EEVC/CEVE

European Experimental Vehicles Committee

Cycle and light powered two-wheeler accidents

Presented to the Ninth IRCOBI Conference Delft September 1984

Table of contents

SUMMARY

Importance of the problem (Chapter 1)

In the various member countries of the European Experimental Vehicles Committee (EEVC) it was concluded that over the last decade a lot of attention was paid to problems related to accidents with cars and those people using them; in recent years attention shifted to other traffic participants and especially to pedestrians for mainly two reasons

- at present they are largely unprotected and therefore vulnerable in today's very complex traffic scene
- statistics show that pedestrians actually form a large group of casualties.

Considering the scientific work already done for those groups in many countries the public, Parliament, researchers and authorities became aware of the growing importance of traffic safety problems for the users of two-wheelers, relatively speaking but to some extent also in absolute terms. The accident statistics as described in chapter 1 indicate the following figures for bicyclists and mopedriders (studied together because their position in traffic in many ways is comparable):

- in some countries this group is the second largest after car users in terms of killed and severly injured, in other countries it ranks third after car users and pedestrians
- the percentage of killed (light-powered) two-wheeler users ranges from 6,7% (United Kingdom) to 28,4% (the Netherlands), with an average value of 15,8% for the participating countries (for pedestrians: from 13,3% in the Netherlands to 33,3% in the United Kingdom; an average of roughly 22% in 1979)

Chapter 1 gives a detailed description of those and other figures: numbers of injured, of vehicles in use etc.; it relates those figures to indicate some reasons for the variance between countries (numbers of casualties per 100.000 vehicles and per 100.000 inhabitants in various age groupes). Work is presented to indicate the important influence on possible conclusions of differences in definitions and requirements (differences in accident registration systems and the related problem of "underreporting"; differences in the technicalities of the vehicles). A separate paragraph describes the importance of economic assessment of these accidents and remedial measures, and some problems related to the available methods.

Description of bicycle and light-powered two-wheeler accidents (Chapter 2)

Chapter 2 gives details on typical types of accidents; accident type, collision type and manoeuvre type are defined and related (in-depth) studies are cited, indicating at the same time available knowledge on resulting injuries and speed at impact.
All material available shows that cars most frequently are the collision partners (50 to 99 %); there is no single category of road users ranking second: it ranges from other two-wheelers to heavy goods vehicles, depending on various factors.
Single vehicle light-powered two-wheeler accidents occur so frequently that they deserve special attention.

It is shown that the frequency of an accident type is not the only relevant parameter; some indication of the seriousness is considered important too: a definition of "lethality" is suggested, indicating it's influence on priorities. This approach gives more "weight" to collisions with HGV's.
By describing collision types and to some extent manoeuvre types. It is shown which parts of the vehicles are mostly involved; some similarity exists with

pedestrian accidents, but additionally the sides of cars and the sides and rear-end of HGV's are involved (especially in crashes with light-powered two-wheelers), as well as some parts of the two-wheeler.

The kinematics of a rider during a collision is indicated as one of the important factors; due to the range of accident and collision types for two-wheelers, a much wider variety of kinematics is seen for riders when compared with pedestrians; especially the presence of the two-wheeler and its own speed contribute.

As to injuries, literature gives a variety of distributions; most studies are hard to compare, for reasons indicated in paragraph 2.5., but some conclusions and tendencies are noted. The -limited number of- studies available indicate that the frequences of injuries for various body-parst -and their ranking- depends on the injury severity level considered and on the type of two-wheeler.
Most studies conclude that the head has the highest frequency (especially when considering more severe injuries and for bicyclists with even higher frequencies than for riders of light-powered two-wheelers); arms and legs come in second and third places.
The injury scaling problem associated with long-term impairment, as mentioned in the report of EEVC-WG7 on pedestrian accidents seems to be relevant for some two-wheeler accident types too.
The relative speed at impact is considered to be a very important factor. The limited number of studies indicating vehicle speeds show higher values than for pedestrian accidents: 50th percentile speed between 10 and 50 km/h, 90th percentile between 37 and 72 km/h. (EEVC-WG7: 50 perc.: between 16 and 36 km/h, 90 perc.: between 44 and 58 km/h.)

Injury influencing parameters (Chapter 3)

Contrary to the situation for car accidents, very little is known about these parameters for two-wheeler accidents. Therefore only a short description is given, mainly of a theoretical and inferrential nature and based on general knowledge from studies of various accident types, indicating the probably most important factors for each of the collision types which seemed important from chapter 2.

Research methods and results (Chapter 4)

A global presentation of various research principles is given, indicating the advantages and disadvantages and especially indicating the usefulness of combining two or more methods.
The following division is made:

a accidents studies

  - accident statistics (police data level)
  - intermediate (hospital/insurance data)
  - in- depth studies

b experimental research methods

  - full-scale tests
  - component (or body segment) tests
  - mathematical models

Until recently little research work was done specificly relating to bicycles and mopeds (and then mainly accident statistics). What has been done - and can be used to some extent here too - was useally directed at pedestrians or motorcyclists;

nevertheless a few bicycle-related studies are cited (accident-studies of various levels as well as development work on mathematical models, together with the necessary related full-scale and component tests).

Current knowledge on human tolerance (Chapter 5)

The accident-situation for two-wheelers is different from the situation for other groups of road-users, as mentioned before. This fact may influence typical injury influencing parameters (kinematics; loading place, direction and level) and therefore one would have to look for typical cyclist and moped rider information regarding human tolerances. Only very few studies have been performed especially for cyclists and moped riders (and then mainly related to helmets and head tolerance); for other elements one has to rely on work for pedestrians, motorcyclists and car users.
For various body-parts parameters and tolerance values are given, for some of them the relevance for two-wheeler users has to be studied further.

Injury prevention measures (Chapter 6)

Starting from the basic philosophy of the integral approach of a safe vehicle (integration of requirements for the benefit of various -groups of- road users), three aspects were seperated:

1. proposals for the benefit of two-wheeler users,
2. consequences of these proposals for other road users,
3. consequences of requirements for the benefit of other road users on two-wheeler users.

Ad 1
As research work in this area started more or less recently, availability of literature is limited, especially regarding concrete proposals.
Based on information from earlier chapters, work concentrated on the car, the heavy goods vehicle, the two-wheeler and it's rider.

Regarding cars, as for the pedestrian - to - car accidents, interest is focussed on the stiffness of frontal parts. Some differences may exist: the generally somewhat higher -seating- position and a difference in the population (less younger children involved) may cause a different influence of various car-components on the kinematics and loading of the human body in a crash; for two-wheeler users the windshield and the higher parts of it's frame become important too. Considerations regarding the vehicle shape follow the same lines as for pedestrians.

Regarding heavy goods vehicles two approaches exist:

- improvement of shape and stiffness would be benificial at the vehicle-front, just as for cars.
- for the HGV-sides and -rear, concrete proposals are indicated regarding underrun-protection devices and improved rear-view mirror systems and requirements (accident avoidance).

Regarding the two-wheeler itself various protection devices are discussed both for frontal and lateral collisions. Various types have been developed for motorcycles; whether they can be practically used on lighter two-wheelers and even whether they are advantageous on such vehicles is unclear still. This concerns side protection devices (e.g. knee-bars) as well as knee-paddings for frontal collisions.
Avoiding sharp protrusions on two-wheelers will help against -minor- injuries: examples introduced to some extent are sunken filler caps and handle bar expander-pins.

For the passenger, especially the younger one, dress-guards at the rearwheel and, up to a certain age, child seats are considered important against e.g. spoke injuries.

Regarding the rider, various well-known possibilities are described, such as safety helmets and protective clothing.
Although they are widely accepted (and helmets even mandatory) in many countries for motorcyclists, this is not the same for -all- riders of light-powered two-wheelers and certainly not for cylists (the use of special types of cylist-helmets has been introduced in some countries nevertheless). Possible effects are indicated in the text.

Ad 2 Consequences for other road users:

Little influence for others is expected from the above proposals regarding cars. Underrun guards should not create any negative effects for other road users. Rear-view mirrors on heavy goods vehicles might be dangerous for pedestrians and bicyclists during overtaking manouevres, if not properly designed.
Some doubt is expressed as to whether knee-paddings may cause a rider to fly into a car's compartment; helmets may be dangerous for unprotected road users.

Ad 3 Consequences of measures for the benefit of other road users:

Bumperheight is determined in e.g. SAE- and ECE-prescriptions, mainly for the car-to-car situation; serious doubts are expressed on the appropriateness of these values for pedestrians and two-wheeler riders.
Other requirements, e.g. for car-to-car crashes, are not expected to have much effect on two-wheeler-riders.

Testprocedures (Chapter 7)

Testprocedures, aiming at ensuring conformity of a vehicle or component with relevant reuirements, are discussed. The chapter was kept short because a there are very few concrete proposed measures to evaluate during type-approval (chapter 6) and b a lot of development work has to be done on the methods themselves (e.g. integration of integral tests, component tests and/or mathematical models; development of a dummy).

Accident prevention (Chapter 8)

Injury prevention or minimization is clearly not the only and possibly not the best way to protect road users; accident prevention would be far be preferable, but it is not expected to be effective enough for many years to come.
The chapter describes various elements of the vehicle-system that may cause (or contribute to) accidents to happen.
Research work is described to improve these elements: active lighting systems, reflectors, spacers, braking systems,stability and manouevrability; as a special aspect, the influence of the state of maintenance is discussed.
Various proposals are described; in many cases they might be feasible for many countries because relevant technology has already been introduced in some other countries today.

PRIORITIES AND RECOMMENDATIONS

Introduction

The working group has, based on the discussions in the group, pointed out priorities for action, general recommendations and recommendations for future research.
One of the conclusions is that the injury prevention research for two-wheeler riders got even less attention than injury prevention for pedestrians. (Working Group 7). More attention is necessary, especially since the accident process of the two-wheeler rider is even more complex than that of the pedestrian because of the contribution of the two-wheeler itself to the injury producing process. Also the speed of the two-wheeler rider and his position in traffic situations leads to other collision types and speeds at impact.

Priorities for action

1. The use of energy absorbing materials in the front structure of the car will be benificial for the two-wheeler rider, similar to what was found for pedestrians by WG7. Whether other locations on the car should also be padded cannot be decided today. Preliminary results of experiments using dummies indicate that impact location of the two-wheeler rider's head on the car is somewhat higher than in the case with pedestrian heads in similar frontal collisions. Second priority should be given to the side of the car due to the relatively frequent occurring side collisions with light-powered two-wheelers.

2. The use of well dimensioned side underrun-guards on heavy goods vehicles will reduce the effect of the serious and relative numerous collisions of mopeds and bicyclists with the side of heavy vehicles. The risk of getting run over by the wheels will also be reduced.

3. Modern standards should be developed for lighting equipment, including reflectors, and braking performance (especially under wet conditions) of bicycles.
   The introduction of a high-standard retroflector at the rear-end of the bicycle will probably reduce the effect of the frontal car collision with the rear-end of bicycles, which is a serious type of collision.
   At the sides of bicycles, spoke reflectors and/or reflecting tires are recommended.

General recommendations

- More attention should be given to accidents of bicycles and light-powered two-wheelers, especially to:
  - accident registration systems, e.g. underreporting of these accidents by police
  - standardization of definitions for a better comparison of the results of national accident statistics and research projects of the different countries. Especially needed is a more uniform definition of the different classes of light-powered two-wheelers.
- When introducing a new legal measure, a proper before and after evaluation study is necessary. Some reasons are:
  - optimizing the measure
  - giving arguments for possible introduction elsewhere.
- In view of the differences in the proportion of head injuries between (not helmeted) cyclists and (helmet wearing) motorized two-wheeler riders, it seems preferable that cyclists shall wear a (specially designed) helmet too. Padding of certain parts of the car might have a comparable beneficial result, depending on whether the car or the ground is the leading cause of injury. This question has to be answered yet by research.

- The use of better or additional side mirrors on heavy goods vehicles will give better overview to the truck driver. Even the present EEC directive is not sufficient (an amendment is underway).
- Riders of bicycles and light-powered two-wheelers should wear conspicuous clothing.
  For day-time the use of a jacket of fluorescent material is recommended. Smaller areas of such material e.g. on armbands or shoulderbands are less effective. The brightest materials (highest luminance factor) should be used. Bands of reflective material applied to the jacket will help other road users to recognise the presence of a rider. Spacers (i.e. devices attached to the side of a bicycle to discourage drivers passing too close when overtaking) are of use and should be promoted as a low cost safety accessory.
  However, it should be noted that the wearing of a conspicuous jacket has an effect on the gaps left by overtaking vehicles similar to that produced by the most effective spacer.
  (The last recommendation is based on research and theoretical considerations. In part it is supported by accident studies.)

Recommendations for future research

A. Real accident studies

Information of real accidents is needed to get better insight in injury influencing parameters.
The first important question is: What is the leading cause of injury taking into account speed at impact and collision type: the car, the two-wheeler or the ground?
From this it may follow that for some collision types severe injuries occur mainly due to very high impact speeds regardless of other influences (for instance outside built-up areas). In those cases accident avoidance measures seem to be more suitable than injury reducing ones.
The next important question is: What is the influence of car shape and car stiffness on kinematics, on short and long term injury and on injury severity of the two-wheeler rider. Again taking into account impact speed and collision type, but also human parameters such as age, length and mass distrubutions.
Whether accident avoidance or injury prevention measures should be taken, may be decided with the help of cost-effectiveness considerations.

B. Human tolerance

Further research is needed on injury producing mechanisms in order to develop more precise ranges of values of human tolerance criteria as a function of age, mass, height and impact speed (visco-elastic behaviour). Special attention should be given to the influence of translational and rotational accelerations of the head on head (brain) injury.

C. Mathematical models

Computer models should be further developed and validated.
This validation should be based on real accident information together with the results of cadaver or dummy experiments.
The development of a simple mathematical model, capable to detect the kinematics of the rider versus the shape and stiffness of the car, could be usefull for standard test procedures in the near future.

D. Dummies

The dummies presently available for pedestrian research are not quite fit. For two-wheeler rider purposes this deficit is analog. Further development is needed to obtain dummies that give more realistic representations of two-wheeler riders.

GENERAL

- The recommendations of A, B, C and D above must be seen as complementary, so they strengthen each other. A trend must be set to use as many tools as possible to solve this complex problem.
  This is an important argument for internatinal cooperation and coordination of the research activities in the various countries.
- Due to the fact that two-wheeler riders collide with passenger cars and heavy goods vehicles in more different collision types than pedestrians do and due to the different parts of the body of the two-wheeler rider that are impacted in the different collision types, injury prevention research should be focused on following collision types:

  passenger car
  - front of car to (left) side of bicycle/light-powered two-wheeler
  - front of car to rear end of bicycle
  - front of car to front of light-powered two-wheeler
  - side of car to front of light-powered two-wheeler

  heavy goods vehicle
  - front of HGV to side bicycle/light-powered two-wheeler
  - front of HGV to front bicycle/light-powered two-wheeler
  - side of HGV to side of bicycle/front of light-powered two-wheeler
  - side of HGV to front of bicycle/side of light-powered two-wheeler

  single vehicle light-powered two-wheeler rider accidents.

- Research should be undertaken into long term consequences of injuries. Very little is known about these consequences, especially about their severity. This is considered a deficiency of existing injury scaling systems.
- When using humans or human substitutes for two-wheeler rider protection research, the choice should be such that they represent the age of the real accident victims e.g. for cyclists 5-25 years and older than 65. For light-powered two-wheeler riders this age group is: 15-25 years.
- Research is needed for more reliable bicycle lighting equipment.
- Optimalization of crash helmets should be undertaken:
  - Legal standards should be based on appropriate biomechanical criteria.
  - The influence of the surface of the outer shell of the helmet on rotational acceleration of the brain and its resulting injuries should be studied.
  - Research should be undertaken into the problem of losing crash helmets during accidents (although suggestions for improvements have been tabled in the relevant UN-ECE group of rapporteurs).

INTRODUCTION

In 1981 and 1982 the EEVC working group 7 "Pedestrian Injury Accidents" was preparing its report. At that time the Dutch delegation suggested that attention should be given to bicycle-car accidents because in the Netherlands this accident type happened more frequently than the pedestrian-car accidents.
In 1982 the EEVC accepted to set up a new working group that whould deal with bicycle accidents and as far as possible, also light-powered two-wheeler accidents.
The Dutch members of EEVC were invited to prepare a discussion paper for this group. The intention of this working group, described in the paper, was agreed by EEVC and the group was set up. This intention is focussed on number of accidents, integrated safety approach and international coordination. From this discussion paper the following is cited:

Concerning the number of accidents:

"Compared to other European countries the relative proportion of bicycle casualties in the Netherlands is considerably higher, though the absolute numbers of those killed and those injured as reported from the different European countries also seem quite high. They indicate that proper measures in this field may save thousands of lives and injured, while reducing the severity of injuries".

Concerning an Integral Safety Approach:

"Some conclusions with regard to changes of the car drawn from studies of pedestrian-car accidents may be useful for the bicycle-car situation too; others may be indifferent but some may be contrary to the bicycle case. For an integral approach to car safety, changes made (or to be made) for the benefit of one group of road users have to be carefully checked against knowledge about the characteristics of other groups.
This can be illustrated by e.g. bumperheight, for which a SAE recommendation exists, as well as an UN/ECE-Regulation. From research on lateral car collisions a recommendation for a lower bumperheight may follow.

From pedestrian accident research follows considerable doubt whether the SAE recommendation is an advantage for pedestrians. Considering two-wheeler accidents the effects are even less predictable as yet".

Concerning international coordination:

"It seems that the study of car-bicycle accidents ultimately may contribute a great deal to improvement of traffic safety.
There is a need for accident data, there also seems to be a need for more experimental and human-tolerance data, as well as for better tools to gather those data.
Investigations on crash protection for two-wheelers are starting in several countries.
Research on crash protection for pedestrians has started more then ten years ago, which was followed some years later by international coordination. Now it seems to be the right moment for similar actions concerning bicyclists, while coordination of research is possible from an earlier stage".

As a result EEVC gave the working group the following Terms of Reference:

- Review the available accident data concerning fatal accidents and injuries to bicyclists of different ages, involved in road accidents in Europe and examine the accident data of light-powered two-wheelers.
  (The exact definition belongs to the task of the group).

- Make recommendations including priorities for action on the vehicle to reduce the severity of such accidents and injuries. Recommendation may e.g. include direct measures to change bicycles and cars, as well as specified proposals for research.

Priority will be given to possible influences of certain proposed measures on the safety of bicyclists; changes to the car should be considered with respect to the benefit of non-occupant road users (see also WG7).

During the first meeting of the working group it was decided to deal also with light-powered two-wheelers, because in some participating countries the number of light-powered two-wheeler casualties is higher than that of the bicyclists, and because it was the group's opinion that there were great similarities between the two categories of road users. The group was aware of the difficulties that could arise because of differences in definitions of light-powered two-wheelers between the countries. Therefore the group decided to include a list of requirements (including definitions) for light-powered two-wheelers for the different countries.
During the first meeting the group decided to deal with accident avoidance aspects related to vehicles too.
The aim of accident avoidance is obvious and many efforts have already been made by improving the construction of passenger cars and heavy goods vehicles (brakes, tires etc.) and by changes in infrastructure (e.g. bicycle lanes). However, there is considerable scope for improving the lighting devices and retro-reflectors fitted to many bicycles and for improving the braking performance in the wet, especially of rim brakes.
The decision of the group was that only specific two-wheeler, car and heavy goods vehicle aspects in relation to two-weeler accidents will be described in this report.

It is not realistic to expect (on a short term) measures or solutions that will prevent accidents from happening at all. Some elusive elements will always remain. This is the main reason for injury prevention work.
The aim of injury prevention is either to prevent injuries or to minimize injury severity by influenzing the kinematics of the victim and to minimize loads to the struck body parts, for instance by minimizing the relative impact speeds between victim and struck object.

HISTORY OF BICYCLE AND LIGHT-POWERED TWO-WHEELER

Bicycle

The question whether the first bicycle was designed by the Frenchman De Sivrac or by the German Kessler in ± 1790 (ANWB [2]) is irrelevant since it appeared some years ago that the first drawing of a bicycle was made by Leonardo da Vinci or one of his pupils in ± 1450 (Gibbs-Smith [3]). This bicycle was already chain driven (fig. 1) contrary to the bicycles made by De Sivrac and Kessler that had to be pushed forward.
The first bicycles driven by means of pedals had frontwheel drive. To reach a higher speed the frontwheel was enlarged (fig. 2), even to such an extent that it became dangerous when drivers fell off. Therefore the first "Safety bicycle" was designed by H.J. Lawson in 1874. It had a front- and rearwheel of equal diameter and the rearwheel was chain driven. The first practical production machine, the "Rover Safety", was made in 1885 by John Starley (fig. 3). When later (1888) equiped with pneumatic tires, invented by the Irish veterinary surgeon John Dunlop, the safety bicycle caused a bicycle boom in Europe and America (Popish [1]). The safety bicycle had a design similar to the present one, though it lacked the seattube as a part of the frame structure.

Bicycle use in some countries became enormous, and will probably grow even more due to rising energy prices, increasing spare time and health care. At this moment a lot of alternative bicycle designs and prototypes are produced. They have in common that the bicyclist is lying backwards and in some designs he or she is protected against weather conditions (Scientific American [5]).

Light-powered two-wheeler

According to Rauck [6] and Schneider [7] the first powered two-wheeler was constructed by Wolfmüller and Hildebrandt in 1894 (fig. 4).
According to Elsevier [4] the first attempt to construct a light powered two-wheeler dates from 1920; it is named the "Briggs and Stratton".
(1894-1920: a matter of definition?).
The engine was connected directly to a wheel next to the rear wheel. In later years the engine could be found almost anywhere on the two-wheeler, but nowadays the engine is normally placed under in the frame, between front and rear wheel, driving the rear wheel.
The use of the moped e.g. in the Netherlands increased strongly after 1960, but decreased after 1975 and is still decreasing.

References

1. L.N. Popish; R.B. Lytel
   "A study of bicycle-motor vehicle accidents"
   Santa Barbara Public Works Department, June 1983.

2. Koninklijke Nederlandse Toeristenbond ANWB; Stichting fiets
   "De grote fietsatlas van Nederland"
   Kosmos B.V., Amsterdam, 1975.

3. C. Gibbs-Smith
   "The Inventions of Leonardo da Vinci"
   Phaidon Press Limited, London, 1978.

4. "Grote Winkler Prins Encyclopedie" 7th edition
   Elsevier Nederland B.V., 1974.

5. Scientific American
   December 1983.

6. M.J.B. Rauck; G. Volke; F.R. Paturi
   "Mit dem Rad durch Zwei Jahrhunderte"
   AT Verlag, Aarau - Stuttgart, 1979.

7. P. Schneider
   "Das Zweirad im Wandel der Zeit"
   Deutsches Zweirad Museum, Neckarsulm
   Ismaning (München): Eigenverlag P. Schneider.

LIST OF MEMBERS PARTICIPATING IN THE WORKING GROUP

Prof. B. Aldman	Chalmers University	Sweden
Mr. P. Ardoino	Fiat Auto Spa	Italy
Dr.-ing. B. Bonis	Fiat Auto Spa	Italy
Mr. D. Cesari	ONSER	France
Mr. A. Edelman	SWOV	The Netherlands
Mr. P.W. Hoekstra (chairman)	RDW	The Netherlands
Mr. J.J.W. Huijbers (secretary)	SWOV	The Netherlands
Dipl.ing. K. Masseck	VFM	F.R. Germany
Dr. M. Ramet	ONSER	France
Dr. A. Sporner	HUK-Verband	F.R. Germany
Dr.-ing. U. Stocker	BASt	F.R. Germany
Dr. G.R. Watts	TRRL	United Kingdom

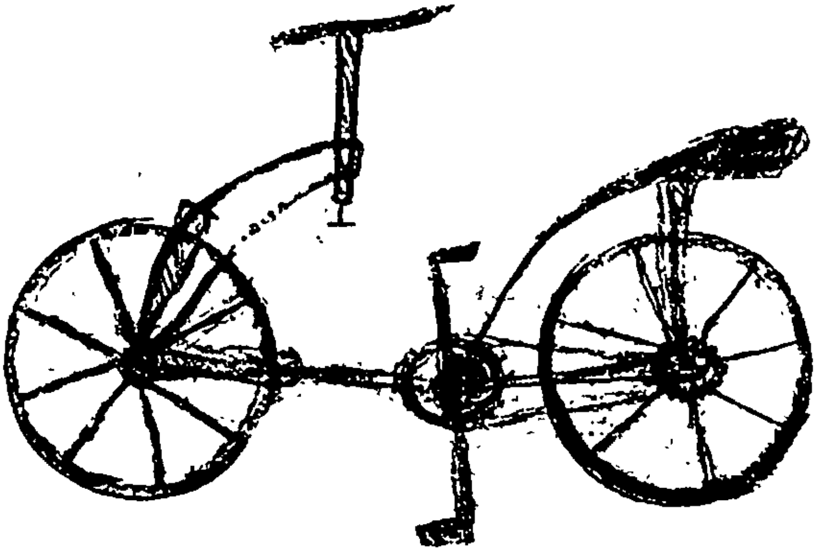


fig. 1: Bicycle designed by Leonardo Da Vinci.
(± 1450)

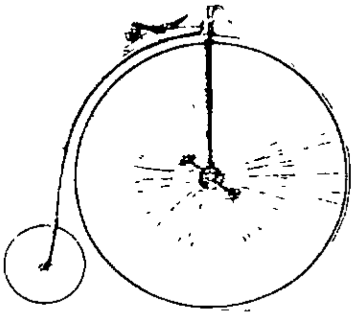


fig. 2: Bicycle with enlarged front-wheel.
(± 1880)

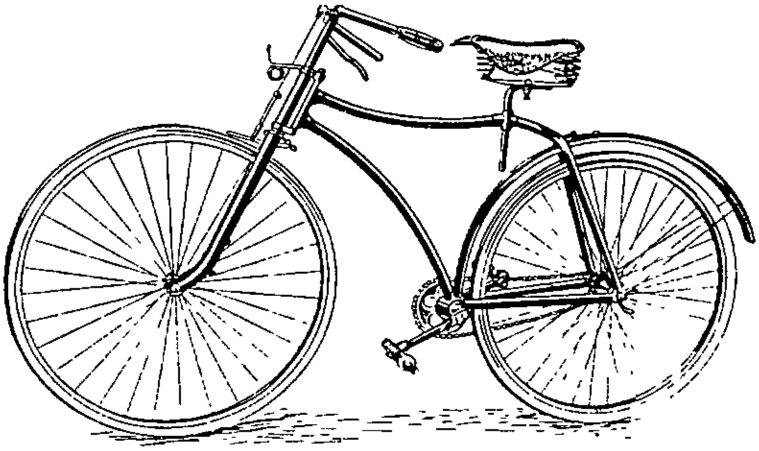


fig. 3: Rover "Safety Bicycle".

(± 1885)

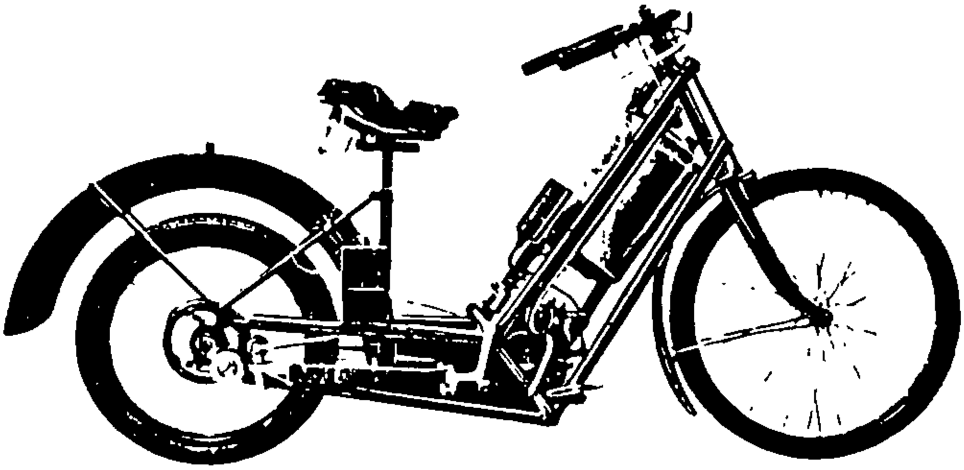


Fig.4 : First patented, serially produced motorcycle by Hildebrandt and Wolfmüller; München, 1894.

1. DESCRIPTION OF TWO-WHEELER ACCIDENT STATISTICS

1.1. Introduction

The chapter deals with a comparative survey of the situation of vehicle numbers and numbers of persons involved in accidents in general. Special emphasis is placed on describing the situation of pedal cyclists and riders of light-powered two-wheelers in the member countries participating in the working group: France, Federal Republic of Germany, Great Britain, Italy, The Netherlands and Sweden. The interpretation of the data will have to be undertaken with great caution since the definitions, e.g., of a light-powered two-wheeler are different in the participating countries.
The definition of a fatally (or severely or slightly) injured accident victim can also differ considerably as well as the associated parameter definitions in the national accident statistics. Beyond that, other influencing parameters should be included in a comparative assessment as well, such as mileage (vehicle-kilometers per annum), road network, land use, topgraphy and climatic conditions of the countries under study.

This is just to show that a statistical analysis based on an only one-dimensional way of looking at things (e.g., the number of accidents in a population of a defined age group) can easily lead to wrong conclusions. It is for this latter reason that only the tendencies of developments are going to be pointed out in this chapter.

1.2. Definitions of bicycle, light-powered two-wheeler, road accident, killed, severely injured and slightly injured

The definitions of bicycle, light-powered two-wheeler, road accident, killed, severely injured and slightly injured, enabling a better classification of the numbers of accident victims within the overall context, are summarized in tables 1 to 5. The definitions of a bicycle found in table 1 are largely based on the characteristics laid down in the Vehicle Codes, e.g. [1]. In some countries, bicycles are additionally subject to certain legal regulations, as listed by HORN [2] and in table 2.

Defining a light-powered two-wheeler and thus its description is more difficult. In table 3, the spectrum of the principal characteristics of a two-wheeler is represented on which a definition can be based. Taking the Federal Republic of Germany as an example, it can readily be seen that the moped is only one of the three classes of light-powered two-wheelers. According to the definitions given for mopeds and mokicks, the only difference between these vehicles appears to be the presence or absence of pedals or footrests. In contrast to that, the definition of a mofa as for the legal speed limit, minimum age of rider and driving licence regulations is a basically different one.
Legal speed limits for light-powered two-wheelers vary from 20 km/h (NL, snorfiets) to 48 km/h (GB, moped). The lowest possible first time user age varies from 14 years (Italy) to 16 years (in most other countries).

Compulsory helmet use also does not apply in all countries to all categories of light-powered two-wheelers. And furthermore, the regulations relating to the use of cycle lanes in the various countries have led to different forms of integrating the light-powered two-wheeler into road traffic as a whole: in some countries for light-powered two-wheelers it is mandatory to use cycle tracks, in others they may use them.

Then there are countries where light-powered two-wheelers are banned from cycle tracks and others where they are tolerated with engine off. Applicable definitions of ar road accident in the various countries, which are summarized in table 4, differ only slightly. It can be assumed that these are definitions of characteristic features. However, for the inclusion of accidents in the national accident statistics, the following additional information will generally be required:

- event site and time
- road users and vehicles involved
- direct causation factors and accident circumstances as recorded by the police
- accident injury consequences.

The definitions of accident consequences applying to casaulties in the various countries are summarized in table 5. The definition of a person killed in an accident varies in terms of the time period applied in each country within which a victim dies, i.e., between 6 days and 30 days. A period of 30 days is used in the majority of the countries. The definitions of severely or slightly injured accident victims also differ considerably, the extreme case being the Italian statistics where such difference is not made at all.
In most cases severely and slightly injured accident victims are distinguished by the kind of medical treatment required: hospitalization or out-patient treatment.

1.3. Total vehicle numbers (vehicle population)

The vehicle numbers grouped in vehicle categories are found in table 6 for all the countries participating in the working group. It should be pointed out that these populations, being subject to dynamic development processes, cannot be regarded as stable quantities. The development of mofas in the Federal Republic of Germany is a good example.
Mofas were introduced in 1966, in 1974 the mofa population exceeded a million and reached a peak in 1980 with 1,4 million vehicles. In 1981 there was a slump in the numbers of mofas and they went down to 1,2 million, The development of the mofa population from 1981 must be assedded in the light of another development, namely the introduction of the newly developed "Leichtkraftrad" in 1980 (80 cc, 80 km/h, min. age: 16 years).
Table 7 shows the numbers of vehicles in each vehicle category per 100.000 inhabitants. The peak value in the passenger car category, with a figure of 38.000, is displayed for the Federal Republic of Germany, Great Britain, with 27.000, shows the lowest figure in this category. The bicycle peak value is displayed for The Netherlands (76.000); here again the lowest number is found in Great Britain (24.000). France has the highest number of light-powered two-wheelers (9.100) and Great Britain once more the lowest (700).

1.4. Statistical records on persons killed and injured in road accidents

The total number of casualities with a breakdown in light-powered two-wheeler victims and users of bicycles are represented in diagrammatic form below for the years 1977-81. The development of the numbers of accidents in the various countries in the same time period is found in figures 1 to 6. Compared with the overall development of numbers of accident victims, a striking decline in fatalities in the Federal Republic of Germany, The Netherlands and Sweden is noticed.

The group of the severely injured also displays a slight downward trend with the exception of The Netherlands where a pronounced decline can be noticed in this group too. In all the countries under study, the numbers of the slightly injured also continued to decline. Great Britain, Italy and France, however, display a quite different development of the overall number of road accident victims. In Great Britain, all three categories display a slight downward trend. In Italy, the numbers of persons killed in accidents remained nearly constant, whereas the numbers of injured accident victims display an upward trend. Casualty numbers in France, apart from the absence of extremely low values and clear peaks, remained more or less constant.

The development of casualty numbers in the group of bicycle riders in the participating countries also displays considerable variations in the three casualty groups. In the Federal Republic of Germany, the numbers of killed bicycle riders display a clear decline; the numbers of the severely injured remained at a nearly constant level, whereas the numbers of the slightly injured increased considerably. The development of the numbers of casualties in France appears to be balanced in all three categories in the years 1877-81.
In Great Britain, although the numbers of bicycle riders killed in accidents remained nearly constant during this period, the numbers of severely and slightly injured accident victims display upward trends. The Italian statistics show a slight decline in the numbers of accident victims in both injury categories. In The Netherlands, the numbers of killed bicycle riders dropped continuously (an exception being the year of 1980), but is still on a high level.
The numbers of several injured victims remained at a nearly constant level whereas the numbers of the slightly injured display increasing rates. In Sweden too, with the exception of 1980, the statistics show a clear decline in the numbers of killed riders of bicycles whereas an overall rising trend is displayed by the overall number of severely and slightly injured accident victims.

In the group of light-powered two-wheeler riders involved in accidents, the statistics display a clear downward trend in the numbers of casualities in France, Great Britain, The Netherlands and Sweden. The reductions in this category in France and Sweden even appear disproportionally high. In the German statistics the absolute numbers of riders and passengers of light-powered two-wheelers involved in fatal accidents display clearly downward sloping curves. The numbers of the severely and slightly injured increased till 1980. In 1981, a reverse in trend took place and the numbers again reached the values recorded in 1977. In Italy, the numbers of persons killed remained nearly constant during the time period considered, whereas slight increases were found in the numbers of injured accident victims.

The magnitude of the numbers of pedal cycle and light-powered two-wheeler accidents in the various countries is seen clearly when relating them to the total number of road casualties. The percentage of killed pedal cyclists and users of light-powered two-wheelers in 1981 is given in table 8. The table shows in particular the importance of the accident involvement of this categroy of two-wheeler users in The Netherlands. As an example, the percentage of killed pedal cyclists is from two to four times as high as in other countries.
Great Britain with an overall rate of about 7 p.c. is the only country clearly remaining below the 10 p.c. level.

When the verhicle population is changing, the casualty rate in terms of the number of casualties per 100.000 vehicles shows the trend more clearly. The rates for killed pedal cyclists and users of light-powered two-wheelers for 1981 are found in table 9. The table shows that if calculations are performed on this basis The Netherlands no longer are outside of the accident patterns displayed by the other countries participating in the study. In this case, it is Sweden which shows up as a positive example with its low rates both for fatal pedal cycle and fatal light-powered two-wheeler accidents. The Federal Republic of Germany shows up as the leading country in the group of fatal light-powered two-wheeler accidents.

The absolute numbers of killed and injured users of bicycles and riders or passengers of light-powered two-wheelers, classified into age groups, are shown in tables 10 to 15.

In all countries, fatality, severe and slight injury peak values are reached in the age group of 10 to 14 year-old users of bicycles. The age group of 65 years and over also displays a high frequency of fatalities. In the Federal Republic of Germany, fatalities in the age group of 65 years and over are three times more frequent than in the age group of 10 to 14 years-old riders of bicycles, the ratio for the severely injured accident victims being 1 : 2. Similar ratios were found in The Netherlands. In Sweden and Italy, the comparison revealed still more unfavorable figures for the elderly.

The numbers of accident victims among the riders and passengers of light-powered two-wheelers reach peak values at a later age: the group of the 15 to 17 year-olds. Compared with the bicycle riders aged 10 to 14 years, the fatalities displayed numbers which, on average, were two or three times as high.

With the exception of Italy, the numbers of fatalities in the age group of 65 years and over are generally much lower than in the case of cyclists.

Tables 16 to 21 show the numbers of accident victims per 100.000 inhabitants of each age group. High frequencies and peak values are similar to those found in the absolute numbers (with the exception of Sweden where fatality and injury peak values are reached in the higher age groups of bicycle users). A striking fact, revealed by the Italian and Swedish statistics, is the fairly low fatality rate in the group of 10 to 14 year-old juveniles generally considered to be a particularly high-risk group. Compared with these numbers, the increased fatality rate for the elderly, especially in the age group of 65 years and over, should be noted, in particular.

Fig. 7 and 8 show population-based numbers of casualties enabling a comparison between the participating countries.
The numbers of killed and injured pedal cyclists are given in fig. 7 and the numbers of killed and injured users of light-powered two-wheelers in fig. 8.

Extremely high casualty figures for pedal cyclists are displayed by the Netherlands and the Federal Republic of Germany. This applies to all degrees of injury severity, but particulary to the group of severe injuries. Once more, the diagrams are an evidence of the fact that the proportion of persons aged 65 and over increases disproportionally with increasing injury severity, Great Britain being the exception.

The variation in the numbers of casualties per 100.000 inhabitants for users of light-powered two-wheelers is not as large as for pedal cyclists. They are narrowly concentrated around the age group of the 16-year-olds. France, The Netherlands and the Federal Republic of Germany display the highest figures in all these accidents. France, in particular, displays a remarkable death rate for the age group over 40 years.

1.5. Unreported accidents

The most important systematic error in all national accident statistics results from the material damage and injury accidents which are not reported.
These so-called unreported accidents can reach considerable values, particularly with decreasing accident severity.
Various studies have been consulted:

Sweden:
ROOSMARK/FRAKI [4] and THORSON/SANDE [5] concluded that on the whole not more than half of the traffic casualties are reported in the national accident statistics. In the case of material damage, unreported numbers are estimated at 85 p.c. even.
BUNKETORP [11] determined, based on a regional study in Goteburg, a correction factor to describe the relationship between the overall number of accidents and those recorded by the police.
For fatale accidents a factor of 1,0 was found, for severe injury accidents 1,4 and for light injury cases 1,8. This corresponds to unreported rates of 0 p.c. for fatal accidents, one of 29 p.c. for severe injury cases and one of 45 p.c. for light injury accidents.

Denmark:
NORDENTOFT [6] revealed in 1972 in the Odense area an estimation of unreported injured accident victims of more than 60 p.c.
Unreported numbers are reportedly particulary high in the case of single-vehicle injury accidents.

Switzerland:
HEHLEN [7] reports a high percentage inside urban areas at 70 p.c. and outside urban areas at 63 p.c. The unreported accidents of cyclists were estimated at 81 p.c., and for mofa riders at 74 p.c.

The Netherlands:
A study on unreported numbers, published in 1982, was conducted in The Netherlands (MAAS [9]). This study was based on the time period 1977-79 and revealed that the proportion of unreported numbers appeared to have remained unchanged over the entire period.
A comparison with police accident records for 1979 showed that in the case of accident victims hospitalized as a consequence of their accidents only 17 p.c. appear to remain unreported. The underreporting seems to be a function of mode of transport.
The "CBS/SMR" ratio of <u>reported</u> accidents (police information/hospital information) is in vehicle categories and pedestrians the following:

CAR OCCUPANTS	MOPEDS	BICYCLES	PEDSTRIANS
98 P.C.	97 P.C.	82 P.C.	78 P.C.

Germany:
A study conducted by LENHARDT [10] in 1982 (still unpublished) was based on approximately 4.000 accidents and arrived at an estimated percentage of unreported numbers of about 54 p.c. The numbers of unreported cases drop with increasing severity. The proportion of unreported fatalities is estimated at 4,8 p.c., in the case of severely injured accident victims 22,3 p.c. and in that of slightly injured victims 37,5 p.c.
The global estimate of 54 p.c. comprises material damage accidents.
A breaksdown in vehicle categories and pedestrians has not been undertaken in this conjunction.

Great Brittain:
PEDDER [12] revealed the numbers of unreported accidents shown in the table 23. The figures are based on data collected by PEDDER (1977-1978) and BULL (1973) at Birmingham Accident Hospital and by HOBBS at a hospital in Berkshire.

The comparison shows how difficult it is for a regional study of this nature to arrive at a conclusive result of general validity. The year of data collection (PEDDER: 1977-78; BULL: 1973) and the legal framework and social conditions applying therewith certainly would also affect an interpretation of the large differences found in the estimates, but also differences in sample sizes of the studies may contribute.

1.6. Injury severity and hospitalization of users of two-wheelers (including an approach to an overall economic assessment)

It has generally been found that data are not collected on a national scale in any of the participating countries on the various degrees of injury severity and length of in-patient treatment. The research findings available are results of regional studies and thus involve the problem of translation to be of value at national level.

A thorough analysis would additionally have to consider the economic significance of human accident costs which apart from hospital costs (during the period of a victim's hospitalization) also include e.g. the production loss during the period of a victim's inability to work (involving a much larger time (and cost) factor than the period of treatment as an in-patient). However, these are aspects which would be outside of the scope of a regional study on a medical treatment facility concentrating on the classification of injuries into appropriate categories (e.g. AIS, OAIS, MAIS).

For the Federal Republic of Germany, first hints for an analysis of the time and cost factors involved in treating accident victims are found in the studies conducted by OTTE [14] and in the comparison of OTTE's findings with the results obtained by WILLEKE [15]. In table 23, the periods of hospitalization relating to the various degrees of injury severity (OAIS) are shown (on average in terms of days).

Attention is to be paid to the fact that WILLEKE's study is based on an all-road-user sample whereas OTTE concentrated on the users of two-wheelers only. The term "sum total of days of in-patient treatment" may include readmittance to the hospital, where necessary. The number of cases studied here was 123. Based on 282 case studies, OTTE arrived at average periods of in-patient treatment (including complications or not) as stated on the last line in table 23.

For the calculation of the costs of treatment, the average length of hospitalization in each AIS group was linked with the hospital costs/day charged currently by the Medical University of Hanover (DM 310,--). The costs of medical treatment for users of motorized two-wheelers involved in injury accidents with resulting injuries of the OAIS 2 category (without complications) are thus estimated at DM 3.950,--. If complications have to be considered in addition, the costs rise to DM 10.000,-- (base: 123 cases).

A survey concerning the length of the hospitalization in relation to the severity of injuries (MAIS) can be found in a study by DANNER [16]. One remarkable result of the study is that the high number of leg injuries with long treatment period are dominating at the injury-scale MAIS 3, whereas at MAIS 4 and 5 head injuries determine the injury pattern (table 24).

A study conducted by KRUPP [17] describes the periods of hospitalization and the resulting costs for severely injured riders of bicycles and motorized two-wheelers. The medical treatment costs and the costs with a breakdown into categories accounting for the absence and presence of effects on earning capacity, as estimated by health insurance companies or insurance companies for occupational accidents, are found in table 25.

A survey among nearly all hospitals in The Netherlands [18] shows as a result the following average number of days in hospital for bicyclists and users of powered two-wheelers: bicyclists 18 days; moped riders 20 days; motorcyclists 20 days. The average total costs per patient don't differ so much: bicyclists 6200 HFL; moped riders 6900 HFL; motorcyclists 6800 HFL.

In the TRRL study by HOBBS [8] the period of hospitalization and degrees of accident severity are considered separately for cyclists and users of motorized two-wheelers. In the case of cyclists, the degrees of injury severity primarily fall into the AIS 2 en 3 categories. On account of the limited number of case studies, the periods of hospilatization were classified into those of less or greater than two days. The group of accident victims with injuries in the AIS 2 category mainly involved periods of in-patient treatment of $\leq$ 2 days (57 out of 83 cases). In the case of injuries of the AIS 3 category, the period of hospitalization is clearly greater than two days (in 22 out of 29 cases). In 57 out of 85 cases, accident victims of the group of users of motorized two-wheelers, whose injuries had been classified as corresponding to AIS 2, had to undergo hospital treatments of $\leq$ 2 days. The peak value reached by the injury cases of the AIS 3 category also exceeds two days of hospilatization by far: between 11 and 20 days in 27 out 100 cases. Injury cases corresponding te AIS categories other than 2 or 3 were so few that statistically significant information was not obtained.

1.7. Summary.

The chapter presents a survey of the national accident statistics of the countries represented in the wordking group. The frequencies of injuries of cyclists and users of light-powered two-wheelers are considered at greater depth. At the beginning, the numbers of registered vehicles are presented and the definitions of a bicycle and a light-powered two-wheeler as applicable in the various countries, summarized. In the case of the numbers of injured accident victims, given as overall figures and with a breakdown by vehicle categories, the distributions found are fairly heterogeneous and often also display falling trends, in particular in the case of fatalities.

A consideration of the development of vehicle numbers in each vehicle category needs to be included in the study. In addition, the numbers of vehicles per 100.000 inhabitants need to be considered both in the evaluation of the numbers of accidents and in the assessment of relative accident numbers. Due to the complex nature of the relationships and the basically different definitions given, e.g., of light-powered two-wheelers, a ranking of the countries by their rates of injured accident victims was refrained form in this conjuction.

With respect to the numbers of unreported accidents, there is still the problem of translating the results of regional studies to the conditions at national level. On the whole, it was found that the percentages of unreported accidents tend to increase with decreasing injury severity.

No statistically supported findings on a national level can be given on the correlation between injury severity and periods of hospitalization. Only initial data material is available from regional studies.

1.8. National statistical data - sources:

FEDERAL REPUBLIC OF GERMANY:
Strassenverkehrsunfälle; Verkehr,
Fachserie 8, Reihe 3.3, 1982
Statistisches Bundesambt Wiesbaden

THE NETHERLANDS:
Statistiek van de verkeersongevallen
op de openbare weg - 1981
Centraal Bureau voor
de Statistiek, 1983

SWEDEN:
Road traffic accidents with
personal injury 1981
Statistics Sweden, Stockholm
1982

ITALY:
Statistica degli incidenti stradali
edizione 1981, Instituto Centrale
di Statistica, Roma 1982

GREAT BRITAIN:
"Accidents in Great Britain 1981"
Department of Transport 1982

1.9. References

1. Bundesgesetzblatt Teil II:
   Gesetz zu den Übereinkommen vom
   8 November 1968 über den Strassenverkehr und über Strassenverkehrszeichen, zu den Europäischen
   Zusatzübereinkommen vom 1. Mai
   1971 zu diesen Übereinkommen
   sowie zum Protokoll vom 1. März
   1973 über Strassenmarkierungen

2. B.E. Horn
   Helping to Identify Key Issues
   in Bicycle Safety through International Assessment
   OECD, Road Research Secretariat

3. RAI techniek
   no. 11; Oct. 80
   Nederlandse Vereniging de Rijwiel-
   en Automobielindustrie

4. P.O. Roosmark; R. Fräki
   Interview Investigation of Road
   Traffic Accidents
   in: Accident Analysis and Prevention, Vol. 1, 1969,
   S.279-291

5. J. Thorson; J. Sande
   Hospital Statistics on Road
   Traffic Accidents
   in: Proceedings of the 3rd
   Triennial Congress, 1969
   Michigan, Highway Safety Research Institute, 1971

6. E. Nordentoft; et al.:
   Rapportering af Trafikulykker
   Med Personskade
   in: Radet for trafiksikkerhedsforsking, Rapport 13,
   Kopenhagen, 1972

7. P. Hehlen
   Unfälle an Strassen-Kreuzungen
   und -Einmundungen
   14. Tagung des Institutes fur
   die gesamte Unfallforschung in
   Zürich, April 1976 (unpublished)

8. C.A. Hobbs; et al.:
   Classification of Injury Severity
   by Lenght of Stay in Hospital
   TRRL, Report 871, 1979

9. M.W. Maas
   De Politieregistratie van Verkeersgewonden in Ziekenhuizen
   SWOV, Report R-82-34, 1982

10. W. Lenhart
    Grundauswertung des korrigierten
    Datenbestandes zu FP 7537
    BASt, Köln 1982 (unpublished)

11. D. Bunketorp; et al.:
    Traffic Accident Registration and
    Analysis in Göteborg
    VII. IRCOBI conference, Köln, 1982

12. J.B. Pedder; et al.:
    A Study of Two-Wheeled Vehicle
    Casualties Treated at a City Hospital
    IRCOBI Conference, Salon de
    Provence, France 1981

13. J.P. Bull; B.J. Roberts
    Road Accident Statistics - A Comparison
    of Police and Hospital Information
    Accident Analysis and Prevention
    1973, 5, 45-53

14. D. Otte; E.G. Suren
    Verletzungen und deren Langzeitfolgen bei
    verunfallten motorisierten Zweiradbenutzern
    1. Bochumer Workshop zur Zweiradsicherheit,
    Februar 1983

15. R. Willeke; et al.:
    Ein Optimum an Sicherheit;
    Nutzen-Kosten-Untersuchungen
    fur Verkehrssicherheitsmassnahmen
    Schriftenreihe VDA, Heft 25, 1978

16. M. Danner; et al.:
    Optimiering des passiven Unfallschutzes
    für motorisierte Zweiradfahrer
    BASt, FP 7806,(unpublished)

17. R.Krupp; M. Bressin
    Personenschaden infolge von Strassen
    verkehrsunfallen- Ein Vergleich
    zwischen Pkw-Insassen,
    motorisierten Zweiradfahrern,
    Fussgangern und Radfahrern -
    BASt, 1983 (unpublished)

18. Groepering van statistische
    gegevens betreffende slachtoffers
    van verkeersongevallen opgenomen
    in ziekenhuizen 1979,
    Ministerie van Volksgezondheid
    en Milieuhygiene, 1982

19. ECE Statistics of Road Traffic
    Accidents in Europe (1981)
    United Nations 1982.

1.10 Figures and tables

FRANCE:	A VEHICLE WHICH HAS AT LEAST 2 WHEELS AND IS PROPELLED ONLY BY MUSCULAR FORCE.
FEDERAL REPUBLIC OF GERMANY:	BICYCLE MEANS ANY VEHICLE WHICH HAS AT LEAST TWO WHEELS AND IS PROPELLED SOLELY BY THE MUSCULAR ENERGY OF THE PERSONS ON THAT VEHICLE, IN PARTICULAR BY MEANS OF PEDALS OR HANDCRANKS.
ITALY:	BICYCLE IS A VEHICLE WITH TWO OR MORE WHEELS, PROPELLED BY MUSCULAR POWER THROUGH PEDALS OR SIMILAR MECHANISM.
THE NETHERLANDS:	NO EXACT LEGAL DEFINITION " A CARRIAGE OR VEHICLE THAT ISN'T A MOTORVEHICLE". (WVR art. 1.1)
SWEDEN:	1. A VEHICLE DESIGNED TO BE PROPELLED BY PEDALS WHICH IS NOT A TOY VEHICLE. 2. ELECTRICAL WHEEL-CHAIR DESIGNED FOR A MAXIMUM SPEED OF 15 KM/H.
GREAT BRITAIN:	HAS NO POWER ASSISTANCE AND INCLUDES TOY CYCLES RIDDEN ON THE CARRIAGEWAY, TANDEMS AND TRICYCLES. (FROM SEPT. 1983 THE DEFINITON OF PEDAL CYCLES FOR THE PURPOSE OF REGULATIONS HAS BEEN CHANGED TO INCLUDE "ELECTRICALLY ASSISTED PEDAL CYCLES"; 0,2 KW, 24 KM/H)

Table 1: Definition of a bicycle

REQUIREMENTS FOR BICYCLES	FEDERAL REPUBLIC OF GERMANY	FRANCE	ITALY	THE NETHERLANDS	GREAT BRITAIN	SWEDEN
BRAKES						
- ONE FRONT AND ONE REAR	X	X	X	-	X	-
- ONE BRAKE	-	-	-	X	-	X
LIGHTING						
- HEADLAMP WHITE	X	X	X	X	X	X
- REARLAMP RED						
- BY DAY AND NIGHT	X	-	X	-	-	X
- BY NIGHT OR POOR VISIBILITY	-	X	-	X	X	-
REFLECTORS	X(1)					
- ON PEDALS						
- OBLIGATORY	X	X	X	X	-	-
- ADMITTED	-	-	-	-	X	X
- RED REAR	X	X	X	X(3)	X	X
- WHITE FRONT	-	-	-	-	-	-
WHITE REAR MUDGUARD	-	-	-	X(2)	-	-
REFLECTING TIRES ADMITTED	X(1)	-	X	X	X	X
BELL	X	X	X	X	-	X
OTHER CONSTRUCTION REQUIREMENTS	X	-	-	X(4)	-	-

1)IN 1983 ALL NEW BICYCLES MUST HAVE REFLECTORS IN THE SPOKES OR REFLECTING TIRES

2)YELLOW REFLECTING IS ADMITTED

3)ADDITIONAL HIGH-PERFORMANCE REFLECTOR(MIN1000MCD/LX) REQUIRED,SEPERATE FROM THE REARLAMP (-REFLECTOR)

4)SOME REQUIREMENTS ON THE SEATING POSITION OF CHILD-PASSENGERS UNDER AGE 10

Table 2: Some of the relevant legal requirements for bicycles [3]

	FEDERAL REPUBLIC OF GERMANY			FRANCE	GREAT BRITAIN	ITALY	THE NETHERLANDS		SWEDEN
NAME OF CLASS	MOFA	MOPED	MOKICK	CYCLOMOTEUR	MOPED	CICLOMOTORI	SNORFIETS 4)	BROMFIETS (1) 4A)	MOPED 17)
CLASS INTRODUCED IN	1965	1954	1967	1970	1977	1959	21.4.1976	SINCE 21.11 1966 WITH PEDALS	JULY, 1.1952
SPEED LIMIT [km/h]	25	40	40	45	48 10)	40	20 5)	30/40 5A)	30
PISTON DISPLACEMENT [CC]	≤ 50	≤ 50	≤ 50	≤ 50	≤ 50	≤ 50	≤ 50 6)	≤ 50 6)	≤ 50
MINIMAL AGE [YEARS]	15	16	16	16 1)	16	14	16	16	15
HELMET OBLIGATORY SINCE	NO	24 7.78	24 7.78	1979	1973	NOT YET OBLIGATORY	NO	YES, SINCE 1 2.1975	SEPT. 1.1978
DRIVING LICENCE	ONLY THEOR. TEST CERTIFICATE	YES	YES	NO	YES	NOT NECESSARY	NO	NO	NO
DRIVING ON BICYCLE TRACKS ALLOWED/MANDATORY	MANDATION	NOT ALLOWED	NOT ALLOWED	MANDATION	PERMITTED 11)	NOT ALLOWED	MANDATION 7)	MANDATION 7)	ALLOWED
PEDAL OR FOOTREST	PEDAL	PEDAL	FOOTREST	PEDAL	PEDAL 12)	NOT SPECIFIED	PEDAL	PEDAL	NO REQUIREMENTS
MIN. AND MAX. DIAMETER OF THE WHEELS	B.T. 3) MIN. 580	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED	NO 13)	NOT SPECIFIED	254 mm ≤ 305 mm	≥ 405 mm	NO REQUIREMENTS
MAXIMUM MASS [kg]	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED	250 14)	16 (ENGINE)	NO LIMIT 8)	NO LIMIT	2 WHEELS NO LIMIT 3 WHEELS 400
ADMITTED NUMBER OF PASSENGERS	0	1	1	1 2)	1 15)	0	1	1	0
BRAKES	2	2	2	2	2 16)	2	2 9)	2 9)	2

1) 14 YEARS OLD WITH A SPECIAL SCHOOL TRAINING
2) PLUS PASSENGER IF LESS THAN 14 YEARS OLD
3) MINIMUM OUTER DIAMETER OF THE BACK TYRE
4) "BUZZLE BIKE"
4A) MOPED
5) IN "WOONERVEN" NOT FASTER THAN "WALKING SPEED"
5A) 30 km/h IN BUILT UP AREAS, 40 km/h OUTSIDE BUILT UP AREAS (AND 5))
6) ≤50 CC OR APPROVED ELECTROMOTOR
7) SOME TRACKS MANDATED, OTHER TRACKS ALLOWED WITH ENGINE OFF
8) 50 kg FOR "EMPTY" VEHICLE, FULLY READY FOR USE
9) $\geq 5\ m/S^2$ (BOTH BRAKES TOGETHER)
10) MUST HAVE A DESIGN SPEED NOT GREATER THAN 48 km/h IF REGISTERED LATER THAN AUGUST 1977
11) PERMITTED IN SOME CASES BUT NEVER MANDATORY
12) IF REGISTERED BEFORE AUGUST 1977 MUST BE EQUIPPED WITH PEDALS BY MEANS OF WHICH THE MOPED IS CAPABLE OF BEING PROPELLED
13) NO REQUIREMENTS FOR PNEUMATIC TYPRES, 670 mm MIN. DIAMETER FOR NON-PNEUMATIC TYRES
14) 250 kg IF REGISTERED LATER THAN AUGUST 1977
15) ONE PASSENGER IF PROPER SEAT FITTED
16) EITHER MUST HAVE A SINGLE SYSTEM WITH TWO MEANS OF OPERATION OR TWO SYSTEMS OPERATING INDEPENDENTLY
17) SINCE JANUARY 1984 MOPEDS ARE DIVIDED INTO CLASS I AND CLASS II. CLASS I MOPED OLD DEFINITION CLASS II VEHICLE KERB MASS ≤ 60 kg AND A TRANSMISSION INCLUDING MAXIMUM TWO GEARS OR AN AUTOMATIC TRANSMISSION WITHOUT STEPS

Table 3: Definitions and requirements for light-powered two-wheeler

FEDERAL REPUBLIC OF GERMANY:	ACCIDENTS IN ROAD TRAFFIC WITH KILLED OR INJURED PERSONS ON PUBLIC ROADS AND PLACES (REGISTERED IN OFFICIAL STATISTICS; STVUNFG, BGBL. 1982, 2069).
FRANCE:	ACCIDENT IN ROAD TRAFFIC WHICH GENERATES AT LEAST ONE VICTIM OCCURRING ON A PUBLIC OPEN ROAD AND INVOLVING AT LEAST ONE VEHICLE OR RIDDEN ANIMALS.
GREAT BRITAIN:	ONE INVOLVING PERSONAL INJURY OCCURING ON THE PUBLIC HIGHWAY (INCL. FOOTWAYS) IN WHICH A VEHICLE IS CONCERNED, AND WHICH BECOMES KNOWN TO THE POLICE.
ITALY:	ROAD ACCIDENT IS A COLLISION INVOLVING VEHICLES OR ANIMALS ON PUBLIC ROADS, WICH GENERATES PERSONAL INJURIES.
THE NETHERLANDS:	ACCIDENTS INCLUDED ARE THOSE 1. WHICH OCCURRED OR ORIGINATED ON A HIGHWAY OR STREET OPEN TO PUBLIC TRAFFIC 2. WHICH RESULTED IN ONE OR MORE PERSONS BEING KILLED OR INJURED AND 3. IN WHICH AT LEAST ONE MOVING VEHICLE WAS INVOLVED.
SWEDEN:	ACCIDENTS INCLUDED ARE THOSE 1. WHICH OCCURED OR ORIGINATED ON A WAY OR STREET OPEN TO PUBLIC TRAFFIC 2. WHICH RESULTED IN ONE OR MORE PERSONS BEING KILLED OR INJURED AND 3. IN WHICH AT LEAST ONE MOVING VEHICLE WAS INVOLVED.

Table 4: Definition of a road accident for national statistics for casualties

FEDERAL REPUBLIC OF GERMANY	KILLED	SEE ECE*
	SEVERELY INJURED	AN INJURY FOR WHICH A PERSON IS DETAINED IN HOSPITAL AS AN 'IN-PATIENT'
	SLIGHTLY INJURES	AN INJURY FOR WHICH A PERSON IS NOT HOSPITALIZED
FRANCE:	KILLED	VICTIM DIED IMMEDIATELY OR DURING 6 DAYS AFTER THE ACCIDENT
	SEVERELY INJURED	ACCIDENT VICTIM WHO HAS SUSTAINED A TRAUMATISM NEEDING MEDICAL TREATMENT WITH AT LEAST A 6 DAYS' STAY IN THE HOSPITAL
	SLIGHTLY INJURED	ACCIDENT VICTIM WHO HAS SUSTAINED A TRAUMA NEEDING MEDICAL TREATMENT WITH LESS THAN A 6 DAYS' STAY IN THE HOSPITAL
GREAT BRITAIN	KILLED	SEE ECE*
	SEVERELY INJURED	AN INJURY FOR WHICH A PERSON IS DETAINED IN HOSPITAL AS AN 'IN-PATIENT',OR ANY OF THE FOLLOWING INJURIES WETHER OR NOT HE IS DETAINED IN HOSPITAL: FRACTURES,CONCUSSIONS, INTERNAL INJURIES, CRUSHINGS, SEVERE CUTS AND LACERATIONS, SEVERE GENERAL SHOCK REQUIRING MEDICAL TREATMENT, INJURIES CAUSING DEATH 30 OR MORE DAYS AFTER THE ACCIDENT
	SLIGHTLY INJURED	AN INJURY OF A MINOR CHARACTORS SUCH AS A SPRAIN, BRUISE OR CUT NOT JUDGED TO BE SEVERE, OR SLIGHT SHOCK REQUIRING ROADSIDE ATTENTION
ITALY	KILLED	ALL PERSONS, WHO DIE WITHIN THE NEXT SEVEN DAYS AFTER THE ACCIDENT
	SEVERELY/ SLIGHTLY INJURED	ARE NOT DISTINGUISHED IN ITALIAN STATISTICS
THE NETHERLANDS	KILLED	SEE ECE*
	SEVERELY INJURED	VICTIMS WHO ARE HOSPITALIZED FOR MORE THAN ONE DAY
	SLIGHTLY INJURED	OTHER INJURED VICTIMS
SWEDEN	KILLED	SEE ECE*
	SEVERELY INJURED	FRACTURE, CONCUSSION, INTERNAL LESIONS, CRUSHING, SEVERE CUTS AND LACERATION, SEVERE GENERAL SHOCK REQUIRING MEDICAL TREATMENT AND ANY OTHER SERIOUS LESIONS ENTAILING DETENTION IN HOSPITAL
	SLIGHTLY INJURED	ALL INJURED NOT BELONGING TO KILLED OR SEVERELY INJURED

Table 5: Definition of casualties; distinction between persons killed, severly or slightly injured in road accidents.

*ECE Definition of killed: any person who was killed outright or who died within 30 days as a result of the accident (For further definitions see ECE [19]).

	CARS	GOODS VEHICLES	MOTOR CYCLES	MOPEDS	MOFAS/ SNORFIETS	PEDAL CYCLES *
FRANCE	19 725	2 568	645	4 900	-	19 000
FEDERAL REPUBLIC OF GERMANY	23 730	1 307	690	652	1 224	38 500
ITALY	17 686 (1980)	1 338 (1980)	828 (1980)	3 461 (1980)	-	17 500
THE NETHER-LANDS	4 594	339	114	700	10	10 800
SWEDEN	2 893	186	16	205	-	6 000
GREAT BRITAIN	14 796	2 286	973	398	-	13 000

* ROUGH ESTIMATED DATA

Table 6: Vehicle population in 1981 (in 1000)

	(1000s)			
	CARS	PEDAL CYCLES	LIGHT-POWERED TWO-WHEELERS	INHABITANTS 1 9 8 1
FRANCE	36	35	9,1	53.960
FEDERAL RE-PUBLIC OF GERMANY	38	64	3,0	61,680
GREAT BRITAIN	27	24	0,7	55.830
ITALY	31	31	6,1	57,200
THE NETHER-LANDS	32	76	5,0	14.250
SWEDEN	35	72	2,5	8.320

Table 7: Vehicle numbers (in 1000) per 100,000 inhabitants in 1981

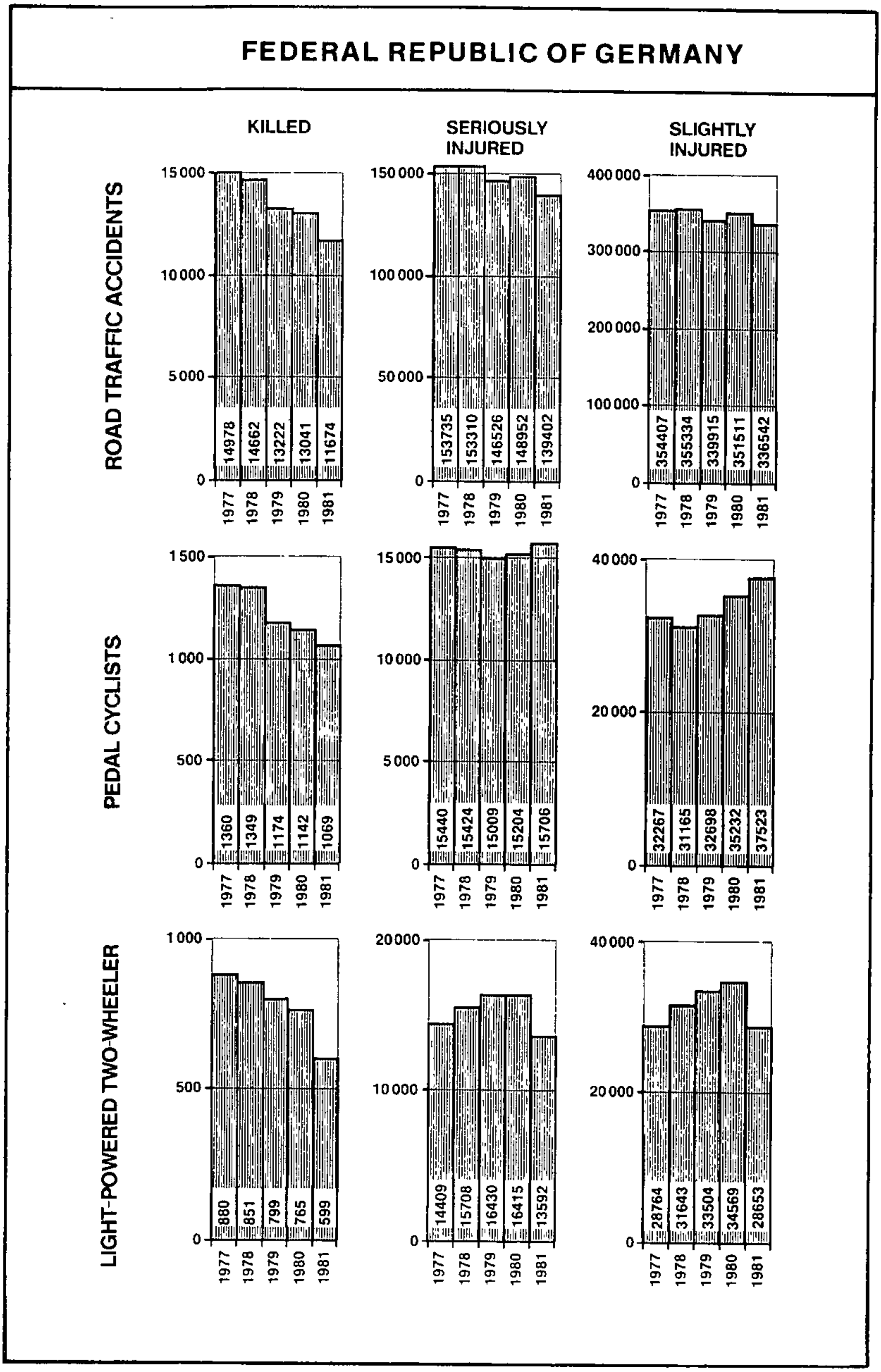

FEDERAL REPUBLIC OF GERMANY
KILLED
SERIOUSLY INJURED
SLIGHTLY INJURED
ROAD TRAFFIC ACCIDENTS
15 000
10 000
5 000
0
14978
14662
13222
13041
11674
150 000
100 000
50 000
153735
153310
146526
148952
139402
400 000
300 000
200 000
100 000
354407
355334
339915
351511
336542
PEDAL CYCLISTS
1 500
1 000
500
1360
1349
1174
1142
1069
15 000
10 000
5 000
15440
15424
15009
15204
15706
40 000
20 000
32267
31165
32698
35232
37523
LIGHT-POWERED TWO-WHEELER
1 000
500
880
851
799
765
599
20000
10 000
14409
15708
16430
16415
13592
40 000
20 000
28764
31643
33504
34569
28653
1977
1978
1979
1980
1981

Figure 1

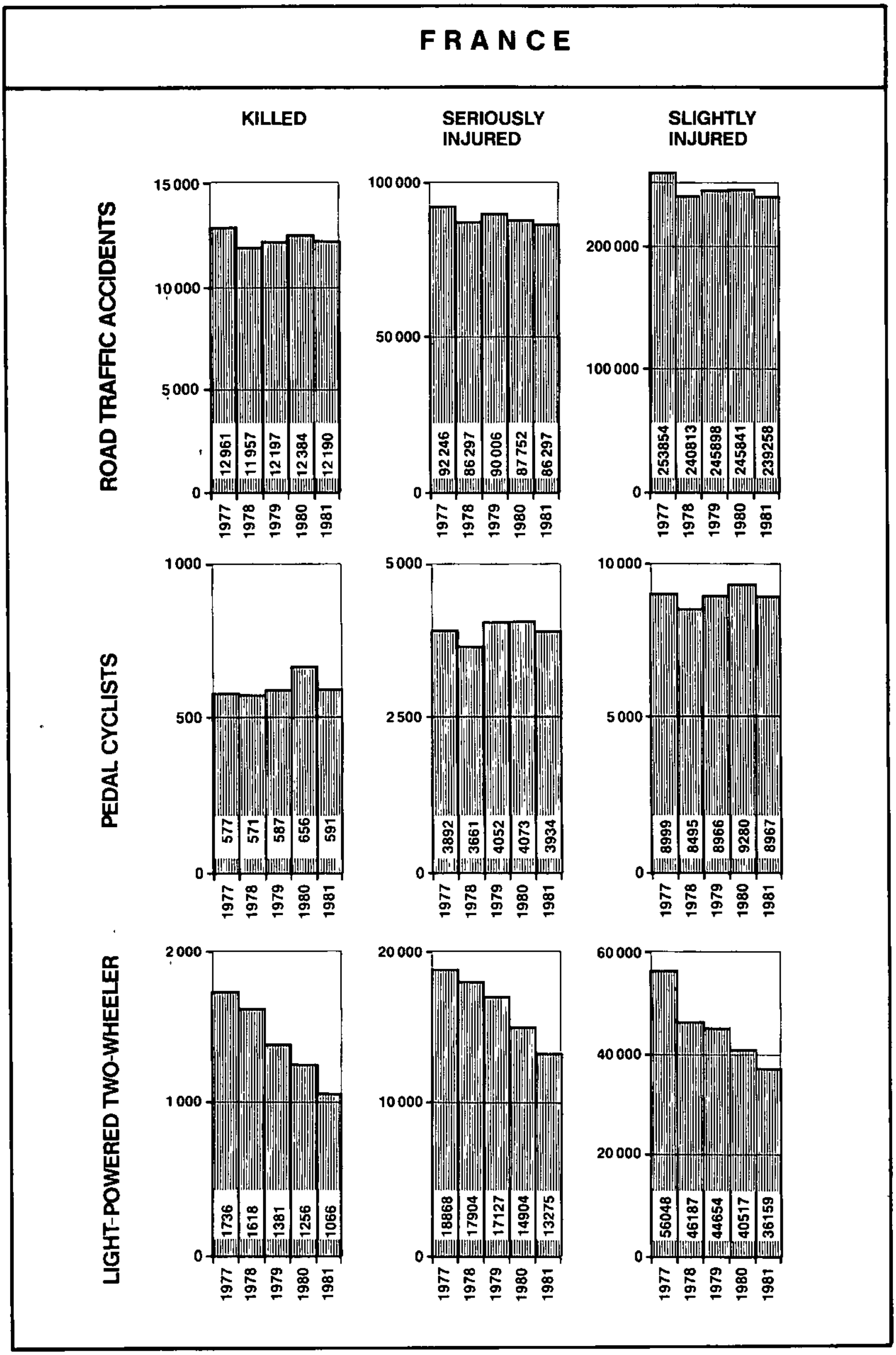

FRANCE
KILLED
SERIOUSLY INJURED
SLIGHTLY INJURED
ROAD TRAFFIC ACCIDENTS
15 000
10 000
5 000
0
12 961
11 957
12 197
12 384
12 190
100 000
50 000
0
92 246
86 297
90 006
87 752
86 297
200 000
100 000
0
253854
240813
245898
245841
239258
PEDAL CYCLISTS
1 000
500
0
577
571
587
656
591
5 000
2 500
0
3892
3661
4052
4073
3934
10 000
5 000
0
8999
8495
8966
9280
8967
LIGHT-POWERED TWO-WHEELER
2 000
1 000
0
1736
1618
1381
1256
1066
20 000
10 000
0
18868
17904
17127
14904
13275
60 000
40 000
20 000
0
56048
46187
44654
40517
36159
1977
1978
1979
1980
1981

Figure 2

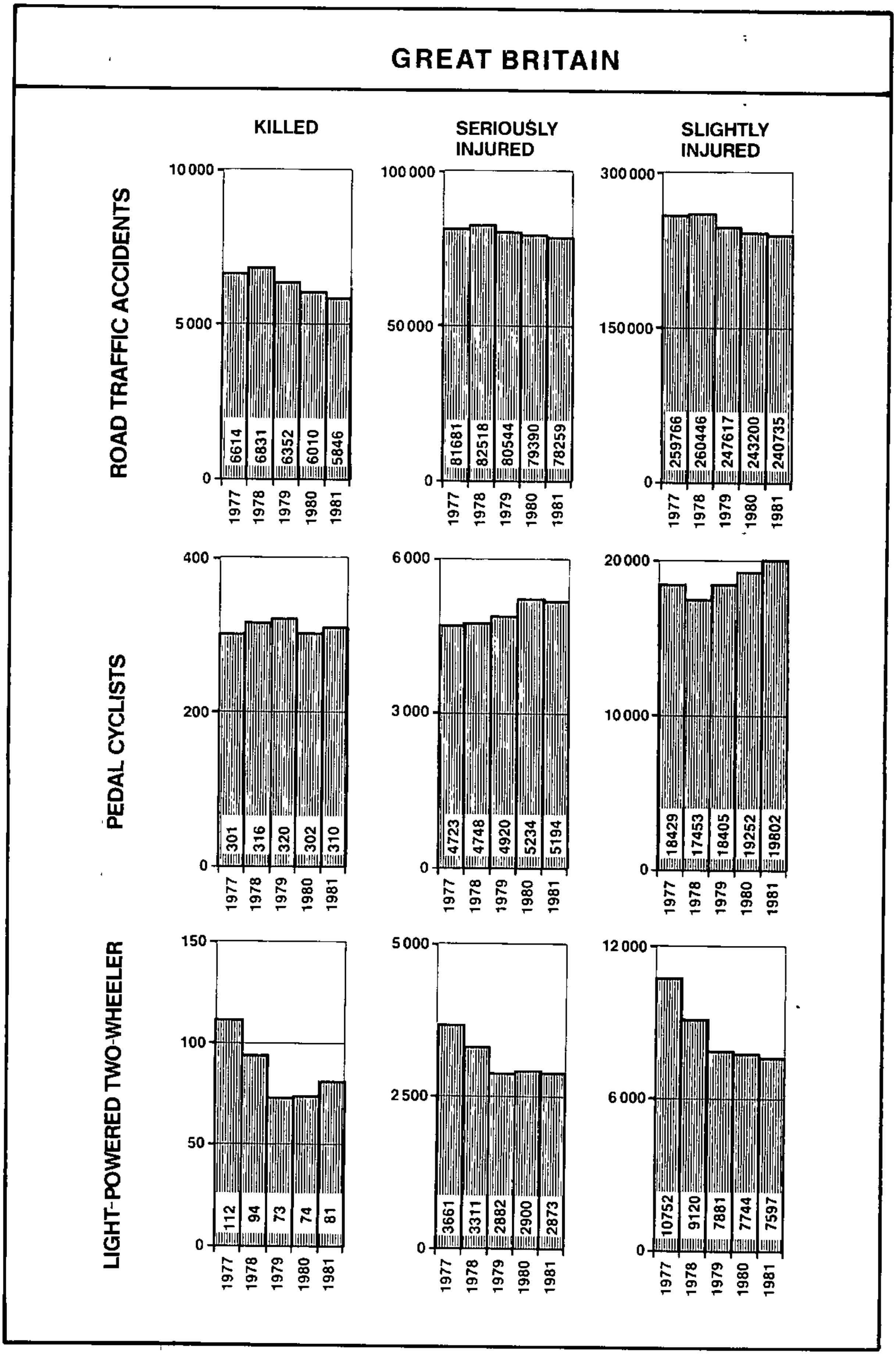

GREAT BRITAIN
KILLED
SERIOUSLY INJURED
SLIGHTLY INJURED
ROAD TRAFFIC ACCIDENTS
10 000
5 000
0
6614
6831
6352
6010
5846
100 000
50 000
0
81681
82518
80544
79390
78259
300 000
150 000
0
259766
260446
247617
243200
240735
1977
1978
1979
1980
1981
PEDAL CYCLISTS
400
200
0
301
316
320
302
310
6 000
3 000
0
4723
4748
4920
5234
5194
20 000
10 000
0
18429
17453
18405
19252
19802
1977
1978
1979
1980
1981
LIGHT-POWERED TWO-WHEELER
150
100
50
0
112
94
73
74
81
5 000
2 500
0
3661
3311
2882
2900
2873
12 000
6 000
0
10752
9120
7881
7744
7597
1977
1978
1979
1980
1981

Figure 3

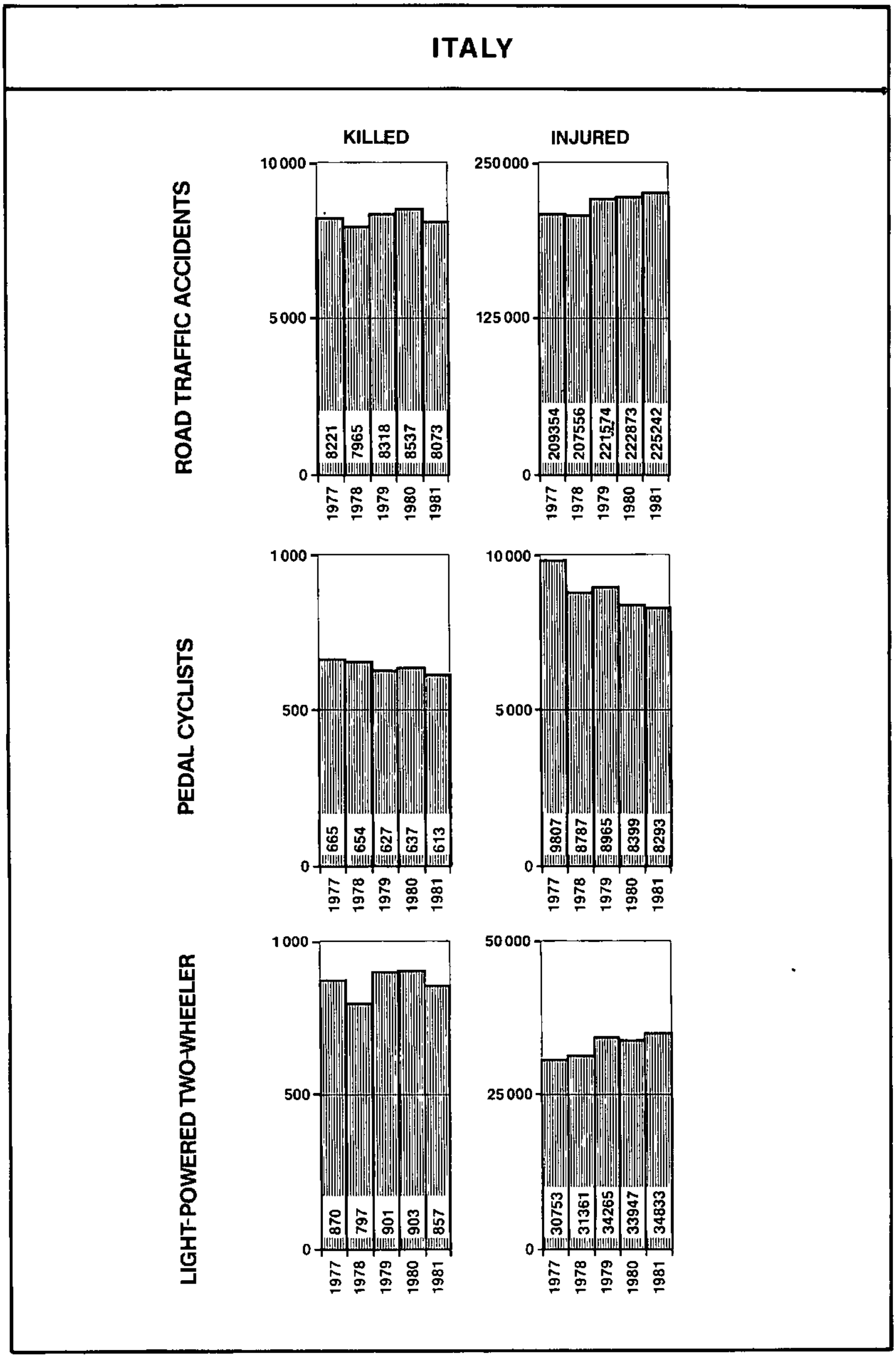

ITALY
KILLED
INJURED
ROAD TRAFFIC ACCIDENTS
10 000
5 000
0
8221
7965
8318
8537
8073
1977
1978
1979
1980
1981
250 000
125 000
0
209354
207556
221574
222873
225242
1977
1978
1979
1980
1981
PEDAL CYCLISTS
1 000
500
0
665
654
627
637
613
1977
1978
1979
1980
1981
10 000
5 000
0
9807
8787
8965
8399
8293
1977
1978
1979
1980
1981
LIGHT-POWERED TWO-WHEELER
1 000
500
0
870
797
901
903
857
1977
1978
1979
1980
1981
50 000
25 000
0
30753
31361
34265
33947
34833
1977
1978
1979
1980
1981

Figure 4

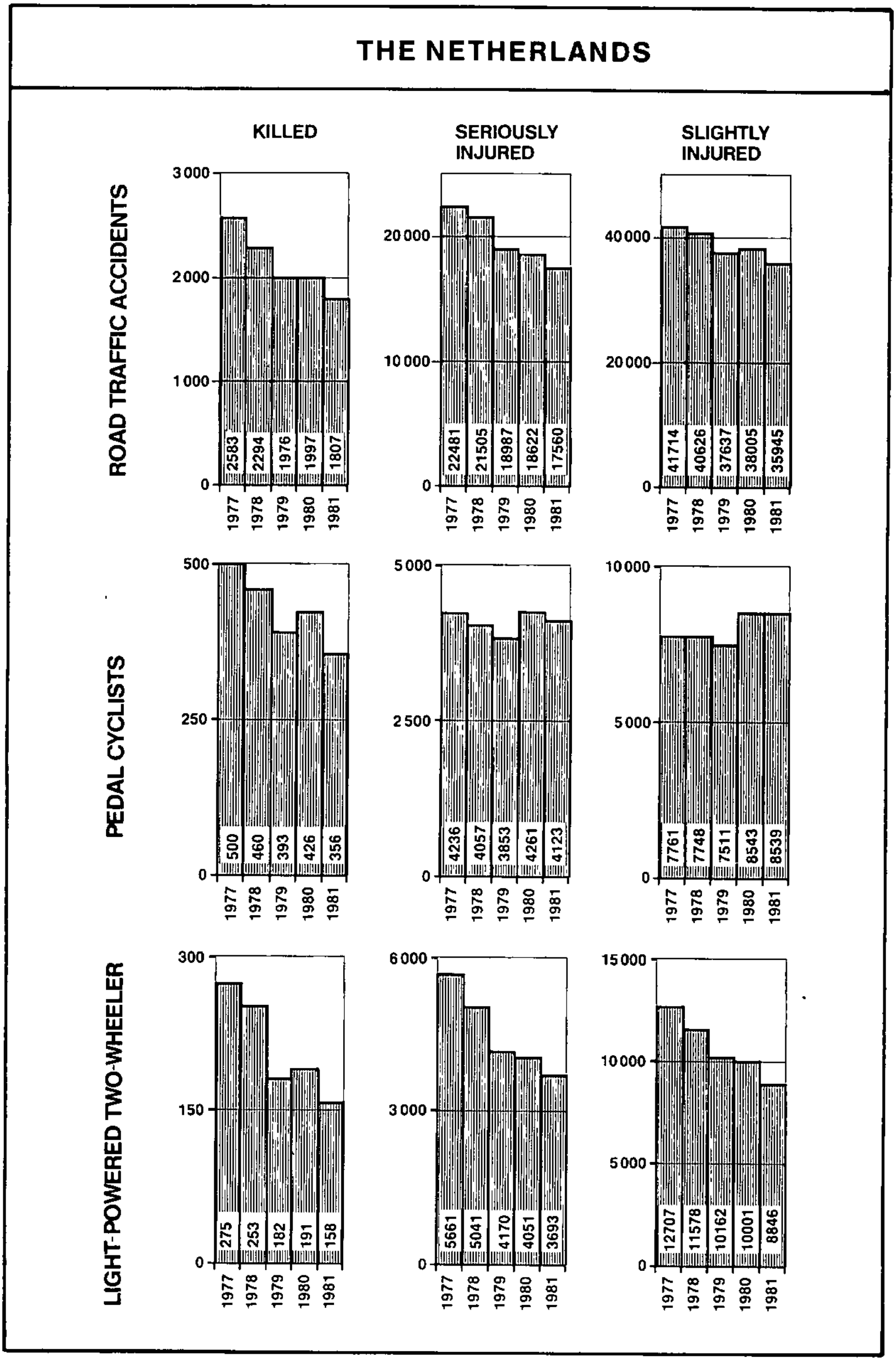

THE NETHERLANDS
KILLED
SERIOUSLY INJURED
SLIGHTLY INJURED
ROAD TRAFFIC ACCIDENTS
3000
2000
1000
0
2583
2294
1976
1997
1807
20000
10000
22481
21505
18987
18622
17560
40000
20000
41714
40626
37637
38005
35945
1977
1978
1979
1980
1981
PEDAL CYCLISTS
500
250
500
460
393
426
356
5000
2500
4236
4057
3853
4261
4123
10000
5000
7761
7748
7511
8543
8539
LIGHT-POWERED TWO-WHEELER
300
150
275
253
182
191
158
6000
3000
5661
5041
4170
4051
3693
15000
10000
5000
12707
11578
10162
10001
8846

Figure 5

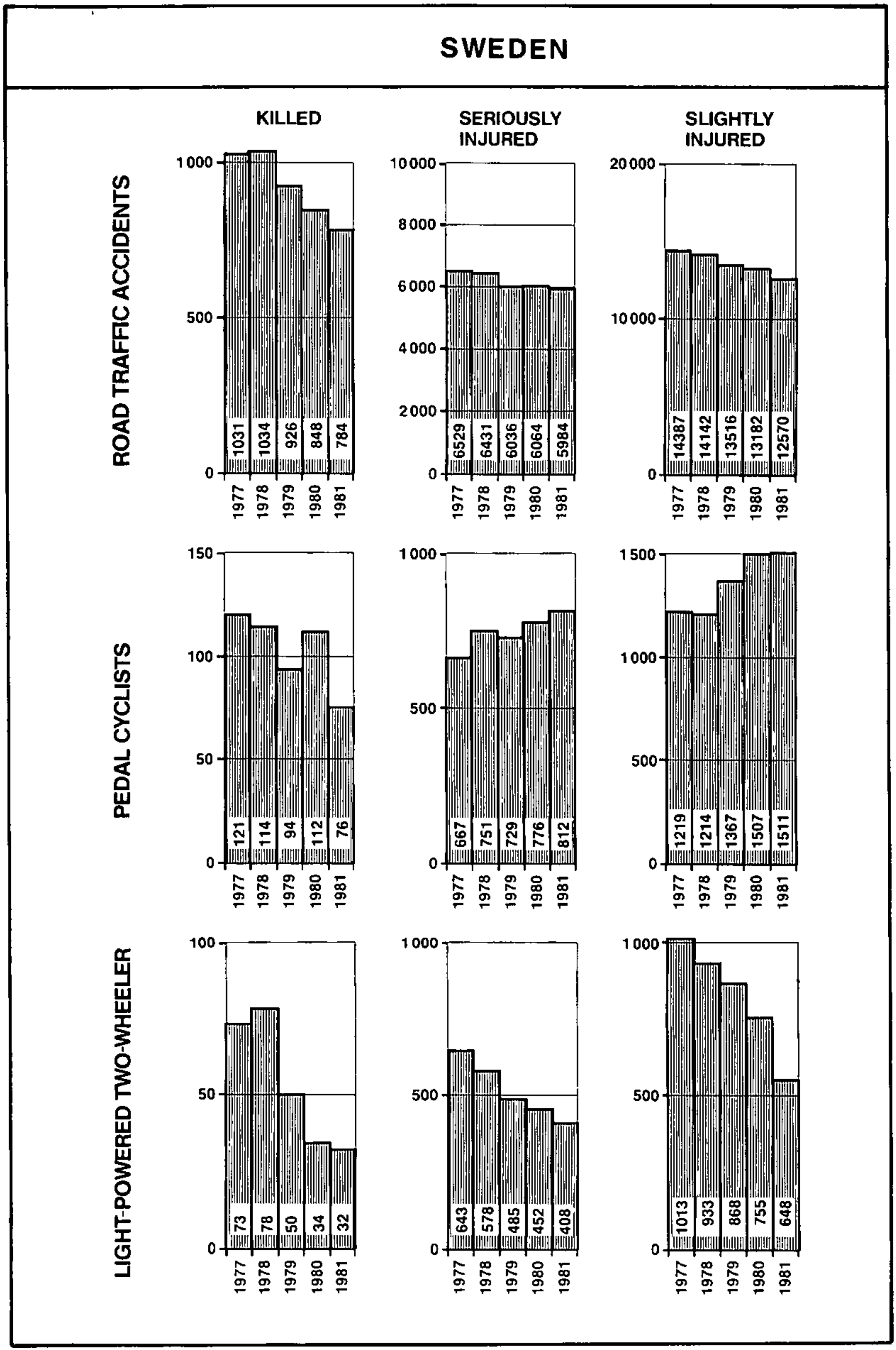

SWEDEN
KILLED
SERIOUSLY INJURED
SLIGHTLY INJURED
ROAD TRAFFIC ACCIDENTS
1031
1034
926
848
784
6529
6431
6036
6064
5984
14387
14142
13516
13182
12570
PEDAL CYCLISTS
121
114
94
112
76
667
751
729
776
812
1219
1214
1367
1507
1511
LIGHT-POWERED TWO-WHEELER
73
78
50
34
32
643
578
485
452
408
1013
933
868
755
648
1977
1978
1979
1980
1981
0
50
100
150
500
1000
1500
2000
4000
6000
8000
10000
20000

Figure 6

1981	PERCENTAGE OF KILLED PEDAL CYCLISTS IN TRAFFIC	PERCENTAGE OF KILLED USERS OF LIGHT -POWERED TWO-WHEELER IN TRAFFIC	TOTAL
FEDERAL REPUBLIC OF GERMANY	9,2	5,1	14,3
FRANCE	4,8	8,7	13,5
GREAT BRITAIN	5,3	1,4	6,7
ITALY	7,6	10,6	18,2
THE NETHERLANDS	19,7	8,7	28,4
SWEDEN	9,7	4,1	13,8

Table 8: Percentage of pedal cyclists and users of light-powered two-wheelers killed in road traffic

1981	NUMBER OF KILLED/100.000 VEHICLES	
	BICYCLISTS	LIGHT-POWERED TWO-WHEELERS
FEDERAL REPUBLIC OF GERMANY	2,8	31,5
FRANCE	3,1	21,8
ITALY	3,5	25,2
THE NETHERLANDS	3,4	22,6
SWEDEN	1,3	16,0
GREAT BRITAIN	2,4	20,3

Table 9: Number of killed pedal cyclists and users of light-powered vehicles per 100.000 vehicles

FEDERAL REPUBLIC OF GERMANY (1981)

AGE GROUPS		0-5	6-9	10-14	15-17	18-20	21-24	25-34	35-44	45-54	55-64	≥ 65	UKN	TOTAL
PEDAL CYCLISTS	KILLED	10 (2)	69 (3)	137 (3)	54 (-)	21 (-)	16 (-)	43 (-)	67 (-)	118 (-)	118 (-)	416 (-)	- (-)	1061 8
	SEVERELY INJURED	308 (57)	1710 (28)	3908 (42)	1708 (17)	722 (3)	573 (2)	906 (2)	1231 (1)	1381 (-)	1247 (-)	1990 (-)	28 (-)	15554 (152)
	SLIGHTLY INJURED	724 (327)	3206 (103)	9788 (93)	4828 (39)	2223 (15)	1845 (8)	3162 (5)	3593 (2)	3177 (2)	2176 (-)	2709 (-)	92 (-)	36929 (594)
LIGHT-POWERED TWO-WHEELERS	KILLED	- (-)	- (-)	14 (11)	221 (21)	67 (6)	21 (3)	31 (-)	47 (-)	53 (-)	41 (-)	104 (1)	- (-)	557 (42)
	SEVERELY INJURED	4 (4)	10 (9)	259 (146)	7289 (633)	1838 (135)	592 (26)	789 (25)	869 (10)	906 (13)	498 (7)	531 (8)	8 (-)	13592 (1016)
	SLIGHTLY INJURED	22 (22)	22 (21)	341 (229)	16119 (1449)	4040 (375)	1338 (64)	1737 (51)	1861 (35)	1605 (17)	785 (11)	726 (3)	57 (-)	28653 (2277)

FRANCE (1980)

AGE GROUPS		0-4	5-9	10-13	14-15	16-17	18-19	20-24	25-34	35-44	45-54	55-64	≥ 65	TOTAL
PEDAL CYCLISTS	KILLED	2	46	85	30	22	13	29	68	66	74	66	149	656
	SEVERELY INJURED	14	424	773	395	252	136	186	371	325	370	322	467	4073
	SLIGHTLY INJURED	26	622	1718	1049	840	463	658	935	794	835	645	720	9360
LIGHT-POWERED TWO-WHEELERS	KILLED	0	5	10	93	186	114	108	129	95	180	136	191	1256
	SEVERELY INJURED	4	22	171	2036	3662	1966	1531	1457	1014	1275	940	761	14905
	SLIGHTLY INJURED	31	59	420	5472	10910	5898	4765	4403	2755	2855	1690	1116	40513

GREAT BRITAIN (1981)

AGE GROUPS		0-4	5-9	10-14	15	16	17-19	20-29	30-39	40-49	50-59	60-69	≥ 70	TOTAL
PEDAL CYCLISTS	KILLED	5	13	66	18	15	29	19	17	18	32	23	53	310
	SEVERELY INJURED	19	547	1444	343	285	491	651	378	292	327	234	168	5179
	SLIGHTLY INJURED	131	2216	7011	1775	1614	2577	3527	1890	1377	1302	908	600	24928
LIGHT-POWERED TWO-WHEELERS	KILLED	0	0	1	2	29	14	9	3	7	4	7	5	81
	SEVERELY INJURED	0	0	26	24	1139	679	316	177	191	184	94	37	2867
	SLIGHTLY INJURED	0	1	31	25	2987	1885	968	521	456	446	168	67	7555

Table 10 - 12: Killed and injured pedal cyclists and users of light-powered two-wheelers by age groups (FRG, F, GB); passenger casualties in brackets

ITALY (1981)

AGE GROUPS		- 5	6-9	10-14	15-17	18-20	21-24	25-29	30-44	45-54	55-59	60-64	≥ 65	TOTAL
PEDAL CYCLISTS	KILLED	- (1)	20 (-)	48 (3)	18 (-)	6 (-)	8 (-)	12 (-)	33 (-)	65 (1)	43 (-)	59 (-)	275 (-)	608 (5)
	INJURED	40 (30)	368 (27)	1378 (38)	623 (39)	311 (7)	261 (4)	228 (3)	929 (5)	874 (2)	572 (1)	1797 (3)	154 (4)	8087 (206)
LIGHT-POWERED TWO-WHEELERS	KILLED	- 3	- 4	48 8	181 21	49 6	25 3	13 -	70 2	97 2	68 -	47 -	183 2	800 57
	INJURED	1 (65)	- (93)	2452 (726)	10870 (1726)	4733 (625)	2078 (213)	1282 (75)	3028 (95)	2321 (39)	1080 (16)	780 (11)	1760 (15)	30889 (3944)

THE NETHERLANDS (1981)

AGE GROUPS		0-4	5-9	10-14	15-19	20-24	25-34	35-44	45-54	55-64	65-69	70-74	≥ 75	TOTAL
PEDAL CYCLISTS	KILLED	1 (1)	18 (3)	52 (1)	28 (-)	17 (1)	21 (1)	21 (-)	14 (-)	39 (1)	34 (-)	39 (1)	61 (2)	345 (11)
	SEVERELY INJURED	18 (20)	323 (21)	830 (16)	638 (15)	266 (6)	325 (5)	279 (3)	287 (2)	364 (2)	209 (-)	227 (-)	260 (-)	4033 (90)
	SLIGHTLY INJURED	22 (58)	431 (64)	1686 (52)	1595 (69)	782 (14)	981 (12)	693 (4)	607 (3)	631 (2)	260 (-)	258 (-)	267 (1)	8252 (287)
LIGHT-POWERED TWO-WHEELERS	KILLED	- (-)	- (-)	2 (1)	89 (6)	6 (-)	7 (-)	1 (-)	8 (-)	15 (1)	7 (1)	4 (1)	9 (-)	148 (10)
	SEVERELY INJURED	- (-)	- (8)	48 (39)	2398 (203)	280 (22)	176 (10)	115 (2)	129 (7)	110 (7)	56 (7)	30 (1)	36 (2)	3381 (312)
	SLIGHTLY INJURED	1 (2)	- (10)	44 (122)	5750 (594)	770 (69)	413 (32)	300 (16)	253 (23)	212 (20)	70 (6)	44 (2)	33 (1)	7914 (932)

SWEDEN (1981)

AGE GROUPS		0-2	3-6	7-14	15-17	18-19	20-24	25-34	35-44	45-54	55-64	⩾65	UKN	TOTAL
PEDAL CYCLISTS	KILLED	-	-	5	3	2	3	1	5	6	7	44	-	76
	SEVERELY INJURED	-	19	147	68	26	49	80	85	84	107	147	-	812
	SLIGHTLY INJURED	1	24	288	150	72	121	223	166	146	147	167	6	1511
LIGHT-POWERED TWO-WHEELERS	KILLED	-	-	5	13	2	1	-	1	2	-	-	-	32
	SEVERELY INJURED	-	-	46	254	11	9	6	11	17	17	-	-	408
	SLIGHTLY INJURED	-	-	48	441	18	12	18	14	17	30	3	-	648

Table 13 - 15: Killed and injured pedal cyclists and users of light-powered two-wheelers by age groups (I, NL, S); passenger casualties in brackets

FEDERAL REPUBLIC OF GERMANY (1981)

AGE GROUPS		0-5	6-9	10-14	15-17	18-20	21-24	25-34	35-44	45-54	55-64	≥65		TOTAL
PEDAL CYCLISTS	KILLED/ 100 000	0.283	2.76	2.74	1.7	0.695	0.435	0.52	0.73	1.55	2.00	4.36		1.72
	SEVERELY/ 100 000	8.73	68.4	78.16	53.71	23.91	15.57	10.95	13.41	18.19	21.10	20.84		25.25
	SLIGHTLY/ 100 000	20.51	128.24	195.76	151.82	73.61	50.13	382.3	39.14	41.86	36.82	28.37		59.95
LIGHT-POWERED TWO-WHEELERS	KILLED/ 100 000	-	-	0 28	6.95	2.22	0.57	0.375	0.512	0.698	0.694	1.09		0.904
	SEVERELY/ INJURED	0.113	0.4	5.18	229.21	60.86	16.09	9.54	9.47	11.94	8.43	5.56		22.06
	SLIGHTLY/ 100 000	0.623	0.88	6.82	506.89	133.7	36.36	21.00	20.27	21.15	13.28	7.60		46.51

FRANCE (1980)

AGE GROUPS		0-4	5-9	10-13	14-15	16-17	18-19	20-24	25-34	35-44	45-54	55-64	≥65	TOTAL
PEDAL CYCLISTS	KILLED/ 100 000	0.1	1.1	2.6	1.9	1.3	0.8	0.7	0.8	1.1	1.2	1.3	2.0	1.2
	SEVERELY/ 100 000	0.4	10.4	23.3	24.6	14.5	8.0	4.4	4.3	5.4	5.8	6.5	6.2	7.6
	SLIGHTLY/ 100 000	0.7	15.3	51.8	65.2	48.3	27.3	15.6	10.9	13.2	13.0	13.1	9.6	17.4
LIGHT-POWERED TWO-WHEELERS	KILLED/ 100 000	-	0.1	0.3	5 8	10.7	6.7	2.6	1.5	1.6	2.8	2.8	2.6	2.3
	SEVERELY/ 100 000	0.1	0.5	5.2	126.6	210.6	115.9	36.3	17.0	16.8	19.9	19.1	10.2	27.7
	SLIGHTLY/ 100 000	0.8	1.5	12.7	340.3	627.4	347.8	113.0	51.3	45.7	44.6	34.3	14.9	75.2

GREAT BRITAIN (1981)

AGE GROUPS		0-4	5-9	10-14	15	16	17-19	20-29	30-39	40-49	50-59	60-69	≥70	TOTAL
PEDAL CYCLISTS	KILLED/ 100 000	0.2	0.3	1.6	2.0	1.6	1.1	0.3	0.2	0.3	0.5	0.4	1.0	0.6
	SEVERELY/ 100 000	0.6	14.4	33.3	37.4	31.1	18.6	8.4	5.1	4.8	5.1	4.3	3.1	9.5
	SLIGHTLY/ 100 000	4.0	58.5	161.5	193.8	176.4	97.6	45.7	25.7	22.4	20.3	16.5	11.1	45.8
LIGHT-POWERED TWO-WHEELERS	KILLED/ 100 000	0	0	<0.1	0.2	3.2	0.5	0.1	<0.1	0.1	0.1	0.1	0.1	0.1
	SEVERELY/ 100 000	0	0	0.6	2.6	124.5	25.7	4.1	2.4	3.1	2.9	1.7	0.7	5.3
	SLIGHTLY/ 100 000	0	<0.1	0.7	2.7	326.4	71.4	12.5	7.1	7.4	7.0	3.0	1.2	13.9

Table 16 - 18: Killed and injured per 100.000 inhabitants of age groups;pedal cyclists and users of light-powered two-wheelers (FRG, F, GB)

ITALY (1980)

AGE GROUPS		0-5	6-9	10-14	15-17	18-20	21-24	25-29	30-44	45-54	55-59	60-64	≥65	TOTAL
PEDAL CYCLISTS	KILLED/ 100 000	0.1	0.6	0.9	0.5	0.3	0.5	0.1	0.3	0.9	1.2	2.1	4.2	1.1
	INJURED/ 100 000	1.2	13.1	29.2	21 2	12.3	7.3	5.8	7.9	13.1	18.1	28.1	23.2	14.3
LIGHT-POWERED TWO-WHEELERS	KILLED/ 100 000	0.05	0.1	1.1	5.4	2.8	0.9	0.4	0.6	1.4	2.0	2.6	2.7	1.5
	INJURED/ 100 000	0.09	0.1	49.1	374.4	175.7	57.1	32.3	27.6	32.7	35.1	32.7	22.0	52.8

THE NETHERLANDS (1981)

AGE GROUPS		0-4	3-9	10-14	15-19	20-24	25-34	35-44	45-54	55-64	65-69	70-74	≥75	TOTAL
PEDAL CYCLISTS	KILLED/ 100 000	0.23	2.16	4.36	2.23	1.47	0.94	1.09	0.93	3.03	6.22	8.87	9.40	2.49
	SEVERELY/ 100 000	4.27	35.41	69.66	51.92	22.13	14.03	15 28	19.18	27.60	38.23	50.31	38.79	28.86
	SLIGHTLY/ 100 000	8.99	50.95	143.12	132.3	62.67	42.25	37.70	40.46	47.69	47.56	57.18	39.98	59.76
LIGHT-POWERED TWO-WHEELERS	KILLED/ 100 000	-	-	0.25	7.55	0.49	0.30	0.12	0.53	1.20	1.46	1.11	1.34	1.11
	SEVERELY/ 100 000	-	0.82	7.16	206.8	24.58	7.92	6.38	9.00	8.72	11.52	6.78	5.67	25.85
	SLIGHTLY/ 100 000	0.33	10.29	13.66	504.5	68.29	18.94	17.03	17.30	17.26	13.90	10.19	5.06	61.91

SWEDEN (1981)

AGE GROUPS		0-2	3-6	7-14	15-17	18-19	20-24	25-34	35-44	45-54	55-64	≥65		TOTAL
PEDAL CYCLISTS	KILLED/ 100 000	-	-	0.55	0.81	0.91	0.55	0.08	0.43	0.68	0 72	4.69		0.91
	SEVERELY/ 100 000	-	4.81	16.30	18.38	11.60	8.94	6.59	7.42	9.52	11.03	15.67		9.76
	SLIGHTLY/ 100 000	0.35	6.08	31.93	40.54	32.14	22.08	18.37	14.49	16.55	15.15	17.80		18.15
LIGHT-POWERED TWO-WHEELERS	KILLED/ 100 000	-	-	0.55	3.51	0.89	0.18	-	0.08	0.22	-	-		0.32
	SEVERELY/ 100 000	-	-	5.10	68.65	4.91	1.64	0.49	0.96	1.93	1.75	-		4.90
	SLIGHTLY/ 100 000	-	-	5 32	119.2	8.04	2.19	1.48	1.22	1 93	3 09	0.32		7.79

Table 19 - 21: Killed and injured per 100.000 inhabitants of age groups; pedal cyclists and users of light-powered two-wheelers (I, NL, S)

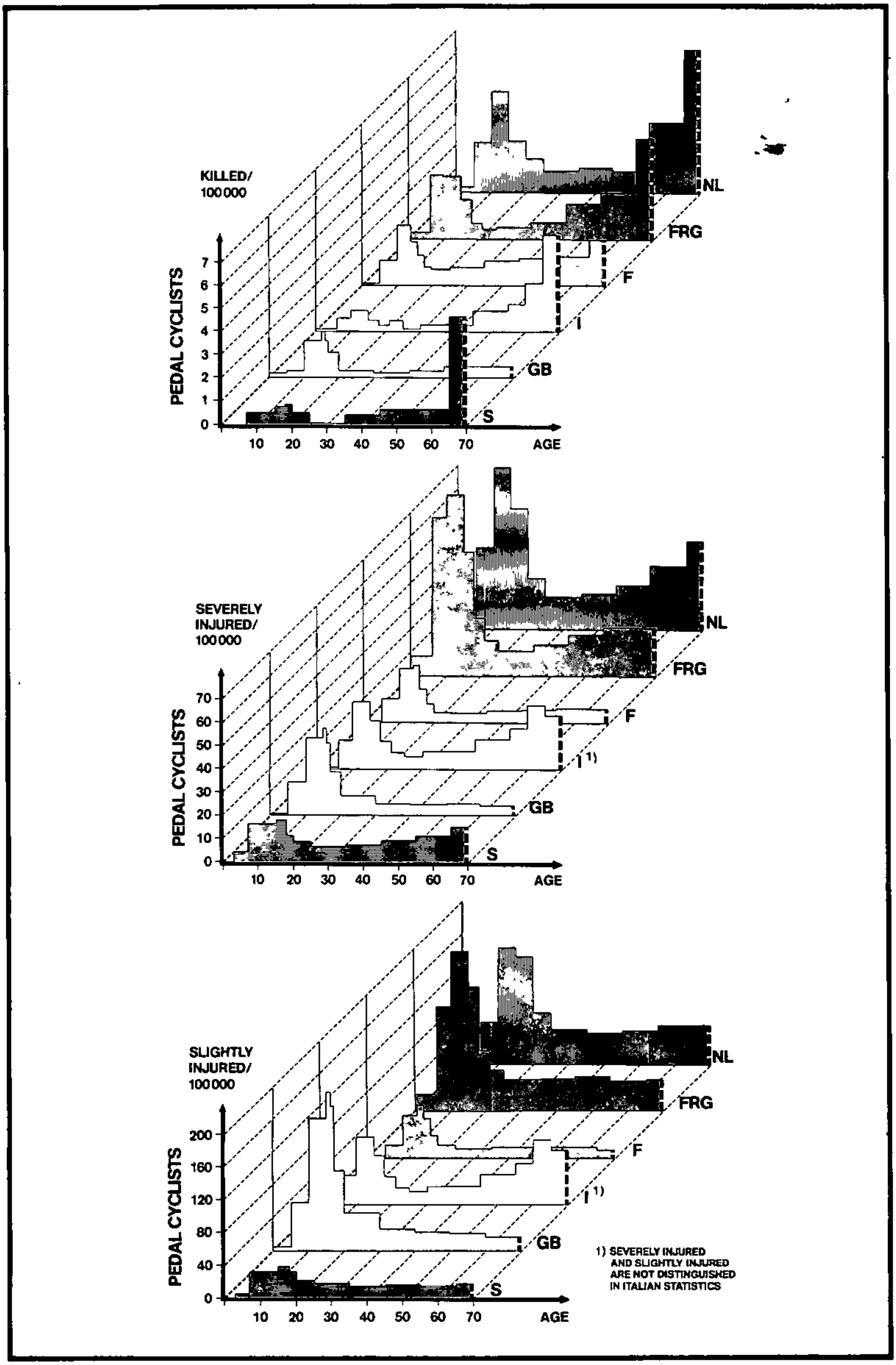


Fig. 7: Killed and injured pedal cyclists per 100.000 inhabitants/age group (dotted lines for age 70 stands for age group ⩾ 65)

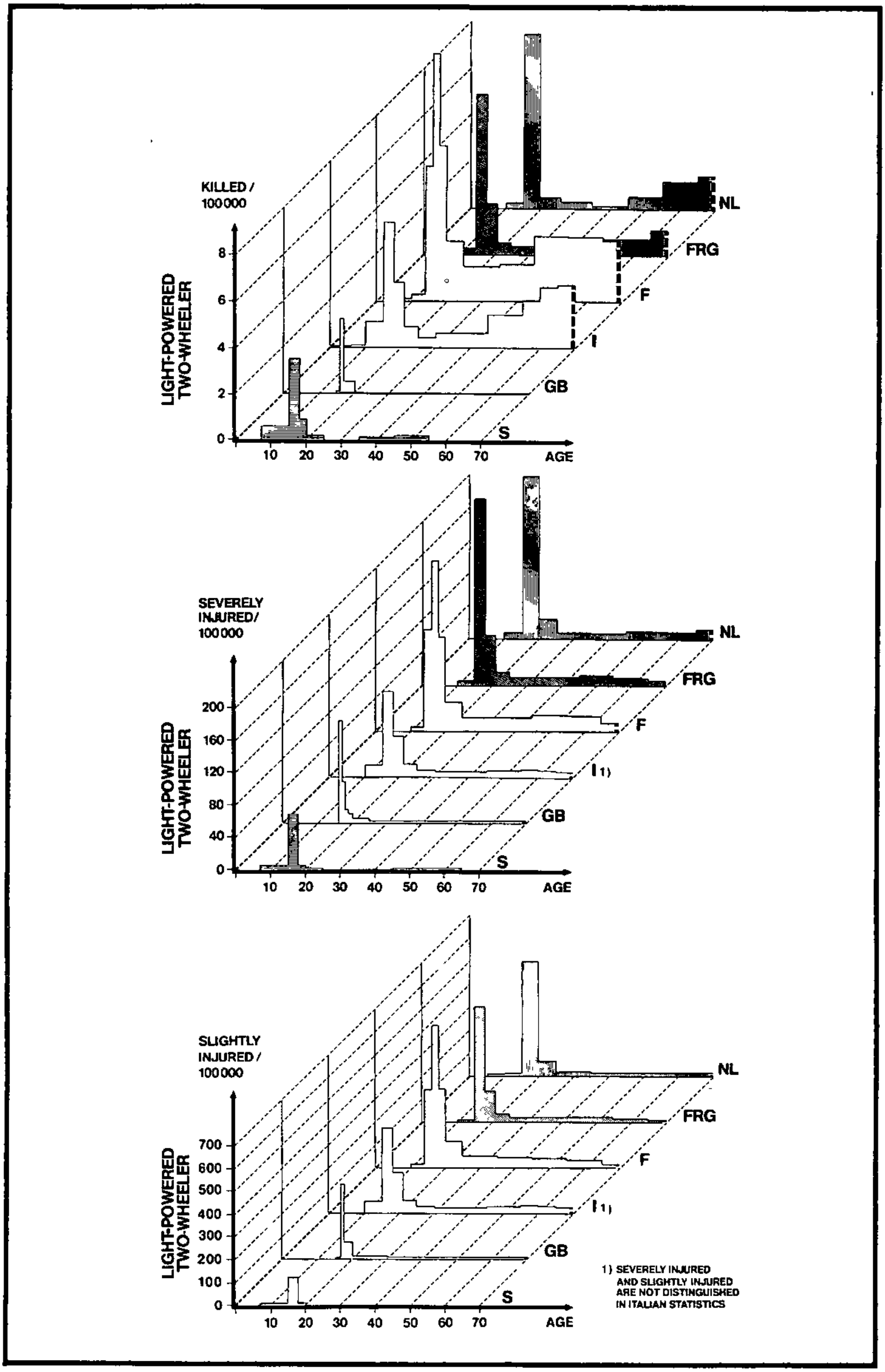


Fig. 8: Killed an injured users of light-powered two-wheelers per 100.000 inhabitants/age (dotted lines for age 70 stands for age group ≥ 65)

	TWO WHEELED MOTOR VEHICLES			PEDAL CYCLE		
	SLIGHTLY INJURED P.C.	SERIOUSLY INJURED P.C.	TOTAL SAMPLE SIZE [1]	SLIGHTLY INJURED P.C.	SERIOUSLY INJURED P.C.	TOTAL SAMPLE SIZE [1]
PEDDER [12]	58	29	540	91	83	459
BULL [13]	37	28	145	81	65	145
HOBBS [8]	45	27	754	71	59	488

[1] FATALITIES HAVE BEEN EXCLUDED

Table 22: Casualties in non-reported accidents

	OAIS	1	2	3	4	5	6
ALL ROAD USERS	ACCORDING TO WILLEKE	3	16	42	59	53	5
USERS OF TWO-WHEELERS Σ = 123 CASES	ACCORDING TO OTTE (WITHOUT COMPLICATIONS)	-	13	31	32	-	-
	ACCORDING TO OTTE (WITH COMPLICATIONS)	-	33	80	58	-	6
	ACCORDING TO OTTE (SUM TOTAL OF DAYS OF IN-PATIENT TREATMENT)	-	35	83	87	-	-
USERS OF TWO-WHEELERS Σ = 282 CASES	ACCORDING TO OTTE ON AVERAGE	3	16	32	39	29	1

Table 23: Length of hospitalization indays related to OAIS

TIME IN HOSPITAL	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	MAIS 6
UP TO 2 WEEKS	29	36	9	-	1	2
UP TO 2 MONTHS	4	55	60	10	9	-
UP TO 1 YEAR	1	5	37	10	5	-
OVER 1 YEAR	-	-	-	2	-	-

Table 24: Length of hospitalization of injured motorcyclists (base: 275 cases) [16]

	USERS OF BICYCLES		MOTORIZED TWO-WHEELERS	
	WITHOUT EFFECTS ON EARNING CAPACITY	WITH EFFECTS ON EARNING CAPACITY	WITHOUT	WITH
LENGTH OF IN-PATIENT TREATMENT *	11	34	11	43
COSTS /‾DM_7	1800	5900	1900	7800

Table 25: Time and cost factors involved in hospitalization with and without effects on earning capacity [17]

* [Days}

2. DETAILED DESCRIPTION OF BICYCLE AND LIGHT-POWERED TWO-WHEELER ACCIDENTS

2.1. Introduction

This chapter deals with some more detailed data of bicycle and light-powered two-wheeler accidents, such as collision partners, collision types, resulting injuries and speed at impact.
This data is in general not available from national statistics. Therefore most of the information is obtained through special accident studies.
Nevertheless, as is the case in the Netherlands, useful and more detailed information is gathered on a national base by the police and computerised at the Road Accident Record Office. (VOR)
To give direction to the injury prevention research of bicyclists and moped riders, some priorities in the distributions of accident types and collision types are made in the Netherlands (Huijbers [9]).A lot of criteria may be used for this but for some practical reasons magnitude and severity were used.
For magnitude the number of killed and severely injured road users are used.
Severity of road accidents is a very complex term. A lot of dimensions are involved, such as damage, injury, cost of delays etc.
In injury prevention research the injury dimension of accident severity is used. But injury can also be distinguished in place, nature and severity.
Injury severity is complex too and can be defined by threat to life, disability etc. Scaling with the Abbreviated Injury Scale (AIS) seems to be the most appropriate for this moment, although there is some concern about the influence of long term effects on the scaling (EEVC [4]).
For the Dutch accident situation only the number of killed or severily injured road users for the accident and collision types were available.
Therefore as a criterion for injury severity 'lethality' was used. (Lethality = 100 x number of killed / (number of killed + number of severely injured)).

There is a general problem concerning the accident data of different countries with regard to motorized two-wheelers.
The problem is that in most cases this group cannot be divided into motorcycles and mopeds, the last one may even contain several types. This is needed for a proper comparison of the data, since the distribution of these two groups differ considerably for the different countries.

Another more general problem in comparing the results of the different accident studies is caused by sample differences, e.g. the large differences in underreporting figures for the different countries as shown in chapter 1; in the Netherlands reporting of killed and severely injured road users is complete enough to use this information to indicate priorities in injury prevention research.

The chapter starts with a description of collision opponents of the two-wheeler riders, with respect to kind of opponent (accident type) and with respect to collision direction (collision type), with some information about the manoeuvre of the collision opponents just before the accident.

Thirdly the resulting injuries (injury pattern) will be described. A review of the impact speed, as mentioned in a number of accident studies concludes this chapter.
Information about braking (of the collision partners) before, during or after the collision, as was described in the report of EEVC Working Group 7 about Pedestrian Injury accidents, was not found in literature.

2.2. Accident type

The particular combination of a two-wheeler and its collision opponent is called accident type (for instance bicycle-car; moped-car; moped-heavy goods vehicle).
The distribution of collision opponents will depend on the severity class of injuries considered, therefore a large variety of distributions in the various studies may be noticed.

2.2.1. Great Britain

The distribution of collision opponents (motor vehicles only) for bicyclists according to Hardy [7] is:

car and taxi	75%
light goods vehicle	9%
heavy goods vehicle	3%
medium goods vehicle	1,5%
others	11,5%

The group consists of the accidents in 1974, reported by the police. There is no information about the collision partners of mopeds.

More recent information (1980) from national statistics [16] about accident types of two-wheeler casualties, excluding accidents with three or more vehicles, reported to the police is given in table 1:
The car is the most frequent collision partner in bicycle and two-wheeled motor vehicle accidents (73,1%; 60,3%) followed by the light goods vehicle and two-wheeled motor vehicle for the bicyclist (6,1%; 6,1%) and the light goods vehicle for the two-wheeled motor vehicle rider (4,8%).
The share of single vehicle accidents (no pedestrian involved) for two-wheeled motor vehicle users in much higher (23,7%) than for the pedal cycle users (7,7%). In fact these shares will probably be much larger due to the already mentioned underreporting.

2.2.2. Germany

A distribution of collision partners in Germany for 1982 is given in table 2.
The group consists of killed road users in a single vehicle accident or in collision with a car or a heavy goods vehicle.
The table shows that in collisions with another road user the car is in most cases the collision partner (55% for bicyclists and 57% for motorized two-wheeler riders).
Single vehicle accidents occur more often with motorized two-wheeler riders (13%) than with bicyclists (11%).

2.2.3. The Netherlands

The Dutch data of the distribution of accident and collision types based on police information for 1978 and 1979 are available seperately for fatal two-wheeler accidents and for accidents in which the two-wheeler riders were taken into hospital for a least one day.

The data was coded by the "Dienst Verkeersongevallen registratie" (VOR), manipulated by SWOV and reported by Huijbers [9].
These accidents are very well reported as already stated:
almost 100% of the two-wheeler fatalities and 80% of the hospitalized casualties are reported by the police (Maas [10]).

The bicycle and moped accidents can be divided into the following groups.

A - Accidents with a pedestrian or a (parked or moving) vehicle
B - Accidents with no other vehicle or pedestrian involved, divided into 1) collision without obstacle (tree, pole, animal, etc.)
2) collision with an obstacle.
C - Multi (> 2) vehicle accidents.

For 1979 the total numbers of killed and severely injured bicyclists and moped riders are divided over these groups:

A :	Killed	Severely injured
Bicyclist	89%	79%
Moped rider	72%	78%

B_1 : The shares for bicyclists and moped riders are identical:

Killed	Severely injured
4%	8%

B_2 :	Killed	Severely injured
Bicyclists	1%	3%
Moped rider	17%	7%

C : 5 - 10%

The group defined in A will be considered for the distribution of collision partners.
The results for 1979 are shown in table 3 and visualized in fig. 1 and 2.

Fatalities

The car is the most frequent collision partner for bicyclists (62%) and moped riders (48%).
The second most frequent collision partner is the heavy goods vehicle: 23% for bicyclists and 21% for moped riders.

Severely injured

For the severely injured the car is also the most frequent collision partner for bicyclists (69%) and for moped riders (74%).
The second most frequent collision partner is the moped for bicyclists (10%) and for moped riders themselves (7%), together with the heavy goods vehicle (7%) for moped riders.
When lethality is used as a severity criterion, the collision with a tram or train has a high severity because there are only few registered severely injured patients. But the amount of these accidents is small.
For bicyclists the collision with a heavy goods vehicle has the next priority, followed by the collision with a delivery van.
The collision with a car does not seem to be so severe.
For moped riders the collision with a motorcycle (or a scooter) has the next priority, followed by the heavy goods vehicles and delivery vans.
The collision with the car does not seem to be relatively so severe (relatively; fig. 1 and 2).

2.2.4. USA

In Cross [2] a distribution from the USA is given. This group consists of bicycle casualties.
In 87% the car was the collision opponent and in 9% a pick-up or van.

2.3. Collision type

A collision type is a particular combination of impact sites of the two-wheeler and its collision opponent (for instance front of a two-wheeler against side of a car).
The different collision types will probably result in different impact places on the body, for some types caused by the car and for others by the two-wheeler. This may cause different injury patterns.
This paragragh mainly deals with the car-to-bicycle, car-to-moped, heavy goods vehicle-to-bicycle and heavy goods vehicle-te-moped accident types. As far as possible, collision type or impacted sites of two-wheelers and its opponents are given, as specified in the different accident studies. Comparison of the results of these different studies is clearly limited due to sampling differences as mentioned earlier.

2.3.1. Great Britain

Whitaker [15] gives a summary of impact sites on motorized two-wheelers. Frontal impacts occur in 59%, followed by lateral impacts in 38% of the cases.
More left side than right side impacts were found. No information is given about the impacted sites of the collision opponent.

Bicycle - heavy goods vehicles

Riley [17] studies fatal accidents involving heavy goods vehicles: 37% of the bicyclists hit the front of a heavy goods vehicle, 57% the side and only 2% the rear end.
No information about the impacted site of the bicycle.

2.3.2. Germany

Otte [12] states that in bicycle-to-car accidents 46% of all casualties occur with collision type front of car-side of bicylist, followed by the collisions type front of car-rear end of bicyclist (20%) (fig. 3 and 4).
In frontal collision (front of car-front of bicyclist) 17% of the persons were killed or injured and in side collisions (side of car-front of bicyclist) 15% of the casualties occurred. The distribution of some collision types causing casualties for motorized two-wheelers is:
28% in collision type front of car - side of motorized two-wheeler
24% in collision type front of car - front of motorized two-wheeler
21% in collision type side of car - front of motorized two-wheeler.
From this information it seems that the distribution of the collision types for the motorized two-wheeler-to-car accidents is much more homogeneous that the distribution of the bicycle-to-car accidents.
The collision type front of car - rear of two-wheeler occurs relatively often for the bicyclist but not for the motorized two-wheeler.
The distribution of collision-types for heavy goods vehicles can be seen in a study of the HUK-Verband, Büro für Kfz-Technik, which treats the problem of truck-accidents [18].

In almost 80% of all bicycle-accidents the contact area on the truck was the front or the right side, in nearly equal proportions.
For the light-powered two-wheelers the contribution is a little more homogeneous. (fig. 4a).

2.3.3. The Netherlands

For the Dutch accident situation priorities for injury prevention research within the distribution of collision types (1978/1979) were based on the criteria magnitude and severity ("lethality"), see par. 2.1. First of all the collisions were categorised in some collision types (fig. 5).

Bicycle-to-car accidents (fig. 6)

Most of the cyclists were hit in the side by the front of the car (type F1): 65% of those killed and 60% of the severely injured. The left side of the bicycle was hit twice as much as the right side.
The other collision types did not occur so much: of these the types F2 and F3 were most important. The collision with the side of the car happened most of the time with the front of the bicycle (type S1): in 10% of the cases with severely injured cyclists.
With lethality as a criterion, collision type F3 (front of car-rear end of bicycle) was the most severe.

Moped-to-car accidents (fig. 7)

In the case of moped-to-car accidents the collision type F1 (front of car - side of moped) dominated too: 62% of the killed moped riders. The severely injured moped riders were hit nearly as often sideways (F1) as frontal (F2) by the front of the car (39%; 31%).
Frontal collisions with the side of the car happened nearly as infrequently for the killed moped rider (13%) as for the severely injured. The collision type F3, where the front of the car hit the rear end of the moped, did not occur so much as for cyclists (3% killed; 1% severely injured); although this collision type had the highest "lethality" in analogy with the bicycle-to-car accident.
The opposite rear-end collision (R1) happened for 10% of the severely injured moped riders. The lethality from this type was minimal because there were no killed moped riders registered in this collision type.

Bicycle-to-heavy goods vehicle accidents (fig. 8)

The collision front of heavy goods vehicle-to-side of bicycle (F1) happened most frequently (42% for killed and severely injured cyclists). The second most frequent collision type was F2 (front of heavy goods vehicle-to-front of bicycle) for killed (19%) and S1 (side of heavy goods vehicle-to-front of bicycle) for severely injured cyclists (18%). The frontal collision with the rear end of the heavy goods vehicle (R1) happened relatively often with severely injured cyclists (11%). The collision types F2, F3, S2 and R2 have nearly the same and highest lethality.

Moped-to-heavy goods vehicle accidents (fig. 9)

The collision type distribution for this accident type is more or less homogeneous.
Collision type F1 dominated for killed moped riders but the collisions with the front of heavy goods vehicles (F1 and F2) happen nearly as frequently as the collision with the rear end (R1) for the severely injured moped riders (28%), followed by the collision with the side of the heavy goods vehicles (S1).

The collision type side of moped-to-side of heavy goods vehicle (S2) seems to be the most severe, followed by F1.

2.3.4. USA

Data from the USA about impact points from car-to-bicycle crashes in Roland [14] show nearly the same pattern as in the Netherlands:

	car	bicycle
front	63,2%	25,6%
left side	10,7%	49,6%
right side	23,4%	21,2%
rear	1,9%	3,6%

The sides of the car are struck more frequently than in the Netherlands. This may be due to differences in injury severity in the samples. There is no information about collision types.

2.4. Manoeuvres:

The majority of accidents involving cyclists and light-powered two-wheeler riders in urban areas take place at road junctions (OECD [20]). In Great Britain accident statistics show that nearly two-thirds of injury accidents involving a pedal cycle occur at junctions (Downing [21]).
In a study of accidents occurring at intersections the Danish Council of Road Safety Research [22] found that for urban accidents involving a bicycle and another vehicle the most frequent manoeuvre type was where each was traveling on different road before the collision. This was also the finding in a British study of national accident statistics.
According to Gauss [18] nearly 45% of the heavy goods vehicle-two-wheeler accidents happened when one of the vehicles was changing direction.

2.5. Injuries

Injury is for the injury prevention research the most important output variable in the accident system.
Injury can be described in terms of place, nature and severity.
In literature all these three dimensions are described, mostly separately.
The place of the injury is reported in most of the studies, sometimes in relation to severity. Severity is mostly scored with the Abbreviated Injury Scale (AIS)system. Injury severity is a complex term. Probability of death but also temporal or permanent impairment will influence severity. The role of these long term consequences in the AIS is under discussion, in particular for the pedestrian injuries (EEVC [4]).
Whether this is also important for bicyclist or light-powered two-wheeler rider injuries cannot be answered at this moment, but for outcome variable injury severity, the scaling with the AIS seems to be the most suitable for injury prevention research at this moment.

There is a wide variety of injury distributions in literature.
As stated in EEVC [4] it is hardly possible to compare the results of accidents studies because of some major differences, for instance:
- differences in levels of injury severity in the sample (e.g. fatalities only, fatalities + hospitalised)
- differences with respect to accident type (some studies contain all accident types, some only collisions with cars, some only specific collisions types).

What matters are the main tendencies, common for all studies and the differences and similarities within seperate studies between injuries of bicyclists and moped riders (motorized two-wheeler riders).
It seems quite obvious that injury distributions are dependant on accident type and collision type because of differences in relative impact speed and impacted body areas.
Therefore, as already stated, comparisons have to be made carefully.

When all injuries are considered Pedder [13], Whitaker [15], Otte [12] and Grattan [5] state that the arms and the legs are the most frequently injured body areas, followed by the head.
Pedder [13] finds for bicyclists more arm injuries than leg injuries and the opposite for the motorized two-wheeler riders. The other studies mentioned do not support this finding.

From Huijbers [9] and Nicholl [11] it follows that the head is the most frequently injured body area.
The data from the first study are available from the "Stichting Medische Registratie" (SMR), containing information on 95% of all Dutch hospitalised casualties. The data of the second study are from a British hospital.

When the more severe injuries (AIS $\geq$ 2) are taken into consideration in the studies of Pedder, Whitaker, Otte and Grattan, the head is the body area most frequently injured.

2.6. Speed at impact

Speed at impact seems, like it was with the pedestrian -to- car accident, one of the more important parameters.
It is better to speak of relative impact speed, since not only the impact speed of the car but also the impact speed of the two-wheeler, and the direction of impact (collision type), have a big influence on the relative impact speed.

In this chapter data on impact speed from the different studies are presented like in the report of Working Group 7 of EEVC [4].
In some studies it is not quite clear what is meant by impact speed.
There were no impact speed dat related to specific collision types.
Therefore the results must be looked at with great care.

Some results (fig. 12):

- Otte [12] indicates that at impact, speeds of cars in collisions with motorized two-wheelers are in general lower that those in collisions with bicyclists.
- There is a wide variety in impact speeds of cars for the various studies:
  50th percentile speed varies from 10 km/h to 50 km/h
  90th percentile speed varies from 37 km/h to 72 km/h
  This variety is larger than for pedestrian accidents (EEVC [4]).
- Gauss [18] found that the speeds at impact depend on the collision types, but in general the speed at impact of the two-wheeler was remarkable higher than the speed of the heavy goods-vehicle.
  Nearly two out of three two-wheelers collided with a speed between 31 and 60 km/h.

2.7. Summary

In all studies mentioned cars are the most frequent collision opponents, rating from 50 to 90% of all opponents in bicycle and light-powered two-wheeler accidents. This is more or less similar to the situation for pedestrians as mentioned in EEVC [4]. Second are vans and heavy goods vehicles. In the Netherlands mopeds are the second most frequent collision partner for the injured bicyclists and moped riders.
With motorized two-wheelers single vehicle accidents (in collision with an obstacle) happen relatively often.
If a criterion like lethality (par. 2.1.) is used, for accident severity, collisions with heavy goods vehicles seem to be the most severe accident type for bicyclists and the second severest for moped riders.
The accident between a moped and a motorcycle or scooter seems to be the most severe for moped riders.
The collision with a car does not seem to be very severe in relation to the other accident types.

From this it looks quite obvious that the attention of injury prevention research for bicyclists and light-powered two-wheeler riders should be focused on the confrontation with cars (magnitude) and heavy goods vehicles (severity).
The single vehicle motorized two-wheeler accidents happen so often, that this accident type must be considered too.

For the determination of the collision types that have to be studied in the next chapter a distribution of the collision types for the various countries was made.
This information gives also some indication on which parts of the motorvehicle have to be taken into consideration in injury prevention work for bicyclists and moped riders.
There are some differences in the results of the presented studies. These differences may partly be caused by sample differences, especially levels of injury severity. Other differences, such as infrastructure, modal split etc., may also be present and may influence the outcome. But also some similarities between the results of the various studies were noticed:
In most bicycle -to- car accidents the bicycle is impacted at the (left) side by the front of the car. The collision type front of car -to- rear of bicycle occurs more often in accidents where the bicyclist was killed than when he was hospitalised.
Collision types involving the side of the car did not occur often in the more severe bicycle accidents.
In light-powered two-wheeler-to-car collisions the two major collision types are front car - (left) side light-powered two-wheeler and front car - front light-powered two-wheeler, followed by side car - front light-powered two-wheeler. The front of the light-powered two-wheeler therefore plays a more important role than the front of the bicycle. When lethality was taken into consideration, the collision type front car - rear bicycle (light-powered two-wheeler) seems to be the most severe, followed by the most frequent occurring type front car -to- side of bicycle (or light-powered two-wheeler).

It seems obvious therefore that the attention of injury prevention should be directed both towards the front of the car (as for pedestrian accidents) and to the side, particularly with respect to light-powered two-wheeler accidents.

Data of heavy goods vehicle accidents with bicyclists and light-powered two-wheeler riders from the Netherlands and Germany suggest that for the bicycle collisions with the front of heavy goods vehicles happen most often. But collisions with the side of heavy goods vehicles are also relatively frequent.
Accidents with light-powered two-wheelers happen nearly as often with the front, the side as with the rear end of heavy goods vehicles. Therefore it seems obvious that the attention of injury prevention work should be given to all sides of heavy goods vehicles.

Literature gives a wide distribution of injuries as a result of bicycle and light-powered two-wheeler accidents. These results can hardly be compared due to differences in e.g. injury severity or collision types under study. But the various results indicate that the head has the highest frequency especially when considering the more severe injuries.
The arms and the legs are the second and third most injured body areas.

Relative speed at impact depends not only on the speeds of the collision partners at impact but also on collision type.
The speeds at impact found in literature have a wider variety than for pedestrian car accidents.
The 50th percentile values range from 10 km/h to 50 km/h, the 90th percentile values from 37 km/h to 72 km/h.
In heavy goods vehicle-two-wheeler accidents it was found that the speed of the two-wheeler was remarkably higher than the speed of the heavy goods vehicle.

2.8. References.

1. P. Bourret; P. Sejourne; P. Orsoni; C. Cavallero.
"Lower Limb Injuries of Two-Wheelers".
Salon de Provence Hopital; ONSER.
IRCOBI 1981; Salon de Provence.

2. K.D. Cross; G. Fisher.
"A study of bicycle/motor-vehicle accidents.
Identification of problem types and countermeasures.
Approaches'. Volume 1.
Anacapa Sciences Inc., Santa Barbara, California 1977.

3. J.F. McDermott; P.A. Wood
"Pedal Cycle Injuries".
Emergency Department Nurses Association.
Seattle Washington
19th AAAM. 1975 San Diego, California.

4. EEVC Working Group 7.
"Pedestrian injury accidents".
ESV Conf. 1982 Kyoto.

5. E. Grattan; J.A. Hobbs; M.E. Keigan.
"Anatomical Sites and Severities of injury in Unprotected Road Users".
IRCOBI 1976, Amsterdam.

6. D.M.P. Guichon; S.T. Myles.
"Bicycle Injuries: one year sample in Calgary Foothill's Hospital".
Calgary, Alberta, Canada.
The Journal of Trauma, 6. 1975.

7. W.W. Hunter: D.G. Cole; E.G. Leggett.
"An Analysis of Bicycle accidents in North Carolina 1974-1976".
University of North Carolina, 1978.

8. J.J.W. Huijbers.
"Een beschrijving van fiets- en bromfietsongevallen ten behoeve van prioriteitsindelingen bij het letselpreventie onderzoek".
SWOV, not yet published.

9. M.W. Maas.
"De politieregistratie van verkeersgewonden in ziekenhuizen".
SWOV, 1982.

10. J.P. Nicholl.
"The use of hospital in-patient data in the analysis of the injuries sustained by road accident casualties".
Transport Studies Group, University College London.
TRRL SR 628, 1980.

11. D. Otte.
"A Review of Different Kinematic Forms in Two Wheeler-Accidents. Their influence on Effectiveness of protective measures".
T.U. Berlin.
24th Stapp Car Crash Conference. Troy Michican 1980.

12. J.B. Pedder; S.B. Hagues; G.M. Mackay; B.J. Roberts.
"A study of Two-Wheeled Vehicle Casualties Treated at a city Hospital".
Univ. Birmingham; Birmingham Hospital. IRCOBI 1981; Salon de Provence.

13. H.E. Roland; B.J. Campbell; W.W. Hunter.
"Investigation of Motor Vehicle/Bicycle Collision Parameters".
Volume 1. Final report.
University of Southern California, Los Angelos 1979.

14. J. Whitaker.
"Motor Cycle Safety - accident survey and rider injuries".
TRRL SR 239, 1976.

15. "Accidents in Great Britain 1980".
Department of Transport 1981.

16. B.S. Riley; H.J. Bates.
"Fatal Accidents in Great Britain in 1976 involving heavy Goods Vehicles".
TRRL SR 586, 1980

17. Strassenverkehrsunfalle 1981.
Statistisches Bundesamt Wiesbaden, 1983.

18. Gauss F., Langwieder K., et al.
"Äussere Sicherheit von Lkw und Anhängern"
FAT Schriftenreihe Nr. 27

19. OECD.
"Safety of two-wheelers."
OECD research group, March 1978.
Paris France.

20. DOWNING, C.S.
"Pedal cycling accidents in Great Britain."
Paper presented at the British Psychological Society conference on road safety.
Cardiff 1981.

21. DANISH COUNCIL FOR ROAD SAFETY RESEARCH.
"Accidents with two-wheeled vehicles in traffic."
Memorandum No. 89.
Copenhagen, 1973.

2.9 Figures/tables.

	SINGLE VEHICLE					TWO VEHICLE			
	NO PEDESTRIAN	WITH PEDESTRIAN	PEDAL CYCLE	2-WHEELED MOTOR VEHICLE	CAR	BUS OR COACH	LIGHT GOODS VEHICLE	HEAVY GOODS VEHICLE	TOTAL
PEDAL CYCLE USER	1794 (7,7%)	140 (0,6)	229 (1,0)	1411 (6,1)	17013 (73,1)	457 (2,0)	1433 (6,1)	807 (3,5)	23284
TWO WHEELED MOTOR VEHICLE USER	15522 (23,7%)	1950 (3,0)	765 (1,2)	2434 (3,7)	39428 (60,3)	615 (0,9)	3146 (4,8)	1504 (2,3)	65364

* Excludes three or more vehicle accidents and accidents where details are not known.

table 1. Number of two-wheeler casualties (all severeties) reported to police for different accident types in Great Britain (1980). Department of Transport [16].

1982	Accidenst with two participants		single vehicle accidents	Total number of killed.
	Car	Vans and HGV's		
BICYCLE	598	127	116	1.085
"Mofa/Moped"	305	57	71	543

Source: BASt

table 2. Number of killed bicyclists and light powered two-wheeler riders for different accident types in Germany (1982).

casualties / in collision with	bicyclist			moped rider		
	% killed	% in-patients	"letality"	% killed	% in-patients	"letality"
car	62	69	9,2	46	74	2,6
delivery van	5	4	12,1	8	4	7,3
heavy goods vehicle	23	5	34,2	21	7	11,2
motor/scooter	3	3	9,8	5	1	17,9
train or tram	2	-	54,5	10	-	56,5
bicycle	-	6	0,0	-	3	0,0
moped	3	10	3,1	4	7	2,2
other 2 wheelers	-	-	-	-	-	-
pedestrians	-	1	0,0	-	2	7,4
others	2	2	10,1	4	2	-
total	100 %	100 %	-	100 %	100 %	-
N total	349	3.082	-	131	3.169	-

Tab 3 Distribution of accident types resulting in killed and severely injured cyclists and moped riders; Letality of the various accident types (Huijbers [9

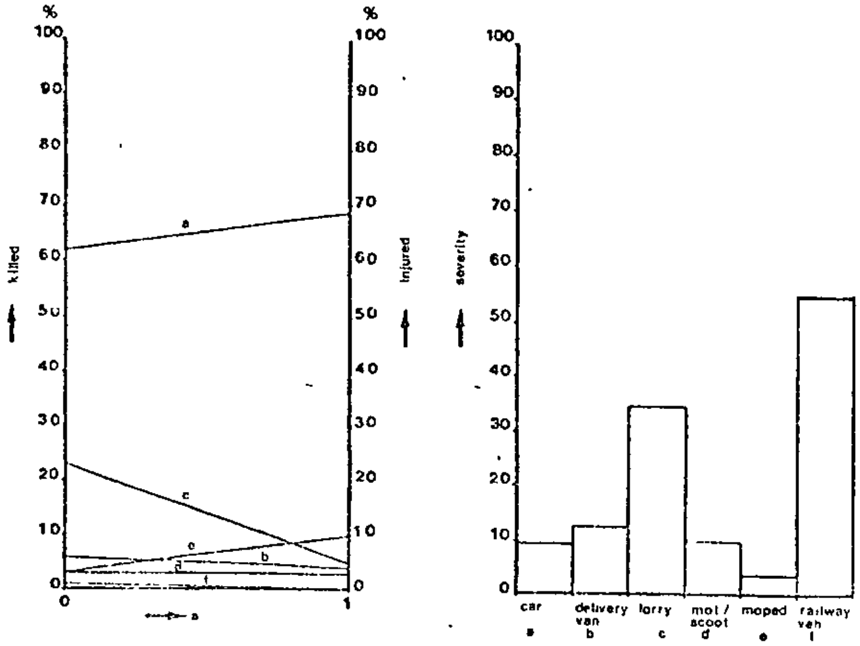


Fig 1 Priorities within the various accident types resulting in killed and severely injured bicyclists. (Huijbers [9])

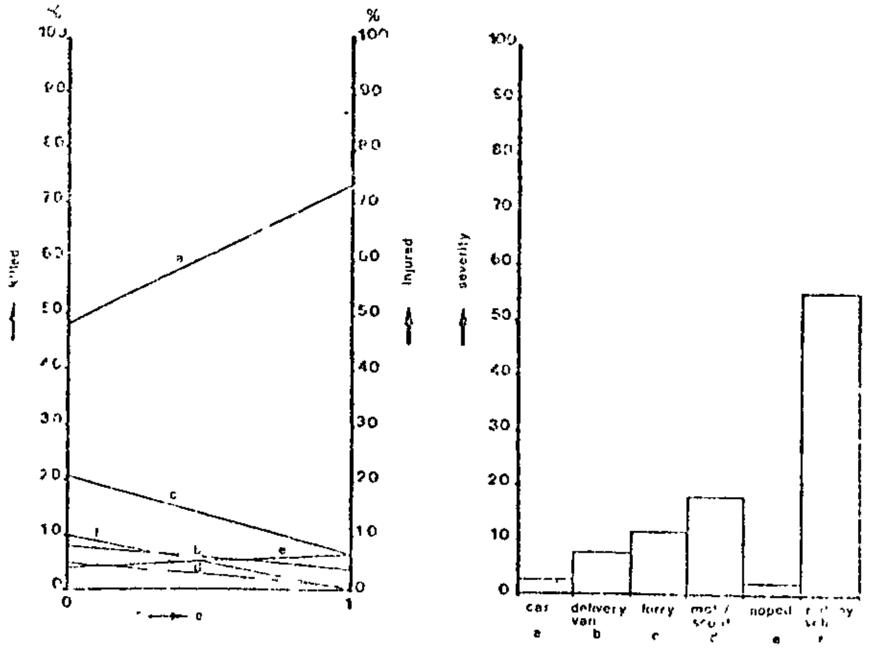


Fig 2 Priorities within the various accident types resulting in killed and severely injured moped riders. (Huijbers[9].

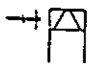
collision type		 I	 II	 III	 IV	 V	other types
number of accidents		37 (29%)	29 (23%)	22 (17%)	25 (20%)	11 (9%)	3 (2%)
persons involved		43 (28%)	36 (24%)	28 (18%)	32 (21%)	[illegible] (7%)	4 (2%)
VERLETZUNGSSCHWERE GRAD-VERTEILUNG overall AIS [%] injury severity	0	0	2,8	7,1	0	9,0	
	1	16,7	27,8	17,9	37,5	27,3	
	2	23,8	13,9	28,6	31,3	18,2	
	3	35,7	25,0	17,9	18,0	18,2	
	4	11,9	8,3	1,79	6.2	0	
	5	4,8	2,8	0	0	0	
	6	7,1	19,4	10,7	6,2	27,3	

Fig. 3. Distribution of two-wheeler collision types in motorized crashes. (Otte[12]).

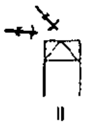
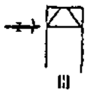
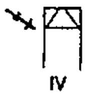
collision type		 I	 II	 III	 IV	 V	other types
number of accidents		62 (45,6%)	22 (16,2%)	21 (15,4%)		28 (20,6%)	3 (2,2%)
person involved		63 (45,7%)	23 (16,6%)	21 (15,2%)		28 (20,3%)	3 (2,2%)
VERLETZUNGSSCHWERE GRAD-VERTEILUNG overall AIS [%] Injury severity	0	1,6	4,4	——		——	
	1	12,7	13,0	14,3		21,4	
	2	34,9	30,4	28,6		42,8	
	3	27,0	26,1	19,0		17,9	
	4	4,8	4,4	9,5		3,6	
	5	12,7	21,7	23,8		3,6	
	6	6,3	——	4,8		10,7	

Fig. 4. Distribution of two-wheeler collision types in bicycle crashes. (Otte [12]).

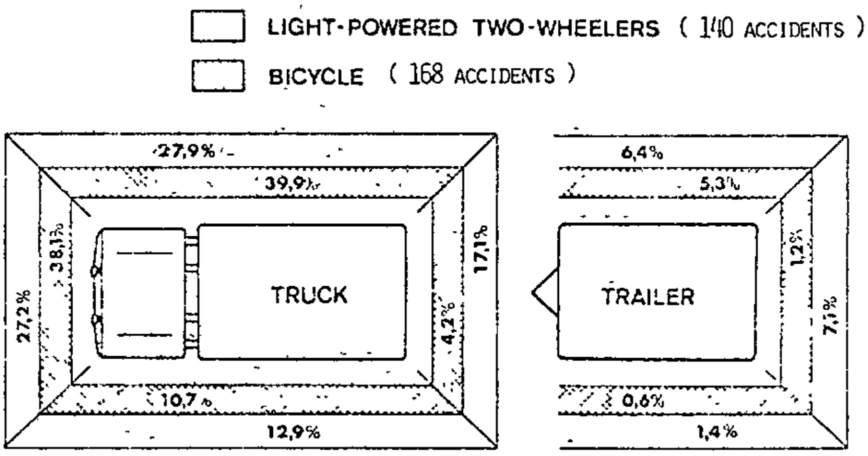


Fig. 4a HEAVY GOODS VEHICLE REGION CONTACTED BY BICYCLE OR LIGHT-POWERED TWO-WHEELERS GAUSS F., LANGWIEDER K., ET AL [19]

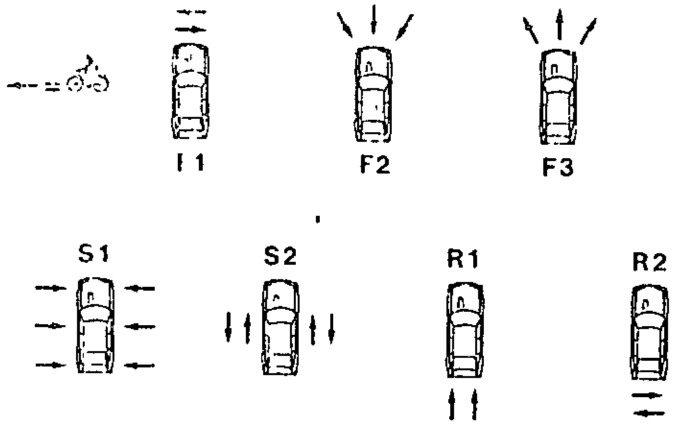


Fig.5. Definition of specific collision types. (Huijbers [9]).

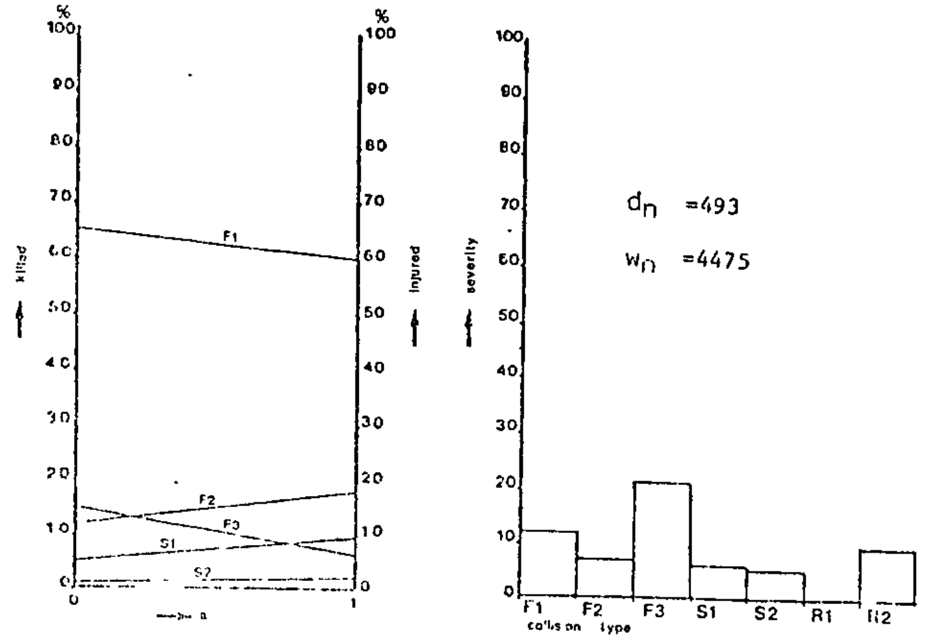


Fig.6. Priorities within the various collision types for bicycle to car collisions. (Huijbers [9]).

d_n = number of people killed

w_n = number of people injured

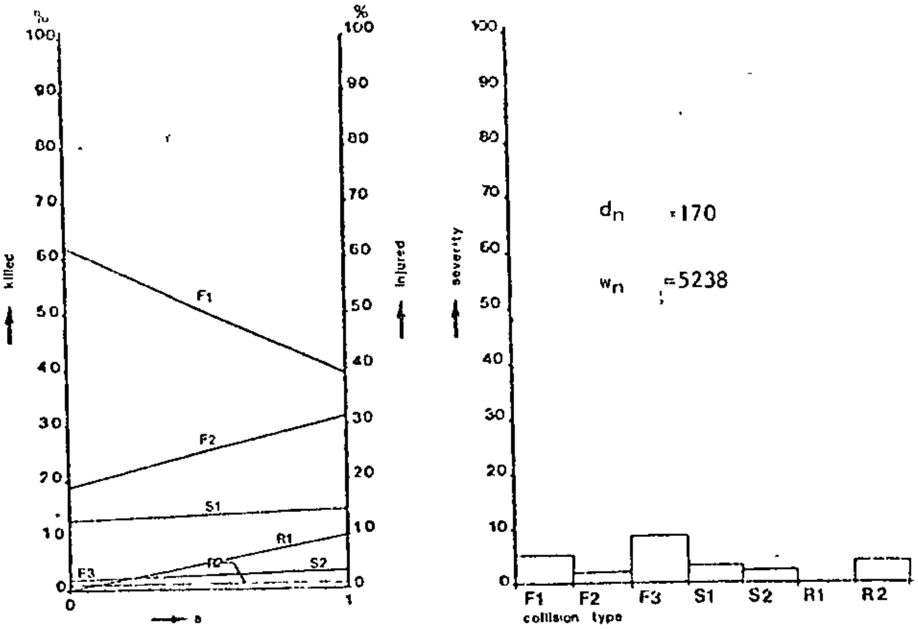


Fig. 7 Priorities within the various collision types for moped to car collisions. (Huijbers [9])

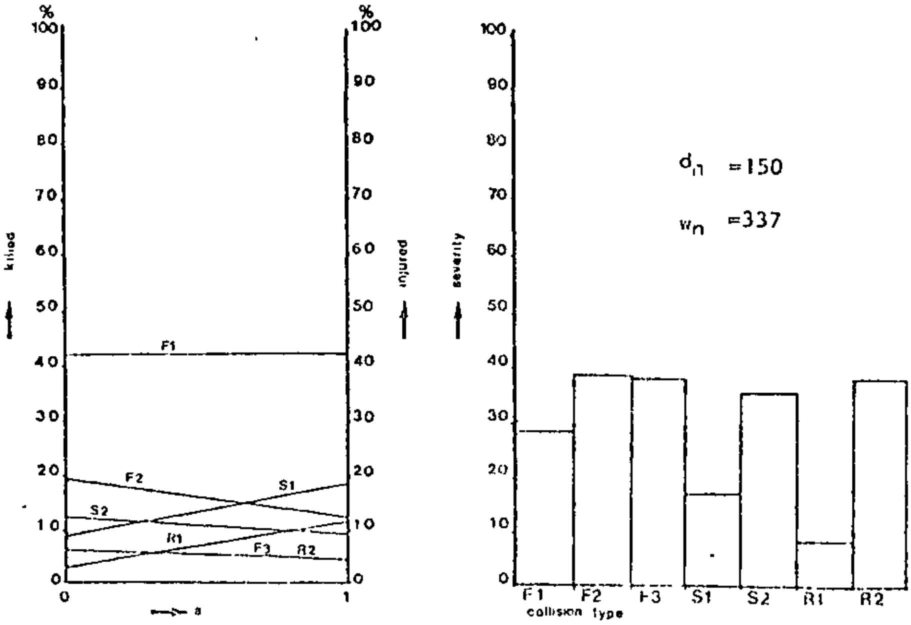


Fig. 8 Priorities within the various collision types for cycle to heavy goods vehicle collisions. (Huijbers [9])

d_n = number of people killed

w_n = number of people injured

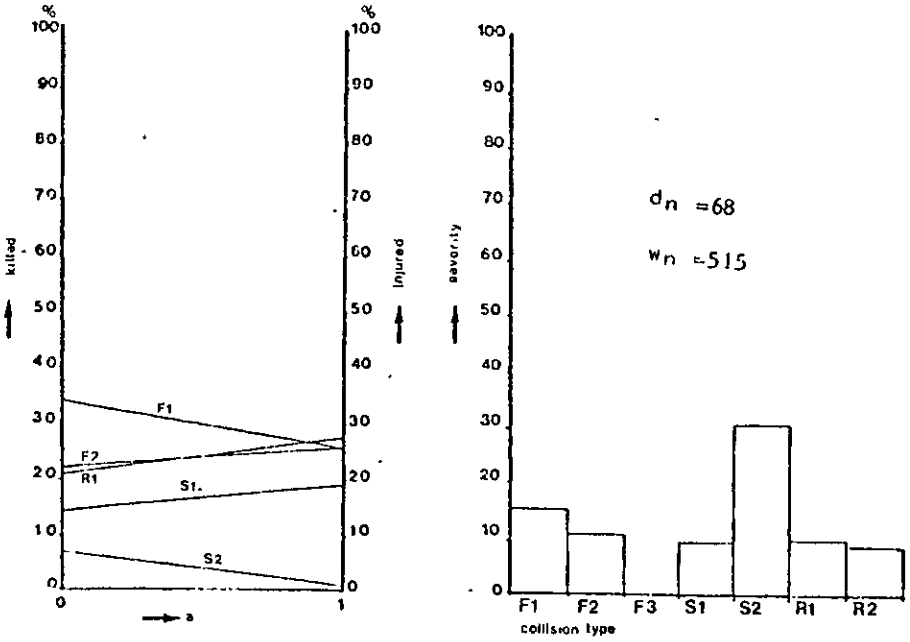


Fig 9 Priorities within the various collision types for moped to heavy goods vehicle collisions. (Huijbers [9]).

d_n = number of people killed

w_n = number of people injured

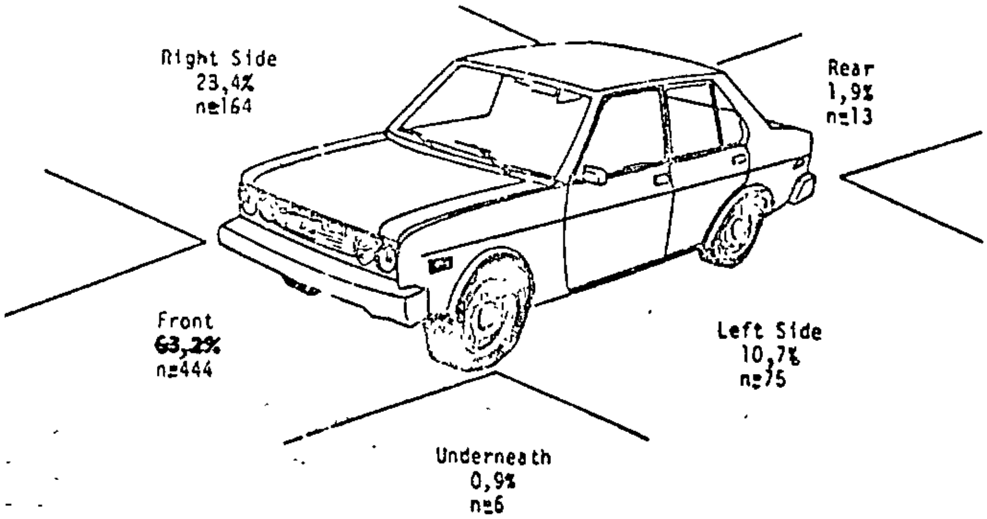


Fig. 10. Motor vehicle region contacted by bicycle/bicyclist (n=702 cases). (Roland [12])

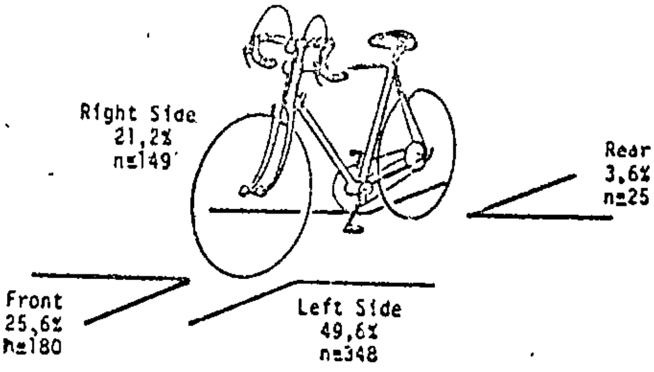


fig. 11. Bicycle region contacted by motor vehicle (n=702 cases). (Roland [12])

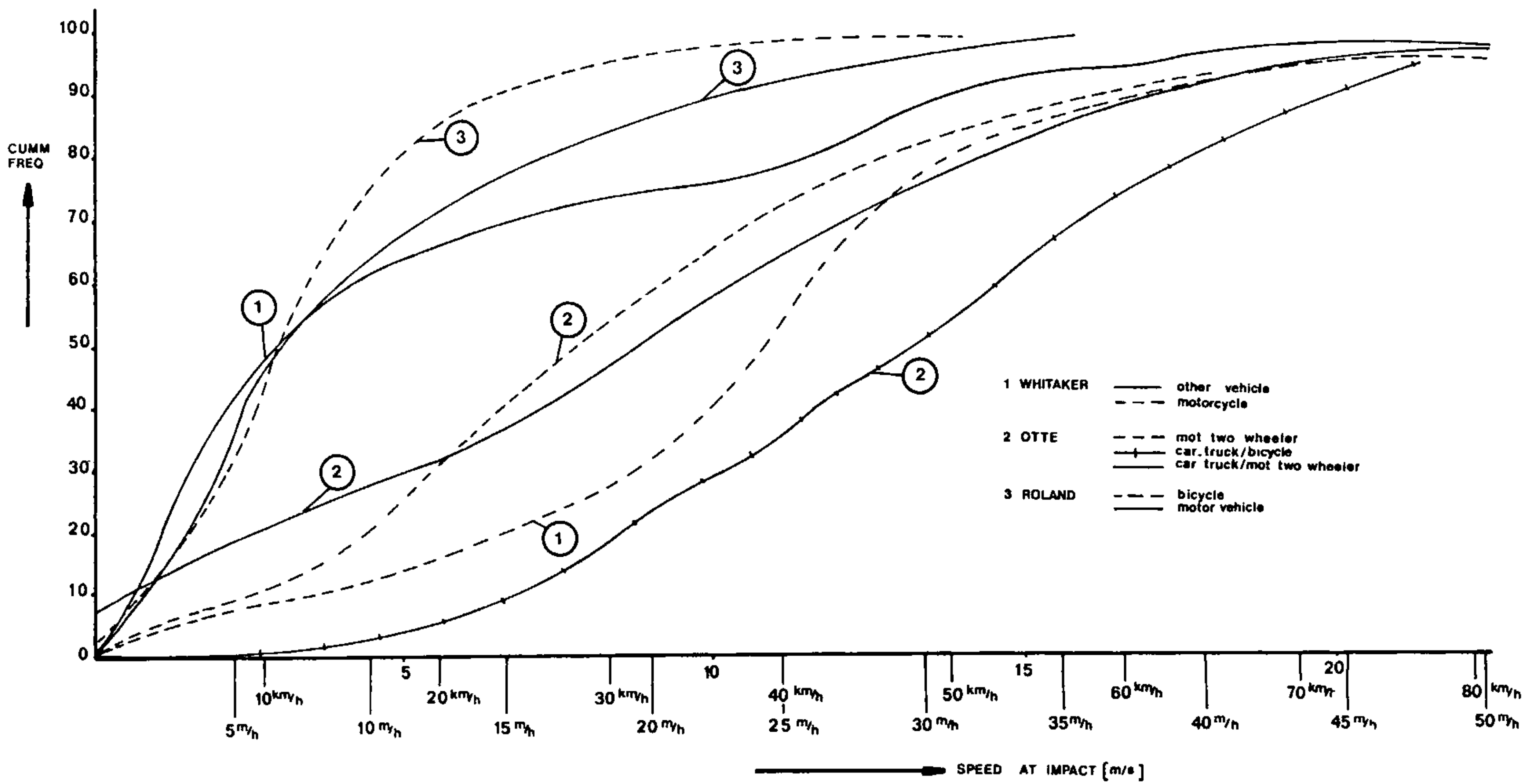


fig. 12. Cumulative distribution of vehicles speeds at impact in two-wheeler/car accidents by several studies.

3. INJURY INFLUENCING PARAMETERS

3.1. Introduction

Knowledge of injury influencing parameters in different types of road traffic accidents is gained through in-depth investigations at the scene of the accidents combined with detailled reconstructions and experimental studies.
A large number of reports from this kind of investigations is found in the literature regarding cars colliding with fixed obstacles, other cars, motorcycles or pedestrians. Very little is known about light (motorized) two-wheeler accidents. The following account of injury influencing parameters in such accidents is therefore mainly inferrential and rests upon deductions from what is generally known in this field of research. The main part of this chapter therefore deals with comparisons with other accident types and the conclusions drawn from these can of course be disputed.

Nevertheless it was considered desirable to have this kind of a résumé of factors thought to be of importance for the production of injuries to two-wheeler riders colliding with cars and heavy goods vehicles.

The rider is here, if not otherwise stated, generally supposed to be a teenager or an adult person and the two-wheeler a bicycle or a moped with an internal combustion engine but otherwise of essentially the same basic construction as a bicycle. The car is considered to be an average sized European type sedan.
For children on smaller bicycles the kinematics may be similar to those of adults although the front structures of the car may hit the child's trunk rather than its lower extremities. In some cases the child may have a more upright posture than an adult rider and the kinematics may than be more like that of a child pedestrian.

The kinematics of the two-wheeler rider in this kind of accident depend upon the type of collision, the velocities of the two vehicles, the rider's posture at the moment of impact and the construction of the two-wheeler.

While a pedestrian hit by a car usually upright at the moment of first contact, the rider of a two-wheeler is thought to be in a more or less seated position. This implies that his feet are usually at some distance off the ground , the head may be at about the same level as that of an upright pedestrian but this depends very much on the posture of the rider.
The centre of gravity of the rider's body may well be at approximately the same level above the ground as that of a standing adult pedestrian. While the velocity of a pedestrian if often negligible in relation to that of the car, the two-wheeler travels much faster. His velocity may sometimes be as high as 50-70 km/h, and has therefore to be taken into account in may accident situations. However, the parameter of importance for injury production is of course not the speed of travel but the relative velocity between the riders body and that of the car at the time of impact and for each body part.

Another important difference between pedestrians and riders of two-wheelers is the presence of the two-wheeled vehicle; this presence may influence the kinematics of the rider.

The inertia of its mass may in some collision types place extra load on the riders body and his extremities may get entangled in the main structure of the vehicle during the accident sequence.
A two-wheeler with an engine may also have parts which are hot enough to cause burns if the rider contacts them during the accident sequence.

3.2. Collision types

The collision types referred to below are those depicted in figure 5 of chapter 2. Due to existing knowledge and the priorities indicated in chapter 2, this paragraph will mainly deal with the collisions with passenger cars.

Passenger car

Type F1

In this type of accident the front of the car impacts the left or right side of the two-wheeler travelling in a direction perpendicular to that of the car.

This collision type is similar to the most frequent type of car-pedestrian impacts. In both cases the adult victim is hit below the centre of gravity and comes into contact first with the bonnet or windscreen and then with the ground. One obvious difference is the usually higher speed of the two-wheeler at the time of impact. This implies that the rider's upper body will often hit the bonnet at a point further in the direction of his travel than that of a pedestrian would. The ratio between the speeds of the two vehicles will be decisive for where the rider's head and trunk will impact the car structures. In some cases this ratio may of course be such that the upper body of the rider does not impact the car structures at all, but instead he falls directly to the ground.

The seated position of the rider at impact may sometimes induce a rotation of his body about its longitudinal axis. This is particularly the case when the car structures are low relative to the riders torso and the thigh on the struck side is at about a right angle with the rider's torso. The lower leg and to some extent the arms are then accelerated by the car at an earlier moment than the rest of the body. The direction of rotation therefore is such that the back of the rider's trunk and head are turned against the car.

The rider's legs will thus be accelerated by the front structures of the car and may then be loaded also by the inertia of the two-wheeled vehicle's main structure. His torso will usually impact the bonnet or the upper parts of the wings.
Where the head impact will take place will depend on the speed of the car and the car configuration parameters (e.g. bumber height, bumper lead angle and lenfth of its bonnet). It may be either on the bonnet, the upper parts of the wings, the windscreen or the windscreen frame. The compliance of these car structures varies considerably and is, as has been pointed out in connection with pedestrian-car accidents, an important injury influencing parameter. The speed of the car and the weight and construction of the two-wheeler are also important parameters.

Type F2

The two-wheeler is travelling in the opposite direction to that of the car and the impact occurs front to front; the closing speed is the sum of the speeds of the two vehicles.
The mass of the two-wheeler is small compared to that of the car. This may therefore be the most violet accident situation. It is also a situation where the rider's body may be travelling with the head as the leading part of the body.Even of the trunk is not stooped forward before the impact the legs may get caught by the handle bar of the two-wheeler during the accident sequence and this may induce a forward rotation of the trunk. Should the impact then be head first into the windscreen area the axial load of the body would often lead to severe fractures at the base of the skull and in the cervical spine. This kind of injuries are usually lethal even at low velocities. In this situation the total velocity change is the most important parameter and the compliance of the impacted structures - or the usage of a helmet by the rider - can probably influence the outcome only to a minor degree.

Type F3

The direction of travel is the same for both the car and the two-wheeler; the difference between the speeds of the two vehicles is a decisive factor.
The position of the rider's upper body then governs his kinematics. He may more or less remain in his original position, slide over the bonnet and impact the windscreen area with the lower part at his back. Severe back injuries can result form this type of accident. The main injury influencing parameter is again the velocity and the compliance of the structures is of secondary importance.

Type S1

In this type of accident the two vehicles move perpendicularly to each other or the car may be stationary but the two-wheeler impacts either side of the car. Due to the higher speed of the two-wheeler this type of accident has more similarities with the corresponding type of motorcycle accident than it has with the case when a pedestrian walks into the side of a car

If both vehicles are moving in this configuration the front of the two-wheeler will be influenced by the moving car in such a way that the two-wheeler will rotate during the sequence and the rider will impact the car side in an oblique way. Usually the rider's head will be at or above the roof area of the car.

If the impact occurs at the passenger compartment in the middle of the car the rider's body generally will be stopped by the car's side structures. The velocity of two-wheeler and the compliance of the car's side structures will be the injury influencing parameters and to some extent the structure of the two-wheeler.

If the impact occurs at the front or the rear of the car, where the car structures are lower, there is a possibility that the rider of the two-wheeler will pass over the car and fall to the ground on the other side. While airborne the rider may tumble and it is therefore difficult to predict his attitude when impacting the ground.

Types S2 and R2

In the case of a "near miss" or a side sweep only one leg and possibly one arm and shoulder of the rider may impact a front corner of the car. Axial or near axial loading of the femur is then possible and severe leg injuries, at high speed impacts even traumatic amputations are seen in this type of accident.
Compliant car structures may be of some help but the relative impact speed is probably more important. The arm and the shoulder may be injured in a similar way but the direction of force is probably more favourable.

Type R1

The two-wheeler impacts the rear of a car and the relative velocity is likely to be less than in most of the other accident types. The car structures, other than vertical ones, are therefore probably less important but attention should be drawn to the possible existence of spoilers, which should for this reason be as compliant as possible.

Oblique impacts

Oblique impact directions may produce a combination of the injury mechanisms mentioned above. When a rider's upper body impacts the top of the bonnet a higher relative velocity may result in a more oblique head impact than is the case for pedestrians. It is not possible to state on the basis of present knowledge whether or not this may lead to more severe head injuries due to angular acceleration of the head.

Accidents involving busses and lorries

In the case of the frontal collision types (F_1, F_2, F_3) the configuration parameters don't seem to have so much influence on the kinematics and injuries of the two-wheeler rider.
Compliance seems to be important.

The configuration of the sides of the heavy goods vehicles seems to be important for the injuries of the colliding two-wheeler rider, due to the large gaps between the wheels of the truck. The two-wheeler rider will be hit at head or neck level by the relatively stiff parts of the heavy goods vehicle.
The risk of being run over seems to be important too, just as the speed of impact of the two-wheeler rider.

3.3. The structures of the two-wheeler

When the two-wheeler is hit from the side there is a possiblity for the leg of the rider to be squeezed between the two vehicles. The construction and the inertia of the two-wheeler is then of importance for injury production. If the two-wheeler collides in a frontal or oblique direction with another vehicle or an obstacle it is possible that the rider is caught by the handle-bar in the groin area. This may sometimes lead to vascular and/or nerve injuries and may change the kinematics of the rider. Any other protruding detail on the two-wheeler may cause injuries if the rider hits it during the accident sequence.
A special type of injuries occur when children are carried as passengers on two-wheelers without adequate protection for the child's legs.
If the child's foot gets caught in the wheel it will be squeezed between a spoke and the frame and the resulting injury usually requires hospitalization.

3.4. The ground

For pedestrians it is now believed that the ground is of little importance in relation to the car for injury production. The same is probably to some extent the case for two-wheelers. At higher speeds there may be a more substantial influence by the ground. The oblique impact of the head to the ground and possible kerbstone impacts may then become important for the severity of brain injuries. Another important factor is the dirt on the road surface. Open wounds caused by the primary impact to the car or resulting from the sliding of the rider on the ground after impact may be smeard with dirt. This prolongs the healing process and may lead to complicating infections. Normal cloths are of little use for protection since they are easily torn under these circumtances.

3.5. Obstacles

In the streets there are several obstacles which a two-wheeler can contact violently after loss of control. Street appertunances are sometimes designed to break away or yield when hit by cars in order to mimimize the risk of injuries to car occupants. Because of their low mass, two-wheelers will normally not be capable of deforming these structures to any appreciable degree. Hence, the risk of having an injury is much greater for these categories. In country roads trees and fences can also cause injuries if violently contacted by the rider of a two-wheeler.

Particularly children and teenagers sometimes use their vehicles also in playing grounds, parks and other places outside the roads where there are several possibilities for contacting fixed obstacles. The types and severities of the resulting injuries from such contacts depend upon many variables, such as type of accident which determines the kinematics and attitude of the body at impact, the velocity, the object struck etc.

Children seem to more prone then adults in overturning to fall on the end of the handlebar in such a way that abdominal injuries occur. Due to the very low tolerance of the child abdomen to the high level of loading resulting from this kind of impact very little can be done with the bicycle to prevent these injuries.

4. RESEARCH METHODS AND RESULTS

4.1. Introduction

Injury prevention research for two-wheeler riders got less attention than injury prevention research for pedestrians.
The accident process of the two-wheeler rider is even more complex than that of the pedestrian because of the contribution of the two-wheeler itself to the injury producing proces. Also the speed of the two-wheeler and its position in traffic situations lead to other collision types and speeds at impact.
There are several ways to study two-wheeler injury protection:
One is analysis of accident data and another is experimental research.

4.2. Accident studies

4.2.1. Accident studies give samples of reality in order to estimate the size of the problem, defining priorities within this problem and developing hypothesis in which relations between injury influencing parameters and injury severity are postulated.
Accident studies also give results with regard to the quantification of these relations. The study of the effect of a specific (legal) measure is a special application of this type of accident investigation.

4.2.2. One might distinguish at last three levels of depth of accident studies:

1) accident statistics (police data level)
2) intermediate level studies
3) in-depth studies.

To describe the size of the problem, the relative proportions of collision types etc., level 1 and 2 data are needed.
These data may also form the basis for experimental studies under laboratory conditions. In chapter 1 and 2, level 1 and part of level 2 are described.

The difference between level 2 and level 3 data is normally that in level 3 far more detailed data are gathered including data on scene for each accident.
Emphasis with level 2 data is on the statistical side, which means that sample size, sampling method and detail of information are balanced with respect to representativeness and statistical analysis. For both levels investigators of more than one discipline are often used (i.e. technical, medical etc.)

Since accidents involving two-wheelers are complicated with respect to the exact cause of injury (for instance contribution of vehicle and road factors) the in-dept level of data gathering is often used.

Level 3 in-dept data may provide for each case:

- data form observation on scene, soon after the accident, helping to understand the sequences of the collision phases.
- data on the vehicles or obstacles involved, with emphasis on vehicle types, damage, marks for reconstructing the collision type, collision severity and if possible injury mechanisms.
- general data on two-wheel riders, especially their position on the two-wheeler, their means of protection etc.
- detailed injury description for every casualty, if possible by direct observation or through hospital records.

Level 2 data may also contain valuable information in injuries and the accident in general and since emphasis is on representativeness, a far more reliable picture of all occurring crashes is acquired than by means of police data (level 1).

Level 2 studies may be based on insurance data, hospital data (though these will be restricted to only part of the injury population), tow-away accidents or any other starting point.
As in level 3 studies, both damage, accident and injury information will be gathered, often on a statistical basis (e.g. by a written enquiry to car owners, occupants, hospitals or police). Visiting the sence of the accident is not part of this method, since this would take too much time and effort.

For two-wheeler accidents a visit to the scene and a full investigation of the surroundings and the vehicles involved seems necessary if all injury causing factors are to be known.
However the in-depth approach limits the quantity of cases to be studied in a given period of time.
Therefore level 2 data are needed to get view on the problem and its relevant distributions as part of reality, especially if level 1 data is not available or imcomplete, as is the case in many countries.

4.2.3. Some results:

Cross [4] studied 753 non-fatal and 166 fatal bicycle casualties in collisions with motorvehicles (level 3).
From the non-fatal group only 17,5% remained in hospital longer than one day. Contact with the road surface seemed to be the cause of injury in 60% of the cases.
Contact with the motorvehicle in 23% and contact with the bicycle in 6,2%.
The conclusion from Roland [5], after examining 700 motorvehicle-to-bicycle accidents (level 3), is an agreement with this last statement as far as the injury causation of the bicycle is concerned.
Roland [5] concluded that the bicycle did not seem to be a major source of severe injuries.
There were only four injuries resulting from a contact with the bicycle that produced an AIS rating greater than one.
There is a significant overrepresentation of the motor vehicle as the source of injury rather than the environment.
For all the defined speed categories more severe injuries tend to result when the contact source was the motorvehicle as opposed to the bicycle or the environment. This does indicate that the injuries are being produced in the initial contacts rather than from secondary contacts with the environment.
No significant influence on injury severity was found for:
estimated speed of bicycle prior to impact, bicyclist's age, handle-bar type, bicycle region contacted.
Significant influence of the following motorvehicle variables was found:
estimated speed at impact, vehicle manoeuvre prior to impact.
Some studies described specific injuries:
The influence of the bicycle on intra-abdominal injuries (Esterer [21], Aldman [19]. These injuries are usually caused by falling on the free end of the handle-bar.
Bicycle spoke injuries (Juhl [20]): these lesions occur if the (child) passenger's foot is caught in the wheel of the bicycle.

4.2.4. Some advantages and disadvantages of accident studies in relation to experimental research:

advantages:

- The only way to establish the size of the problem.
- The only method that gives insight in the injury influencing parameters in the real accident situation.

disadvantages:

- Approximation of some of the accident data (e.g. speed at impact, contactplaces).
- Only the influence of the values of the parameters, as they exist in real traffic, can be studied.

4.3. Experimental research methods

In a collision between a two-wheeler and a car, type and severity of injuries sustained by the two-wheeler user may depend on its kinematics but also on the relative speeds of the two vehicles. (chapter 3). The two-wheeled vehicle may have an important speed. Moreover the crash configuration can differ from one case to another in a large range (chapter 2).
The main collision types are: F1, F2, S1 (chapter 2).
Experimental research on bicycle and moped collisions is mostly focused on type F1. Type S1 is dealth with in motorcycle collision experiments. The posture seems to have a small influence on the kinematics and one can imagine that differences in height would also have minor influence, as most of the two-wheeler users are adults.

Three main methods are available for research in two-wheeler safety:

1. The full scale test between a two-wheeler and a car (or a mobile barrier), the two-wheeler rider being a dummy or a cadaver.
   Even if they have the advantage of being realistic, for car/two-wheeler collisions they will have to be performed in a large number of configurations as the potential collision types are numerous and the impact speed can vary in a large range. The problem of impact "with escape" may be difficult to reconstruct.
2. The body segment test (or component test) in which the safety problems involving a specific body area are investigated.
   They would not be fundamentally different from research made on pedestrian safety, as the same body segments are concerned. Moreover, specific research dealing with two-wheeler safety concerns head injury protection with crash helmets, as well as some other parts of cars, trucks etc.
3. The mathematical model: this can be used as a general tool to evaluate and predict two-wheeler rider kinematics and dynamics.
   Mathematical models are especially useful in parameter variation studies. As a result, mathematical modelling has the advantage (and may be the only practical tool capable) of determining generalised output for complete populations.
   The use of mathematical models in two-wheeler safety research is relatively recent. The method is promising for the near future. Mathematical models have to be validated with test-results and/or accident investigation output.

4.3.1. Full scale approach of two-wheeler safety research.

This approach generally consists in reconstructing a collision between a car and a two-wheeled vehicle on which a model of a human being is seated (Sacreste [8], Taneda [9]).
The impacts sustained by the two-wheeler rider ejected from his vehicle can be analyzed in relation to car/two-wheeler collisions or to impacts against objects in the surroundings (Chretien [10]).
Two main research projects used this car/two-wheeler full scale approach to study two-wheeler protection.
For the first one (Kraus [2]) 22 collisions between a passenger car and a moped were recontructed. These tests were made in 6 different configurations, most of the tests representing a road crossing collision, the moped being either striking or struck.
All the tests, except 2, were performed with a 50th percentile dummy; the other 2 used cadavers.
In 13 tests, the two-wheeler user was helmeted whereas in the other 9 his head was not protected.

Main results:
this research found that, in the case of struck moped, the two-wheeler user kinematics can be compared with pedestrian kinematics.
From the point of view, the car modifications made to protect a pedestrain can be favorable for two-wheeler users too.
The head-ground impact gave higher HIC values than the head-car impact. The helmet ensures a certain measure of head protection; it is less effective in the temporo-parietal area. Finally, an interaction between the moped and the dummy pelvis has been found in several cases.

The second study (Taneda [9]) was made in Japan. For this research 10 collisions were performed, in which a standing motorcycle was struck laterally by a car or a rigid mobile barrier. The aim of this research is to study lower limb protection of motorcylists, so the tests were made with a 50th percentile dummy equiped with frangible legs.

Main results:
the modifications of cars in order to optimize energy absorbtion would allow to ensure a better protection of the rider against leg injuries. It seems possible to protect from leg injuries at a speed up to 40 km/h and the authors think that the other injuries are acceptable in this range of speed.
The protecting device tested in lateral collisions would have a beneficial effect in other crash configurations, especially avoiding leg crush under the motorcycle in case of rollover and underride of the motorcycle under a car.
The effect of the rider ejected from his motorcycle and impacting a guardrail has been studied experimentally (Chretien [10]), with tests in which a dummy is laid down on the back, the head forward, on a mobile platform which is suddenly stopped; the dummy is projected forward and hits a guardrail, the head first and under a chosen angle. This research has shown that it is possible to design deformable shields avoiding the direct impact between the two-wheeler rider and the rigid and sharp parts of the guardrail (posts and rails).

The third study is done at TNO (Janssen [17]).
Dummy tests were executed (type F1) as a first step to validate the MADYMO mathematical model.
The first results indicate that the kinematics of the bicylists resembles that of a pedestrian but that the impact places of the bicyclist-head on the car is somewhat higher.
Further results will be presented at IRCOBI 1984 in Delft.

Advantages and disadvantages of the full scale approach for two-wheeler protection research.

This approach would give generally a realistic view of the two-wheeled vehicle/car collision but the realism of the reconstruction is limited by the behaviour of the dummies and by the selection of crash configurations.

Especially making tests with a standing vehicle decreases the interest of this approach.

These tests do not have a good repeatability and each test can only allow a safety evaluation in one specific configuration, whereas the accidentology shows an important diversity of real crash configurations.

The two-wheeled vehicle type has a big influence on the results of the tests; thus these results can not be applied to all two-wheeled vehicles (e.g. mopeds versus motorcycles).

4.3.2. Component tests used in research for two-wheeler safety.

Many researches using the component test approach, dealing with two-wheeler protection have been performed: most of them concerned head protection, i.e. study of crash helmet protection.

Some of these studies are limited to the verification of helmet performance in tests similar to standard tests (Taneda [9], Chretien [10]).

Other more fundamental studies allow to better know the mechanisms which govern the head protected with a helmst and then to increase the performance of these devices.

One biomechanical research project (Fayon [13]) investigated injury mechanisms and head protection possibilities on the basis of drop tests. 11 tests have been performed with cadavers, 9 of them were helmeted: the drop height was 1,83 m or 2,50 m.

The subject was inclined at 30° downwards, the head first hitting a rigid flat surface.

These tests were completed by some tests using only the helmeted head of a Hybrid II dummy or a helmeted metallic head model.

In this study the HIC values are very high even in tests performed at 1,83 m, but the measures were not obtained at the center of gravity of the head.

Tests performed with a head only (dummy head or metal form) gave HIC values lower than those obtained in tests using whole bodies.

An other research (Aldman [14]) studied in the influence of horizontal velocity of the head when it hit the ground, on the kinematics and the linear and angular accelerations sustained by the head.

Helmeted head and neck of a dummy, attached by a lever arm to a rail guided carriage, sustained free falls on a ring simulating the road surface. The horizontal ring rotated in order to simulate the horizontal component of the head speed related to the ground.

These tests showed that in these conditions the head sustained important angular accelerations and speeds while the HIC value, which takes into account only the linear acceleration components staid generally below 1000.

This study concludes that some helmets have a shell made of material which is too soft to provide a desirable low friction between helmet and road surface.

An other study (Bastiaanse [15]) compared the energy absorbtion characteristics of a protective helmet and a coconut shell, and showed on the basis of experimental tests, that the coconut has greater energy absorbtion capacity than the foam used for helmets. The author proposed to design helmets without rigid external shell.

Advantages and disadvantages of component tests as a basis of two-wheeler rider protection research:
Component test methods allow to make researches based on a large, number of tests, having a good repeatability at relatively low cost. But these tests are notable to give only a global view of the two-wheele accidents as they reproduce just one phace of the accident.
Moreover, the conditions in which they are performed are simplified (2D motions) and so their realism is limited.
From this point of view, the conclusions found in researches using the component tests approach should be validated trough full scale tests.

4.3.3. Mathematical models for research in two-wheeler protection.

It seems that there is no mathematical model which is especially designed for bicycle and light powered two-wheeler safety research. Existing models of car occupants or pedestrains could be used for two-wheelers but their adaptation and validation would need a sufficient number of test results.
The three dimensional CVS 3 Calspan model has been adapted by the Denver Research Institute to study the behaviour of crash victims in motorcycle accidents (Fleck [16]). In the Netherlands, SWOV and IW-TNO are working on a program that is set up to produce a validated mathematical model for two-wheeler accidents with cars.
At this moment dummy-tests have taken place as a first step to validation (Janssen [17]).
In Germany a mathematical model exists which simulates the impact of a motorcycle in the side of a standing car (Sporner [18]).
In fact, it seems that up to today there are practically no results of light-powered two-wheeler safety research using mathematical modelling.

Advantages and disadvantages.

Mathematical models have potentially many advantages as they allow to investigate a large number of situations in a short time at low cost, without repeating experimental test. For that reason they can generalise output (complete) populations involved in certain (or all) crash configurations. The accuracy of the results of mathematical model studies are largely depending on the quality of the validation of the model. For validation not only full-scale test results must be used, but also results from (in-depth) accident investigations and specially developed validation test results can be used.
Compared with full-scale tests, the results of mathematical models can be stated to be at least as realisitc.
The condition of the representation of the real situation with dummies or cadavers is somewhat questionable.

4.4. References

1. J. Dedoyan
   Etude médicale et technique d'accidents impliquant des usagers de deux roues à moteur
   Thèse Lyon 1979

2. Kraus J.F., Riggins R.S., Franti C.E.
   Some epidemiologic features of motorcycles collision injuries
   Amer, Jl. of Epidem. 102, 1, pp 74/109

3. N.H.T.S.A.
   Motorcycle accident factors study
   Sept. 1980

4. K.D. Cross, G. Fisher
   A study of bicycle/motor vehicle accidents : identification of problem type and countermeasur approaches. Final report
   US Dept of Transportation, NHTSA, Sept. 1977

5. H.E. Rolant, W.W. Hunter, J.R. Stewart, B.J. Campbell
   Investigation of motor vehicle/bicycle collision parameters. Final report
   US Dept of Transportation, NHTSA, feb. 1979

6. Jamieson K.G., Icelly D.
   Crash helmets reduce head injuries
   Med. J. Australia, 1973, 2, 17, pp 806/809

7. ONSER
   Etude des moyens de protection des usagers de 2 routes, 1976

8. J. Sacreste, J. Masset, A. Fayon
   Collisions expérimentales voitures/cyclemoteurs
   Rapport ATP n° 1, 1979

9. K. Taneda
   Experimental investigation of motorcycle safety
   IRCOBI 1976, pp 270/282

10. B. Chretien, J.C. Cayet
    Accident de 2 roues heurtant un dispositif de retenue
    ONSER, rapport 311.79.03

11. T.D. Dunham
    Safety helmet performance investigation
    NHTSA report, Nov. 1974

12. V.J. Jehu
    Shock absorbtion test methods for protective helmets
    Aspects techniques de la sécurité routière n° 58, Bruxelles, 1974

13. A. Fayon, C. Tarriere, G. Walfish, C. Got
    Performance of helmets and contribution to the definition of the tolerances of the human head to impact
    IRCOBI 1976, pp 291/300

14. B. Aldman, B. Lundell, L. Thorngren
    Non perpendicular impacts - An exeperimental study on crash helmets
    IRCOBI 1976, pp 322/331

15. J.C. Bastiaanse
The natural crash helmet
IRCOBI 1976, pp 375/384

16. J.F. Fleck, F.E. Butler
Calspan 3D crash victum simulation program
IRCOBI 1976, pp 283/290

17. E.G. Janssen, C.G. Huiskens
letselpreventie wielrijders
Tussen rapport, IW-TNO, 1984

18. A. Sporner
Experimentelle und Mathematische Simulation von Motorradkollisionen
im Vergleich zum realen Unfallgeschehen.
Diss., TU München, mai 1982

19. B. Aldman, J. Thorson, A. Äsberg
Bicycle accidents to children and blunt trauma to the abdomen
IAATM, 1969

20. M. Juhl
Bicycle spoke injuries
IRCOBI 1976

21. H. Esterer, A. Opitz, E. Schima
Intra abdominelle organverletzungen durch Sturtz auf die
Fahrradlenkstange
Unfallheilkunde 77, 1974.

5. CURRENT KNOWLEDGE ON HUMAN TOLERANCE

5.1. Introduction

Accidents involving bicyclists and moped users can occur in various situations, and contrary to pedestrians, mechanisms producing two-wheeler users injuries are numerous and can be very different from on case to the others.
For this reason, it is not possible to describe a typical kinematic of a two-wheeler user involved in a traffic accident.
The human tolerance can also vary according to the loading process: (age, diseases, conditions, anthropometry, impact speed ...) and may therefore be different for cyclists and riders of light-powered two-wheelers.

Tolerance can be considered in terms of severity: injuries sustained in real world accidents can have several degrees of severity, as simple bone fracture or severe internal organs contusions which are corresponding to AIS 2 or 3, are considered as tolerable.

There are few studies conducted to determine human tolerance of two-wheeler users involved in traffic accident. Nevertheless some of the studies dealing with pedestrians or car occupants can be taken into account.

5.2. Head tolerance

Concerning head tolerance, it is necessary to investigate separately cranial and/of facial head injuries and brain injuries.

5.2.1. Bone injuries

The tolerance of skull to fracture depends mainly from the dimensions of the impacting structure. The main values published by the literature are reported in table 5.1.

Impacted area	Small	Large
frontal	5 [1]	7 [2]
temporal	1,8 [3]	8,3 [4]
partietal	3,4 [1]	8,5 [2]
occipital	?	9,6 [4]

Table 5.1. : Tolerance of skull to fracture in kN

The tolerance of the facial bones is lower than the tolerance of the skull.
Table 5.2. summarizes the main results found in the literature.

	Tolerance force	
zygoma	800 to 1800	[5]
maxilla	650 to 1000	[4,5]
mandible	800 to 3000*	[5]
nose	1300	[6]

*depending on impact direction

Table 5.2. : Tolerance of facil bones to fracture (in N)

These two tables show the potential effect of helmets in avoiding small impacts which correspond to the lowest skull tolerance, and in protecting facial bones from direct impact.

5.2.2. Tolerance of the brain (brain concussion)

The brain tolerance is not well established, and brain injuries have no evident correlation with skull fractures. Tolerance of head as a function of pulse duration has been established by Lissner [7] and is called "Wayne State Curve". The corresponding parameter to this curve is the GSI (Gadd Severity Index) which is defined by:

$$\mathrm{GSI} = \int_{o}^{t} a^{2,5} .dt$$

in which a is head acceleration in g's and the value of 1000 is considered as the tolerable limit.

A more recent index called HIC has been developed and is used for car occupant frontal impacts. The HIC is defined by:

$$\mathrm{HIC} = \left. \left[\frac{1}{t2 - t1} \int_{t1}^{t2} a(t).dt \right]^{2.5} . \ (t2 - t1) \right|_{\max}$$

The proposed limit of tolerance for HIC is 1000 or 1500, but recent studies have shown that this criterion is not very pertinent to predict head injuries. Some other criteria have been proposed but none were widely accepted. However in the absence of a pertinent criterion, the HIC can be accepted in dummy tests.

Two-wheeler accidents can correspond to large body motion and the wearing of a safety helmet could increase the amplitude of head motion. For these reasons the rotational acceleration which has been proposed to be correlated with brain injury would be considered as a tolerance parameter.
Theorical analysis using the mechanics of similitude seems to indicate that children has a higher brain tolerance than adult (Dejeammes [8]),either if we consider translational acceleration or rotational one; this is confirmed by the higher breaking strenght of arterial tissues of children found by Yamada [9].

5.3. Thoracic tolerance

Recent studies on thoracic tolerance indicate that the tolerance to rib fractures is more correlated to thoracic deflexion than to thoracic acceleration either in frontal or in lateral impact (Verriest [10], Walfish [11]). However the tolerance is not the same for frontal and for lateral loadings. The proposed value of tolerance is 30-35% of the half torax width in lateral impact.
Comparison of rib characteristics between children and adults seems to indicate that children can sustain higher thoracic deflexion without rib fracture but in this case internal thoracic injuries can occur. In general way, increasing the number of rib fractures enlarge the risk of thoracic internal organs injuries.

5.4. Abdominal tolerance

The tolerance if the abdomen has been studied with cadaver free falls hitting laterally an arm rest model (Walfish [12]).
This study proposes a limit of 28% of abdomen width corresponding to 4,5 N impact force, as a human tolerance. These tolerance data concern mainly liver injuries.

5.5. Pelvis tolerance

The tolerance of the pelvis bones has been studied for car occupants either in frontal or in lateral impacts.
In frontal impact the pelvis is loaded through the femur, when knees are impacted this mechanism can be found as well in car occupants as in some two-wheeler accidents. The proposed tolerance in this cases is close to 10 kN (Evans [13]).

In side impact the pelvis can be loaded either through the hip or directly on the illac wing. These mechanisms can occur in some two-wheeler accidents, as for example when a two-wheeler is hit laterally by the front of another vehicle. The proposed tolerance in this case is 10 to 12 kN impact force (Cesari [14]).

5.6. Lower limb tolerance to fracture

Several studies dealing with leg tolerance have been made either for car occupants or for pedestrains.
The tolerance of the femur in bending fracture depends from the point of impact, the lower tolerance corresponding to the mid-shaft impact. In this case the tolerance seems to be close to 10 kN.

Tibia tolerance to horizontal loading seems to be between 3000 N and 9800 N depending on the impacted area with an average value of 5000 N [15].
However a recent study conducted in Sweden dealing with pedestrain safety (Bunketorp [16]) has found a much lower value of lower limb tolerance. The value of the momentum corresponding to the fracture is about 200 Nm (Ashton [17]). However these values are related to a small surface impact and the tolerance in a bumper-like impact is probably higher. In general the child seems to have a tolerable bone strenght higher than the adults (Dejeammes [8]).

5.7. References

1. J.W. Melvin, P.M. Fuller, R.P. Daniel, G.M. Pavliscak
Human head and knee tolerance to localized impacts
SAE 690477, 1969, Mid. Year Meeting, Chicago II, May

2. G.E. Voigt, V.R. Hodgson, L.M. Thomas
Breaking strength of the skull vs. Impact surface curvature
Contract n° DOT HS 146.2.230, final report, 1973

3. R.L. Stalnaker, J.W. Melvin, G.S. Nusholtz, N.M. Alem, J.B. Benson
Head impact response
Proc. of 21st Stapp Car Crash Conf., paper 770921, 1977

4. V.R. Hodgson, W.A. Lange, R.K. Talwalker
Injury of the facial bone
9th Stapp Car Crash Conf., 1965

5. D.C. Schneider, A.M. Nahum
Impact studies of facial bones and skull
16th Stapp Car Crash Conf., paper 720965, 1972

6. J.J. Swearingen
Tolerance of the human face to crash impact
Federal Aviation Ag, Office of Aviation Med., 1965, Rept AM. 65.20

7. H.R. Lissner, M.J. Lebow, F.G. Evans
Experimental studies on the relation between acceleration and intracranial pressure changes in man
Surg. Cyn. Obst., 1960, volume III, pp 329/338

8. M. Dejeammes, C. Tarriere, D. Kallieris, C. Thomas
Exploration of biomechanical data towards a better evaluation of tolerance for children involved in automative accidents
27th Stapp Car Crash Conf., 1983

9. H. Yamada
Strength of biologicals materials
Robert E. Krieger Publishing Company New York 1973

10. J.P. Verriest, A. Chapon, R. Trauchessec
Cinephotogrammetrical study of porcine thoracic response to belt applied load in frontal impact. Comparison between living and dead subjects
25th Stapp Car Crash Conf., 1981

11. G. Walfish, F. Chamouard, D. Lestrelin, A. Fayon, C. Tarriere, C. Got, F. Guillon, A. Patel
Tolerance limits and mechanical characteristics of the human thorax in frontal and side impact and transposition of these characteristics into protection criteria
7th International IRCOBI conf. on the Biomechanics of Trauma, Sept. 1982

12. G. Walfish, A. Fayon, C. Tarriere, J.C. Rosey, F. Guillon, C. Got, A. Patel, R.L. Stalnaker
Designing of a dummy's abdomen for detecting injuries in side impact collisions
5th Intern. IRCOBI conf. on the Biomechanics of Impact, Sept. 1980

13. F.G. Evans
Stress and strain in bones
CC Thomas Publisher, 1957, pp 92/98

14. D. Cesari, M. Ramet
Pelvic tolerance and protection criteria in side impact
26th Stapp Car Crash Conf., 1982

15. J.W. Young
Applied forces of lower leg impact, 1966
reported by R.C. Snyder, human impact tolerances
1970 Internat. Auto. Safety Conf. compendium

16. O. Bunketorp, A. Aldman, R. Jonson, B. Romanus, B. Roos,
L. Thorngren
Experimental studies on leg injuries in car pedestrain accidents
6th IRCOBI, 1981

17. S.J. Ashton, J.B. Pedder, G.M. Mackay
Pedestrain injuries and the car exterior
SAE Transactions, paper 770092, SAE, Warrendale, USA, 1977

6. INJURY PREVENTION MEASURES FOR BICYCLISTS AND RIDERS OF LIGHT-POWERED TWO-WHEELERS

6.1. Introduction

This chapter will deal with:

1. Proposals for injury prevention of two-wheeler riders.
2. Consequences of these proposals for other groups of road users.
3. Consequences of (proposed) legal requirements for injury reduction of other groups of road users to the injuries of bicyclists and light powered two-wheeler riders.
   The philosophy of the integral approach of the "Safety Vehicle" will take a central place; at the same time it will be quite obvious that the amount of concrete proposals is limited due to just starting research activities in this area.

As stated in chapters 2 and 3 this chapter will deal with the proposals as a function of the different relevant collision types. The proposals made in this chapter are mainly based on information from literature.

6.2. Proposals for injury prevention of two-wheeler riders

From chapter 4 it follows that the contact with the car is the leading cause of injury. Therefore efforts concerning the injury prevention have to be directed to these contacts.

The proposals can be distinguished in proposals concerning:
- the car
- the heavy goods vehicle
- the two-wheeler
- the two-wheeler rider

In general:
the aim of these proposals in to influence kinematics and to minimize the loads to the struck body parts.

A. Car - two-wheeler collision

Car
The collision types F1, F2 en F3 (fig. 5, chapter 2) for bicyclist collisions and F1 and F2 for moped rider collisions seem to be the most important (chapter 2); in these collisions the front of the car is hit.
Changing the stiffness of some parts of the car will probably have the same positive effect on the injury minimization for two-wheeler riders and pedestrains.
The optimum values for the stiffness from a view point of biomechanical tolerance cannot be answered at this moment.
The parts of the car that have to be taken into consideration depend on the collision types but vary from bumper to the upper side of the windshield frame.

For shape the same variables as for pedestrain impacts seem to be important but no concrete proposals can be made for this moment, but it seems obvious that sharp protrusions and "popping up" headlamps should probably have a negative effect.

Two-wheeler
F1: Side protection devices for motorcycles are proposed by Bourret [3], Rau [6] and Taneda [9] (fig. 1 and 2).
According to Bourret the leg injury severity in a F1 type of collision is strongly related to the mass of the two-wheeler.

Whether these side protection devices are realistic for mopeds (or even bicycles) cannot be answered at this moment.
F2: The question whether the two-wheeler rider has to be ejected over the colliding object (if possible) or has to be tightened to his two-wheeler cannot be answered either at this moment.
Knee paddings were first proposed by Langwieder [12] (fig. 3).
The aim is to avoid contact with the colliding object. Whether this can be effective in a frontal impact (F2) is doubtful.
If a rider is launched with his head first and he contacts the motor-vehicle, this will probably lead to brain stem injuries.
The helmet cannot protect against this kind of injury. Filler caps or expander pins on handle bars are the cause of (minor) injuries (chapter 4), therefore sunken caps are applied on motorcycles and sunken pins on bicycles.

B. Heavy goods vehicle - two-wheeler
Chapter II indicates that the collision types F1, F2, S1, S2 and R1 are most important.

Heavy goods vehicle
For F1 and F2 the same remarks as for the passenger car about stiffness and shape apply.
For S1, S2 and R1 side and rear- end underrun guards seem to be the most concrete proposals at this moment (Volvo [11]; Riley [7]; Gauss [13]; fig. 4, 5 and 6).
The use of better or additional side mirrors will be beneficial, to give the truck driver a better overview (see par. 8.3).

Two-wheeler
F1, S1 and R1: The knee padding proposal made by Langwieder [12] does not seem to be so effective due to the dimensions of the heavy goods vehicle.
F2: Whether the suggested side protection will be effective for this accident type is an open question because the first impact point will probably take place at a higher level then for collisions with a passenger car.
S2: No protection proposals known.

C. Two-wheeler injuries
Adequately designed child seats and/or a simple dress-guard can prevent bicycle spoke injuries.

D. Two-wheeler riders
Helmets and protective clothing can prevent injuries. The positive effect of crash helmets in motorcycle accidents is well documented. The effect of moped helmets is not so well known.
In a Dutch study made by SWOV it is described as "a decrease in the chance of getting fatally injured of 40% and a saving of 500-600 lives for the years 1975 until 1977". (SWOV [8]).
The proportional share of head injuries differs considerably for the (not helmeted) bicyclists and the helmet wearing moped riders for the different studies:

	bicyclists	moped riders
Grattan [14]	48%	26% *
Huijbers [15]	51%	36%
Nicholl [16]	75%	52% *
Otte [17]	85%	60% *

(* including motorcycle riders)

The wearing of helmets seems to be an obvious explanation for these differences, but differences in accident type and collision type for bicycles and mopeds may also contribute.
Adequate protection against head injuries may be achieved by the use of helmets. For bicyclists this kind of protection is still not very widely accepted.
The reason for this is to some extent that existing bicycle helmets tend to become uncomfortable due to indequate ventilation.
For moped or motorcycle helmets there is amongst others an European set of requirements (ECE Regulation number 22); some countries already have requirements for bicycle rider helmets (Technisearch [10], Gilies [4]).
According to the studies of Otte [17], Appel [19], Pedder [20], and Ramet [21] some of the crash-helmets came off during accidents.
The wearing of protective clothing by motorcyclists has some positive effect on the minimazation of injury severity, according to Hunt [6] and Aldman [1]. The question is whether this is a practical solution for riders of lighter two-wheelers?

E. Speed at impact
Speed at impact will probably be strongly related to injury severity, especially for the impacts with the fronts of motor vehicles.
Lowering the speeds at impact, in any way, will therefore be favourable.

6.3. Consequences of these proposals for other groups of road users

A. Car
As far as stiffness is concerned the consequences may be a (small) reduction of the decelerations for e.g. car-to-car collisions.
Because there are no concrete proposals for shape at the moment there are no consequences either, but contradictions may occur.

B. Heavy goods vehicle
If dimensions of the side and rear-end underrun guard are properly chosen, a positive effect for other accident types may be expected.
Rear view mirrors mounted on the sides of vans and small trucks may extend beyond the sides of the vehicles and pose a hazard to other road users, e.g. two-wheeler riders (Fife [18]).

C/D Two-wheeler
The proposed knee-paddings may have a negative effect. If the attempt is not so succesfull the two-wheeler rider might fly into the interior of the car and hit the driver or a passenger, just as in other cases without knee-padding.

E. Two-wheeler rider
Contact between a helmeted two-wheeler rider and a not-helmeted victim may be a hazard for the unprotected one.

6.4. Consequences of (proposed) legal requirements for injury reduction of other groups of road users to the injuries of bicyclists and riders of light-powered two-wheelers

As far as bumperheight is concerned, there is some doubt whether the required value is benificial for pedestrains. (e.g. ECE Reg. 42).
Considering two-wheeler accidents the effects are even less predictable as yet.
The other requirements, as e.g. for front-front or front-side impacts, do not seem to have so much effect on the injuries of two-wheeler riders due to the differences in the amount of energy to be dissipated.

6.5. References

1. B. Aldman; I. Cacciola; H. Gustatsson; A. Nygren; I. Wersall:
"The protective effect of different kinds of protective clothing worn by motorcyclists".
IRCOBI 1981, Salon de Provence.

2. "HGV side-underrun guards: a design opportunity".
Automotive Engineer, April-May 1983.

3. P. Bourret; P. Sejourne; P. Orsoni; C. Cavallero:
"Lower limb injuries of two-wheelers".
Salon de Provence Hospital.
IRCOBI 1981, Salon de Provence.

4. N. Gillies:
"Helmets for use by bicycle riders".
Traffic Accidents Research Unit, Department of Motor Transport, New South Wales.
March 1980.

5. H.H. Hurt, J.V. Quellet, I.J. Wagar:
"Effectiveness of motorcycle safety helmets and protective clothing".
AAAM October 1981, San Francisco.

6. H. Rau:
"Simulation von Zweirad Kollisionen".
T.U. Berlin
From "Sicherheit bei motorisierten Zweirädern".
TÜV, 1980, Köln.

7. B.S. Riley; P.P. Chinn; H.J. Bates:
"An Analysis of fatalities in heavy goods vehicle accidents".
TRRL-LR 1033, 1981.

8. SWOV
"Invloed van het gebruik van helmen door bromfietsen en autogordels door inzittenden van personenauto's op de verkeersveiligheid".
SWOV, 1978.

9. K. Taneda:
"Experimental investigation of motorcycle safety".
Japan Automobile Reasearch Institute, Inc.
IRCOBI 1976, Amsterdam.

10. "Bicycle Products, Brakes Lights and Helmets".
Technisearch Ltd., Collingwood, Australia; June 1981.

11. AB Volvo:
"Accident Investigation.
(Heavy commercial vehicles/unprotected road-users) Report 1."
AB Volvo, Truck Division Traffic Safety Department, Decemver 1973.

12. K. Langwieder:
"Collision characteristics and injuries to motorcyclists and moped drivers".
21st Stapp Car Crash Conference, 1977.

13. F. Gauss; K. Langwieder; W.D. Schmidt; M. Wrobel:
"Aussere Sicherheit von LKW und Anhängern".
FAT Schriftenreihe nr. 27, 1982.

14. E. Grattan; J.A. Hobbs; M.E. Keigan:
"Anatomical Sites and Severities of Injury in Unprotected Road Users".
IRCOBI 1976, Amsterdam.

15. J.J.W. Huijbers:
"Een beschrijving van fiets- en bromfietsongevallen ten behoeve van prioriteitsindelingen bij het letselpreventie-onderzoek".
SWOV, not yet published.

16. J.P. Nicholl:
"The use of hospital in-patient data in the analysis of the injuries sustained by road accident casualties".
Transport Studies Group, University College London.
TRRL-SR 628, 1980.

17. D. Otte:
"A Review of Different Kinematic Forms in Two-Wheel-Accidents. Their influence on Effectiveness of protective measures".
T.U. Berling
24th Stapp Car Crash Conference, Troy Michican 1980.

18. D. Fife; J. Davis; L. Tate:
"Two fatal injuries from Extended Rear View Mirrors".
The Journal of Trauma vol 23 no. 8, 1983.

19. H. Appel; D. Otte; E.G. Suren:
"Schwerpunkte des Unfall-geschehens aus Untersuchungen am Unfallort".
Sicherheit bei Motorisierten Zweirädern, dec. 1980, Koln.

20. J.C. Pedder:
"A study of 93 fatal two-wheeled motorvehicle accidents".
IRCOBI 1979, Gothenburg.

21. M. Ramet; D. Cesari; A. Dedoyan:
"Two-wheeler accidents, injury mechanisms and means of prevention".
IRCOBI 1981, Salon de Provence.

6.6. Figures

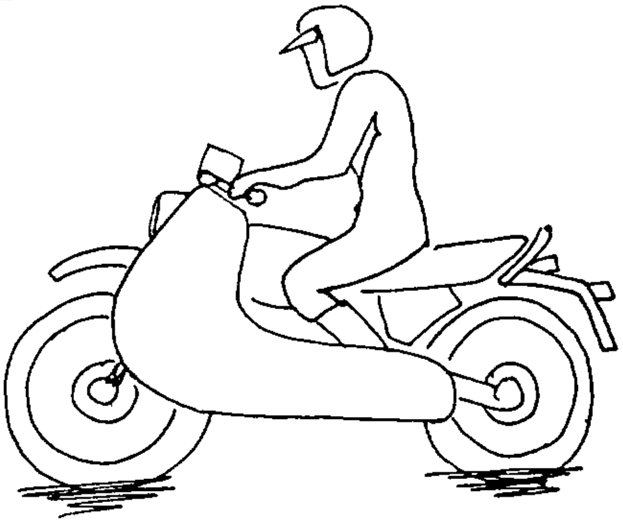


fig. 1 Side protection device proposed by Bourret[3].

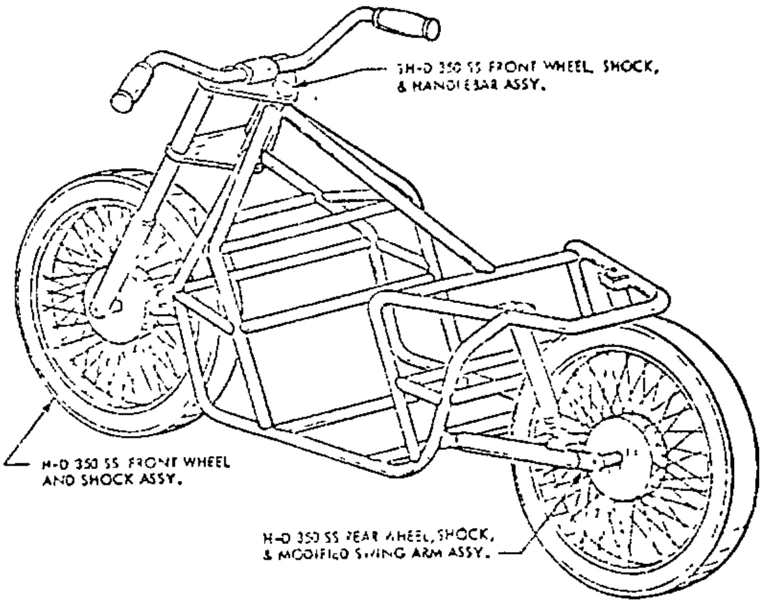


fig. 2 Side protection device proposed by Rau [6].

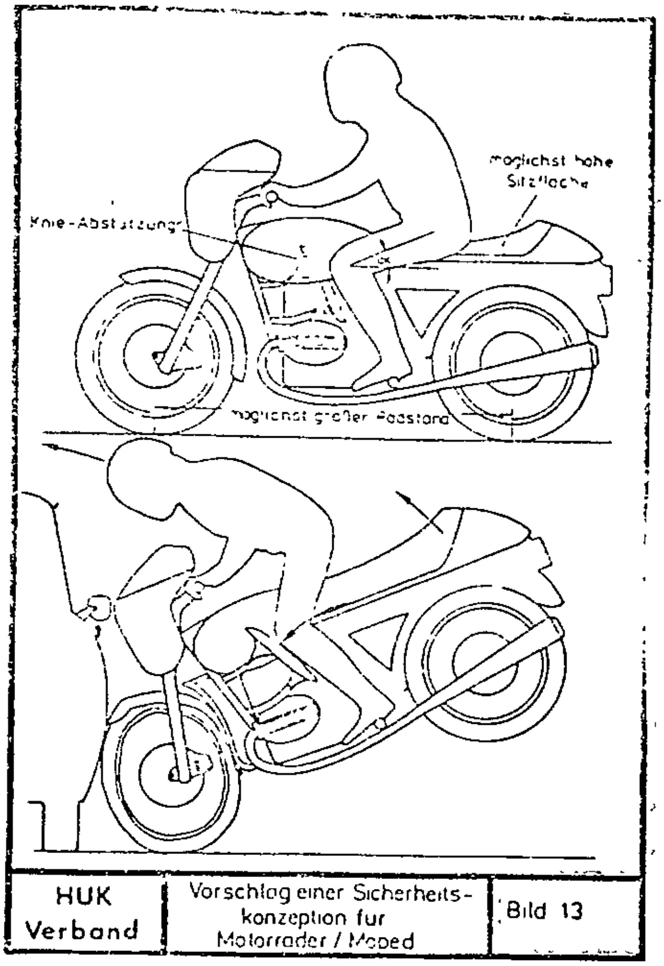


fig. 3 "knee-padding" ejection device proposed by Langwieder [12].

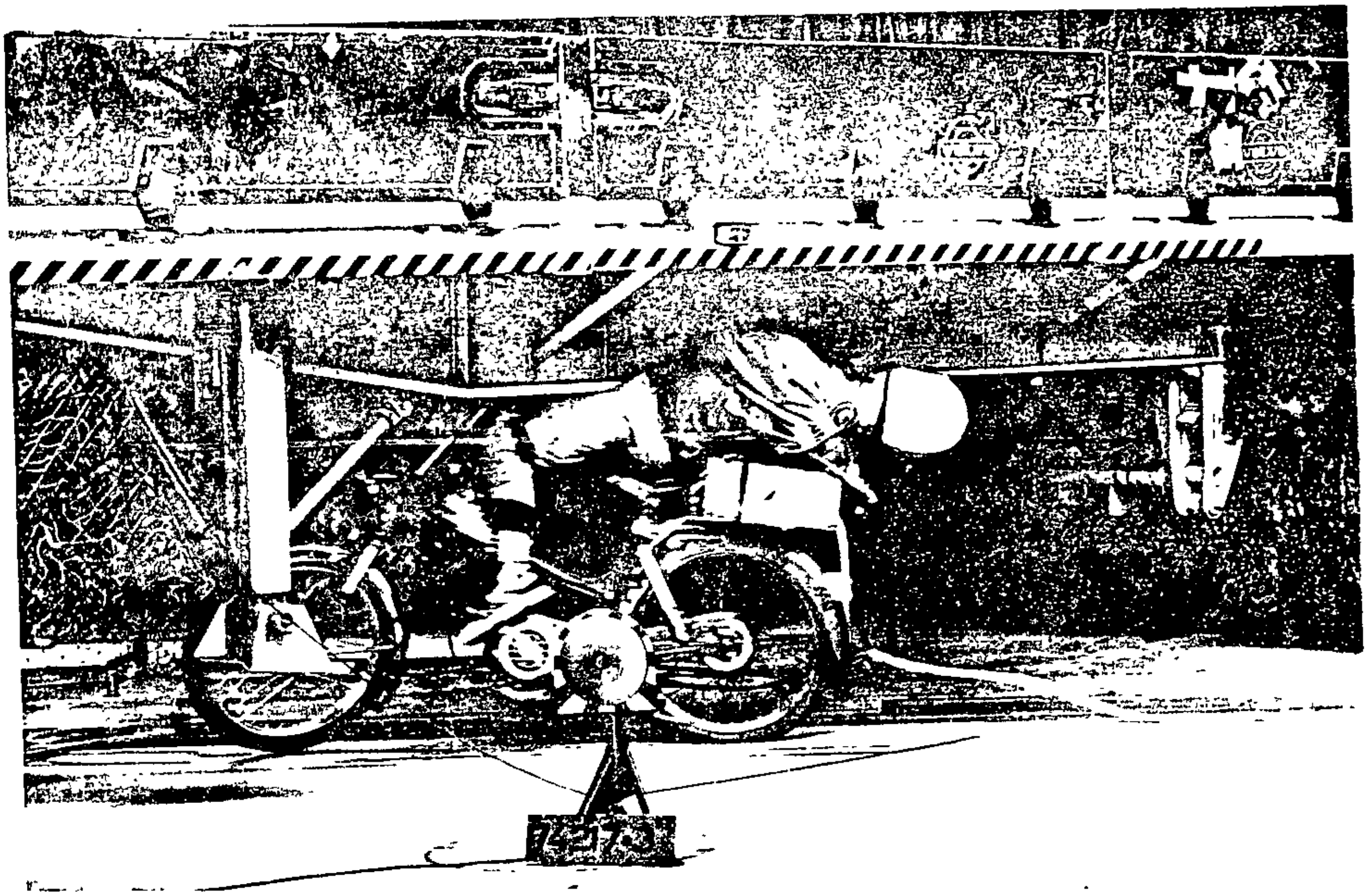


fig. 4 Moped-heavy goods vehicle collision simulation (type S1) Volvo [11].

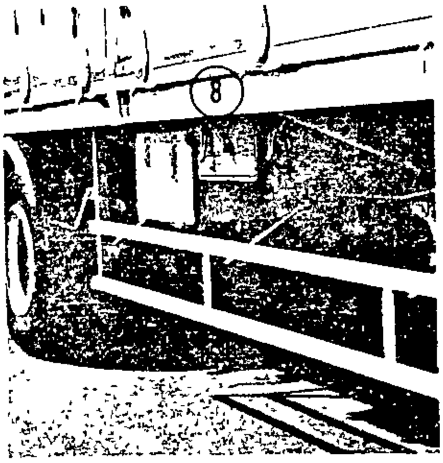


fig. 5 Side protection device for heavy goods vehicle. Volvo [11].

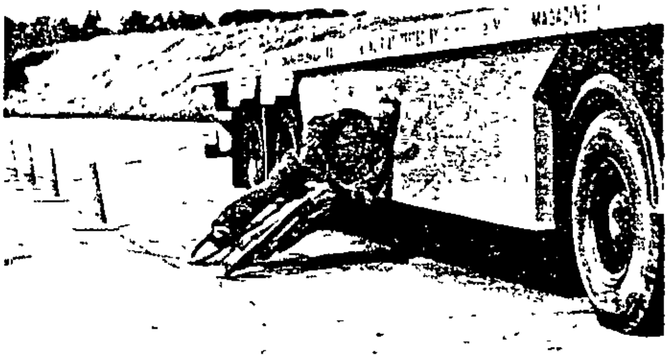


fig. 6 Side protection device for heavy goods vehicle. Automotive Engineer [2].

7. TEST PROCEDURES

7.1. Introduction

The test procedures examined in this chapter are aimed at ensuring conformity of the vehicle (bicycle, moped car and truck) and/or safety device (helmet, underride protection, etc.) to bicycle and moped rider protection requirements.
As said in the previous chapters accident case history for bicycle and moped riders is ample and cannot be reduced to a single standard situation.
Doubts also exist (see chapter 2) about the possibility of considering the bicycle and moped together for studying any countermeasures. It seems, in fact, that the two vehicles give rise to two different types of accidents.
Because of this complexity, proposals on test procedures for bicycle and moped rider safety are practically nonexistent or incomplete.
To conclude, it is evident that, as far as test procedures for the protection of bicycle and moped riders are concerned, there are no exhaustive proposals.
It is therefore necessary to draw from the experience acquired in other areas of safety and to extrapolate the methods that must obviously be verified expermentally to make sure that they are feasible and meet the objectives.

7.2. Discussion on possible test methods

The test methods which can be adopted are as follows:
- Component tests
- Full-scale tests
- Sub-system tests
- Validation tests by mathematical models

Each of these methods has advantages and disavantages and, depending on the situation, it may be more convenient to adopt one method rather than another, or even use them together.
It is, however, important to point out that the degree of knowledge of the phenomenon and the devices available determine the test method to be developed.
For example, it is impossible to develop a test method based on a full-scale test if the accident mode is unknown (impossibility of obtaining "the test conditions" scientifically) or if a reliable dummy is not available (impossibility of having a "reliable conformity response").

7.2.1. Component tests:

are tests performed on a single component or on a single safety device. Requirements are either design (geometrical and/or stiffness) or, in the more sophisticated cases, biomechanical.
Included in this category are some of the first regulations developed for vehicle safety; it is, in general, a primitive approach whereby the result on a single component is often taken to represent overall safety provided by the vehicle.
When component tests belong to a series of tests whose scope is to cover the various aspects of safety, there is a shift towards methods based on "sub-system tests".
Component tests are still valid today in those cases in which it is demonstrated that the objective is attained with a specific solution (e.g. if the objective is protection of the cyclists head wherever it will strike, the "helmet" solution can be accepted and this component can be submitted to various tests).

By applying the above to the specific case of the bicycle and moped rider it is possible to state that a method based on component tests has the following advantages and drawbacks:

- It is relatively easy to define, in the sense that a single aspect of the phenomenon can be examined (e.g. impact of the head) and that requirements can be provided even with very little knowledge of the overall phenomenon
- Method efficiency is low and the method itself can prove to be inadequate because influence of the vehicle shape on bicycle and moped rider is not taken into account.
  In this case, design requirements would prove particularly detrimental because they would be applied to all vehicles (even where not needed) and limit design.
  The result would be a poor quality product and a high cost for the user, but upgrading of safety would not be ensured (e.g. when a bonnet is specified).
- This method can be applied correctly only to tests on particular safety devices developed for a specific purpose such as helmets.

7.2.2. Full-scale tests

A full-scale test reproduces the conditions of a typical road accident. This method poses many problems, the most important point being, however, the definition of test conditions. It is, in fact, necessary that the full-scale test be equivalent to the actual accident. In the case of the bicycle and moped rider (see chapter 2) more than one test condition must be defined and this poses a few serious economic problems when a new model is developed and approved.
The situation with regard to the test equipment to be set up is, instead, more complicated. In particular, no reliable dummies representative of cyclists are available today and may be that the physical parameters traditionally recorded on dummies are inadequate for this type of accident.
Moreover, for full-scale tests aimed at evaluating the effectiveness of a modification to the bicycle or moped, there would also be the problem of designing one or more standard impactors.
As to this method, it is possible to conclude that its adoption for rider protection is more difficult than for other types of accidents. Because of the need to conduct more that one full-scale test and the lack of reliable dummies, other methods should be adopted.

7.2.3. Sub-system tests

Are those "series of tests on different components" whose results permit an assessment of the overall degree of protection provided to the rider in a specific accident.
The difficulty of developing sub-system tests, as defined is due to the need to know the phenomenon perfectly and to the required capability to shear it into many single tests; this taking into account the interaction between the impacts of the various components and body segments (e.g. for a given impact speed the shape of a vehicle can determine particular data on speed, area and direction of impact of the cyclist's pelvis against the bonnet; the type of impact of the pelvis and vehicle shape affect the head speed, area and direction of impact; etc.).

7.2.4. Validation tests by mathematical models

Development of a test method based on mathematical models will not be feasible for many years, because the use of mathematical models in two-wheeler safety research is relatively recent.

It should also be noted that the use of mathematical models for type approval on different computers and at different Test Centers poses the problem of issuing such procedure standards as to ensure response identity. This is a field of activity for which the existing Technical Services are probably not yet prepared.
But it enables a simulated vehicle to be assessed before it is actually produced.

7.3. Summary

None of the methods examined is capable today to verify the degree of protection that can be provided to a struck cycle or moped rider. There are no proper validated mathematical models of cyclists colliding with cars or heavy goods vehicles at this moment and, above all, problems for transforming a model in a type approval instrument would arise.
The full-scale test approach is likewise unfeasible. There is no single equivalent test.
Several full-scale tests should have to be carried out and the test device (dummy) is not reliable, component tests neglect the effect of vehicle shape on the kinematics of the cycle and moped rider.

Knowledge of rider collision is insufficient to permit the development of a method based on sub-system tests.
The only approach feasible, in which it is desirable to carry out research, studies and design of adequate devices is the development of a hybrid method based on the use of a bicycle and moped rider elementary mathematical model to determine the impact conditions of each body segment and on tests of the corresponding elements.
The elementary model is not used to evaluate impact severity but only to determine the initial conditions for testing the parts struck by the pelvis, chest and head. Moreover, this model defines the angle, direction and impact velocity for each body segment.
It is, in practice, a sub-system test method integrated with an elementary mathematical model.
An approach of this type can only be feasible when the approach for protection of the pedestrian is also of the same type. In fact, both pedestrians and cyclists are unprotected road users for which similar countermeasures should be developed.

7.4. References

1. L.R. Lewicki - J.A. Newman
"Head Protection of the Bicyclist"
19th AAAM Conference

2. Katsunori Taneda
"Experimental Ivestigation of Motorcycle Safety"
IRCOBI Conference - Amsterdam, 1976

3. G. Stcherbatcheff
"Kinematics of a Pedestrian and a Two-wheeler
Impacted by the Front of a Car"
IRCOBI Conference - Amsterdam, 1976

4. A. Sporner
"Experimentelle und mathematische simulation von motorradkollisionen im vergleich zum realen unfallgeschehen".
Technical dissertation at the Technischen Universität of
Munchen, 9-2-1982

8. ACCIDENT PREVENTION

Accident prevention or primary safety measures can make important contributions to the safety of the cyclist or moped rider. Accident studies suggest that conspicuity is a factor in accidents involving the two-wheeler and another vehicle.
The parameters influencing conspicuity are related to the two-wheeler and its rider (active lighting, retroreflective materials and the riders clothing), to the other vehicle (optimal head-lamps, good view) and the surroundings (other light sources).
In the overtaking situation the gap left by the driver when overtaking the two-wheeler is critical and experiments show that the percentage of vehicles passing very close can be substantially reduced by "spacers" and conspicuity aids.
Better brakes will reduce injuries by avoiding accidents or reducing speed at impact, specially in rainy conditions.
Test results are given showing that with the correct combination of rim and brake block significant improvements are possible. The state of maintenance of the two-wheeler has been found to be an important factor in many accidents and results of a survey are given. Studies on bicycle stability and manoeuvrability are also reported which show significant differences between styles of bicycles and mopeds.

8.1. Conspicuity

8.1.1. Introduction

The conspicuity of bicycles and mopeds is an important factor for the prevention of accidents. The conspicuity presupposes an observer for which the different objects must be conspicuous: this observer obviously is in many cases the driver of a car. A number of factors may influence hamper or even obstruct the visual observations to be made by those drivers. Conspicuity will be described for daytime and for nighttime.

8.1.2. Daytime conspicuity

8.1.2.1 Accident studies

From accidents studies described in Chapter 2 it follows that two-thirds of the injury accidents involving a pedal cyclist occur at junctions, when in most cases the collision partners were travelling on a different road before collision.
In another study interviews with involved drivers who had not given way when emerging from junctions into the major road indicated a lack of awareness of the presence or movement of the cyclist [4]. Cyclists often wear dark clothing and in one survey only about 10 per cent of cyclists were wearing high visibility aids.
In addition a two-wheeler rider presents a relatively small area to other road users, the frontal area being only a third of that of an average sized car. The rider is also readily obscured by roadside objects, other vehicles, windscreen pillars etc. The rider is often near the edge of the road and may be overlooked if a driver carelessly directs his attention only at heavier faster vehicles closer to the centre of the road.
In cases where the driver fails to give way the conspicuity of the frontal aspect of the rider is likely to be most important and since most accidents occur during daytime, initial studies at TRRL concentrated on comparisons of frontal conspicuity in daylight.

From the accident analysis in Chapter 2 it is not possible to determine the number of cases where the driver failed to give way to the cyclist or moped rider.
Where the rider is at fault the importance of conspicuity may be less although in instances where he is highly visible the driver may see the rider sooner and appreciate his speed and direction more accurately allowing more effective avoiding action to be taken.

8.1.2.2 Tests and surveys

In a TRRL-study it was decided to use a peripheral detection technique similar to that used by Horberg and Rumar [5] to evaluate high visibility aids for cyclists because the experimental conditions resembled a cycle accident situation that is common at junctions.

The test conditions are shown in Figure 1.
Under constraint of an operational task (subjects were required to fixate a visual display and repeat random numbers that appeared), the driver had to signal when he first became aware of the cyclist. The detection distances were used a measure of conspicuity.
Initial tests [6] indicated that bicycle attachments were not as effective as clothing items in making the cyclists detectable and that the brightest materials (highest luminance factor) performed best against commonly encountered backgrounds. Colour was found to be a less significant factor than brightness.
Further tests [7] were therefore aimed at establishing the most effective clothing styles (see table 1) all made from one type of bright material. This was a fluorescent greenish yellow woven nylon material with luminance factor of 74 per cent.
The average detection distances for each option are given in table 1.
Testing between means it was shown that the jacket was most effective having a significantly longer average detection distance than the other items.

The effectiveness of conspicuity aids in the overtaking situation where the visibility of the back is likely to be important was assessed by measuring the gaps left by overtaking vehicles.
It was considered that an effective aid would be one that significantly reduced the number of close passing vehicles i.e. those passing within 0,8 m of the cyclist's elbow on the off-side.
An ultrasonic device attached to a front carrier of a bicycle was used which when actuated by the test cyclist automatically recorded the closest passing distance between the bicycle and nearside of the overtaking vehicle. It measured the gap to within a few centimetres and automatically recorded the distance in one of eight passing distance bands. The clothing items described above were tested in turn in daylight on four straight sections of road. The average results are given in Table 2. It can be seen that the jacket had the largest effect. The number of close passing vehicles was more than halved compared with the controle. The effect of brightness of fabric was established by making a number of jackets of similar colour (greenish-yellow) but of widely different luminance factor.
Results are given in Table 3.
Tests were also carried out on white, yellow and orange coloured jackets of similar brightnesses and as expected their effects on passing vehicles were not significantly different.
In addition to providing effective conspicuity aids for the rider there are other measures that may prove effective.

A number of factors may influence the visual observation made by drivers. The visual scene could be structured so there is less demand on drivers limited attention span, thus irrelevant objects that could distract or hamper the observation of the cyclist could be removed or repositioned.
Glare from the sun can be annoying and dangerous and signalling lights should have adequate luminous intensities to ensure a conspicuous signal under most of these conditions.

8.1.2.3 Discussion and conclusions

There was good agreement between the results from daytime detection and public road experioments indicating that a jacket was more effective than all the other aids tested. A waistcoat styled aid was the second most effective in both studies.
When viewing from the rear it is likely that the arms of the jacket contribute only a small amount to the overall conspicuity because the backs of the arms were poorly illuminated. From the front, however, the tops of the arms were visible and these were relatively well illuminated, receiving the direct light from the sky and therefore they contributed significantly to the visibility of the cyclist. In this study and in a previous pilot experiment [6] a jacket was shown to be more effective than a waistcoat when viewed from the front. Driver's increased awareness of the presence of the rider and earlier detection when approaching are possible for the larger gaps left by overtaking vehicles.

The relatively small and statistically non-significant effects of the armbands and belt are probably due to their small total area. For its size the hat performed well and this is probably due to its relatively high illumination receiving direct light from the sky. Its domed shape resulted in high luminance or brightness levels when viewed from most directions. The jacket is preferable to the other aids for the additional reasons that arm signals are more conspicuous and the sides of the rider are likely to be more visible. Tests on the roads with jackets of various reflectances and colours indicate the importance of brightness rather than colour in determining the conspicuity of clothing. However there are likely to be a number of situations where colour contrast may aid detection because luminance contrast is low. For example where the rider is viewed against a bright desaturated background such as a concrete façade or cloudy sky.
To offer maximum visibility a conspicuous garment should be made from material having both high luminance factor and highly saturated colour.

Finally a conspicuous garment must be attractively styled and be comfortable to wear as well a retailing at a reasonable price if its use is to be encouraged.

8.1.3. Night-time conspicuity

8.1.3.1 Accident studies

A comparison of accidents in Belgium, Denmark, Spain, Germany and Ireland [1] showed that the percentage of casualties occurring in darkness ranged from 18 to 33 per cent for bicycles and from 26 to 38 per cent for mopeds. In the Netherlands recent data [8] has shown that 21 per cent of severe injuries to cyclists involved in collisions with other vehicles and 24 per cent of severe injuries to moped riders occur at dusk or at night.

It was found that accidents after dark were more serious and the cyclists concerned were usually older and more frequently struck from behind. In Great Britain a total 4.549 (18 per cent) pedal cyclists were reported as killed or injured on the roads during the hours of darkness in 1980 [9]. A study in the Netherlands [10] has shown that the risk of a fatal collision between a cyclist and a travelling motor vehicle is nearly four times greater under dark conditions. It is not known to what extent the poor conspicuity of the pedal cycle or cyclist is a factor in night time accidents but obviously cyclists riding without adequate lights are likely to incur considerable additional accident risk.

8.1.3.2 Tests and surveys

Cyclists in Great Britain as in most other countries are legally required to show a white light to the front and a red light to the rear when riding after dark. Observations were made in four towns in England to determine the extent to which cyclists comply with these lighting regulations [11].
Details relating to over 2.500 bicycles were collected in a two week period during December 1980.
Observations were made after darkness and it was shown overall that approximately 25 per cent did not have complete lighting and 9 per cent had no visible lights at all. Where lamps were fitted 9 per cent were off and nearly a quarter were either dim or gave an unsteady output. Three-quarters of the lamps observed were battery powered. It therefore appears that many cyclists at night will be inconspicious and therefore at increased risk. Interviews with over 600 cyclists revealed some reasons for this state of affairs. Many only replaced batteries when they were exhausted and important reasons given for the poor performance of lamps were damage and poor connections.

The observations showed that dim lamps were common and in order to establish the importance of bicycle refelctors for safety tests were carried out on the TRRL test-track after dark to compare the detectability of two reflectors (25 mm and 75 mm diameter) and a common type of battery lamp modified to give two levels of light output [11]. These levels were low and corresponded to dim lamps where the batteries were close to being exhausted. The testtrack lay-out is given in figure 2.
The average detection distance for the reflectors and two levels of light output against the glare source are given in Table 4, for observers closing in on the bicycle with 35 km/h.
Not only is early detection of the rider by the approaching driver important but also recognition at an early stage. Early recognition of the rider can be important since for safety the driver needs to know the likely behaviour of the road user he is about to overtake. In further tests the distances at which observers were certain that a cyclist was present were used as a measure of effectiveness. Since the motion of the cyclist on the cycle was tought to provide important cues to recognition a test cyclist rode the bicycle on rollers. The options were a commercially available flashing amber lamp designed to be attached to the cyclist's clothing, a reflective jacket, a reflective shoulder and waistbelt, a reflective spacer and a set of pedal reflectors. Each of the options was tested in turn in conjuction with the control, i.e. rear light and mudguard reflector. The average detection and recognition distances based on results from six subjects are given in Table 5.

A survey in the Netherlands [12] has shown that 4 per cent of front lamps and 4 per cent of rear lamps were missing. It was also shown that 7 per cent of the front lamps were defective in some way. The legally required large rear reflector was present in 93 per cent of cases.
Some indication of the effectiveness of this large rear reflector and pedal reflectors in reducing accidents can be judged from another Dutch report [13] which details the change in accident rate to cyclists following their legal requirement in November 1979. This preliminary report using only "one year's after" data, records a drop in casualties.
As accident data accumulates it may be possible to precisely quantify their controbution to the reduction in accident risk.

The Institute of Road Safety Reasearch SWOV [8] has carried out an analysis of accidents and has concluded that a small reduction in casualties will result from the mandatory use in the Netherlands of spoke reflectors or reflective tyres.

In the USA Burg and Hulbert conducted a series of tests on bicycle spoke reflectors and reflective tyres [14]. Using dipped head-lamps it was found that spoke reflectors were detected at a greater distance than reflective tyres, when viewing the side of the bicycle. The average detection distance for the most effective spoke reflector was 354 m while for the most effective reflective tyre it was 297 m. However in static viewing tests the reflecting tyres were easier to recognise. In dynamic trials where observers had to correctly determine the direction, the reflective tyres were more effective at indicating direction of travel.

In West Germany viewing trials were held to assess the contribution to conspicuity of various types of reflector [15].
Spoke reflectors were judged to be superior to reflective tyres.

The international Federation of Senior Police Officers (FIFSP), after a study of safety equipment for bicycles [16], concluded that a large rear reflector would be beneficial and that dynamo lighting systems should be provided which should automatically switch to battery power when the bicycle is stationary.
They also attached special importance to flank protection of the bicycle rider and recommended the use of retro-reflective tyres [16, 17].
In addition to ensuring that two-wheeler lighting and reflectionisation is adequate, there are other vehicle factors that are important for adequate visibility. The transmission of light trough motor vehicle windscreens os of obvious importance since modern cars have windscreens that usually make an angle of 35° to 40° to the horizontal plane. These small angles seem to be unfavourable for the transmission of the incident light coming from the traffic scene especially where dim lamps naer the threshold of perception are being viewed.
A dirty, scratched, tinted or highly raked windscreen will limit transmission of light or reduce contrast and could cause a poorly lit cyclist to be missed. Poorly aligned vehicle headlamps are a problem in that they can cause high levels of glare which can interfere with the detection of lights and can cause destraction.

8.1.3.3 Discussion and conclusions

It has been demonstrated that a reflector having a coefficient of luminous intensity of 1450 mcd/lx (75 m dia reflector measured at zero entrance angle and 0° 12' observation angle) can perform reasonably well when compared with a dim rear lamp.

In fact under the worst conditions of glare (bicylce positioned 1 m from glare source) the detection distance of the large reflector was similar to that of the dimmest lamp. Without reflector or rear light of any description visibility distances are dangerously low (41-64 m) when it is considered that at a speed of 110 km/h a driver may need a distance of up to 200 m to stop after an unexpected object becomes visible. The light output from a dim front or rear lamp when viewed from the side can be very low indeed and the provision of side reflectors in this case can substabtially improve conspicuity. The obvious disadvantage of a reflector is that its visibility depends on the illumination it receives from the driver's head-lamps. If the head-lamps are dim or misaligned or the two-wheeler is not directly ahead of the vehicle then the reflectors may prove ineffective. In addition the performance of most reflectors decreases with increasing entrance angle although "wide angle" reflectors are available and these significantly decrease the reduction in reflected light at large entrance angles.

In Great Britain and to a lesser extent in the Netherlands, it has been shown many bicycles are not equipped with adequate lights at night even though they are legally required.
The widespread use of a good quality bicycle reflectors might make a worthwhile contribution to safety in these and other countries where such problems exist.
Should the lights flicker, dim or go out completely a bicycle equipped with good reflectors should be visible in a number (but by no means all) of accident situations.
It is of course desirable that bicycle lighting performance should improve to a point where reflectors are needed only very rarely for the purpose of ensuring the bicycle is visible. Bicycle reflectors are useful for the purposes of not only aiding detection but also improving recognition.

After the rear light of a bicycle has been detected by an approaching driver early recognition that a cyclist is ahead is probably important on many occasions. Pedal reflectors proved most effective at increasing recognition distance as they more than doubled the distance at which a cycle equipped with a rear lamp and mudguard reflector could be recognised.
The reflective jacket was also effective; observers quickly recognised the cyclist by the side to side motion and outline of the cyclist.
In addition both these aids should give the driver a useful indication of the distance to the cycle. For example the amplitude of the pedal motion can be clearly seen soon after the pedal reflectors have been detected and this is likely to be a useful cue in judging distance.
Tests have shown that large errors in judging distance can result when only a single red light is visible and this could be a possible cause of accidents. Reflective tyres have been shown to indicate the presence and direction of travel of a two-wheeler when viewed from the side. Spoke reflectors are more effective at improving detection distance in this situation but are less efficient at improving recognition.

The need for adequate bicycle reflectors has been recognised.
In the Netherlands a high performance rear reflector and pedal reflectors have been required on a bicycle since 1979. The international Federation of Senior Police Officers has recommended the use of a large rear reflectors and retro reflective tyres on bicycles.

The Britsh Standards Institution [19] has published a standard specifying minimum requirements for bicycle reflectorisation. This standard is based on the work of the International Organisation for Standardisation and specifies high grade reflectors at the front, rear and side of the bicycle as well as for the pedals.
The British government has been considering the possibility of ensuring that all bicycles offered for scale should meet these and other safety requirements.

8.2. Bicycle spacers

8.2.1. Introduction

Because of the inherent instability of two-wheeled vehicles, cycle and moped riders need to be given sufficient clearance by the overtaking driver to take account of possible course deviations. Experimental studies of course holding by cycle and moped riders under a range of conditions [20] show that riders need a road width in excess of 1 m; an additional safety margin is necessary.

A spacer is a device attached to the bicycle to discourage drivers from passing too close to the cyclist when overtaking.
Commercially available spacers usually consist of a plastic rod with either a flag or disc attached at the end, the overall length being about 400 mm. It is to be mounted horizontally on the rear off-side of the bicycle so it projects into the road.
They have been widely used in Scandinavia but have only recently gained acceptance in Great Britain.

8.2.2. Accident statistics

In Great Britain national accident data for 1980 indicate that about 30 per cent of fatal pedal cycle casualties occur in situations where the other road users collides with the cyclist while overtaking or strikes the rear of the bicycle, both vehicles initially travelling in the same direction and going ahead. French and Danish accident studies show that the dominant manoeuvre type involving cycles and mopeds in rural areas is that of the overtaking situation [1]. In Chapter 2 it has been shown that when "lethality" was calculated for bicycle-car accidents the collision front of car-rear end of bicycle or moped appeared to be most severe. Clearly attention should be given to reducing the risks in this particular accident situation.

8.2.3. Evaluation of spacers

Previous studies in Great Britain, Finland, Sweden and France [21, 22, 23, 24] of the effects of spacers on the gaps left by overtaking drivers (used as a measure of the accident risk) have shown a range of effects from none up to an increase in average passing distance of 220 mm.
Differences in road conditions, driver behaviour and measurement technique could account for these differences.
At TRRL the ultrasonic range finding technique described above was used to measure the effect of spacers of various lengths during day and night time [25].
Because of the ease of measurement and subsequent analysis it was possible to quantify for the first time the effects of spacers of various types in reducing the percentage of drivers passing very close.

For determining the effects of spacer length a red reflective disc shape* 9000 mm^2 in area was employed. The shaft of the spacer was 8 mm in diameter and white in colour. The overall lengths of the spacers tested were 0,35, 0,40, 0,45 and 0,50 m.
These lengths covered the range of those commercially available and produced estimated projections beyond the rider's elbow of 25, 75, 125 and 175 mm. The rider's elbow was the part closest to overtaking vehicles. For comparison purposes the cyclist wore a black jacket of near zero luminance factor and this acted as the control when testing without a spacer present. Four sites were chosen for test purposes. Road width varied from 5,1 to 6,3 m and speed limits from 48 to 96 km/h. Broken centreline markings were present along all sections. Each spacer was tested several times at each site in a balanced order to reduce the effects of time dependent factors.

Data collected at the four test sites were combined as there were no substantial differences between the results.
Table 6 gives the averaged results for daylight and nighttime tests. Statistically significant differences at the 0,1 per cent level were found under both lighting conditions.

Further tests were carried out to compare the effects of the longest spacer (0,5 m) and the yellow jacket used in the detection distance studies described in Section 8.1.1.2. Table 7 gives the results.

8.2.4. Discussion and conclusions

The effects produced by spacers in increasing median overtaking distances and decreasing the percentages of vehicles passing very close are probably due to the increase in the effective width of the bicycle and rider although some of the effect may be due to increased conspicuity. In most cases the increase in effective width is not quite matched by a corresponding increase in median passing distance. This could be a result of the knowledge that the consequences of striking the end of the spacer when overtaking are not as severe as hitting the cyclist. The results show that using a spacer 0,5 m in length the percentage of overtaking vehicles passing less than 0,8 m from the cyclist was approximately half that recorded when no spacer was present. This spacer had a similar effect on overtaking behaviour across a wide range of road and traffic conditions.
Results obtained in the day were similar to those recorded at night.
As the length of the spacer decreased, effectiveness was reduced such that a spacer of length 0,35 was only about half as effective as a spacer 0,50 m long.
The effects on overtaking drivers of the long spacer were very similar to those of a fluorescent yellow jacket across a range of daytime road conditions. The fluorescent jacket would obviously confer extra benefits on the cyclist by increasing overall conspicuity. However the cost of a spacer is low and if of sufficient length offers good value.

* The material has a luminous factor of 0,51 and its colour specification in CIE coordinates was x = 0,58, y = 0,36.
Its coefficient of luminous intensity under typical viewing conditions (0° 12' observation angle and zero entrance angle) was approximately 1,200 mcd/lx.

8.3. Field of view of truck drivers

From a Dutch study [2] it followed that most of the accidents, in which a two-wheel-rider collided with the side of a heavy goods vehicle, happened when the heavy goods vehicle turned to the right.
From an analysis of the EEC directives on rear view mirrors it appeared that certain areas could not be seen when the vehicle was only equiped with mirrors according to these requirements (fig. 5).
Therefore additional requirements need to be recommended.

8.4. Braking

8.4.1. Introduction

The rim brake has been fitted to bicycles for many years in some countries and is widely used on all types of bicycle.
On applying the brake lever the rubber block is forced against the metal wheel rim. The latter is normally chrome plated steel and often gives a very low coefficient of friction when wet resulting in poor braking performance [26, 27]. In dry conditions the braking force can be high and there exists the possibility of the rider going over the handlebars during emergency braking. Hub (both internal-expanding and back-pedalling) and disc brakes have generally superior performance in wet weather because the braking surfaces are not so exposed to water. However they are more expensive, heavier and can make wheel removal difficult. This is perhaps the reason for many new lightweight bicycles being equipped with rim brakes.

It is difficult to obtain reliable estimates of the number of injury accidents due to inefficient brakes but bicycle accident reports received by the Consumer Product Safety Commission of the USA [28] show that many injuries to children result from the inability of the bicycle to stop quickly in emergency situations. In West Germany, Wobben [27] refers to the complaints of many cyclists concerning the inadequate braking efficiency of rim brakes in the wet.
Currently the British government is considering setting minimum permitted wet and dry braking efficiencies for new bicycles based on the recent British Standard for cycles [19]. TRRL has been involved in preparing this Standard and has conducted a series of tests on rim brakes.

8.4.2. Braking studies

In one study at TRRL the size of the problem was established by allowing children to carry out emergency braking tests under wet conditions [29]. In addition road tests were carried out to determine the performance of a common type of caliper brake, using a number of different brake blocks and wheel rims to determine whether or not one or more combinations would prove satisfactory in both dry and wet conditions. Recently manufacturers have produced new types of brake blocks which are claimed to be effective in wet conditions.
Nine commercially available brake blocks sets were tested:
three synthetic blocks, five rubber blocks of various hardnesses and patterning and one leather block. All nine sets of blocks were tested on plain chrome plated and light alloy rims and three sets, representing the three types of material, were further tested on dimpled and grooved chrome plated rims.
The test bicycle was a standard touring model with 686 mm diameter wheels and fitted with a side pull caliper brake. To reduce variation between tests one adult rider was used. The bicycle was equipped with a water reservoir and jets to each wheel which applied 4 ml/s at each

rim and brake force was controlled by attaching brake lever stops to the ends of the handlebars. These were adjusted so that loads of 180 N were effectively applied 25 mm from the lever ends when the brake levers were pulled up to the stops. (Tests have shown that loads of this magnitude are possible to achieve by male adults under emergency braking conditions. However many children and adult females would not be expected to exert these forces). The braking distances were measured from a speed of approximately 16 km/h for each combination of block and rim. The rims were tested both dry and when continuously wetted.
Table 8 gives the average decleration achieved for each set of brake blocks under dry and wet conditions together with the expected braking distance from a speed of exactly 16 km/h.
Figure 3 illustrates the relative effectiveness of the various types of block.

Nineteen children whose ages ranged from 6 to 11 also took part in further tests. In this case a small bicycle was used (457 mm dia wheels) equipped with chromed rims and rubber blocks.
They each made 4 runs under wet conditions similar to those described above. The average braking performance was 0,08 g corresponding to an expected braking distance of 12,6 m from a speed of exactly 16 km/h. The lowest rate of 0,047 g (equivalent to a braking distance of 21,4 m from 16 km/h) was achieved by the youngest child and the highest rate of 0,113 by the eldest.

8.4.3. Discussion and conclusions

The result of the tests involving children illustrate well the very poor performance that may result in wet conditions where rubber brake blocks are used on chromed rims. This is in agreement with a previous study [30]. The youngest child would have travelled over 20 m in braking to a halt from the modest speed of 16 km/h. This level of performance may result in an inexperienced rider failing to give way at a road junction and emerging dangerously into the major road. On hill descents very much longer stopping distances may result.
Under controlled tests, braking distances were about 4 1/2 times those measured under dry conditions. Neither hardness nor patterning of the rubber blocks or the use of dimpled and grooved rims significantly affected stopping distances. By contrast leather blocks on chromed rims produced a statistically significant improvement and adequate braking was achieved in the wet.
With wet alloy rims adequate levels of braking performance were achieved with the synthetic blocks. The leather and rubber blocks (e) and (g) (see Table 8) were slightly less effective and the other rubber blocks were less effective still.

In the dry, braking efficiencies with any of the combinations of block and rim were good, however very high levels of braking were found with synthetic blocks on the plain chromed rims. This is potentially dangerous since the longitudinal stability of the bicycle is poor compared with other road vehicles. Calculations for the rider and bicycle employed showed that the rear wheel would be expected to lift at a deceleration of 0,56 g. This is in reasonable accord with the observation that consistent rear wheel lift occurred where average declerations were significantly greater than this value.

The reduction of accident risk in both wet and dry is likely if the correct combination of brake block and rim is selected.
Even if a collision is unavoidable the relative velocity at impact may be reduced with better brakes. This can lead to less severe injury.

Leather blocks are now available in Great Britain and one major manufacturer fits them to all their bicycles equipped with chromed rims. British Standard BS 6102 part 1 specifies a maximum wet braking distance of 7,5 m from 16 km/h which would exclude the fitment of the worst combinations of brake block and rim. (This is a significant improvement on the ISO standard (ISO 4210) on which it is based, which specifies a braking distance twice as long (15 m)). As mentioned above the British government is considering making the standard mandatory for all bicycles sold.

8.5. Defects and maintenance

8.5.1. Introduction

The two-wheeler rider will have less chance of avoiding an accident if his machine is not maintained in good condition.
Defects in brakes, transmission and tyres, for example, may delay or otherwise reduce the effectiveness of accident avoidance manoeuvres. Obviously direct failure of frame or parts can be the prime cause of accidents; for example, failure of pedal crank or forks can easily lead to loss of control. Lighting that flickers, dims or goes out completely can lead to virtual invisibility in poorly lit areas.

8.5.2. Accident studies

TRRL carried out on-the-spot investigation of 183 accidents involving two-wheelers from 1970 to 1972 [31]. They considered that 14,5 per cent of bicycles and 4,7 per cent of the motorcycles invloved had defects which contributed to the accident. A Finnish study on 74 bicycle fatalities [32] indicated that defects were a contributory factor in 4 per cent of cases.

8.5.3. Maintenance survey

In order to get an estimate of the size and nature of the problem a survey was carried out by TRRL into the state of maintenance of bicycles ridden to primary and middle schools [33].
It was found that of the 439 bicycles examined over a third (151) were categorised as in a 'dangerous' condition and only 36 per cent were regarded by the examiners as being in good condition. A fault was categorised as 'dangerous' if it was possible for it to be a contributory factor in an accident.
The component showing the largest number of dangerous faults was the rear brake. Twelve per cent were in a dangerous conditions and nine per cent of front brakes were similarly categorised.

No firm conclusion can be drawn from the existing data on the direct contribution of defects to accidents but they do indicate the need for remedial action. This could take the form of vehicle inspection schemes and instruction on regular maintenance especially for younger riders.
The standard BS 6102 referred to above has minimum requirements for the strength of essential parts such as brake system, frame and fork assembly, wheels, pedals and chain.
It also includes requirements on sizes of protrusions and sharp edges that may come into contact with the rider during normal use. In addition it contains a requirement that instructions be provided with each bicylce. These include, among many items, instructions on brake adjustment and recommendations for replacement of brake blocks, correct chain tension, lubrication and recommended tightening of fasteners related to handlebar, saddle and pillar and wheels. Also it contains recommendations on safe riding, e.g. regular checks on brakes, tyres, steering and lighting.

The design of the bicycle to aid adjustment or eliminate it would be advantegeous. For example it is often difficult to adjust brakes; yet selfadjusting brakes are already on the market [34].

8.6. Stability and manoeuvrability

8.6.1. Introduction

A certain degree of skill is required to ride any two-wheeler.
To become proficient there is a learning process and the rider must aquire sufficient experience in a range of traffic and road conditions. To reduce accident risks the two-wheeler must be easy to manoeuvre so obstacles can be avoided quickly and must also be stable so that it follows the intended course when for example the cyclist is signalling or is caught in a cross wind. The extent to which bicycle design affects rider performance has been examined in a number of experimental situations.

8.6.2. Studies of stability and manoeuvrability

In an early study at TRRL [35] an attempt was made to assess manoeuvrability of cycles and motor assisted cycles by the number of faults committed on an obstacle course and on a slow riding test.
Similar tests were carried out using school children [30] on a number of bicycles both on smooth and bumpy surfaces. These tests showed that there were large differences between the performances of riders and small differences between different cycles.
A swedish study [3] tested cyclists attempting to hold a straight course while looking behind which intended to simulate a common turning manoeuvre involving crossing the traffic stream. With three types of bicycle investigated (small-wheeled, standard touring and rodeo type) the probablility of making errors in following the course and assessing the situation behind ranged form 10 to 50 per cent.

A Dutch study [20] also found differences between different machines. In one of several tests the riders had to follow a track consisting of a sloping road section immediately followed by a sharp left turn. The riders attempted to stay within two lines 0,15 m apart. The percentage of time spent outside the prescribed course was used as a measure of performance.
When riding down the slope speed increased which made the bend more difficult to negotiate and so both good stability and manoeuvrability were important for course holding. Figure 4 shows the average percentage of time outside the prescribed course when negotiating the curve with one and two hands. It can be seen that differences between the bicycles and mopeds are comparatively slight. However the performance of the racing bicycle and standard model with high handlebars differs significantly from that of the other two bicycles. With these other models, path deviation (averaged over condtions) occurred for about 25 per cent of the time. For the racing bicycle this was nearly 50 per cent while for the bicycle with high handlebars this was 40 per cent.

It appears from these studies that bicycle design has an infuence on stability and manoauvrability although it is not yet possible to quantify the contribution of a particular design feature to the accident risk.

8.7. Recommendations concerning accident prevention measures

When compared with motor vehicles, bicycles generally have inferior lighting and braking systems and are poorly maintained.

In the case of bicycle lighting, surveys and observations have demonstrated that a large problem exists. Better lighting systems are required not only to provide more reliable lighting in order that the cyclist may be easily seen at all times but also to provide an adequate beam to illuminate the road ahead. Further work in this area should be benificial. Improvements to the nighttime visibility problem can be made by requiring that bicycles are equipped with a range of high performance reflectors that will be readily visible in most situations and will also aid recognition. Of particular importance is an effective rear reflector and pedal reflectors. The cost of providing such reflectors is small especially if it is carried out during manufacture. Better legal requirements for lights and reflectors are indicated.

The increasing popularity of light-weight bicycles indicates that rim brakes are now more widely fitted. It has been demonstrated that dangerously long stopping distances occur in wet conditions if rubber brake blocks are used with the chromed steel rims. Since this is a common combination of block and rim a legal braking requirement based on wet and dry braking standards should improve the situation. Such a requirement could apply to all new bicycles offered for sale.

Regular bicycle maintenance checks may reduce the number of poorly maintained bicycles. This could be carried out at schools or by the Police. At the present time it seems unlikely that an annual inspection similar to that required for motor vehicles would be feasible.
Steps could be taken to persuade manufactures to improve bicycle design so that maintenance is reduced to a minimum;for example the fitting of brakes that are automatically adjusted. Consideration should be given to a requirement that there should be no sharp edges and dangerous protrusions on bicycles and mopeds and chain guards should be fitted. In addition, there may be a case for a minimum requirement for the strenghts of essential parts such as brake system, frame and fork assembly, wheels, pedals and chain.
A measure that could be taken to reduce the risk of accidents to both bicycle and moped riders is the promotion of the wearing of conspicuous clothing particularly during daytime and twilight.
It would be helpful to have a standard for conspicuous clothing so that only high visibility clothing of an adequate standard would be promoted in publicity and training courses. Consideration should also be given to the encouragement of the use of cycle spacers.
Since they have been shown to decrease the numbers of vehicles passing very close they should reduce the risks in the overtaking situation. They have the advantage of being very cheap to fit.

If a safety requirement is introduced on a large scale it is recommended that relevant accident statistics are compared before and after the change so that the effectiveness of the measure in reducing the accident risk can be established.

8.8. References

1. OECD. Safety of two-wheelers. OECD research group, March 1978 Paris, France

2. A. Blokpoel & J.A.G. Mulder. Het zichtveld van de bestuurders van vrachtwagens SWOV, 1981.

3. P.W. Arnberg, E. Ohlsson, A. Westerberg and C.A. Ostrom. The ability of pre-school and schoolchildren to manoeuvre their bicycles. Report No 149A. National Swedish Road and Traffic Institute, Stockholm.

4. A.M. Mackie. Research for a road safety campaign - accident studies for advertising formulation, TRRL Report LR 432, 1972.

5. U. Horberg and K. Rumar (1975). Running lights conspicuity and glare. Report 178. Department of Psychology, University of Uppsala, Sweden.

6. G.R. Watts. The evaluation of conspicuity aids for cyclists and motorcyclists. Human factors in transport research Vol I.

7. G.R. Watts. Evaluation of conspicuity aids for pedal cycles TRRL report LR1103, 1984

8. Welleman. Traffic safety of bicycles and mopeds. SWOV - to be published.

9. Department of Transport. Road Accidents Great Britain 1980. HMSO 1981.

10. P.C. Noordzij. Cycling in the dark: an analysis of fatal bicycle accidents in the Netherlands. Journal of Safety Research. Vol 8, No 2, 1976.

11. G.R. Watts. Pedal cycle lamps and reflectors - some visibility tests and surveys
TRRL report LR 1108, 1984.

12. H. Groot. et al. Inventarisatie: Visuele waarneembaarheid van Tweewielers; verslag aan V & W/DVV. IWACC 1983-1, Jan. 1983.

13. J. Van Minnen. The effect of rear reflectors and reflecting pedals on the safety of cyclists. SWOV, Leidschendam, October 1982.

14. A. Burg and S.F. Hulbert. Reflectorisation of bicycle wheels Verkeerskunde vol 27, no 12, p590-1, 1976.

15. K. Masseck. Note on reflecting items for bicycles - private communication, 1983.

16. G. Kratz. The effect of safety equipment for bicycles. Study by the International Federation of Senior Police Officers (FIFSP). July 1980.

17. FIFSP. Prevention of two-wheeled vehicle accidents in the darkness. Report by the International Federation of Senior Police Officers (FIFSP) March 1977.

18. A. Blokpoel, D.A. Schreuder and F.C.M. Wegman The perceptibility of the bicycle form the side in the dark. SWOV Leidenschendam, November 1982.

19. British Standard Institution. Cycles: specification for safety requirements for bicycles. British Standards Institution BS 6102 Parts 1 and 2, 1981.

20. J. Godthelp and P.I.J. Wouters Course holding by cyclists and moped riders. Applied Ergonomics 11, 4, 227-235. 1980

21. G.R. Watts Bicycle safety devices - effects on vehicle passing distances. TRRL Report SR 512, 1979.

22. L. Oranen Report on the effect of protective pennants on the behaviour of motor-vehicle drivers. Traffic Safety Research Department Pamphlet 29/1979. Traffic Safety Department, Helsinki, 1976.

23. Volkswagen Factory Wolfsburg AG. Effect of disctance bars on the distance allowed between motor vehicle and bicycle when overtaking. Biotechnological Group. Supplementary Report No. 19. 1973

24. Centre d'Etudes Techniques de l'Equipment. Etude d'efficacite du gabarit 2 roues ou ecarteur de danger. (4 e-me-partie-mesures de distance de depassement). CETE Bordeaux division UTC, December 1981.

25. G.R. Watts Evaluation of pedal cycle spacers. Transport and Road Research Laboratory, report SR 820 - to be published in 1984.

26. F.R. Whitt and D.G. Wilson Bicycling science - ergonomics and mechanics. MIT Press 1962.

27. D. Wobben Rim brakes in the rain. Radmark + 3. P88-90. 1983

28. D.E. Marlow The CPSC road test of bicycle braking performance - experimental evaluation. National Bureau of Standards, Washington DC, 1973.

29. G.R. Watts Brakes on pedal cycles. Inst. of Mechanical Engineers conference on "Braking of road vehicles". March 1983. Loughborough.

30. G.D. Lewis The manoeuvrability and braking performance of small-wheeled bicycles when ridden by children. TRRL Report LR 500, 1973.

31. TRRL. Vehicle defects and their contribution to road accidents LF 374, 1973.

32. Traffic Insurance Institute. Light traffic (pedestrians and cyclists) accidents report in certain areas of Finland in 1971-75. Helsinki, 1976.

33. P. Wells The state of maintenance of bicycles ridden to primary and middle schools. TRRL Report.

34. P.I.J. Wouters Problems of riding on a bicycle or a moped. SWOV, Voorburg 1980.

35. H.J.H. Starks and R.D. Lister Some safety aspects of pedal and motor-assisted cycles. Road Research Technical Paper No 38, 1957.

8.9. Tables and figures.

TABLE 1

Average detection distance of clothing options

Option	Detection distance (m)
Jacket	63.2
Waistcoat	55.8
Hat	53.9
Armbands	49.8
Black jacket (control)	49.6
Shoulder and waist belt	47.1

TABLE 2

Passing distances for clothing options of different styles

Option	Median (m)	Percentage less than 0.8m	Number of readings
Jacket	1.20	8.4	547
Waistcoat	1.16	10.1	544
Hat	1.14	11.0	520
Armbands	1.13	14.1	475
Shoulder and waist belt	1.09	16.4	482
Black jacket (control)	1.03	21.1	526

TABLE 3

Passing distances for jackets of different luminance factor

Option	Colour specification*			Median	Percentage less than 0.8m	Number of readings
	x	y	Y			
Thin nylon	0.39	0.44	0.49	1.10	15.2	841
Thick nylon	0.36	0.51	0.74	1.13	12.4	833
Reinforced PVC	0.38	0.52	0.95	1.15	12.1	840
PVC	0.38	0.53	1.37	1.17	9.4	879
Black jacket	(not measured but expected reflectance close to zero)			1.05	23.5	927

TABLE 4

Mean detection distances of rear lamps and reflectors

Distance of glare source from bicycle	Rear lamp Luminous intensity (cd)		Reflectors Coefficient of luminous intensity (mcd/lx)*		No reflectors or lamps (control)
(m)	0.65	0.15	1450	101	
1	358	241	247	153	41
3	635	507	399	214	64

*Coefficients of luminous intensity were measured at 0° 12' observation angle and 0° entrance angle. The observation angle is the angle between the straight lines connecting the reflector to the source of illumination and to the observer's eye. The entrance angle is the angle between the line perpendicular to the plane of the reflector face and the straight line connecting the reflector to the source of illumination.

TABLE 5

Mean detection and recognition distances for conspicuity aids
(glare source 3m from bicycle)

	Rear lamp (11.1cd) and reflector (100mcd/lx*)	Flashing amber beacon	Reflective jacket (10,000mcd/lx)	Shoulder & waist belt (1000mcd/lx)	Spacer (500mcd/lx)	Pedal reflectors (100mcd/lx each)
Detection distance	651[+]	588	284	185	292	182
Recognition distance	54	59	102	68	60	124

*Coefficients of luminous intensity were measured at 0° 12' observation angle and 0° entrance angle

[+] Maximum detection distance was limited to just over 650m corresponding to the length of the range.

TABLE 6

Passing distances for spacers of various lengths

Lighting condition	Length of spacer (m)	Projecting length (from elbow) (m)	Median gap (m)	Percent passing less than 0.8m	Number of measurements
Day	Control (no spacer)	-	1.097	14.97	855
Night	" "	-	1.076	16.14	477
Day	0.35	0.025	1.156	11.50	844
Night	"	"	1.198	8.85	407
Day	0.40	0.075	1.132	9.74	780
Night	"	"	1.134	11.08	415
Day	0.45	0.125	1.192	9.16	819
Night	"	"	1.194	7.28	481
Day	0.50	0.175	1.215	7.83	855
Night	"	"	1.221	6.92	492

TABLE 7

Comparison of longest spacer with a conspicuous jacket (daylight)

Option	Median gap (m)	Percent passing less than 0.8m	Number of measurements
Control	1.060	21.77	698
Spacer	1.157	11.37	686
Yellow jacket	1.162	11.09	712

TABLE 8

Mean decelerations and expected braking distances from 16 km/h

Block	Type	Condition	Plain chrome		Light alloy		Dimpled chrome		Grooved chrome	
			Decel-eration (g)	Braking distance (m)	Decel.	Braking distance	Decel.	Braking distance	Decel.	Braking distance
(a)	Patterned synthetic	Dry	0.76	1.3	0.46	2.2	0.58	1.7	0.58	1.7
		Wet	0.21	4.9	0.39	2.6	0.24	4.2	0.20	5.0
(b)	Plain synthetic	Dry	0.71	1.4	0.51	2.0	-	-	-	-
		Wet	0.27	3.7	0.42	2.4				
(c)	Plain synthetic	Dry	0.66	1.5	0.51	2.0	-	-	-	-
		Wet	0.28	3.6	0.43	2.3	-	-	-	-
(d)	Plain rubber	Dry	0.57	1.8	0.45	2.2	0.47	2.1	0.47	2.2
		Wet	0.12	8.1	0.25	4.0	0.13	7.5	0.12	8.5
(e)	Patterned rubber	Dry	0.54	1.9	0.47	2.2	-	-	-	-
		Wet	0.12	8.8	0.35	2.9	-	-	-	-
(f)	Patterned rubber	Dry	0.52	1.9	0.45	2.2	-	-	-	-
		Wet	0.12	8.6	0.21	4.8	-	-	-	-
(g)	Patterned rubber	Dry	0.55	1.8	0.48	2.1	-	-	-	-
		Wet	0.12	8.6	0.36	2.8	-	-	-	-
(h)	Patterned rubber	Dry	0.50	2.0	0.43	2.3	-	-	-	-
		Wet	0.11	8.9	0.26	3.9	-	-	-	-
(i)	Plain leather	Dry	0.40	2.5	0.46	2.2	0.46	2.2	0.48	2.1
		Wet	0.44	2.3	0.36	2.8	0.44	2.3	0.41	2.5

Rounding errors account for apparent discrepancies between columns.

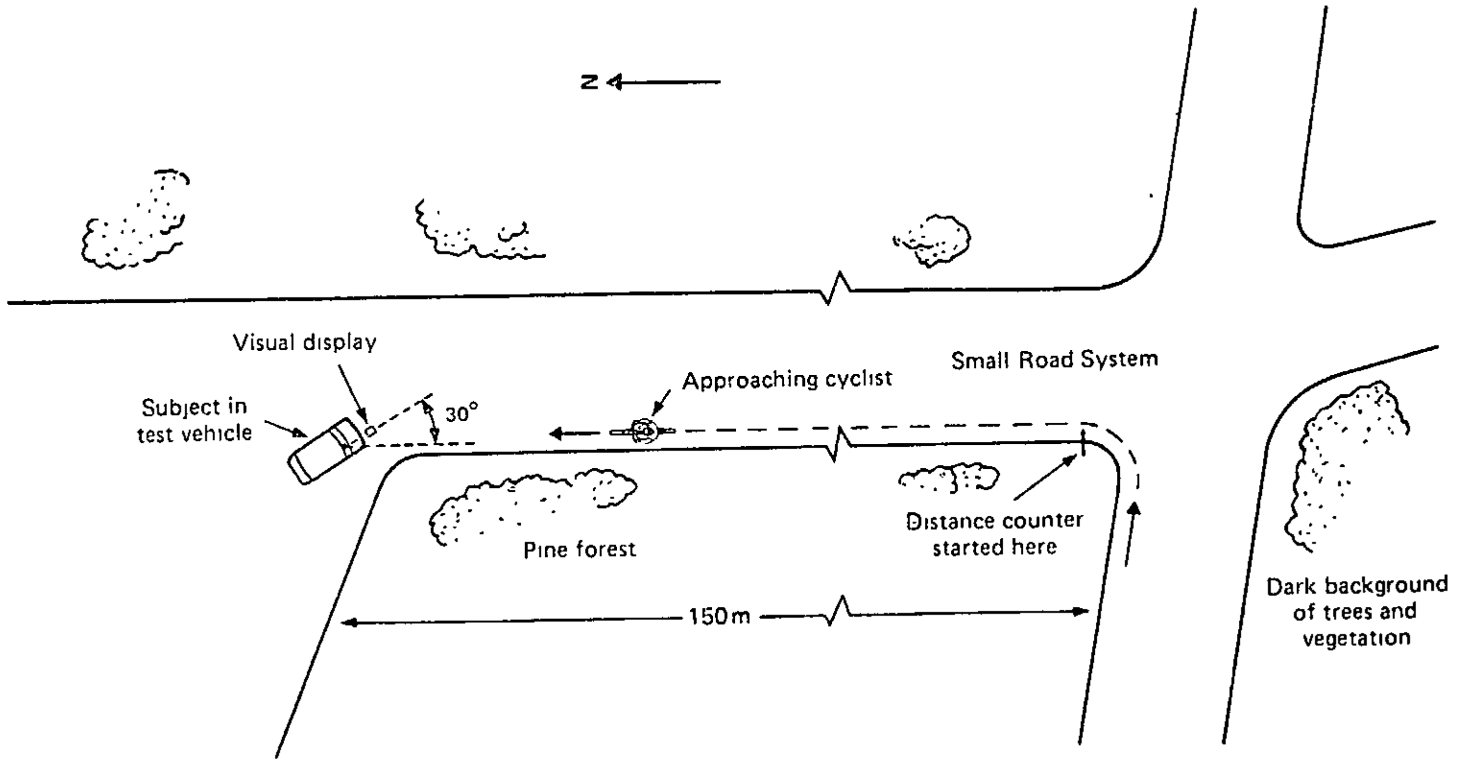


Fig. 1 Test conditions for conspicuity aids

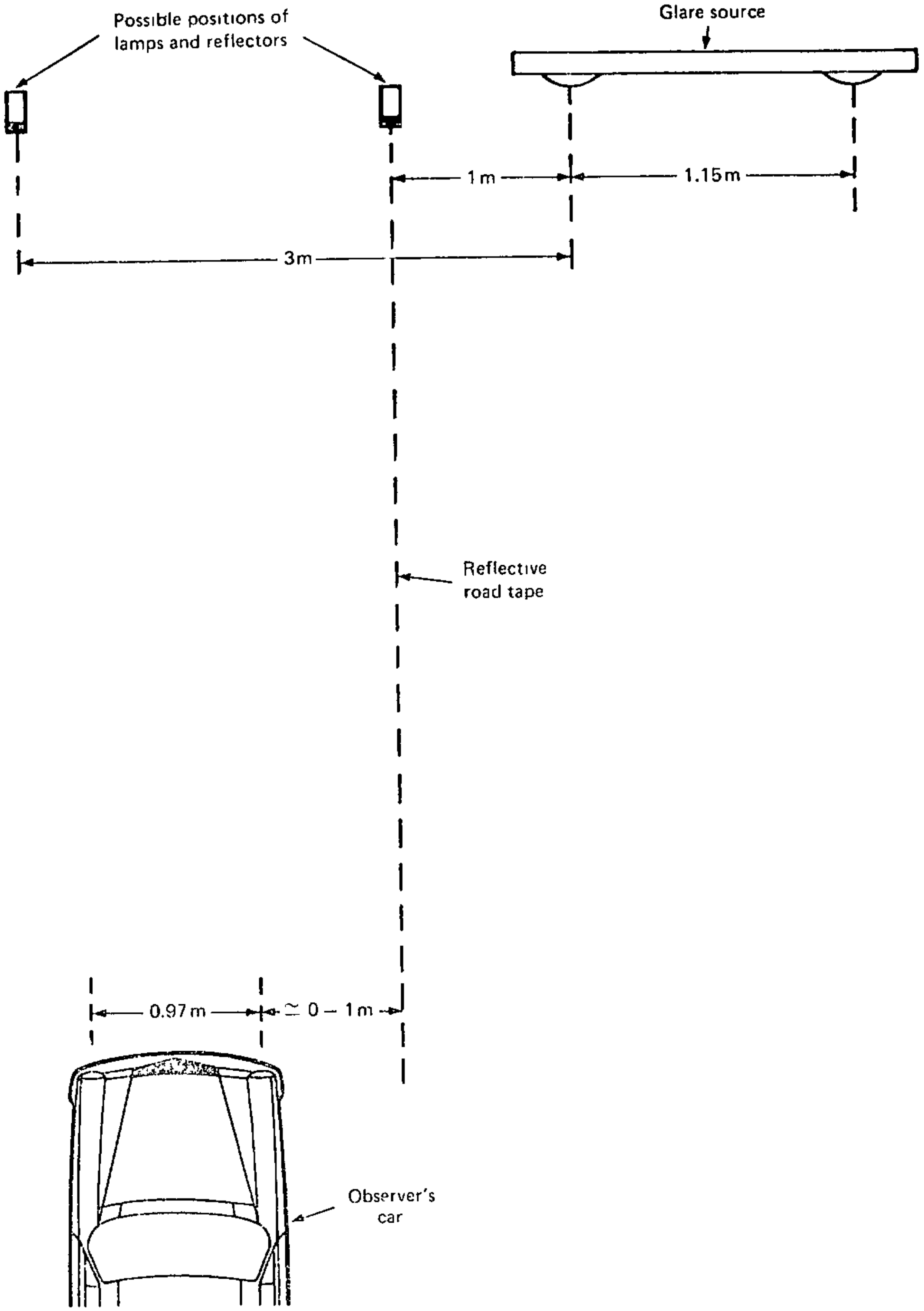


Fig. 2 Layout for visibility studies

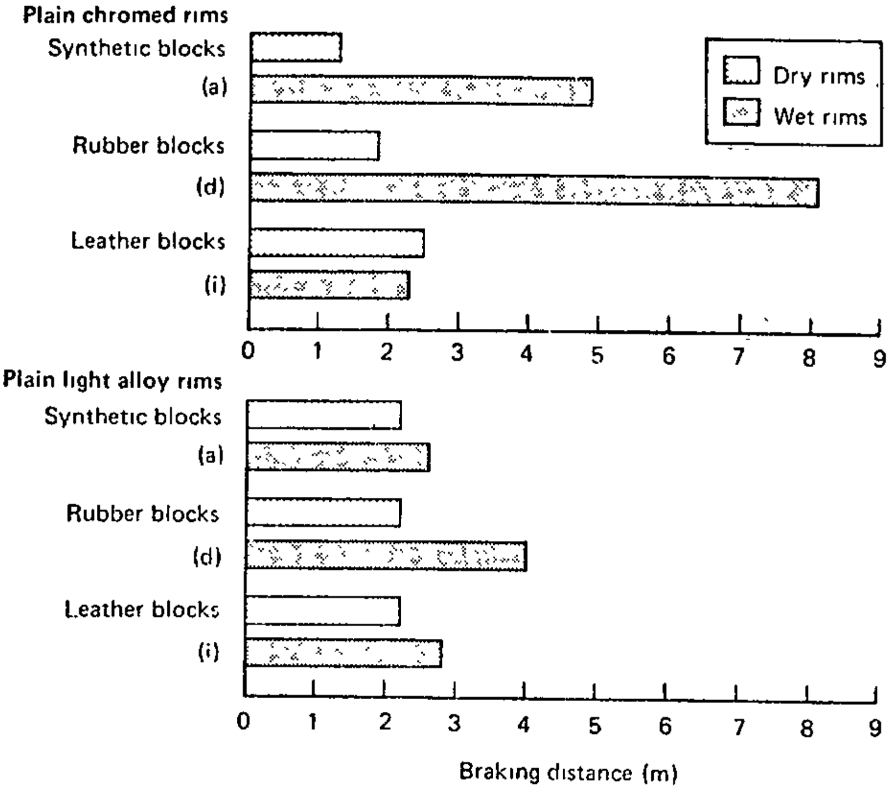


Fig. 3 Expected braking distances from a speed of 16km/h

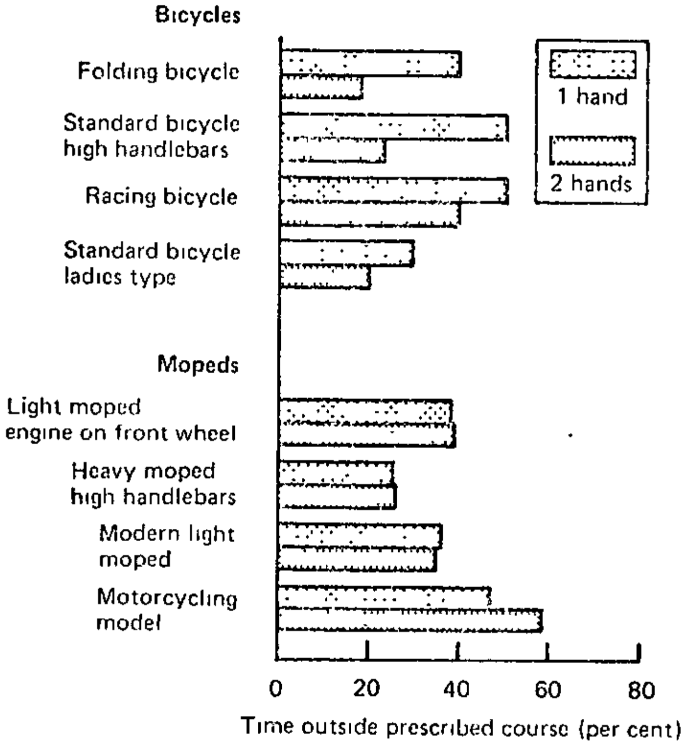


Fig. 4 Time (per cent) outside prescribed path in test 2: 'Course holding in a curve' (768 runs)

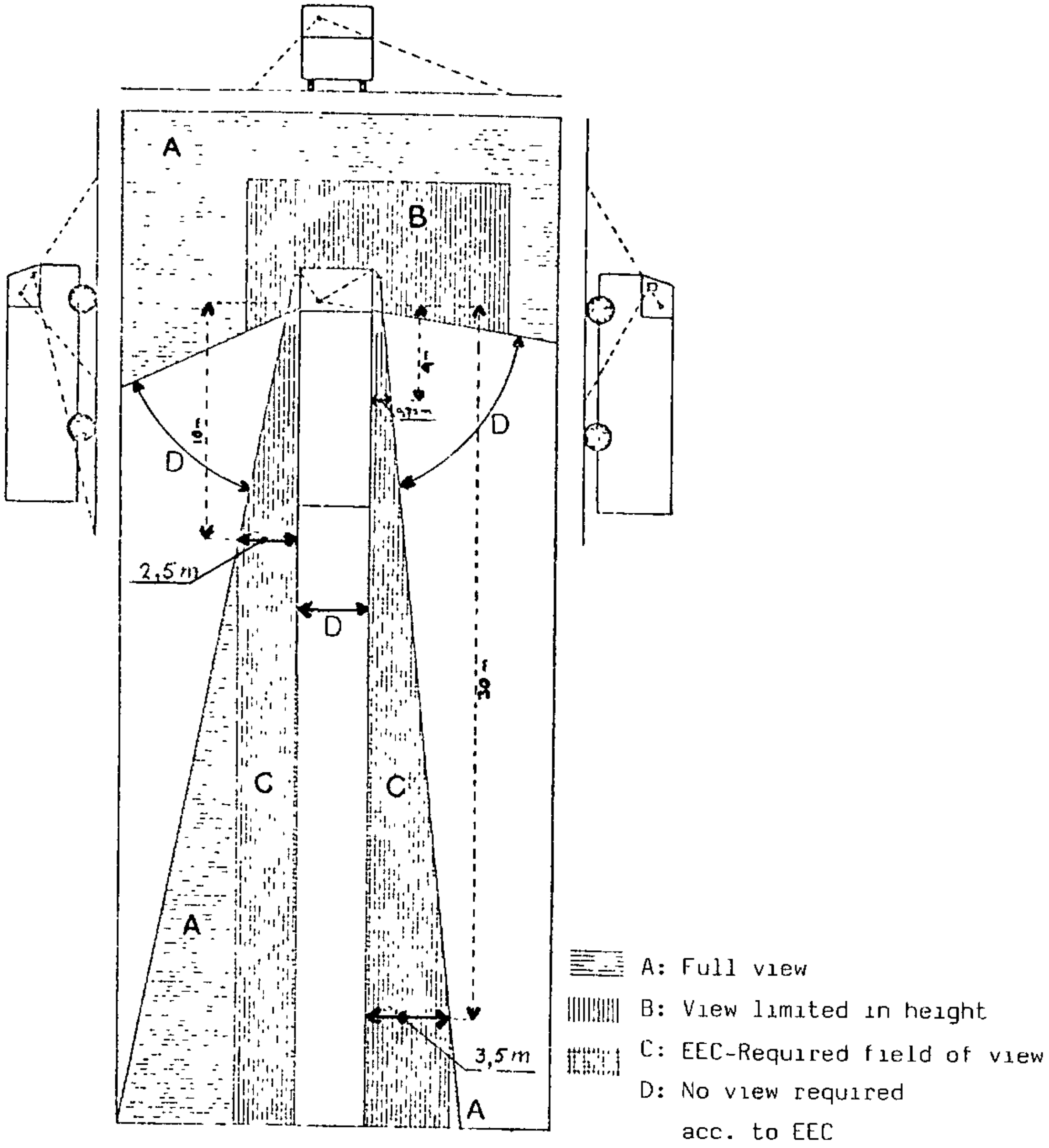


Fig. 5: Field of view for heavy goods vehicles, right-hand traffic; right and left external mirrors according to EEC-requirements. (Blokpoel [2]).