share of age groups that belong to the group above 35 years. Female riders and their share differ from country to country, and (can) have a varying development. In Germany this percentage share of female motorcyclists is constantly growing, whereas data of France shows a decreasing tendency for motorcycles as well as for mopeds.

The age group of younger riders of 18 to 30 years is no longer the majority group of motorcyclists. On the one hand this can be related to a constant change of age and use of motorcycles, but on the other hand as well as a social reason because at first a four-wheel vehicle has the advantage of individual mobility in relation to motorcycles. Behind this a second more economic reason for younger riders is foreseeable, it can be related to the costs for a motorcycle license. In some countries the costs will be doubled in relation to a car license.

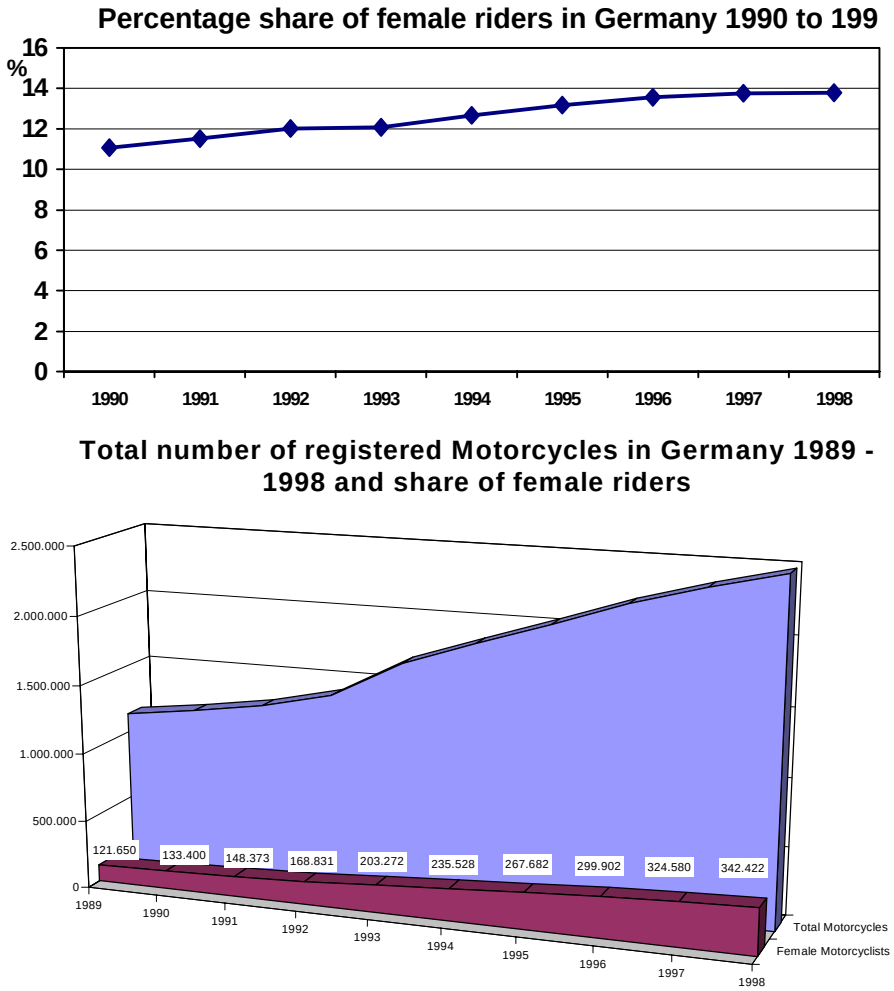


Figure 2.20. *Percentage share of female riders in Germany (KBA).*

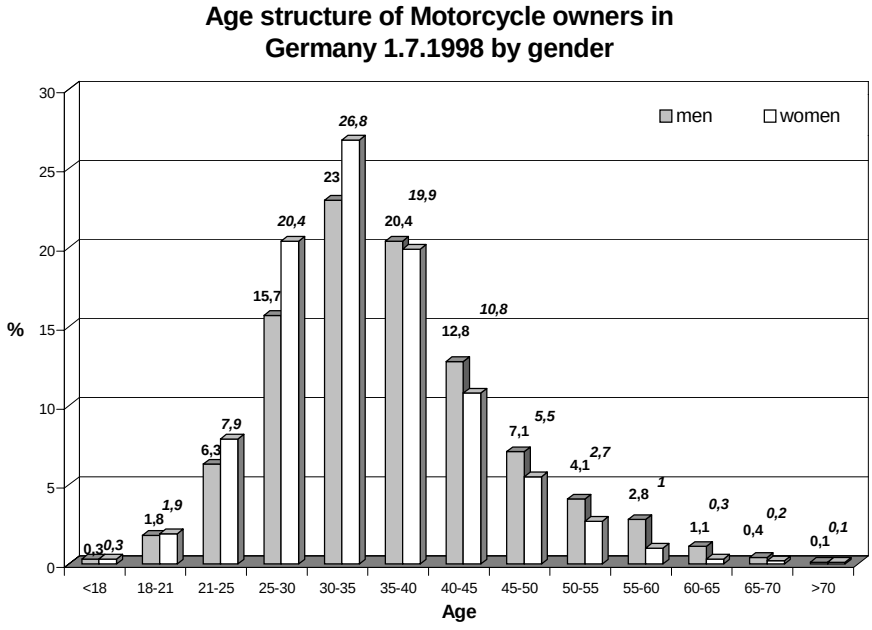


Figure 2.21. *Age structure of motorcycle owners by gender July 1st 1998 (KBA).*

2.4.4. *Motorcyclists and social structure*

Like for other research aspects, the flow of data for a description of the social structure of motorcyclists is very small and if data is accessible it is too old. For instance the French data is based on the year 1989 (Carré & Filou, 1991) and data in Germany on the year 1988. Newer data which is supposed to give different results, because motorcycling has developed into all social-demographic classes, cannot be discovered for this topic.

Following results from the basis of the existing older social-demographic figures of motorcyclists are given: In France 38 % of all moped rider are ‘students/pupils’ and 28 % ‘others not gainfully employed’, which seem to be the typical riders group in this moped category. In comparison with this, motorcyclists have a high share of workers (27 %), employees (22 %) and ‘intermediary professions’ (21 %).

In Germany, results of the data which are based on a survey of the ‘Motorpresse-Verlag’ in the year 1988 give the following picture (Schulz & Hagstotz, 1993). The average age of women was 25.7 years and men 28.3 years; 42.3 % women were ‘employees’ and 24.7 % ‘students/pupils’; 13.2 % of female motorcyclists are "workers" and 10.4 % ‘executive employees’. In comparison with that, men were 40.3 % ‘workers’ and 23.2 % ‘employees’. 18.4 % were ‘students/pupils’ and 12.7 % ‘executive employees’. The share of unemployed motorcyclists was 6.8 % for women and 3.2 % for men.

From the education point of view, 37.4 % of women had a ‘secondary school certificate (10^{th} class)’ and 25.2 % ‘primary school certificate / working people’; 24.4 % had a ‘secondary certificate (13^{th} class)’ and 7.4 % were ‘without primary school certificate’. Another 5.7 % had a ‘graduate study diploma’. Men had a portion of 40.8 % ‘primary school certificate/working people’, 30 % a ‘secondary school certificate (10^{th} class)’ and to 18.4 % a ‘secondary school certificate (13^{th} class)’. 6.7 % had a ‘graduate study diploma’ and 5.8 % were ‘unemployed’. In general female motorcyclists were 3 years younger than men and had a slightly higher education.

Although this data seems to be viable, one has to keep in mind the year of data recording. Like age and gender have shown, there are more elder motorcyclists to be found in the years between 1993 and 1998 and it can be expected that they have a different social-demographic structure in many other cases.

2.4.5. *Motorcyclists and mileages and utilisation*

Motorcycles and annual mileages is one factor that is sometimes used for a relative accident rate per Mill. vehicle kilometres, which is one of the best and reliable accident rates. But the information about the annual and total mileages of motorcycle riders is often only estimated or incomplete data, and in this sense face a real problem of reliability (remark of OECD to *Table 2.4*).

Nation	1980	1990	1991	1992	1993	1994	1995
A	285	93	74	54			
B							
CH		1,211		1,338			
D[1]	2,300	5,800	8,300	8,600	8,896	9,159	8,843
DK		300	295	300	296	317	
E	1,657*	1,963		1,431*		1,408	745
F					900		
FIN*	600	800	900	900	900	900	900
GB	6,025	6,400	6,300	5,000	4,200	4,146	4,120
GR							
I	6,334	16,152	16,397	18,169		14,000	14,000
IRL*	342	241	266	249	237	259	278
N	99	199	202	210	224	243	268
NL	780	880	970	1,084	1,206	1,700	1,300
S		700	400	400	450	597	612
Total	16,765	34,739	34,104	36,304	17,309	32,284	31,066
Average	1,863	2,895	3,410	3,025	1,923	3,228	3,452

Table 2.4. *Estimated total motorcycle kilometres (Mill.) in Europe; * with mopeds, [1] 1980 only former FRG (Source: UN).*

	Mopeds '90	Motorcycles '90	Mopeds '92	Motorcycles '92
Annual Mileages	1,950 km	2,950 km lightweight 7,750 km powerful	2,601 km	Avg. 4,569 km 9,497 km powerful
Daily	49 %	41 %		
Weekends only	12 %	18 %		
Summer only	21 %	26 %		
Home-work Avg. km (2-way)	32 % 13 km	50 % 26 km	20 %	
Home-study Avg. km (2-way)	16 % 13 km	8 % 26 km	20 %	19 % lightweight
Professional use Nr. of days/week	5 % 4.4	10 % 3.2		
Misc. trips Leisure time Avg. km	 62 % 14 km	 68 % 45 km		
Recreational use Time used Avg. km a month	36 % 6.9 25 km	75 % 4.8 117 km		

Table 2.5. *Utilisation of PTWs in France (Carré & Filou, 1991; Filou et al., 1994).*

"The share of PTWs in surface transport in Western Europe is about 3 % (133 bn passenger kilometres a year, mopeds included). This share may look small, but it equals half the transport volume of Europe's railways." (Moscato & Sergeys, 1998).
In France mopeds are used up to 54 % in urban areas whereas motorcycles are more or less used in rural areas (58 %). The 'main or sole means of transport' is 44 % for mopeds and 27 % motorcycles (Carré & Filou, 1991) (*Table 2.5*).

The German situation of motorcycles seems to be different to France related to the daily use of motorcycles, as is shown in *Table 2.6.*

	Female motorcyclists	Male motorcyclists
Daily	42 %	46.2 %
Several Days per Week	36.3 %	38.4 %
One day per week	14.1 %	10.5 %
< 1 day per week	7.6 %	4.9 %
Solo trips	51.3 %	30.9 %
Sometimes with passenger	36.0 %	46.4 %
Only with passenger	12.7 %	22.7 %

Table 2.6. *Utilisation of motorcycles in Germany (Schulz & Hagstotz, 1993).*

A new IfZ research study of 125 cc motorcycles in Germany between 1996/1997 (Brendicke & Forke, 1998) had the following results concerning the utilisation of motorcycles, gathered in *Table 2.7.*
The utilisation of 125 cc PTWs in Germany is quite different to the French situation of 1992 with the result of 2,950 km average kilometres of *lightweight* vehicles. In Germany these vehicles have average annual kilometres of 7,247 km with a predominately use for work and leisure time in urban areas (*Table 2.7*).

	Total request	Age group > 35 years
Annual mileages	7,247 km	6,830 km
Daily use	66.7 %	59.8 %
Only weekend use	13.2 %	14.9 %
2-day use	19.0 %	24 %
Trip to work	11.9 %	12.7 %
Work / shopping use	7.6 %	4.4 %
Work / leisure use	65.4 %	69.6 %
Shopping / leisure use	8.4 %	12.3 %
Use of road areas	urban	urban

Table 2.7. *Utilisation of 125 cc motorcycles in Germany 1996/1997 (Brendicke & Forke, 1998).*

As a conclusion, the utilisation of PTWs seems to change although this vehicle category is as well other individual traffic modes used for leisure time purposes. For the category of 125 cc motorcycles, the urban traffic mode and the function for dual purposes seem to be reliable if we look at the figures for daily use and utilisation for 'trips to work'.

The total number in Mill. vehicle kilometres changes not considerably from year to year with a high decrease in the year 1993 without data of Italy. But we do not face this problem only in European statistics. For example, in Germany data about vehicle kilometres is varying from study to study (see *Table 2.8*).

Study	1984	1988	1990
DIW	4,400	4,200	4,100
Otte	6,757	5,732	
Motor Presse	12,500	10,145	8,565
Schulz/Hagstotz			
BASt			6207
BVZ			4461
Total	23,657	20,077	23,333
Average	7,886	6,692	5,833

Table 2.8. *Annual mileage of motorcycles in different questionnaires/studies in Germany*

The above mentioned data have a range of 8,100 km per year (1984) to 4,465 km per year (1990) and it is foreseeable that each data related to accidents would result in a totally different accident rate. The reason for that is that each interviewed sample of motorcyclists has more or less variations, or the data were collected in a micro census research with all the statistical problems.
Therefore mileage data are to be used with respect to their statistical problems and single data often is not reliable.

2.4.6. *Motorcyclists and motivation for riding*

Motorcycling changed in the last 30 years from a pure utilisation (Koch, 1990b; 1990c) use into a leisure-time vehicle (Rheinberg, 1990, Rheinberg, Dirksen & Nagels, 1986), and today gets more favourable as mobility form with dual purposes. Researches about motivations for riding a motorcycle are not present for the first period. Psychologists had their interest in the phase when the motorcycle was more-or-less used for leisure time purpose in the 80's. Motivational studies addressing motorcycles (Rheinberg, Dirksen & Nagels, 1986; Schulz, Kerwien & Koch, 1989) indicated changes in attitudes of riding. According to Rheinberg it is an exclusively and intrinsically motivated leisure time activity and Schulz et al. (1989) differentiated types of motivations for different categories of motorcycles e.g sport, custom, off-road, or touring bikes. A first systematic approach of riding motives has been presented by Koch (1977) and a psychoanalytically orientated study, based

on interviews by Dellen and Bliersbach (1978). Rheinberg, Dirksen & Nagels (1986) worked out a catalogue of driving motives of bikers based on interview data and analyses of biking advertisements.

All psychological motorcycle studies assessed the motivational and emotional aspects of an intrinsically motivated activity, as in combination with:

- *Positive experiences* in this intrinsically activity with motives like joy, fun and pleasure. Battmann (1984) and Koch (1990) add hedonistic experiences. Nowak (1979) includes the motive escapism, an escape from everyday reality and civilisation. It includes self-discovery and being in a good mood.
- *Dynamic aspects of riding*: when riding experiences of acceleration, speed, manoueverability and cornering are related to the physics of motorbikes (Rheinberg, Dirksen & Nagels, 1986; Schulz, Kerwien & Koch, 1989).
- *Performance aspects*: testing the performance limits of oneself and the machine. This can include as well sport and competitive behaviour (Dellen & Bliersbach, 1978; Rheinberg, Dirksen & Nagels, 1986; Schulz, Kerwien & Koch, 1989).
- *Social aspects*: Group activities and feeling as part of a special social peer group.
- *Control beliefs*: Individuals/people who are concerned of their own driving qualifications as perfect. They believe that they can control themselves, the vehicle, other road users, and the traffic situation (Dellen & Bliersbach, 1978; Rheinberg, Dirksen & Nagels, 1986).
- *Identification with the motorbike*: some bikers experience motorcycling as an activity that becomes an important part of their lives and increases their self-esteem (Dellen & Bliersbach, 1978) Often valid for young adolescent age groups.
- *Flow effects*: Csikszentmihalyi (1985) points out a highly intrinsically practised competent form of riding with a loss of awareness and attention for traffic situations that lead to a flow effect action with a subjective complete control of all actions.
- *Sensation seeking*: Dellen & Bliersbach (1978) assign a particular motivational function called “thrill and sensation seeking” linked to a dynamic stimulus of motorcycle riding (Rheinberg, 1990).

Some of the studies have a more sociological descriptive effect of motivations for motorcycle riding. Other studies have a clear impetus to analyse and to explain accident involvement and risky situations for this vehicle group. Although these are motorcycle orientated studies most of the motivations can be admitted for other vehicle types as well.

2.5. **Conclusion**

Motorcycles as well as mopeds got more attractive in the last years. The number of motorcycles, as well as the figure of vehicles per inhabitant in the European countries increased constantly in the last years. Although the numbers of mopeds decreased from 1980 to 1990, they seem to get a new strength related to the advantages of the modal split in urban traffic in the 90's. Obviously there are regional and national differences in Europe. In Southern European countries the relation between mopeds and motorcycles is different to the Northern EU-nations. The Southern European nations show a

high share of mopeds in comparison with the northern parts of Europe, whereas motorcycles as the major form of riding a powered one-track vehicle is more widespread in northern nations in Europe.

These regional differences could be seen by the absolute number of the registered mopeds and motorcycles as well as in the ratio's of vehicles per inhabitant. F and GB have a strong reduction of registered mopeds as well as registered motorcycles in the past 15 years. But it should be noted, that even countries with small absolute numbers of registered vehicles could have a high one-track vehicle ratio per inhabitant, like the figures in CH obviously show. Due to this, numbers of vehicles per inhabitant should be only used if background information about the vehicle fleet is known. The total share of mopeds and motorcycles in the EU show that in southern European countries this form of mobility is very favourable in relation to the northern EU nations expect Germany, which may be a result of different climatic conditions.

3. Legislation on mopeds and motorcycles

3.1. **EU Driving licence scheme and motorcycle licensing scheme 91/439 EC**

In the year 1980, the Council of Ministers of the European Communities took the first steps towards a harmonisation of the law governing driving licences that was achieved 1991, when the Second Directive on Driving Licences was adopted with the following changes (Jagow, 1996; Neumann-Opitz & Heinrich ,1995; Von Hebenstreit, 1993):

- Obligatory categories for the driver licences with categories A, B, C, D, E, that will replace other national categories e.g. in Germany class 1 to 5, with defined sub-categories.
- Minimum requirements concerning theoretical and practical tests.
- A maximum of equality for the definition of the new categories, although national definitions or limitations are allowed in the first step.

3.1.1. *Category A*

The European licencing scheme for category A motorcycles is given in *Table 3.1*.

3.1.1.1. Two-stage graduated licence scheme

The Directive also contains a provision on two-stage licences for category A motorcycles. Persons aged 18 and above may acquire this licence after taking appropriate instruction and passing a test. Subsequently, the motorcycle-beginner must, first of all, gain at least two years of riding experience on motorcycles with an engine power not exceeding 25 kW and a power-to-weight ratio not exceeding 0.16 kW/kg before he is allowed to ride all kinds of motorcycles (without power restrictions). After these two years, another test will not be required.

A	Motorcycles with or without side cars; piston capacity >50cc or design speed >50 km/h	Minimum age and requirements
Step I	Limited motorcycle licences; motorcycles up to 25 kW, not exceeding 0.16 kW/kg	18 years
Step II	Motorcycle licences with no power restrictions	20 years; will not be granted until drivers have at least two years of experience on motorcycles Step I
Direct Access	Motorcycle licences with no power restrictions	21 years; authorisation to drive all kinds of motorcycles without two years of experience on a motorcycle with Step I
Sub-Category A1	Licence for lightweight motorcycles; piston capacity not exceeding 125 cc; engine power up to 11 kW.	16 years

Table 3.1. *European licensing scheme for powered two-wheelers.*

3.1.1.2. Direct access

The Member States can permit a 'direct access' to the unrestricted category A if the applicant has at least reached the age of 21.

3.1.1.3. Specific definition of sub-category A1

Motorcycles of the sub-category A 1 are motorcycles with a displacement not exceeding 125 cc and an engine power not exceeding 11 kW (lightweight motorcycles). Member states may restrict this category by imposing further criteria such as a maximum design speed, or power-weight ratio.

3.1.2. *EU Licensing adoptment and implementation in Europe*

The conversion of the EU Licensing Scheme 91/439 in the EU countries took place with the following time tables:

- National implementation until July 1st 1996.

But not all countries have adopted the Licensing Scheme in general because:

- The possibilities of national enforcement's of some classes were offered; and
- The actual acquired rights of existing national licences had to be protected

Therefore the implementation of EU licensing system Ccategory A was not generally adopted by all countries in Europe and we find some national definitions or restrictions of the classes A, A1 and M (e.g. *Table 3.2*).

M	Small motorcycles (mopeds, slow mopeds)	Small-displacement motorcycles and cycles with auxiliary engine with a displacement not exceeding 50 cc / 45 km/h
L	Self-propelled PTW	L: Self-propelled machines up to 25 km/h

Table 3.2. *National driving licence categories for vehicles not covered by the Directive but with a relation to powered two-wheelers*.

3.1.2.1. Implementation of class A

From 14 EU countries 13 countries adopted the Motorcycle Licensing Scheme A Step I with 25 kW and a power-to-weight ratio of 0.16 kW/kg with 18 years onwards. Only in GB the rider can achieve this A Step I licence with 17 years (see *Table 3.3*).
The Step II A licence category was as well implemented by all countries with rider experience in the last two years (*Table 3.3*).
The 'direct access' was converted by 13 of these 14 EU countries; only E has not yet decided this question. The minimum age of 21 was forced into law by 11 countries and two other countries have/or will have a minimum age of 25 years for the direct access for unlimited motorcycles (*Table 3.3*).

Nation	Motorcycles A step I; limited (25 kW /0.16 kW/kg)	Motorcycles A step II; not limited	Direct access
A	Yes / from 18	Yes with 2 years experience	Yes > 21 years
B	Yes / from 18 (from Oct. 1st 1998)	Yes with 2 years experience	Yes > 21 years
D	Yes / from 18	Yes with 2 years experience (>4.000 km)	Yes > 25 (from Jan. 1st 1999)
DK	Yes / from 18	Yes with 2 years experience	Yes > 21 years
E	Yes / from18	Yes with 2 years experience	Not yet decided
F	Yes / from 18	Yes with 2 years experience	Yes > 21 years
FIN	Yes / from 18	Yes with 2 years experience	Yes > 21 years
GB	Yes / from 17	Yes with 2 years experience	Yes > 21 years
I	Yes / from 18	Yes with 2 years experience	Yes > 21 years, specific test
IRL	Yes / from 18	Yes with 2 years experience	Yes > 25 years
N	Yes / from 18	Yes with 2 years experience	Yes > 21 years
NL	Yes / from 18	Yes with 2 years experience	Yes > 21 years
P	Yes / from 18	Yes with 2 years experience	Yes > 21 years
S	Yes / from 18	Yes with 2 years experience	Yes > 21 years

Table 3.3. *National implementation of the EU Licensing Scheme 91/439 EC. Institut für Zweiradsicherheit, 1998, using different sources.*

Only two European countries do not have adopted the general framework of the EU legislation. The licensing models of Switzerland and Greece have similarities, concerning the enforcement of basic motorcycle experience with class A1 motorcycles and a minimum age of 20 years (see *Table 3.4*).

Nation	Regulation
CH	Different graded licence system: Step I: for motorcycles up to 125 cc, from 18 Step II: for motorcycles with no limitation, from 20 with 2 years experience, special test Additional it is possible for members of the Switzerland army and police to get direct access to a licence for unlimited motorcycles.
GR	Different graded licence system: Step I: for motorcycles up to 125 cc, from 18 Step II: for motorcycles with no limitation, from 20 with 2 years experience.

Table 3.4. *Nations with different regulations*.

3.1.2.2. Sub-category A1

For this licence sub-category of the EU Licensing Scheme 91/439 EC the framework of defined capacity and maximum engine power was fixed, but national implementation possibilities were allowed.
Thirteen European countries adopted the sub-category A1 and three of them have national regulations implemented (D, E, GB). In Germany there is a limit for maximum speed for 16 to <18 year old riders, Spain and GB have a power-weight ratio limitation of 0.11 kW/kg (see *Table 3.5*).

Nation	Conversion A1 Licensing Scheme	Age	National regulations	B licence equivalence	National regulations
A	Yes	18	-	Yes	From 23 with 5 years car licence and practical examination (6h) it is possible to drive vehicles wich fulfil the definition of A1
B	since Oct. 1st 1998	18		Yes	with more than 2 years car licence
D	Yes	from 16 to 18	max. speed 80 km/h	Yes	car licence or national licence '4' received before April 1st 1980
		over 18	no speed limitation		
E	Yes	16	Power/weight ratio 0.11 kW/kg	No	-
F	Yes	16	no limitations	Yes	from 20 with 2 years car licence
FIN	Yes	16	no limitations	No	-
GB	Yes	17	Power/weight ratio 0.11 kW/kg	Yes	-
I	Yes	16	no passenger	Yes	from 18, with car licence
IRL	Yes	16	no limitations	No decision	-
LUX	Yes	16	-	-	-
N	Yes	16		No	
P	Yes	16		No	-
S	Yes	16	no limitations	No	-

Table 3.5. *National Implementation of EU Licensing Scheme 91/439 EC: A1, 125 cc / 11 kW in Europe. Institut für Zweiradsicherheit e.V., Essen, Germany September 1998, using different sources.*

Except in Austria, Belgium and GB the minimum age for the A1 licence is 16 years. Austria and Belgium implemented 18 years as a minimum and GB 17 years (*Table 3.5*).

CH, DK, GR, NL do not have implemented the EU A1 motorcycle class. Obviously this seems to be a result of national regulations for the minimum age, because all of these countries have this limit forced to 18 years (*Table 3.6*).

Nation	Minimum age to receive a driving licence for vehicles wich fulfil the definition of A1	Other comments
CH	18	The categorie A1 does not exist as an individual driving licence category.
DK	18	
GR	18	The categorie A1 does not exist as an individual driving licence category.
NL	18	The categorie A1 does not exist.

Table 3.6. *Nations with different regulations concerning vehicles of category A1*.

3.2. **National legislation for mopeds**

The EU Licensing Scheme 91/439 EC has not defined the classes of smaller motorcycles, but has fixed a maximum speed as a definition for M and L class vehicles.

3.3. **Requirements and legal framework for PTWs in Europe**

3.3.1. *Licensing training / instructions*

Although there is a high level of harmonisation of the licensing scheme in Europe, the EU Licensing Scheme 91/439 EC does not include the requirements and conditions for reaching a licence very much detailed. Therefore we find national standards and *Tables 3.8 and 3.9* give a detailed view of the requirements for the licensing scheme in different European countries (CIECA, 1997).

Nation	Implementation of EU directive	National indication	Age	Actual national legislation	Additional national regulations	Car licence include moped
A	Yes	AK	16	- <50 cc - speed limit 45 km/h	from 16 with obligatory theory-test	Yes
			24		without any test allowed to drive	
B	Yes	A	16	- <50 cc - speed limit 25 km/h	without any test allowed to drive	Yes
		B	16	- <50 cc - speed limit 45 km/h	with practical and theoretical test	
CH	Yes	Mofa	14	- <50 cc - speed limit 30 km/h - automatic	theoretical test	Yes
		F	16	- <50 cc - speed limit 45 km/h	with theoretical and practical test	
D	Yes	Leichtmofa	15	- 20 km/h bicycle with aux. 30 cc engine	without any test	Yes
		Mofa	15	- 25 km/h	with theoretical test and practical examination	
		Moped	16	- <50 cc - speed limit 50 km/h	with theoretical and practical test	
DK	Yes		16	- speed limit 30 km/h and max power 0,9 kW/h	with theoretical and practical test	Yes
			18	- speed limit 30 km/h	without any test or licence	
			18	- speed limit 45 km/h	with A or B licence	
E	Yes	Moped	14	- <50 cc - speed limit 45 km/h	theoretical test	Yes
			16		without any test	
F	Yes		14	- <50 cc - speed limit 45 km/h	with a road safety diploma at school, followed by practical and theoretical test	Yes
			16		without any test	
FIN	Yes		15	- <50cc - speed limit 45km/h	without any test	Yes
GB	Yes	P	16	- <50cc - speed limit 45km/h	with practical and theoretical test	Yes
GR	Yes		16	- speed limit 50 km/h	with theoretical and practical test	no data
I	Yes		14		unknown	no data
IRL	Yes		16	unknown		Yes
N	Yes	Moped	16	- <50cc - speed limit 45 km/h	practical and theoretical test	no data
NL	No	Snorfiets	16	- 25 km/h	with practical and theoretical test	Yes
		Bromfiets	16	- <50cc; - speed limit 45km/h		
P	Yes	Moped	14	- <50cc - speed limit 45km/h	with practical and theoretical test	Yes
			16		no test	
S	Yes, from Oct. 1st 1998	Moped	16	- 25 km/h; 1,1 kW	with practical and theoretical test	Yes
			16	- <50 cc - speed limit 45 km/h	with practical and theoretical test	

Table 3.7. *National Legislation for Mopeds / EU Licensing Scheme 91/439 EC: M: displacement not exceeding 50 cc, speed limited to 45 km/h. Institut für Zweiradsicherheit, 1998, using different sources.*

	Length of the practical test (min)		Special manoeuvres practical test category A															
	A1	A	u-turn	circle	slalom	eight	keeping balanced	parking on stand	shoving	braking performance	emergency stop	riding across a plank	small passage	evasive action	90° -turn at sustained speed	angle start	slow ride	moving off uphill
A	-	20																
B	45	45																
CH	60	60																
D	45	60		a	o		a	o		o	o			o			a	a
DK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E	5	5																
F	45	45																
FIN	-	30																
GR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IRL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N	-	50																
NL		65																
P		30																
S	45	45																
UK	45	45																

Table 3.8. *Practical test for category A1 and A. a=alternative, o=obligatory (CIECA, 1997).*

Nation	Theoretical test			Number of questions			
	Individual	Group	Aid	A1		A	
				Total	Correct	Total	Correct
A	oral					14	
B	computer	computer		40	32	40	32
CH		written		50	45		
D		written		30		30	
DK	-	-	-	-	-	-	-
E		written		40	35	40	35
F		written	slides			40	35
FIN	computer	computer	slides			60	49
GR	-	-	-	-	-	-	-
I	-	-	-	-	-	-	-
IRL	-	-	-	-	-	-	-
N		written				50	41
NL		computer	slides			50	45
P		written				25	22
S	written/oral	written/oral		40	36	40	36
UK		written		35	30	35	30

Table 3.9. *Theoretical test for category A1 and A (CIECA, 1997).*

3.3.2. *Legislative framework for moped and motorcycle riders in Europe*

	Speed limits				Mandatory daytime use of headlights	Mandatory use of safety helmets	Other regulations
	motor-ways	dual carriage ways	rural roads	urban roads			
A	130	100	100	50	only for PTW	Yes	first aid equipment for MCs and mopeds obligatory; no special speed limit for MCs with trailer
B	120	90	90	50	only for PTW	Yes, except moped class A (<25 km/h)	no special speed limit for MCs with trailer; trikes and quads are not allowed to use motorways
CH	120	100	80	50	only for PTW	Yes	max. speed on motorways for MCs with trailer 80 km/h
D	130*	130*	100	50	only for PTW	Yes, except mofa <20 km/h	individual signed speed limits for MCs on motorways with parallel (longitudinal) grooves; max. speed on motorways for MCs with trailer 60 km/h; riding without hands is not allowed
DK	110	110	80	50	for all vehicles	Yes	since June 10th 1998, trailer use on motorcycles with an engine larger than 125 cc is allowed
E	120	100	90	50	only for PTW	Yes	for MCs no trailer use allowed
F	130	110	90	50	only for PTW	Yes	novice drivers in the first 2 years max speed limits: motorways and carriage ways 110 km/h, rural roads 80 km/h no special speed limit for MCs with trailer
FIN	80-120	80-120	60-100	50	for all vehicles	Yes	max. speed on motorways for MCs with trailer 80 km/h
GB	112	112	96	48	no	Yes	max. speed for MCs with trailer: rural roads 80 km/h, motorways 96 km/h
GR	120	110	90	50	unknown	Yes	for MCs no trailer use allowed; speed limit 40 km/h for MCs on urban roads
I	130	110	90	50	no	Yes, except moped riders over 18 years	for MCs no trailer use allowed; PTWs up to 150 cc are not allowed to drive on motorways; riding without hands is not allowed; "wheelie" is not allowed
IRL	112	112	96	48	unknown	Yes	no special speed limit for MCs with trailer
N	90-110	90-110	80	50	for all vehicles	Yes	for MCs no trailer use allowed
NL	120	100	80	50	unknown	Yes, except snorfiets	max. speed on motorways for MCs with trailer 80 km/h
P	120	90/100	90	50	unknown	Yes	no special speed limitation for MCs with trailer; novice drivers in the first year: speed limit 90 km/h
S	90-110	90-110	70-90	50	for all vehicles	Yes	trailer use only with a special permit from road authority, max speed on motorways 80 km/h

Table 3.10. *Legislative framework for moped and motorcycle riders; *guided speed limit, not obligatory*.

3.3.3. *Speed limits*

National speed limits for PTWs are normally the same as for two-track vehicles. Only in Greece there is a speed limit of 40 km/h for motorcycles in urban areas in relation to 50 km/h for cars. Differences are existing for the regulations for 'use of trailers in connection with motorcycles'. Four nations (E, GR, I, N) do not allow a trailer use at all: In GR, I, N trailer use is only allowed for tourists. The speed limits for MCs + trailer on motorways differ from 60 km/h in D to 130 km/h in F.

The rate of speeding offences of MCs in France are particularly high (Carré & Filou, 1991). The problem of speeding offences of MCs seems to be no individual motorcycle problem. It is more a problem of the age groups and their traffic behaviour.

3.3.4. *Helmet law and enforcement*

The use of helmets for motorcycle riders and pillion passengers is mandatory in all member states of the EU. For mopeds as well the helmet use is mandatory except for 'slow' mopeds in Belgium, the Netherlands and for drivers of mopeds in Italy, which are older than 18 years. In Germany there is an additional sub-category of powered two wheelers defined as 'Leichtmofa' (capacity 30 cc/ 0.5 kW /maximum speed is 20 km/h) that can be driven without a helmet.
Although mandatory use of helmets for motorcyclists are enforced, the question about real use of helmets is researched in various studies from F, E, GR, D, CH. The results cannot be compared with each other because of different methodologies. Some studies use causality data others observe the use of safety equipment in the daily traffic in urban or rural areas.
For example in Germany the helmet use in urban areas is nearly 100 % (1995), only in the eastern part of Germany 2 % of the pillion passengers are wearing no helmet (see *Table 3.11*).

	1991		1992		1993		1994		1995	
	former	new	former	new	former	new	former	new	former	new
Rider with helmet	99	99	99	99	99	99	99	100	100	100
Passenger with helmet	98	90	99	92	99	94	100	94	100	98
Rider with complete clothing	65	39	67	44	60	48	60	53	43	55
Passenger with complete clothing	44	11	43	20	52	33	39	15	25	31

Table 3.11. *Percentage of helmet and complete motorcycle safety clothing use on urban roads in Germany, 1991 to 1995. (N=2500) (Haas, 1996).*

Similar results can be applied from Switzerland: in the year 1997 99 % of the motorcycle and 96 % of moped users were wearing a helmet (Allenbach, 1997). This is almost equivalent to the French situation: 96 % of the motorcycle riders and 89 % of the moped riders wear a helmet in rural areas. The 'Direccion General de Trafico' of Spain (1995) surveyed the helmet use of motorcyclists, moped riders and passengers by an inquiry at gas stations. 2,225 motorcyclists were questioned (1,468 in urban areas; 757 in rural areas). 95 % motorcycle riders in urban areas and 97 % in rural areas wear a helmet. For moped riders this figure was 78 % in urban (4,112) and 84 % in rural (1,105) areas. The study also refers to the correct fit and fastening of helmets. Inside urban areas helmets are worn not as correct as in rural areas. Reason for an incorrect use was the fear of being fined not wearing a helmet and to be conform with the legal rules. Riders with a correct fit of helmets see their own safety as the major point.

In Greece all motorcycle accidents in the year 1985 and in the year 1994 - which were recorded to the police - were analysed as well in respect to helmet use of motorcyclists. Only about 15 % of drivers and 8 % of passengers (same figures 1985 and 1994) involved in an accident wore a helmet. The probability of being fatally injured in an accident for non-helmet users is 50 % higher than for helmet users. In Greece the high fatality rate may be considered in relation to the low figures of helmet use in general (Petridou et al., 1998).

Data's concerning the effectiveness of helmet use are also shown in different studies (EC, 1996; Koch & Flügel, 1983; Otte et al., 1998). Overall the risk of fatal injuries more than halved when a helmet is worn and head injuries are clearly reduced. Important is a correct way of wearing the helmet in order not to lose it in a case of an accident.

The example Greece shows that it is not sufficient to enact a helmet law. There also have to be control mechanisms and campaigns, which support the real use of helmets.

3.3.5. *Daytime use of headlights for motorcyclists*

Daytime use of headlights are mandatory for PTWs in A, B, CH, D and E, for motorcycles with 125 cc and more in F, in DK, FIN, N, S for all 2-track vehicles and motorcycles, in DK for mopeds too. In various nations the compulsory daytime use of headlights were discussed or tested for a period of time (e.g. NL). The results of these studies will be discussed later.

4. Accident statistics and analysis of accidents

4.1. **Introduction**

Accident data of different nations can't be compared to each other under all aspects, because geographical, social and economic differences, unequal road environments, differences in the extent of urbanisation, the rate of motorisation or different enforcements from road safety authorities are to be seen. In examining the available international statistics on motorcyclists' road accidents (CEMT/OECD) some difficulties are to be handled and they should be interpreted with care. Beside fragmentary or provisional data for some countries, significant differences in the definitions of killed and injured persons for different countries are found. However, official sources are used and statistic data gaps are filled with relevant information from other national or international resources.

For accident data no uniform definition of injured or severely injured persons exists. Some countries do not have a distinction at all, others vary in different categories. Although fatalities are at least beset by differing definitions in terms of the time period applied in each country, they are the most valid criteria for a comparison. The number of killed was corrected by a factor (death within 30 days) that gives an accurate figure for all countries. Casualty means all fatally, slightly or seriously injured motorcyclists, although the definition for the injury categories mentioned last differ from nation to nation. Interpretation may vary, but a reasonably consistent guide is when a casualty is taken to hospital at once or within a short time. Slightly injured often means a short stay in the hospital within at least under on day, whereas serious injury can vary in outcome from observation leading to discharge from hospital in a period of days or for the rest of life.

Apart from that the counting of registered vehicles seems to be inadequate for some countries and differ between sources and as well from the point of the accounted date (middle or end of the year). Fatality or casualty rates per average or million kilometres are only an estimated figure which imply serious reliability problems for these rates.

4.2. **PTW accident statistics in Europe**

4.2.1. *Motorcycles*

European countries represent a positive trend in relative safety and accident rates of powered-two-wheelers (PTWs) in the decade between 1980 and 1990 and in a comparison between the year 1990 and 1995 (last available complete data). The available data is presented in *Figures 4.1 and 4.2* and in *Table 4.1*.

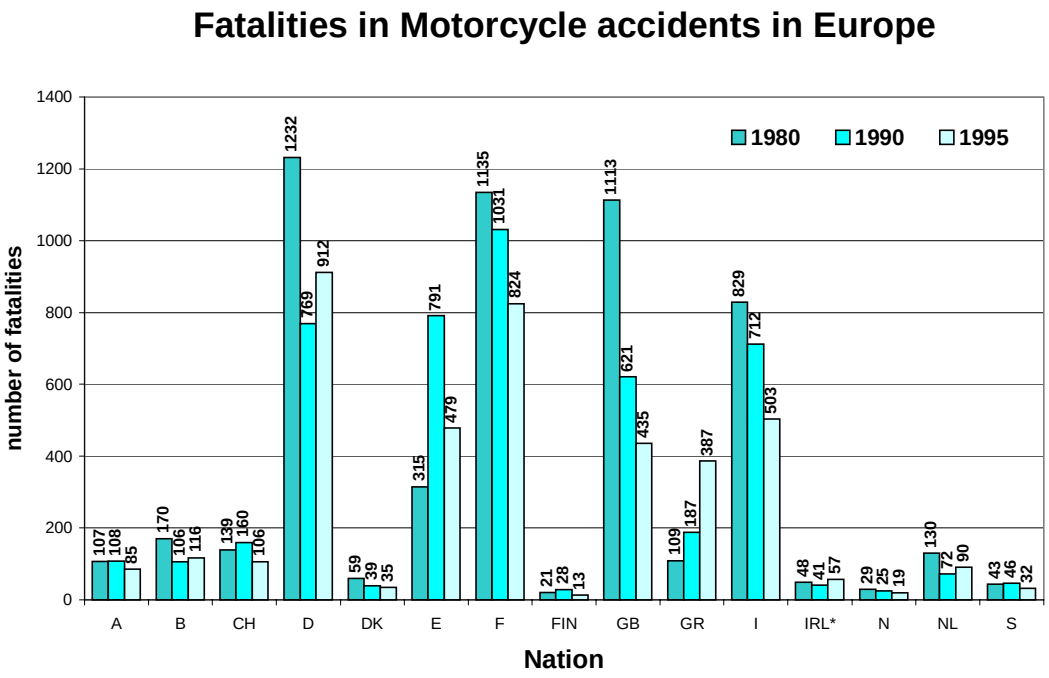


Figure 4.1. *Fatalities in motorcycle accidents in Europe*.

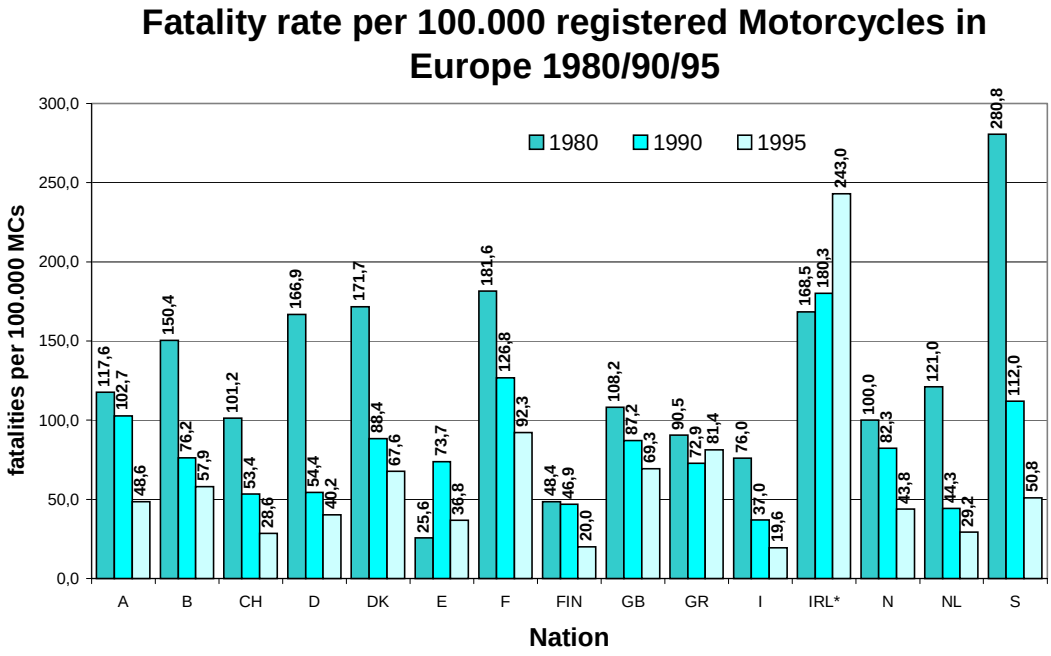


Figure 4.2. *Fatality rate per 100,000 registered motorcycles in Europe*.

Nation	1980	1990	1995	%change 1980/1990	%change 1990/1995	registered motorcycles 1990	rate per 100,000 registered vehicles 1990	registered motorcycles 1995	rate per 100,000 registered vehicles 1995	%change of rates 1995/1990
A	107	108	85	0.9	-21.3	105,177	102.7	175,000	48.6	-52.7
B	170	106	116	-37.6	9.4	139,174	76.2	200,258	57.9	-23.9
CH	139	160	106	15.1	-33.8	299,764	53.4	370,699	28.6	-46.4
D	1,232	769	912	-37.6	18.6	1.413,674	54.4	2,267,428	40.2	-26.1
DK	59	39	35	-33.9	-10.3	44,111	88.4	51,753	67.6	-23.5
E	315	791	479	151.1	-39.4	1,073,457	73.7	1,301,180	36.8	-50.0
F	1,135	1,031	824	-9.2	-20.1	813,000	126.8	893,000	92.3	-27.2
FIN	21	28	13	33.3	-53.6	59,716	46.9	65,000	20.0	-57.3
GB	1,113	621	435	-44.2	-30.0	712,000	87.2	627,479	69.3	-20.5
GR	109	187	387	71.6	107.0	256,594	72.9	475,688	81.4	11.6
I	829	712	503	-14.1	-29.4	1,922,000	37.0	2,570,000	19.6	-47.2
IRL*	48	41	57	-14.6	39.0	22,744	180.3	23,452	243.0	34.8
N	29	25	19	-13.8	-24.0	30,369	82.3	43,413	43.8	-46.8
NL	130	72	90	-44.6	25.0	162,677	44.3	308,000	29.2	-34.0
S	43	46	32	7.0	-30.4	41,066	112.0	63,000	50.8	-54.7
Avg.	365	316	273				82.6		61.9	

Table 4.1. *Fatalities of motorcyclists in Europe 1980/1990/1995 and accident rate per 100,000 registered motorcycles. *in the number of fatalities from IRL fatalities of moped accidents are included. Source: UN.*

4.2.1.1. Fatalities

Total numbers of fatalities and percentage change between the years 1980 and 1990 and 1995.

The total number of fatalities in these European countries during 1990 was 4,736 fatally injured motorcyclists and 5,479 in the year 1980. From 1990 to 1995 the figure fell to 4,093 fatal accidents. Changes over this last decade show a significant -13.6 % decrease and another decrease of -13.6 % for the year 1995.

The declining percentage change of motorcycle fatalities range between -9.2 % in France and -44.6 % in the Netherlands. Percentage changes of more than -10 % of total numbers of fatalities are obvious between 1980/1990 in the following nations:

B	-37.6 %	D	-37.6 %
DK	-33.9 %	GB	-44.2 %
NL	-44.6 %		

That means a reduction from a total of -20 (DK) to -492 (GB) fatally injured motorcyclists in Europe 1990.

A serious increasing percentage change has to be stated for Spain (+151.1 %), Greece (+71.6 %), Finland (+33.3) and Switzerland (+15.1 %), where from +7 (FIN) to +476 (E) more motorcyclists were fatally injured between 1980 and 1990.

The declining tendency could as well be found in the comparison between the years 1990 and 1995, when the percentage change of motorcycle fatalities range between -10.3 % in Denmark and -53.6 % in Finland. Percentage changes of more than -20 % of total numbers of fatalities are obvious between 1990/1995 in:

A	-21.3 %	CH	-33.8 %
E	-39.4 %	GB	-30.0 %
I	-29.4 %	N	-24.0 %
S	-30.4 %	FIN	-53.6 %

That means a reduction from a total of -4 (DK) to -312 (E) fatally injured motorcyclists in comparison between 1990 and 1995.
A serious increasing percentage change has to be stated for Ireland (+39.0 %) and Greece (+107.0 %).

Comparison of fatality rates per 100,000 registered motorcycles between the years 1980/1990 and 1990/1995

Fatality rates per 100,000 registered motorcycles correspond to the total amount of motorcycles in different countries. During the year 1980 the fatalities in most western European countries were over 100 per 100,000 vehicles in use. Apart from Ireland and Greece this rate declined in all countries until the year 1990. Five countries have a fatality rate between 30 to 55 and six countries between 72 to 89 fatalities per 100,000 registered motorcycles. Austria, France, Ireland and Sweden still had over 100 fatalities per 100,000 registered vehicles in 1990.

In the comparison of 1990 and 1995 eight countries had a rate under 50 per 100,000 vehicles and six countries under 93 fatally injured motorcyclists. Only Ireland had a rate over 200 motorcyclists per 100,000 motorcycles.

The percentage change of fatality rates per 100,000 vehicles indicates a positive trend between the years 1990 and 1995. Only Ireland (+34.8) and Greece (+11.6 %) produced increasing percentages in these five years.

All other countries had a declining fatality rate percentage change between -20.5 % (GB) and -54.7 % (S). Countries with a percentage declining of more than -40 % are:

A	52.7	CH	46.4
E	50.0	I	47.2
N	46.8	S	54.7
FIN	57.3		

A decrease of more than -15 % of fatality rate percentage change between the years 1990 and 1995 are found in following countries:

B	23.9	D	26.1
DK	23.5	F	27.2
NL	34.0	GB	20.5

Almost all countries have improved in relative motorcycle safety measured by the percentage change of this fatality rate per vehicle population, although the total numbers of fatalities are fluctuating.

The average fatality rate per 100,000 registered vehicles in 15 European countries was 82.6 in 1990 and declined to 61.9 in 1995 (-25.1 %).

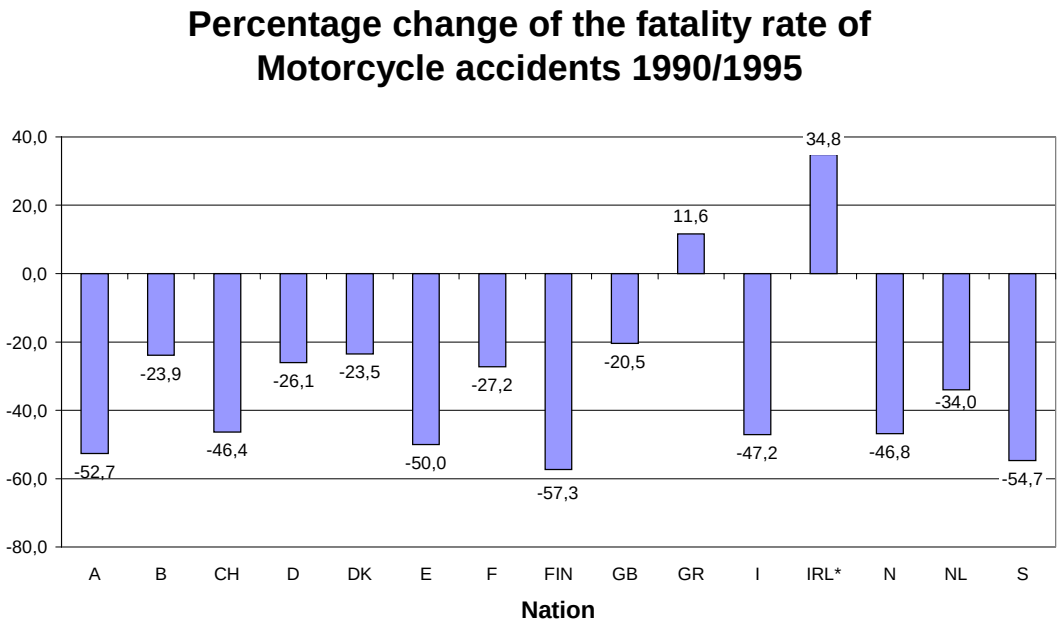


Figure 4.3. *Percentage change of fatality rate of motorcycles 1990/1995*.

The percentage share of motorcycle fatalities by road user groups is 9.4 % of all fatalities (CEMT DATA 1994 without GB/I/S). Other vulnerable road user groups like pedestrians (17.3 %) have a higher share. Bicycles (8.5 %) and mopeds (5.2 %) have smaller amounts (*Figure 4.4*).

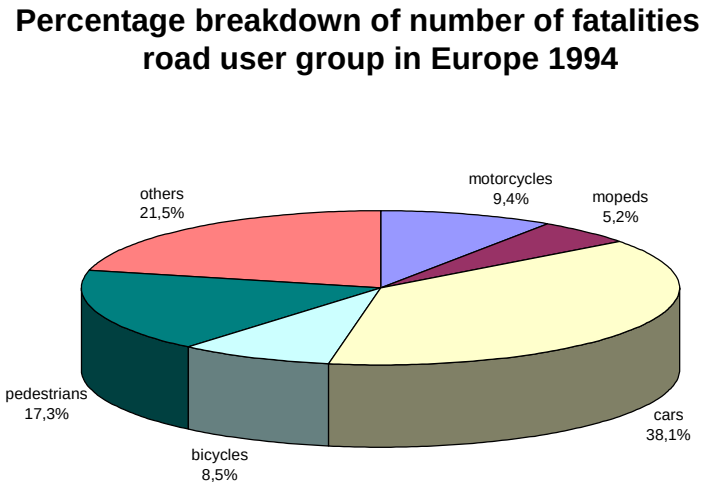
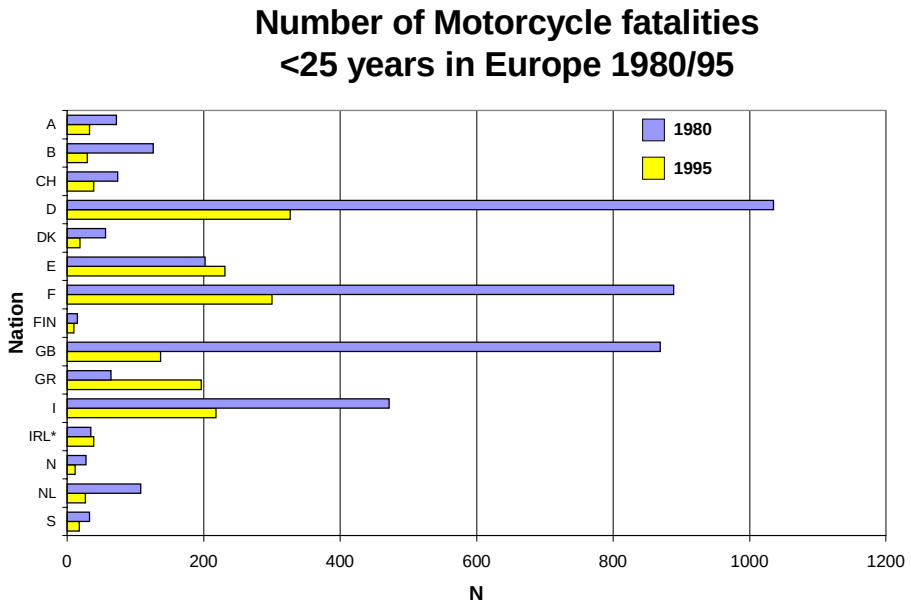


Figure 4.4. *Percentage breakdown of number of fatalities by road user group in Europe; Source: CEMT.*

A comparison between the year 1980 and 1995 by age groups shows a reduction of -31 % of fatalities (without GR, refers to age: 1980:5334 / 1995:3683) of all age groups (*Figure 4.5*).

An analysis of the motorcycle age groups <25 years and >25 years points out a change of age relations to fatalities with a declining tendency of motorcyclists under 25 years (-59.8 %) and an increasing tendency for motorcyclists greater 25 years (77.6 %) between 1980 and 1995 which is related to changes in the age structure of the motorcyclists population.



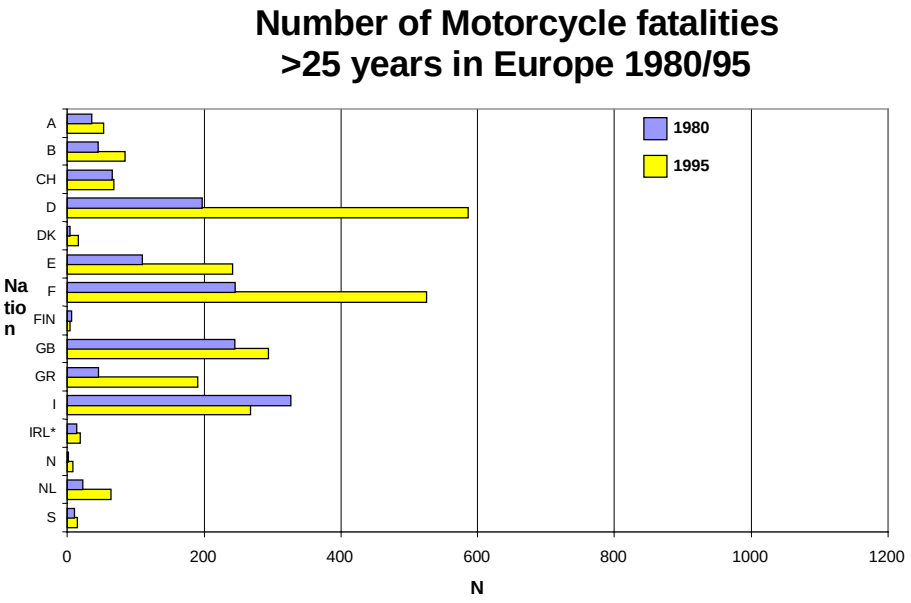


Figure 4.5. *Number of fatalities in motorcycle accidents by age*.

4.2.1.2. Injuries

From 1980 to 1990 the number of injuries fell by -37,443 cases (average minus 2,496 injuries in 15 EU countries). From 1990 to 1995 another reduction of 29,562 injury-cases of motorcyclists can be found (average of 1,971 injuries in 15 EU countries). We find a reduction of -19.5 % (80/90) and -19.1 % (90/95) as an average.

Therefore the percentage rate of injured motorcyclists per 1,000 registered motorcycles fell in all countries except IRL from 1990 to 1995 by a percentage average of minus 31.2 for the year 1995.

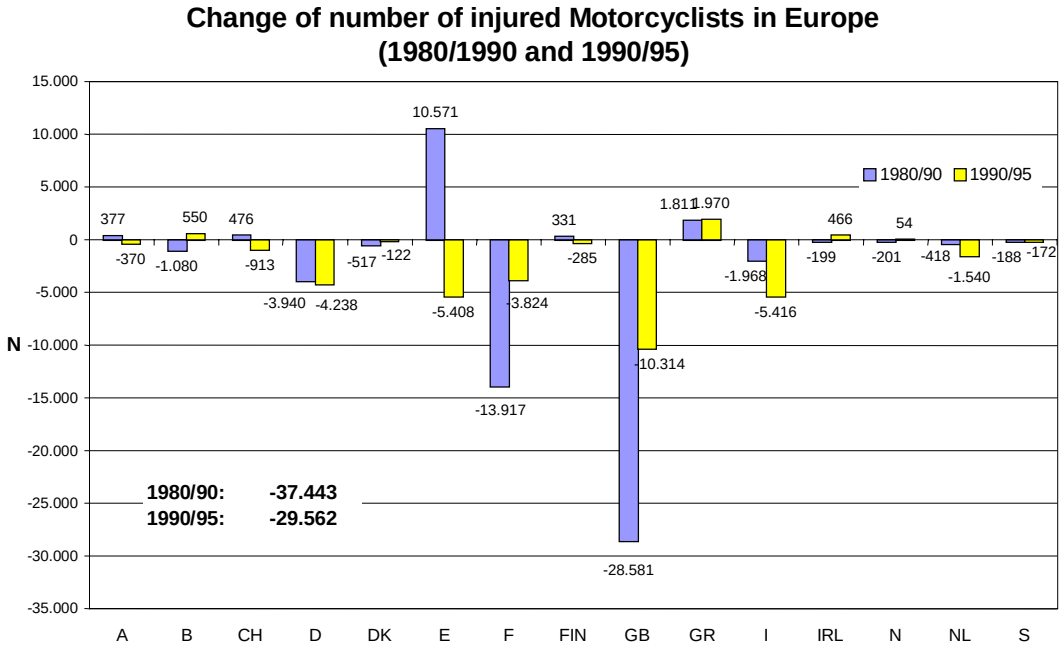


Figure 4.6. *Change of number of injured motorcyclists in Europe*.

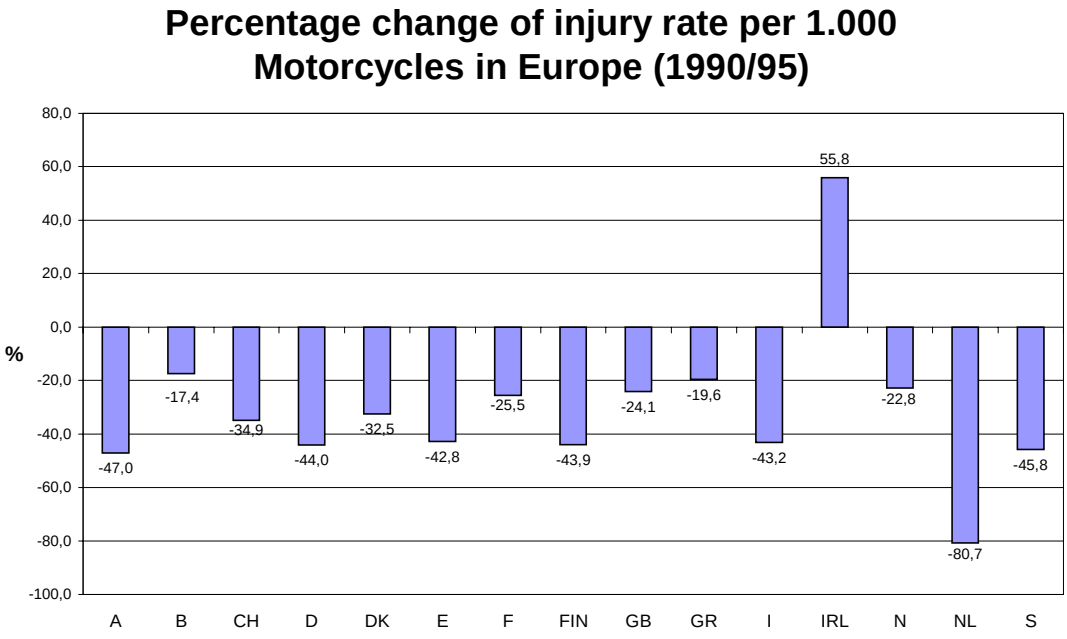


Figure 4.7. *Percentage change of injury rate per 1,000 vehicles in Europe*.

4.2.1.3. Casualties

For various EU countries (CEMT Data 1994, without GB/I/S) motorcycles have a percentage share of 8.5 % of all casualties. Other vulnerable road user groups like pedestrians (10.4 %) bicycle- (11.1 %) and moped riders (8.7 %) have a higher amount in the percentage breakdown by road user groups (*Figure 4.8*).

The casualty rate per 1,000 vehicle population in Europe declined in the comparison between the year 1990 and 1995. Only IRL has a higher accident rate in 1995 (*Figure 4.9*).

The percentage change of the casualty rate has an average of minus 31.3 % between 1990 and 1995 for all EU countries (*Figure 4.10*).

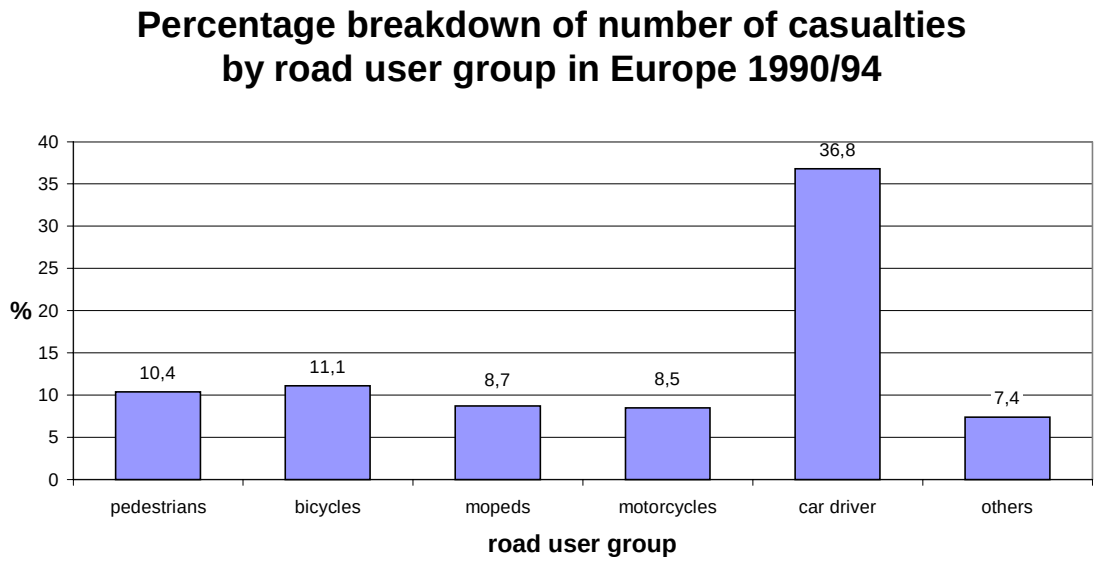


Figure 4.8. *Percentage breakdown of casualties in Europe per vehicle group*.

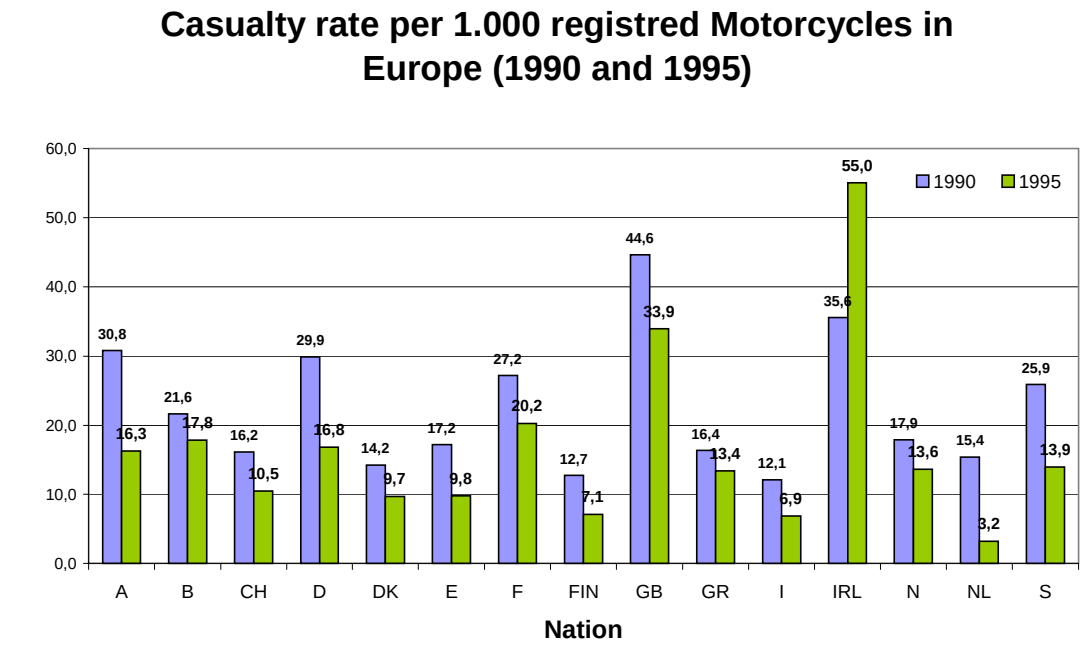


Figure 4.9. *Casualty rate per 1,000 vehicles in Europe.*

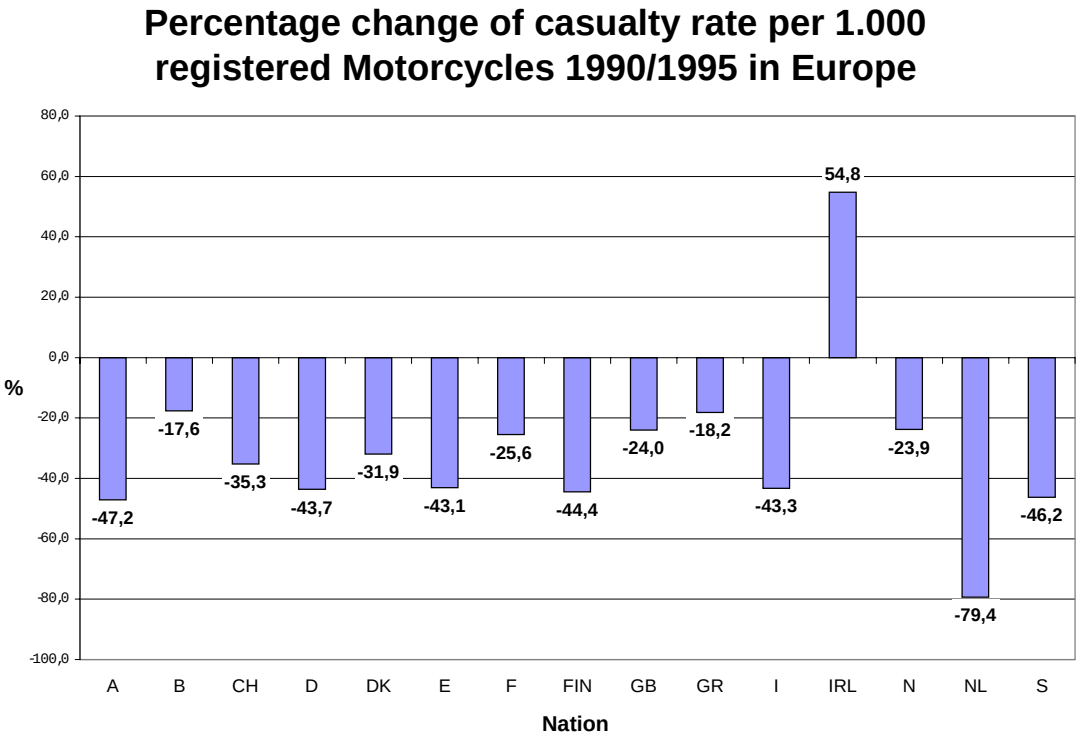


Figure 4.10. *Percentage change of fatality rates in Europe.*

4.2.1.4. Motorcycle accident researches on special topic

Rural and urban motorcycle accidents

Accident figures and -rates show a decreasing trend in the last 10 years. This could be concluded for almost all European countries (*Figure 4.11*). But there are differences between the trends of accidents in urban and rural areas. These general differences will be explained using as an example the situation in Germany. A study from SWOV in the Netherlands surveyed this data in a time period from mid-1993 to mid-1994. The percentage shares are different in other countries but the general trends are comparable.

In urban areas the figure of motorcycle accidents shows a reduction of -12 % in the years from 1990 to 1995. This trend was much stronger in build up areas than in rural areas. In rural areas the reduction in the same period of time was only -7 %.

Motorcycle accidents with slightly injured motorycle riders are found more often in build up areas than in rural areas (*Figure 4.12*). In the 90ies the figure of accidents with slightly injured motorcycle riders stagnated in rural areas. Accident numbers in urban areas show some fluctuation that can be interpreted in relation to the weather conditions in several years. For example in 1994 and 1995 long dry and sunny weather periods can be responsible for the slight increase of accident figures in these two years. Within good weather conditions more motorcycle riders use their vehicle and at the same time the distances travelled increase.

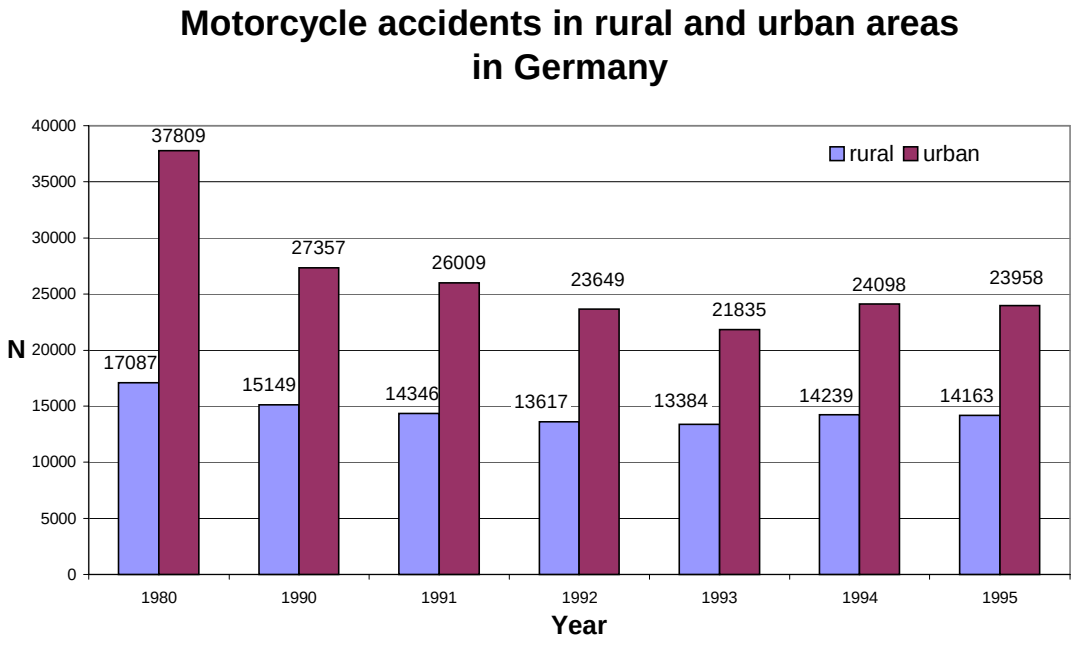


Figure 4.11. *Accidents in rural and urban areas in Germany (StBA).*

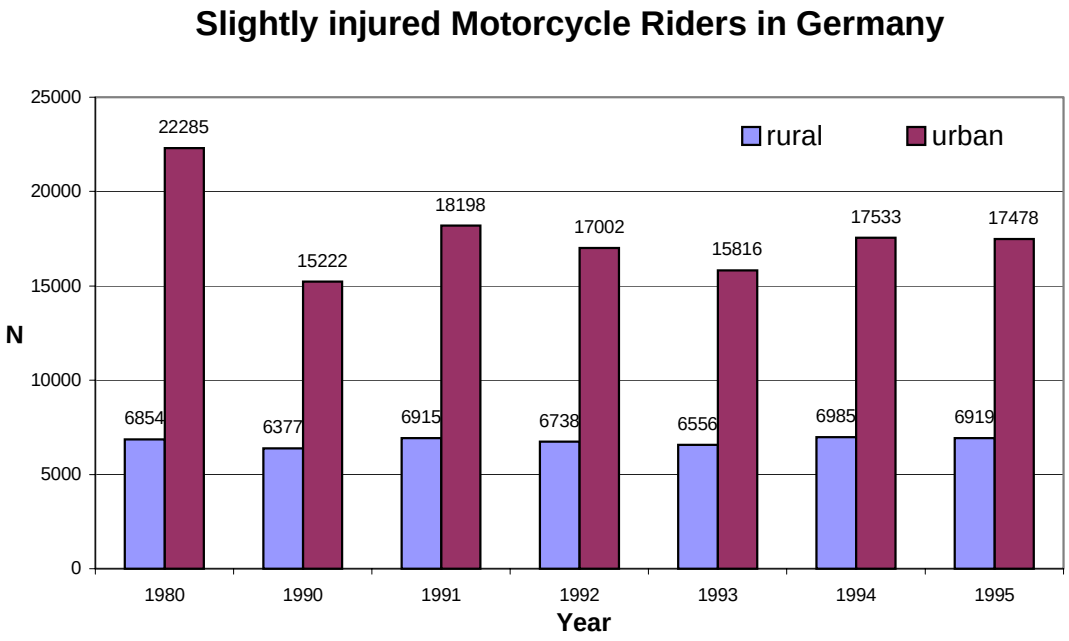


Figure 4.12. *Slightly injured motorcycle riders in rural- and urban accidents in Germany, 1980/1990 former FRG only (StBA).*

The absolute figure of motorcycle accidents with seriously injured motorcycle riders stagnates in rural areas (*Figure 4.13*). In comparison in urban areas the figure of accidents with seriously injured motorcycle riders shows a reduction in the 80ties and stagnation in the 90ties. Nowadays in opposite to the 80ties there is nearly an equal share of 50 % each for serious accidents in urban and rural areas with a slightly higher share of serious accidents in rural areas in the last years.

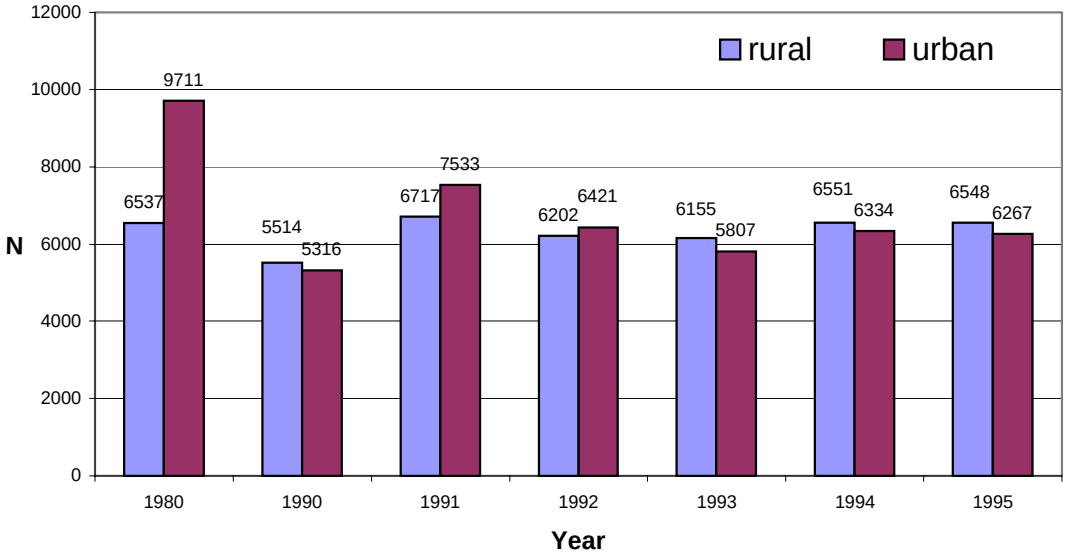


Figure 4.13. *Seriously injured motorcycle riders in rural- and urban accidents in Germany, 1980/1990 former FRG only (StBA).*

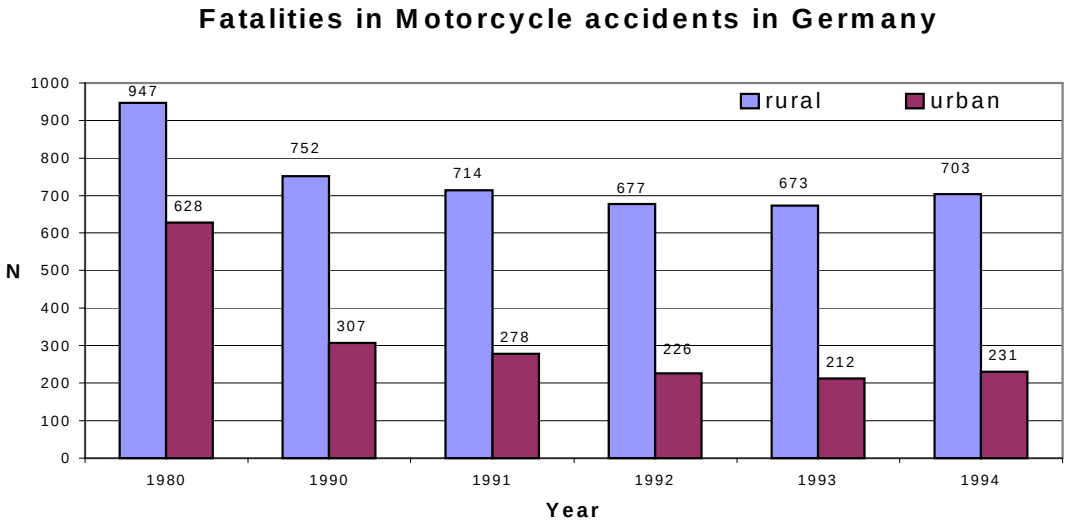


Figure 4.14. *Fatalities in motorcycle accidents in rural and urban areas in Germany (StBA).*

The figure of fatal accidents is much higher for rural than for urban areas (*Figure 4.14*). 2 out of 3 fatally injured motorcycle riders are fatally injured in an accident on a rural road.

The risk of being fatally injured in an accident on a rural road is up to 5-6 times higher than the risk in an accident in an urban area. Between 1990 and 1995 in rural areas the accident figures show a reduction of only -7 % whereas in urban areas a reduction of -30 % could be found.

One reason for the higher severity of the accidents in rural areas may be the higher travelling speed of the motorcycles. But also the higher speed of the collision partner, in most cases a car could lead to a higher accident severity.

Overall it can be concluded:
- Accident figures are smaller for rural areas than for urban areas.
- The accident development is better for urban than for rural areas.
- More than 70 % of all slightly injured motorcycle riders are injured in an accident in an urban area.
- The most serious accidents occur in rural areas. More than 2/3 of all fatally injured motorcycle riders were fatally injured in rural areas.

Motorcycle accidents - Age and causation of accidents

Chapter 2 has shown that young motorcyclists in Germany between 18 and 25 years own only ten percent share of all registered motorcycles. The portion of young riders raised between 1991 and 1996 by only 11.9% in relation to over 200% for riders greater than 25 years.

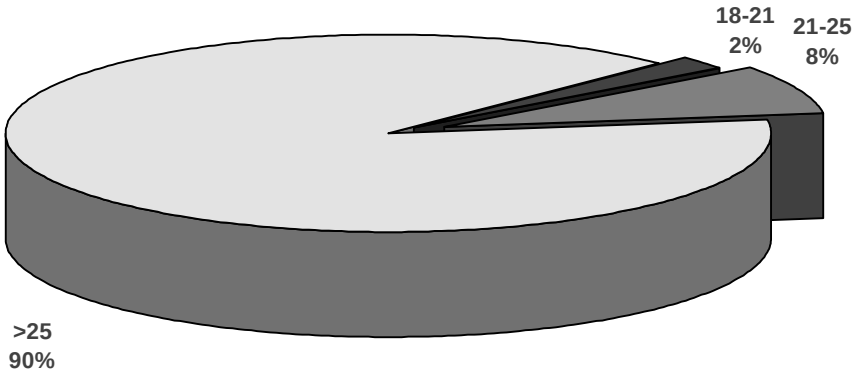


Figure 4.15. *Percentage share of age groups motorcycle fleet in Germany 1.7.1996 (KBA).*

In consideration of the development of age groups (registered vehicles) the absolute number of young riders is lower than for elder motorcyclists over 25 years. The absolute accident figures for the group lower 25 years are decreasing and the figures for riders older 25 years are going up in relation to the growing fleet portion.

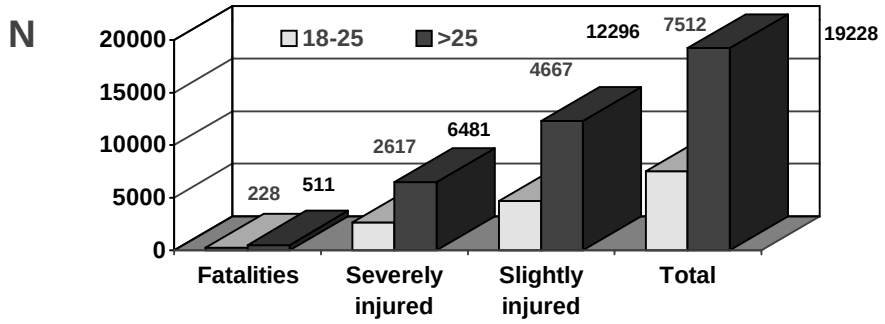


Figure 4.16. *Absolute numbers of injuries 1996 by age in Germany (StBA).*

But if we use a relative accident involvement rate per 1,000 motorcycles registered in Germany the rate is 2.9 times higher for younger motorcyclists than for riders over 25 years. The injury figure for the elder age-group is 9.2 per 1,000 vehicles whereas for the younger injured riders between 18 to 25 years it is 26.9 per 1,000 motorcycles in use.

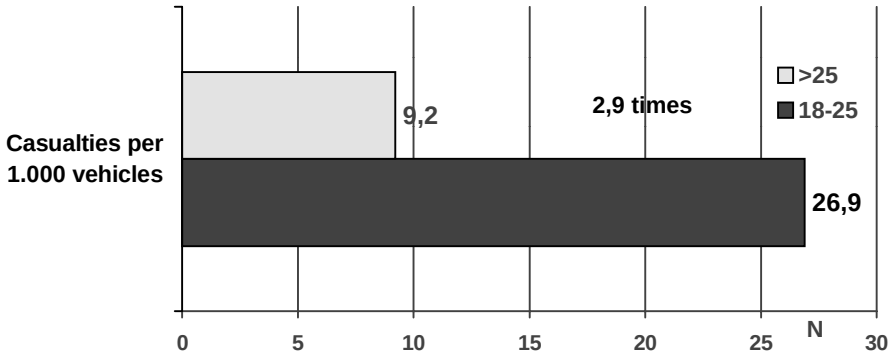


Figure 4.17. *Accident rate of motorcycle riders per 1,000 registered vehicles in Germany 1996 (StBA).*

That the reduction of accidents of the age group 18 to 25 years is not only a reason of the cut down of vehicles in use, can be seen by the next figure. If these accidents are related to 1,000 vehicles in use the percentage change of the casualty rate between 1991 and 1995 shows a decrease of -35.5% for younger riders and minus 24.1% for riders older than 25 years.

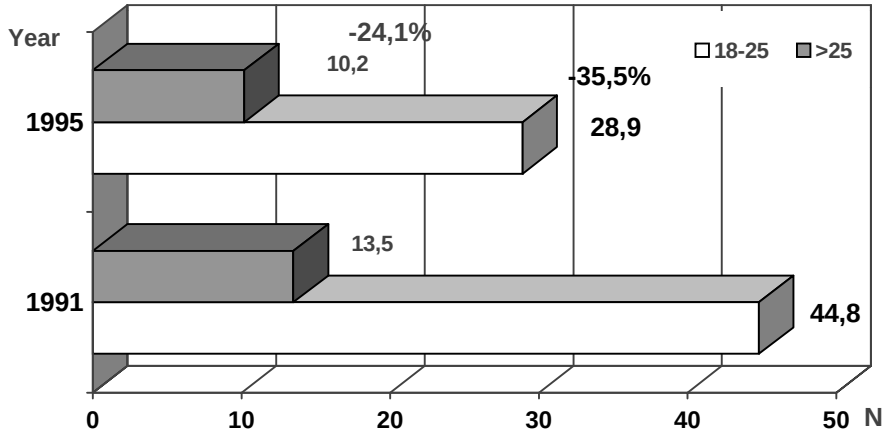


Figure 4.18. *Percentage change of accident rate of motorcycle riders by age Germany 1991/95 (StBA).*

The accident figures document that the risk of accidents of younger riders per 1,000 registered vehicles dropped more than the rate for the age group over 25 years.

But the youth risks respectively beginner's risks could be still found in accident statistics. For GB in the year 1988 the peak of motorcycle fatalities lies by 17 years, the beginners age limit for the use of motorcycles is in GB the same for category A1 and A Step I. The percentage share of fatally injured young rider was 1988 37 %, mainly male riders.

In relation to motorcycle riders the situation is quiet different in Germany as well as in the Netherlands because of the changing age structure of motorcyclists.

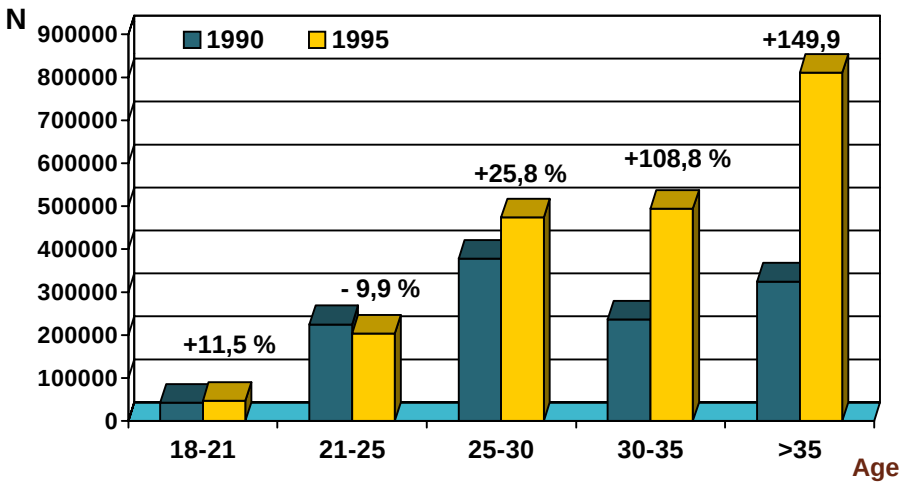


Figure 4.19. *Change of age structure of motorcyclists in Germany 1990/1995 in relation to registered vehicles*.

In Germany the group of 25 to 30 years of age has the highest absolute figures between 1992 to 1997 although their increase of registered vehicles was minor than that for the age-groups greater 30 years. But if we take a relation between accidents and development of vehicles in the age group, the following results give a clear hint of youth related risks:

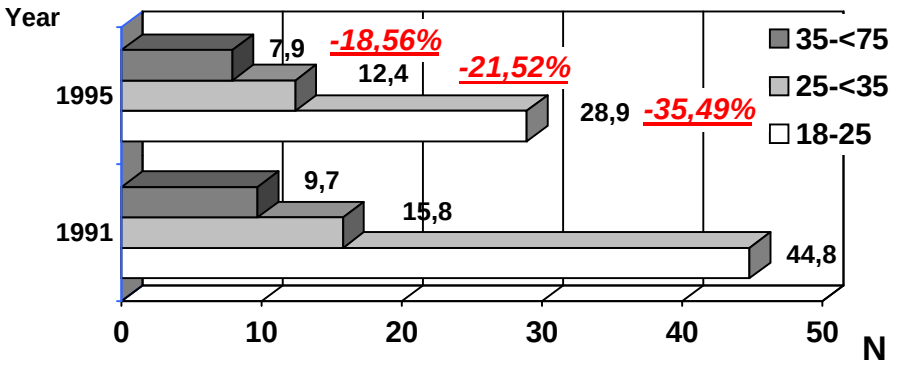


Figure 4.20. *Casualties of motorcyclists per 1,000 registered vehicles in Germany by age classes 1991/1995*.

Although the number of accident figures may have a peak in one age class that will not be described as youth weighted, the relative accident rates show a higher rate for lower age classes with a high rate for young motorcycle riders between 18 and 25 years.

Similarities and differences are to be found for drivers and riders by a comparison of the causes/major fault of accidents, which are related to vehicle groups "cars/motorcycles" and age groups (18-25/>25years) per 10,000 vehicles registered (*Figure 4.21*).

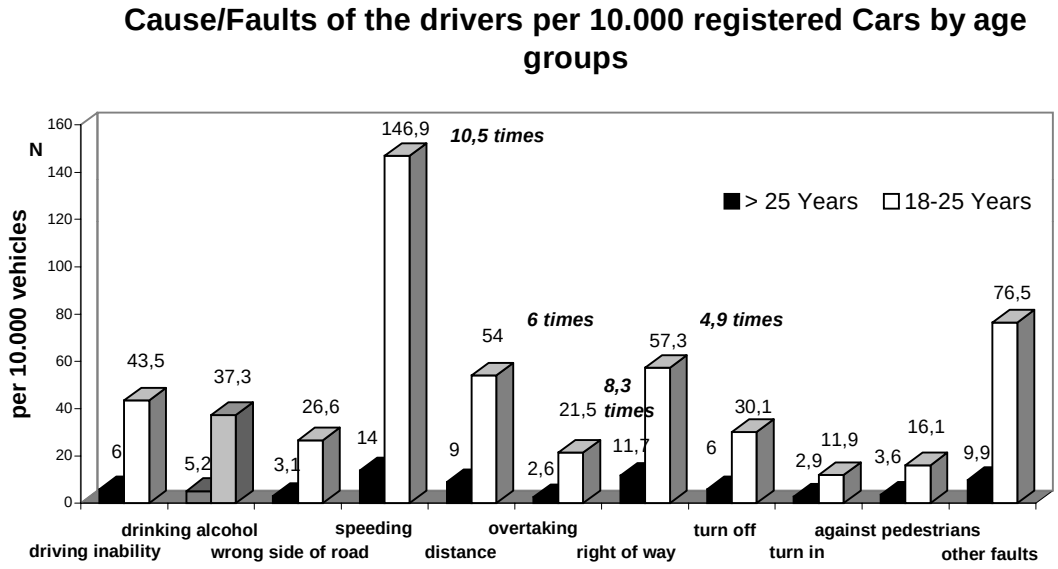


Figure 4.21. *Causes/Faults of car drivers per 10,000 cars in use and age groups (StBA).*

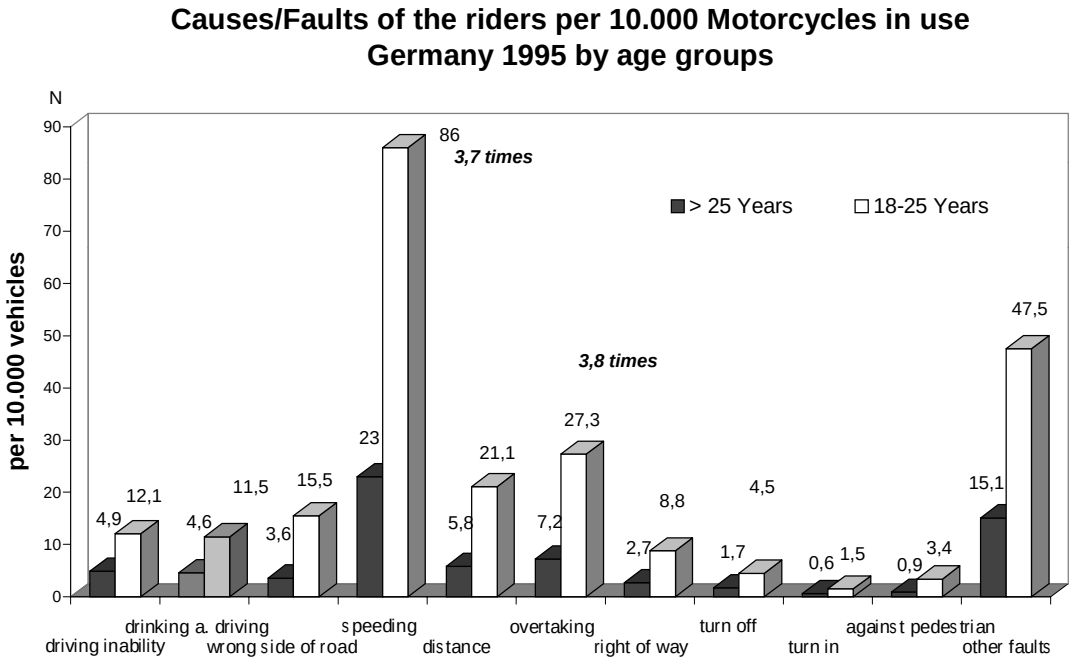


Figure 4.22. *Causes/faults of motorcyclists per 10,000 vehicles in use Germany 1996 by age (StBA).*

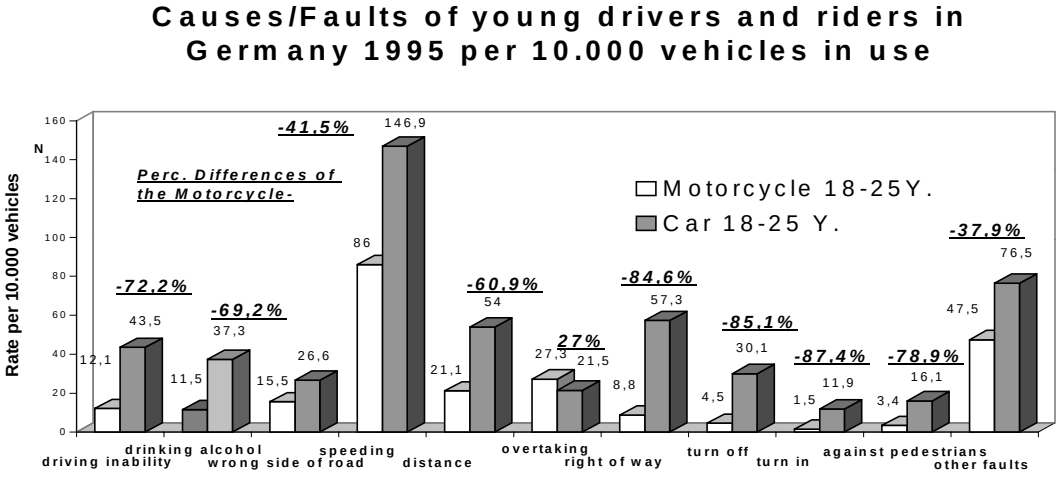


Figure 4.23. *Causes/Faults of young drivers and riders 18-25 years per 10,000 vehicles in use in Germany 1995 (StBA).*

Young riders and drivers are more often to blame for faults that cause accidents in relation to the elder age group. A look at the differences between young car drivers and young motorcycle riders results in *Figure 4.23.*

To summarize the results:

- For car drivers under and above 25 years higher rates per 10,000 vehicles for the causation of accidents are to be found compared to motorcycle riders.
- The main reason for all accidents in all age groups and vehicle categories is “speeding”.
- In a direct comparison between young car and motorcycle users under 25 years it is obvious that motorcycle riders have lower shares of accident causation than car drivers under 25 years.
- Only for “faults when overtaking” the motorcyclist rate is higher.
- For young riders “speeding”, “fault by overtaking” “distance fault” or “use of wrong side of road” are major causes.
- Young car drivers typical faults are “speeding”, “faults in giving right of way”, “distance faults” and “alcohol”.
- Obvious differences between car drivers and motorcyclists are the “priority of right of way” and “alcohol” which was found much more frequently for the car drivers.
- Young motorcyclists have a clearly lower rate of “alcohol” as an accident reason.
- Young car drivers show more frequently faults by “giving right of way”, “distances” and “turning in” in relation to the same motorcycle age group.

As a conclusion for young riders and drivers the major fault is “speeding”. The high percentage of “fault giving priority of way” for car drivers in each age group shows similarities to general accident researches, where the car driver in up to more than 70 % (average) is to blame for the typical motorcycle accident when he does not give the priority of way to the motorcyclist. Looking at this accident cause the motorcyclists have a rate that is minus 84.6 percent in relation to the car drivers. This result is underlined

by *Figure 4.24* that explains a majority of car driver faults for all age classes compared to motorcycle riders.

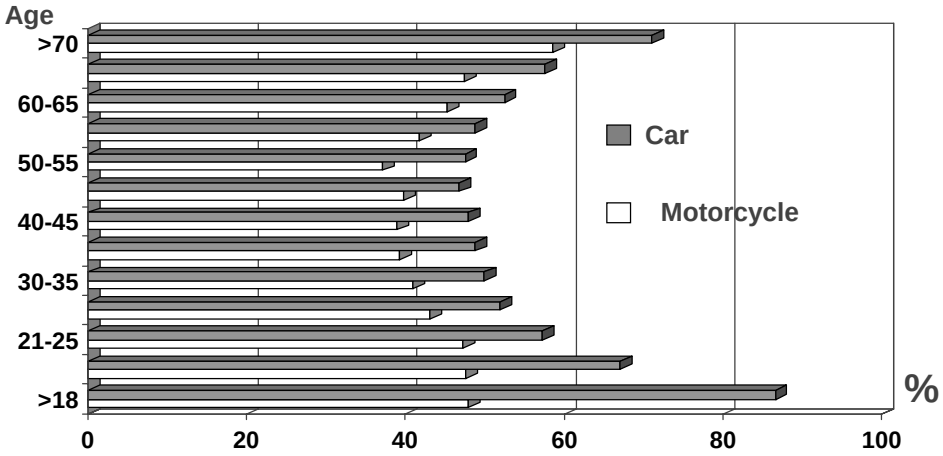


Figure 4.24. *Percentage share of main causation by accidents with personal damage in Germany 1996 by vehicle category and age (StBA).*

Motorcycle accidents and special vehicle categories

The new European licensing scheme legalised a motorcycle sub category A1 which are one-track vehicles with a maximum of 125 cc and 11 kW. This category was not usual for all European countries and was not national converted in all European countries. There is a vital interest to have information about the accident involvement of this new motorcycle category which can be driven by a car license in several European countries (see Chapter 3)

First results were given in France and in Germany. In France as well car drivers can use a 125 cc motorcycle like in Germany. In Germany the condition is a license made before April 1st 1980 (cars,heavy-trucks, small motorcycles).

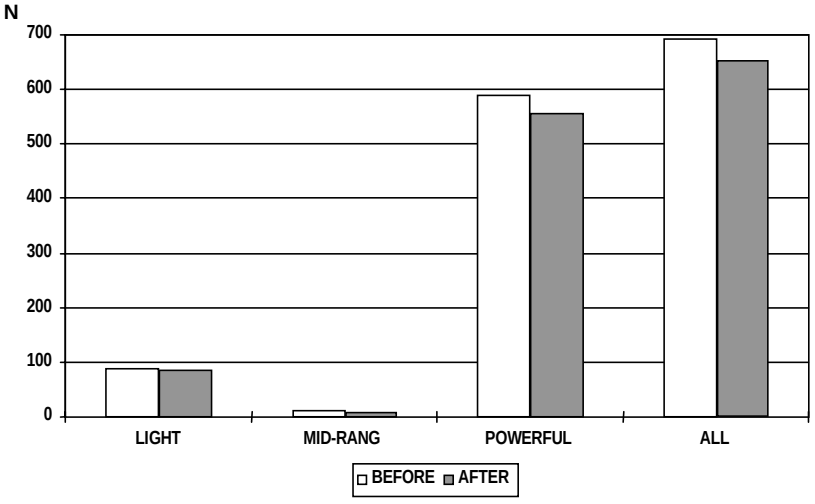


Figure 4.25. *Development of fatally injured riders in France before and after the PTW licensing changing reform (July 1995-June 1996 / July 1996-June 1997) (Filou, 1998).*

French figures for fatally injured riders decreased by 3.3% for lightweight motorcycles. This positive result is encouraging for young but as well for license B (for cars) riders. The accident rate per 1,000 motorcycles in use is equal before and after the legal implementation of the A1 125 cc class.

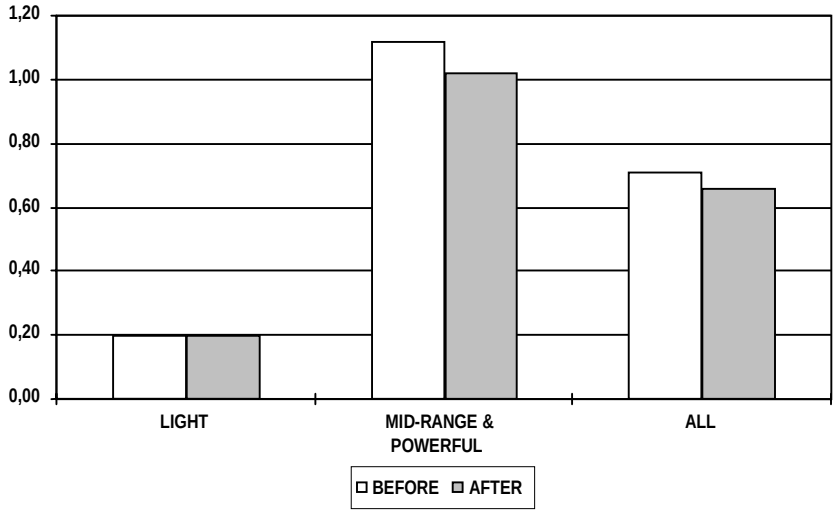


Figure 4.26. *Accident rate of fatal injured motorcyclists per 1,000 motorcycles before and after the implementation (Filou, 1998).*

In France this question will be further examined in relation to increasing numbers of fatally injured riders in accidents in the year 1997 with an increase of 42 % for lightweight vehicles.

In Germany the registration of motorcycles defined as lightweight vehicles was rising with the implementation of the EU licensing scheme and the new definition of this Mc class as 125 cc motorcycles with 11 kW. These vehicles were limited on the one hand by speed of 80 km/h for young riders between 16 and lower 18 years on the other hand car drivers with licences before April, 1st 1980 could ride these vehicles as well (11 kW like users above 18 years with no speed limit).

On the 23 of February 1996 the EU Licensing Scheme (A1 125 cc) was converted into national legislation and in the same year there was an increase of 11.4 % registered vehicles compared to the year before on July 1st of each year. In the year 1997 43.6 % more 125 cc vehicles were in use. This means an increase of 59.9 % from 200,572 (1995) to 320,745 in the year 1997 (see *Figure 4.27*).

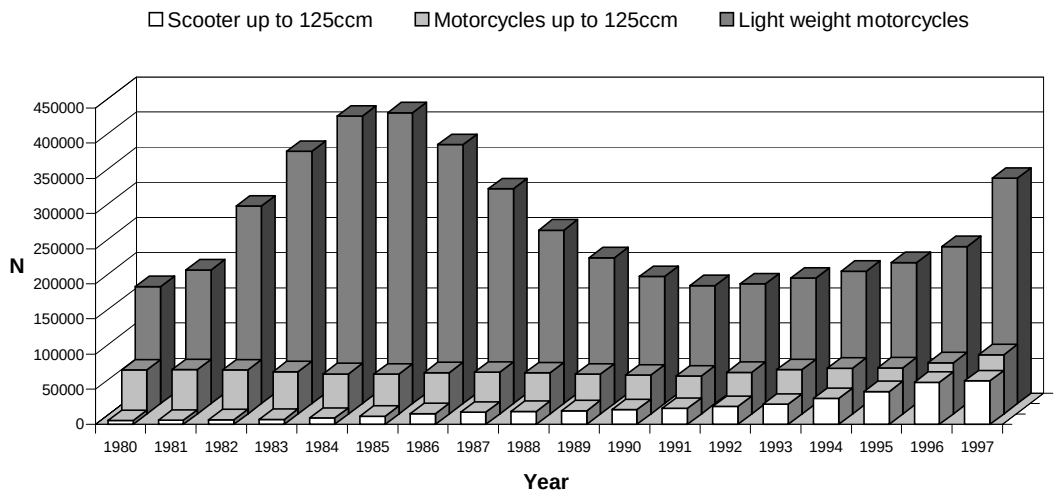


Figure 4.27. *Development of lightweight vehicles and motorcycles and Scooter with 125 cc in Germany*.

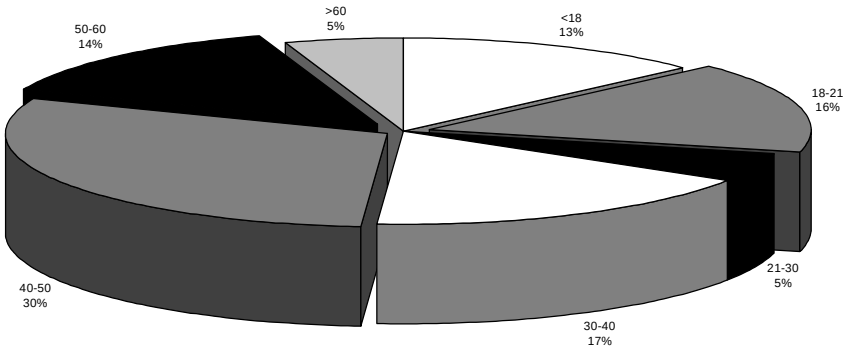


Figure 4.28. *Lightweight motorcycles in Germany 1997 by age classes*

Obviously the age group between 40- to 60 years has a percentage share of 44 % in the year 1997 (*Figure 4.28*). If the age-group 30- to 40- years is added this would be 61 % of all lightweight 125 cc vehicles.

The accident analyses of lightweight vehicle users lower or greater 35 years of age will include the group of users with only car licences (> 35 years), which is the most interesting question in this case.

Beside the increase of registered vehicles for the age-group older than 35 years it is obvious that all accident rates of the riders over 35 years have lower figures than the rates of riders younger than 35 years. Although the number of fatally injured rose by 2 persons in the year 1997, the rate per 100,000 vehicles decreased from 20 to 12.9 per vehicles in use (*Figure 4.29*). This decreasing figures are as well to be found for other severity rates.

Age	Registrations[1,3]	%	fatally injured[2]	per 100,000 vehicles	severely injured[2]	per 1,000 vehicles	slightly injured[2]	per 1,000 vehicles
1996								
<15-35	103,423		66	63.8	2,149	20.8	5,007	48.4
35->70	109,844		22	20.0	327	3.0	772	7.0
1997								
<15-35	123,308	+19.2	75	60.8	2,348	19.0	5,735	46.5
35->70	186,328	+69.6	24	12.9	426	2.3	1,050	5.6

Table 4.2. *Casualties of riders and passengers of lightweight vehicles by age groups in Germany. [1] July 1st each year (KBA); [2] Total year; [3] Without legal persons and unknown (KBA, StBA).*

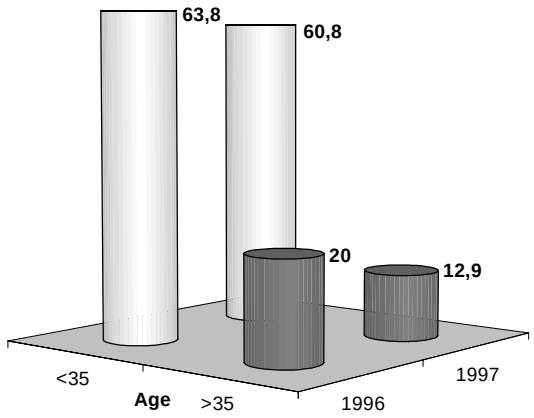


Figure 4.29. *Rate of fatally injured riders per 100.000 Lightweight vehicles (50-125 cc) in Germany 1996/1997 by age groups*.

A look at the rate of young and older 125 cc riders results in a three to four times higher rate per 100,000 registered vehicles for the younger age-group. Overall the accident figures declined in relation to the number of vehicles in use while at the same time the older age group had the greatest increase of registered vehicles. A research study by IfZ (Brendicke & Forke, 1998) shows that the age group older than 35 years has a high amount of traffic experience related to kilometres travelled with other vehicles e.g. cars or has former experience with other one-track vehicles. On this background the harmonisation of the European licensing system in the year 2000 can clearly be supported to the fact that the 125 cc A1 motorcycle is not only an alternative in questions of mobility related to space and economy of use, but that the use of this motorcycles by a group with only car licenses is not contrary to safety aspects.

4.2.2. *Mopeds*

4.2.2.1. Fatalities

The number of fatal accidents of moped riders declined between the compared years 1980, 1990 and 1995 in almost all European countries (*Figure 4.30*). Between the year 1980 and 1990 this was a reduction of -26.9 % for all European countries. From 1990 to 1995 another minus 28.2 % of fatalities could be found. For the comparison of the years 1980 and 1990 this can be a result of the declining number of vehicles in use, but for the years 1990 to 1995 with a higher number of registered vehicles we can state a positive safety effect for this powered-two-wheeler category.

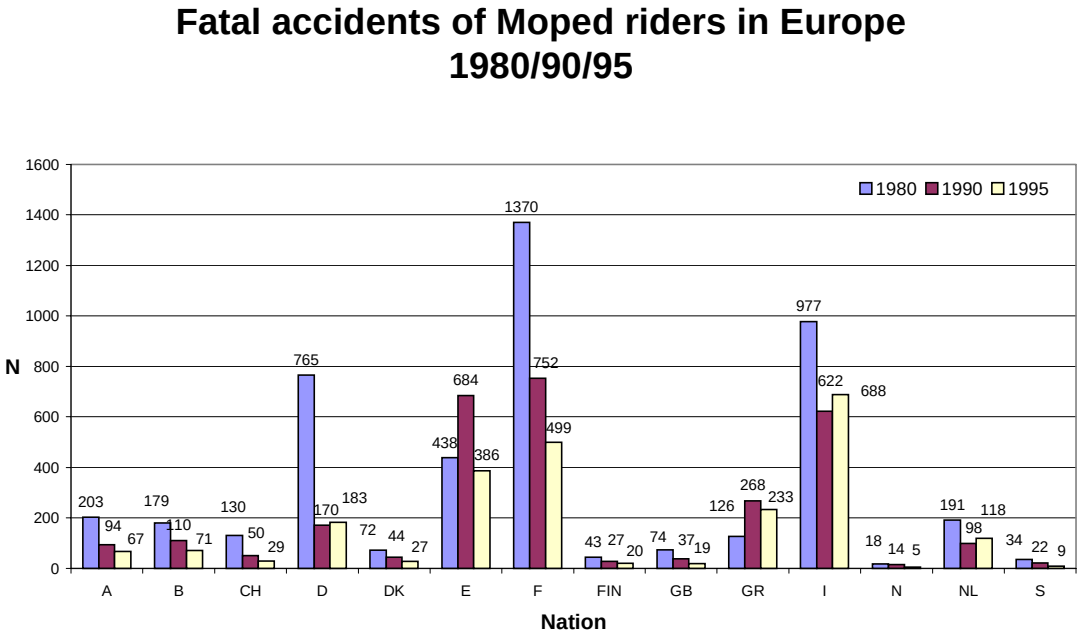


Figure 4.30. *Fatal moped accidents in Europe 1980/1990/1995 (UN).*

The number of moped fatalities declined in most European countries between 1980 and 1990 (*Figure 4.31*). Only in Spain and Greece these figures increased by 56.2 % respectively 112.7 %. For the comparison of the years 1990 and 1995 the same effects have to be stated: only in Germany, Italy and The Netherlands the number of fatalities increased between 7.6 % and 20.4 %.

Despite Spain, Denmark and France the fatal accident rate per 100,000 vehicles in use declined between 1980 and 1990. From 1990 to 1995 a further reduction can be stated for all countries except GB, I and NL (*Figure 4.32*).

The percentage change of the fatality rate per 100.000 vehicles in use explains that only E, DK and F have increasing rates between 1980 and 1990. For the comparison between 1990 an 1995 only GB, I and the NL have

an increasing tendency. In Germany and Austria the rates were halved in the first decade and in Sweden from 1980 to 1990 there was a minus of 67 %.

In the following five years in Denmark and France the negative trend reversed and the fatality rate fell by more than -54 % in DK respectively -13 % in F. The percentage reduction from 1990 to 1995 compared with the previous decade was only stronger in Norway (-57.3 %) and Belgium (-35.5 %) and Finland (-14.1). In Sweden the extremely positive trend was continued from 1990 to 1995 (-60.5 %). In all other countries there is a smaller reduction.

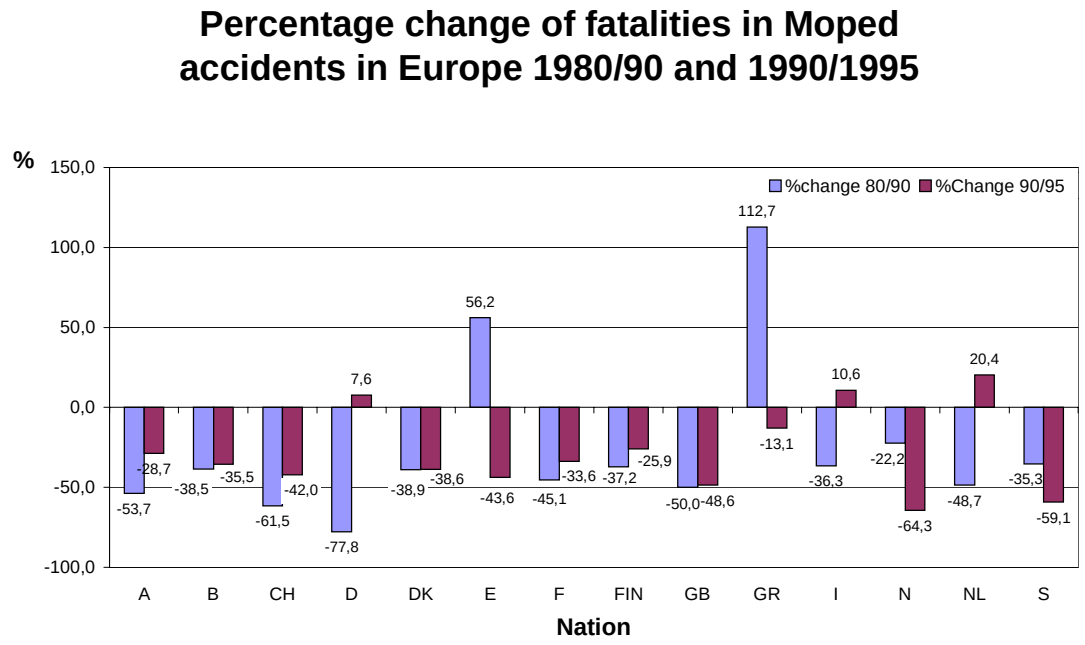


Figure 4.31. *Percentage change of fatalities in moped accidents in Europe 1980/1990 and 1990/1995*.

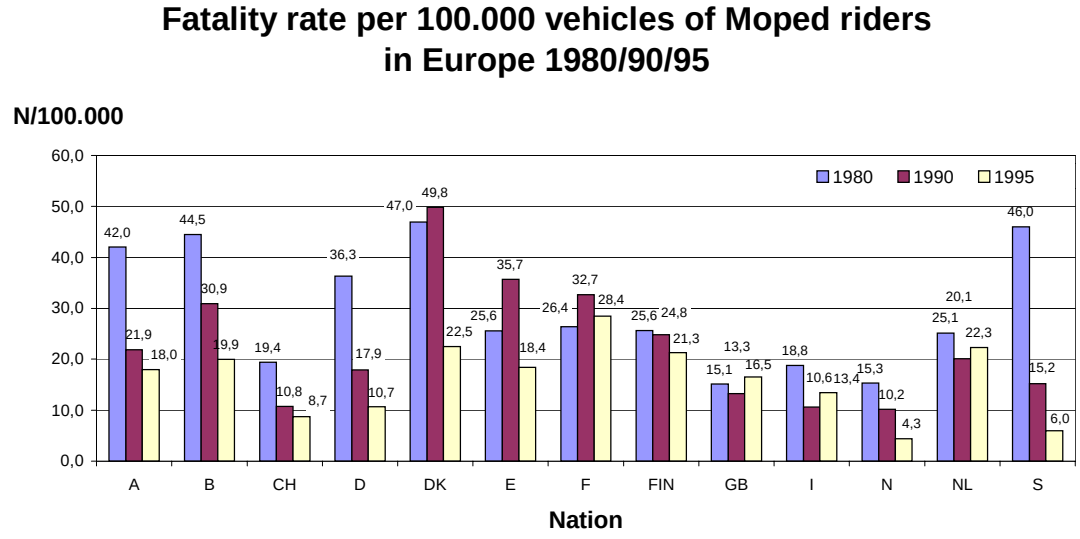


Figure 4.32. *Fatality rate of moped rider accidents in Europe 1980/1990/1995*.

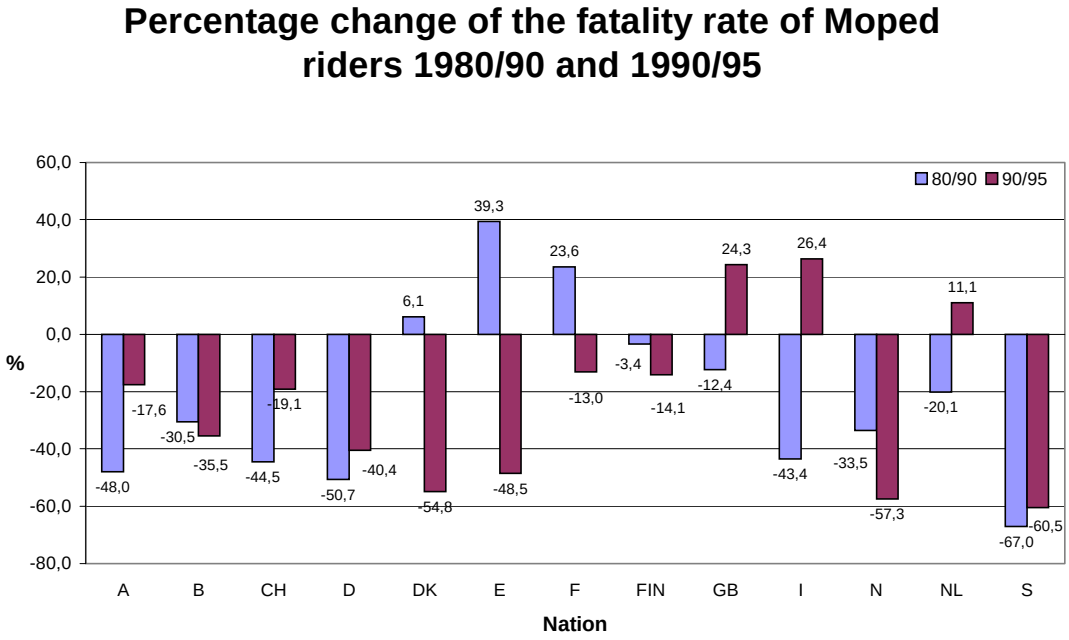
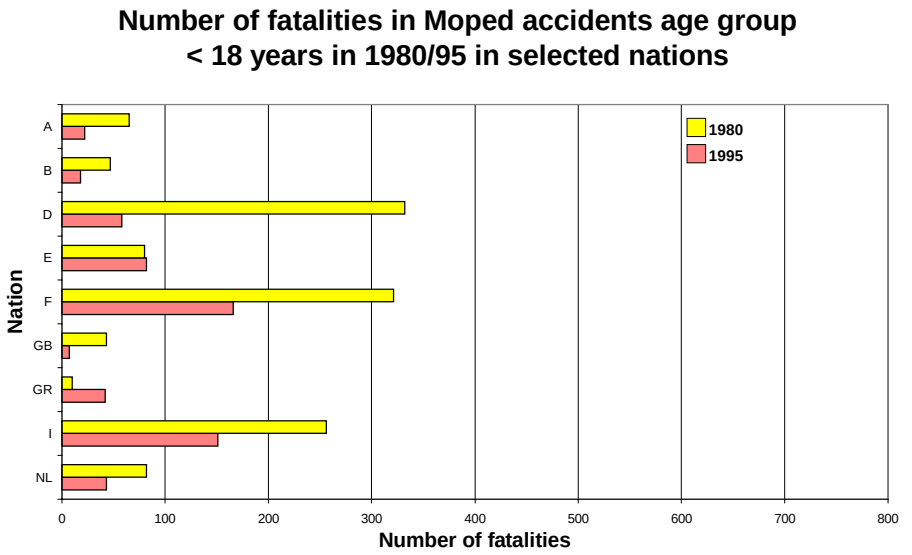
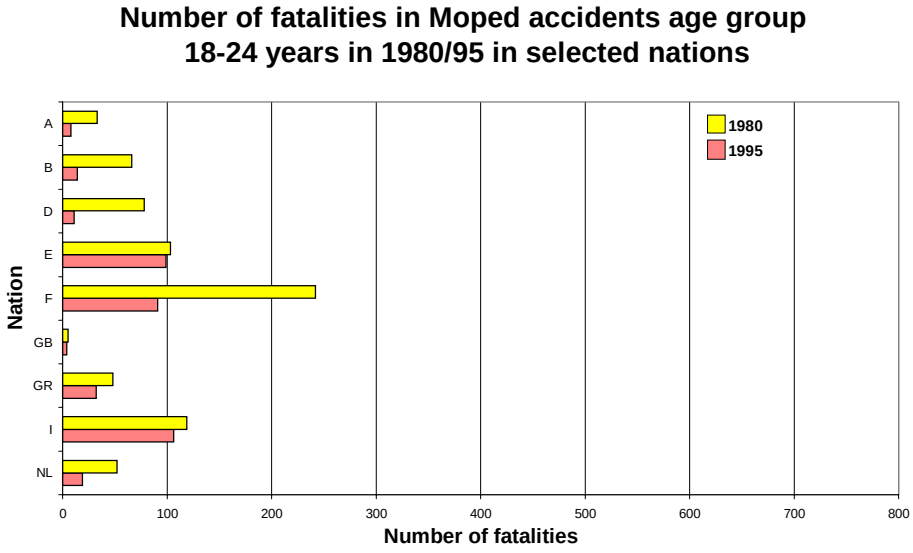


Figure 4.33. *Percentage change of the fatality rate of moped riders 1980/90 and 1990/95*

A comparison of the fatalities of moped accidents by age shows that concerning the main „moped nations“, along with the age group under 18 years the age group of older than 25 years is highly affected. Except in GB and NL in all other nations most of the fatally injured moped riders are older than 25 years. In 1980 in E, F and I more than half of the fatalities belong to these age groups *(Figure 4.34*).





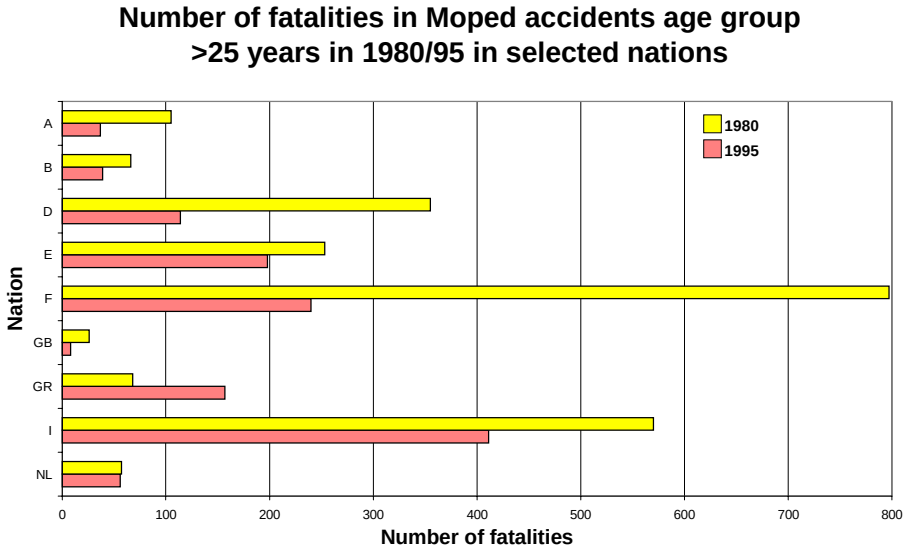


Figure 4.34. *Number of fatalities in moped accidents by age*

4.2.2.2. Injuries

Injuries of moped riders have decreased between 1980 and 1990 respectively between 1990 and 1995 in seven European countries. In France the injury rate increases lightly in both periods. In B, E, FIN, GB and in NL the injuries increased in the first decade, and in 1995 the rate decreased.

The accident rate of injured moped riders fell between 1980 and 1990 by a percentage of -18.4 % in Denmark up to -62.7 % in S. For B, E, F, GB, NL and FIN in this decade the figures were going up to a maximum of 114.2 % in Spain. From 1990 to 1995 the percentage change declined in all European countries except Italy (+65.8 %) and France (+2.8 %) countries from -11.2 % in S to a maximum of -83.8 % in NL.

As for the motorcycles also for the moped riders a youth risk could be found in accident statistics. In Germany the peak for moped riders lies between 15 and 18 years during the years 1992 to 1997.

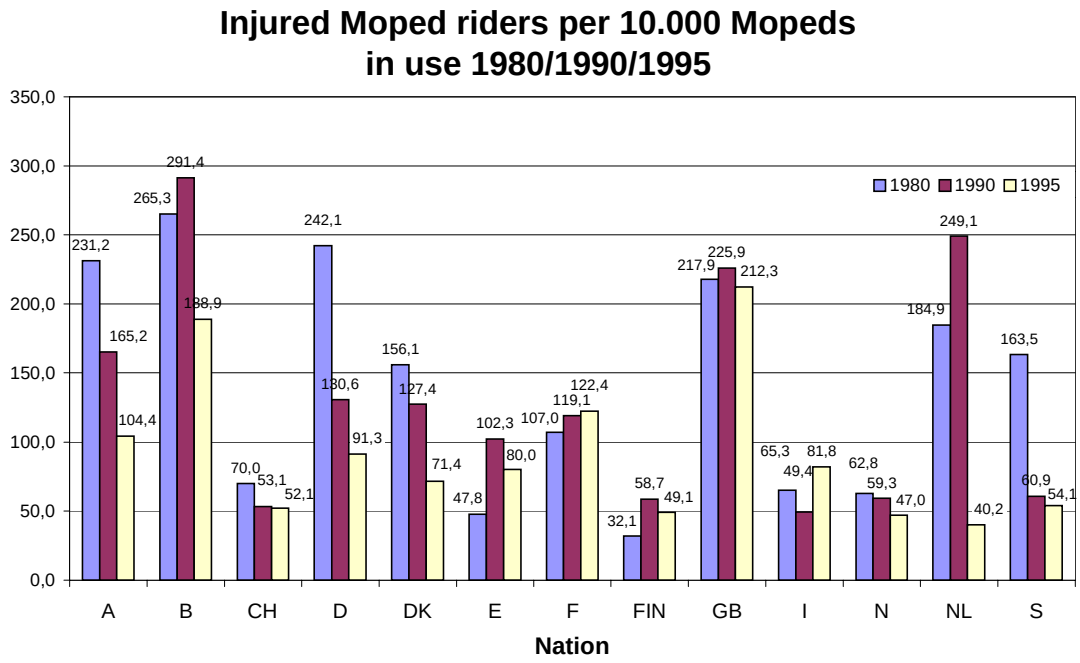


Figure 4.35. *Injured moped riders per 10,000 mopeds in use.*

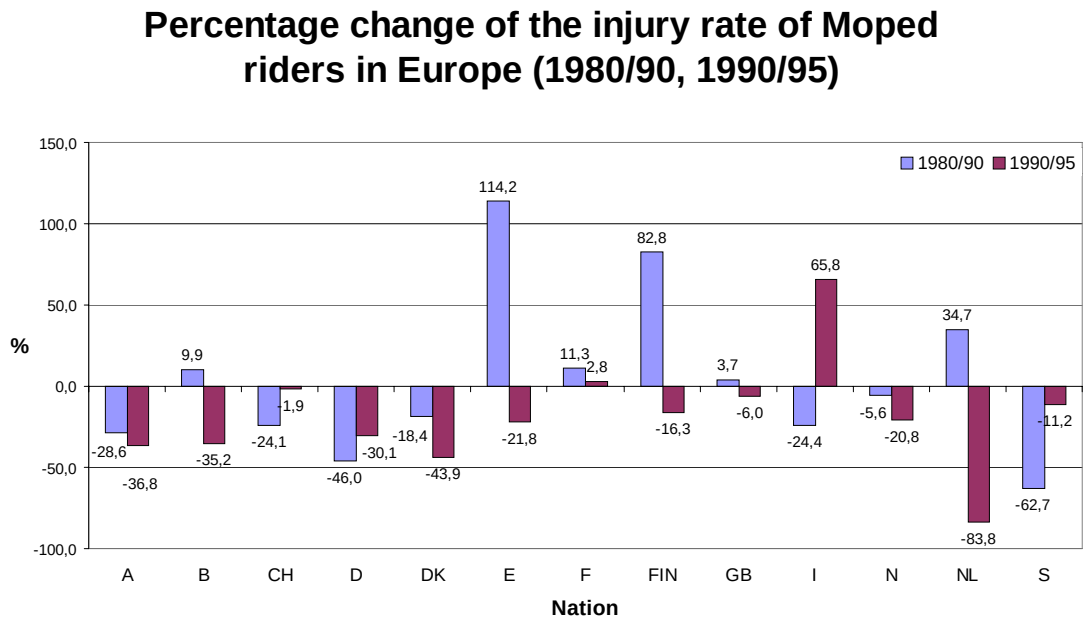


Figure 4.36. *Percentage change of the injury rate of moped riders in Europe*

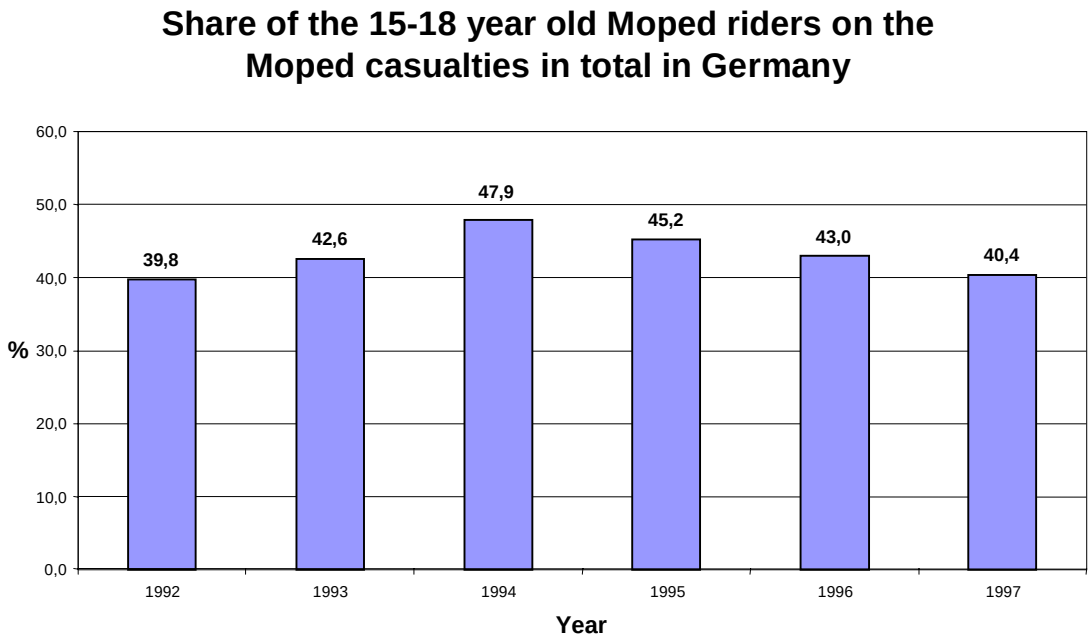


Figure 4.37. *Share of the 15-18 year old moped riders on the moped casualties in total in Germany.*

4.2.2.3. Moped accident researches and special topics - moped accidents in rural and urban areas

This chapter examines moped accidents in urban and rural areas in Germany. The percentage shares may differ again between the various countries, but the general trends are comparable.

Accident figures show a decreasing trend in the last years (except in Greece and Ireland). In urban areas the reduction between the years 1990 and 1995 was -27.5 % in Germany. In rural areas the reduction in the same period was -33 %. The reduction of moped accidents in rural areas was stronger than in urban areas which is opposite to the situation of motorcycles. Most accidents occur in urban areas with nearly 79 % of all moped accidents (1995) (*Figure 4.38*).

Only 70 % of moped riders which have an accident are slightly injured. Moped accidents with riders "slightly injured" predominate in urban areas (83.4 %) and only 16.6 % are to be found in rural areas in the year 1995 (*Figure 4.39*).

89.3% of all seriously injured moped rider accidents are to be found in urban areas (*Figure 4.40*). Opposite to motorcycle accidents the figure of seriously injured moped riders is higher in urban than in rural areas. 27 % of all casualties of moped riders which are seriously injured can be related to build up areas whereas 42 % of all seriously injured are found outside a build up area.

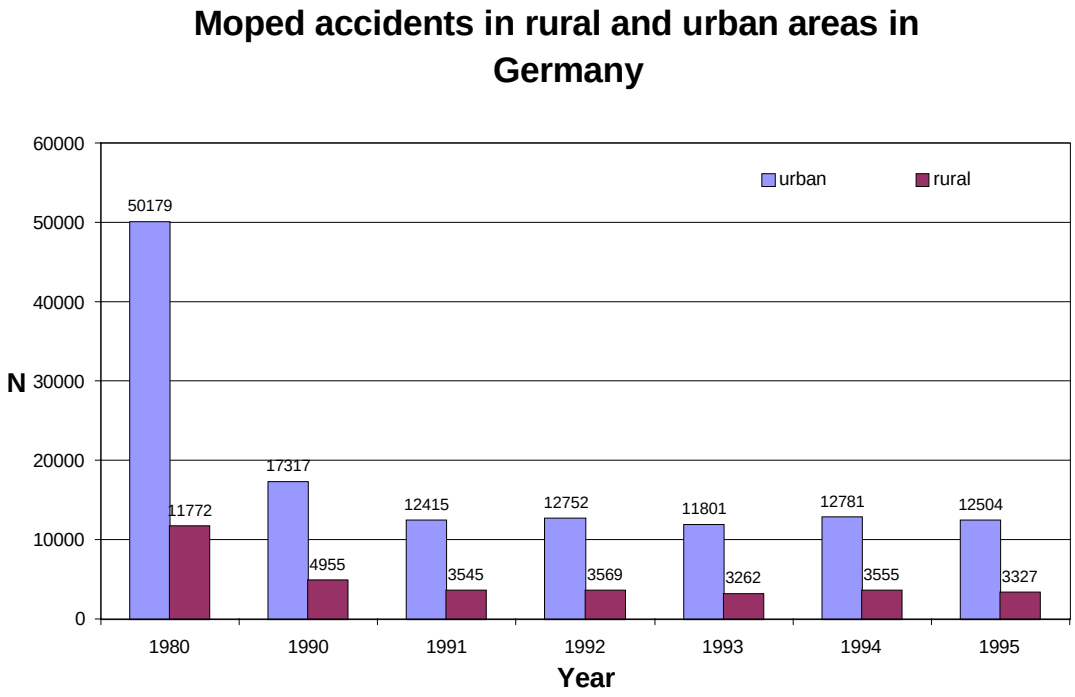


Figure 4.38. *Accidents in rural and urban areas in Germany (StBA).*

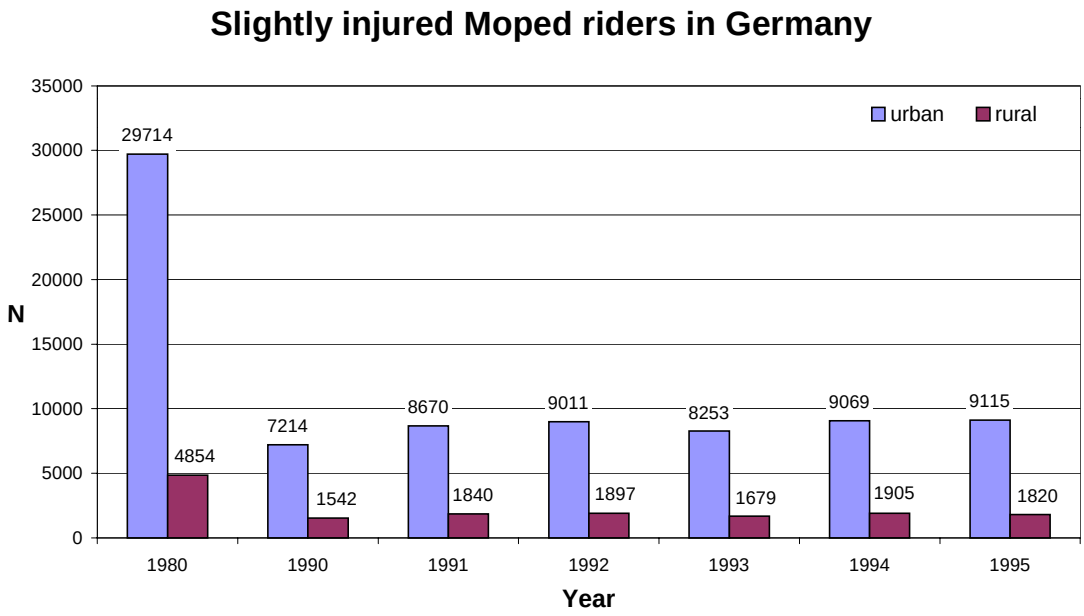


Figure 4.39. *Slightly injured moped riders in rural and urban accidents in Germany, 1980/90 former FRG only (StAB).*

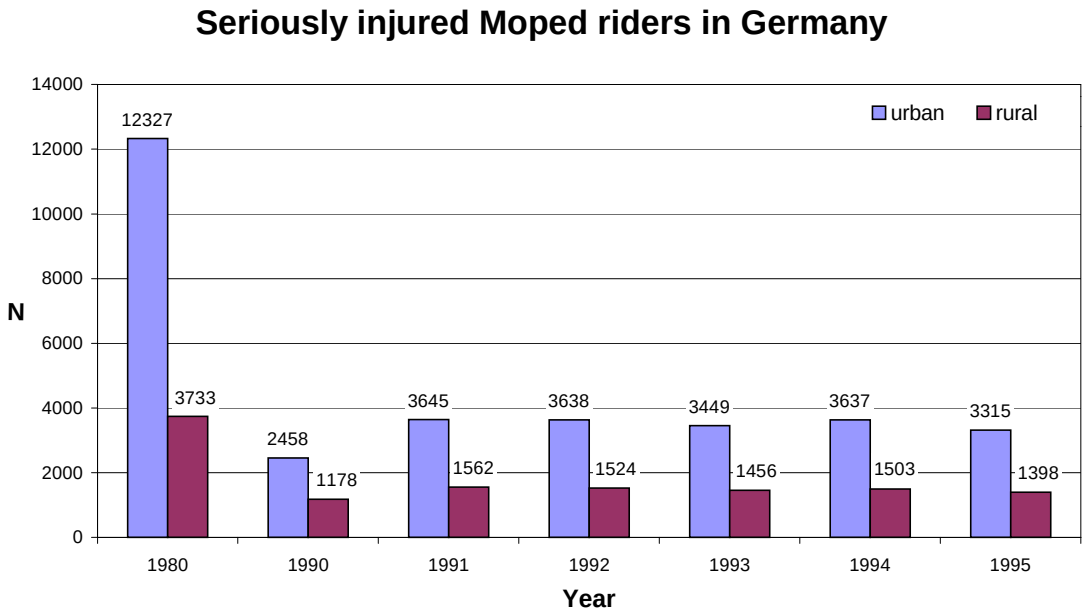


Figure 4.40. *Seriously injured moped riders in rural and urban accidents in Germany; 1980/90 former FRG only (StBA).*

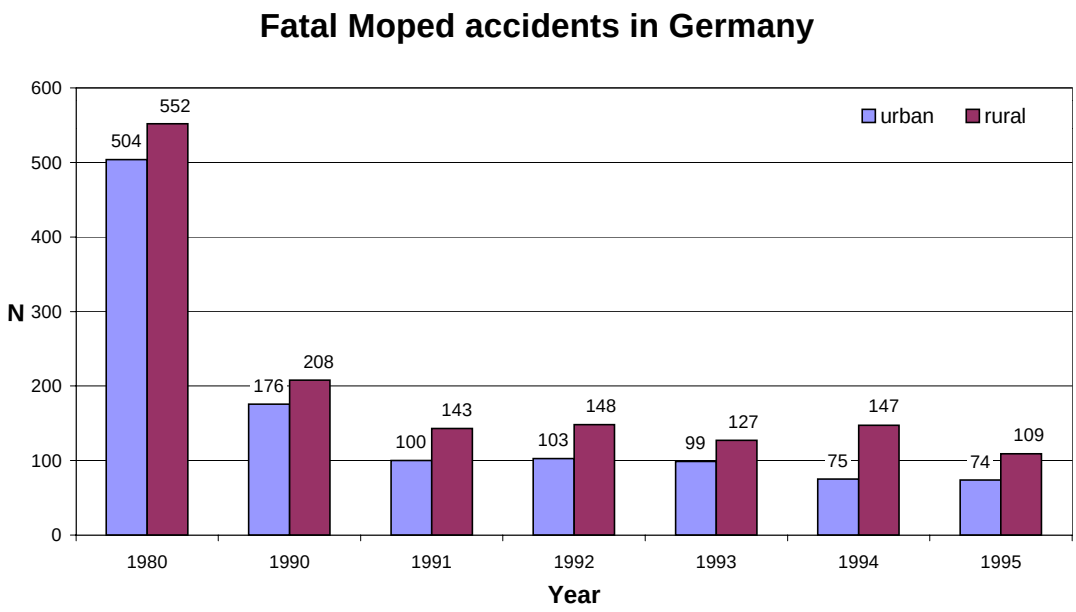


Figure 4.41. *Fatalities of moped riders in rural and urban accidents in Germany (StBA).*

Most of the fatally injured moped riders were injured outside a build up area, with a share of 59.6 % injured moped riders in rural areas in the year 1995.

But the differences between rural and urban areas are not as clear as for motorcycle accidents. One cause may be the different kind of use of mopeds and motorcycles. Mopeds are more often used in urban zones and less often for longer trips on rural roads. Due to their relatively low maximum speed they are not very suitable for trips on rural roads.

In Germany the risk of being fatally injured in an accident on a rural road is up to 6 times higher than in an accident in an urban area.

Summary of facts about moped accidents:

- The accident development is better for rural than for urban areas.
- Accident figures are smaller for rural than for urban areas.
- Up to 79 % of all slightly injured moped riders are injured in an accident in an urban area.
- The most severe accidents occur in rural areas. The risk of getting fatally injured in an accident is 6 times higher in a rural than in an urban area.

4.3. **Characteristics of PTW accidents**

4.3.1. *Motorcycle accident configurations*

Different national motorcycle accident researches explain to some extent general factors of motorcycle accidents. These general remarks on motorcycle accidents demonstrate, that a motorcycle accident is a unique form of traffic accident incidents with manifold individual explanations for each case (Cercarelli, Rosman & Ryan, 1996; Dielemenn, 1998, Gilchrist & Mills, 1996; Koch, 1988; Lynn, 1990b; Marshall, Langley & Begg, 1993; Noordzij & Vis, 1998; Robbins, 1997; Rohm & Schimmelpfennig, 1997; Rosman & Knuiman, 1996; Rosman et al., 1996; Simard, 1990, Tani et al., 1993; Vis, 1995; Yoshida, 1980).

The risk of getting injured by a motorcycle accident is higher than for cars (93 %), while two-third of the car accidents result only in material damage (65.5 %) (Brendicke, 1993; Koch, 1990d; Koch, 1987; Koch & Brendicke, 1989; Koch & Hagstotz, 1990; Koch & Schulz, 1991; Otte & Schlichting, 1991; Taylor & Maycock, 1990).

On principle two-wheeler accidents can be subdivided into two categories:
- Single vehicle accidents 25 to 30 %.
- Multi-vehicle accidents 60 to 75 % (Albus, 1993a; Appel, Middelhauve & Otte, 1986; Koch & Brendicke, 1989), which as well can be categorised between:
  By fault of the accident partner (up to 70 %)
  By fault of the rider (up to 40 %).

Following findings are reliable for motorcycle accidents:
- Motorcycle accidents occur predominantly in urban areas.
- Higher injury severity of accidents on rural roads.
- In up to 75 % of all collisions a passenger car is involved.
- Accidents occur predominantly at or nearby urban intersections (75 % of all cases).
- The most frequent type of accident is a collision of a motorcycle and a car which turns.
- The most frequent cause is a violation of the motorcyclists' right of way by other vehicles (67 %).
- In up to 71 % of all collisions car drivers are to be blamed for the accidents.
- The average collision speed is less than 50 km/h.

The risk of having a motorcycle accident is 2-8 (relying on each study) times higher than for passenger cars (Koch, 1990d; Taylor & Maycock, 1990). This can be explained by the following aspects. For two-wheelers as single track vehicles any loss of the substantial "balance" or "adhesion" results in a lack of stability and control of the vehicle that lead to the hitting on to the road surface or/and to a secondary contact with road side furniture which results into personal damages (Taylor & Maycock, 1990).

The following aspects have to be considered:

- The stronger rider-specific influence of motorcycles due to the fact that motorcycles are single-track vehicles (balance, braking, stability etc.).
- The higher manoeuvrability of a motorcycle makes it quite different from cars and also influences accident configurations.
- Motorcycle riders do not have a protective passenger compartment and their exposed sitting position always results in a contact with the accident opponent or road furniture.
- The poor visibility of motorcycles for other vehicle drivers and their false interpretation of PTW-speed - due to their small silhouette - seems to be a serious accident-causing factor.
- Sensitivity to braking by the rider, skidding of the motorcycle in connection to different road surfaces or materials (Bayer & Weidele, 1986; Otte & Schlichting, 1991; Schweers & Brendicke, 1993; Whitaker, 1980; White, 1980).

4.3.2. *Accident types of motorcycles*

4.3.2.1. Single-vehicle accidents

About thirty percent of all motorcycle accidents are single vehicle accidents that cannot only be described as a fault of the motorcycle rider, because this includes situations where the motorcyclist avoids a collision with other road vehicles.

- In nearly one third of all single vehicle accidents the motorcycle and the rider hit the road surface (Otte, Suren & Appel, 1989).
- Single vehicle accidents are to be found more frequently on rural roads (Jessel & Rüter, 1987; Noordzij & Vis, 1998).
- Speeding as a cause means often an inappropriate speed for the radius or the layout of curves (Brendicke, 1993b).
- Risk to get into contact with road side furniture e.g. metal parts of crash barriers that can lead to severe or fatal injuries of the rider (Brendicke, Forke & Gajewski, 1995; Domhan, 1987; Schüler et al., 1984).
- Parts of the motorcycle itself sustain injuries of the motorcyclist (Otte, Suren & Appel, 1989).

4.3.2.2. Multi-vehicle accidents

The dominant type of motorcycle accidents is the collision with other road vehicles that normally occurs on urban roads. These multi-vehicle accidents lead to an impact with the front, side or rear part of the other vehicle mainly with a passenger car (approximately 75 % of all accidents) (Katayama, Noguchi & Motoki, 1994; Newman & Webster, 1974; Noordzij & Vis, 1998; Ueyama, 1987). The risk of getting injured severely or fatally is higher for the motorcyclist in these cases (Hurt et al., 1981b; Otte et al., 1982; White, 1980).

- The main collision partners are cars with 62.0 % and obstacles, road side furniture etc. with 18.4 % (Otte, 1989b).
- The main collision type of motorcycle accidents is a turning collision by a car generally turning left - respectively right in countries with left hand

drive - that lead to a collision with an oncoming or overtaking motorcycle (Hurt et al., 1981b; Otte et al., 1982; White, 1980).
- The main location of motorcycle accidents is in or outside intersections (45 %), 30 % of all accidents happen in curves (Brendicke, Forke & Gajewski, 1995, Carré & Filou, 1991; Hurt et al., 1981b; Koch, 1985; Koch, 1988; Koch, 1990d; Otte et al., 1982; Whitaker, 1980).
- The risk and seriousness of injuries increases with the impact speed. The majority of collisions take place at relative low speed of 30 to 50 km/h (Engel, 1992; Hurt et al., 1981b; Whitaker, 1980).
- In cases when the motorcyclist "flies" over the obstacle the AIS is limited to three, even in collision speed up to 80 km/h and more (EEVC, 1993; Engel, 1992). But if the motorcycle rider cannot "fly" over the obstacle (e.g. a car) the AIS exceeds three.
- Mainly multi vehicle accidents are caused by the collision partner "passenger car" when the car driver fails to notice the approaching motorcycle due to the small silhouette of two-wheelers.
- The car driver's fault of violating priority traffic rules happens in over two third of cases. Only one third of all accidents is forced by motorcycle riders (Hurt et al., 1981b; Otte et al., 1982; Sporner, ; White, 1980).
- The misjudgement of the motorcycle's speed and distance are the major factors which cause motorcycle accidents (Noordzij & Vis, 1998).

4.3.3. *General characteristics of moped accidents*

Data about moped accidents in the EU is very infrequent. Some countries are counting mopeds within the category of motorcycles without the possibility to separate them. Even the definition of a moped differs between single countries, like the "bromfietser“ (mopeds) and "snorfietsers" (slow mopeds) in The Netherlands or the "mofas" (slow mopeds) and the "mopeds" in Germany. In other countries only a single definition of mopeds is to be found. In contrast to motorcycle accidents only a small figure of studies are related to the topic "moped accidents".

As mentioned in Chapter 2 only four European nations held a share of over 85 % of the total moped fleet in Europe. These countries are France, Spain, Italy and Germany. Due to this fact only the moped orientated EU states like France or the Netherlands have detailed studies of moped accidents.

In France the risk of getting injured in a moped accident is equivalent to motorcycles and higher than that for car drivers (up to 7-10 times). But the risk of being fatally injured by a moped accident is lower than in motorcycle accidents (1.8 - 2 times) (Filou, 1995; Filou et al., 1994). On principal moped accident can be subdivided into two categories. The main difference to motorcycle accidents is the share of single and multi-vehicle accidents.

- Single-vehicle mopeds accidents are only 10 to 15 % (Filou, 1995, StBA), 17 % of the fatally injured moped riders were fatally injured in this type of accident (Filou et al., 1994).
- Multi-vehicle accidents which can be divided by the different manoeuvres of the vehicles.
- Most of the moped accidents occur in urban areas (79 %), especially at intersections (42 %) (Filou, 1995; Filou et al., 1994; Noordzij, 1998;

StBA; Suren, Otte & Grabhöfer, 1980; Wierda, van Schagen & Brookhuis, 1989).
- Most serious accidents occur outside build-up areas (DENCO, 1998; Filou, 1995; Filou et al., 1994; StBA).

The risk for moped riders to be seriously injured is in France two times higher outside an intersection than in an intersection. In the year 1995 only 14 to 20 % of all moped accidents occur outside build-up areas but with a share of approximately 50 % of all fatally injured moped riders. In France the risk to be fatally injured on a rural road is up to six times higher than in a town (Filou, 1995).

A detailed investigation of statistics in Germany results in the fact that in more than 55 % of the moped accidents the collision partner is to blame for the accidents.

The use of a helmet is now mandatory for moped riders in many European Countries (Direccion General de Trafico, 1995; Filou, 1995; Filou et al., 1994). A study from INRETS gives a proportion of nearly 100 % for helmet use in the year 1995 in France (Filou, 1995). In Greece the situation is quite different from that. The percentage share of moped riders wearing a helmet is relatively small and 25% of fatally injured and injured riders wear a helmet (DENCO, 1998). In The Netherlands there is no mandatory law for helmet use for riders of snorfitsen (Noordzij, 1998).

But it should be noted that under the victims of moped accidents the share of riders who have no helmet (11 %) is higher than for motorcycle accidents (8 %). For riders not wearing a helmet, the severity of the injuries is 2,5 higher than for helmet users (Filou, 1995, Filou et al., 1994). Only 31 % of the riders not using a helmet had no head injuries.

In over 60 % of the moped accidents the collision speed was below 30 km/h (Otte, Suren & Nehmzow, 1995). In some countries, e.g. in the Netherlands tempered mopeds are still a problem. In the Netherlands young riders (aged 16-17) with tempered mopeds have the highest accident risks (Filou, 1995; Noordzij, 1998; Twisk & van der Vorst, 1994).

Although in France one out of four fatally injured moped riders could be found between 18-21 h most accidents with injured moped riders occur between 15-18 h (Filou, 1995).

4.3.4. *Moped accident configurations*

In the following detailed description analyses the multi-vehicle moped accidents in France (Filou et al., 1994) are existing (1991/1992):

- In 60 % of the moped accidents the moped rider keeps his course without a change of direction (e.g. crossing an intersection)
  - In 32 % the car changes direction
  - In 44 % the car also keeps on course (crossing traffic)
- In 19 % of the moped accidents the moped rider changes the direction
  - In 71 % the car keeps on course
  - In 17 % the car was overtaking the moped

- In 9 % of the moped accidents the moped rider was overtaking a car
  - In 55 % the car changes the direction
  - In 18 % the car is entering or leaving the traffic
  - In16 % the car keeps on course
- In 7 % of the moped accidents the moped rider loses control (which can be initiated due to heavy reactions that may be forced by a car.)
  - In 78 % the car keeps on course
  - In 18 % the car changes direction

The most frequent type of collision is a lateral collision and/or a hitting at the back of the moped (Carré & Filou, 1991; DENCO, 1998; Filou et al., 1994; Huijbers, 1984; Suren, Otte & Grabhöfer, 1980). The general accident research found that for motorcycle collisions - although the accident opponent is mostly to blame for it - the motorcycle run into the other vehicle whereas for slower one-track vehicles the accident opponent run into the mopeds. The main collision partner is a car with a percentage share of up to 75 % (Carré & Filou, 1991; DENCO, 1998; Filou, 1995; Filou et al., 1994; Huijbers, 1984; Noordzij, 1998; Otte, Suren & Nehmzow, 1995; Santillo & Antonelli, 1998; StBA; Suren, Otte & Grabhöfer, 1980).

The following findings are reliable for moped accidents:

- Most of the moped accidents occur in urban areas.
- The severity of accidents on rural roads is higher than for accidents in urban zones.
- In up to 75 % off all collisions the collision partner is a car.
- Accidents in urban areas occur predominantly at intersections.
- The most frequent accident type is "crossing traffic".
- The main collision speed is under 30 km/h.
- In up to 55 % the collision partner of the moped rider could be blamed for the accident.

4.3.5. *Comparison of moped and motorcycle accidents*

The accident characteristics of moped and motorcycle accidents show parallels. For both types of vehicles the accident situation can be described as followed:

- Moped and motorcycle accidents occur predominantly in urban areas.
- Higher injury severity of moped and motorcycle accidents on rural roads.
- For both moped and motorcycle accidents the main collision partner is a car.
- Accidents in urban areas occur predominantly at or nearby intersections.

The greatest differences between moped and motorcycle accidents can be found for the collision speed and the collision type. The average collision speed for mopeds is 30 km/h, for motorcycle accidents it is 50 km/h.

The main collision type for moped accidents is the collision type1 (front car - side moped) as whereas for motorcycles the main collision is a collision with a car which turns.

Another great difference between moped and motorcycle accidents is that the moped rider more often could be blamed for the accident than the motorcycle rider.

A deeper look at the accident situation for mopeds and motorcycles shows further differences.

The share of the urban accidents for moped users is much higher than the share for urban motorcycle accidents. A cause for that is the different kind of use as described before.

In opposite to moped accidents the share of seriously injured motorcycle riders in rural and urban accidents is nearly equal. In motorcycle and moped accidents most of the fatally injured riders are registered in rural areas. This trend is stronger for motorcycle accidents. The risk to be fatally injured in a motorcycle accident on a rural road is 2 times higher than in a moped accident. This can be explained by a higher travelling and impact speed, the different kind of use can be another explanation.

4.3.6. *Accident risk of motorcyclists per vehicle kilometre and in relation to other vehicle categories*

Despite this main facts general there still is a higher risk for the traffic participation of motorcyclists like for other forms of mobility of vulnerable road user groups. For motorcycles a general problem exists in relation to fatalities in comparison to other road user groups. The rates which are related to these figures have often no reliable basis and the rates are changing dramatically from research to research. Therefore the accident risk for PTW in relation to cars are between twice to eight times higher. As an example the rate per Mill. vehicle kilometres for five European countries is given in *Table 4.3* (vehicle km are estimated).

Nation	1980	1990	1995	Passenger cars '95
D	20.3	7.3	4.3	0.64
E	4.5	9.4	17.1	0.65
GB	10.1	5.0	5.2	0.50
I	4.0	1.4	1.3	0.45
NL	3.8	2.8	0.8	0.06

Table 4.3. *Casualties per million motorcycle km 1980 to '95 in comparison to passenger cars in 1995 (UN).*

In Germany a research from the Federal Highway Council (BASt) (Albus, 1993a) came to the following description of risk figures for motorcycles and cars (*Figure 4.42*).

For the year 1990 the risk of having an accident with a motorcycle in relation to the same amount kilometres was two times higher than for cars.

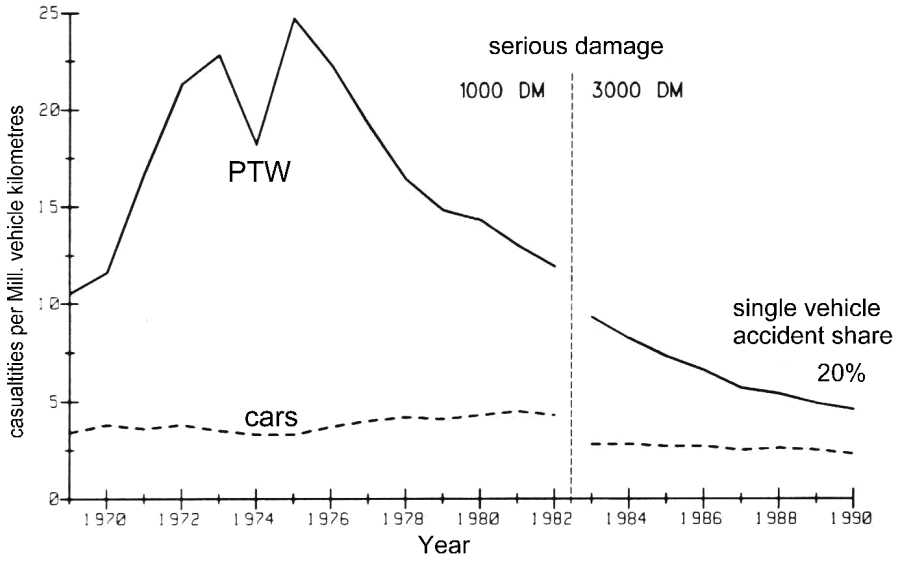


Figure 4.42. *Casualties per Mill. vehicle kilometres between 1970 and 1990 motorcycles /cars.*

5. Factors influencing the safety of mopeds and motorcycles

5.1. **Introduction**

Motorcycle accidents cannot be compared to accidents of other road vehicles like e.g. to car accidents, because to a greater extend the accident configuration is determined by a complex network of individual variables and the interaction between them (*Figure 5.1*). Motorcyclists have not only greater specific influences on the handling of a one-track vehicle in relation to braking, balance and stability, they are as well influenced more by environmental factors of the road and by personal factors of driving behaviour or risk taking behaviour. Furthermore legal national and European regulations influence age and mobility through licensing requirements or different regulations and the road environment. In this sense legal regulations are the framework of all influencing factors related to motorcycle accidents. Taking all solely factors into consideration the system approach of rider, vehicle and environment is the only suitable way to examine relevant influences to draw appropriate conclusions for safety measures for motorcyclists (Albus, 1993a).

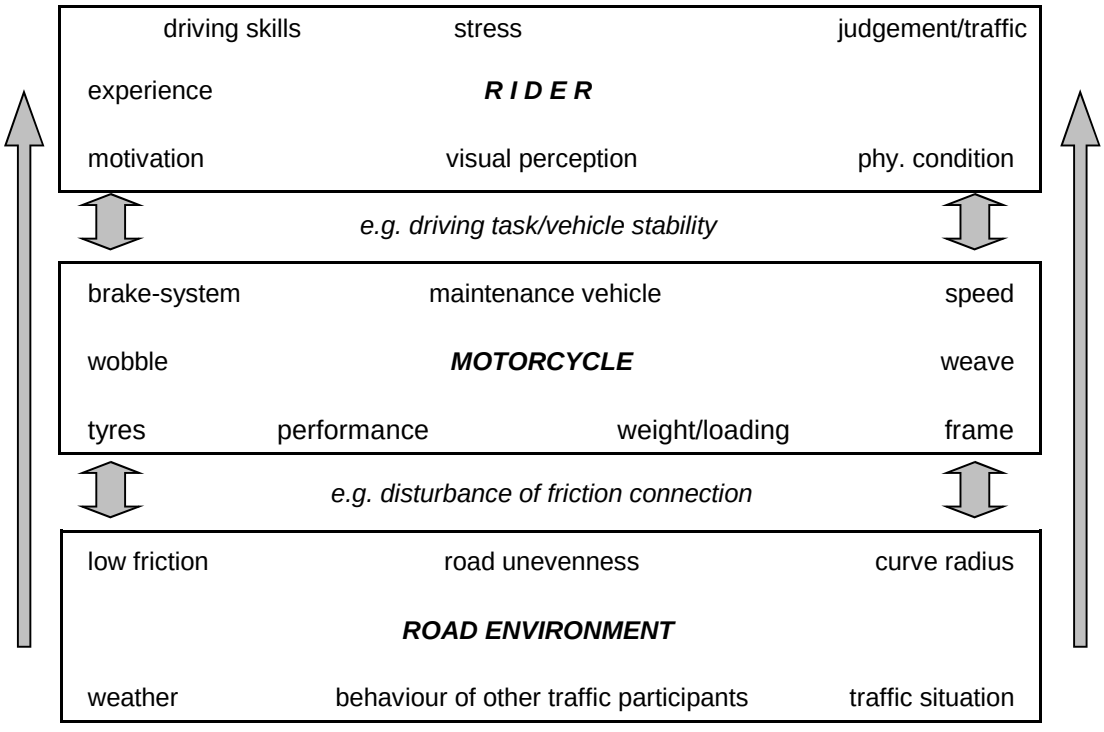


Figure 5.1. *IfZ-system approach "Rider-Vehicle-Environment"*

In this interactive system the rider as the "human factor" is the controlling interface between vehicle and road environment. Numerous scientific studies have confirmed that motivation and attitudes, information-processing abilities and the motorcyclist's driving skill play a decisive role in this interaction of the man-machine-system, which can cause an accident.

Causation by vehicle failure or mechanical problems are only 5 % of all two-wheelers accidents which is very similar to the situation of four-wheelers. The technical development of motorcycles has improved tremendously. Better braking systems, tyres and suspension have contributed to smoother and safer machine handling.
This can mean that in the field of primary safety the benefit of positive technical innovations is limited by the "human nature" and possibilities of additional integration of secondary safety devices are currently limited.

5.2. **The rider**

Apart from the accident analysis different influencing factors are apparently related to the rider as the “human factor”. Unlike to all other motorised road vehicle groups the rider is an integrated element of the man-machine-system motorcycle which has more frequently direct influences from e.g. the traffic system or road system. Moreover drivers or riders have specific traffic behaviour or risk taking behaviour that can be related to variables like age, annual mileage or experience, that play a significant role in accident situations.

Psychological researches of motorcyclists are often combined to youth related risks and to leisure time researches. Although there are no researches to be found, which distinguish clearly between different road user groups and their specific risk behaviour, it seems to be obvious that the youth related risks can imply problems with self-esteem or negative psychological factors by young users of all vehicle classes.

Motivations for riders are mainly described by three categories:

- sport motives (dynamic aspects, performance, thrill, and rivalry);
- driving pleasures/self orientated motives (escapism, hedonism, flow, identification, and social aspects); and
- security beliefs motives (control beliefs and safety motive) (Koch & Brendicke, 1990; Schulz & Kerwien, 1990).

The above mentioned psychological motives are evident for single accidents of motorcyclists, which have a share of one third of all motorcycle accidents. The main accident type “collision with another vehicle” with a majority of faults by the accident opponent demands different requirements of the rider state. Rider stress, rider skills or fatigue or reaction time before a motorcycle accident occur are variables that can influence the accident involvement. Furthermore these variables of the actual rider state are influenced by traffic-experience that can be related to age or average/ total mileage.

5.2.1. *Age and motivations - Comparison of young and elder riders*

Empirical studies reveal that in spite of a general decrease of accident numbers young riders aged between 15 - 20 are still overrepresented in accidents, which is related besides the beginners risk to riders' attitudes towards risk exposure due to so-called youth risks.

Generally there are remarkable differences in attitudes between the different age groups and especially for the young riders aged between 15 plus and 20

the PTW is an essential element of their leisure-time activities and offers various possibilities of social contacts. Young riders consider the motorcycle as an opportunity to get more self-esteem and have new sensational experiences or try to escape the monotony of their everyday lives. The young riders in particular seem to as well experience dynamic aspects and performance limits of their bikes and have a tendency to ascribe the performance of their vehicle to own abilities.

The relevant literature on the subject offers two explanations for the over-representation of young traffic participants in accidents:
- the so-called beginner risk, which means difficulties in coping with the rather complex traffic system
- the so-called youth risk, which means problems due to the adolescents' developmental crises

The commonly held opinion in traffic education and psychology explains the high accident rate of young riders by an interdependency of both aspects. Numerous reports on this subject provide further details on the nature of these factors (Massie, Campbell & Williams, 1995; Schlag, Ellinghaus & Steinbrecher, 1986; Schulz & Kerwien, 1990; Schulze, 1990).
Young motorcycle riders are often considered to reveal a high propensity for risk situations, to overestimate their riding skills and to have a tendency to demonstrate or perform their riding skills to other road users (Schlag, Ellinghaus & Steinbrecher, 1986; Schulz, Kerwien & Brendicke, 1990; Schulz, Kerwien & Koch, 1989). These tendencies are accompanied by a lacking of riding experience and the resulting insufficient risk cognition. Aspects which are normally not valid for older riders, having more experience in riding which can reduce negative traffic behaviour and accident involvement. The incline to demonstrate riding skills in traffic, however, bears risks. This general tendency of young riders can be explained by a stronger orientation towards power and dynamical aspects of motorcycle riding.

The young riders using their machine to demonstrate their individual performance limit can explain the relationship existing between positive feelings and the experience of performance limits. The experiencing of upper limits and the pleasure and joy in mastering dangerous situations as described above, seems to attract especially young male riders who have little riding experience only and who reveal deficits in danger cognition. Although not very frequently researched and with low number of cases, female riders seem to have a similar tendency (Schulz & Hagstotz, 1993).In addition to that the lack of knowledge implies a potential danger of motorcycle riding (see § 5.2.1).

The fascination of motorcycle riding is often characterised as an extraordinary intensive experience in high technology society (Schulz, Kerwien & Koch, 1989). The motorcycle offers an opportunity to escape from the restrictions of everyday life and allows new and sensational experiences while riding (see § 5.2.1).

According to results of empirical studies especially the young riders have a tendency to plunge into the flow-experience, were proved that young riders tend to underestimate potential risks in traffic and simultaneously

overestimate their own capacity to control and manage unsafe situations (Schulz & Kerwien, 1990).

Studies on the leisure time activities of young riders reveal that two-wheeled as well as four-wheeled vehicles play an important role concerning the juveniles' social status (Schulze, 1990). In this context the car and, still the more, the motorbike is a linking element within the peer-group and often leisure time activities centre around the powered vehicle. The function as a means of transport for the young riders is less important aspect as far as the usage of the vehicle is concerned. Motorcycle riding especially for young rider's means a leisure-time activity performed together with people of similar interests.

*Conclusion*s

- Young riders have a higher accident risk than elder ones.
- In cases of minor accidents the risk of younger motorcycle riders is considerably higher than for older ones.

Single vehicle accidents are influenced by the age and the experience of the rider. For multi-vehicle accidents this can not be stated because of the majority of multi-vehicle accidents where the accident opponent is to blame for it and because traffic experience doesn’t matter (Brendicke, 1991; Brendicke, 1997; FIM, 1996; Kerwien, s.a.; Koch, 1987; Koch & Brendicke, 1990; Pfafferott & Müffeler-Röhmer, 1991; Schlag, 1997).

5.2.2. *Gender and motivation*

Most of the comparative data for men and women refers to driving styles in relation to cars and their attitudes to cars (Massie, Green & Campbell, 1997). Schulz & Hagstotz (1993) surveyed the attitudes of female motorcycle riders.

There are significant differences for male riders especially in relation to speed and competition in comparison to female riders. The motivation to ride with higher speed or in a competition is smaller for female riders. Female riders are just "riding relaxed" or "going on tour ", which is the main reason for their motorcycling with less sport orientated feeling. These attitudes lead to a lower accident involvement of female riders, especially in comparison to young male riders (Schulz, Gresch & Kerwien, 1991; Schulz & Hagstotz, 1993).

Average annual mileage control the influence of driver/rider and gender with their accident involvement (Massie, Green & Campbell, 1997).

5.2.3. *Annual mileage and driver experience*

The variables annual and total mileage's as the average or/and the total number of kilometres travelled per year/rider career have a dominant influence on the accident involvement of all vehicle/rider groups. These aspects are directly combined as one part to traffic experience of riders/drivers.

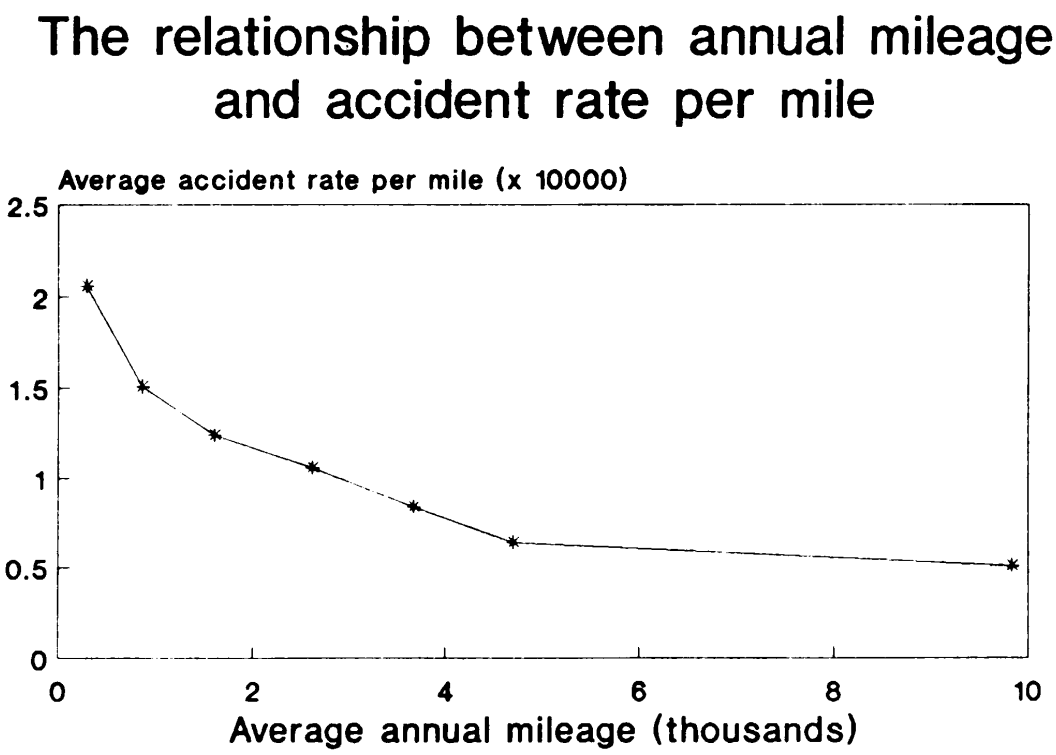


Figure 5.2. *The relationship between annual mileage and accident rate per mile (Taylor & Lockwood, 1990).*

Taylor & Maycock (1990) analysed the influence of annual mileage by a survey of 10,000 registered PTW users in GB. It was shown that on the one hand the accident risk per mile decreases with increasing mileage, on the other hand the accident frequency per year raises with increasing mileage. But generally spoken more experience lead to less frequent accidents (*Figure 5.2*).

The strong influence of kilometres travelled can vary much and depends both on the age and/or the career of riders. In case of increased annual mileage the rider's competence seems to be increasing to a higher degree than the general accident risk by exposition to traffic. This seems to be caused by a "learning-by-doing-effect".

Influencing factors can reverse the situation: on the one hand in case of accidents involving third parties. The accident risk increases linearly according to the annual mileage. Thus the conclusion can be drawn that simply due to the status as a road user the risk and thus the accident involvement risk generally increases. This means on the other hand that more mileage can lead to a break even point that revises the positive tendency of experiences through the normal risk to be involved in an accident.

- Lower mileages lead to a higher risk of a single vehicle accident obviously due to the motorcyclist's limited experience.
- Increasing mileage does achieve a decreasing risk of accidents although there is a "break even point" that revises this positive tendency.

- In the case of multi-vehicle accidents a linear risk has to be stated. This risk is related to the exposure in traffic participation for motorcyclists (Koch & Hagstotz, 1990).
- Previous experience with other two-wheeler categories causes a declining risk of suffering a motorcycle accident in the first years (Koch & Hagstotz, 1990).

5.3. **The vehicle**

The physics of a one-track vehicle is quite different to a four-wheel vehicle. The one-track vehicle is a three dimensional system whereas the four-wheeler has a two-dimensional physical system, which can be very vividly seen when riding a PTW in a bend. Here only a lateral inclination of rider/vehicle of about least 45° (riders reach normally 20° plus inclination) is possible and the rider does not feel lateral forces and has no information from the noise of a side slip tyre like a car driver has.

Different forms of vehicle stability by gyroscope effects in relation to speed can lead to an unequal balance of the vehicle at low speed. The utilisation of friction connection between tyres and road surface is more problematic for one track vehicles that have no reliable source of information of the interaction between tyre and road surface. The absence of a feedback of the actual state of riding and e.g. environmental aspects like the µ-value for the friction of the surface can lead to a lock of the front wheel when braking.

The second pair of wheels by cars can stabilise the handling when problems of friction connection or instabilities occur. Furthermore the rider of the vehicle is a more integrated part of the rider/vehicle system with a weight ratio of 1:1 to 1:4 and has more influence on the handling of the PTW in general.

Therefore one of the most difficult activities when handling a motorcycle is correct braking. The motorcycle rider has at the same time to maintain stability, to prevent the wheels from locking and sliding and to provide the shortest possible stopping distance in combination with the highest possible deceleration by a ideal ratio of front (70-80 %) to rear brake force (20-30 %) distribution by normal separated brake systems. Even when motorcycles are equipped with anti-lock braks or more over with so-called combined or integrated brake systems the problem of braking on bends has no solution up to now.

This chapter covers technical variables, predominantly those of primary safety. It includes, for example, the effectiveness of the braking system as well as the stability and handling of motorcycles and does not reflect limits of secondary safety of one-track vehicles. Another aspect being studied is the power or capacity of the motorcycle. However, numerous researches have not assessed engine power or capacity as a determinant of accident involvement in general.

5.3.1. *Braking*

In spite of the problems related to motorcycle braking concerning the rider it has to be stated that the modern equipment with hydraulic disc brakes,

combined braking systems or antilock devices (ABS) provide a high technical standard for motorcycle braking in general (Nishimoto et al., 1991; Schott, Schwieder & Weidele, 1989; Tiebken, 1993; Walker, 1996; Watts, 1980; Willumeit, 1994).

The lack of (hydraulic) combination of front and rear brakes, however, involves specific tasks for the rider and problems, which are unknown to car drivers:
- achieve the optimum of deceleration by
- the correct combination of front(hand) and
- rear(foot) brake on a conventional motorcycle (Post, Bayer & Breuer, 1984)
- under all weather, road surface and friction conditions

to
- achieve correct brake force, not to
- lock the front wheel
- over-brake and capsize the front wheel (for the rear wheel this is not this serious problem)

Nevertheless, although there are appropriate brake systems, the motorcyclist faces minor disadvantages related to the basic physical reasons:
- No four-wheel “stability” concerning braking.
- Braking in curves/bends imply an unstable riding processes with all brake systems (as well with ABS and combined systems).
- Appropriate braking force to the grip of road surface.
- Wide Range of brake forces that differ from load conditions (solo riding, riding with pillion passenger, additional weight by luggage) (Post, Bayer & Breuer, 1984).
- Strong rider attitude to the “freedom” of braking with separate brake systems.

For years - at least for fast and heavy models - the state of the art of motorcycle brakes has been the hydraulically actuated disc brake on front and rear wheel (Weidele & Breuer, 1989). The front and rear brakes are normally strictly separated one from another, providing advantages in the sense of redundancy.

There is no reason to worry about the effectiveness, safety and fading resistance of modern motorcycle brakes. The development of brake pads made of sintered metal lead to further improvements of the braking potential particular in wet circumstances. Most large motorcycles of today's standard are equipped with two disc brakes on the front wheel and one disc brake on the rear wheel, thus taking into account the dynamic load distribution of motorcycles and being nearly "oversized" for a two wheeled vehicle (Weidele & Breuer, 1989).

Braking a on-track vehicle involves difficulties which are unknown to car drivers: how to achieve the optimum of deceleration by the correct combination of front (hand) and rear (foot) brake on a conventional motorcycle under all weather, road surface and friction conditions (Post, Bayer & Breuer, 1984). There surely exist a certain, though unknown, number of accidents in which incorrect brake force distribution leads to an

accident. If the brake force distribution is not correct, either wheel locking or a loss of deceleration (and enlarging of the stopping distance) is the result. If the front wheel locks, the rider will hit the ground. Only a locked, over-braked rear wheel normally can be compensated by the rider in terms of stability.

Therefore, the motorcycle industry is offering some models with so-called combined or integrated brake systems (Post, Bayer & Breuer, 1984). These systems provide a good force distribution by actuating the brakes of both wheels by using only one means of operation. From a technical point of view it is rather difficult to apply a correct brake force distribution for a motorcycle for all load conditions (solo riding, riding with pillion passenger, additional weight by luggage) (Post, Bayer & Breuer, 1984).

Anyway, it is of utmost importance, that in case that the rider actuates too high pedal forces, the rear wheel locks first (before the front wheel) in order to maintain a sufficient degree of vehicle stability. Unfortunately, even a combined braking system cannot prevent wheels from locking. This fact led to the development of special antilock brake systems for motorcycles. For physical reasons (the riding dynamics of a single-track vehicle differ considerably from those of a "stable" four-wheeler) it was impossible to simply adopt automobile systems.

Nowadays, several motorcycle manufacturers offer some models with antilock brakes. The motorcycle riders should appreciate this development, even if rather sports-inclined riders sometimes seem to suffer - similar to combined brake systems - a certain "loss of freedom" and feel manipulated by an automatic device. Nevertheless, antilock brake systems may become, similar to what happened already in the automotive area, more and more standard equipment for motorcycles. The industry (Nishimoto et al., 1991; Post, Bayer & Breuer, 1984), as well as research institutes (Donne, 1989) are investigating, testing, and improving theses systems. Further research is still necessary.

The ABS-systems used with series models actuate braking force to the front and to the rear wheel. As it is in nearly all cases a locked front wheel that leads to an accident risk, an anti-locking device for the front wheel is supposed to be more sufficient in relation to a locked rear wheel, that can be controlled by the rider him/herself. Furthermore modern ABS systems have no longer a distinct prolonging of the stopping distance, which has been inevitable when using older ABS systems.

One very special problem for motorcycle riders is the braking on bend (with and without antilock device) (Hikichi, Tomari & Katoh, 1991; Schott, Schwieder & Weidele, 1989). As a result of the width of the front tire, under a roll angle (which is absolutely necessary for cornering) a steering torque arises that - as a function of the gyroscopic effects of the rotating and steered front wheel - has the tendency to set the motorcycle upright (what is absolutely harmful for safe cornering). The result is that the motorcycle changes its original travelling path and tries to leave the curve by the tangent, even before the tires might loose their grip to the road surface (in case of no antilock system).

An actuated antilock device of a motorcycle works, like with cars, with a certain frequency of the brake force. This normally results, in combination with the above mentioned steering torque, under cornering conditions in a pulsation of the handlebar and - as a consequence - in a "wobbling" movement of the whole motorcycle in addition to the tendencies mentioned above. Thus, a very uncomfortable handling and even risky situation as well as dynamic oscillation arises, vehicle reactions, which are unknown to car drivers and which are very typical for single-track vehicles. This problem is subject of several theoretical and practical studies (Donne, 1989; Hikichi, Tomari & Katoh, 1991; Schott, Schwieder & Weidele, 1989; Weidele, 1994).

A proposal for a solution of this problem by a steering head design change has already been made (Schott, Schwieder & Weidele, 1989; *Figure 5.3*). Progresses in the development of braking steering moment prevention device (Schott, Schwieder & Weidele, 1989) however, have not been successful yet, so that a take over of this device in series models will not be realised in the near future. In spite of the problems related to motorcycle braking it has to be stated that the modern equipment with hydraulic disc brakes and especially the already started introduction of antilock devices in general provide a high standard for motorcycle braking.

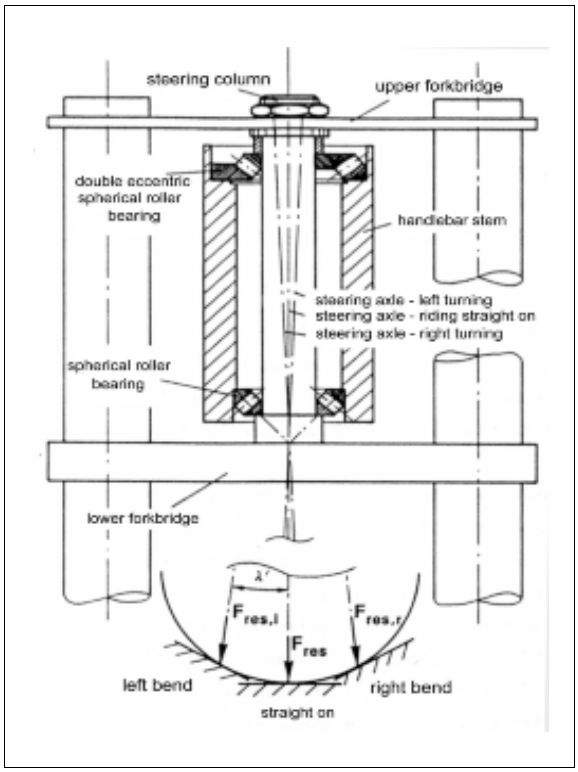


Figure 5.3. *Braking steering moment prevention device (Weidele, 1994).*

5.3.2. *Stability and handling*

Although four instability modes of motorcycles are technically known:

- Capsizing: this is the "natural" non-oscillating tendency to roll/fall to one side, mainly at low speed.

- Wobbling: this is an oscillating steering motion with about six to ten Hertz (shimmy) frequency, mainly being a phenomenon of the front wheel system and the front suspension (fork) at speeds below 100 km/h.
- Weaving: this is an oscillating mode at high speeds with a frequency around three Hertz. It is a combined and complicated steer/roll/yaw motion of the whole motorcycle.
- Kick back: this is an oscillating, mainly steering motion with a frequency around five Hertz, strongly influenced by road irregularities, at medium to high speeds.

This seems to be no longer a general problem for motorcyclists, that can affect accident situations. However it has to be stated that there is a principle physical difference in handling and obstacle avoidance for motorcycles in comparison to cars (Bayer, 1986; Giorgetta et al., 1990; Koch, 1980; Köhler, 1993; Oishi, Sano & Machii, 1980; Rammoser & Teubert, 1992; Tani et al., 1993; Watanabe & Soshida, 1973; Weidele, 1989; Weidele, 1991; Weidele & Breuer, 1989; Weidele, 1994; Willumeit & Teubert, 1994; Wisselmann & Iffelsberger, 1989).

There is hardly any other topic within the research field of two-wheeled vehicles, which has been as much in the centre of interest as the dynamics of motorcycles (Bayer, 1986; De Molina, 1990; Hagstotz, 1990; Hikichi, Tsuchida & Thiem, 1989; Koch, 1980; Rammoser & Teubert, 1992; Roe, 1973; Sharp, 1971; Weidele, 1989; Weidele, 1991; Weir & Zellner, 1980; Wisselmann & Iffelsberger, 1989). At first, stability and handling have to be distinguished. As a second step, the influence of vehicle design parameters can be identified. Stability means the ability of the motorcycle/rider combination to maintain the upright, or in curves a well defined inclined position without disturbances, especially by oscillations which could cause the motorcycle tires to exceed the road adhesion.

Handling is the transient behaviour of a motorcycle during lane changing or entering a curve or when avoiding an obstacle (Weir & Zellner, 1980). Methods for describing the handling by text methods or calculation are known, but difficult to conduct (Roe, 1973; Weidele, 1989). Quick handling, without "nervousness", is desired and today state of the art for easy control of a motorcycle (Weidele & Breuer, 1989). However, it must be reported that there is a principle physical difference in handling and obstacle avoidance for motorcycles in comparison to cars.

When introducing an evasive action, the rider has (due to the gyroscopic effects of a one-track vehicle) to start with a steering torque input to the handlebar into the opposite direction, that means he has to do an input to the left in order to initiate the motorcycle to turn to the right and vice versa. Thus, changing the lane for a motorcycle takes the same period of time, or even longer, than with a car (Weir & Zellner, 1980). This fact is widely unknown by car drivers and results sometimes in misunderstanding and wrong estimation of the quickness and ability of a motorcyclist in changing his travelling direction.

Frame and wheel suspension design of modern motorcycles show a big variety of constructions: steel or aluminium, tubes or "boxes" for frames (Koenen, 1981), telescopic front forks or types of centre hub steering,

monoshock or conventional rear suspension. This wide field of different layouts today provides similar results in terms of stiffness (Dreyer, 1987), durability and fatigue resistance, precise steering, good handling, sufficient riding stability (Watanabe & Soshida, 1973), and comfort.

Solo-accidents due to uncontrolled weaving have not been mentioned within the last about five years, whereas in former times this oscillation mode had been of great concern and sometimes subject of accidents (Giorgetta et al., 1990).

Wobbling as a low-speed instability is uncomfortable but has never been really dangerous or accident-related. Only two things remain to be dealt with in the near future: i.e. kick back and aerodynamic fairing and their influence towards ergonomics and safety. The kick back phenomenon occurs as a mixture of high speed stability disturbance due to road irregularities, dynamic tire properties and motorcycle design parameters like front fork rigidity, moment of inertia around steering axis and rotating moment of inertia of the front wheel. It seems that too stiff frames and too rigid front wheel suspensions, in combination with wide tires and a short moment of inertia around the steering axis (good for handling and high speed weave damping!) and low (dynamic) front wheel load do favour the not yet well-known kick back mode.

Fairings are nowadays an instrument of motorcycle styling. The aerodynamic behaviour and stability of a motorcycle are of course strongly influenced by these accessories which today normally are directly adapted to the vehicle by the motorcycle manufacturer and are no longer only additional after market equipment. Injuries caused by fairing are relatively seldom (0.7 %) and mainly correspond to injury severity according to AIS 1-2. Sporner(s.a.) states an injury reduction by fairings by influencing the trajectory of riders who suffered a collision. However, there is not yet sufficient knowledge concerning fairings and their influence on injuries and aerodynamics. Additional research is recommended.

As a summary, it can be stated that although totally different design and construction concepts of motorcycles and their components (like frames, suspensions, and wheels) exist, identical results concerning primary riding safety can be achieved and that thus, there is no need for a "standard design". There is only little lack of knowledge in some boundary fields.

5.3.3. *Tyres*

Tyres are the most important and necessary links for the power transmission from vehicle to road. Due to the numerous ways of use of modern motorcycles and the resulting high demands concerning the riding dynamics, special tyre constructions for each motorcycle type are requested. Modern motorcycle tyres realise a maximum deceleration of more than 1 *g* under dry road conditions (Bayer, Kronthaler & Hagl, 1989; Kronthaler & Bayer, 1987; Weidele & Schmieder, 1990). With wet road surfaces, as well, high medium deceleration performances (6-7,5 m/s^2) are possible (Breuer, 1985). The demanding riding dynamics of motorcycles, as compared to two-track vehicles, lead to high-quality standard tyres which are superior to the construction of car tyres (cf. low section tyres, radial carcass) in some ways.

For street bikes, for example, low section tires are standard meanwhile. They are able to meet the rising annual mileage and the rather high weights of the machines. The development of broad low section tires results in an enlargement of the contact between tire and road. Thus the tire pressure as well as the transferable forces increase and, as a consequence, the tires are of higher durability. Simultaneously, the contour radius of the running surface increases in order to enlarge the contact between tire and road when cornering.

In general, there are three kinds of tires: tires with diagonal structure, belted structure (Bayer & Breuer, 1983) and radial structure. The latter, which is a special variation of the belted structured tire, is the latest technical development in this field. The advantage of this tire is the constant surface contact of tire and road for all velocities.

5.3.4. *Scooters and mopeds*

Mopeds and scooters as well had a positive technical development in the last years and the technical standards for modern scooters and mopeds are not far away from a motorcycle. This positive technical development is part of the registration increase for this vehicle category.

5.3.4.1. Braking performance of scooters and mopeds

In former times the braking systems of mopeds and scooters were of poor quality. Slow mopeds for example were equipped with rim brakes. But in the last years the technique of the braking systems for scooters and mopeds has made great progress.

5.3.4.2. Scooters

Nowadays nearly all scooters with a capacity of more or equal than 50cc are equipped with hydraulic disk brakes on the front wheel and with drum brakes on the rear wheel. Even scooters with anti-lock devices and combined braking systems are nowadays available.

Braking tests from a speed of 50 km/h with scooters (50 cc) show good braking performances of modern scooters. The tests show decelerations of 6.43 to 8.39 m/s^2 with an average of 7.5 m/s^2 on dry tarmac. Various braking tests were made with scooters with a capacity of 125 or 250 cc. The average deceleration in these tests was 7.31 respective 8.44 m /s^2 (*Table 5.1*) related to an emergency braking from 50km/h.

5.3.4.3. Braking performance of slow mopeds

For slow mopeds with a maximum speed of 25 km/h drum brakes are nowadays the standard. The advantages of the drum brakes are low costs with a reliable braking performance and the long service intervals.

Brake tests with 10 slow mopeds showed that the drum brakes achieve an acceptable deceleration of up to 5.4 m/s^2 on dry tarmac with $\mu = 1.0$, which is convenient in relation to the maximum speed of this vehicle class. A slow

moped at high speed needs an emergency braking distance of only 4.46 m on dry tarmac (Burg & Schlögl, 1994).

Overall it could be stated that the braking performance of modern scooters and mopeds is at a high technical level.

Model	Braking distance	Deceleration [m/s^2]
A	15 m	6.43
B	14.5 m	6.65
C	14.8 m	6.52
D	13.5 m	7.15
E	11.5 m	8.39
F	11.8 m	8.18
G	12.5 m	7.72
H	12 m	8.04
I	11.5 m	8.39
Average	13.01 m	7.5

Table 5.1. *Braking distance and deceleration of various 50cc scooters from a speed of 50 km/h; Source: SCOOTER Magazine*.

5.3.4.4. Stability and handling of mopeds and scooters

One reason for the poor stability of scooters in earlier times was the small wheel size. Scooter wheels have had a size of only 8 inch that raised to a size of 14 or even 16 inch.

A bigger size of wheels and tyres makes the vehicle on the one hand more comfortable and on the other hand more stable due to the fact of the greater gyroscopic effects of the wheel. This means that the handling of the vehicle improves. For mopeds with a large wheel diameter this never was a problem.

Successful developments are as well to be seen in relation to frames. Scooter frames in former days were not stiff enough for unevenness of roads (e.g. a hole) that lead to a twisting reaction of the vehicle. Frames of scooters and mopeds are nowadays designed stiff enough to provide a good stability and handling in almost all-riding conditions.

Improvements could also be found on many other elements of scooters and mopeds. For example the suspension systems are on a high technical standard with various adjustments possible or scooters with axle pivot steering are available today.

5.3.4.5. Conclusion

Overall it could be concluded that the technical standard (except the lighting systems) of scooters and mopeds has made an enormous improvement in the last years. Braking performance, stability and handling has reached a level, which is not far away from motorcycles.

One slight technical problem of scooters and mopeds was the quality of the lighting systems. Relative low engine revs of slow mopeds and 50 cc scooters cannot supply a bulb with a high watt power. The power of the alternator was not high enough if the engine is idling at low revs. Modern scooters or mopeds with a battery reduce this problem. The new EU directive 97/24/EG that has to be fulfilled by the manufactures from June 17th, 1999 requests a 15 watt bulb on the front light as a minimum for new vehicles. A potential of further developments might be foreseeable.

5.3.5. *Motorcycle performance*

The specific question regarding whether there is a relation between the engine power of motorcycles and the frequency of motorcyclists' involvement in accidents are based on:

1. The *analysis of officially registered accidents*.
   These analyses generally contain more specific accident circumstances as well as reports on the persons involved and characteristics of the vehicles involved in accidents. Furthermore, the numbers of motorcycles registered are taken into account for the units of analysis under study (Broughton, 1988; Broughton, 1991; Lynn, 1990b; Mayhew & Simpson, 1989; Schulz, 1990a; Schulz, 1990b; Taylor & Lockwood, 1990; Taylor & Maycock, 1990).

2. *Surveys of the accidents experienced by a representative group of motorcyclists*.
   These studies gather more precise information on accidents, aspects of driving behaviour including the distance driven per year, reports on the vehicles involved as well as relevant information on the rider (Lynn, 1990b; Taylor & Lockwood, 1990; Taylor & Maycock, 1990).

The following results have been obtained using the *first method*:

In Australia (McLean, 1979) and Japan (Woltman & Austin, 1974) the same method shows that the frequency of accidents also grows with increasing capacity. In the USA, Kraus et al. (1987) have used the same methods to try to show that particularly more powerful motorcycles with very sporty designs are involved more frequently in accidents than less sporty machines. Similar findings have also been obtained from official accident statistics in Canada (Simard, 1990), Australia (Hallion & Nelles, 1987) and Great Britain (Broughton, 1988; Broughton, 1991). Kroj and Stöcker (1986) have reported an increasing frequency of injury as a function of engine power in an analysis of West German official accident records for the years 1980 and 1981, although the number of cases from accident statistics collected in the state of North Rhine-Westphalia are very low (Albus, 1993b; Stöcker, 1990). The most recent findings from France (Filou, 1998) indicate that motorcycles with capacities between 600 and 725 cc show the highest involvement in accidents when annual distances travelled are taken into account, but regional and national differences are to be taken seriously into consideration.

By the *second method* Thompson (1980) in New Zealand and Hurt et al. (1980) in the USA have analysed accident data while taking account of mileage as a measure of risk exposure. They both found a decreasing involvement in accidents as a function of increasing capacity.

No relations between motor volumes and accident involvement could be found in four more studies in New Zealand, Canada and the USA (Bragg, Dawson & Jonah, 1980; Broughton, 1988; Hull, 1981) when mileage was taken into account.

A re-analysis of data from Hallion and Nelles (1987) and Broughton (1988; 1991) revealed that a basic error can be made when the mileage travelled is neglected. In both cases, there was a trend towards lower accident involvement as a function of increasing capacity when mileage was controlled. In Germany, Koch (1987) showed the independence of accident involvement from motorcycle power by using survey methods. The same direction is taken by the results of the most comprehensive representative study on this topic from Great Britain (Lynn, 1990b; Taylor & Lockwood, 1990; Taylor & Maycock, 1990). This research was unable to confirm any direct relation between motor capacity and accident involvement. In rural areas, there even was a lower accident involvement of larger capacity motorcycles when combined with the location of the accident.

In four of the studies undertaken by Schulz on variables influencing the accident involvement of motorcyclists it was impossible to find that accident involvement increased as a function of motor power in the range of lower to intermediate powerful motorcycles for various types of accidents while controlling for mileage (Schulz, 1990a; Schulz, 1990b; Schulz, 1998; Schulz & Hagstotz, 1990; Schulz & Koch, 1991). Influences are more related to the rider of the motorcycle (Schulz, 1998).

An impact of motor capacity on increasing accidents while controlling for mileage could be confirmed only in two Australian studies (Johnston, 1976; Vaughan et al., 1977).

Findings that focus more attention on the person of the rider have been able to confirm clear relations between accident involvement and the leisure-time motivation for riding motorcycles (Schulz, 1993). A further study has shown that increased acting-out tendencies of motorcyclists are linked to a higher quota of single-vehicle accidents (Schulz, Kerwien & Haase, 1996).

In the recent TNO study on behalf of the European Commission in order to discuss and analyse the accident involvement of motorcycles with engine power lower and greater 74 kW, no evidence for accident involvement and engine power was found (TNO, 1997).

To summarise the major findings from the internationally wide range of studies, one can perform the following evaluation in line with Simpson & Mayhew (1984), Mayhew & Simpson (1989) as well as Taylor & Maycock (1990):

Driving a motorcycle with greater engine capacity or engine power may have a possible relationship to an increase of accident risk, but according to nearly all known findings, this increased accident involvement is due to a higher risk exposure in the form of an increased mileage per unit of time or due to the drivers risk taking behaviour and not the engine performance (Schulz, 1998).

In summary, one can state that the scientific findings remain ambiguous in some ways, but by the use of methods and measures of exposure data there is no relation between accident involvement and horse power of motorcycles.

Conclusions

- Different studies concluded that the engine size does not represent a risk factor in collisions (Koch & Schulz, 1991; Mayhew & Simpson, 1989; Simpson & Mayhew, 1984; Taylor & Maycock, 1990; TNO, 1997). Apart from that special effects were obviously due to accident types.
- In less severe accidents the powerful motorcycles had the lowest accident rates (Koch & Hagstotz, 1990).
- Multi-verhicle accidents normally occur on urban roads at a low speed, where the engine performance does not play a role at all (Simpson & Mayhew, 1984).

5.3.6. *Visibility*

Rear-view mirrors of motorcycles sometimes offer a limited back view only. In fact, there are cases in which the rider's arms are reflected and thus restrict the visual field behind. Research seems to be successful in managing this problem. Determinations valid for Europe on the whole described in the 97/24/ECE from June, the 17th 1998 comprise a standardisation of the mirror equipment, of the distances between mirrors and of the visibility to the rear.

5.4. **Road environment and traffic**

The environment of moped and motorcycle riders is related to the road conditions from street design to the roadside environment and other vehicles that use the road. The quality and conditions of the road environment influences the road safety for all traffic user groups. But road design and road maintenance is orientated towards the biggest registered vehicle-group, the car users. Often this orientation of road authorities is at the expense of vulnerable road users. Groups like pedestrians; cyclists and motorcyclists have to suffer from negative influences by these legal decisions, because the basic and scientific information for road authorities is often not available directly. Although there seems to be a change in favour of a more user-friendly orientation for pedestrians and bicyclists, little regard to mopeds and motorcycles can be found in general.

5.4.1. *Other vehicles*

Related to accident avoidance and the reduction of accident consequences the compatibility between other road vehicles and the motorcycle is the major aim. In this context the following primary developments can be found:

A fact (related to primary safety) is the *aerodynamic "canal effect*", induced by long trucks or busses to single track vehicles (Bayer, 1986; Hackenberg, 1985; Oishi, Sano & Machii, 1980). Weave reactions of the motorcycle can be the result, but due to the high level of modern motorcycle chassis design, this should not be regarded as a serious problem.

The spilling of *diesel fuel* as a function of overfilling and/or not correct locking of the fuel tank cap especially of trucks sometimes causes motorcycle accidents because the tire/road friction, which is essential for safe motorcycling, is affected negatively. Modern systems do not allow overfilling and have internal self-locking devices. They have already been developed and should become standard equipment for Diesel-powered vehicles.

5.4.2. *Road surface*

There are a lot of aspects which are interesting with respect to the road surface (Brendicke, Forke & Gajewski, 1995):

- slippery surfaces;
- bad road repairs with different µ-spots;
- bitumen;
- road mending;
- unevenness;
- road markings (Brendicke, Forke & Gajewski, 1995; IfZ, 1988; Paulmann & Breuer, s.a.);
- parallel (longitudinal) grooves;
- use of cobbles.

Skid resistance spots (µ-Spots), leading to instability in handling one-track-vehicles, are caused - among other factors like pools of diesel and oil on the road - by road mendings when Bitumen is used (Bayer & Weidele, 1986).

Bitumen is an important repair material in modern road construction works and it is mainly used in order to fill and patch fissures or to repair minor road damages. Bitumen normally can be found in parallel and diagonal direction. Unfortunately, it was and still is used for rather extensive road repair works as well.

The danger for motorcycle riders caused by bitumen has been proved by numerous researches and a series of tests which tried to find out the physical vehicle reactions when crossing bitumen in comparison to crossing tarmac road surfaces.

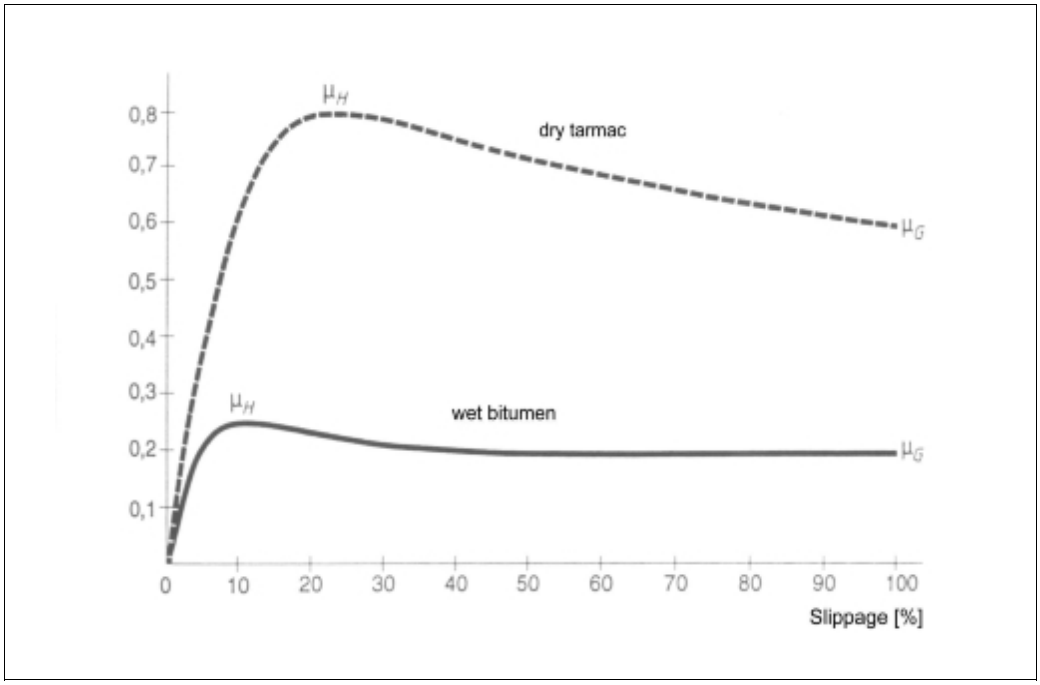


Figure 5.4. *Difference of the μ-level of wet bitumen and dry tarmac (Brendicke, Forke & Gajewski, 1995).*

Skid resistance measurements revealed a clear reduction of the my-spot value with wet bitumen (μ = 0.25) as compared to wet tarmac (μ = 0.8). A value of μ = 0.25 corresponds to the value of black ice. In practical terms, the crossing of bitumen causes considerable steering reactions, both, when riding in leaning attitude as well as when braking while riding straight.

The crossing of wet bitumen in leaning attitude leads to the following results:

- the resulting speed of the steering angle reveals a clear offset from the track (track-pawning);
- all test riders revealed a rather safe value of appr. 20°/sec. speed of the steering angle;
- even experienced riders do hardly only exceed this value of 20°/sec. in real traffic situations;
- only very experienced riders have enough safety reserves;
- less experienced riders do not have subjective safety reserves;
- the originally intended branch line is left due to the offset of the track;
- the risk of an accident increases excessively by the resulting physical vehicle reactions;
- thus the risk of a collision with the oncoming traffic or with a crash barrier increases dramatically.

The process of braking when crossing bitumen results in:

- in case of an emergency stop out of 50 km/h, the stopping distance increases by more than 100 % on wet bitumen, as compared to a stop on wet tarmac;
- a piece of bitumen of 0.5 m enlarges the stopping distance of a motorcycle equipped with ABS (speed appr. 60 km/h) by more than 20 %;
- a piece of bitumen of 1 m enlarges the stopping distance by 45 % (same conditions);
- the danger of locking wheels increases;
- thus the risk of suffering an accident or a collision substantially enlarges.

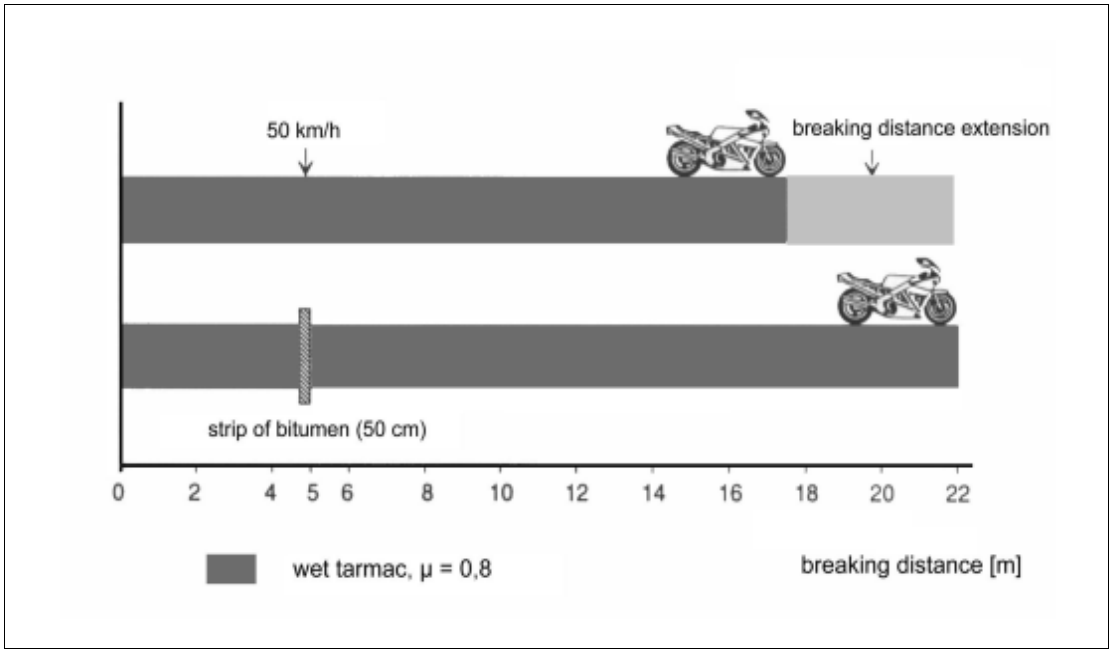


Figure 5.5. *Increase of braking distance due to bitumen use on surface (Schweers & Brendicke, 1993).*

The results clearly point out a higher accident risk for motorcycle riders when crossing road sections repaired with bitumen. If possible, the responsible road departments are required to take care of a reasonable and economic use of bitumen and to avoid extensive repair work with this material (Bayer & Weidele, 1986).

Road markings may lead to considerable deterioration of the riding dynamics of motorcycles, depending on the quality of the markings and the given weather conditions. Deterioration in particular means wobbling track pawning of the motorcycle, which can be dangerous for a loss of control of the vehicle. If the deterioration of the vehicle occurs under bad weather conditions with a high water level this can lead to a loss of tire grip in relation to the road marking surface (Bayer & Weidele, 1986). It is especially this loss of adhesion between tires and road surface/marking which turns out to be particularly negative for the handling of the motorcycle. Thus the possible leaning angle of appr. 45° with vf = 40 km/h (good weather and road

conditions) declines to 40° when crossing dry markings. If the motorcycle deteriorates when crossing a wet road marking the leaning angle is reduced even to 25°. In addition to that, the stopping distance doubles if the rider brakes on wet road markings compared to dry not marked road surfaces (tarmac).

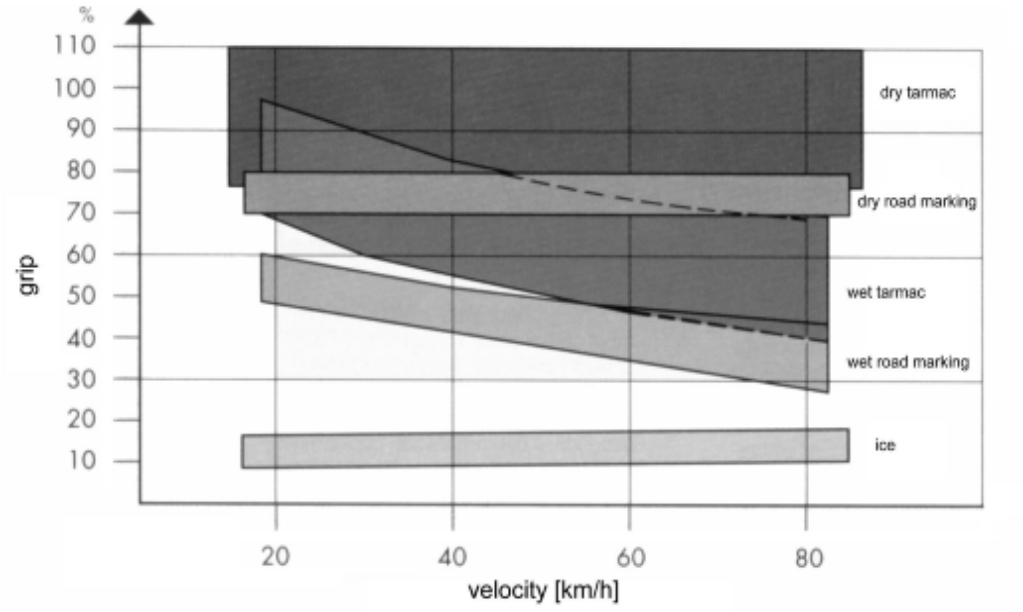


Figure 5.6: *Different grip on various road surfaces (Brendicke, Forke & Gajewski, 1995).*

The crossing of profiled road markings causes strong steering impulses leading to deviations from the nominal track of about 100 mm. In addition to that, profiled road markings prompt one-track vehicles to weave, with high speed there is even a tendency for permanent weaving (degree of attenuation D = 0).

High water level surrounding profiled markings may cause aquaplaning. In conjunction with the influence of air resistance this may cause the front wheel to raise and thus results in a considerable reduction of the front wheel load. For two-wheelers, each of the above mentioned factors increases the risk to suffer an accident or a collision (Brendicke, Forke & Gajewski, 1995; Brendicke, 1998; EEVC, 1993). But, the critical riding situations when crossing wet road markings may be minimised by concrete measures.

Parallel (longitudinal) grooves in the road surface mean a further risk for the riding stability of motorcycles. These grooves, which are supposed to avoid aquaplaning, cause the motorcycle to oscillate. On a scientific basis this has not yet been examined.

Although there are some measures and some are legalised the insufficient knowledge of the effects of parallel grooves on motorcycles should be improved by clear research designs and projects, in order to neutralise similar risky situations.

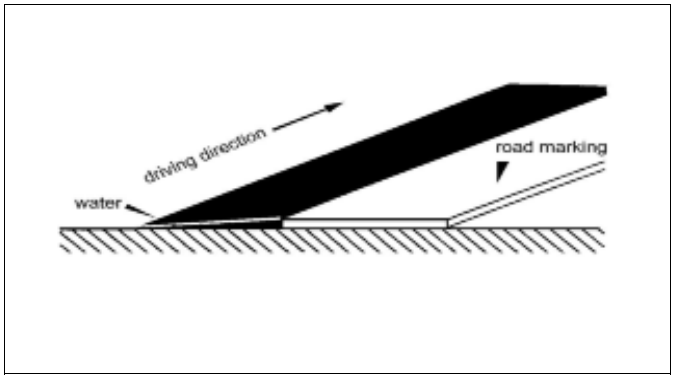


Figure 5.7. *Aquaplaning caused by road markings (Brendicke, Forke & Gajewski, 1995).*

"Sleeping policemen" and the use of cobbles belong to the measures of traffic calming and speed reduction, particularly in inner-city areas. Warning signs should be installed here in order to avoid instability for motorcycles when crossing these sections.

5.4.3. *Traffic signals*

Traffic lights at intersections, junctions and pedestrian crosswalks are adjusted to the acceleration and deceleration potential of two-track vehicles. For one-track vehicles this could lead to vehicle specific problems while approaching to signals which swich from green to red.

Under good road and weather conditions, motorcycle riders are able to decelerate sufficiently in front of a traffic signal with changing phases. However at bad road and/or weather conditions the period of time between green lights and red lights rather often is too short for one-track vehicles in order to realise a sufficient deceleration without risk. In addition to that the road surfaces in front of traffic signals are often equipped with road markings and have a lot of tyre abrasion which leads to higher skid danger at wet conditions compared with the other parts of the surface.

In Germany the regulation for switch phases follows the requirement of an adjustment for differnt approaching speeds (FGSV, 1992; *Table 5.2*), but is related normally to the dynamic and deceleration of cars. A variation should be useful in a relation to a longer yellow time phase of signals, which are normally only installed up to a speed regulation of 70 km/h in Germany.

Speed limit [km/h]	Yellow phase[s]
50	3
60	4
70	5

Table 5.2. *Dependence of yellow phase lasting and signed speed limit in Germany (FGSV, 1992).*

The deceleration of a motorcycle at wet road conditions can be calculated with an assumed approaching speed of v_0 = 70 km/h which means theoretically 19.44 m/s. On the basis of a average deceleration on a wet and dirty surface with a = 3 m/s^2 this results in a theoretical deceleration distance of: s = v_0^2/2×a = 19,44^2/2×3 = 63 m. The reaction time of 1 s and more forces the stopping distance to approx. 82.4 m (1 s).

One possible solution might be an appropriate speed limit for all vehicle categories and a realisation of a practically orientated switch phase for all traffic users. But the problem of deceleration of motorcycles in front of traffic lights has not yet been examined scientifically enough. Thus there is a need for further research.

5.5. Other road users - The perception of motorcycles and mopeds

Motorcyclists and moped riders share the roads with other road users, mostly car drivers. These other road users have to react to their presence in accordance with the official rules and to avoid collisions with them. In general this is not different from reacting to the presence of other cars, but there are some aspects making this more dificult in the case of motorcycles and mopeds. There are problems with the perception of motorised two-wheelers which have to do with their physical characteristics as well as (or even more) with the low expectation and low relevance of seeing a motorcycle or moped. This is discussed in more detail in the following paragraph.

To a certain extent these problems are made worse by the behaviour of the riders. Because of their smaller size, motorised two-wheelers can overtake where cars can not and this is one of the advantages of riding a two-wheeler. For some riders the motivation is to accellerate and go fast in relation to the conditions and/or in relation to other road users. Other road users are not likely to expect this behaviour or, in other words, they may not look for motorcycles and mopeds in places where they do not have to look for cars and they do not anticipate higher speeds and shorter approach times than for cars. Some of this behaviour of riders may be legal, some illegal. Even if it is legal, it may still be dangerous because other road users are not prepared for this. It will even be more dangerous if the rider him/herself does not recognise that other road users have these problems of perception.

Many accident studies show that the perception of motorcycles and mopeds is problematic and a contributory factor to collisions with cars. A typical example of such an accident is when a car driver comes from a side road, waits for a gap and then enters the main road at the moment a motorcycle is passing (e.g.Vis, 1998). Similar accidents can be found with mopeds (Noordzij, 1995).
This finding has led to a large number of studies to find out if the perception of motorcycles is worse than of cars, what are the reasons for poor perception and how this can be prevented. Wulf et al. (1989) present an extensive review of older studies into the contribution of poor perception to motorcycle accidents and into potential solutions. Donne (1990) gives a review of studies in Great Britain and remarks that poor perception of motorcycles may even be more important during night than daytime.

5.5.1. *Comparison between motorcycle and car*

Cercarelli et al. (1991) have made a comparison between accidents with motorcycles and with cars. They were unable to find significant differences between the two groups of accidents in the proportion of multi-vehicle accidents during day or night. This does not necessarily mean that the perception of motorcycles is not a special problem. It could also mean that the perception of cars is equally poor or that motorcycles have a special problem with single-vehicle accidents as well. The latter is not at all unlikely. Olson (1989) argues that poor perception of cars is also a contributory factor to accidents and that both cars and motorcycles are less likely to be involved in accidents with their headlights on during daytime. He also admits that in a number of car-motorcycle collisions the car driver could not see the motorcycle because it was hidden by other vehicles or by roadside objects. Because of the smaller size, this happens more often with motorcycles than with cars. He also mentions that on theoretical grounds it must be more difficult to estimate the distance and approach speed of motorcycles. His main point, however, is that conspicuity of motorcycles may not be worse than that of cars.
Wulf et al. discuss various explanations for the poor perception of motorcycles. The first two were also mentioned by Olson: the smaller size of a motorcycle compared to cars and the difficulty of judging distance and speed with a small frontal area or with only one headlight. A third explanation according to Wulf et al. is the small number of motorcycles in traffic. Because of this, car drivers do not expect to meet a motorcycle and therefore are less likely to notice or recognise a motorcycle. The lack of relevance of seeing a motorcycle for most car drivers is the fourth explanation. Objects in which an observer is interested or with which he/she is familiar, are more likely to be noticed. Wulf et al. even suggest that since the impact of a collision with a motorcycle is less severe for a car driver than with a car, a car driver is inclined to ignore the presence of a motorcycle.

Anyway, the comparison between motorcycles and cars is not very relevant as long as accidents with motorcycles can be prevented by improving their perception.

5.5.2. *Perception*

The discussions by Olson and Wulf et al. show that the perception of motorcycles in traffic is not a simple matter of being able to detect, i.e. to see and recognise a motorcycle. The most essential element of perception seems to be the direction of attention to relevant objects. Some objects are more conspicuous than others, i.e. they get more attention from observers. This is on the one hand a matter of attracting attention to an object by its physical properties (and its context), on the other hand a matter of noticing objects with particular characteristics which the observer is actively searching for. By experience, observers learn where and when to expect and look for relevant objects and how to recognise them. Car drivers, or road users in general, have developped a strategy to scan the road for the presence of other road users that may be relevant to them (i.e. they have to take action now or in the near future to avoid a collision). At this scanning stage, relevant other road users may be missed because the observer did not scan the right place at

the right time, or because the other road user could not be seen or was not recognised as being relevant. In a next stage, an accurate judgement has to be made of distance, speed of the other road user, of the chances of collision and of which of the road users is going to take action to avoid the collision. If this judgement is incorrect, a collision may result. Both stages will always contain some degree of uncertainty or inaccuracy, which road users may try to diminish by taking more time for observation. Given some uncertainty, road users can take more or less risk by making optimistic or pessimistic choices.

5.5.3. *Motorcycle studies*

Studies into the improvement of the perception of motorcycles have used very different methods. The visual presentation to observers has made use of photos as well as videos in the laboratory, or a real road with or without other traffic. Observers have been instructed to report seeing a motorcycle, its position, physical appearance, speed or to mention any relevant road users or choosing a reaction such as overtaking. These instructions have also been combined with other tasks that had to be performed at the same time. Each method has its own balance between the ease of collecting results and being as close to real life situations as can be. The experimental method comes close to reality if the observer is unaware of the purpose of the study, i.e. if the experiment does not change the observer's expectation and relevance of seeing motorcycles.

Wulf et al. give a summary of all the older studies. By daylight, a motorcycle is better noticed with headlight on or with a large, white fairing. Motorcycles with (blinking) warninglights are also better noticed during daytime. Reflective material, indicating the contours of the motorcycle is helpful in recognising a motorcycle at night. Other front lights in addition to or different from standard headlights do not give much improvement, or at least not as much as standard car headlights. Fluorescent clothing is effective during daylight, but not against a bright background. At night retroflective clothing gives little improvement.
Hole et al. (1996) present the results of a more recent study into the effects of headlight and clothing on the perception of a motorcycle. Observers had to react as soon as posibble when they noticed a motorcycle. Photoslides were shown, half of which showed a motorcycle in different positions, at different distances and against various backgrounds. Distance was found to be a major factor: at short distance the motorcycle was seen faster and more often and it did not matter whether the headlight was on or against which sort of background the motorcycle was shown. At longer distances, the results were much better with headlight on, but only against a complex background. What characterises a complex background is not quite clear. A similar study by Langham (s.a.) with videopresentations gave similar results. Hole et al. also found that the effects of bright or patterned clothing depended on the type of background.

The benefits of motorcycle headlights during daytime may be less if cars also have their headlights on. A laboratory study on this subject was done by Brendicke, Forke & Schäfer (1994). They showed pictures of traffic situations to observers who had to report which vehicles they had seen. The pictures contained motorcycles with headlight and or cars with or without headlights on urban as well as rural intersections and road sections. In urban

situations the motorcycles (with headlights) were seen as often as cars with or without headlights. Rural road sections gave the same result, although both cars and motorcycles were more often noticed than in urban situations. On rural intersections motorcycles were less often noticed than cars and even less so in combination with cars with headlights. Cars with headlights were again noticed equally often as without headlights (although both slightly less often than in other situations). There is no easy explanation why car headlights reduce the benefits of motorcycle headlights only in this situation.

5.5.4. *Discussion*

Factors such as small frontal area, small number of motorcycles in traffic, behaviour of motorcyclists (such as position on the road, speed, overtaking) which is different from car drivers, all seem to contribute to the problem of perception of motorcycles. But noticing and recognising a motorcycle at short distance is never a problem for observers who are prepared to look for motorcycles. Headlights will improve the perception during daytime, at least at longer distances and under most conditions. Large fairings, retroflective striping, bright clothing will do so only against certain types of background. However, the effects of background are not well understood.

With the experimental studies into the improvement of the perception of motorcycles, the question is if the results are valid in real life. In the case of motorcycle headlights, there is actual experience with compulsory use in some countries. Bijleveld (1997) has recently analysed Austrian data. His conclusion is that headlights give a reduction of 35% of severly injured motorcyclist from daytime car-motorcycle collisions. The matter of combined use of headlights by motorcycles and cars has also been adressed with real life data: Koornstra, Bijleveld & Hagenzieker (1997) used data from Norway and Denmark. In these countries compulsory daytime headlight use was first introduced for motorcycles and several years later for cars. They could not find a significant increase in car-motorcycle collisions. It is difficult to decide if these results are consistent with the experimental studies, which showed that motorcycle headlights improve the perception at longer distances, but not at short distance.

A general problem with the validity of most of the experimental results is that several options to improve the perception of motorcycles were shown to observers in random order. The only exception is a study by Hole&Tyrrell (1995). Their study is similar to the one by Hole et al. (1996), except that the motorcycles that were shown always had their headlights on or off. It was found that motorcycles with no headlights on were noticed far less often after a series of presentations in which all motorcycles had headlights on. In a follow-up study they were able to show this effect even if 60% of the motorcycles in the preceding series had headlights on. In other words, observers learned from experience to recognise motorcycles by their headlights. In real life this will be an advantage on condition that the majority of motorcycles use headlights.

Another problem with the validity of the experimental studies is that observers may have been aware of the purpose of the study and expected to see motorcycles. In real life, road users may not realise that motorcycles are relevant objects for them. In fact, this may even be one of the explanations for

the poor perception of motorcycles. However, there is no study that systematically looked into the effects of relevance of noticing motorcycles as compared to cars. The assumption has simply been: if one solution is relatively better in the experiment it will also be so in practice. In future studies relevance could be systematically studied e.g. by paying different bonusses for reporting motorcycles or by using groups of observers with different interst in motorcycles.

All the studies were concerned with the perception of motorcycles rather than mopeds. To a certain extent the problem will be the same. Mopeds too have a small frontal area, and their number is small compared to cars. Daytime headlights will most likely improve the perception of mopeds, the same as with motorcycles. However, the effect may be reduced since in general the quality of the lighting system of mopeds is at a lower level. The effectivenes of headlamps in improving the perception of vehicles depends on their intensisty and their background. During daylight a 1000 cd lamp will be very effective, but will cause glare during twilight. 100 cd will be sufficiently effective during twilight, without much effect in bright daylight. 400 cd seems to be a good compromise, which roughly translates to the use of a white 15 W bulb.
In general mopeds also have lower speed and a position to the edge of the carriageway and in dense traffic they may overtake cars left, right or between lanes. Apart from the lower speed, this behaviour may again contribute to the problem of perception of mopeds.

6. Review of accident studies and injuries

6.1. **Introduction**

In order to make any mode of transport safer it is first necessary to gain a proper understanding of the ways in which accidents happen and the causes of injury. Then it may be possible to take action to reduce the likelihood of accidents occurring and to minimise the severity of the injuries sustained when an accident happens.

In examining the available statistics on motorcyclists' accidents there are inevitable difficulties with different definitions used in different countries. For example, it is usual to categorise severity of injuries into slight, severe and fatal, but even "fatal" can be categorised differently in different countries, depending on how long after the accident death occurs. The distinction between "slight" and "severe" is much less clear, since for routine accident reporting the judgement is generally made by the police, with no medical qualification. For the most part, injuries requiring hospitalisation are likely to be defined as severe, while those which do not as slight, unless they involve fractures needing only outpatient treatment, but there is very considerable latitude in categorisation. Where injuries are categorised by medical staff, this report will classify severity according to the widely used Abbreviated Injury Severity (AIS) scale, ranging from slight injuries at AIS 1 to almost certainly fatal injuries at AIS 6. There are likely to be inconsistencies between medical and police assessments of injury severity, of course, and there is also a high level of under reporting of motorcycle accidents (Lynn, 1990).

Global statistics for "motorised two wheelers" encompass machines ranging from motor-assisted pedal cycles to multi-cylinder bikes with more power available than the average car. Naturally, the different types of machine will have different types of use, and different users, so that they are also likely to have different types of accident. Categorisation by size is rare in the available literature. It is often not clear whether all motorised two-wheelers are included or whether the data exclude mopeds or scooters. Because of this, this report focuses on full-sized motorcycles with engines over 50cc. If the conclusions are also relevant to smaller machines the point will be made.

The rest of this report considers first accident and injury rates in different countries, to establish the size and seriousness of the motorcycle safety problem. Consideration is then made of accident causes and configurations to determine which risks may be reduced. Finally, injury mechanisms are identified, pointing to ways in which injuries might be decreased.

6.2. **Accident causes and configurations**

6.2.1. *Object struck by the motorcycle*

6.2.1.1. General

The EEVC review of motorcycle safety (1993) identified that the object struck most frequently, in a half to two thirds of collisions, is a car, and in a quarter to one third of accidents, where the struck object is known, the motorcycle did not impact with any other vehicle. Carré & Filou (1993) found that the great majority of two wheeler injury accidents, 7% involve another vehicle (1093 out of 1554 accidents in our sample) and this was generally a car.

It is interesting to note that these findings are similar to those of Preusser (1992) for the US as *Table 6.1*. below shows.

Motorcycle crash type	Single-Vehicle	Multiple-Vehicle	All	
	Crashes	Crashes	Crashes	%
Ran off road	831	26	857	(41.3)
Ran traffic control		375	375	(18.1)
Oncoming		225	225	10.8
Left turn oncoming		176	176	8.5
Motorcyclist down	83	69	152	7.3
Run down		69	69	3.3
Stopped/stopping		66	66	3.2
Road obstacle	49	2	51	2.5
Lane change		28	28	1.4
Cut-off		25	25	1.2
Other/unknown	33	17	50	2.4
All	996	1078	2074	100

Table 6.1. *Distribution of motorcycle crash types by single-vehicle and multiple-vehicle crashes*.

A much more recent study showed that little has changed (Otte et al., 1998); some 60% of accidents were collisions with cars and 27% involved only the motorcycle. A different study by Otte (1998) showed that most motor scooter accidents occur within built-up areas, 89% compared with 79% for motorcycles. As a result there are more scooter accidents at junctions, 57% compared with 51% for motorcycles.

Otte noted that it is surprising that 33% of scooter accidents were with the scooter alone, compared with only 21% for motorcycles.

That the figures have remained comparable over such a long period suggests that in spite of changes to the motorcycle the accident pattern remains the same. Therefore, in designing protection for motorcyclists it is obviously sensible to concentrate on collisions with cars and on contact with the road; this is particularly relevant to helmet design.

6.2.1.2. Collisions with crash barriers

Brailly (France, 1998) has studied accidents whereby a motorcyclist has collided with a crash barrier. The results showed that the risk of fatality per accident is five times as great as the national rate for all motorcycle accidents. The study was in two parts and comprised an analysis of national statistics recorded between 1993 and 1996 and a site analysis of 240 accidents that occurred on non urban roads and involved at least one motorcyclist and an impact with a crash barrier. The study showed that a yearly average of 63 fatals, 114 serious and 118 slight cases resulted from impacts into a crash barrier. These account for 8% of all motorcycle fatalities and 13% of fatalities on rural (outside of towns) roads. More than 30% of the fatalities amongst motorcyclists killed by hitting an obstacle on roads outside of towns were caused by motorcycles impacting crash barriers.

The most frequent location of these accidents was on tight bends with a radius of typically less than 250 m. Accidents on bends took place mainly on the outside lane irrespective of the direction of the bend (left or right hand) and irrespective of the road category. However, accidents with barriers were far more frequent on right-hand than on left-hand bends irrespective of road category and there was no evidence to suggest that motorcyclists were more at risk on roads leading onto motorways, where it is a common practice to put a barrier, than on other types of road.

An analysis of the accidents showed that the rider contacted the barrier in about a half of the cases but was considered not to have contacted the barrier in about a third. This shows that a shield covering the barrier may be beneficial for about 50% of motorcycle accidents into a barrier. Safety zones at area of high risk was also proposed.

6.2.2. *Speed*

The EEVC report (1993) on motorcycle safety shows that the mean motorcycle speed is not high and is in the range 30 to 45 km/h and the mean speed for the car is very low and typically 15 km/h. Mopeds impact speeds tend to be lower and the median is typically 30 km/h or less.

As with all vehicle collisions, the risk and seriousness of injury increases with impact speed. Nevertheless 90% of all injuries tended to occur at less than 60 km/h and some 85% of AIS I to 3 injuries at less than 50 km/h. Otte (1998) showed from a study of 402 motorcycle accidents in the Hannover region that the mean speed of the motorcycle was 40 km/h and that 80% of collisions occurred at an impact speed of 62 km/h or less for the motorcycle. The report also shows that there is frequently a second impact, 143 cases, and that 80% of these occur at 40 km/h or less. *Figure 6.1.* below shows the cumulative frequency of speed for the first and second impact taken from Otte's paper.

Otte's recent data is very similar to what was previously reported (EEVC, 1993), albeit with a trend for a slightly higher collision speed. It is clear that the majority of motorcycle collisions continue to take place at relatively low speeds and, although, injury severity increases with impact speed, a substantial proportion of serious injuries, and fatalities, occur at modest speeds where there is an opportunity of providing protection.

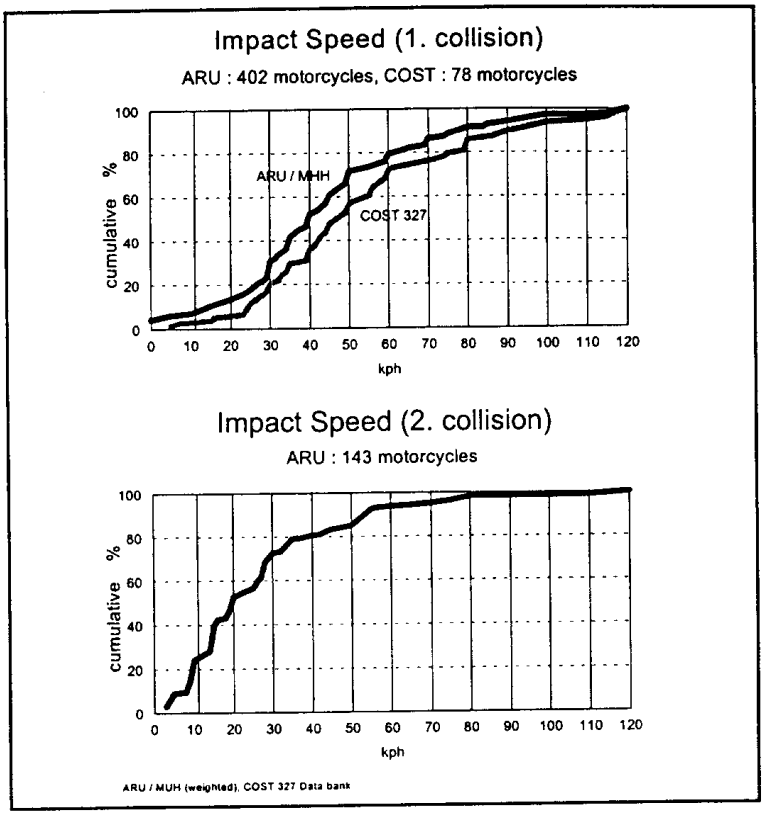


Figure 6.1. *Distribution of motorcycle impact speed (Otte et al., 1998).*

Otte (1998) also showed that scooters have a lower relative impact speed than motorcycles with 80% of accidents occurring at less than 40 km/h compared with motorcycles for which 50% occurred at a relative speed of greater than 40 km/h.

6.2.3. *Impact configuration*

Because a motorcycle is generally relatively light in relation to the object it is impacting, and loses stability once struck, the dynamics of motorcycle collisions tend to be more complex than for four wheel vehicles. The rider's trajectory is more complex and variable than that of a vehicle occupant. After impact the bike tends to rotate about the impact point, so that evidence relating to the points of impact on both motorcycle and struck vehicle tends to be more reliable than information about the angle between bike and struck vehicle immediately before impact. The findings of the EEVC report (1993) quote Otte and Whitaker who both found that over 80 percent of impacts are within ±20 degrees of the front of the motorcycle.

Accident investigators tend to categorise impact directions by clock face angles, which limits the accuracy of angular information to 30 degree slots. Thus precise directional distributions are often not available. Also quoted in the EEVC report 1993 is Sporner et al. (1989) who found the angular distribution shown in *Figure 6.2.*, which is repeated here to show the difference between light (including mopeds) and heavy motorcycles. There is a high concentration around the motorcycle front. Larger and heavier motorcycles in particular are likely to collide frontally into another vehicle, while the slower mopeds are relatively more likely to be hit by the opposing vehicle from the side or rear. Sporner et al. also found that the first contact area was the front wheel in 39 percent of cases, plus front wheel/fork in a further 27 percent, the engine, tank and rider's leg in 29 percent, and the motorcycle rear in only 5 percent.

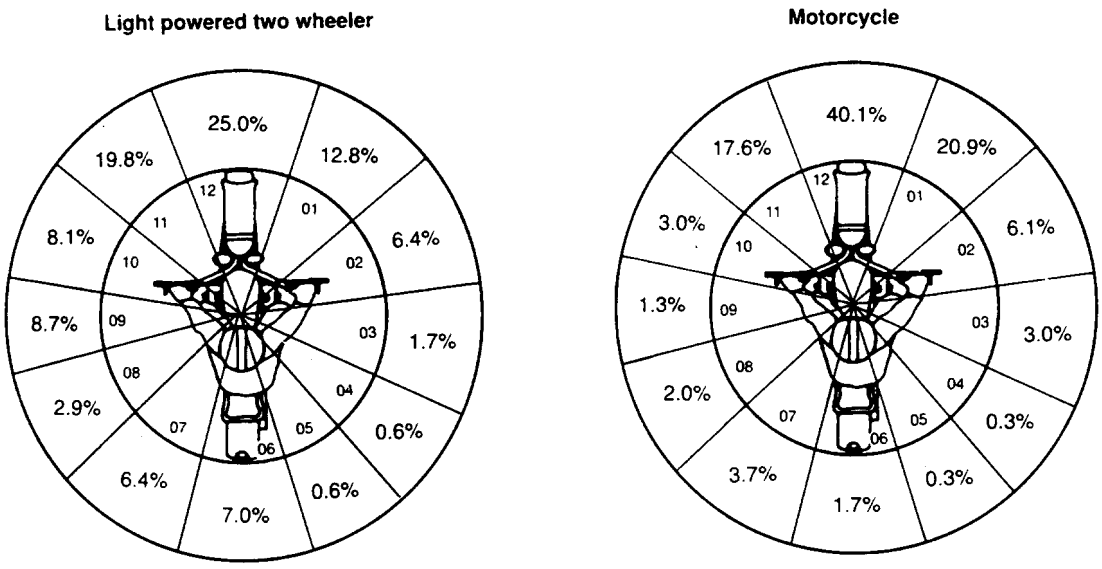


Figure 6.2. *Angular distribution of first impact (from EEVC 1993).*

A statistical analysis (Carré & Filou, 1993) was made on the basis of an INRETS file of 1/50th of the injury accidents which occurred in France in 1991 and 1992. The accidents involving a two-wheeler represent 26% of all the accidents recorded in this sample (1448 / 5664). The 1557 two-wheelers have been divided into four categories, according to the type of vehicle: bicycles (235), mopeds (624), light motorcycles (155) and powerful motorbikes (543).

The individual driver manoeuvre at the moment the accident occurs and the part of the vehicle struck in the collision, characterise the type of two-wheeler within the group as a whole. For mopeds the characteristic manoeuvre was a change of direction ,17% and they were generally hit in the front, 68%. Light and heavy motorcycles were frequently involved in an accident when overtaking ,15% and 17% respectively; the more powerful motorbikes were more often impacted in several places, 23% or on their right side 8%.

The differences between riders of high-power motorcycles and the two-wheeler rider group as a whole were significant. This first group was more often involved in single-vehicle accidents, 15%, and in accidents with more than two vehicles (27%); the accident was due to a loss of control 16% and occurred on a motorway, 7%, or a major road, 22%; there was doubtless a correlation between these results and the speeds at which these motorcycles were driven.

Otte's team (1998) has very recently investigated and reconstructed a sample of 402 motorcycle traffic accidents in the Hannover region. Accidents were categorised by type, and location, and related to MAIS and head injury by AIS. *Table 6.2.* indicates the categorisation by impact configuration, and it can be seen that the most frequent occurrences are with the motorcycle running obliquely into the front or rear corner of the car (or other four-wheeled vehicle) 23.7%, the bike and car in frontal impact with each other 16% and the motorcycle impacting the side of the car 5.2%. Accidents not involving a collision with a four wheeled vehicle were grouped together and include cases where the motorcycle simply lost control; this group accounted for 38% of the total.

Frequency by Collision Type and Distribution of Head Injury Severity by AIS and MAIS

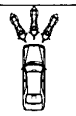
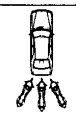
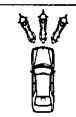
Collision Types		ARU / MUH				COST 327			
		n=400	AIS Head 0	1	2+	n=60	AIS Head 0	1	2+
		n=402	MAIS Motorcyclist 0	1	2+	n=61	MAIS Motorcyclist 0	1	2+
		100%	----------100%----------			100%	----------100%----------		
1		4.6%	85.3%	12.1%	2.6%	1.7%	100%	-	-
		4.5%	-	76.2%	23.8%	1.6%		100%	
2		16.0%	85.9%	8.2%	5.9%	6.7%	-	25.0%	75.0%
		16.2%	-	71.0%	29.0%	8.2%	-	25.0%	75.0%
3		5.2%	88.0%	4.8%	7.2%	16.7%	70.0%	10.0%	20.0%
		5.1%	-	84.1%	15.9%	16.4%	-	77.8%	22.2%
4		23.7%	74.1%	13.2%	12.7%	31.7%	57.8%	21.1%	21.1%
		23.9%	3.7%	62.4%	33.9%	31.1%	-	50.0%	50.0%
5		12.3%	80.1%	16.0%	3.9%	5.0%	33.3%	66.7%	-
		12.2%	6.0%	68.3%	25.7%	4.9%	-	100%	
6		-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
7		38.2%	83.6%	7.6%	8.8%	38.3%	26.1%	30.4%	43.5%
		38.1%	11.3%	60.3%	28.4%	37.8%	4.5%	40.9%	54.6%

Table 6.2. *Categorisation of collision types (Otte et al., 1998).*

The EEVC report concluded that there was a preponderance of serious injuries produced with the motorcycle either at roughly 90 degrees to the face of the impacted vehicle, or at relatively small angles to it as when the motorcyclist runs into the side of a vehicle pulling out or overtaking, or when a vehicle runs into the side of a motorcycle. Otte's more recent analysis agrees only in part with these findings (Otte, 1998). Otte indicates that some 55% of accidents where the MAIS was 2 or greater occurred in impacts where the motorcycle impacted the four wheeled vehicle at roughly 90 degrees to the side (category 3, *Table 6.2.*) or at a slightly more oblique angle into the front or rear corner. Twenty four percent of this group were from impacts of the car into the side of the motorcycle.

Otte has provided the only recent study of motorcycle accidents and there is a clear need for more accident studies. Moreover, the available data relate only to injury accidents. It is also desirable to know about accidents in which injury was avoided in order to identify those aspects which might prevent injury. In particular, there is a lack of reliable information on impact angles, though in the literature generally there seems to be a fairly clear distinction between glancing and head-on impacts. But, whatever the initial heading angle, it is clear that the impact points are concentrated at the front of the motorcycle, acting primarily within the front quadrant. This is supported by Carré & Filou (1993) who found that two-wheeler accidents were characterised y their extreme severity and that the most serious types of accident were caused by head-on collisions, loss of control and overtaking.

The EEVC report showed that over 90% of casualties with serious injuries sustained them while still in contact with their machine, and that only 10% occurred during body contact with the road, kerb or ground. This offers hope that it may be possible to reduce injuries by appropriate design of the machine.

6.2.4. *Solo accidents: motorcycles and mopeds*

The EEVC report (1993) found that a quarter to a third of all motorcycle accidents are solo accidents without collision with another vehicle. Again the only recent report is that of Otte (1998) who found that some 19% were in this category both for the UK and Germany. This is a large proportion of accidents albeit slightly lower than previously indicated. It should be noted that these figures include situations where the motorcyclist was avoiding collision with another vehicle, so not all solo accidents can be ascribed to the fault of the motorcyclist. Scooters have a greater solo accident rate at 33% (Otte, 1998).

Carré & Filou (1993) studied trends in TWMV accidents in France. They found that despite a trend for improvement during the years of the study, a specific characteristic of motorcycle accidents was the prevalence and the severity of accidents in which the motorcycle was the only vehicle involved. More than one third of the motorcyclists killed (39%) were in this type of accident. For moped drivers, the proportion of deaths in this type of accident was half as much (17%).

Nearly 30 per cent (15) of all solo accidents involve the motorcycle falling over onto the road surface, generally after a loss of road adhesion. In nearly all of these cases the injuries caused are not very serious with an AIS less than three.

Wearing protective clothing, not only a helmet, is very helpful minor injury in this type of accident. If the motorcyclist crashes into roadside furniture, e.g. metal posts of crash barriers, the injuries are likely to be more severe.

6.3. **Patterns of injury**

6.3.1. *General injury distribution and rider trajectory*

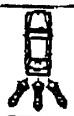
The EEVC report (1993) concluded that the most frequently seriously injured parts of the body were the legs, 40 to 60% of all injuries, the head typically 25% and the arms 20 per cent. Eighty per cent of casualties suffered some injury to the leg, 56 per cent to the arm and 48 per cent to the head.

However, the head injuries were more serious, at an average AIS score of 2.4, than leg injuries, AIS 1.9, or arm injuries, AIS 1.5. Thoracic and pelvic injuries were not frequent, but those recorded were often severe. Thus it was concluded that prevention of head injuries was a high priority, but nevertheless it was also thought important to pay attention to leg and arm injuries.

It is interesting to compare these conclusions with the findings of Otte's recent study, (1998). However, Otte's study describes a data base that comprises data from three centres, Hannover, Munich and Glasgow. The data base was compiled for "COST 327" where the emphasis was on motorcyclists who had sustained a head impact although this data base is frequently compared with a more random sample of cases collected by the Hannover team.

Table 6.3. gives a distribution of injury types with collision types. Collision type 1 was infrequent in the COST data base and generally only the legs and arms were injured. This indicates that if the car struck the side of a motorcycle then the main injuries were to the extremities.

In frontal collisions, type 2, all of the casualties suffered a head injury usually from impact with various parts of the car such as the bonnet ,windscreen and the roof. Some 67% of riders in collision with the rear of a car suffered a head and neck injury and 100% in collision with the front, suffered a head injury. A leg injury was most likely to be sustained in collision types 3 and 4 where 90% of riders suffered a leg injury. Collisions with objects, type 7, are characterised by frequent head and leg injuries. In these accidents the leg was often caught between the motorcycle and the car, when the motorcycle swung toward the car during the impact, or between the motorcycle and the road surface.

Collision Types		total n=60	Injured Body Regions of Motorcyclists						
			Head	Neck	Thorax	Arms	Abdo-men	Pelvis	Legs
1		1.6%	-	-	-	100%	-	-	100%
2		8.2%	100%	25.0%	50.0%	50.0%	25.0%	50.0%	50.0%
3		16.4%	30.0%	20.0%	30.0%	60.0%	-	20.0%	90.0%
4		31.1%	42.1%	31.7%	36.8%	68.4%	10.5%	26.3%	84.2%
5		4.9%	66.7%	66.7%	33.3%	-	33.3%	-	33.3%
6		-	-	-	-	-	-	-	-
7		37.8%	73.9%	17.4%	43.5%	65.2%	13.0%	17.4%	82.6%

The total number of all injured body regions is more than 100%, because motorcyclists often have more than one injury in more than one body region.

Table 6.3. *Distribution of injury types with collision types*.

Table 6.4. gives a comparison between the COST data base and 338 cases from the Hannover data base collected during the same period.

In the Hannover data base 18.4% of helmeted riders sustained a head injury and 12.7% suffered a neck injury whereas in the COST date base 55.6% suffered a head injury and 205 sustained a neck injury. This is to be expected given that the main criterion for inclusion in the COST data base was evidence of a head impact, though not necessarily an injury. However, what is interesting is that in both data bases well over 70% of riders sustained a leg injury, which indicates that leg injuries are a very frequent occurrence regardless of the overall injury distribution.

Also of particular interest is that in the COST data base 80% of those motorcyclists with an injury MAIS 3 or greater sustained a head injury. Fatally injured casualties tended to be multiply injured with 72.7% head, 36.4% neck and 63.6% thorax injuries; the cause of death was usually attributed to the head injury.

Head Injury Severity					
ARU / MUH					
AIS Head	**n**	**%**		**n = 96 with head injury %**	
uninjured	238	80.4	---- 100 % ----		
AIS 1	37	9.9		50.5	---- 100 % ----
AIS 2	48	8.1		41.3	
AIS 3	1	0.1		0.6	
AIS 4	4	0.8		4.3	
AIS 5	3	0.4		1.9	
AIS 6	3	0.3		1.4	
total	**334**	**100.0**		**100.0**	

COST 327					
AIS Head	**n**	**%**		**n=51 with head injury %**	
uninjured	38	42.7	---- 100 % ----		
AIS 1	22	24.7		43.2	---- 100 % ----
AIS 2	12	13.5		23.5	
AIS 3	2	2.2		3.9	
AIS 4	3	3.4		5.9	
AIS 5	5	5.6		9.8	
AIS 6	7	7.9		13.7	
total	**89**	**100.0**		**100.0**	

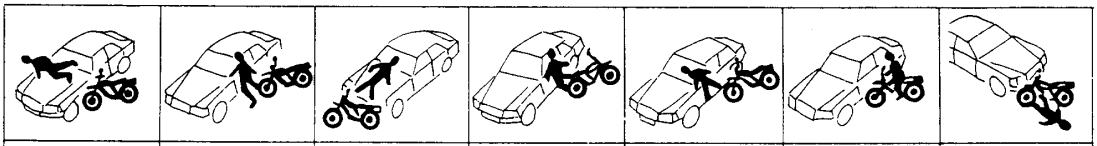
Tab. 4: Head injury severity
Source 1 : ARU / MUH
(100% = 334 motorcyclists, weighted, 4 motorcyclists with AIS Head = unknown)
Source 2 : COST 327 Data bank
(100% = 89 motorcyclists, 1 motorcyclist with AIS Head = unknown)

Table 6.4. *Injured body regions, COST 327 and Hannover data bases compared.*

Otte (1998) also showed that scooter riders have a greater risk of head injuries, 24%, than motorcycles riders, 18%, but the severity is generally lower for scooter riders 3.7% AIS2 and greater compared with 9.2% for motorcycle riders.

Little information has been published since the EEVC review as to the trajectory of the motorcyclist during an impact. The following is an extract and has been included here as the only source of such information.

When the motorcyclist is in collision with a four-wheeled vehicle, Otte et al. (1982) has categorised the interaction as shown in *Figure 6.3.*, where it can be seen that it is relatively rare for the rider to fly over the vehicle without impact (8.8 per cent), though in a further 11.4 per cent of cases the rider landed upon the vehicle, rather than impacting it fully. In cases IV, V and VI, which account for 54 per cent of the total, there is direct impact. It should be noted that in the Table the diagrams are illustrative only, so that the impact can be with the front or rear, as well as the side. Category VH refers to situations where the motorcyclist has already fallen prior to impact by another vehicle.



I	II	III	IV	V	VI	VII
Flight without impact	Slipped off the collision partner	Thrown upon the collision partner	Impact on the collision partner with change in direction	without change in direction	Direct impact and seated	Indirect collision
8.8	3.3	11.4	25.4	16.9	11.8	21.2

% frequency

Figure 6.3. *Categorisation of motorcycle rider trajectories.*

Overall from the studies it appears that leg injuries occur mainly when the leg becomes trapped between the motorcycle and the car in acute angled impacts, and in impacts to the front and rear where the legs are likely to make direct contact with the opposing vehicle. Head injuries occur in head-on impacts where the motorcycle is at roughly 90° to the front or side of the target vehicle, usually a car, and the rider is thrown forward over the handlebars into the side, front or rear of the vehicle.

It is clear that head and leg injuries are the two most important body regions for injury prevention and reduction, therefore they are considered separately below. Arm injuries are frequent and are generally less serious, although they can cause permanent disability: as yet no effective way to address the problem has been proposed, beyond the limited protection offered by good clothing.

6.4. **Head injuries**

6.4.1. *The effect of speed, object struck and head impact location on injury type and severity*

In 1981, work carried out by Vallée et al. (1981) showed that although the highest proportion of collisions are with cars, in fact they account for only 33% of the objects struck by the rider's head - 40% for moped riders and 22% for motorcyclists - this is because the rider's head often does not strike the collision vehicle, but the trajectory of the rider after collision brings the head into contact with other objects, often the road, motorcycle or roadside furniture. This fact is supported by *Table 6.5.* below, which shows that the environment represents the major proportion of contact surfaces that the head hits.

The study also classified obstacles according to their shape and their stiffness and according to whether a moped or motorcycle was being ridden *Figure 6.5.* The objects of types 4-8 are found on vehicles, whereas those of types 1-3 are found from ground contacts; there are two types of objects, "plane" (types 3, 5, 6) and "corner" (types 1, 7). These objects were classified according to a criterion where the sum of the head AIS is raised to the cube and the results are given in *Figure 6.5.*

Obstacle Type	Object struck by Head/Helmet	Moped riders		Motorcyclists	
		N	%	N	%
Other vehicle	Sheet metal	13	(8)	4	(4)
	Stiff structure	32	(20)	12	(11)
	Glazed area	17	(11)	3	(3)
	Tyres/wheels	3	(2)	5	(4)
Others	Ground/road	87	(54)	69	(63)
	Fixed, stiff structure	7	(4)	16	(14)
	2-wheel machine	2	(1)	1	(1)
Total		161	(100)	110*	(100)

*Excluding 22 cases where object hit was not known

Table 6.5. *Nature and type of obstacles struck by rider's head or helmet (Vallée et al., 1981).*

By using the criterion $(\sum AIS)^3$, Vallée et al. attempted to allow for the rapid rise in injury cost with increasing $\sum AIS$. The report suggested that the increase in this value as a function of the severity of the injury is not linear but cubic. This method is not widely accepted, a point which should be noted when regarding *Figure 6.5.*

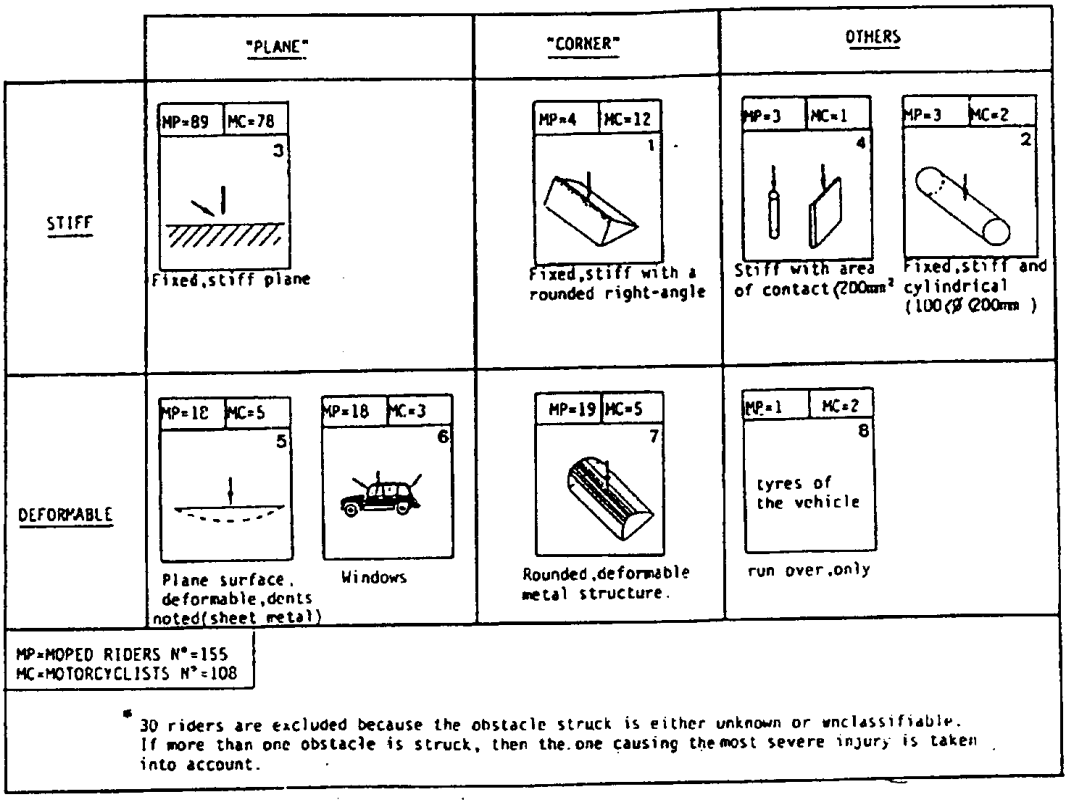


Figure 6.4. *Classification of obstacles according to their shape and their stiffness and according to the type of rider (Vallée et al., 1981).*

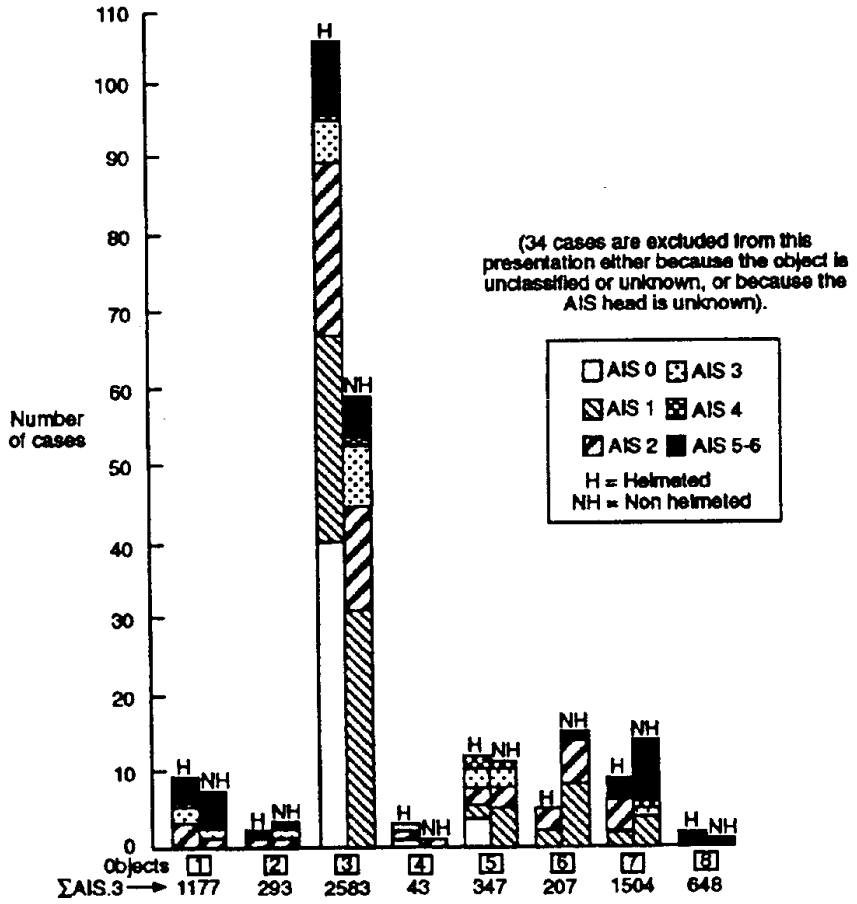


Figure 6.5. *Frequency and severity of head injuries according to obstacle type struck with and without helmet (Vallée et al, 1981).*

From *Figure 6.4.* it is clear that "plane" type fixed and stiff objects (type 3-ground) give the highest value in terms of $(\sum AIS)^3$ and of the "corner" types (7 and 1), type 7 has the higher $(\sum AIS)^3$, although it has a smaller percentage of AIS>3. Other surfaces were less significant - either they happened infrequently (as with 'run over'- type 8 and types 4 and 5) or they generally caused only slight injuries, as was the case with window or windscreen impacts (type 6).
Figure 6.4. also shows that moped riders are substantially more likely to strike some part of a car, probably because the impact speed is generally lower and, therefore, the rider is less likely to be thrown over the car. This is consistent with Sporner et al. (1990) who note that, for 90 degree impacts into the side of a car, the motorcyclist's head is at a very similar level to the roof edge or cant rail of the car. The seriousness of the head injury can be very dependent on just where the head strikes, or whether the rider is launched above the car cantrail, and this depends on the design of the bike. A moped is usually a step-through and the rider is less likely to be launched into the air by this design.

Otte's much more recent analysis (1998) indicated that 43.5% of head injuries were soft tissue, 10.4% were concussion and 13.1% were fractures and brain injuries, other than concussion, accounted for 27.8%. The columns 'Total head injuries' of *Table 6.6.* give the details.

Figure 6.6. shows the estimated speed of head impact for each type of injury. It can be seen that 80% of soft tissue injuries occurred at a head impact speed of up to 55 km/h and 80% of concussions at 70 km/h or less and are thus characterised by a low head impact speed, whereas 80% of fractures were sustained at speeds of up to 90 km/h, with 60% occurring at above 40 km/h.

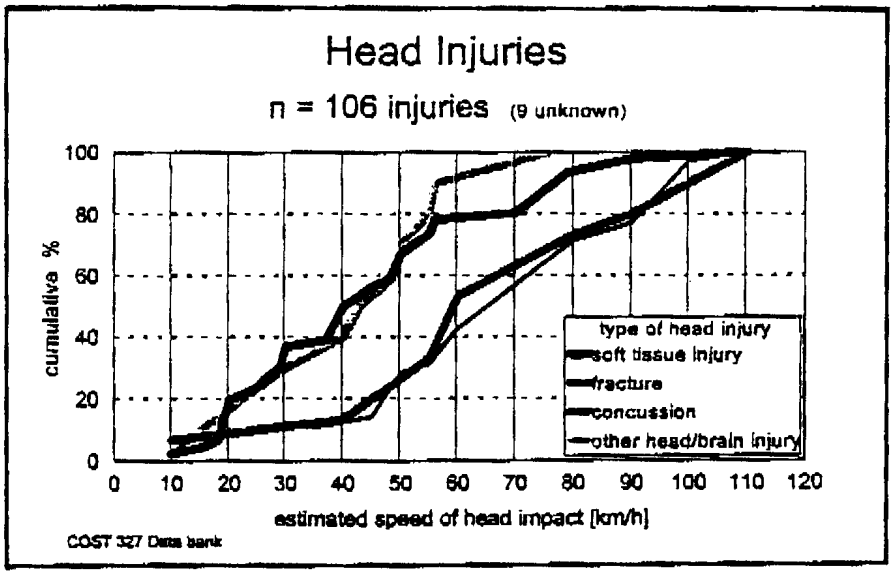


Figure 6.6. *Estimated speed of head impact for each type of head injury (100%=all head injuries of one type with known head impact speed. Source COST 327 data bank.*

Otte also looked at the link between injury location and head impact speed and showed that lateral head impact occurred mainly at a high impact speed with 80% in the range 50 km/h to 93 km/h; there were no lateral impacts below 50 km/h. Facial injuries occurred at lower speeds, 80% at 74 km/h or below.

Object shape influenced the injury type. Most (70%-75%) of the soft tissue injuries and concussions were caused by round objects whereas almost 80% of other brain injuries, such as haematoma, cerebral contusions and cerebral compressions were caused by round and flat objects; edge objects caused only 3.1% of this injury type. *Table 6.6.* gives full details.

It should be noted that of all those casualties who suffered a head impact 55% sustained a head injury and 20% a neck injury.

Type of head injury	Round		Edge		Flat		No information		Total head injuries	
	N	%	N	%	N	%	N	%	N	%
Soft tissue injury	34	68.0	2	4.0	3	6.0	11.0	22.0	50	43.5
Skull fracture	4	57.1	-	-	3	42.9	-	-	7	6.1
Facial fracture	6	75.0	-	-	2	25.0	-	-	8	7.0
Concussion	9	75.0	-	-	1	8.3	2	16.7	12	10.4
Brain injury	18	56.2	1	3.1	7	21.9	6	18.8	32	27.8
Other head injury	5	83.3	-	-	-	-	1	16.7	6	5.2
Total	76	66.1	3	2.6	16	13.9	20	17.4	115	100.0

Table 6.6. *Shape of the object struck by the head and type of head injury (Otte, 1998).*

6.5. **Leg injuries**

Since the EEVC 1993 report the only study that describes the problems of leg injuries is that of Otte 1996. Much of what is contained below is from Otte's report but it is was considered important to give a very brief extract from the EEVC report for comparison, as follows:

Mackay (1985) suggests two general mechanisms of leg injury, direct impact with the other vehicle and crushing between the motorcycle and the other vehicle, and this distinction between a direct blow and trapping between the two vehicles is clear in many injury studies, for example Hurt et al. (1981a) and Nyquist, Savage & Fletcher (1985), who document the production of rider nearside lower leg injuries due to trapping between motorcycle and the other vehicle, or the pinching action experienced when the cycle 'slaps' against the car. Moreover, Hight, Siegel & Nahung (1976) have extended this distinction to three categories in a study of 126 injured motorcyclists from California:

Direct blow to leg:

i rider remained with motorcycle: 83 % received moderate to serious leg injuries, mainly to knee and femur, often through the patella.

ii rider ejected during impact: 72 % received moderate to serious leg injuries from impact with the car bonnet (hood) or ground; generally much less severe than in i or iii.

Trapping of leg:

iii rider and motorcycle deflected by the impact to travel along a different line: 93 % received moderate to serious leg injuries from a glancing blow from the vehicle or object that they were trying to avoid; crushing and retarding forces transmitted to and through the leg, causing multiple fractures of the femur, tibia and fibula and sometimes traumatic amputation.

However, many of the above studies are somewhat old and the only recent study is that of Otte, therefore, this was examined in detail to determine how the current patterns of leg injuries differ from those described above. Otte completed this study to analyse the risk to motorcyclists of leg injuries in

accidents and to find the opportunities for leg protection by comparing risks for those injured on machines with and without leg fairings. Each injury was analysed by type, leg area and severity (AIS) and correlated to the impact situation with impact direction, impulse angle, load and characteristics of kinematic behaviour; 258 motorcyclists accidents with cars were analysed for leg injuries.

The statistics show that motorcycling in Germany is becoming safer and devices, such as crash helmets and protective clothes contribute towards this reduction in the injury risk. However, whilst improvements in helmets have contributed to a reduction in head injuries, there is no reduction apparent for the leg injuries. Otte's study confirms previous findings, that some 60% of the motorcyclists in accidents sustained leg injuries, mostly fractures of injury severity AIS 2-3.

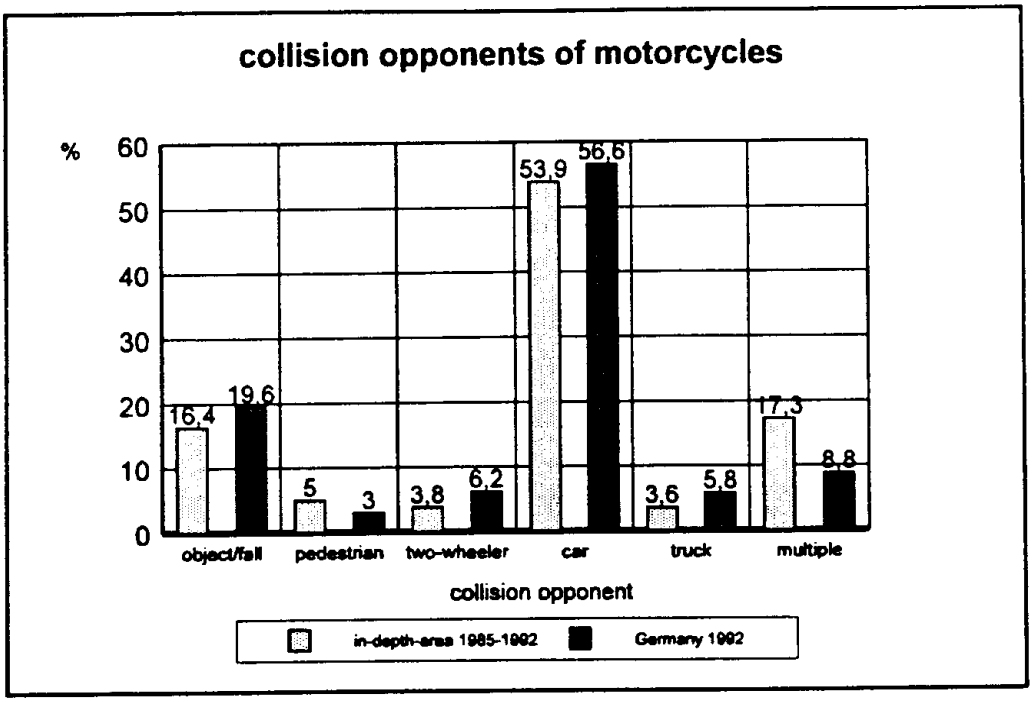


Figure 6.7. *Distribution of collision opponents of 496 motorcycle accidents correlation between research area and situation in the whole country.*

To establish the leg protection given by fairings the analysis of leg injuries was analysed by type, severity and location. Collisions of a motorcycles with a car or solo accidents and collisions with solid objects are included in the analysis although collisions with trucks are excluded because of the variation and complexity of the mechanisms.

Table 6.7. below gives the results of the analysis, which shows that the injury severity of the legs is reduced by the presence of a leg fairing. Of casualties riding with a fairing 28.3% sustained a leg injury compared with 33.7% for those without a fairing and furthermore the severity of the leg injuries that did occur was less with only 14.2% with a fracture on the faired machines compared with 23% on the unfaired motorcycles.

	Total		With fairings		Without fairings	
	496	100%	136	100%	360	100%
Severity of leg injuries						
AIS0	148	29.8%	46	33.7%	102	28.3%
AIS1	265	53.3%	76	55.6%	189	52.5%
AIS2	59	11.8%	9	6.6%	50	13.8%
AIS3	22	4.5%	5	3.6%	18	4.9%
AIS4	1	0.2%	0	0.2%	1	0.2%
Type of leg injuries						
Soft tissue isolated	271	79.1%	74	85.8%	196	77.0%
Fracture	78	20.9%	16	14.2%	62	23.0%
Cause of leg injuries						
Impact (car or object)	162	48.6%	47	51.9%	124	47.5%
Fall	127	35.4%	31	34.7%	87	35.7%
Both fall and impact	59	16.0%	12	13.4%	47	16.8%

Table 6.7. *Leg injuries: cause, type and severity by AIS.*

This trend of reduced risk of fracture for motorcyclists using machines with leg fairings is repeated in all collisions with cars or in solo accidents and for various collision types as detailed in *Table 6.8* in which Otte gives the results for 7 collision types. Otte claims that these statistics show that even standard fairings provide substantial protection to the legs.

Otte's analysis of head and thorax injuries are given in *Table 6.9.*

The presence of fairings has little effect on the overall incidence of head and thorax injuries ; 19.3% with and 18.1% without fairings for the head and 25.9% with and 22.8% without fairings for the thorax. However, Otte makes the point that a change in the rider kinematics is observed with leg fairings and this accounts for the different distribution of injuries among the collision types. He concludes this analysis by claiming the potential effectiveness for leg protectors as:

engine bars:	20% of the injuries can be avoided or reduced
lateral impact protection:	44% effectively frontal impact protection
frontal impact protection:	68% effectively

Collision type	Type 1 & 2	Type 3 & 4	Type 5 & 6	Type 7
With leg fairings				
Number of collisions	17	33	20	19
Severity of leg injuries				
AIS 0	63.9%	68.6%	88.4%	56.5%
AIS 1	80.8%	88.9%	97.3%	65.5%
AIS 2	8.0%	7.3%	-	26.0%
AIS 3	11.3%	3.8%	2.7%	8.4%
AIS 4	-	-	-	-
Type of leg injuries				
Soft part only	80.8%	91.1%	89.2%	73.9%
Fracture	19.2%	8.9%	10.8%	26.1%
Cause of leg injuries				
Impact (car or object)	46.4%	58.7%	63.0%	24.5%
Fall	37.9%	27.9%	26.3%	59.7%
Both fall and impact	15.7%	13.3%	10.8%	15.8%
Without leg fairings				
Number of collisions	45	88	54	62
Severity of leg injuries				
AIS 0	92.9%	71.6%	84.7%	64.9%
AIS 1	69.4%	78.4%	78.6%	67.9%
AIS 2	21.3%	14.1%	20.6%	25.1%
AIS 3	9.3%	7.4%	0.8%	7.0%
AIS 4	-	-	-	-
Type of leg injuries				
Soft part only	71.1%	78.2%	82.0%	75.4%
Fracture	28.9%	21.8%	18.0%	24.6%
Cause of leg injuries				
Impact (car or object)	46.5%	64.6%	48.7%	20.4%
Fall	30.2%	16.6%	40.4%	65.8%
Both fall and impact	23.3%	18.8%	10.9%	13.8%

Table 6.8. *Risks for leg injuries (severity, types and causes) for different collision types.*

Leg injuries are predominantly soft-tissue lesions and the low frequency of fractures in motorcycle accidents may lead to the opinion that leg protection is unnecessary. However, traumatising of the legs is combined with considerable long-time effects and costs. An investigation of persons with leg injuries established an average national expenditure of DM 33.202,-, basing on the new injury cost scale (ICS) by Zeidler, Mattern & Eichendorff (1989). Details are in *Table 6.10*.

Collision type	Type 1 & 2	Type 3 & 4	Type 5 & 6	Type 7	All types
With leg fairings					
Number of collisions	17	33	20	19	89
Percentage head injuries	21.5%	17.0 %	13.7%	27.3%	19.3%
Severity of head injuries					
AIS 1	8.7%	9.2%	13.7%	13.9%	11.1%
AIS 2	9.4%	3.0%	-	13.4%	5.8%
AIS 3	2.3%	-	-	-	0.4%
AIS 4	-	4.7%	-	-	1.8%
AIS 5	-	-	-	-	-%
AIS 6	1.2%	-	-	-	0.2%
Percentage thorax injuries	34.0%	25.1 %	11.3%	35.4%	25.9%
Severity of thorax injuries					
AIS 1	18.7%	19.4%	7.0%	13.1%	15.1%
AIS 2	15.3%	4.6%	-	17.8%	18.4%
AIS 3	-	1.1%	2.1%	4.5%	1.9%
AIS 4	-	-	2.2%	-	0.5%
AIS 5	-	-	-	-	-
AIS 6	-	-	-	-	-
Without leg fairings					
Number of collisions	45	88	54	62	249
Percentage head injuries	15.0%	14.8%	16.2%	26.6%	18.1%
Severity of head injuries					
AIS 1	7.8%	9.7%	12.3%	14.8%	11.2%
AIS 2	6.4%	5.1%	3.3%	8.0%	5.7%
AIS 3	-	-	0.6%	0.6%	0.3%
AIS 4	0.8%	-	-	-	0.5%
AIS 5	0.8%	-	-	-	0.2%
AIS 6	-	-	-	1.8%	0.4%
Percentage thorax injuries	12.4%	24.8%	17.4%	32.4%	22.8%
Severity of thorax injuries					
AIS 1	6.6%	18.5%	15.9%	19.3%	16.0%
AIS 2	3.8%	4.0%	1.5%	9.1%	4.7%
AIS 3	1.2%	1.6%	-	1.9%	1.2%
AIS 4	-	0.7%	-	0.8%	0.5%
AIS 5	0.8%	-	-	-	0.2%
AIS 6	-	-	-	1.3%	0.3%

Table 6.9. *Injury situation of head and thorax for different collision types*

	Number	ICS isol. legs (DM)	ICS all body regions (DM)	ICS without leg injuries (DM)	Reduction (%)
Total	348	10665	33202	26186	21,1%
Collision type					
Type 1&2	63	16093	32677	22333	31,7%
Type 3&4	121	8941	27584	23161	16,0%
Type 5&6	75	9675	22372	14638	34,6%
Type 7	81	11068	53745	45368	1

Table 6.10. *ICS Costs of leg injuries of German motorcyclists*.

For leg injuries expenditure amounted to DM 45,777 and it is estimated that an overall reduction of 21.1% can be achieved with leg protection. The most expensive collision types are 1 and 2 for which an estimated reduction of 31.7% (DM 5101) can be achieved and type 5 and 6 for the greatest percent reduction, 34.6% (DM3347) is estimated to be possible with leg protection. Of these injuries, foot fractures represent a very high proportion.

Constructional suggestions for leg protectors include recommendations for the foot to be covered from the side and front and the design of protection to include elimination of compression effects. The tibia must be protected in the front by an energy absorbing element and the tibia must be allowed to move upwards during the collision phase. A lateral load to the tibia can be prevented if the impact force is transmitted against the rigid part of the foot. Car manufacturers should design the bumper of the car to be positioned at the same height as the motorcyclist foot protection. Ejection of the motorcyclist from his motorcycle has to be made possible and bending forces between foot and tibia must be eliminated by rigid frames as the latter could lead to an increase in injury to the ankle joint.

6.6. **Pillion passengers**

Since the EEVC report nothing has been published on the risk for pillion passengers thus an extract is included as follows:

The presence of a pillion passenger is likely to have an important effect on the outcome of a collision. In general, the rider is likely to receive more severe injuries due to the load caused by the passenger's momentum, while the pillion is likely to receive less severe injuries, especially to the head, because of the cushioning effect of the rider in front, and possibly in some circumstances because the passenger is launched upwards by the back of the rider and thus flies over the impacted vehicle (Grandel, 1987; Otte 1989a). However, Otte (1989a) also notes that, on the whole, injury levels to riders accompanied by pillion passengers are actually lower than those to solo riders, and he attributes this to lower average impact speeds for rider/passenger combinations than for solo riders.

7. Measures to improve the safety of mopeds and motorcycles

7.1. **Legislation on age and licensing**

The majority of the western European nations have implemented the EU driving licence scheme concerning the vehicle definitions, age classes and test criteria. But the EU Licensing Scheme 91/439 EC does not include detailed requirements and conditions for reaching a licence or for preparation for the practical licensing test. Therefore different national education and training systems exist. E.g. the European nations like IRL, I, GR, P, E have no official requirements for rider education to issue a licence, other nations like A, D, DK or NL have a professional training with a curriculum for theoretical and practical education.

The EU driving licensing directive 91/439 EC has only minimum requests for the practical and theoretical test of novice riders and minimum requests on the physical and mental suitability for driving a motor vehicle before passing the final test by legal authorities. The directive does not discuss the form of driving educational system or the methods of learning vehicle control and traffic knowledge or demands on traffic behaviour, because different educational systems exist in each member country and only mean changes are required through the EU directive.

E, GR, I, IRL and P have no legal requirements for rider education before passing the final tests, which is legalised by all European countries. A, B, D, DK, FIN, LUX, NL, N and S require a professional tuition without unaccompanied riding on public roads before passing the tests. In B, FIN and GB the legal alternative is to take a compulsory course of basic training and than to gain experience unaccompanied on public roads. In B for up to 10 months, in FIN for up to 3 months and in GB for up to 2 years (Tomlins, 1998b).

The German and the British riding licence scheme are examples for the differences of rider education in Europe. In Germany the novice riders have to go through a complete curriculum of theoretical and practical lessons in a professional and approved driving school to reach for example a A-Step I license. 16 theoretical lessons with a duration of 90 min and in summary 450 min practical training, which are divided in 225 min on rural roads, 135 min on motorways and 90 min in twilight or dark time are standard. Additionally the rider has to learn in several lessons basic riding skills, which are part of the practical test too. After passing the theoretical test normally while having practical lessons, the rider can apply for the practical test. After passing the practical test he is allowed to ride a A step I motorcycle. Approximately 3 month are necessary from beginning theoretical education to passing the practical test. As a novice rider he has a probation license for two years.

In contrast in GB the novice riders first have to pass a compulsory basic training, which is normally completed in one day, on a closed area and a minimum of 2 hours on public roads in a Driving Standard Agency. After

these basic skills the rider is allowed to use unaccompanied public roads as a learner rider on a learner motorcycle (up to 125 cc) with a learner "L-plate" up to 2 years. During this period with a "provisional licence with motorcycle entitlement" the rider is not allowed to ride with pillion passengers and on motorways. Within two years he has to pass the theoretical test and has to apply for a practical test. After passing the practical test, absolved on a motorcycle from 120 to 125 cc with a top-speed of at least 100 km/h, he is given permission to ride the EU A Step I vehicle. The duration of riding education can last up to a maximum of 2 years.

Both educational systems can be described as follows:

Germany:
- intensive theoretical and practical lessons with the opportunity to influence the rider skills, behaviour and attitudes and knowledge individually before reaching the final test;
- training of riding skills on public roads in daily traffic and at different light and weather conditions;
- riding with a vehicle that fulfils the A step I motorcycle definition
- high costs for the rider.

Great Britain:
- Short and compact one day basic training skill and than self experiences in traffic with provisional license and L plate use
- Rider will be allowed to ride without requests and he can gain experiences by himself in relative time period to a maximum of 2 years
- low costs for the rider education
- no option to influence the riders behaviour or attitudes before attempting the road like in the Germany system but for car license an optional possibility with accompanied passenger with a car license is possible
- no orientation to the defined A step I motorcycle
- limitation to ride with pillion passenger and use of motorways

Obviously at first side these different educational systems come to no varying results and further research is needed to distinguish influences of different educational systems and contributing factors. Each systems is bound to national experiences and is evident for the national licensing scheme.

Because of the fact that the beginners are the highest risk-taking group of riders it is necessary to reduce the danger with individual measures. The group of beginners in the age group above 18 and up to 25 years has the highest accident risk in many European nations. But without doubt rider education training in combination with intensive theoretical education give the opportunity to discuss problems like risk taking, risk recognition or co-operative traffic behaviour, although the results are not foreseeable.

Rider education should be enforced, but there is a need to get more information about the scientific effects behind rider training and national education systems to evaluate the different training systems. Obviously these national training systems influence as well different safety measures like the riding without pillion passengers in GB. Therefore various safety measures for riders are only to be explained by the national educational system for licensing.

Beside the training of rider in driving schools there are existing different regulations in relation to the vehicle category and/or the inclusion of PTW-licensing for different licences. Related to the rider the following measures are to be seen:

- Minimum age;
- Graduated licensing schemes;
- Inclusion of PTW-licenses in other licences;
- Practical and theoretical education;
- Regulations concerning inclusion of PTW licences in car licences.

7.1.1. *Measure 'Minimum age'*

For motorcycles (class A Step 1) the minimum age in all European nations except Great Britain is 18 years. Only Great Britain has different age limits for A Step 1 and the sub-group A1 with a limit of 17 years for both vehicle groups (chapter 3). The direct access is limited by the majority at 21 years and only two nations legalised for 25 years of age (D,IRL). For lightweight motorcycles the most EU nations set the limit to the age of 16 years (D, E, F, FIN, I, IRL, LUX, N, P, S) and other nations to the age of 18 years (A, B, CH, DK, GR, NL).

It is not possible to evaluate the effect of different age limits because e.g. international data about lightweight motorcycles and motorcycles are combined to a single category of one-track vehicles > 50 cc . The reason why various nations limit the minimum age for lightweight motorcycles on 16 or 18 years can only be explained by former national legislations which have evidence for each country. There are obviously interrelations between different licensing schemes and age limits that make a direct comparison impossible.

For direct access of the full motorcycle licence in A, B, DK, F, FIN, I, IRL, N, NL, P and S a minimum age of 21 years is requested and in D and IRL 25 years. The aim of these regulations is to minimise youth related risks that could be foreseeable by lower age limits and by an implication that riders with these age limits will have gained traffic experiences with other vehicles, which will help to ride in a safe mode. It is necessary to observe the further development on accident involvement concerning the direct access.

For mopeds and other small PTW classes the minimum age varies from 14 to 16 (Chapter 3). In CH, E, I and F the minimum age are 14, in D and FIN it is 15 and in A, B, DK, GB, GR, N, NL, P and S 16. The international data for moped accidents is not sufficiently differentiated, so that it is not possible to make general suggestions to this age limit topic. As a remark, the EU driving licensing scheme does not influence these vehicle classes. Although it is evident that elder persons have a high share of this small capacity fleet the younger moped rides have the highest rates of accidents.

The minimum age varies very frequently between different countries because the question of age limits is bound to national influence of experiences with a defined age class or the adoption of licensing classes. If age limits are legalised by national authorities the effect aims on the youth and beginners

related risks. Although no researches about different age limits exist, there is on the one hand a need for more information about effects. On the other hand a harmonisation in the EU should be made to have same age limits for young riders.

7.1.2. *Measure 'Graduated licensing scheme for motorcyclists'*

The implementation of a graduated licence scheme for motorcycles in various European nations had the aim to reduce the high accident involvement of younger beginner riders. The regulation combines "power restrictions of the vehicle" with age limitations. There are different research results to the restrictive factors "vehicle power" and "age". Although mainly graduated licensing schemes are seen as positive in relation to the acpects mentioned above other researches stated no significant reduction of the accident involvement of the compared rider-group with and without staged licence scheme (Koch, 1990a). The advantages of a graduated licensing were adopted by the EU Commission and it has become the status quo of European licensing schemes.

7.1.3. *Measure 'Practical and theoretical education'*

Different systems exist to educate novice riders and drivers in Europe. In D, DK, E, GR, LUX, NL and P it is necessary to have professional education with a curriculum of theoretical and practical lessons. In A, B, CH, F, GB, I, IRL, N, S and FIN it is possible to learn riding/driving with the help of layman and/or with learner plates (e.g. B, GB). Equal for all nations is a final test by national authorities. Effects of the extremely different educational systems on the accident statistics are not visible in the statistical data.

But it would be possible that the situation in some nations will improve by a more professional education of riders. An intensive theoretical and practical training could reduce the lack of experience in traffic. Measures to improve the basic education of motorcycle riders should proceed in these both parts. Therefore the curriculum of novice rider training should include the following objectives to influence the traffic behaviour:

- increasing danger recognition
- improving risk recognition
- lowering behaviour to take risk

Tomlins (1998a; 1998b) found as well no differences in licensing schemes but regrets that most rider training programmes are mainly concentrated on rider skills, but not addressed to riders' attitudes and behaviour and that there are too high costs for the education of motorcyclists in Europe.

7.1.4. *Measure 'Inclusion of PTW licences in other licences'*

The EU driving licence directive includes the regulation of A1 motorcycle use for car drivers. The implementation of this differs in the member states. In E, FIN, N, P and S it is not allowed to ride a A1 motorcycle with only a car licence. IRL has not yet decided this regulation. In A, B, D, F, GB and I it is allowed, but under individual prerequisites. In A people have to be 23 years old and hold a car licence for 5 years, additional it is necessary to take 6h of

practical examination. In B and F drivers have to have for 2 years a car licence, in D the car licences have to be issued before April 1st 1980 and in GB only car licence is sufficient. In all western European nations it is allowed to ride a moped with a car licence.

Basic argument for an inclusion of lower capacity one-track vehicles up to the A1 category in the car-license (B) is the traffic experience of the drivers with other vehicles. Brendicke & Forke (1998) underline this argument because often drivers of cars had as well experiences with other motorised one-track vehicles before. Traffic experience with other vehicles (cars) and experiences with other PTWs evidently reduce the accident risk.

Different forms of measures could be adopted in relation to the unique physical system motorcycle and persons who have no experiences in riding a powered two-wheeler:

- self training in closed areas;
- voluntary rider training;
- additional voluntary driving lessons in schools.

7.2. Special measures for beginning riders

Different regulations - which could be partly combined with probation licence - are foreseeable but not only in relation to the novice motorcyclists. The following measures (some of them are more orientated and evident for car drivers and will be discussed in relation to motorcyclists) will be discussed below and are caused throughout beginners-, youth risk and the higher involvement in traffic accidents for younger age groups. Other regulations are bound to the enforcement of rider protection and the improvement of conspicuity:

- probating license schemes;
- riding without pillion passenger;
- compulsory training for riders;
- voluntary /advanced training for riders;
- motorcycle riding simulator for the training of novice motorcyclists;
- practical and theoretical lessons for car licensing in relation to "two-wheelers";
- riding bans on motorways;
- riding ban at the weekend nights;
- zero BAC for novice riders;
- helmet use enforcement;
- Daytime use of headlights for motorcycles.

It should be pointed out that some measures are clearly to be seen in the context of the national licensing scheme (strictly professional licensing supervision system or an educational system where limits are given, but the driver/rider has to undergo experiences without supervision).

7.2.1. *Measure 'Probational licence'*

Although no definite information about these license limits exists for all European countries (more information needed) in D and LUX novice riders/drivers have to absolve a probationary time from 1 to 2 years. If offences in the traffic regulations are noticed the riders/drivers have to undergo additional theoretical or practical education. In Germany the effect of the probation licence for car drivers was investigated by the BASt (Meewes & Weißbrodt, 1992). The traffic risk for young male drivers decreases in urban areas by 5 %, in rural areas there was no remarkable effect visible. The risk for female drivers decreases only little. Probation licences are aimed to careful behaviour of novice drivers, but there seems to be no longer-term effect on the traffic behaviour after the probation phase especially on rural roads. Effects of the probation time on motorcycle riders' accident data and traffic behaviour have not currently been investigated.

7.2.2. *Measure 'Riding without pillion passenger'*

In Italy a legalised ban to ride with a pillion passenger exists for A1 (125 cc, 11 kW) motorcycle riders up to the age of 18. In GB the educational riding scheme allows no riding with pillion passengers if a L-plate is used.

The introduction of this regulation may be caused by the age-related leisure time activities of young riders in connection with a higher liability of pillion passenger use. The measure aims on the one hand for a reduction of the accident risk of the rider himself in relation to a possible passenger and on the other hand for rider learner faults by the vehicle handling in the first phase of riding.

Generally speaking, a ban of riding with pillion passenger should be seen more critical, but this measure has a dependency to the actual national training schemes and should be evaluated by the national requirements. It is necessary for novice riders to gain experience on the road and the performance of the vehicle in different load conditions. If this is prohibited for novice riders in the first one or two years this problems will occur later on. An argument for a ban of pillion passengers for a period of time may be more time to gain riding experiences. Additionally there is a high expenditure to control this regulation and the effect will be minor because of the relatively low share of pillion passengers accidents on the total accident involvement of all motorcycles (e.g. Germany 10.7 %; France 10.3 %).

7.2.3. *Measure 'Additional compulsory training for novice riders'*

Compulsory vehicle trainings in the probation licensing period are submitted to novice riders in LUX and for car drivers in DK, FIN, N and S. This is a skid training on slippery road conditions in northern EU countries and no information about motorcyclists' involvement can be found. These compulsory car trainings should improve driving/riding skill of the novice drivers.

There are only a few and not very actual evaluations about motorcycle rider trainings but one was done in Germany in the year 1983 (Grosse-Berndt &

Niesen, 1983) in relation to the voluntary system of training. For the compulsory training new researches only exist form car training of novice drivers in Northern Europe (Katila, Keskinen & Hatakka, 1996).

The effect of these trainings was surveyed in the four northern European countries (Katila, Keskinen & Hatakka, 1996). Astonishingly there was a slightly negative effect on the accident involvement of young male drivers. They used their learned driving skills for satisfying psychological risk motives like competitive needs or sensation seeking behaviour. This negative result derives a basic problem of solely skill improving training: rider/driver: skills can be used in different ways and can imply a misleading tendency and demands more orientation to traffic and risk recognition and adoption for a training.

Negative consequences of skill based trainings have as well been described in Great Britain. The casualty rates were higher for trained than for untrained riders. (Chesham, Rutter & Quine, 1991, Jonah, Dawson & Bragg, 1981, McDavid, Lohrman & Lohrman, 1989, Mortimer & O'Rourke, 1980).

Skill training should be combined with an effective influence on the rider's traffic and risk behaviour, which could be achieved by accident avoidance strategies, theoretical lessons and improved knowledge.

In relation to the effectiveness of restrictive measures, these measures do always imply a legislative influence on personal self esteem and the major effect could be that this information is not used to develop one's own long-terms driving behaviour. Non restrictive measures mean in this case a voluntary training-use of motorcyclists with the advantages of interested motorcyclists who want to develop their own abilities for riding. In this sense a more personal view and more positive learning results are foreseeable. On the other hand different target groups may not be reached by voluntary training.

Generally the results in the northern part of Europe are not suitable to support this restrictive training measure. In addition to that a German study about an experimental special ambitious two step driving training program for young drivers after licensing results in no positive consequences for the safety related attitudes of the persons involved.

7.2.4. *Riding bans for novice motorcyclists*

7.2.4.1. Measure 'Bans on high speed roads/motorways'

Different forms of riding bans in relation to novice car users or novice riders are to be found. In some North American states the ban are solely used to reduce the accident involvement in relation to alcohol and nighttime disco accidents under alcohol influences and novice drivers. The ban in GB for motorways and learning motorcyclists with L-plate and the ban of lower 150 cc motorcycles on Italian motorways seem to be orientated to the liability of the severity of injuries at high speed traffic accidents. In relation to the motorcyclists it has to be stated that accidents on highways have a small portion of (3 %) in relation to other road classes for example in Germany.

Rural roads have a share of only 34 % but with a higher injury risk and urban roads have a share of 63 % of motorcycle accidents (Germany 1996/1997).

Therefore the effectiveness of this ban is not foreseeable because riders will be forced to use road types which have a higher risk of accident liability and a high risk of severe to fatal injuries on rural roads. Investigations in Canada for novice car drivers had shown that the implementation of this measure resulted in increasing accident figures for novice drivers (Schlag, 1997), so that it was recommended to revoke this regulation.

In relation to the ban in GB for riders with learner plates it has to be stated that the problem will only be shifted to the beginning of the rider career without L-plate and the share of motorcycle accidents on motorways are hopefully in GB at the same lower level like in Germany. Furthermore the rider experience in his educational phase should include all types of roads. In Italy this ban for only up to 125 cc vehicles can not be explained by general speed limits on this road type but more on the avoidance of youth risks in relation to top speed and overtaking.

Generally the effect of these measures seems to be low in relation to different problems discussed above.

7.2.4.2. Measure ‘Riding bans at weekend nights’

One solution for car drivers in some states of the USA was a temporal ban at particularly dangerous night hours like at weekends and aims to problems of alcohol abuse and disco night accidents. This measure for young beginner car drivers was successfully introduced (Schlag, 1997) and the psychological stress of drivers to be fined by night weekend driving seem to be effective for this vehicle group. Information about motorcyclists were not found.

Generally it has to be stated that for motorcyclists the riding in nighttime conditions is not so frequently than for car drivers and moreover that the accident involvement by alcohol abuse is not so often for this vehicle group in Europe although national differences might exist (GB). Because this measure was developed to control alcohol influences in night times after a disco visit of young people it seems to be not effective for motorcyclists, because beside the fact of being not a general motorcycle users behaviour, the control of this ban is limited by the identification of the riders age. Although a special plate on the vehicle can be used, this will not be secure for a rider identification and the use of the vehicle by different riders. Therefore this measure can only be realised by intensive police controls which have to enforce the ban.

7.2.5. *Measure ‘Zero BAC for novice riders’*

The same aims related to youth accidents with alcohol involvement are to be seen. Alcohol is no general problem in accident causation for motorcycles in Europe, although some nations like GB have a larger share of motorcycle accidents where this problem occur. This problem of mainly car-drivers can not be transferred on motorcycle riders generally, because there is a low share of alcohol abuse in most EU countries for motorcyclists. The typical problem of alcohol abuse and driving in night hours can not be related to motorcycles,

because the typical hours for a motorcycle accident involvement are day time hours.

Generally a "Zero BAC" for a specific age group will enlarge the control function of the police authorities to a high extend but a reduction can be expected from this measure. In relation to motorcycles it is very problematic to identify young riders at first side, because the use of helmets make riders more anonymous.

7.2.6. *Measure 'Motorcycle simulator for the training of novice and advanced motorcyclists'*

This measure can be discussed in two different ways. On the one hand in Japan the education of riders is more orientated to the use of simulators but unfortunately there is no scientific data available about the influences for educational training. On the other hand simulators can be used in relation to advanced rider training. Apart from a standardised motorcycle training lasting one or two days efforts should be made to integrate driving/riding simulators in the practical training.

Experiences of the IfZ motorcycle simulator give first hints that individual faults in riding a motorcycle can be improved by the simulator use. The motorcycle simulator gives an opportunity to register and analyse riding behaviour, and, especially, riding and braking errors that can be minimised for traffic situations. Moreover dangerous traffic situations can be simulated and faults in braking performance of the rider can be influenced in a positive and not dangerous way.

7.3. **Measure 'Voluntary 'advanced' training for riders**

Advanced trainings for riders are offered in nearly all western European nations. They are orientated to the training of riding skills and accident avoidance. The evaluation of voluntary motorcycle training in Germany was based on data of the beginning of the 80's (Grosse-Berndt & Niesen, 1983) and came to the result, that there are methodological problems to evaluate rider and driver training and that there are in case no or only slightly positive effects to be seen. As an outlook of this evaluation the pedagogical concept should be improved, which has been done by the DVR (German traffic safety council) in the last 15 years, so that at this actual time as well quality controlled instruments for motorcycle rider trainings are to be found.

Riders who participate these voluntary training options have often two reasons :

- They have a personal need to improve their basic skills; or
- they are convinced of a periodically use of rider trainings

to get used to handle a powered two wheeler after a period of time without motorcycling. Persons who tend to overestimate their riding skills will basically not be reached by this measure. They are convinced that they need no further improvement of riding skills or information about motorcycling.

For this special target group ifz had developed a so called *"race-track" rider training*, which is not orientated on speed and racing, but on learning the difference between race track and street use and has an integration of the theoretical and practical exercises of a one day advanced rider training. In

addition to that, different specific concepts of rider training for various motorcycle categories (e.g. off-road, trial or chopper motorcycles) may improve riding skills and knowledge about this motorcycle category which many be helpful in relation to accident avoidance.

Furthermore IfZ's trainings were also directed at *driving school instructors* to improve their skills and knowledge of motorcycling, which will be useful for the training of novice licensing riders .

Apart from teaching of riding techniques and skills the participants should learn about appropriate traffic behaviour, risk awareness and vehicle handling in emergency situations. The knowledge about risk potentials, rules and questions of social responsibility are seriously treated subjects. This especially refers to the ability of self-observation and self-control. As a consequence and in connection with social and ethical values, this will lead to responsible traffic behaviour towards all other road user groups.

Combined safety trainings for car drivers and motorcycle riders offer the opportunity to show the physical differences between these two kinds of vehicles and thus draw the attention to the characteristic riding dynamics and problems of road users which are not familiar with the particular motorcycle characteristics.

7.4. Legislation on helmets - Helmet law and legal controls

European countries have enforced legislation of helmet use for almost all motorcycle vehicle and age groups because world wide different research studies have proved an increase of safety and protection for motorcycle riders. Generally research results show that the injury rate and the severity of injuries in the head regions is substantially lower for motorcyclists with helmets than without the use of helmets.

The average severity of head injuries related to impact points on cars or road surfaces are four times higher for motorcyclists without helmets. This means that the Abbreviated Injury Scale (AIS) for users without helmets was AIS = 1.8 to 4.4 and for helmet wearing motorcyclists AIS=0.5 to 3.3. An AIS scale between 3 and not greater than 4 means severe serious injuries without life threatening character. The results of AIS scale are as well related to impact points of the motorcyclists and the car roof, A, B and C pillar are contact points with the highest average head injury rates. For an impact with the lower part of the car windscreen-frame the average head injury results in AIS=4.3 for non-helmet users and AIS = 1 for helmet users. This example vividly explains the advantages of a helmet law enforcement. A direct comparison of helmet users versus non-helmet users results in 60 % of unhurt helmet users. On the other hand only 35 % of non-helmet users were unhurt. In general the total number of injuries related to all AIS classes are doubled for non-helmet users.

7.4.1. *Measure 'Helmet use law'*

The above mentioned advantages of helmets for all PTW users should enforce the use for all PTW vehicle classes and age groups (see Italy no mandatory helmet use for moped riders aged over 18) with a km/h above 20 km/h.

7.4.2. *Measure 'Full-face helmets versus open face helmet - A question of climate conditions and primary safety'*

The full-face helmet, which has the highest frequency of use, has some decisive advantages in comparison to an open-face helmet. The chin protection minimises injuries of the lower part of the face and the chinstrap reduces the loss of the helmet (other helmets 7.4 %). Moreover the helmet visor protects the eye not only in accident situations but moreover for small dust particle and insects when riding. A look at the impact points of helmets verifies the advantages of the chin protection. 19.4 % respectively 15.2 % of all impact point are in this helmet area (Otte, 1985; Otte et al., 1998), which are the maximums of impact points on the right and left side of the helmet.

Although the advantages of full-face helmets are obvious, there is a relation to climate conditions in Europe. In hot weather conditions there might be a riders stress throughout the closed layout of the helmet design. This could imply negative primary safety results in concentration on the traffic involvement.

In relation to these facts a primarily orientation on helmet use is enforced in all European countries.

7.4.3. *Measure 'Enforcement to wear the helmets correctly'*

Studies in Spain and Greece have shown that riders do not wear their helmets correctly and have no interest to fulfil the legislative regulation. This should be enforced by localised police control but it is obvious that this could be no solution in general reflecting the social cost of police controls. The enforcement has to be accompanied by information campaigns to be effective in the sense of safety improvement.

7.5. **Measures related to the vehicle**

7.5.1. *Measure 'Power restrictions of motorcycles'*

The EU driving licence directive 91/439 EC includes different power restrictions for motorcycles. For A1 motorcycles limits are 125 cc and 11 kW. Special power restrictions beside the restrictions within the EU directive 91/439 EC exist currently in E and GB especially for lightweight motorcycles (0.11 kW/kg). The effect of this power to weight ratio is not researched up to now, but the usual purchasable A1 125 cc vehicle will not reach this power to weight limit at all.

In relation to the discussion of power restrictions of bigger motorcycles no scientific evidence has been found (Schulz, 1995; TNO, 1997) because the

variables rider and rider behaviour are the major cause for a conceivable higher accident involvement of these powerful vehicles (Schulz, 1998).

Although in France a national restriction of 74 kW is legalised all other European nations have refused a power restriction and a harmonisation in Europe should be enforced. The accident analysis gives as well hints that the typical average collision speed is between 35 km/h and 50 km/h, which means that this will not be affected by the power of the vehicle.

In Germany a "Gentleman Agreement for a limit of 74 kW" existed until the end of 1998. According to the European harmonisation and the European whole vehicle type approval for motorcycles the agreement was cancelled.

7.5.2. *Measure 'Speed limitations of motorcycles / mopeds'*

Only in Germany an age related speed limitation of 80 km/h top-speed for lightweight motorcycles exists for 16 to lower 18 years. This measure aims on the reduction of the risk exposure for young people but it can lead to more frequent overtaking by cars caused throughout the maximum speed on rural roads of 100 km/h in Germany and disturbances in traffic flow (Brendicke & Forke, 1993). In addition to this a higher accident liability in short keeping-distances and risky situations when other vehicles overtake, results throughout the low top-speed. On motorways limited A1 motorcycles face the same problems as well (Brendicke & Forke, 1993). In relation to that it has to be stated once again that rural roads and urban areas are most dangerous for PTWs.

7.5.3. *Braking*

Related to the physics of one-track vehicles (section 5.3) one of the most difficult activities when handling a motorcycle is correct braking. The motorcycle rider has at the same time to maintain stability, to prevent the wheels from locking and sliding and to provide the shortest possible stopping distance in combination with the highest possible deceleration by a ideal ratio of front (70-80 %) to rear brake force (20-30 %) distribution by normal separated brake systems.

Taking into account the critical relation between tyres and road surface under all weather or road and friction conditions in combination with the target to achieve the optimum of deceleration by the correct combination of front (hand) and rear (foot) brake on a conventional motorcycle one can see that PTW have a special relation between stability and braking forces.

Even when motorcycles are equipped with anti-lock braks or more over with so-called combined or integrated brake systems the problem of braking on bends has no solution up to now. Braking in road curves leads to change of lateral inclination (with and without antilock device) by the physics of the vehicle. As a result of the tyre-width under a roll angle (which is absolutely necessary for cornering) a steering torque arises and as a function of the gyroscopic effects of the rotating and steered front wheel the one-track vehicle has the tendency to set itself upright, which is absolutely harmful for safe cornering. The result is that the motorcycle changes its original travelling

path and tries to leave the curve by the tangent, even before the tyres might loose their grip to the road surface.

ABS and/with combined brake systems, which could not be adopted from car development have their total advantages in braking at straight lines and not to capsize the front-wheel and in some researches in a higher deceleration force (Präckel, 1994). These braking systems have a very high standard and are developed continuously. Several motorcycle manufacturers offer nowadays antilock braks not only for the high price class or only touring models, so that some scooters are nowadays equipped with (mechanic) ABS brak systems.

The motorcycle riders should appreciate this development, even if riders orientated at braking distances in some cases seem to suffer - similar to combined brake systems - a certain "loss of freedom" and feel manipulated by an automatic device and slightly shorter braking distances for conventional braking systems (Präckel, 1996).

Furthermore the risk homeostasis theory has to be kept in mind in relation to the rider himself and ABS braking systems, like this was discussed and researched for four-wheelers. For cars ABS braking systems are estimated in relation to their safety effectiveness by the OECD report as "not clear" and moreover as "negative" in relation to the driving behaviour which seems to be more "careless" (Pfafferott & Huguenin, 1991). This correlates with the risk homeostasis theory as well (Wilde, 1978). It was supported by Aschenbrenner, Biehl & Wurm (1992) when 66 % of drivers (taxi cab) with ABS systems said that they drive more risky and of which ten percent are sure that this is justified by this new technique. In relation to accidents it was given evidence that ABS equipped vehicles do not lead to a reduction of accidents in comparison to not ABS equipped cars. More over ABS cars had a higher accident rate under specific conditions like "ice", which was explained by the absence of detailed information about this braking systems. This missing correct information and concrete estimations about the effect of ABS systems was as well regretted by Sievert (1994). In this sense efforts should be made to inform precisely about advantages and limitations of ABS braking systems in relation to normal braking systems.

Moreover a new braking phenomenon can be seen, the so called "Stoppy" when the rear wheel looses contact with the road surfaces under hard braking conditions. Because the high centre of gravity was moved more and more to front wheel in order to improve high standard of motorcycle stability. The maximum braking deceleration is limited by a braking overturn into driving direction rather than reaching the maximum potential of tyre friction, which can as well be found by new developed ABS systems. The possible result is a loss of 2 m/s^2 deceleration (which is a boundary for all braking systems) (Präckel & Bachmann, 1997).

In this sense the problems related to motorcycle braking have no longer a technical evidence and it has to be stated that the modern braking equipment of motorcycles with hydraulic disc brakes and the antilock devices in general provide a very high standard. Nevertheless braking on bends still needs a solution and the basics of the physics of one-track vehicles can not be changed. Measures have therefore to be discussed and concentrated on the human element to improve braking behaviour and skills.

7.5.3.1. Measure ‘Training of motorcyclists in relation to braking skills’

One possible measure is a training /advanced training of motorcyclist to reduce braking faults of the rider. This can be done in two steps: Step I in the mandatory training by driving school education and as Step II by advanced rider trainings. But there is no grant that in emergency situations every braking action will be done correctly.

7.5.3.2. Measure ‘Further developments of ABS and combined braking systems’

To avoid the lock of the front-wheel the ABS and combined braking systems are very reasonable, although the limits of braking on bends and above mentioned rare wheel contact loose with the road surface exists. The development and equipment of motorcycles with ABS and combined braking systems will continue and it is foreseeable like for cars that these systems will have a greater share in the future. One problem seems to be the acceptance by the motorcycle riders, although first researches (Hagstotz & Tsuchida, 1998) are satisfied with these CBS/ABS-brake systems, although only users of these brake systems were interviewed. Therefore it seems to make more sense to improve the correct information about advantages of ABS/CBS systems of PTWs.

7.5.3.3. Measure ‘Development of solutions for braking on bends’

Although first thoughts and ideas have been invested (Weidele, 1994) to reduce the physical problems when braking on bends with a "steering torque cone" there is still a need for research on this topic.

7.5.4. *Anti-tampering of small-capacity two-wheelers*

The form of tampering of vehicles is different between mopeds and motorcycles. Tampering of motorcycles means more or less the change of the exhaust systems in order to receive a "better sound“ of the vehicle. Tampering of mopeds is aimed to the top-speed. In this sense the tampering of mopeds are more related to safety aspects than the tampering of motorcycles.

The manipulation of mopeds imply a high accident risk (Noordzij, 1998) because although the technical standards of mopeds improved, the tampering of the vehicle's top-speed is based on the normal standard of braking -, frame- or suspension systems which are designed for a top speed of 45 km/h to 50 km/h. Tampered mopeds have longer braking distances and more brake fading. Especially for slow mopeds with drum brakes this has to be stated as more serious.

In relation to the below mentioned measures for anti tampering it is necessary to evaluate the effectiveness.

7.5.4.1. Measure ‘Anti-tampering catalogues’

In Germany a catalogue with anti tampering measures was introduced in the year 1986. The aim was to complicate illegal manipulations of mopeds and

lightweight motorcycles. A small and mobile test apparatus was developed to test the maximum speed of mopeds by police controls. The same problem of tampering small one-track vehicles is to be seen in the Netherlands where the industry had agreed on voluntary measures against tampering (Noordzij, 1998).

On June 17th, 1997 the EU Directive 97/24/EC was dismissed. In chapter 7 of this directive several measures are presented to prevent illegal manipulations on powered two wheelers. For example a badge has to be installed with vehicle specifications, which makes it easier to control a possible tampering of smaller PTWs up to 125 cc and 11 kW. Further more very precise regulations for the construction of the carburettor and other technical elements of the vehicle were adopted. From June 17th, 1999 all new powered two wheelers have to fulfil this EU-directive.

With the measures presented by the EU directive it is possible to complicate illegal manipulations and it will be easier to detect manipulations of mopeds for the police. But it has to be considered that this measure only affects the new sold vehicles and the older vehicle fleet can be more easily manipulated further on. Therefore an additional control by police forces should be discussed.

7.5.4.2. Measure ‘Registration and regular technical controls of mopeds’

One problem is that in most European nations mopeds are not registered and therefore are not subjected to a regular technical control by legal authorities. The risk to be fined with a tuned moped is very low. Registration and a regular technical controls could keep young adults from tampering their mopeds, because they have to modify the vehicle very frequently to the original standard which means additional costs.

A not cost efficient additional task is to be seen by national authorities that have to register these vehicles and by the police who has to be enforced to control the vehicles.

Another problem for the control of vehicles is their equivalent vehicle design, so that mopeds and slow mopeds can not be distinguish at first sight, even for professionals. A solution would be the official registration of mopeds with different plate numbers. Drivers with a tuned slow moped could be easier detected and be punished for tampering, which might prevent from illegal manipulations.

The Netherlands will introduce the registration of mopeds and all existing mopeds in the Netherlands will be tested before registration to reduce the number of tampered vehicles as a strategy (Noordzij, 1998). Although this measure will drop the number of tampered vehicles at the time of registration, it is not guaranteed that the mopeds will not be tampered after it. To be effective the measure should be combined with regular police controls and a ban of selling tuning-kits.

7.5.4.3. Measure ‘Ban on the selling of tuning - kits’

The actual status in different European countries is the high availability of tuning kits for slow powered two-wheelers. A ban for selling tuning kits would reduce the problem to zero. France has legalised a ban to sell tuning-kits and the restrictive law has developed an effective control mechanism. One implied problem is the control of the ban outside the national areas, when other countries are distributing these tuning kits. Therefore the control of a selling ban of tampering equipment has to be enforced in all European nations, what can increase the social costs of the measure.

7.6. **Measures related to the infrastructure**

7.6.1. *Measure ‘Diesel tank caps of heavy vehicles’*

In relation to the road surface and a possible capsize of the motorcycle when braking there is a problem of diesel leakage of heavy vehicles. The spilling of Diesel fuel as a function of overfilling and/or not correct locking of the fuel tank cap especially of trucks sometimes causes motorcycle accidents because of the tire/road friction. Modern systems do not allow overfilling and have internal self-locking devices. They have already been developed and should become standard and re-equipment for Diesel-powered heavy vehicles.

7.6.2. *PTW environment road construction*

Measures related to "braking" have shown the physical complexity of one track vehicles which is quiet different to four-wheelers. In this sense the connection between tyres and road surface is the major point that can lead to instability in handling of one-track-vehicles or even slippery conditions that can initiate a fall of the PTW. Skid resistance spots (µ-spots) are caused - among other factors like leakage of diesel and/or oil on the road - by grip values of the tarmac road surface. Moreover it has to be stated that road construction authorities are focused mainly on the four-wheeler vehicle category, although the driving physic is not so problematic than that of one-track vehicles. In this sense the road construction should not be in contradiction to the requirements of vulnerable road users like PTWs.

7.6.2.1. Measure ‘Avoidance of slippery surfaces and µ-spots’

It is essential for motorcyclists that the road surfaces are not slippery to improve problems of vehicle handling and braking. First of all there should be a critical value for the *friction connection of road surfaces* and for µ-spot factors for different road surfaces when road repairs are done. The critical value for the grip of the tarmac surface should be orientated to the classes of vulnerable road users like PTWs.

The *use of road markings* (see below) which are known to have considerable differences in grip to the surrounding road surface should be checked and possibly renewed.

Manhole covers within the road surface can imply negative consequences because of a different µ-spot and sometimes about the height, when they are not on the level with the tarmac surface.

Extensible grooves on ends of road bridges have as well a different µ-spot than that of normal tarmac because they are made of steel and especially under wet conditions very slippery. The length of extensible grooves can imply handling problems of one-track vehicles as well.

But slippery surface does not only mean the µ-spot or grip of the surface but as well the maintenance of roads and road repairs.

7.6.2.2. Measure 'Road repairs'

Road mending/repairs should be done by the *same tarmac* material with same quality related to the critical µ-value to avoid m-spots within the layout of roads. Possible m-spots of the road surface can be very harmful for motorcyclist under different weather conditions.

Like *pure bitumen material* has shown (see Chapters 5 and 6), which is often used to prevent water to enter under a repaired piece of road surface, a causation of accidents can not be neglected if bitumen is not used correctly. If possible, the responsible road maintenance departments are required to take care of a reasonable and economic use of bitumen and to avoid extensive repair works with this form of material. Alternative materials like firstly promoted in Austria should be tested and further research on other material should be enforced.

Road repairs are often made by *loose chipping*. This very cost-effective material for road repairs is very harmful for one-track vehicles. If the surface is not very compact - which is normal because the weight of road user vehicles should compress the surface - it gets driving/riding grooves (longitudinal), that can affect the one-track vehicle handling very seriously. Taking into regard the instability of PTWs related to a vehicle speed of somewhat about 20 km/h, this road repair material is like a loose ground/surface that leads to an effect to ride like in railway lanes. Therefore the speed of riding over such surface material should not be under 40 km/h (vehicle stability of one-track vehicles) and the material should not be used in an intensive way by road repair authorities. Moreover the rider should be informed by a *danger-sign* with an information of the *distance* when and that loose chipping are used.

Parallel grooves by the beginning of road repairs should as well be signed to inform riders of powered two-wheelers to get in no dangerous situations when riding on such a surface. Signs would be convenient.

Generally road repairs are done in relation to small pieces of the surface. Extreme climatic and weather conditions can destroy the tarmac surface. It seems to be very normal that - because of economic costs - road surfaces aren't very frequently repaired completely. But this leads to different m-spots or the extensive use of pure bitumen. In relation to accident and injury costs it seems to be more realistic that complete substantial road repairs are needed.

7.6.2.3. Measure ‘Maintenance of roads’

Moreover the *continuous check and maintenance* of environmental conditions of the street, street furnishings/equipment and the road surface like e.g. wet conditions, dust, sand, oil or other negative changes of the surface should be enforced to have a positive safety effect. If negative road conditions are foreseeable this means basically an *information by sign* about the problem e.g. oils or intensive dirt should be installed. This can adjust the rider to drive safer.

7.6.2.4. Measure ‘Avoidance of unevenness of the road and roadside’

"Sleeping policemen" and the *"use of cobbles"* belong to the measures of traffic calming and speed reduction, particularly in inner-city areas. *Warning signs* should be installed here in order to avoid instability for motorcycles when crossing these sections.

High curbs on roadsides can have a negative influence on an impact and injury situation of rider. Besides injuries through the impact with a curb the vehicle can increase the possibility of a secondary impact of the rider which may result in more severe injuries of the motorcyclist. Curbs should be designed very flat to prevent these impact situations.

Curbs or other road side equipment for traffic calming should not have an *angle* that would imply the same problems for motorcyclists like the parallel longitudinal grooves /see above/ and should not be above or below the *normal level of the road surface*. *Measures could be a coloured tamarc* to make narrow lanes more visible and only very flat angles to imply no handling problems for the vehicle.

7.6.2.5. Measure ‘Road markings with the same µ-spot like tarmac’

Road markings may lead to considerable deterioration of the riding dynamics of motorcycles, depending on the quality of the markings and the given weather conditions. Deterioration in particular means wobbling, track-pawning, and high water levels with resulting loss of road grip (Brendicke, Forke & Gajewski, 1995). It is especially this loss of adhesion between tires and road which turns out to be particularly negative for motorcycle riders. In addition to that, the stopping distance redoubles with wet road markings, as compared to dry unmarked roadways (tarmac). The crossing of profiled road marking causes strong steering impulses leading to deviations from the nominal track of about 100 mm. High water level surrounding profiled markings may cause aquaplaning. In conjunction with the influence of air resistance this may cause the front wheel to raise and thus results in a considerable reduction of the front wheel load.

In respective to this road sections can be equipped with warning signs replacing the foils. *Extensive use of road markings* should be adapted by authorities and eliminated by warning signs.

- Marking foils, causing in wet conditions a considerable reduction of road adhesion, should be used rarely only. The respective road sections can be equipped with warning signs replacing the foils.

- Extensive road markings should be adapted to the surrounding road surface in order to limit skid resistance spots.
- The abrasion or grinding of thick road markings should be eliminated; as well as warning signs should be installed.
- As well the thick road markings should be limited to a maximum height of 2 mm above the road surface.
- Full-line thick markings may be interrupted by unmarked zones in order to avoid aquaplaning resulting from the diagonal inclination of the road.
- Profiled markings should be used with a maximum level-difference of 7 mm to the road surface.
- Equidistant gaps between metal road studs should be avoided in order to prevent motorcycles from weaving.
- Road markings which are known to have considerable differences in grip to the surrounding road surface should be checked and possibly renewed.

7.6.2.6. Measure ‘Avoidance of parallel grooves on surfaces for motorcycles’

Parallel (longitudinal) grooves in the road surface mean a further risk for the riding stability of motorcycles. These grooves, which are supposed to avoid aquaplaning, cause the motorcycle to oscillate. On a scientifically basis this has not yet been examined.

The problem of parallel grooves for motorcycles is well known to the responsible road departments. Thus, in Germany, road sections with grooves are often equipped with additional speed limitations for motorcycles. Actually, this speed limit valid for motorcycles only has to be considered critically: on one hand, the risk of an accident decreases by limiting the riding speed, on the other hand, the homogeneity of the traffic stream will be interrupted by this one-sided limit, resulting in an additional risk for motorcyclists. It appears to make more sense, to have a speed limit for all vehicles. The insufficient knowledge should be improved by further.

In addition to that, the necessity for parallel grooves should be checked and, if possible, they should be avoided. Further on, unproblematic alternative measures should be developed in order to avoid aquaplaning.

7.6.2.7. Measure ‘General measures for road construction’

Although there are some elements of the road side construction which can initiate negative influences for the motorcycle rider *(like a lateral falling gradient of the road surface, tight curve radius or different following curve radius of the street design, blind summits or road hollows / depressions)* these are elements of the road side design which will be faced by all traffic vehicle groups.

In the sense of the typical motorcycle accident which is normally a multi-vehicle accident at intersections and road junctions it seems to be very essential to have a good *"in-sight" view into these road areas in relation to the speed limit on the road.* The same measure has to be stated for braking distance before obstacles may occur or in relation to the riding task "over-taking".

Generally speaking the design of the road should avoid negative viewing distances for drivers and riders to reduce critical situations in traffic.

7.6.3. *Measure 'Separate/special lane use for motorcycles'*

There are examples of innovative approaches by local governments to enforce the use of powered two wheelers in separate lanes in towns. Although these measures are implemented because of problems of local traffic congestion to improve access to town areas there might be on the same hand a positive relation to the safety of vulnerable road users. In relation to motorcyclist's safety the main accident configuration of car/PTW accidents could be influenced positively, because traffic conflicts will be reduced through seperation. PTWs have been allowed (or tolerated) to use bus lanes on roads leading to downtown areas and on a number of streets in the city centre of several towns in Norway, Sweden, Italy and Spain and Switzerland. In Bristol, motorcycles are allowed to use bus lanes as well. This was first introduced as an experiment, but has become a permanent solution (no input TRL). Further research is needed to evaluate the effects of this special lane use of motorcycles and conceivable changing of traffic conflicts after the legislation.

7.6.4. *Measure 'PTW can overtake queues'*

Austria has legalised that motorcycles can get through queuing lines (left and right) and overtake standing vehicles. The same is admitted in Germany for slow mopeds, but with the difference that this should be done only on the right-hand side of a queue. In the Netherlands, France, Italy and Great Britain this motorcycle rider behaviour is tolerated by the authorities. Although this measure is related primarily to mobility and traffic congestion it can still have a positive effect for e.g. on riders stress. The average km/h is at least about 10 to 20 km/h and this is a vehicle speed where one-track vehicles have no stable balance. The rider has to manoeuvre his vehicle constantly to keep in balance and hot weather conditions are not very comfortable if protective clothing is used.

The small width of a one-track vehicle allows a narrow path between a queue and the only problem could be the opening of car doors or a too small path for the motorcycle. Equivalent to the tolerated motorcycle behaviour in the Netherlands one measure could be that motorcycles are allowed only to use the right side of a lane for overtaking other standing vehicles. In Germany this would be as well the rescue lane and all cars should be standing/driven left in the lane. The counter argument "it could close the emergency lane" is not very convincing because the motorcycle will always release into a normal queue gap. An optimum could be found by a combination with the next measure.

7.6.5. *Measure 'Two stop lines at large intersections'*

If motorcycles were allowed to overtake standing vehicles in queues or slow moving vehicles one problem could became obvious: more than two vehicles will stand before a traffic signal. On green light the car and the motorcycle will be accelerating and this could imply traffic conflicts between them. The lane for both is being identified and rivalry between car and motorcycle may be foreseeable. This would be eliminated by a second stop line of which the

first is only allowed for PTWs. Two stop lines at large intersections with the front line reserved for two-wheelers have been introduced in some Belgian, Dutch and Swiss towns. Up to now there is no evaluation about the enforcement of a second stop line.

7.6.6. *Measure 'Access to bicycle paths by slow mopeds'*

Belgium, Germany and the Netherlands have admitted that mopeds with reduced speed can use the bicycle paths. This is mandatory for all mopeds in the Netherlands but will be changed in the next years.

Two basic attitudes towards traffic management are to be seen behind this decision:

1. Traffic separation of different road user groups
2. Traffic integration of different road user groups

In the first case the separation of different road users should avoid traffic conflicts between them, but because there is a high density of road systems to be found other conflicts with other road users are foreseeable. In the case of slow mopeds the speed differences between car and the slow PTW is enormous on the road side. The use of slow mopeds on bicycle paths seem to adjusted in relation to speed.

The other road management theory leads to an integration of different road users with the hypothesis that the self-management of users will reduce the conflicts and will give a more partnership orientated traffic flow. In relation to vulnerable road users it is a difficult question to prefer this second management system.

7.7. **Measures related to other road users**

There are several solutions to the problems of perception of motorcycles and mopeds, or more generally to improve the behaviour of car drivers in relation to motorcyclists and moped riders:

- changing the physical characteristics of the two-wheeler
- education and training of car drivers
- education and training of riders
- changing traffic rules

7.7.1. *Physical characteristics of headlights*

Daytime use of headlights by motorcyclists give a reduction in daytime car-motorcycle collisions of 30-40%. Most European countries already have compulsory use of motorcycle headlights during daytime and even voluntary use may be as high as 90%. Bijleveld (1997) estimates that an increase to 100% in all European countries will still give 7% reduction in accicents and injuries to motorcyclists, which for motorcycle fatalities represents a reduction of 140 per year. The estimate is based on the study of statistics from a limited number of countries.
Few countries have compulsory use of headlights for moped riders and in this case the voluntary use seems to be low. However, there is no proper estimate of the potential reduction of accidents/injuries with 100% use of headlights by

moped riders. There is some concern that the effect of daytime use of headlights by motorcycles and mopeds will be less if cars have headlights as well.
Positive effects of retroflective materials and bright clothing is limited to certain conditions.

Headlights help to draw attention to the presence of vehicles, but do not contribute to the recognition of motorcycles and mopeds. In the Netherlands, several motorcycle organisations have suggested to use yellow headlights on motorcycles to improve their recognition. Both technically and legally, this seems to be a simple measure. But it would only work if almost all motorcycles have yellow lights and almost all cars have white lights. And even then its effectivenes depends on the willingnes of other road users to take action to avoid a collision after having recognised the motorcycle.

7.7.2. *Education and training of car drivers*

Many of the problems between a car and a motorised two-wheeler could be prevented if car drivers:
- anticipated the presence of a two-wheeler (when entering or crossing a road, when turning left and when changing lanes)
- were aware that judging the behaviour of a motorised two-wheeler may be difficult
- were aware of the problems of stability and handling of motorised two-wheelers

Somehow these items do not get enough attention during training to drive a car or they are easily forgotten with actual experience in driving a car. However there are no examples or studies on how to obtain these effects. One suggestion is to include a special part on motorised two-wheelers in the compulsory training and licensing of car drivers.

7.7.3. *Education and training of riders*

Riders of motorides two-wheelers can also help to prevent collisions with cars by:
- approaching intersections and curves with reduced speed to be able to react to hidden dangers
- taking position on the road to be seen by car drivers (when approaching an intersection or when overtaking)
- making sure that the car driver has seen their presence and understood their intentions and/or to act as if the car driver did not see them
- overtaking cars only if their is ample room and after checking that the car drivers have no intention of changing lanes or waiting for other road users or obstacles for which the rider should do the same

Ideally, all these items have to be a part of the basic training of riders as well as be reinforced and detailed in advanced training and other forms of education. For a discussion of these measures see § 7.2.

7.7.4. *Traffic rules*

Insofar as riders of motorised two-wheelers show behaviour which is different from car drivers, and is therefore not expected by other road users, a solution could possibly be found in changing the rules related to that behaviour.

An example is overtaking of cars. Some countries allow moped riders to overtake on the right hand side of cars and overtaking between slow moving lines of cars. Many riders will show this behaviour anyway. The more explicit rules about overtaking cars are supposed to result in more uniform behaviour by riders and in better knowledge and acceptance of it by car drivers. There is no documentation of the effects of such rules. Other countries explicitly make this behaviour illegal.

7.8. **Rider protectiom**

7.8.1. *Vehicle secondary safety system*

7.8.1.1. Method of assessment and ISO 13232

In the last few years improving passive safety for motorised two-wheelers has been one of the basic aims of accident research on two-wheeled motorised vehicles. The main problem is the wide range of possible outcomes of a two-wheeler accident, arising from the complex possibilities of the sequence of motion of both rider and motorcycle, and the injury mechanisms involved, which differ very considerably from those seen in car accidents.

To describe a motorcycle collision with a car or other opposing vehicle, five crucial impact variables need to be defined: motorcycle speed, car speed, motorcycle contact point, car contact point, relative heading angle. Because of this complexity it is not surprising that very few studies are available which have examined all five of these variables. As a result there is often some confusion in discussion of accident research, and some unavoidable speculation in some aspects of the studies. It is therefore of critical importance to the successful development of any safety device that it is tested not only in the impact configurations likely to give rise to the sort of injuries that the device is designed to prevent in real accidents, but also in other configurations to ensure that there is no increase in the risk of other types of injuries.

Because of the need to examine motorcycle safety in this critical way an ISO Standard was developed, ISO 13232, and published in 1994. This comprises eight parts starting with accident data, collection and analysis, which is used to identify the seven most important impact configurations and then the remaining parts define the specialised motorcycle dummy components, test methods, assessment of potential injury from the dummy measurements, computer analysis of 200 impact configurations and reporting. Of particular relevance for this report is the ISO calculation of normalised injury costs that can be expressed as a percent change. Thus results from different establishments, using the ISO method can be readily compared and within this report, wherever possible, this has been quoted.

7.8.1.2. Air bags

Background

In impacts head on to the motorcycle, the rider continues to move forward in a seated position and hits the opposing object at close to his pre-impact velocity. These accidents often result in fatal or serious injury to the head and upper body of the motorcyclist. The lower body and legs often become entangled with the motorcycle which can impart an additional rotational component of velocity to the upper body, so increasing the potential for injury. Injury could be reduced if some method of restraint could be provided to protect a rider in frontal collisions by controlling his trajectory and reducing his velocity before he hits the opposing vehicle (Finnis, 1990).

The restraint methods which have been proposed include: belts, saddle restraints, chest pads and air bags located either on the motorcycle or in the rider's suit. Finnis (1990) notes that most of these devices have proved unsuitable. Earlier studies with prototype motorcycle seat belts showed that restraint but not complete retention is desirable to reduce injury severity.

The first crash tests with air bags on motorcycles were published in 1973 (Hirsch and Bothwell, 1973). The air bag, which was rare at that time even in the car sector, was meant to act as a restraint system. So that it could fulfil this requirement air bag volumes of up to 120 litres were used. The results were not entirely satisfactory but gave a clear indication that an airbag system could be beneficial.

In the early 1990’s tests were completed in the UK in which three different types of motor cycle were fitted with an air bag (Happian-Smith & Chinn, 1990). The aim was to achieve maximum restraint by the air bag and as great a reduction in the motorcyclist's speed as possible. The results show that full restraint was not possible above a speed of 30 mile/h, though reducing the rider's velocity and controlling his trajectory could still be beneficial.

However, of more importance are two recent papers describing the development of an airbag system specifically for the motorcycles to which they were fitted.

Development of an airbag system for a Norton Commander: TRL project

Chinn et al (1997)completed the development and testing of a purpose built motorcycle airbag restraint system at Transport Research Laboratory in 1996. The system was developed in structured phases involving mathematical modelling, system manufacture, and then development and evaluation in a series of tests on a Norton motorcycle ranging from static fire to sled tests and finally full scale impacts. A Hybrid III dummy was used throughout the programme and a wide range of parameters were assessed. Results of the sled and full scale impact tests show kinetic energy reduction of between 79% and 100% and low neck-injury measurements compared with tolerance limits. Firing of an airbag is an important part of the system and TRL has undertaken research to determine the characteristics of a trigger system by the

use of theoretical and experimental data. This includes data obtained from accelerometers mounted at different locations on a motorcycle during "rough riding" tests.

As part of the programme TRL commissioned Lotus Engineering to design, manufacture and supply a purpose built airbag system for a large, touring Norton Commander motorcycle for impact testing. The programme started with MADYMO computer simulation of rider kinematics at impact, using load and acceleration impact test data information supplied by TRL, to determine the most suitable location of an airbag on the motorcycle and also to assess the system characteristics. Parametric studies determined the optimum airbag size and shape including tethering, suitable fire times, rate of inflation and pressure. This was followed by the design and manufacture of an airbag module mounted at the rear of the modified fuel tank consisting mainly of an non-coated polyester airbag and a hybrid inflator. Knee bolsters designed to control the rider trajectory but retain the energy absorbing properties defined in the TRL leg protection specification were also mounted into the motorcycle front fairing.

The test phases of the programme included firing the airbag system statically to assess its performance and integrity during deployment. This was followed by a series of sled tests to develop the system and consider the effects of an out of position rider, for example crouching or prone riders, as well as simulating angled impacts. This was followed by the full scale crash tests in which a free-wheeling Norton Commander motorcycle, fitted with an airbag system, was impacted into stationary and moving cars at different speeds, angles and directions to assess performance of the air-bag in as many road accident conditions as possible.

It is well known that the performance of an airbag system depends critically upon the time at which the airbag is deployed during the impact and this in turn depends upon the characteristics of the firing switch. For this reason, the airbag system in these tests was fired remotely with a delay at impact based on the motorcycle fore/aft deceleration pulse obtained from equivalent standard test. The design of the tests was in accordance with ISO DIS 13232 (ISO, 1996).

The characteristics of an airbag switch must be chosen so that the bag is deployed efficiently during an accident but does not deploy when the motorcycle is being ridden even when this is over an extremely uneven surface such as potholes or a kerbstone or very rough terrain. Motorcycle vibrations during such extreme circumstances were evaluated, and the results of this research were used in the development of the system.

The Norton Commander motorcycle was chosen as the test bed for which the airbag system was to be developed. It is a large touring machine, 221 kg, with a full glass-fibre fairing and is representative in weight and size of the larger machines on the market. Although the system was developed specifically for this machine it was intended that the development would formulate principles which are readily applicable to other machines of this class and may, in general, be applicable to many motorcycles of conventional design.

The main objective, and therefore, the main function of the system, was to protect the rider in impacts, approximately head-on to the motorcycle, into moving and stationary vehicles. Additionally, the system should be of some benefit in a range of other impact configurations but it must not be of serious detriment to the rider in any configuration. It should be noted that approximately 75% of motorcycle accidents occur at motorcycle impact speeds of up to 48 km/h and 96% up to 64 km/h (40 mile/h) and that 93% of the serious and fatal head injuries occur at speeds of up to 64 km/h (40 mile/h) (Whitaker, 1980; Sporner, Langwieder & Polauke 1989). It should also be noted that the majority of fatal and serious head and chest injuries occur in impacts approximately head-on to the motorcycle and that in the majority of accidents with an opposing vehicle, the speed of the opposing vehicle is 25 km/h (15 mile/h) or less. It was decided therefore to aim to optimise the airbag system performance for impacts approximately head-on to the motorcycle into stationary and slow moving vehicles (up to 25 km/h) with the additional requirement that injury potential in head-on impacts at speeds up to 64 km/h (40 mile/h) must be reduced.

It was intended that the overall performance of the system be judged against the performance of a standard motorcycle and that the criteria for the optimised case, which was a 50th percentile single rider in normal seating position travelling at 48 km/h, head-on into the side of a stationary vehicle, should be:

- That the kinetic energy at the plane of initial impact be reduced by at least 70% at the motorcycle to opposing vehicle first contact plane AA'. The AA' plane is a fixed vertical plane normal to the direction of motorcycle travel passing through the point at which the motorcycle front wheel first contacts the opposing vehicle.

- That the instrumentation measurements for the head, neck and chest should be substantially reduced.

Results of the trajectory analysis obtained from the tests show that the airbag is effective in reducing the rider velocities at impact. This is illustrated by the results of a test in which a motorcycle at 48 km/h impacts the side of a car moving at 24 km/h at an angle of 225° (i.e. test configuration D). Head velocity is reduced by 64%. The chest velocity is reduced by 75%.

Kinetic Energy Assessment - The rider trajectory analysis of the full scale impact tests shows that the dummy was fully restrained by the airbag with significant reduction in rider forward velocity and corresponding kinetic energy reduction of between 79% and 100% .The kinetic energy was assessed by comparing the head velocity at the initial point of impact with the velocity at the AA' plane. If the head did not cross the AA' plane then the final velocity was 0 km/h. Results presented comply fully with the kinetic energy performance targets defined above and therefore confirm the successful performance of the airbag system.

It should be noted that the injury results indicated by the tests with the standard motorcycle were lower than might have been expected. The Norton Commander motorcycle used in these tests is a large touring machine with a full glass-fibre fairing. The design of the Norton fairing provides partial

protection to the rider during the critical impact period. It is clear from both observation and test results that the fairing design plays a significant role in protecting the rider and therefore needs to be considered seriously by the manufacturer during the design stage.

In the impact tests where both vehicles were moving, the rider was thrown over the rear of the vehicle in the non airbag tests and landed on the ground. It is therefore likely that higher injury potential may have been sustained on landing. However, the results reported were assessed only for the data recorded during the critical impact period. It is intended to further analyse the results to cover the period during which the rider lands on the ground. This may reveal that the airbag is giving greater protection than has been currently measured. It should also be noted that where such impacts are into the side of a larger vehicle, the rider of a standard motorcycle would hit the opposing vehicle, in contrast to the rider of an air bag equipped motorcycle who is arrested by the bag. It is for this reason that the kinetic energy of the rider is considered to be very important.

In summary Chinn's airbag tests with the Norton Commander demonstrated:

1. The airbag module, purposely designed and built for the Norton Commander motorcycle, is a novel system for which the computer simulation was successfully used to determine the system parameters. Design, optimisation and manufacture of a system tailored for a specific motorcycle was considered paramount to the success of the system. The process of development starting with computer simulation and proceeding through design, development and evaluation using static fire tests, sled tests and finally full scale tests and aiming for clearly defined performance targets has proved very efficient and effective.

2. The sled test results showed that the airbag system fully restrained the rider with 100% reduction in rider kinetic energy for all test conditions assessed.

3. The sled test results and those of the full scale impact tests analysed to date comply fully with the design and performance criteria defined at the beginning of the programme and thus confirm the successful performance of the airbag system to date.

4. Full scale impact test results analysed to date indicate that the dummy has been successfully arrested by the airbag. Rider forward velocities are greatly reduced with a corresponding reduction in kinetic energy of between 79% and 100%.

5. All of the neck results for airbag tests reported in Chinn's study are significantly less than the tolerance values, and the majority are low compared to those recorded in standard tests. They show considerable improvements over previous airbag research which commented adversely on the potential for increased neck injuries.

6. The TRL full scale impact test data and the motorcycle rough ride and misuse results, indicate that a fire time is possible within the limits imposed by the requirements for total airbag deployment time. Full

mapping of sensor operation at threshold impact speeds in different configurations will be required to develop a commercial system.

7. ISO DIS 13232 defines a system of calculating the normalised in jury costs for a range of seven impact pairs. This method was applied to the five pairs of ISO tests in the programme and the results showed that the airbag system reduced these costs by over 80%. A further indication of the success of the system.

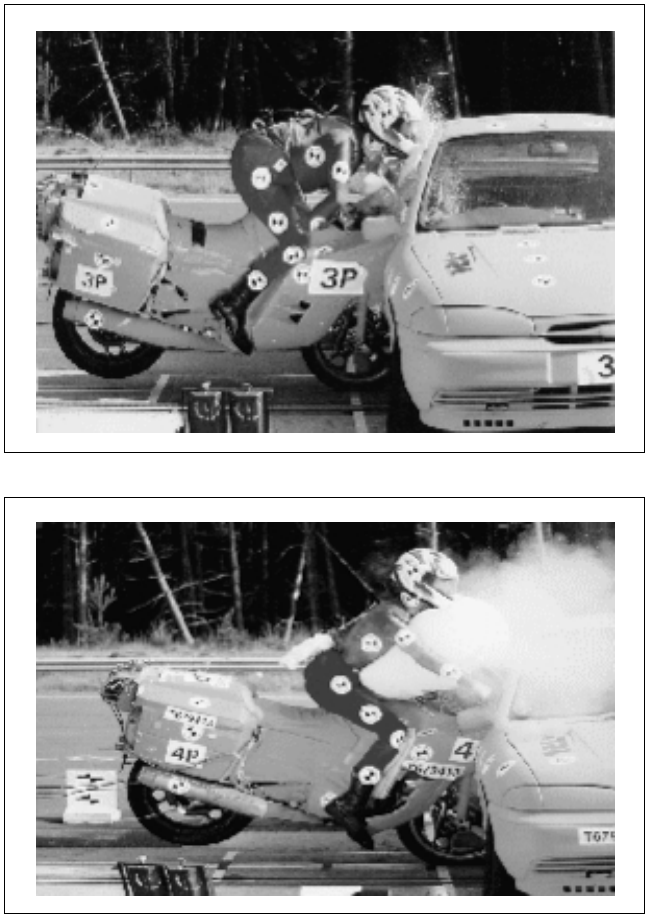


Figure 7.1. *Impact at 90° without and with the TRL/Lotus Engineering airbag system*

An airbag system for a Honda Gold Wing: Honda project

A similar study by Iijima of Honda research of airbags mounted in a large touring motorcycle, Honda Gold Wing demonstrated the airbag is beneficial in four cases, harmful in two cases and has little or no effect in three cases as illustrated in *Figure 7.2* (Iijima et al., 1998).

The shaded portions indicate results for the period prior to 500 ms - the primary impact sequence - during which the motorcycle, dummy and opposing vehicle interactions occur. The unshaded portions indicate results for the entire impact sequence which includes dummy/ground contact and the dummy coming to rest.

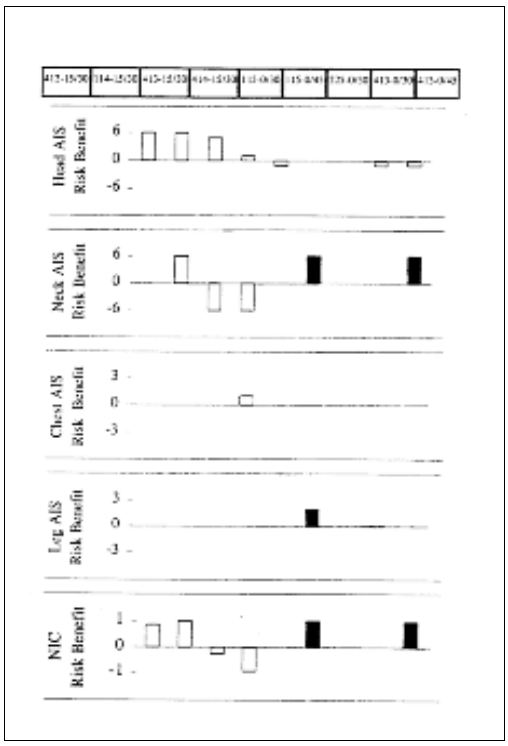


Figure 7.2. *Airbag injury risks and benefits by impact configuration and body region. (Iijima et al., 1998).*

Figure 7.3 from the same study shows the benefit and risk by body region in terms of average change of AIS across all the impact configurations and for the entire impact sequence. The main benefits and risks demonstrated are to the head and neck. For the head and for these impact configurations, the injury benefits are much larger than the injury risks; whereas for the neck, the injury risks are greater although overall there is still a net benefit. When considering this result it should be borne in mind that the Hybrid III MATD dummy neck is substantially stiffer in flexion and extension than a human neck.

At *Figure 7.4* is the average benefit and risk for all test pairs as demonstrated in Iijima's study. This shows the total average injury benefit and risk in terms of average change in NIC across all test pairs and accounting for frequency of occurrence of these impact configurations in accidents. The results indicate the injury benefits are very much greater than the injury risks. This is an encouraging result for a device that was described as an exploratory study.

Iijima completed an impact to the front of a stationery car (impact configuration 115-0/30) with the dummy leaned 45 degrees forward to investigate airbag-to-dummy contact effects in this riding position. When compared to the normal riding position, the test indicated no significant injury potential. The maximum bag internal pressure was 0.40 kg/sqcm. Dummy neck extension and moment increased but were well below the assumed fatal level.

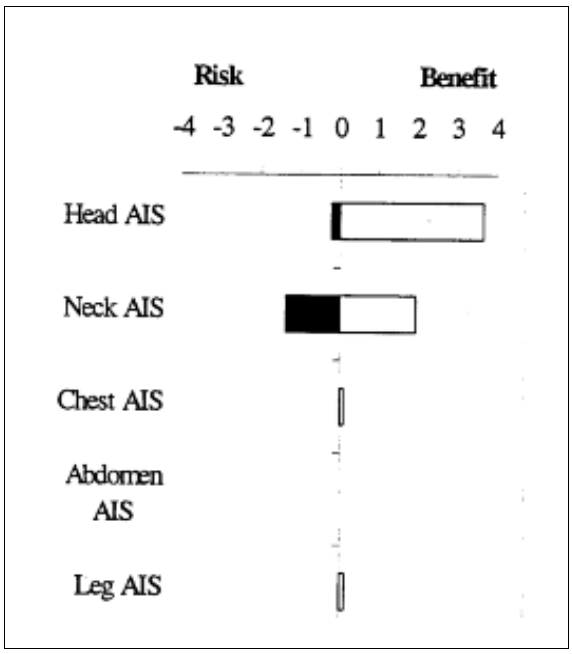


Figure 7.3. *Airbag injury risks and benefits by body region, all test pairs, entire impact sequence. (Iijima et al., 1998).*

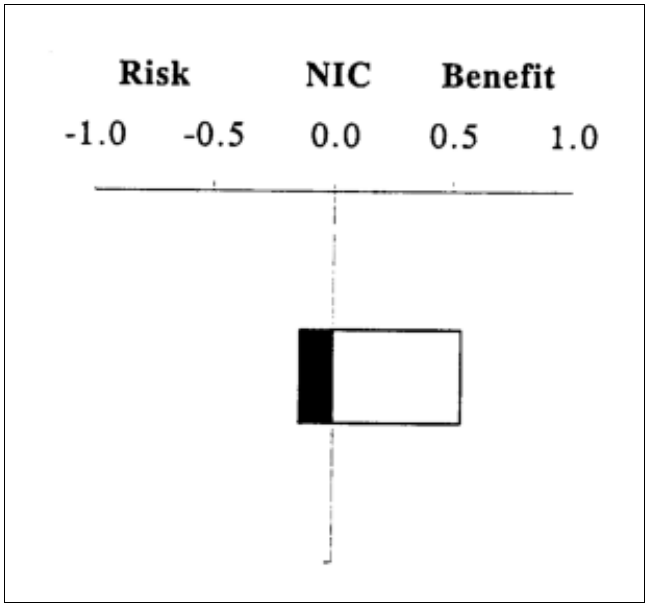


Figure 7.4. *Total average benefits and risks all tests.(Iijima et al.,1998).*

Figure 7.5 presents the overall average positive and negative changes, i.e. injury benefits and risks in terms of Normalised Injury costs, for the 200 simulations taking into account frequency of occurrence for the primary impact period. This indicates an injury benefit during primary impact.

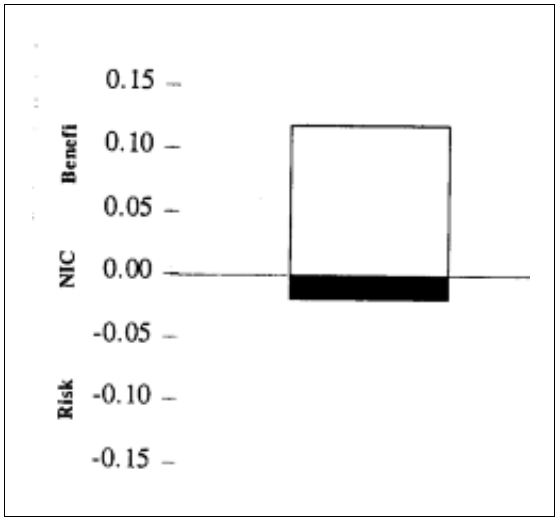


Figure 7.5. *Average positive and negative changes in NIC due to airbags, 200 impact configurations, primary impact period.*

Overall, then, these initial results are encouraging, and it indicates that with further research a fully-practical and affordable safety device can be developed that will reduce injuries to motorcycle-users, especially head and chest injuries.

7.8.1.3. Leg protecting devices

Crash bars

Injuries, particularly fractures, to the lower limbs of motorcyclists are common and a considerable amount of research has been conducted in this area. Generally, lower limb protectors incorporate a bar, “crash bar”, and/or other structure for example a fairing designed to prevent intrusion into the spaces normally occupied by the rider's legs.

Importantly, Craig, Sleet & Wood (1983) observed that 'crash bars' (tube protective devices) were fitted to 21 percent of patients' motorcycles and "appeared to offer no protection to the lower limbs". The authors therefore recommend that: “.. to reduce the incidence of severe lower limb injuries it might help to provide some form of shell surrounding the legs to protect them against impacts from other vehicles which are most likely to strike the outer side of the lower leg (p. 165-66)”.

However, in the same study the authors warned: “.. this form of device offers no protection against impacts after being thrown from the machine, although the resulting lower limb injuries are generally less severe. Special boots with knee protectors made from an impact-absorbent material could help to reduce the injuries if all motorcyclists would wear them - racing leathers are already known to give some protection “.

The need for a standard to ensure the strength of crash bars was noted by Pegg and Mayze (1980). They argued that many of the crash bars fitted were too flimsy or too poorly designed to be effective.

In a more recent study, Quellet (1987) investigated 131 crashes involving crashbar equipped motorcycles. He concluded that: ".. leg space preservation is not strongly related to the occurrence of serious leg injuries in motorcycle accidents, primarily because the leg often does not remain in the leg space during the collision events... thus, conventional expectations of crashbar performance and leg injury mechanisms simply are not supported by the in-depth analysis of actual accident events".

However, in agreement with the conclusions of Craig et al. (1983), Quellet did state that leg protection devices may have the ability to affect favourably those serious leg injuries which result from direct crushing of the rider's leg against the side of the motorcycle during impact. Despite Quellet's relative scepticism, Nairn (1993) argues that such results nevertheless suggest that the severity of leg injuries would be reduced in approximately 50 percent of crashes which involved serious leg injury.

There is considerable concern that structures to provide leg protection may increase overall rider injuries by increasing head and chest impact loads (Quellet, 1990). Although Otte (1998) showed that a fairing can protect the legs without these problems.

Fuel tanks can also sometimes cause damage to a rider's knees or legs (Pegg & Mayze, 1980) or pelvis (de Peretti et al., 1993). In fact, Quellet (1990) notes that suggestions for cleaner design made by the earliest investigations of motorcycle crashworthiness have been largely ignored by recent designers. Bothwell (1971; 1975; cited in Nairn, 1993) recommended that to improve motorcycle collision performance the rider's ejection path should be smoothed and cleared of obstacles or, obstacles should be designed to make them less injurious. For example, care should be taken to ensure that petrol filler caps are recessed, not raised as a potential laceration and collision hazard. Unfortunately, this advice has been largely ignored by 1980's designers, who have placed sharply humped fuel tanks directly in front of the rider's crotch and pubic bone (Quellet, 1990).

It can be seen from the statistics reported in Chapter 6 that certain accident groups show a greater probability of leg injuries than others. These are accidents in which the force is directed into the motor-cyclist's leg. Here the direction of the force against the motor-cyclist's leg is more important than the direction of the force against the motor cycle. The most severe injuries result from the direct force loading, and injuries to the lower extremities caused by contacts during the flight phase are only of secondary importance.

Specially designed leg protecting fairings.

Experimental testing to study different kinds of leg protection have been conducted since the 1970s, and this is fully reported in the EEVC report 1993, and summarised as follows:

Chinn et al. (Chinn, 1984; Chinn & Macaulay, 1986; Chinn & Hopes, 1985; Chinn, Hopes & Finnis, 1989) tested one design of leg protector in 36 full-scale impact tests with three different models of motorcycle. The detailed design of the protection was varied for each model, but the underlying principles were the same in each case, with an energy absorbing component on each side of the bike, well in front of the rider's legs and attached strongly to the frame, but with a facility to break away at very high forces, and a softer knee pad immediately in front of the knees. When compared with a standard machine the tests showed a benefit from leg protection in 61% of cases, no effect in 28% and a detriment in only 11% (IMMA, 1992). Overall, this study concluded that properly designed leg protection can have substantial benefits.

In contrast to this, a study by the International Motorcycle Manufacturers Association (IMMA) carried out 34 full-scale tests, again using three different models of motorcycle (22??). Here too the leg protectors differed somewhat for each machine, but were essentially similar in design. This design contained the energy absorbing and knee protection elements found in the protectors of the first study, but the whole device was considerably more massive and had a blunter profile. Interestingly, these tests used specially-developed dummies with frangible legs. In the latest series of tests, measurements of head accelerations and leg bone breakage were expressed in an overall analysis relating the injury potential to a cost to society. The conclusions were that out of 8 pairs of tests the leg protection was beneficial in 3 pairs and detrimental in 5 pairs. Overall, the study concluded that leg protection increased the net risk of head and leg injuries. Even so, it is interesting that better results for leg injuries overall were obtained in a later design which was lighter and less blunt than the others.

Subsequent to this report both IMMA and TRL pursued their investigations using methods defined by ISO 13232. In particular the use of a motorcycle anthropometric dummy, based upon a Hybrid III and fitted with frangible legs and on-board instrumentation. The IMMA investigations (Rogers, 1998) described tests and analysis of seven test pairs, tests in which the standard Kawasaki GPZ was compared with one fitted with leg protection. The device was found to be beneficial in two cases made no difference in one and was detrimental in four caparisons. Overall the practical tests showed a disadvantage for leg protection.

However, ISO 13232 requires a computer analysis of 200 accident configurations. and these results are described by Kebschull et al. (1998). The results from the simulation of 200 accidents showed that the percentage harmful accidents was 17% and the percentage beneficial was 26%.

7.8.1.4. Combined secondary protection

Safety elements to improve passive safety are possible as a result of the latest developments in motor cycle engineering, but the individual effect should always be assessed in conjunction with all the known accident sequences. Leg protection and even fairings alone can prevent injuries to the lower extremities in some cases, and the air bag and leg pads in front of the rider's legs can influence the trajectory so that a reduction in injury in a frontal collision can be expected.

There is, however, currently some debate over the extent to which leg protection might cause undesirable rotation of the upper part of the body, which occurs in some cases. It seems likely that appropriate design can avoid this problem, but arguments have been made on these grounds against the implementation of this safety element. Similarly, because the air bag only promises a reduction in the injury risk in frontal collisions it has not yet been developed to the extent it actually deserves.

If these assessments are examined more closely, one comes to the conclusion that a combination of these two safety elements is likely to be superior to the sum of its parts, with the two components mutually reinforcing each other, and that this would promote implementation.

Rotation of the upper part of the body, which is detrimental for leg protection and which leads to higher head impact speeds against the accident opponent, can be reduced by an appropriate air bag. Impact tests by Sporner, Langwieder & Polauke (1990) with an impact element in front of the rider's legs, similar to a leg protector, in conjunction with an air bag have shown that this approach promises success. The aim of this impact element in front of the legs was to prevent the motor-cyclist becoming caught up with the handlebars, which obstructs a free trajectory. But this effect would also be achieved by a leg protector, which provides a similar impact element on the side facing the leg. In this combination the leg protector will reduce leg injuries in non-frontal impacts, while the airbag will absorb energy in frontal impacts and the combined devices will raise the rider to a safer trajectory.

In addition to this, special seats have been developed to initiate an upward movement of the motorcycle rider (Berg, Grandel & Queck, 1991; Heyl, 1989; Seidl, 1981). In a frontal collision of the motorcycle, these seats exert an upward component to the rider's motion, so that the head reaches a higher level and, in cases of collision of the motor cycle against the side of a passenger car, there is a good chance that the head of the motorcycle rider will not impact the roof edge. The motorcyclist(s) may fly over the accident partner which is likely to cause less injury than impact with the vehicle side. Here again, it should be straightforward to combine these special seat contours with motorcycle airbags, and to add leg protectors, though comprehensive studies of the combination, across all accident types, will be necessary. In this case, the task of the leg protectors is reduced to leg protection, and not to initiate an upward movement of the motorcycle driver's body. This requirement is left more effectively to the seat and airbag, and there is no reason why leg protectors should reduce that effect.

With all these safety devices in combination, complementing and reinforcing each other's effect, we should at last be close to the aim of a safer motor cycle.

7.8.1.5. Special designs of motorcycle

BMW have launched a TWMV, designated the C1, that is a departure from conventional designs. It is based upon a Scooter layout but also has a “roof” whereby the frame is extended from the rear at the base of the seat base over the rider’s head and joins with the front. *Figure 7.6* is a picture of the C1 and

shows that it is similar in design to the Quasar, built and sold in the UK in the 1980's but only in very small numbers.

Figure 7.7 is a skeletal drawing of the C1 (Kalliske & Albus, 1998) and shows that the frame of the C1 and the roof are of integral construction. The intention is to provide two wheeler transport with greatly improved safety and improved weather protection. The rider is restrained by the use of seat belts and a tuned crumple zone at the front and is further protected in a roll over by the special frame construction that acts as a roll-bar.

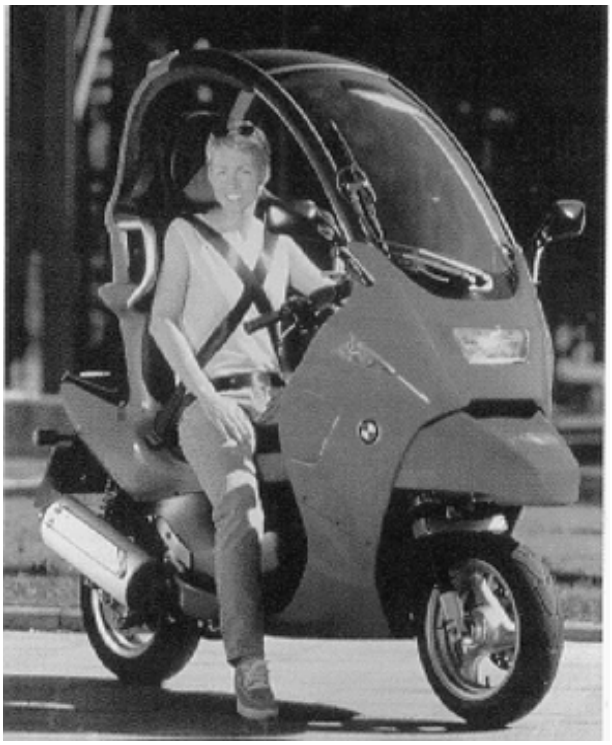


Figure 7.6. *The BMW C1*

The main safety features are:
- Aluminium safety frame with integrated protective roll bars that comply with FMVSS 216 roof crush test.
- Three point lap and diagonal seat belts that comply with ECE-R14
- Safety seat to prevent "submarining"
- Side bars in the shoulder area to prevent sideways slip and intrusion
- Deformable energy absorbing front element
- Front suspension with pitch compensation
- Tempered safety glass windshield

Kalliske & Albus (1998) of BASt have evaluated the performance of the C1 in a series of impact tests and computer simulations. The C1 was evaluated in six impact configurations of which two were in accordance with ISO 13232 and of the remainder, two were impacts into the rear of a car, one into a rigid

barrier and the other, a C1 with a pillion into the side of a car. Specific results are not given but the paper comments that for impacts frontal to the C1,the HIC, was always well below the human tolerance, the neck momentum was reduced by about 50% compared with measurements from a dummy on a conventional two wheeler and the neck force was similar. The chest and hip strain were higher than for a conventional machine but these were similar to what is expected from a belted occupant and were well below human tolerance levels. Lower extremities, leg forces, were very low and only about1/12th of the values normally measured for a two wheeler. Similar results were found for the impacts into the side of the C1 and although the hip measurements were greater they were still below recommended tolerance levels. Head contact with the ground did not occur in these tests although it was thought to be possible.

Computer simulation was used to evaluate the HPC, head acceleration and GAMBIT for the C1 and a conventional scooter, in all seven ISO configurations. The results, although not quoted, indicated that in all configurations, these measurements were very much lower for the C1 than for a conventional scooter. In conclusion BMW AG believe that this type of vehicle is much safer than a conventional two wheeler and should and will provide future road users with a very convenient and safe form of transport.

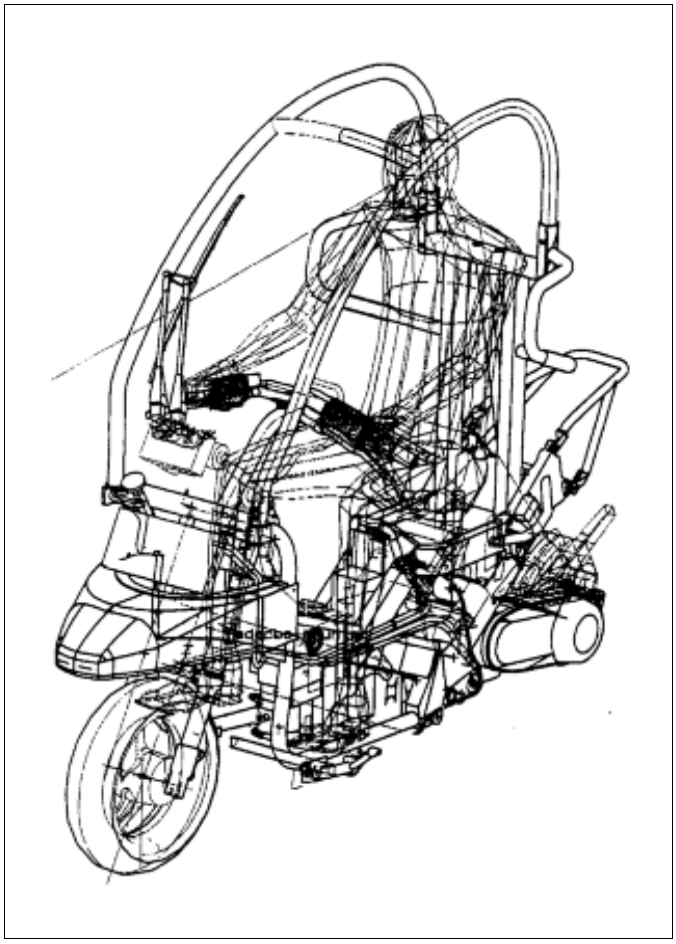


Figure 7.7. *Presentation of the principles of the C1 two-wheeler*

7.8.2. *Rider protection: helmets and clothing*

7.8.2.1. Introduction

Apart from a helmet, the clothing worn by motorcyclists varies from only plimsolls and shorts in hot climates to a complete set of clothing, often of leather or wax impregnated cotton material. Standards exist for helmets in most countries, but only in Sweden does a standard exist for motorcyclists' clothing. This section reviews, first helmets and then protective clothing.

The message that helmets are currently effective but could be improved is explained with reference largely to the COST 327 Literature Review on Motorcycle Helmets and Head Injuries 1997. The COST 327 action is over half completed and will provide comprehensive recommendations on how helmets can be improved. This will have been based upon a better understanding of head injury mechanisms from the accident data collected as part of the study and how such knowledge may be used to improve test methods and, in turn, helmet Standards.

Protective clothing such as leather gloves, jackets and trousers can significantly reduce soft tissue injury, such as lacerations, contusions and abrasions (Motorcycle Safety Foundation, 1993). In addition, protective clothing designed specifically for motorcycling can move the thresholds for more serious injury to higher collision velocities ("The implications...", 1991). The Motorcycle Safety Foundation (1993) are of the view that only protective clothing specifically designed for motorcycling will continue to afford the best combination of fit and protection whilst actually riding. Most motorcyclists, though not moped riders, in Northern European countries wear protective jackets although it estimated that only about half of these riders wear protective trousers and gloves. Riders in hot countries in Southern European frequently wear only ordinary clothing, including shorts and plimsolls, that offers no protection.

It is interesting to note, as a prelude to the information below, that cost-benefit calculations for compulsory wearing of protective clothing by motorcyclists and pillion passengers (Torpey et al., 1991) demonstrated that this countermeasure would need to be only 2.5 percent effective to reach break even point. These calculations were based on police-reported crashes. If these figures were adjusted to account for the under-reporting of crashes, the effectiveness needed for the measure to reach break even point would be further reduced.

Improvements to protective clothing have been proposed which see it playing a more reactive" role in reducing injury. Toms (1990) comments that "I like the concept of turning a motorcyclist into a ' Michelin Man' in a crash. This centres the protection on the rider, and the quality of his or her protection, instead of the motorcycle. Air vests, inflatable clothing, padded plastic shielding, and semi-structural clothing - they all have merit" . However, research into the effectiveness of the " Michelin Man" concept has yet to be reported.

The potential for different types of clothing to protect a rider have so far not been clearly identified in a single document. This chapter attempts to rectify this by bringing together the available knowledge. Injuries which good clothing could protect against are identified and the accident mechanisms described. Different materials and the different types of construction currently used are discussed and the most efficacious of these are identified and described. A CEN standard for protective clothing is currently being prepared and it is hoped that this will cater for the main requirements outlined here.

7.8.2.2. Head injuries and criteria

It is worth noting that the most severe head injuries occur when the head impacts directly with a vehicle (usually a car) or with other even less yielding objects such as roadside furniture or the kerb. Although brain injuries in particular are complex and not adequately described by simple criteria, for research purposes it is necessary to use single indicators to measure the potential for head injury, and these are explained briefly here in order that the uninitiated reader may better understand the requirements.

Head Injury Criteria (HIC and other criteria)

The "Head Injury Criterion" HIC which is in widespread use was developed from the experimentally-derived Wayne State concussion tolerance curve based on observations on volunteers and animals (Versace, 1971). Its rather complex form is a result of attempts (using logarithmic transformations) to produce a simple algorithm:

$$HIC = [\frac{1}{(t2 - t1)} \int_{t}^{t} 1 2a(t)dt)]^{2.5} (t2 - t1)$$

to provide a mathematical "best fit" to a set of experimental data. Here, a(t) is the head acceleration at time t measured in g; t1 and t2 are times (in seconds) of the beginning and end of the head contact.

Most crash helmet impact test standards specify peak acceleration as the criterion, without any limits of duration, and some researchers recommend this approach. However, the use of peak acceleration alone without any allowance for how long the pulse lasts will not detect the difference between a helmet that is a good energy absorber and one that is not. It is encouraging to note that the most widely used Standard, ECE Regulation 22, now incorporates HIC as part of the -04 series of amendments.

The COST 327 Literature Review describes fully the effects of rotational motion, as opposed to linear motion and the resulting brain injuries. The review findings were: that the research reviewed provides fairly consistent findings in relation to linear acceleration and the values in terms of peak g and HIC which correspond to the onset of potentially fatal head injury. In contrast, the findings for rotational acceleration seem to indicate that, although it is likely to be highly injurious, at what level remains uncertain.

7.8.2.3. Current helmets: reported benefits and problems

The following are extracts from the COST 327 Literature review (1997) and serve as a guide to the current situation.

There has been much studied and written on the effect of helmet law repeal and reinstatement in various States in the USA. However, as noted by de Wolf (1986), this type of study evaluates the effect of the repeal of helmet use laws on (in this instance) the motorcycle fatality rate. It does not evaluate the effectiveness of motorcycle safety helmets because there is no direct comparison between helmeted and unhelmeted riders. This is largely true of all such studies and for that reason they are not discussed here except to say that in almost all cases of repeal the incidence of head injury, fatal and otherwise, increased.

Hurt et al. (1981) surveyed over 900 injured motorcycle riders, of which 60% were non-helmet wearers and 40% wore a helmet. The analysis of injuries at the critical to fatal threshold showed that there were 3.5% above this threshold for the wearers but 8.2% above this threshold for the non-wearers. It can be concluded from this that the risk of death is more than halved if a helmet is worn. In his conclusions Hurt states that "helmeted riders and passengers showed significantly lower head and neck injury for all types of injury at all levels of severity".

Otte, Jessl & Suren (1984) studied 272 motorcyclists injured in road accidents around the Hanover area. Non-helmeted riders accounted for 72.5% of the total injuries and yet this group were outnumbered (by how many is not stated) by the helmet wearers. Overall (including figures from a previous study) Otte et al claim that 70% of non-helmeted riders suffer head injuries whereas only 45% of helmeted riders sustain head injuries.

Open versus full-face helmets

For some years there has been an increasing tendency for riders to wear a full-face (integral) helmet rather than an open face (Jet) helmet, largely in the belief that greater protection is afforded by the full-face helmet. However, a full-face helmet is heavier, and it may also increase the tendency for the visor to mist over. It is particularly important that the benefits of open faced helmets are quantified because these are more likely to be worn by moped riders.

Of more statistical significance is Hurt et al.'s analysis (1981) of 900 motorcycle accidents which shows that the advantage of injury reduction increased significantly with increased helmet although a full-face helmet offers greater protection without any disadvantage from increased weight.

Otte & Felten (1991) analysed 598 accidents in which a full-face helmet had been worn and found that the highest percentage of impacts, 34.6%, were in the chin region and that persons who experienced a chin impact were far more likely to have suffered severe head injuries. Otte noted that a frequent side effect of a chin impact is fracture of the base of the skull; Harms' analysis

(1984) shows that skull base fracture is an injury slightly more likely to occur with a full-faced than an open-faced helmet, a finding which is consistent with Otte's. Overall the risk of facial injury is greatly reduced with a full-faced helmet, but the risk of skull-base fractures may be increased.

Improving helmet protection.

Hopes & Chinn (1989) investigated the effect of helmet shell and liner stiffness on the ability of a helmet to protect the head. Helmets made to pass British Standard BS6658 were compared with helmets similar in size and shape, but with liners of different stiffness, ranging from well below to above that of the standard liner: shells with increased stiffness were also tested at stiffnesses 1.5 and 1.8 times that of the standard helmet. All possible combinations were tested. The conclusions were that the stiffer the liner or shell, the higher the peak acceleration and HIC from a given drop height.

The standard helmet was considered to be too stiff and too resilient. For example, when impacted at 6.7 m/s the peak resultant acceleration was 305g and the HIC was 3351. A helmet with a standard shell but a lower density liner gave results of 189g and 1825 HIC. The standard helmet does not absorb energy efficiently in an impact of the sort of severity that a rider may be able to survive. At an impact speed of 6.7 m/s a HIC of 3351 was measured, and yet only 70% of the energy absorbing capacity of the liner was used. It was not until the impact velocity was raised to 12.5 m/s that nearly 100% of the energy absorbing capacity was used, but at this velocity the HIC became nearly 9000, almost certainly unsurvivable. Helmet shells are also too resilient, so that they rebound and thereby increase the total acceleration.

In the same study an experimental helmet was made from an aluminium shell, which had little resilience and a low density liner. This was tested at 6.7 m/s giving a peak acceleration of 102*g* and a HIC of 602 compared with the 305*g* and HIC of 3351 of a standard helmet. This experimental helmet has a greatly superior performance, but the materials would be insufficiently durable for a practical helmet. Nevertheless, it indicates the sort of improvement which might be possible. Gilchrist & Mills (1987) has also studied the effect of materials on helmet efficacy and their conclusions are similar to those of Hopes and Chinn (1989).

Overall, it seems that helmets are too stiff and too resilient. However, while the use of peak acceleration alone as a standard criterion can control the stiffness of a helmet, it cannot ensure that the helmet absorbs energy efficiently, and the use of a time-dependent criteria such as HIC is essential for this purpose.

Helmet standards

That current helmets afford good protection is in no doubt, but it is clear that there is much room for improvement and the route is through improved standards. Efficient energy absorption with the optimum impulse, minimum tendency to induce rotational motion and a comprehensive evaluation of the whole helmet including the chin guard of a full face helmet are features for

which standards should require tests. Currently only the British Standard 6658 includes tests for rotation and the chin guard.

7.8.2.4. Protective clothing

Injury prevention and reduction

It is essential to understand what protective clothing can and cannot protect against. It is desirable that some indication should be given to prospective purchasers of clothing that will indicate to what extent the clothing will achieve protection as follows:

a. Prevention of most laceration and abrasion injuries that occur when a rider slides on the road surface after falling off.
b. Prevention of contamination of open fractures by road dirt.
c. Reduction in the severity of contusions and fractures, with the prevention of some fractures and joint damage.
d. Reduction in the severity (or prevention) of muscle stripping and degloving injuries, particularly to the lower leg and hands.
e. Prevention of accidents by maximising the conspicuity of the rider.
f. Prevention of accidents by maintaining the rider in good physiological and psychological condition by keeping the rider dry, warm, comfortable and alert.

Limitations of the protection offered by clothing

Some accidents involve mechanisms and forces on the body that clothing cannot, so far as is known, significantly mitigate. These include:

a. Severe bending, crushing and torsional forces to the lower limbs, which occur in particular when the leg becomes trapped between the motorcycle and another vehicle or the road.
b. Massive penetrating injuries on any part of the body.
c. High energy impacts on the chest or abdomen causing injuries through shock waves, and severe bending forces such as when the torso strikes an upright post.

Theoretical calculations suggest that the necessary thickness and mass of an effective rib cage or spinal column protector is such that they cannot be incorporated in motorcycle clothing using current technology.

The collation of data from crash damaged suits enables the determination of the strength required by particular areas of garments to remain intact in accidents. *Figure 7.8* shows the areas of abrasion recorded from 20 consecutive suits examined in a study by Woods, as yet unpublished. *Figure 7.9* shows the abrasion perforations and tears on a total of 60 suits including the above twenty, and *Figure 7.10* shows seam and zip failures on the same 60 suits.

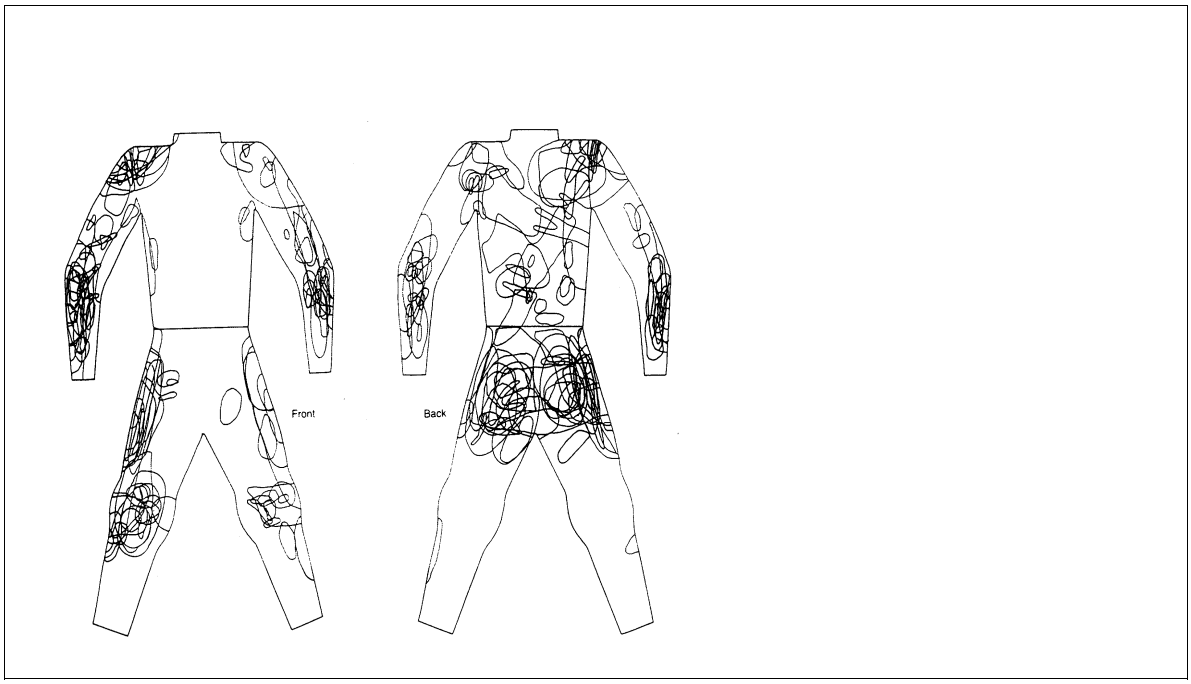


Figure 7.8. *Areas of abrasion damage from 20 accident-damaged leather suits*.

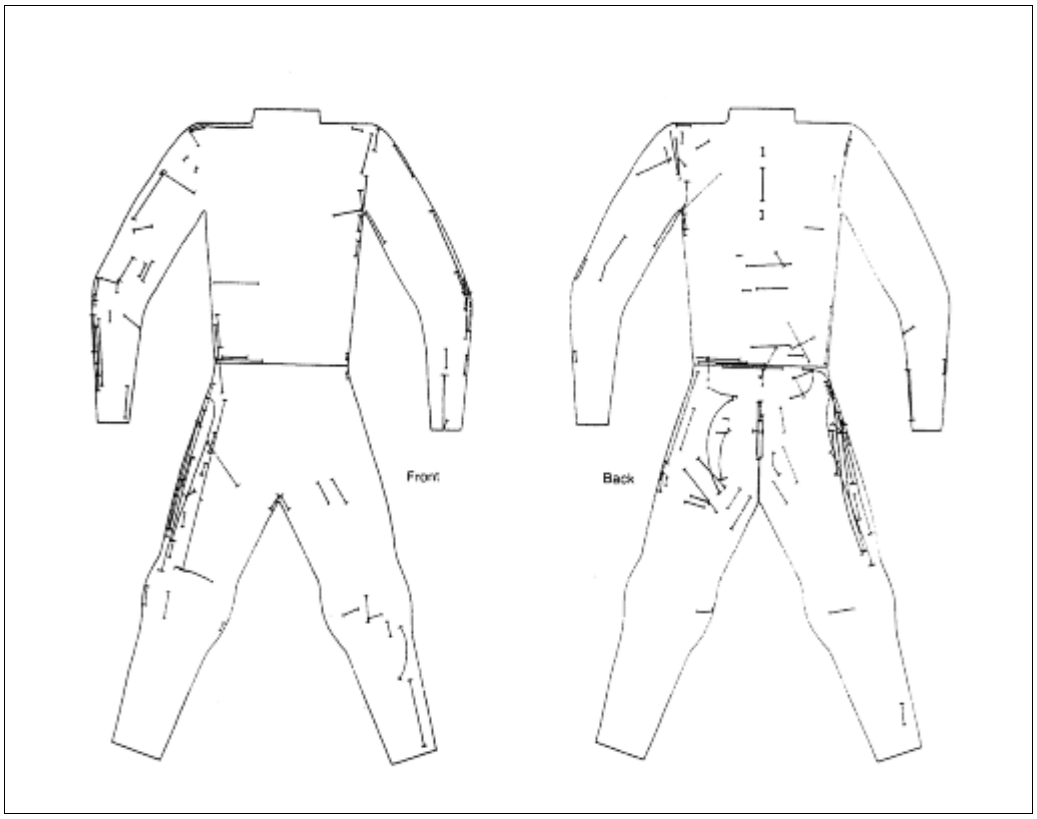


Figure 7.9. *Abrasion holes and tears on 60 accident-damaged leather suits*.

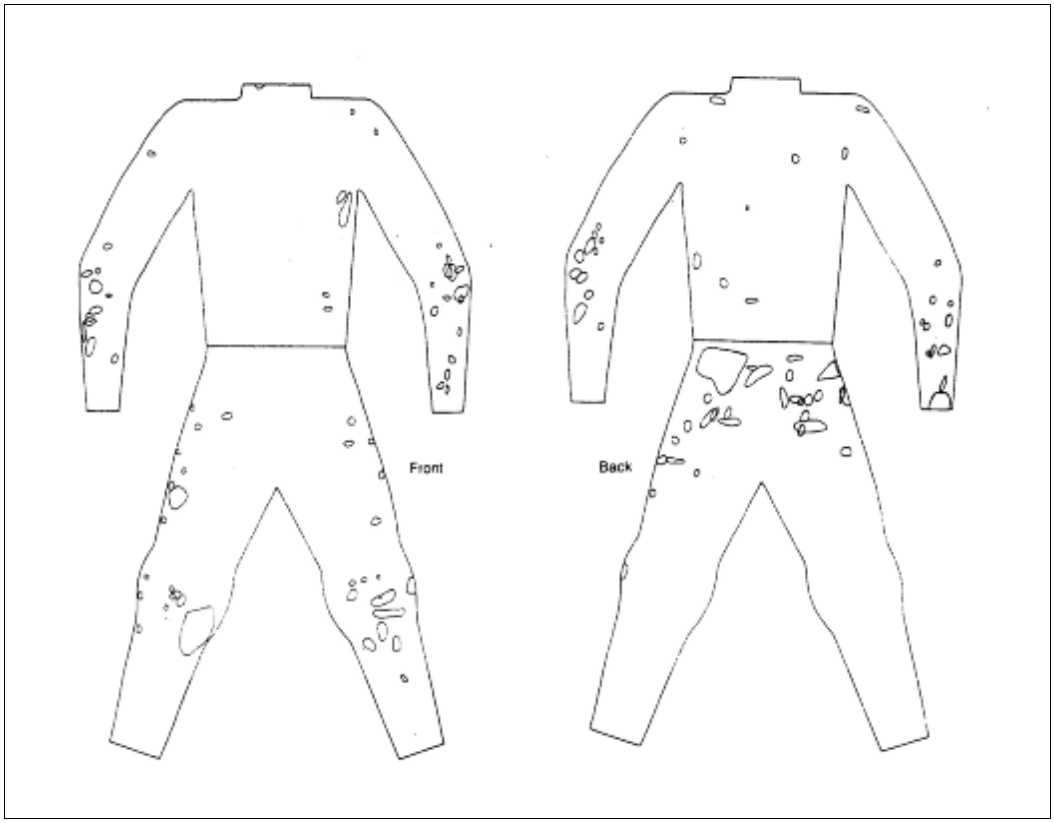


Figure 7.10. *Seam and zip failures on 60 accident-damaged leather suits*.

Other evidence supports these findings. The extent of burns to the lower extremities can be reduced by covering the legs and wearing adequate footwear; for example, thick jeans and long leg boots (Pegg & Mayze, 1980). Heel flap injury can easily be prevented by the wearing of protective footwear while riding, and by the installation of wheel guards (Das De & Pho, 1982). Toms (1990) comments that "reinforced, sturdy and lightweight motorcycle boots, not unlike the motocross variety, are clearly beneficial. Padded knee shield and thigh pads, like hockey and football players use, are also helpful. Styling and crash research on these concepts awaits attention". Relatively little attention has been given to the reduction of very common, but not severe injuries, although their total cost is likely to be considerable.

7.8.2.5. Physiological stress and clothing

Stress: Types and reduction

The discomfort caused by physiological stress is important because it can increase the likelihood that a rider might have an accident. It can cause:

a. Impaired sensation and thus perception and a reduction in the accuracy of the control of actions.
b. Dulled responses and increased reaction times.
c. Impaired motor responses.
d. Increased fatigue.

Physiological stress occurs when physiological work has to be done to counter the discomfort, when there is a homeostatic physiological response to the changes the physical factors have caused in the body, or when a task is continued to the point when fatigue occurs. These problems were quantified in a survey by Robertson & Porter (1987), who showed that riders suffered the following stresses:

a. 60% reported muscular stress.
b. 33% reported thermal stress.
c. 27% reported noise stress.
d. 22% reported vibration stress.

The clothing worn can both increase and reduce these problems and therefore correct choice is essential for improved safety.

Preventable physiological stress: Cold stress.

Clothing effectiveness in preventing cold stress is directly related to the thickness of the insulating air layer and the stillness of the air in it. Therefore, clothing should permit neither wind entry nor forced convection to be caused by wind buffeting. The protection needed against cold stress depends on the riding conditions and riding duration. Data is available from measurements on motorcyclists riding at motorway speeds (around 110 km/h) in the UK (Woods, 1983; 1986).

A third of the basal heat production of riders can be lost from the neck and face if they are not adequately protected in cold conditions. Except for the nose, around the eyes and where the helmet is a close fit, all the skin should be covered with at least 10mm of insulation contained within a completely windproof cover (Woods, 1982). To provide adequate protection the lower edges of the garment must be inside the body oversuit and should be designed to allow the head to turn fully for traffic observation.

The hands are kept warm by blood flowing to them, and the bloodflow is halted either by nervous control from the brain if the whole body becomes cold, or by a local response if the hands themselves become cold. For the hands to remain warm the body must be at or above normal temperature, and the insulation over the hands must keep the skin warm (Woods, 1982): under these conditions the hands sweat slightly.

Foot heat supply and bloodflow control is similar to that of the hands. The motorcyclist's shins are more subject to cooling than the forearms which are more active. If the shins become cold, foot bloodflow is negligible. Insulation for the feet generally has to be within the impact protective layers of the boots. It is very important that significant pressure is not exerted on the foot or ankle skin as this will also halt bloodflow.

Wet stress

Many garments on sale are ineffective at preventing wet stress, though knowledge is available to do this. The most suitable overgarment materials

(for example, some polymeric coatings) will provide water vapour permeability when the outer surface is wet. These fabrics are available in high visibility fluorescent colours, which should be used to provide high conspicuity under the poor visibility conditions of wet weather.

Vibration and noise stress.

Some protection against vibration can be provided in boots and gloves by incorporating gel or foam materials in areas that contact the motorcycle (materials used in industrial clothing for this purpose may be suitable). Clothing should be designed so that it does not flap or vibrate in the airstream created during riding, particularly near the helmet.

Postural stress

Postural stress cannot be prevented by clothing, but clothing should not contribute to it. Clothing that is close fitting and is designed specifically for standing and walking is likely to cause postural stress during riding.

Heat stress

Little attention has been paid to designing clothing that will minimise heat stress in motorcyclists, but this is important if riders are to be able to wear impact protective clothing in warm conditions, particularly in the south of Europe. Significant progress has been made in the design of military and industrial clothing for use in hot situations, particularly when mechanical and chemical protection are also required. The following points are of relevance to the design of motorcycling clothing:

a. It is unlikely that air-conditioned clothing with a pumped cool air supply will be practical for motorcyclists.
b. The available cooling mechanisms are the windflow generated by the rider's motion and his sweating mechanism. Potential points for air to enter clothing are those with air pressure on them. These are the forward facing parts of the body such as the torso, wrists, forearms and legs. Air exit points may be placed wherever the internal pressure in the clothing exceeds the external pressure. The air must flow freely over the skin to evaporate sweat.
c. Entry and exit points, and permeable or ventilated materials, should not compromise the impact protection offered by the clothing.
d. Perforated leather, woven or knitted aramid fibre fabrics without coatings and coated net materials are available that have adequate tensile strength and abrasion resistance.
e. Infra-red absorbence and reflectance by the outer layers of clothing are important and particularly so in hot climates where long wavelength rays can be emitted by the road surface. Clothing should be designed to reflect, not absorb, if the rider is to be kept cool.

7.8.2.6. The selection of clothing for particular uses

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

a. Clothing must be able to protect against, wet, cold and heat even when these occur for long periods.
b. If the hazard is a single event such as a collision the likelihood of it occurring should be assessed. Falls and impacts are common in all types of riding (including off-road) except on motorways. The severity of the collisions is dependent on the surface impacted. However because it is not possible to control where a rider will travel at any one time, the clothing must satisfy all requirements.
c. A set of clothing may be bought by a rider from different sources. It is therefore important that advice should be given on compatible items. For example there should not be a gap between boots and trousers. The outermost layer should always be of high conspicuity even in wet weather.
d. Clothing should be designed to ensure that all tasks required of a motorcyclist are easily accomplished and in particular movement must not be restricted.
e. Manufacturers of motorcycle clothing should be required to state the conditions for which an item of clothing is suitable, and with which other items it is compatible.

7.8.3. *Other vehicles: structural changes*

Motorcycle riders are a minority in traffic and they collide most frequently with cars. The best that can be done is to reduce the likelihood of conflict and to ensure compatibility between the structures of the motorcycle and other vehicles. However this can be difficult.

It is possible to design the outer surfaces of four-wheel vehicles to minimize injury to motorcycle riders. Modern cars have rounded edges and "soft" contours to improve their aerodynamics, and this can also benefit motorcycle riders in a crash. However, little has been done to design cars specifically to improve the safety of riders in an impact, but various possibilities exist, and these would also be of benefit to pedestrians. German universities (1,2) have proposed many ideas for improvement, these including a "soft nose", a polyurethane-covered hood and energy absorbing material on the front and side of the roof.

The EEVC has already formulated a test procedure for the front of cars to ensure that injuries to any pedestrian they collide with will be minimized, and it has also demonstrated the sort of modifications which would be necessary to current car designs to meet the test requirements. These modifications are likely to impose relatively little additional cost, and they need not restrict the appearance of the vehicle front unduly. The test procedure is currently being considered by the European Commission for adoption as a Directive (3). If cars are designed to meet these requirements they will also reduce injuries to motorcyclists (and pedal cyclists) in frontal impacts, though the problem of serious injuries caused by the hard A pillars and windscreen header remains to be solved. But it is conceivable that similar attention to the side panels of

cars, and especially to the roof edge, could be beneficial in reducing injuries in other accident configurations.

Motorcycles rarely collide with trucks, but when they do the rider is usually severely injured (4). Rear and side under-run guards are now obligatory in many countries (2). It is recommended that this kind of protection be further improved and fitted to the front of trucks to prevent an injured motorcyclist being run over by the truck. The EEVC has recently reported on the benefits and likely effectiveness of underrun guards fitted to the fronts of trucks (5), and discussions are currently taking place in the United Nations Economic Commission for Europe Motor Vehicles Committee to formulate a regulation for this type of protection. Here again, the protection is not considered primarily for its benefits to motorcyclists, but there is no doubt that, if they are adopted, they will reduce some motorcyclist injuries.

A factor related to primary safety is the aerodynamic "canal effect", induced by long trucks or buses on single track vehicles (6, 7), which tends to suck the bike towards the larger vehicle. Weave reactions of the motorcycle can be the result, but improved motorcycle aerodynamics and modern suspension have reduced the potential for problems.

Spillage of diesel fuel reduces the friction between the tyre and the road and can be especially dangerous to motorcycle. Modern systems which prevent the fuel tank being overfilled and with fuel cap self-locking devices have been developed, and these should become standard equipment for all diesel powered vehicles.

7.8.4. *Crash barriers and safety fences*

The road environment is often overlooked as a motorcycle hazard. Broadly, relevant countermeasures are concerned with improvements to highway guard railing and road surface.

Approximately 3.5 percent of motorcycle fatalities in the US in 1984 involved guardrails. Regional surveys in the Federal Republic of Germany suggested that in 1986 and 1987, approximately 15 percent of motorcycle fatalities involved crashes with guardrails (Koch & Brendicke, 1988). The injuries reported were generally severe due to the aggressive nature of guardrail design.

Brailly (France, 1998), has studied accidents wherby a motorcyclist has collided with a crash barrier. The results showed that the risk of fatality per accident is five times as great as the national rate for all motorcycle accidents and account for 8% of all motorcycle fatalities and 13% of fatalities on rural (outside of towns) roads. The report strongly recommends that the use of a shield on barriers and also recommends tha introduction of a safety zone near the hard shoulder on left hand bends (presumably right hand bends for countries driving on the left) with a radius of less than 250 m and a wider section for the hard shoulder on the left of right hand bends, before the protective barrier in the centre. The shield may reduce tha fatalities by up to a half.

Experimental designs which utilise both a lower W-beam and an impact attenuator (made of neoprene that envelops the guardrail post) to protect fallen riders and pillion passengers continue to be examined in France and Germany. Specifically, Domhan (1987) reported that protective devices of these types have been installed on about 80 kilometres of guardrail in several federal states of Germany.

Although roadside furniture is frequently a hazard to motorcyclists safety fences or crash barriers are of particular relevance because they provide valuable safety protection in preventing vehicles from crossing into opposing traffic or leaving the road and they work perfectly well for four wheeled vehicles, they can present a severe hazard to motorcyclists (8).

An analysis of motorcycle accidents involving crash barriers revealed that 15 % of all fatalities are caused by direct impact of the rider's body against the crash barrier. Domhan (1987) found that, among 50 motorcycle riders who suffered a collision with crash barriers, 3 were killed, 31 persons were seriously injured and 16 were slightly injured. There are several different designs of barrier, and in general testing of their effectiveness is limited to four-wheel vehicles, so that potential problems for two-wheel riders may not be identified. Most safety fences in current use consist of horizontal steel beams ("tensioned corrugated beams" or "open box beams") supported on vertical posts which are designed to break away when impacted by a car or larger vehicle, but there is increasing use of concrete barriers, and wire rope fences are also coming into use.

Possible and effective ways of reducing motorcycle casualties caused by crash barriers are the dismantling of unnecessary crash barriers, and for steel beam fences the use of so called Sigma posts instead of the standard IPE-100 posts, covering posts with energy-absorbing protectors and the addition of a second spar.

The most significant feature of Sigma-posts is that they have a considerably less aggressive outline compared with IPE-100-posts (*Figure 7.11*), a property which greatly reduces the probability of a serious injury in an impact. The addition of a lower spar prevents direct impact or contact between the motorcycle rider and the post itself. This feature seems to be especially effective where road layout encourages angles of acute lean and high riding speeds and, consequently, high impact speeds against the barrier.

Padding of the barrier face itself with some form of protective padding seems unlikely to be practical or cost-beneficial, but covering the crash barrier support posts with energy-absorbing material can produce a clear reduction of injury severity. Domhan (1987) reports that in comparable accident situations the injury severity could be reduced from AIS = 4 to AIS = 1 or 2 by the use of crash barrier protectors. Domhan also analysed the cost-benefit of equipping German crash barriers with safety features. He examined two possible solutions: the covering of crash barrier posts with energy absorbing material and fixing a second spar to the original crash barrier. Results show that equipping all crash barriers with additional safety features will incur high costs which are unlikely to be outweighed by the saving in injuries. This is true for both of the above types of safety measure. However, if account is taken of the fact that motorcycle accidents are likely to be concentrated on

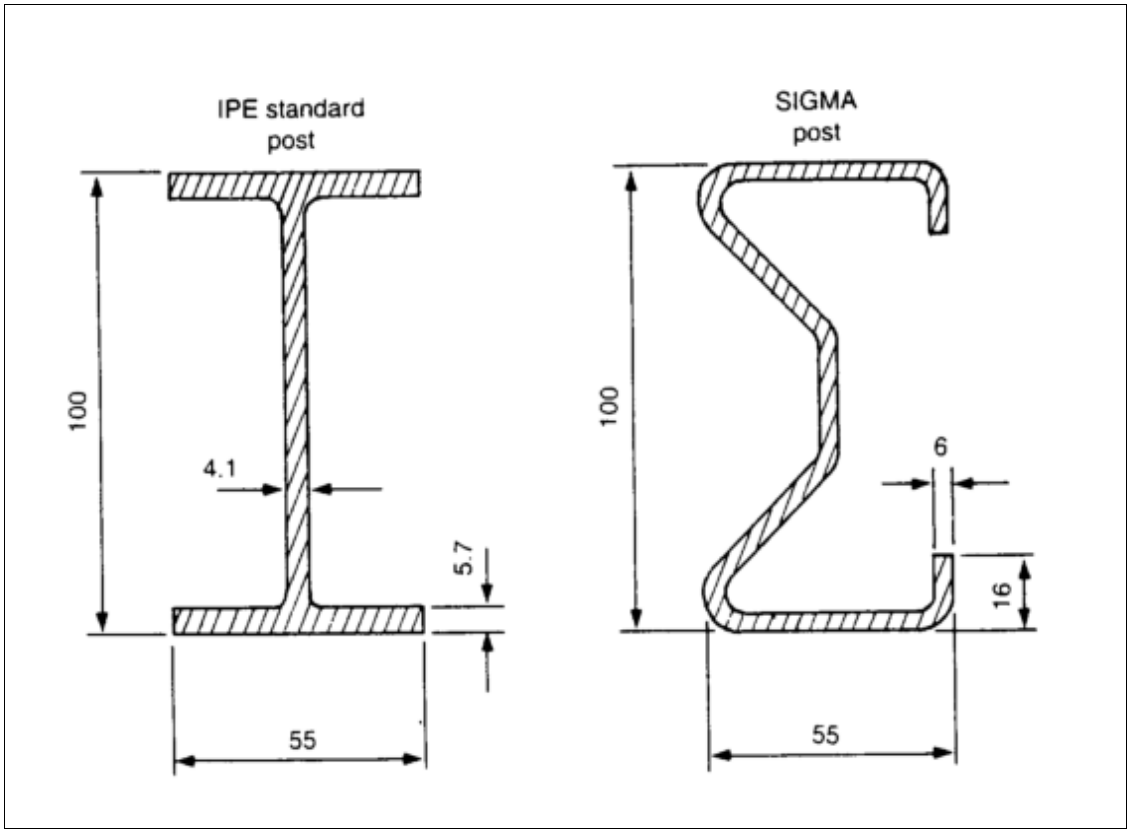


Figure 7.11. *Sigma posts compared with standard posts*.

certain sections of road and the improvements are implemented only at these points then the results of Domhan's study change considerably. If it is further assumed that in 10 % of all sections equipped with crash barriers there are between 20 % and 40 % of all motorcycle accidents with heavy bodily impacts, the benefit becomes greater than 4 times the cost.

7.8.5. *In conclusion*

It is clear that wearing a helmet reduces the risk of a fatality by about half, but even when a helmet is worn head injuries remain the main cause of motorcycle fatalities. There is no evidence that wearing a helmet increases the risk of neck injury, although neck injuries may be slightly more frequent with full-face than with open-face helmets. However, full-face helmets offer better protection then open-face helmets for the face and chin area. Despite the effectiveness of helmets, they could be improved. Current designs are too stiff and too resilient. Energy is absorbed efficiently only at values of HIC well above those which are survivable. Helmet shells and helmet liners should be less stiff and absorb energy efficiently from HIC of about 1000 upwards. Rotational acceleration is also likely to be an important cause of injury, though at what level remains uncertain, and helmet design should ensure that the potential for rotation is minimised.

Good protective clothing can reduce the incidence and severity of laceration and abrasion injuries and minor fractures, but it cannot prevent crushing, bending and torsional injuries, nor massive penetration. Clothing is also important in protecting the rider from physiological stress caused by excess of heat, cold or wet. It is extremely important that clothing designed to reduce the severity of injuries does not in turn cause accidents by increasing the potential for physiological stress.

Helmet standards need to be improved, and protective clothing Standards should be introduced for normal road use to ensure better protection. A test for the chin guard of a full-face helmet should be introduced, and the potential for rotation should be measured. The current CEN Standard for protective clothing covers only protectors, if fitted, and racing clothing this is inadequate and any clothing sold as protective clothing should be clearly marked and indicate the extent of protection.

8. Summary and discussion

8.1. **Rider population**

Statistical information in this report refers mostly to Western Europe, i.e.: A, B, D, DK, E, F, FIN, GB, GR, I, IRL, N, NL, P, and S. Sufficient information on Eastern European countries was not available. Some of the information was not even available for all western European countries.
In Western Europe the *absolute number of mopeds* is 13-14 million. This number has not changed much over the last ten years, but used to be higher before that. France shows a remarkable decline in number of mopeds from over 5 million in 1980 to less than 2 million in recent years.
The *absolute number of motorcycles* in Western Europe is lower than the number of mopeds, with almost 10 million. This number is slowly, but constantly increasing. Great Britain is an exception with decreasing numbers of motorcycles and mopeds.

There is a clear regional pattern with many more mopeds/motorcycles in Southern European countries as compared to Northern Europe. The number of *vehicles per 1000 inhabitants* is ca 50 mopeds for southern countries and 30-40 motorcycles. For northern countries the rates are c.20 for mopeds and 10 for motorcycles. Switzerland has remarkably high rates for both mopeds and motorcycles: c.50/1000 inhabitants.
Absolute numbers of mopeds and motorcycles are also high in Southern Europe, with Italy having the highest numbers: 5 million mopeds and 2.5 million motorcycles. In midwest Europe, Germany has about the same number of motorcycles as Italy (2.5 million), but a much lower absolute number of mopeds (1.7 million). The absolute numbers of mopeds/ motorcycles in northern countries is again low.

Because of the low minimum legal age for moped riding, many of the riders are young. During recent years, scooter models became popular. Motorcycle riders used to be young as well, but there is a long-term trend with fewer young riders and many more older. Today about 75% of motorcyclists are older than 25 years. The population of female riders of both moped and motorcycle is small and seems to vary from country to country. For example, in France less than 5% of motorcyclists are female, whereas in Germany the proportion is slowly increasing and is now almost 15%. For mopeds, the proportions of female riders seem to be slightly higher than for motorcycles. There is a trend towards more powerful engines for motorcycles, but street, touring and custom models seem to be more popular than sports models. Recently the use of 125cc motorcycles has become more popular with older riders in Germany and France, after a change in legislation.

Little is know about the actual use of mopeds/motorcycles, i.e. their kilometrage, kind of trips, types of road etc. For some of the midwest European countries, the average number of kilometres per year are estimated at 2000-3000 per moped and 5000-6000 per motorcycle. Motorcycles are mostly used for recreational trips, but the proportion of riders who use their

motorcycle daily is nevertheless close to 50%. Daily use of mopeds is probably higher than for motorcycles.
It seems obvious that climate is an important factor in the use of mopeds/motorcycles, with not only more vehicles but also more kilometres per vehicle per year in Southern European countries.
Other factors that are likely to influence the number and use of mopeds/ motorcycles are the direct costs involved (of the vehicle, taxes and insurance) as well as legislation (such as minimum rider age, training and licensing requirements, and special traffic rules) and the range of models on the market. Owning and using a moped/motorcycle also has a strong emotional value. Being in control of the vehicle with the whole body, directly sensing the speed, testing the limits of safe riding, competing with other road users, being different from the majority of road users, may all be important motives for certain groups of riders. Others may enjoy being in the open air away from everyday life. With increasing numbers of cars on the road and the congestion problems as a result of this, the use of a moped/motorcycle can also be more practical, saving time and money as compared to using a car.

8.2. **Legislation**

As a result of European regulations, the legislation concerning mopeds and motorcycles has become more uniform in recent years. But there are still many differences in detail.
In most European countries *mopeds* now have a speed limit of 45 km/h and an engine of less than 50cc. The minimum age for riding a moped varies between 14 and 18 years. Some countries have special sub-categories of mopeds with lower speed limits.
Many countries, but not all, require the passing of a special test. This is usually a theoretical and practical test, but some countries only have a theory test. Several countries allow riding a moped at a lower age after passing a test, resp. at a higher age without a test, or with a car or motorcycle license instead of a special test. Countries with low speed mopeds usually have a lower age limit for riding these mopeds and/or a simpler test or no test at all. Some countries allow riders of (slow) mopeds to use bicyle facilities; some countries do not allow passengers on mopeds; in some countries the wearing of a helmet is not compulsory for all moped riders.

The European regulations require a minimum age of 18 for riding a *motorcycle* with limited engine performance, and a theoretical and practical test. Great Britain makes an exception with an age limit of 17 years. Riding an unlimited motorcycle is allowed after at least two years of riding a limited motorcycle. The European regulations also provide the option of an age limit of 21 for unlimited motorcycles (and a theoretical and practical test) without prior experience on a limited one. Most European countries have now adopted this option.
A special category of light-weight motorcycles with an engine of less than 125cc and limited performance is recognised by the European regulations. The minimum age for this category is 16 years and there is an option allowing the use with a car license instead of a special theoretical and practical test. Not all countries have adopted the 125cc category and of those which have, some have a higher age limit than 16 and some have chosen the option of a car license replacing a special test. Some countries have special

restrictions for beginning riders such as a ban on passengers or on motorway riding.
With regard to riding speed and position on the road, motorcyclists follow the same traffic rules as car drivers. Some European countries require the use of headlamps during daytime by all motor vehicles (including moped/ motorcycle) and some have this requirement only for mopeds/motorcycles. Helmets are compulsory for motorcyclists in all countries, although actual wearing rates may be lower than 100%.

8.3. **Accidents**

The number of *motorcycle fatalities* in western European countries is more than 4000 per year. For *moped fatalities* the number is about 2500. Together they represent 10-15% of all traffic fatalities. These numbers are high in relation to the numbers of vehicles. Since there are more mopeds than motorcycles, the *rate of fatalities per 10^5 vehicles* is even worse for motorcycles. However, the use of motorcycles in terms of kilometrage is probably higher.

France has a high rate of moped fatalities (circa $30/10^5$ mopeds/year) and this has not changed much over time. Sweden and Norway have shown a considerable decline and now have a very low rate (circa 5). The trends are quite different between countries.
For motorcycle fatalities, the rate is again high for France ($100\text{-}90/10^5$ motorcycles/year) and in this case low for Italy (20). Except for Greece, the rate is decreasing. Great Britain shows a strong decline in absolute number of fatalities because the number of motorcycles declined as well as the rate of fatalities per number of motorcycles.

Several factors contribute to the wide variation between countries in fatality rates of mopeds and motorcycles. The characteristics of the rider population may be different. As a consequence of differences in legislation ,the age distribution and level of training will vary. The conditions of riding in terms of type of road, other traffic etc. may also differ between countries. But to what extent these factors actually contribute in the case of each country is not known.

In most European countries, the absolute number of moped fatalities under 25 years of age is about the same as for older riders. For both moped and motorcycle, the rate of fatalities per 10^5 vehicles is much higher for young than for older riders. Nevertheless, there are more motorcycle fatalities over 25 years than younger. This does not apply to Greece, Spain and Italy, where the numbers are about equal in both age groups. Ten to fifteen years ago most countries used to have many more young rider fatalities, but the age distribution of the motorcycle rider population has changed to more older riders.

For both moped and motorcycle more than two-thirds of the serious accidents are collisions with a car, many of these at intersections with the car driver coming from a side road or turning in front of the rider. Of course there are some differences between moped and motorcycle accidents related to their use (lower speed and more short trips in urban areas for mopeds).

8.4. **Safety problems**

Both mopeds and motorcycles have some special characteristics which directly or indirectly contribute to their relatively high number of accidents. They are single track vehicles, without a bodywork. The fact that they are *single track vehicles* means that the rider has difficulty controlling the vehicle, in particular when cornering or braking and even more so in emergency situations. Even though modern mopeds/motorcycles have good brakes and tyres, the control of the vehicle in all kinds of situations requires special training and experience. The single track character also implies that riders have more difficulty coping with imperfect road surfaces and obstacles on the road. This does not seem to be fully recognised by road authorities.
A *small frontal area* contributes to the problems of the perception of mopeds/ motorcycles by other road users. Small numbers of mopeds/motorcycles on the road also contribute to this problem as does the behaviour of the riders insofar as it is different from car driver behaviour. Because of the small numbers, other road users may not realise that mopeds/motorcycles are relevant objects for them, i.e. they have to search for their presence and take action to avoid a collision. This means that riders of a moped/motorcycle need training and experience in recognising situations in which other road users may not react adequately to their presence.
The *small size* of a moped/motorcycle and their *low weight in relation to their engine performance* provide opportunities to their riders for behaviour which is different from car drivers. They can overtake where cars can not, they can accelerate faster. Other road users may not expect this behaviour and riders who behave like this will have to realise this and learn how other road users will (not) react to this.

All this serves to explain why *age and experience* are important for the safety of riding a moped or motorcycle. *Motivation or the style of riding* is important as well. Most riders will enjoy the direct sensation of speed (offered by the absence of a bodywork) and the control of the vehicle with the whole body. Other riders are more attracted to use a moped/motorcycle because of the opportunities to overtake, to accelerate and go fast. This behaviour seems to be particularly attractive to many young riders, but is potentially dangerous because of the small safety margins and the (lack of) reactions by other road users. To a certain extent a rider will chose a moped/motorcycle model which reflects or actually allows the kind of behaviour to which the rider is attracted. This explains why a statistical relation may be found between moped/motorcycle characteristics and accident rate. But it is the rider motivation or riding style, rather than the vehicle characteristics which can explain this relation.

The *absence of a bodywork* means that riders of a moped/motorcycle have little or no protection against collision impact. It is this same vehicle characteristic which adds to the sensation of (fast) riding, which is one of the attractions of riding a motorcycle. Until now, there has been little attention to the characteristics of both moped/motorcycle and collision object/vehicle in contributing to the injury consequences to the rider of a moped/motorcycle.

8.5. Safety measures

Because of the high accident rate of mopeds and motorcycles, there is a great need for more and/or more effective safety measures. It may even be argued that in the case of riding a moped/motorcycle, safety measures should be stricter than for the use of other vehicles. It might at least be accepted that some measures are specially designed and applied for the safety of riders of mopeds and motorcycles. Since the lack of protection can only partly be compensated by protective devices, much depends on the effectiveness of other measures.

Training and experience of riders are important to control the moped/ motorcycle in all kinds of situations, to cope with imperfect road surfaces and obstacles on the road, to recognise situations in which other road users may not react adequately to their presence and to learn the consequences of behaviour which is different from that of car drivers and how to cope with these consequences. This is all in addition to what all road users or car drivers have to learn about safe behaviour. In other words, learning to ride a motorcycle safely may take longer and to a certain extent is different from learning to drive a car. Since mopeds have a lower speed, this is only partly true for learning to ride a moped.
From research into learning to ride a moped/motorcycle, there is no clear answer to such obvious questions as

- What should a learner rider learn as a minimum to be able to safely ride a moped/motorcycle?
- How can this be learned effectively and efficiently, in how much time and in which sequence?
- In what way is learning to ride a moped different from learning to ride a motorcycle or is learning to ride a low performance motorcycle different from learning to ride a high performance one?

In fact there is little evidence that moped/motorcycle training programs contribute to the safety of the riders. For that reason there is a need to do more and better research into the training of moped riders and motorcyclists. However, there is no doubt that riding a moped /motorcycle safely requires both theoretical and practical training. The development of new simulation techniques offers new opportunities for training programs.

Legislation concerning mopeds and motorcycles shows differences in minimum age and training/testing requirements for different categories of moped and motorcycle. These differences seem to be based on the notion that riding a high performance motorcycle requires more maturity and more and special training; less maturity or less (special) training may be compensated by lower engine performance or speed. Apart from the recently introduced higher age limit for riding an unlimited motorcycle, the requirements for motorcyclists are roughly similar to those for car drivers. The same age limit applies to both cars and motorcycles and the duration and content of compulsory training programs and/or testing are roughly the same. For riders of a light weight motorcycle the age limit is lower and still lower for moped riders. The reason for a lower age limit than for car drivers may be that the higher accident rate is mostly a higher rate of injury/death for the riders themselves and not for the other road users with whom they collide. The effects of this legislation have not been thoroughly evaluated. It is obvious,

however, that legislation only gives minimal requirements and that training on a voluntary basis is highly desirable.

Although compulsory training should aim at improving safety, there are some considerations to be made. Providing training programs may improve the safety of those who would be riding a moped/motorcycle anyway, even if there were no training. A program may also invite others to start riding, who would otherwise not have done so. The overall result may be more riders as well as a higher absolute number of accidents. Training programs should teach which actions and conditions are potentially dangerous. Insofar as these actions/conditions are part of the normal use of the road, riders will have to learn how to master them. The question is: which point during training is right for this: basic training, advanced training ,or later? Some actions/ conditions are too difficult or too dangerous to learn without first having learned some basic knowledge and skills. Actions/conditions which are not included in the compulsory training and testing of riders can still be learned by voluntary training programs or by experience. But there is no guarantee that all riders will do so. These programs usually attract riders who are already safety minded. Some actions/conditions can be so dangerous that they are better avoided, even by experienced riders. But riders will still have to learn to recognise, and to avoid them. The problem is that some riders will accept or even choose more dangerous actions/conditions anyhow. The safety of such riders could still be improved by special training programs. Here again there is no guarantee that riders will follow these programs or will avoid these dangerous actions/conditions. Actually these programs may encourage some riders to accept or choose more dangerous actions/conditions than they would without the programs. That is why these programs cannot be made compulsory. But being voluntary, they have to be made attractive to the groups of riders at which they are aimed.
With these considerations in mind, it is not surprising that the details of legislation for beginning riders are different between countries.

Within limits, rider motivation and riding style have more effect on accident rates than *vehicle characteristics*. Because of this, the effects of further limiting engine performance will probably be minor. Significant effects can only be expected with drastic restrictions, such as the already existing lower speed of mopeds. But in some countries the tampering of mopeds to make them go faster is a serious safety problem, since their riders were not properly prepared for these higher speeds.
Over the years, the handling, braking, lighting etc. of mopeds/motorcycles has much improved. But there is continuous need for more development and research into improved control of brakes. At present, improved braking systems are available for expensive motorcycle models only.

To a certain extent, some of the safety problems of riding a moped/ motorcycle could be solved by drastically changing the vehicle characteristics such as adding a bodywork or a third wheel. However, it is doubtful, or at least very much dependent on the exact changes, if such a vehicle would still be attractive to riders. But they might attract new groups of riders, who are not interested in the existing types of mopeds/motorcycles.

The present road network has primarily been designed for the use by cars. Road authorities have to become aware of the special needs of riders of

mopeds/motorcycles in terms of the *design and maintenance of the road*. These riders are much more vulnerable to imperfections of the road surface than car drivers and special requirements have to be recognised for road markings, roadsurface repairs, longitudinal grooves, drainage etc. Although many improvements to the design of roads and traffic control will have the same positive effect on the safety of riders of mopeds/motorcycles as of other road users, this is not the case with all speed reducing measures. These measures may pose special problems for mopeds/motorcycles and should be tested to prevent these. The same applies to the design and location of guard rails which may add to the injuries of riders of motorcycles/mopeds in case of a collision with them.

In general riders of mopeds and motorcycles follow the same *traffic rules* as car drivers, with the exception of a lower speed for mopeds. It might be argued that problems of congestion by cars can be partly solved by replacing cars by mopeds and motorcycles. This can only be done if the safety of the riders is improved. Under this condition, it can even be considered to give riders of mopeds/motorcycles some privileges compared to car drivers, such as overtaking lines of slow moving cars on the left or right, to take position at the head of waiting lines of cars, to ride on lanes, roads or areas with restricted access (such as bus lanes, inner city areas etc.) and to provide special parking facilities. Some of the suggested traffic rules, insofar as they separate motorcycles/mopeds from cars, can also improve the safety of riders, although care should be taken not to introduce other safety problems (e.g. collisions of motorcycles/mopeds with pedestrians or cyclists, or with cars, at places where the motorcycles/mopeds are not expected). Special traffic rules for motorcycles/mopeds have been tried in several places in Europe, but so far no results are known. Some riders already take advantage of the small size of their vehicle and act as if they have these privileges which can be dangerous if other road users do not expect or accept this kind of behaviour. More explicit rules are supposed to result in more uniform behaviour by riders and better knowledge and acceptance of it by other road users.

The *perception of mopeds/motorcycles* is a special problem for other road users. This can only be partly solved by the use of daytime headlights by riders of mopeds/motorcycles. This measure is estimated to reduce (daytime) collisions with cars by 30-40%. Given the present use of daytime headlights by motorcyclists in Europe, this translates into an estimated reduction of 7% of (daytime) collisions with cars and a reduction of some 140 motorcyclist fatalities per year (on a total of c.4000). There is some concern that the effects will be less if cars have their lights on as well.
Another part of the problem is that other road users are not prepared to search for mopeds/motorcycles and to take action to avoid a collision. Car drivers have to be made aware of this and learn to change their behaviour for the safety of riders of mopeds/motorcycles. There are no studies on how to obtain these effects. One suggestion is to use yellow headlights on motorcycles to improve their recognition.

The lack of *protection of riders* of mopeds/motorcycles can only partly be compensated by wearing a helmet or other protective clothing. Wearing of a helmet is compulsory for motorcyclists in all European countries. Actual wearing rates may be close to, but not exactly 100%. However, helmets are not always worn correctly, which may greatly reduce the protective effect.

Some countries seem to have very low wearing rates (e.g. Greece with c.20%). The effects of wearing helmets are well documented: they reduce the risk of a fatality by half, with much scope for further improvement. Most countries also require moped riders to wear a helmet, with the exception of Italy (only for riders 16-18 years), Belgium ,and Holland (not for low speed mopeds). Actual wearing rates for moped riders are not known.
More development and research is needed before other protective devices such as airbags or leg protectors can be introduced. In the future, cars and roadside obstacles have to be designed to provide better protection for riders of mopeds/motorcycles who collide with them. Several studies have shown the adverse consequences of a motorcyclist colliding with a guard rail. New studies will lead to the development of better constructions and will identify locations which should get priority treatment.

Data collection and research are not safety measures by themselves, but serve to study the need for and the effects of such measures. In the case of mopeds and motorcycles there is a strong need for more reliable data and more and better research.

8.6. Implementation of safety measures

The review of safety measures in this report has not been concentrated on technical and non-restrictive measures as was originally intended. It is, however, not difficult to identify these measures. They concern the design of the vehicle for improved handling, braking, lighting etc., the design and maintenance of the road, and the design of the two-wheeler as well as of collision objects like cars and guard rails to protect the rider against injury. The lack of protection can only partly be compensated by protective devices and apart from helmets require further development and research. Other improvements in the design of motorised two-wheelers are continuously developed by the industry and gradually introduced, but may add to the costs of riding.

Of the technical measures, the design and maintenance of the road in view of the safety of mopeds/motorcycles seems to have been neglected. This in turn may be related to a wrong image of riders of mopeds/motorcycles as a minority group of mostly young riders with a high accident rate because of their own behaviour. What is needed in this situation is first of all a correction of this image based on the information in this report. The population of motorcyclists has changed over the years and most riders are now over 25 years of age and their number is still increasing. Apart from Southern European countries, there are more motorcycle fatalities over 25 years than under 25 years. Because of the low minimum age, moped riders are younger than motorcyclists, but even the number of moped fatalities is about the same for both young and old riders. As far as their behaviour is concerned, riders with a dangerous riding style are a minority among all riders.

Policy makers will therefore have to recognise the role of mopeds and motorcycles as road users and the need for measures to improve their safety. In view of their high accident rate, this should not only include technical and non-restrictive measures. From this report it is obvious that there is a need for other measures as well. Some of these look simple: wearing of a helmet by riders and passengers, use of daytime headlights by mopeds/motorcycles,

anti-tampering measures for mopeds. One of the reasons for not taking these measures could be the lack of knowledge on their effectiveness. In that case this report is offering the available evidence. But it is also likely that countries that have not yet introduced or enforced these measures have special reasons for this.

This report also shows the importance of training of riders of mopeds/ motorcycles. Such a measure, or rather package of measures, depends to a large extent on the willingness of riders to accept the measure and to improve their behaviour. Acceptance of a measure is much greater if the target group has been involved in the development and introduction of the measure. Motorcyclists in many countries have some degree of organisation, which makes it easier to discuss measures with representatives of the group of motorcyclists. For moped riders there are no special organisations representing their views and needs, although tourist organisations and the industry may offer to represent them.

9. Recommendations

Safety measures have to be based on (accident) statistics and research results. In view of the absolute as well as relative numbers of motorcycle and moped fatalities in Western Europe, it is surprising how little information is available on the subject. There is a strong need for more and more reliable statistics and better research.
All countries should provide the necessary statistical information on the safety and use of motorcycles/mopeds. This includes:

- number of vehicles per type of moped/motorcycle and per standard age group,
- kilometres per type of vehicle, per age group, and if possible per type of road,
- numbers of accidents/injuries per type of vehicle, age group, and if possible per type of road.

Countries which have no official registration of mopeds should consider introducing this, among other things, to improve the collection of information on the use and safety of mopeds.
Accident statistics should provide levels of severity of injury and details of the type of collision, based on an international standard.
In addition to accident statistics, it is highly desirable to have detailed accident studies in each country with information on both causes and consequences of accidents with motorcycles/mopeds.

Given the special vehicle characteristics, learning to ride a motorcycle may take longer and to a certain extent is different from learning to drive a car. This is also partly true for learning to ride a moped. An effort could be made to obtain international agreement on the minimum content and form of basic training programs, based on the present knowledge on safety problems of riding a motorcycle/moped. At the same time, more research has to be done on the development and evaluation of such programs.

Recent European regulations have resulted in more uniform legislation concerning access to the riding of motorcycles, but more uniformity could be reached in the case of minimum age and compulsory training and licensing for moped riders. Countries with a relatively low minimum age for riding a moped or without compulsory training or licensing should reconsider this, either with or without the option of a low speed moped with lower requirements.
In order to obtain more uniformity in legislation on riding a 125 cc motor-cycle, special studies have to be done on the evaluation of existing and newly introduced legislation.
Countries should promote the availability and participation in voluntary training programs. These programs could be based on examples from other countries like Germany and Holland and be aimed at different target groups of riders.

Controlling a motorcycle/moped is relatively difficult, in particular when cornering or braking. Continuous research is needed on the subject and the introduction of improved, relatively cheap braking systems has to be stimulated.

Tampering of mopeds to make them go faster is known to be a problem in some countries. All countries are advised to provide information on this subject and to exchange the information on the effectiveness of anti-tampering measures. The recent introduction of European anti-tampering regulations has to be carefully evaluated.

Road authorities seem to have neglected the special needs of riders of motorcycles/mopeds in terms of the design and maintenance of the road surface and fixed roadside objects. These authorities have to be informed on these special needs and special requirements have to be developed based on these needs for road markings, road surface repairs, longitudinal grooves, drainage, timing of traffic lights (for longer braking distances on wet surface) etc.
Infrastructural measures to reduce speeds (such as humps or lane narrowing) have to be re-evaluated from the point of safety for riders of mopeds/ motorcycles.
Guardrails have been designed for car collisions, but have adverse consequences in case of motorcycle collisions. Special studies from the point of motorcycle safety have to be done to result in special requirements for the design and location of guardrails.

Special traffic rules (such as overtaking slow-moving lines of cars, to ride on lanes with limited access) could be used to give riders of motorcycles/mopeds some privileges compared to car drivers and, insofar as they separate motorcycles/mopeds from cars, could improve their safety. There is little empirical information on the effects of such rules. Countries are recommended to evaluate such rules where they already exist, and to promote demonstration projects to gain more experience with them.

Daytime use of headlights is estimated to reduce collisions of motorcycles with cars by 30-40%. Countries which do not have compulsory daytime use of headlights for motorcycles/mopeds are advised to introduce this. Countries which already have such a compulsion for cars or are considering to introduce this, are advised to start research (both laboratory and large scale field experiments) into negative effects on motorcycle safety, and into options to prevent these.
Problems of perception of motorcycles/mopeds by other road users is also partly a problem of the behaviour of car drivers in relation to motorcycles/ mopeds as well as of the behaviour of the riders themselves. All countries are suggested to promote campaigns to improve the behaviour of car drivers in relation to motorcycles/mopeds and campaigns to improve the behaviour of riders to prevent collisions with cars.

Riders of motorcycles/mopeds have little protection against collision impact, but every effort should be made to provide as much protection as possible. For that reason, countries have to be stimulated to participate in in-depth studies of motorcycle/moped accidents to provide the necessary data on which standards for the design and evaluation of protective devices can be based. Research on the design of helmets, rider clothing, motorcycle design elements, and car fronts for the protection of riders has to be supported.
Helmets are known to reduce the risk of fatality by half, but some countries make exceptions to the compulsory wearing by moped riders or have low wearing rates despite a compulsion, and helmets are not always worn correctly. These countries are encouraged to reconsider the reasons for

making these exceptions, resp. to enforce the compulsory wearing of helmets more strictly.
All countries should make an effort to promote the wearing of protective clothing.

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