Bicycle and light-powered two-wheeler accidents- Report of EEVC-WG8 *)

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A. Introduction.

Research and measures for improved road safety have been concentrated largely on the users of motorized roadvehicles and especially private car users all around the world. In a later stage special attention rose for pedestrians. 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 type of accident happened more frequently than the pedestrian-car accidents.

In 1982 the EEVC accepted to set up a new working group that would 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 focussed on: number of accidents, integrated safety aproach, and international coördination. From the discussion paper the following extracts can be 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".

(Note: we found that the number of killed cyclists per 100.000 bicycles is not much higher in the Netherlands than in various other countries; see tables 8 and 9 of the WG8-report).

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. - bumperheigth, for which a SAE recommendation exists, as well as an UN/ECE-Regulation.From research on lateral car collisions a recommendation for a lower bumperheigth may follow.

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

*)EEVC: European Experimental Vehicles Committee.

Concerning international coördination:
"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 than ten years ago, which was followed some years later by international coördination. Now it seems to be the right moment for similar actions concerning bicyclists, while coördination is possible from an earlier stage".

As a result the 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 to examine the accident data of light-powered two-wheelers. (Defining "light-powered two-wheeler" is a task of the group).

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

- Attention 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 WG 7's report).

The working group held four meetings to discuss the method of work, the global content of the report and -later- various drafts. In May 1984, the report was presented to EEVC at it's meeting in Crowthorne (UK), where it was accepted.
During the first meeting of the working group, it was decided to deal also with the 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 rise because of differences in definitions of light-powered two-wheelers in the countries. Therefore the group decided to include a list of requirements (including definitions) for light-powered two-wheelers - as used in this report - for the different countries (see table 3 of the report).
During the first meeting the group also decided to deal with accident avoidance aspects related to vehicles.
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.
It was decided that only specific two-wheeler, car and heavy goods vehicle aspects in relation to two-wheeler 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.
The aim of injury prevention is either to prevent injuries or to minimize injury severity by influenzing the kinematics of the victim and by minimizing loads to the struck body parts, e.g. by reducing the relative impact speeds between victim and struck objects and by avoiding dangerous shapes and stiffnesses.

B. 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 is irrelevant since C.Gibbs-Smith published in 1978 the book "The inventions of Leonardo da Vinci", with the first drawing of a bicycle made by Leonardo da Vinci or one of his pupils in ± 1450.
This bicycle was already chain driven, 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, 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. When later (1888) equiped with pneumatic tires, invented by the Irish veterinary John Dunlop, the safety bicycle caused a bicycle boom in Europe and America. 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.

Light-powered two-wheeler.

The first powered two-wheeler was constructed by Wolfmüller and Hildebrandt in 1894. It seems that 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?).

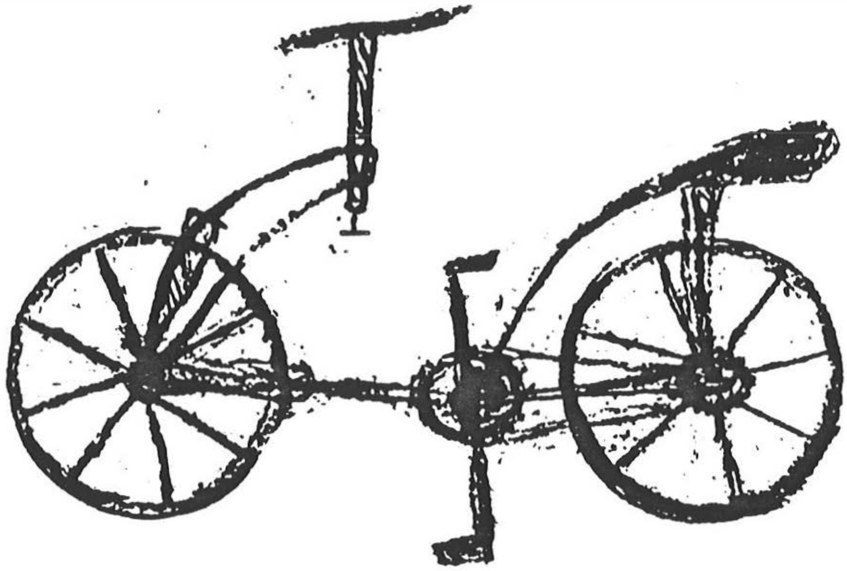

fig. 1: Bicycle designed by Leonardo Da Vinci.

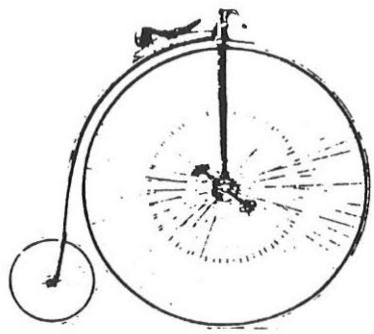

fig. 2: Bicycle with enlarged front-wheel.

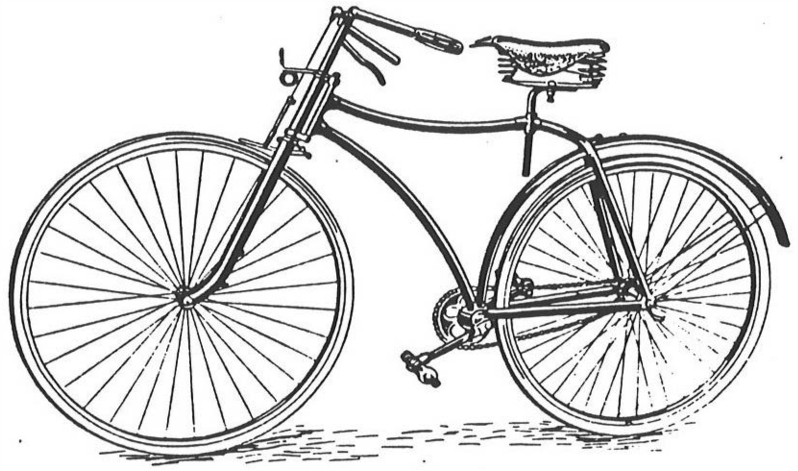

fig. 3: Rover "Safety Bicycle".

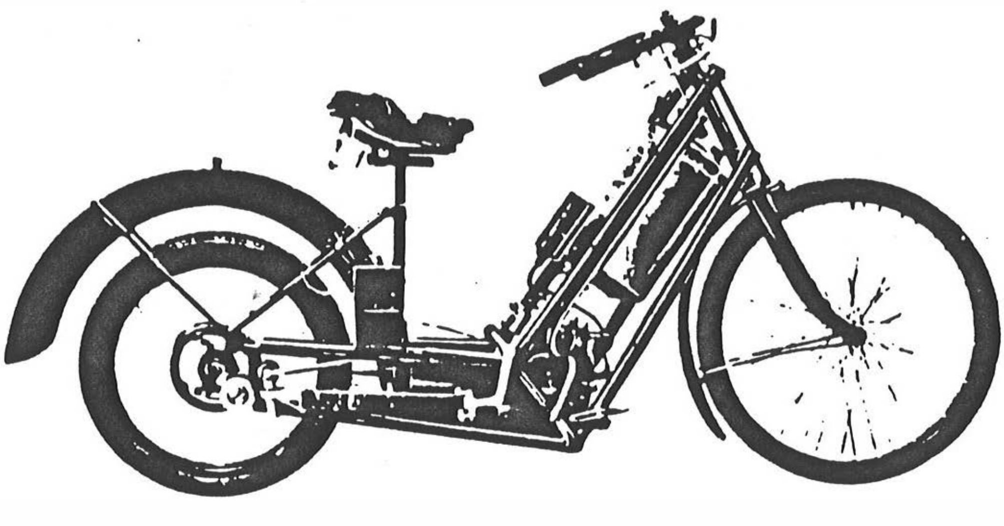

Fig.4 : First patented, serially produced motorcycle by
Hildebrandt and Wolfmüller; München, 1894.

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.

C. Contents of the report of WG8

I. Importance of the problem.

In various EEVC-member countries it was concluded that over the last decade a lot of attention was paid to the prolems 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 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 I 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 pedestians: rougly 22% - 1979).

Chapter I gives a detailed description of those and other figures: numbers of injured, of vehicles in use etc.; it relates thos 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 groups). 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 technicalities of the vehicles). A seperate paragraph describes the importance of economic assessment of these accidents and remedial measures, and some problems related to the available methods.

II. Description of bicycle and moped accidents.

Chapter II gives details on typical types of accidents; "accidents 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 collisions partners (50 to 90%); 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 moped 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 mopeds), 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 the report, but some conclusions and tendencies are noted. The studies available indicate that the frequencies of injuries for various body-parts depend 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; for bicyclists the frequency is even higher than for moped riders); arms and legs come in second and third places.
The injury scaling problem associated with long-term impairment, as mentioned in the EEVC-report 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 an 72 km/h.

III. Injury influencing parameters.

Contrary to the situation for car accidents, very little is known about these parameters for two-wheeler accidents. So 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 II.

IV. Research methods and results.

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. accident 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 specifically relating to bycicles and mopeds (and then mainly accident statistics). What has been done -and can be used to some extent her too- was usually directed at pedestrians or motorcyclists; nevertheless a few bicycle-related studies are cited (accident-studies of various leves as well as development work on mathematical models, together with the necessary related full-scale and component tests).

V. Current knowledge on human tolerances.

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 than 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.

VI. Injury prevention measures.

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 separated:
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.

VI. 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 shape and 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.
Regarding heavy goods vehicles two approaches exist:

- improvement of shape and stiffness would be beneficial 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. Knee-bars, knee-paddings, elimination of sharp protrusions (fillercaps, handlebar expander-pins e.g.), dress-guards at the rearwheel and childseats are mentioned in this sub-chapter, although it is not clear for all those elements whether they can be applied to the lighter two-wheelers.

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 moped-riders and certainly not for cyclists (the use of special types of cyclist-helmets has been introduced in some countries nevertheless). Possible effects are indicated in the text.

VI.2. Consequences for other road users.
Little influence for others is expected form 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.

VI.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.

VII. Testprocedures.
Testprocedures, aiming at ensuring conformity of a vehicle or component with relevant requirements, are globally discussed.

VIII. Accident prevention.

Injury prevention or minimization is clearly not the only and possibly not the best way to protect road users; accident prevention would by 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 manoeuvrability; 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.

D. Priorities and recommendations

1. 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 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.

2. 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 as well as for pedestrians. The exact locations on the car where these materials should be applied is not decided today. Nevertheless, preliminary results of experimental frontal collisions 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.
   Second priority should be given to the side of the car due to the relatively frequent occuring side collisions with mopeds.
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 goods 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 retroreflector 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.

3. 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 various classes of light powered two-wheelers).
- When introducing a new legal measure, a proper before and after evaluation study is necessary.
- 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 concerning the improved required field of view will enter into force soon.
- Riders of bicycles and mopeds 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 are usefull and should be promoted as a low cost safety accessory. (The last recommendation is based on research and theoretical considerations. In part it is supported by accident studies).

4. Recommendations for future reseach.

a. Real accident studies.

Information of real accidents is needed to get better insight in injury influencing parameters

The first imporant 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?

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, and also human parameters such as age, length and mass distributions.

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, 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 useful 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 recommendtions 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 international cooperation and coördination 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 the following collision types:

For the passenger car:

- front of car to (left) side of bicycle/moped
- front of car to rear end of bicycle
- front of car to front of moped
- side of car to front of moped

For the heavy goods vehicle:

- front of HGV to side bicycle/moped
- front of HGV to front bicycle/moped
- side of HGV to side of bicycle/front of moped
- side of HGV to front of bicycle/side of moped

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 in relation to 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.

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