TNO report

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Literature survey of motorcycle accidents with respect to the influence of engine size.

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Abstract

For completion of the type approval of two- or three-wheeled motor vehicles, and in particular of Directive 95/1/EC of the European Community, the Directorate General III (Industry) commissioned a study to examine whether there is a relation between motorcycle accident occurrence and motorcycle engine power exceeding 74 kW. This report presents the results of a literature survey of existing studies, together with the factors that are likely to have a bearing on motorcycle accidents.
Studies investigating the relation between performance properties and involvement of motorcyclists in accidents or the accidents risk used several different methods:

1. Studies searching for direct evidence of the following relationships:
   - Analysis of officially registered accidents, where accidents are weighted on the basis of the respective motorcycle population;
   - Questionnaires/interviews among a representative group of motorcyclists and accident-involved motorcyclists, where accidents are weighted on the basis of exposure to a collision (mostly distance travelled);
   - Combination of the two methods (both data sources).
2. Studies searching for indirect evidence of the relationships by investigating the effects of engine size/power restrictions for novice motorcyclists.

The direct studies generally have corresponding results with respect to engine size and the occurrence of motorcycle accidents; engine size does not emerge as a risk factor in accident involvement. These results are obtained from the major studies which weighted the accident rate on the basis of distance travelled as a measure of risk exposure. The distance travelled and accident frequency per rider per year both increase with engine size. In combination, the effect of engine size diminishes. This effect is the origin of the conflicting conclusion of the statistical database studies which do not take distance travelled into account and conclude that the accident rate (based on motorcycle population) increases with engine size. This conclusion is misleading because the amount of exposure to an accident is responsible for this effect.

The results of the indirect studies give weak, inadequate, and even conflicting evidence, and do not change or confirm the conclusions of the direct studies.

The conclusion of this literature survey is that there is no scientific evidence that engine size is a major factor in motorcycle accidents; engine size does not emerge as a risk factor.

Contents

1 Introduction

For completion of the type approval of two- or three-wheeled motor vehicles, and in particular of Directive 95/1/EC of the European Community, the Directorate General III (Industry) commissioned a study to examine whether there is a relation between motorcycle accident occurrence and motorcycle engine power exceeding 74 kW. This report presents the results of a literature survey of existing studies together with the factors that are likely to have a bearing on motorcycle accidents.

Many studies have been performed in the past decade to determine the factors involved in motorcycle accidents. These factors range from motorcycle properties (engine size, power, power-to-weight ratio), driver characteristics (gender, age, experience, annual mileage, attitude, etc.), accident site characteristics (bend, crossing, {non} built-up area, etc.), road characteristics (wet, dry, icy), weather (wet, dry), and other factors (usage of helmets, visibility, etc.).

Governments of several countries proposed the introduction of legal restrictions for motorcycles used by novice motorcyclists in order to decrease the number of casualties. The reason for this was that the performance properties of high-powered motorcycles results in a higher accident rate than those of low-powered motorcycles. Powerful motorcycles have higher accelerations and higher maximum speeds which could have a negative influence on accident involvement.
The performance of motorcycles is a complex phenomenon and difficult to characterize in only one single property. For legislation purposes, engine size, engine power, and power-to-weight ratio are normally used. These properties are related to maximum speed and acceleration of the motorcycle, but do not fully characterize the road-holding performance of the motorcycle. They are the direct and simple performance measures which are available.
Several countries have motorcycle restrictions for novice motorcyclists (European Community, Australia, Japan, etc.). Before and after the introduction of these restrictions, numerous studies were performed to find proof or evidence for a relation between accident involvement and motorcycle performance. Most older studies only use engine size as a performance property, but nowadays engine size does not have a direct linear relation with engine power. Thus the more recent studies also use engine power and, in rare cases, power-to-weight ratio. The last property closely corresponds with the acceleration power of a vehicle.

The aim of this literature survey is to provide an overview of existing studies about the correlation between engine size, engine power, or other performance properties and motorcycle accidents.

It should be mentioned that a motorcycle is a two-wheeled, single-track vehicle which, due to its design, is vulnerable in critical situations. The motorcyclist has must not only steer the vehicle but also stabilize it. Both controlling functions are influenced by the properties of the single-track vehicle and are interrelated functions.

Studies which investigate the relation between performance properties and involvement of motorcyclists in accidents or accidents risk used several different methods:

1. Studies searching for direct evidence of the following relationships:
   Two main methods have been applied:
   - Analysis of officially registered accidents, where the accidents are weighted on the basis of the respective motorcycle population;
   - Questionnaires/interviews among a representative group of motorcyclists and accident-involved motorcyclists, where the accidents are weighted on the basis of exposure to a collision (mostly distance travelled);

   and thirdly
   - Combination of the two methods (both data sources).

   The difference between the methods is not only the type of data source but also, with respect to the accident rate, the dimension of the exposure to the occurrence of an accident in road traffic. The first method weighs the number of accidents on the basis of the number of registered or actual motorcycle population, whereas the second method weighs on the basis of the actual driven annual distances of the actual motorcycle population. The exposure measure appears to be a very important factor in the accident rate and is an item of discussion. The background of the second method is that it is not the possession of a motorcycle that has a relation with a possible collision but driving the motorcycle, thus the usage. One of the measures which is mostly used is the distance travelled or annual mileage; increasing the distance travelled will also lead to an increase in accidents. Thus, it is the definition of risk exposure that greatly influences the interpretation of results.

2. Studies searching for indirect evidence of the relationships:
   Several governments have restricted engine size and/or power of motorcycles in their regulations for novice motorcyclists. Examples are Australia, New Zealand, Japan, Great Britain, and Germany. Recently this is also applicable for the whole European Community. Studies which investigate the effects of these measures may indirectly provide evidence that engine size or power is a critical factor in accident involvement.

The intention of this literature survey is to search for relationships between engine size/power of the motorcycle and motorcycle accident occurrence.

Answers will be sought in existing studies with respect to the subject of this literature survey.

The databases DKF, IRRD, NTIS, PASCAL and SAMCAD were used for this survey as well as the literature brought to our attention by the European Commission, governmental organizations and organizations of motorcycle manufacturers and motorcyclist groups.
The keywords used in the search of the above-mentioned databases are:
- motorcycle & motor(w)cycle;
- motorbike & motor(w)bike;
- accident;
- unfall & unfälle (only DKF);
- power & hp;
- puissance (only PASCAL);
- leistung (only DKF);
- engine capacity;
- speed;
- statistics.

Chapter 2 discusses the relationships found in the direct studies, followed by Chapter 3 which analyses the results of a few indirect studies. Because the motorcycle, as a single-track vehicle, plays an important role, some of the other motorcycle properties are mentioned in Chapter 4. Lastly, Chapter 5 presents the conclusions of this literature review.

2 Direct studies on motorcycle accidents

The aim of the direct studies is to determine the relationship between motorcycle performance properties and accident involvement by determining the accident involvement or rate of "large" or powerful motorcycles compared to "small" or less powerful motorcycles. These studies, take several other factors into account which have a bearing on accident involvement:

- human factors:
  - age of the rider;
  - experience of the rider;
  - annual mileage;
  - attitude of the rider;
  - alcohol level in the blood.
- environmental factors:
  - meteorologic conditions;
  - state of the road.
- legal factors:
  - driving licence;
  - engine power limits;
  - speed limits.

As mentioned in the introduction, most of these studies have been initiated due to the proposal of governments to introduce restrictions for motorcycles of novice motorcyclists in order to reduce the number of accidents. The background of these measures is that novice motorcyclists do not have enough experience to ride large motorcycles with their higher maximum speeds and accelerations, and this lack of experience results in higher accident frequencies.
Due to the large number of studies, only those are mentioned which can be regarded as representative for a group of studies, have different conclusions, use large data sources, etc. At this point, the work of Mayhew & Simpson [21] should be mentioned as it is different from the others. The main part of their work is a literature survey in which almost all studies before 1990 are analysed in detail. But besides the very outstanding and large literature survey, they also give and discuss their own material. Mayhew & Simpson are one of the few who have also looked at other technical factors of motorcycles than engine size/power which may influence accident involvement. They could not give results with respect to relations between these other technical factors and accident occurrence. However, they do mention papers in which these technical factors or motorcycle properties are discussed, most of these not being accident analysis studies.

The direct studies using both methods will be discussed in detail in the next section.

2.1 Analysis of statistical databases studies

Motorcycle accident studies which use statistical databases as source and weigh the accident rates on the basis of the motorcycle(/rider) population have been executed not only recently but also some time ago. For instance, in 1960 Scott & Jackson [32] conducted a study in the USA and found that more powerful machines have higher accident rates. This trend is much more significant if the accident rate is computed per head (i.e. per rider): on this basis, light motorcycles have six times the accident rate of mopeds, and the largest category motorcycles have twice the rate of light motorcycles. If the rates are weighted on the basis of distance travelled, the same trend is found but it is much less marked. In this survey, the tendency of heavier machines to have a higher proportion of serious and fatal accidents has been observed.

Of more recent date, but still more than a decade ago, Kroj & Stöcker [18] studied the official accident registration in 1980 and 1981 in West Germany and, more recently, Stöcker [35] and Albus [1] the accidents statistics of Nord-Rhine Westphalia in 1990.
Based on officially registered accidents in the Federal Republic of Germany and in particular of the state North-Rhine Westphalia, Stöcker [35] investigated the development of the number of motorcycle accidents with respect to engine power and, in particular, motorcycle engine power exceeding 74 kW in the period 1984 to 1988. He found that the number of accidents with high-powered motorcycles increased in this period, but this increase can be directly related to the rapid increase in the vehicle population of this category of motorcycles (4000 to 13000 kilometres).
The number of accident involved motorcyclists and passengers also has an upward trend for motorcycles above 74 kW in the observed period, instead of the downward trend for motorcycles in the 20 kW and 51-74 kW classes. Stöcker indicates that this result for motorcycles above 74 kW must not be overestimated due to the very limited database (statistical uncertainty).
He found that beginners in the high power class have a disproportionally high accident involvement. He concluded that the combination of inexperience and a powerful motorcycle is a fateful one. This conclusion provides evidence for a two-stage licence for motorcyclists, which limits the engine power of the novice motorcyclist to a maximum of 20 kW for the first two years.
Despite the result of the study that powerful motorcycles are invariably more often involved in accidents than less powerful motorcycles, Stöcker states that banning motorcycles exceeding 74 kW cannot be established on this fact alone.

Summary

Data source	:	accident statistics 1984-1988, Germany;
Accident rate	:	per 100 vehicles;
Engine power	:	higher accident rate for motorcycles above 74 kW in the observed time period in contrast with motorcycles in the 20

kW and 51-74 kW class. This conclusion must not be overestimated due to statistical uncertainties (limited database);

Remarks : mileage not used as exposure data.

In Great Britain, Broughton [5] conducted a in-depth study of motorcycle accidents on the basis of officially registered accidents and supplementary information from two other sources: 1985/6 National Travel Survey and a special monitoring of motorcycle accidents by the police between 1983 and 1986. The special monitoring program also recorded the engine size of accident-involved motorcycles. Broughton used the numbers of active motorcyclists and annual mileage as exposure data. He discussed that the measure of exposure is of main importance when interpreting accident data. For instance, the number of motorcyclists can simply be provided by the number of licences or number of vehicles. But they are not the best measures because many licensed drivers do not ride regularly and some owners fail to licence their vehicles to avoid paying Vehicle Excise Duty.
With respect to the supplementary information, the study has the following drawbacks:

1. Only 372 respondents (1.8%) reported riding a motorcycle, a small number leading to statistical uncertainties (large confidence intervals);
2. Very low response rate for the age group 19-20, a group with above average usage;
3. Special monitoring program only covered a small proportion of motorcycle accidents, and this proportion varied with time;
4. Recorded data is not always correct. For example, young motorcyclists who are only allowed to drive 50 cc mopeds were recorded to have driven heavy 500 cc motorcycles.

The pattern of motorcycle usage varies with engine size. The average annual mileage for motorcycles of up to 50 cc is 2600 km, but rises to 10600 km for motorcycles of over 500 cc capacity. Seventy-one percent of the mileage of motorcycles of up to 50 cc is on built-up roads and 45% of motorcycles with more than 500 cc. The use of larger motorcycles is more seasonal.

Broughton found that the rate of injured motorcyclists varied with:

1. Age of the motorcyclist;
2. Engine size;
3. Type of road (built-up/non-built-up area).

The rate per kilometer travelled by young riders was 2.8 times average. This ratio decreases with age to less than 0.5 times average among riders above 40 years. The rates of seriously injured and injured motorcyclists decreases slightly with engine size. The rate of killed riders per kilometer travelled varies less with age, is higher on non-built-up roads, and increases with engine size.

Broughton states that the fatality rate among riders of powerful motorcycles is high. Firstly, the fatality rate per kilometre is above-average on all roads, and

secondly, large motorcycles are used more on non-built-up roads where the fatality rate for all motorcycles is relatively high.
Three factors contribute to this high fatality rate for large motorcycles:
- Involvement in accidents with two or more other vehicles;
- Involvement in accidents at night (10 pm - 4 am);
- Involvement in accidents on bends.

Broughton found that large motorcycles are involved in relatively few accidents on wet roads. This has been explained as evidence that riders of large motorcycles have a higher level of riding skill. However, accidents involving large motorcycles tend to be more severe on dry roads than on wet roads, possibly indicating that this extra skill tends to be offset by more careless riding habits under conditions that are perceived as being safe.

Summary

Data source	:	accident statistics and surveys 1985-1986, Great Britain;
Accident rate	:	per distance travelled;
Engine size	:	accident rates fell slightly with engine size and were at least twice as high on built-up as on non-built-up roads. Exception is the fatality rate which increases with engine size;
Remarks	:	Small number of motorcycles in survey sample.

In his latest study, Broughton [6] summarised the results of his own study [5] and that of Taylor & Lockwood [36] which used different data but yielded complementary results. Broughton states that herewith conclusions can be drawn with greater confidence than if either study had stood alone. Broughton states: "The main factors which affect the likelihood of a motorcyclist being involved in an accident are age, length of riding experience, and annual mileage. Accident risk falls with both age and experience. Age and experience are highly correlated, as most motorcyclists start to ride when young, but it appears that experience is more generally influential than age. In contrast to non-fatal accidents, the risk of a motorcyclist being killed falls more slowly with age, and increases after the age of 50."

And with respect to engine size: "Engine capacity has little effect on accident risk when fatal accidents are excluded, but the risk is slightly less for the largest machines (over 500 cc). A different pattern is found, however, with fatal accidents: risk tends to increase with engine capacity, and is almost three times greater for capacities above 500 cc than for capacities up to 50 cc. The relatively high fatality rate of the largest motorcycles arises in part from involvement in accidents with two or more vehicles, in accidents at night, and accidents on bends."

Summary

Data source	:	accident statistics and surveys in 1985-1986, Great Britain;
Accident rate	:	per distance travelled;
Engine size	:	engine size has little effect on accident risk. Exception is the fatality rate which increases with engine size.

Combination of the work of two studies with complementary results => higher reliability.

Several studies were also performed in Australia. In contrast with the above studies, Rogerson [24,25] used laden power-to-weight ratio as a performance parameter of the motorcycle, instead of the commonly used engine size or power. This property gives an indication of the acceleration power of the machine. The term "laden" indicates that the weight includes a fixed amount of 90 kg for the rider. The motorcycle riders were divided in two groups; novice riders (learners and first year licence holders) with machines up to 260 cc and full licence holders.

Rogerson found that for all riders the accident risk increased with laden power-to-weight ratio up to 200 kW/tonne and that it stays almost constant above this value. This accident risk was weighted by the number of registered motorcycles. When distance travelled is taken into account, accident risk is nearly constant. Remarkable is that, for novice riders, accident involvement increases rapidly with laden power-to-weight ratio, even when it is weighted over the distance travelled.
For the machines up to 260 cc (limit for novice riders), high-powered 250 cc 2-stroke engines are overinvolved in accidents. These machines came onto the market after the introduction of the 260 cc limit for novice riders. This is an example of an increased of accident risk after a government regulation has been introduced to reduce the accident risk for novice motorcyclists. According to Rogerson, limits of the laden power-to-weight ratio of 150 kW/tonne or 125 kW/tonne would result in a reduction of crashes. This expected reduction is not clear because a proportion of motorcyclists will not obey the restrictions. The research identified high levels of non-compliance with restrictions by motorcycle riders.

Summary

Data source :	statistical databases, police reports, databases, manufacturers, etc. in 1984-1990, Australia;
Accident rate :	accident rate per registered population and per distance travelled;
Power-to-weight:	the accident risk per distance travelled for all riders is nearly constant and increases for learners and first year licence holders with machines up to 260 cc. High-powered 250 cc machines are overinvolved in accidents.

Based on data from insurance companies in Norway, Ingebrigtsen [11] found that large motorcycles are more dangerous than small ones. Per 100 insured motorcycles, motorcycles with an engine volume of 825 cc or more are more frequently involved than smaller ones. The data available for testing these hypotheses were somewhat inadequate. The conclusion is therefore somewhat uncertain according to the author.

Summary

Data source	:	insurance companies in 1982-1988, Norway;
Accident rate	:	per 100 insured motorcycles;
Engine size	:	accident rate increases with engine size. Statistical uncertainties due to limited data;
Remarks	:	mileage not used as exposure data.

In their extensive literature survey, Mayhew & Simpson [21] analysed several accident studies which weigh the accident rates on the basis of the motorcycle population. These studies invariably concluded that large and high-powered motorcycles have the highest accident rates (studies of Hurt, Kraus et al., Roth & Cooper, etc.). Some authors indicated that the number of motorcycles is a poor exposure measure and that the differences found between small and large motorcycles or between racing type and street type could be attributable to different amounts of travel, different travel conditions, or differences in the motorcyclist's characteristics. Mayhew & Simpson concluded that the results of these studies could not be associated with a greater accident risk for large and powerful motorcycles.

Summary

Data source	:	literature survey of statistical database studies before 1990, Europe, Australia, Canada, and USA;
Accident rate	:	accident rate based on motorcycle population;
Engine size	:	studies conclude that accident rates increase with engine size, but Mayhew & Simpson conclude that this could not be associated with a greater accident risk for large and powerful motorcycles.
Remarks	:	large number of studies => greater confidence of conclusions. Mileage not used as exposure data.

In a very recent motorcycle accident study by Statistics Norway (under publication), Monsrud [22] found that the accident risk for large motorcycles above 74 kW is slightly higher than those below 74 kW. Due to the limited number of samples, this result can not be proven to be statistically significant. The accident rate per 1000 motorcycles for two high-powered types, "lazy" and "hot-blooded", with engine sizes above 750 cc are investigated and it appears that the "hot-blooded" types are more involved in accidents. Monsrud concluded that the race-image of the motorcycle is a more important factor than the engine power itself. The author doubts whether regulating engine power is the best solution for reducing the number of accidents.

Summary

Data source	:	accident statistics in 1993 & 1995, Norway;
Accident rate	:	per 1000 motorcycles;
Conclusion	:	race-type motorcycles have higher accident rates;
Remarks	:	no data available about statistical significance. Mileage not used as exposure data.

Overall summary statistical database studies

The (statistical database) studies which only use data from officially registered accident databases and weigh the accident rate on the basis of the motorcycle population generally conclude that the accident rate (or frequency) increases with engine size.

The so-called combined studies which also use data from surveys and questionnaires for the characteristics of the rider, the motorcycle, the road, type of usage, etc. give similar results with respect to the same type of accident rate, but also find that annual mileage is an influential factor. The accident rate based on the distance travelled is not (or slightly) influenced by engine size. The combined studies also show that, for only fatal accidents, the accident rate (distance travelled) or accident risk tends to increase with engine size (three times higher for engine size above 500 cc than for engine size up to 50 cc).
Besides age and length of riding experience, annual mileage is a major factor affecting the likelihood of a motorcyclist being involved in an accident. This indicates that it is important to understand which factors are involved in motorcycle accidents. Without enough knowledge about motorcycle accidents, extensive sets of accident data, and sophisticated analysis techniques, there still would be the risk of drawing incorrect conclusions. This is valid for any kind of accident analysis study.

From the results of the combined studies, it can be deduced that the conclusions of normal statistical studies are misleading, for they do not take into account a major influential factor: annual mileage.
It should be mentioned that not all normal statistical studies have concluded that powerful motorcycles are more dangerous. For instance, Stöcker states that banning motorcycles exceeding 74 kW cannot be established on this fact alone. More evidence is needed to be able to conclude that powerful motorcycles are more dangerous than light motorcycles.
Some studies give indications that the type of motorcycle (touring, standard, race, etc.) could be a factor in motorcycle accident occurrence. The reliability of these indications is not very high because of limited data or few observations (statistical uncertainties).

It can be concluded from the combined studies that age, experience, and mileage are major factors in motorcycle accident occurrence. Engine size only influences the case of fatal accidents. The conditions which contribute to this higher fatality rate of large motorcycles are:

1. multiple vehicle accidents;
2. accidents at night;
3. accidents on bends.

On the other hand, large motorcycles have more riding distance on non-urban roads which have higher fatality rates than urban roads.

The statistical database and combined studies find the following factors in motorcycle accidents (including the major factors which are mentioned above):
1. age (or youth) of the motorcyclist;
2. experience of the motorcyclist;
3. attitude of the motorcyclist;
4. mileage;
5. type of road (built-up/non-built-up area);
6. accident location (bend, crossing);
7. weather, including the condition of the road (dry, wet, icy)
8. time of the accident (day/night, weekdays/weekend, season).

As can be expected, most of these factors are related to the motorcyclist, accident circumstances, or exposure data. Many of these factors are strongly correlated.

The reliability of the results of statistical accident studies is dependent upon the information available from accident databases and the motorcycle population. The information in accident databases may be incomplete:
1. not all accidents are reported;
   An important result of Lynn [19] is that officially registered accidents do not correspond to reality, less than one in five is reported to the police. The report rate varies with the severity level of the injuries and the size of the motorcycle. Accidents with large motorcycles and killed persons are more frequently reported than those with small motorcycles and minor injured persons. But even fatal accidents are not all reported.
2. not all accident circumstances are reported and those which are reported may be incorrect;
3. single vehicle accidents are not likely to be reported.
   These accidents are outstanding examples of accidents caused by driver attitude and characteristics as well as skills. Thus to find proof that powerful motorcycles are more dangerous, those single accidents should also be - examined in detail.

The method used to determine the motorcycle population can give deviations of accident rates as well. For the motorcycle population, one could choose the number of licensed riders or the number of registered motorcycles. Neither will give the actual motorcycle population in the observed/analysed period. Thus care must be taken to achieve the active motorcycle(cyclist) population.

2.2 Analysis of studies using questionnaires and interviews as data sources

More than a decade ago (1981), in the USA Hurt et al. [10] conducted a large, in-depth, on-scene investigation on 900 motorcycle accidents and 3600 motorcycle traffic accident reports in the Los Angeles area. The accident data was analysed after factoring in riding distance as a measurement of risk exposure and, in contrast with the statistical database studies, the accident rate does not increase with engine size, but even decreases with engine size. One of Hurt's conclusions was that "large displacement motorcycles are underrepresented in accidents, but they are associated with higher injury severity".
Other important results of Hurt's study are:

- 25% of all accidents are single vehicle accidents of which two-thirds are caused by the driver due to overbraking and running wide in a curve (speeding);
- 75% of all accidents are multiple vehicle accidents of which two-thirds are caused by the driver of the other vehicle (mostly passenger cars).
- conspicuity of the motorcycle and rider is a critical factor in the multiple vehicle accidents;
- riders between 16 and 24 are significantly overrepresented in accidents;
- riders involved in accidents are essentially without training. Half had less than five month's experience;
- alcohol is involved in 50% of the fatal accidents:
- injury severity increases with speed, alcohol involvement, and motorcycle size;
- typical motorcycle accidents allow the rider less than two seconds to avoid an accident;
- in pre-crash time, the accident-involved motorcyclists demonstrate a poor choice of evasion action and execute that choice poorly. About 32% of the riders did NOTHING in the way of evasion action in pre-crash time! Also the front brakes are often not used.

Hurt proposed recommendations and countermeasures on aspects like training, licensing, protective equipment, and conspicuity. Training and licensing are for improving the basic skills of the ,rider also with respect to evasive actions like braking and swerving. This is important for young riders.
Hurt observed that large displacement motorcycles are underrepresented in accidents. This was determined from data on general motorcycle riding population on 505 accident sites relative to the day, time, and environmental conditions that matched the accidents.
In single accidents the accident is normally caused by the driver due to overbraking and running wide in a curve. Running wide in a curve means a too high speed in the curve. The curve conditions and/or the motorcycle cornering capabilities can be misjudged by the rider and without more information about the accident situation this can not be related to large motorcycles.

Summary

Data source	:	in-depth, on-scene investigations and accidents reports in 1980, USA;
Engine size	:	large displacement motorcycles are underrepresented;
Remarks	:	not a recent study. Characteristics of motorcycles, riders, licence, etc. can be different from the present.

Numerous motorcycle accident studies originate from German researchers like Koch, Schulz, Hagstotz, etc. They use questionnaires and surveys as data sources and weigh the rates on the basis of distance travelled.
Since 1987 they have conducted several studies [12-16, 28-31] in West Germany using riding distance as a measure for risk exposure. The databases of registered accidents do not contain this type of information and therefore these investigators had to use questionnaires or interviews to obtain them. The main advantage of these sources are that data can be obtained which are omitted in the statistical databases:
1. mileage;
2. experience (mileage, years, previous experience with a lighter motorcycle);
3. specifications of the motorcycle (e.g. mark, type, engine size, engine power, etc.);
3. light accidents;
4. single vehicle accidents, etc.

On the other hand, care must be taken with these sources for the following reasons:
1. given data can not be checked for they are not registered anywhere. The researchers had to believe that the given information was correct;
2. active motorcyclists involved in serious and fatal accidents can for obvious reasons be underrepresented in the questionnaires;
3. biased answers in case of self-supporting questionnaires;
4. biased answers when the motorcyclists have an idea which trends are searched for (or not);
5. sample of active motorcyclists must be representative of the whole motorcyclist population.

In the first studies of Koch et al., information was gathered from Kawasaki-owners and visitors of two motorcycle exhibitions in 1984 in West Germany. Those groups of motorcyclists are not representative of the whole motorcyclist population in Germany. To overcome this problem, surveys were conducted in 1986 and 1988 among a representative sample (n=1000) of the total population of male drivers. Based on these sources, Koch & Hagstotz [14] concluded:
1. greater risk of severe accidents for young motorcyclists;
2. increased accident involvement of motorcycles with engine size/power (see table 1);
3. increased accident involvement of motorcyclists with higher annual mileage;
4. higher annual mileage of young motorcyclists;

Table 1: *Indexed accident risk and annual mileage for different engine sizes [14]*

engine size motorcycle	<249	250-499	500-749	>750
at least one accident	27%	22%	33%	38%
index value accidents	100	83	125	145
average amount travelled per year [km]	7,500	9,500	10,100	11,400
index value mileage	100	126	134	151

5. higher annual mileage of motorcycles with higher engine size/power (see table 1).

On the one hand, these results mean that young motorcyclists and high-powered motorcycles are more involved in accidents, but on the other hand, these groups have the largest annual mileage. Combination of annual mileage and engine size results in a virtual neutralization of the risk of accident involvement; the increased risk for motorcycles with higher engine size corresponds with higher annual mileage (see table 1). The only exception is the 250-449 cc engine size class, with lower indexed accidents and higher annual mileage than the <249 cc engine size class.

From multivariate analysis the following main factors are found which influence accident events: age, annual mileage, and experience (total distance travelled). Factors like experience with previous lighter motorcycles, type of motorcycle, and gender have no significant influence.

All of these German studies concluded that, with respect to engine size or power of motorcycles, these have no statistically significant influence on the occurrence of accidents based on annual driving distance as a measure of risk exposure instead of the vehicle population.

The group of motorcyclists with the highest accident risk have the following properties:

1. little driving experience;
2. age below 20 years;
3. annual mileage of more than 5000 km.

As mentioned above, one of the other main advantages of interviews in contrast with accident databases is that more light accidents are reported. In many of these type of accidents, the accident is not caused by other vehicles/drivers but by the rider and/or the machine. Koch et al. have found with respect to these light falls:

1. the number of light falls did not depend on annual mileage, but on the number of months driven per year;
2. an increase in falls with youth;

3. a decrease in falls with number of years of regular driving;
4. an increase in falls with previous experience on a light machine.

Young and inexperienced drivers are more involved in these light falls. Driving experience is assessed with age. For young drivers, adolescent risky behaviour is also involved. These two, potentially independent, variables can contribute to increased involvement in accidents. One variable is the age-specific tendency to search for new experiences and test own skills; the other variable is the learner rider's inexperience in riding a motorbike through the complex system of road traffic. Therefore, driving experience is generally assessed with age.

For single vehicle accidents, the following relations have been found:
1. an increase in single vehicle accidents with annual mileage;
2. a decrease in single accidents with the number of years of regular driving;
3. a decrease in single accidents with previous experience.

Many single vehicle accidents are caused by the drivers and their inexperience. Higher annual mileage gives more exposure to accident risk and results in more accidents.

For accidents involving other road users, Koch et al. found:
1. an increase with annual mileage;
2. an additional increase with youth.

Thus, also for non-single vehicle accidents, a higher exposure or higher annual mileage results in more accidents. The additional increase by youth can be explained by adolescent risky behaviour.

Summary

Data source	:	questionnaires and surveys 1984-1993, Germany;
Engine size	:	accident rate by engine size is not statistically significant;
Remarks	:	large number of studies => greater confidence of conclusions.

Around in Great Britain 1990 Taylor & Maycock [37] analysed the way the accident liability varies between motorcyclists by relating their involvement in accidents to individual characteristics (age, gender, riding experience, riding test passed), to exposure (distance ridden, type of roads), and to the characteristics of their motorcycle (engine size). The data were obtained from a survey in Great Britain (Lynn [20]) in which self-reporting questionnaires were used (n=7173, 71.7% response). The most important accident group with respect to severity, namely the accidents where the driver is killed, has for obvious reasons been excluded from this survey.

Taylor found that the accident frequency for larger engine sizes appeared to be lower; 0.33 per year for engines up to 125 cc and 0.13 per year for engines larger than 500 cc. The smaller motorcycles travel few miles and so have an even greater accident rate per mile than large motorcycles. For accident-involved riders, the probability of injury was higher for the younger than older riders, higher for females, but independent of engine capacity.

Taylor developed a model for estimating the rider's expected accident frequency where age, riding experience, and exposure (mileage, road type, and season) are the primary determinants of accident liability. Accident frequencies decrease rapidly with increasing age and experience. The analysis has also shown that on open roads (non-built-up area), large motorcycles have fewer accidents than small motorcycles.

Some of Taylor's conclusions differ from other researchers like Broughton. For example, large capacity motorcycles have fewer accidents! Maybe the exclusion of killed motorcyclists in the data is the reason for this difference. The amount of killed riders among motorcycles with high engine capacities is greater than those of small motorcycles.

Summary

Data source	:	self-reporting questionnaires 1988, Great Britain;
Accident rate	:	annual accident frequency;
Engine size	:	for accident-involved riders, the probability of injury is independent of engine size. accident frequency appeared to be lower for large motorcycles;
Remarks	:	fatal accidents are excluded from the sample and could be responsible for fewer accidents of large motorcycles.

At the same time as Taylor & Maycock, Lynn [19] also analysed the accident liability of motorcyclists based upon questionnaire data from a national British sample of 7173 registered private owners of two-wheeled motorcycles in 1987-1988. The same data was also used by Taylor and Maycock (Lynn [20]). Lynn analysed the effect of age, gender, riding experience, and engine size on the accident liability, estimated accident frequencies for subgroups and in contrast to Taylor & Maycock, he compared the results with that of a similar study in 1977-1978.

The main findings were that the overall accident frequency was 0.26 accidents per rider per year of which 55% involved injury to the rider and 11% involved serious injury to the rider. Annual accident frequency varied greatly for subgroups: Riders aged under 20 had 0.93 accidents per rider per year, whereas the frequency for those aged 40+ was 0.10; the frequency varied from 0.32 for riders of bikes of 125 cc or less to 0.13 for riders of bikes of over 500 cc; it varied from 0.06 for those who averaged no more than 500 miles per year on their bike to 0.50 for those who averaged over 5000 miles. Accident frequency did not vary between males and females.
The injury (to rider) accident frequency was higher for riders of small bikes than others. The serious injury (to rider) accident frequency did not show any obvious relationship with engine size. Both the injury accident frequencies and serious injury accident frequencies for large bikes were similar to those obtained in a study by Broughton [5], but the frequencies for smaller bikes were much higher

than those found by Broughton. Less than one in five accidents had been reported to the police. More surprisingly, only a quarter of the injury accidents, and only half the serious injury accidents had been reported. This is an important result, for it questions the validity of studies only based on registered accidents. The data is not fully representative of the real world and the number of recorded accidents increases with higher injuries.

Lynn found that the estimated average annual mileage of motorcyclists in the sample was 3700 miles. This was about 400 less than the estimate derived in the 1977-78 study. Estimated average annual mileage varied for subgroups: notably the average for males was 4000, compared to only 2100 for females; it varied from 5600 for 19-year-olds to 1800 for those aged 55+. It varied from 2300 for riders of bikes of up to 50 cc to 5700 for riders of bikes of over 500 cc. Similar results have been found by others (Broughton, Mayhew & Simpson, Koch, Schulz, etc.), namely that young drivers and larger motorcycles have more annual mileage.

Table 2: Accidents in the last twelve months vs engine size

Number of accidents	50cc or less %	51cc-125cc %	126cc-500cc %	501cc or more %
0	86	82	88	91
1	9	13	11	7
2	3	4	1	1
3 or more	1	1	1	-
Base (riders with at least one year experience)	1273	1255	990	774
frequency	0.31	0.34	0.19	0.13
Base	1735	1792	1314	1078

In order to estimate the relative magnitudes of the effect of variables like age and experience, age and mileage, mileage and engine size on accident liability, a multivariant accident analysis has been undertaken.
The main results are (see also table 2):
Riders of larger bikes had been involved in fewer accidents (8% of riders whose bikes are larger than 500cc had been involved in an accident, compared with 12% of riders of bikes between 126cc and 500cc, 18% of those between 51cc and 125cc, and 14% of those with 50cc or less).
The accident frequencies confirm that engine size is inversely correlated with accident liability, with riders of bikes of up to 125cc having the greatest accident

liability. These smaller bikes also travel fewer miles, so this implies an even greater accident rate per mile than bigger motorcycles.
Lynn reports that his results conflict with those of Broughton, who had found increasing accident rates for larger motorcycles: "These findings would appear to conflict somewhat with those of Broughton (1987) and Broughton (1988), whose analyses of samples of accidents reported to the police showed that larger bikes were more likely to be involved in injury accidents. The present survey, however, is of all accidents but is likely to exclude the most severe accidents due to the fact that the sample is of people still riding a bike. Thus the two studies look at rather different sets of accidents. Consequently the difference in findings may be due to the fact that although smaller bikes have more accidents, these accidents are likely to be less severe than those involving larger bikes."

Summary

Data source	:	self-reporting questionnaires in 1978 and 1988, Great Britain;
Accident rate	:	accident frequency per year;
Engine size	:	for accident-involved riders, the probability of injury is independent of engine size. Accident frequency appeared to be lower for large motorcycles;
Remarks	:	fatal accidents are excluded from the sample and could be responsible for the fewer accidents of large motorcycles.

In their extensive literature survey Mayhew & Simpson [21] analysed several studies which concluded that large motorcycles do not have a greater risk of accidents. Engine size or power does not appear to be a risk factor in accident involvement with the distance travelled as the exposure measure. Examples of these studies are Hallion and Nelles (1987), Carstenson, Koch [14], Schulz, Hagstotz [14], Broughton [4-6], etc. Some of these studies are also mentioned in this report. Besides a literature review, Mayhew & Simpson analysed accident data from only one province of Canada, Ontario. In Ontario, the make and the engine size of the accident-involved motorcycle was recorded by the police between 1984 and 1988.

The conclusions of Mayhew & Simpson with respect to the literature survey and their own investigation was: "The results of recent studies on motorcycle collisions indicate that differences in the characteristics of crashes between small and large motorcycles are likely due to different patterns of use of these vehicles, particularly the greater exposure of large motorcycles at locations and times of relatively higher risk. The crashes of large motorcycles are generally viewed to be a function of the riders' attributes and characteristics -- it is possible that high risk individuals are attracted to these vehicles -- and not the results of vehicular factors associated with higher performance characteristics of certain types of motorcycles."

"An analysis of serious injury and fatal crashes in Ontario suggested that the power capabilities of large motorcycles are not the critical factor in collision involvement."
"The most likely contributory factor in single-vehicle collisions is alcohol, particularly in collisions involving large motorcycles (over 500 cc). In multiple-vehicle collisions, about half are judged the fault of the other driver. In the remaining collisions in which the riders' pre-collision actions were critical to the crash, alcohol emerged again as a major factor. Consistently, however, the engine size/power characteristics of the large motorcycles do not emerge as risk factors."
Some concerns were raised that the introduction of high-powered, racing type motorcycles would have a major influence on the motorcycle crash problem. Mayhew and Simpson concluded: "An examination of major and fatal crashes in Ontario in 1987 by model year showed that the characteristics of the collisions of recent model year (1981-1988) motorcycles were generally similar to those of older model year, non-racing design (pre-1981) machines. And, we could not find major differences in the characteristics of fatal collisions that occurred in periods before and after the introduction of racing design motorcycles in the early 1980's. Thus, it is unlikely that changes in the performance capabilities of motorcycles have had a major influence on the types of collisions motorcycles typically become involved in. Evidence that indirectly bears on the possible relationship between engine size/power and collision involvement is consistent with the evidence from studies that have endeavoured to test the relationship directly - Engine size/power do not emerge as a risk factor."

Mayhew & Simpson indicate that if a relationship exists between motorcycle engine size/ power and collision involvement, it remains, at best, poorly understood. Collision involvement is more likely determined by factors related to the attributes of the rider and/or to the conditions and circumstances under which they ride. They found no definitive study that clearly establishes the nature, magnitude, and characteristics of the relationship between engine size and collision involvement.

Mayhew & Simpson have conducted the largest and most extensive literature survey on this subject. Despite analysing the most important research reports in Europe, Australia, Canada, and the USA, they concluded that they have failed to discover any consistent evidence that engine size/ power is a risk factor in collisions.

Summary

Data source	:	literature survey of studies before 1990, Europe, Australia, Canada, and USA;
Engine size	:	engine size and power is not a risk factor in accident involvement;
Remarks	:	large number of studies from all over the world => greater confidence of conclusions.

Overall summary studies using data from questionnaires and interviews

The studies of which accident rates are based on a measure of risk exposure, usually the distance travelled, generally conclude that the accidents rates of larger motorcycles do not differ from those of smaller motorcycles. Some studies even find a slight decrease in the accident rate with engine size. This is in contrast with the statistical database studies which do not weigh on a measure of risk exposure but on the motorcycle population. All studies observe the same trend of higher accident frequencies based on the motorcycle population with respect to engine power/size. Taking into account the measure of risk exposure, distance travelled, the increase in the accident rate with engine power disappears or is not significant. Thus engine power or other motorcycle performance does not emerge as a risk factor.

Similar conclusions but based on accident rates per rider per year are observed in two studies in Great Britain: no relation between engine size and accident rate per rider per year. They even find that fewer accidents happen with larger motorcycles than small motorcycles. These results conflict with those of statistical database studies and the other studies using questionnaires; large motorcycles are involved in more serious and fatal accidents. This difference can be explained by the different sets of accident data, namely the sample of the two studies exclude all fatal accidents. Excluding fatal accidents from the samples will result in engine size having little effect on the accident risk according to a combined statistical database study in Great Britain (Broughton [6]).

The reason for similar accident rates for all engine size classes of motorcycles is the inclusion of exposure data, mainly the distance travelled in the accident rate. Large motorcycles have a greater annual mileage (up to 2-3 times of that of small motorcycles) and are frequently used on main roads. Small motorcycles are more often used in urban areas with shorter trip distances. It has been proven that exposure to risk, particularly annual mileage, greatly influences accident involvement and diminishes the influence of engine size.
In their literature study, Mayhew & Simpson state that the differences in the characteristics of crashes between small and large motorcycles are likely due to different patterns of use of these vehicles, particularly the greater exposure of large motorcycles at locations and times of relatively higher risk. The crashes of large motorcycles are generally viewed to be a function of the rider's attributes and characteristics.

This second type of direct studies find the following factors in motorcycle accidents:

1. Age of the rider;
2. Experience of the rider (annual distance travelled);
3. Total experience of the rider (total distance travelled or riding years);

4. Location of the accident (built-up area or non-built-up area, bend, intersection);
5. Weather (raining or dry);
6. Road surface (wet, dry or icy);
7. Time (daytime/night, season, weekday/weekend);
8. Rider's attitude (normal, too fast, loss of control, adolescence risk taking);
9. Alcohol;
10. Visibility.

These factors are similar to those found in the statistical database studies and characterize rider attributes, accident circumstances, and exposure data. Many of these factors are strongly correlated.

Special car must be taken when using questionnaires or interviews with respect to the following aspects, for they may bias the results:

1. the given data can not be checked for they are not registered. The researchers have to believe that the given information is correct.
2. only active motorcyclists during the inquiry phase of the research are questioned. Thus motorcyclists which have stopped driving motorcycles are not part of the investigated group (those riders were part of the motorcycle population for the investigated time period).
3. the sample of motorcyclists must be representative of the active motorcyclist population. A well-designed sample of the group of riders must be taken to avoid this weakness.
4. less information about fatal accidents. It is known that the fatality rate of accidents of larger motorcycles is significant higher than those of small motorcycles.

Advantages of the data sources are:

1. information about the experience of the driver (mileage, years, previous);
2. annual mileage;
3. more light accidents, which are generally not registered. Thus accidents without or minor injured persons, etc.;
4. more single vehicle accidents, etc.;
5. information about mark, type, and other properties of the motorcycle.

2.3 Conclusions direct studies

Both types of direct studies use different data sources and accident rates to investigate the factors which have a bearing on the accident involvement of motorcycles. Both types of studies found similar major factors like age, experience, mileage, etc. With respect to the statistical studies, these results are only obtained for the more recent, combined studies in which annual mileage is taken into account. The other statistical studies do not include annual distance and thus conclude that the accident rate increases with engine size.

The conclusions of both types of direct studies correspond fairly well, namely engine size or other performance properties do not emerge as a risk factor. This is without exception the case for studies which used data from questionnaires and weigh the accident rate with the distance travelled. However, some studies find corresponding results, but based on accident frequency per rider per year. This result conflicts with all other studies, even with the statistical database studies. This conflict can be explained by the fact that fatal accidents are excluded from the samples. For only fatal accidents, the accident risk increases with engine size! Before discussing this result, first something about acquiring data from questionnaires or surveys in both types of studies. Due to obvious reasons, fatal accidents are underrepresented or even excluded from the samples. On the other hand, if engine size is an influential factor in accident involvement, then it has to be valid for other injury severity levels and especially serious injuries. Thus, it can not be concluded from these studies that engine size is a factor involved in motorcycle accidents.

The high number of fatal accidents observed with larger motorcycles has been explained by the following circumstances:
1. multiple vehicle accidents;
2. accidents at night;
3. accidents on bends;
4. non-urban roads.

With respect to the last factor, large motorcycles ride more on non-urban roads for which the fatality rate is higher.

The conclusion from all major direct studies is that they do not provide scientific and statistically significant evidence that engine size, engine power, or power-to-weight ratio is a major factor in motorcycle accidents. Other factors like the rider's attribute and characteristics, type of road, mileage, alcohol, etc. emerge as the major risk factors.

3 Indirect studies on motorcycle accidents

The indirect studies are studies which investigate the effect of engine size restrictions in new or updated motorcycle licences for new riders. The casualty rates before and after the introduction of these engine size limits are investigated. If the accident rates decrease, this can be regarded as evidence that the restriction has a positive influence. From this result, it can be indirectly concluded that larger motorcycles are more involved in accidents than small motorcycles. The indirect studies only look at new or novice riders, which have limited experience and most of them are young. The proportion of large motorcycles in this group before the introduction of engine size restrictions is not likely to be significantly high, for instance, due to the high price of these machines. These and other factors, like decreasing numbers of new novice riders at the time of introduction, the small proportion of novice riders with a new licence in the riders' population, possible different characteristics of the samples of novice riders before and after the introduction of engine size limits, etc., can make it quite difficult to find a strong correlation between a change in casualties with engine size. Only a very limited number of studies have been found, of which the most important are discussed below.

In Great Britain, Broughton [4] investigated the influence of the Transport Act of 1981 in which various measures were introduced to reduce the high accident rate among motorcyclists. The riding test was extended, the duration of the provisional licence was limited to two years, and the maximum engine size for learners was reduced to 125cc. In addition to the last measure, for motorcycles registered in 1982 or later, the maximum power is limited to 9 kW and the power-to-weight ratio to 100 kW/tonne. The effect of the Transport Act was that the number of young licensed motorcyclists fell sharply. This led to a reduction in the number of motorcycles in use and of the distance travelled by novice riders. The average age of motorcyclists which pass the licence tests has risen as well.

Restricting the engine size of motorcycles for learners has a clear effect on the casualty rates per vehicle. The transfer of inexperienced motorcyclists to less powerful vehicles has led to a reduction of one quarter in casualties under learner riders, independent of any reduction caused by the declining number of motorcyclists. Due to the lack of adequate data for the number of active motorcyclists (both learner and qualified), and the fact that at the end of 1985 only half of the active motorcyclists population were qualified under the new regime, there was insufficient evidence that motorcyclists qualified under the new regime have a better accident record. Only if the improvement of the casualty rate (1985 lower than 1984) is sustained in subsequent years, can a possible favourable conclusion be given.

In Australia, Troup et al. [39] investigated the influence of the 260 cc limits for novice riders (learners and first year licence holders) on the accident frequency. The casualty rate began to decrease from mid 1970 and continued to do so until mid 1971. They found 30% lower accident rates for learners and 29% lower for first year licence holders, but, in contrast, 17% more accidents among fully licensed motorcyclists. It is doubtful whether the decrease in accident rates of about a third for novice riders and at the same time an increase of 17% for experienced motorcyclist (total difference of about half) is only caused by the introduction of an engine size limit for novice riders. It looks like other factors are also involved, such as the number and level of exposure of new riders, etc.

There was also concern about a trend in the industry towards producing more powerful 250 cc motorcycles since the legislation. Troup found that powerful 250 cc motorcycles are not overrepresented in accidents. With respect to this latter phenomenon, in later studies by Rogerson [24, 25], he found that the powerful 250 cc motorcycles are overinvolved in accidents.

Besides the above two studies, Mayhew & Simpson [21] also analysed a study of Hallion and Nelles about the influence of the 250 cc limit introduced in 1979 in South Australia for novice riders. They found that the casualty rate (per registered vehicle) generally declined until 1981, after which time it stabilized. The involvement rate (per licence holder) of 16-year-old riders in casualty accidents also experienced a downward trend until 1980 after which time the trend reversed. On the other hand, the casualty rate (per licence holder) for riders of motorcycles up to 250 c generally increased between 1978 and 1985 for all rider age groups.

Based on these findings, the authors conclude that the 250 cc limit had at best a short-term (one-year) effect on crash involvement. They also caution that this short-term effect may not have been due to engine size restrictions but to other factors.

In South Australia, the introduction of a 250 cc limit for novice motorcyclists did not result in a reduction of motorcycle casualty rate. This is in contrast with the results of Troup et al. for Victoria.

Weinand [41] investigated the effectiveness of a two-stage licence in Germany. Statistical data were analysed to answer the question of whether the risk for a 20-year-old rider on a powerful machine with two years previous experience on a lighter machine (<20 kW) is lower than for an 18-year-old beginner without previous experience. His finding from the statistical data was that the risk is lower, thus he concluded that the two-stage licence is successful.
The decrease in the risk is caused by the different age and previous experience of the rider samples. In other studies, like Rutter & Quine [27], the age and especially youth of young riders play a more important role than inexperience.

The accidents were also associated with a particular pattern of behaviour, namely a willingness to break the law and violate the rules of safe riding. This indicates that characteristics like adolescence risk-taking has a major influence on accident involvement. "Older" riders have lower risks because adolescence risk-taking behaviour decreases with age.

The results of this study will not contribute to proof that large motorcycles are more or equally dangerous than light motorcycles, as the different factors are characteristics of the rider and not of the motorcycle.

Conclusion

Before discussing the results of the indirect studies, it should be stated that the conclusions of these studies are not strong due to the methods used. Only when the change in the accident rate has stabilized and become more permanent several years after the introduction of engine size restrictions can this evidence be regarded as providing proof.

We have searched for indirect studies which investigate the effect of maximum engine size/power restrictions for all motorcyclists. However, no such studies were found, not even in France with its restriction of the maximum engine power of 74 kW. The studies found only look at engine size restrictions for novice riders (power<25 kW).

The few studies that have investigated the effect of engine size restrictions for novice riders and learners do not provide corresponding results. The two studies from Australia even produced conflicting results. Troup et al. found a reduction in the accident rate of 30% for learners and first year licence holders, whereas Hallion and Nelles only found a short-term effect on crash involvement, and they also mention that this short-term effect may not have been caused by the engine size restrictions. The trend of the industry towards producing more powerful 250 cc motorcycles since the legislation has not led to more accidents in the studies, but in later studies by Rogerson it appeared that the powerful 250 cc motorcycles are overinvolved in accidents.

In the United Kingdom ,Broughton found that the 125 cc limit was effective in reducing casualties among learners. But due to lack of adequate data for the number of active motorcyclists (both learner and qualified), this evidence can not be regarded as hard proof.

Weinand (Germany) found a reduction in accident risk due to the introduction of stepwise licensing. The reduction may be related to the older age and previous experience of young licence holders for large motorcycles. The conclusions of this study do not contribute to the evidence that engine power and accident rate are related.

The limited indirect studies do not make it clear that there is a relation between high-powered motorcycles and accident involvement. The results are weak, inadequate, and even conflicting. Age, experience, and adolescence risk-taking are some of the rider factors which play an important role.
The restriction of engine power always directed at a specific group of riders; new and young riders. Besides inexperience with motorcycle driving, age (youth) will also play an important role, as well as the adolescence risk-taking of young persons. On the other hand, the number of high-powered machines within this group is limited due to the high price.
Engine size restrictions are focused on not very powerful motorcycles; less than 25 kW. All these aspects make it difficult to provide evidence for a relation between accident involvement and engine size/power, particularly powers above 74 kW. Age, experience, and adolescence risk-taking are some of the rider factors which play an important role.

It should be mentioned that accident risk does not need to be a linear function from low-powered motorcycles (<25 kW) to high-powered motorcycles (>60 kW). Therefore any hard conclusions found about the effect of engine power on the low end of the scale, the uncertainty about the effects on the high end of the scale would not be solved.

4 Other motorcycle properties

The performance characteristics of motorcycles in all studies have been restricted to engine size, engine power, and power-to-weight ratio. Due to its vehicle design, the motorcycle has properties/characteristics which are completely different from passenger cars. Major concerns are stability, vibrational modes, and sensitivity to disturbances. The two-wheel, single-track design of the motorcycle makes it an instable system in which the driver has to fulfil two functions; stabilizing and steering. Due to its design, the motorcycle is also vulnerable to disturbances like road irregularities, side gust, etc. These properties could influence the accident involvement of motorcycles.

As mentioned above, the "steering" of motorcycles is different because the riders have to stabilize the motorcycle against falling over. The stabilizing task will influence the steering task during normal riding, but also when avoiding a critical situation or during evasive actions. The rider's experience is very - important with respect to the actions during an actual critical situation (evasive steering actions, braking or combination of evasive steering actions & braking). Lack of experience may cause a fall even when the motorcycle does not come into contact with another vehicle or obstacle.

Another type of stability problem could occur during braking. If one of the wheels lock up, the vehicle becomes instable (sliding). This is especially dangerous when it concerns the lock up of the front wheel. This is the main reason why many riders do not fully use the capacity of the front brake. This is a disadvantage, because the larger portion of the brake force can be generated by the front brake. Not using the front brake will thus considerably reduce braking capacity. With present-day large motorcycles and when using the full capacity of both brakes, it is possible to achieve deceleration levels above those of passenger cars and for some machines even above 1g. Instead of using the brakes, motorcyclists can take evasive actions to avoid a collision. A motorcycle has great evasive properties with respect to passenger cars if the action can be taken well in advance of an eventual collision.

Vibrational modes can also be dangerous for single-track motorcycles. The dangerous modes are the wobble and weave mode [17]. Wobble is a steer oscillation of 4 to 8 Hz at speeds of 50 km/h to 80 km/h, depending on the machine. This oscillation is a shimmy phenomenon and can not be controlled by the driver due to its high frequency, but by grabbing the handlebars strongly, the vibration can be damped. A possible mechanical solution is to make the front fork more stiff for lateral bending or to increase steer damping.
The weave mode is a very dangerous mode. It is a combined oscillatory weave motion of the main frame and the front fork at frequencies of 0.5 to 2 Hz. Both the energy content of this vibration as well as the frequency is too high for the

driver to control. This phenomenon appears at speeds above 110-120 km/h. This mode can not be actively controlled by the driver. Only changing his body position can be of help. If this phenomenon occurs, the driver must immediately move his upper body towards the tank. This stabilizes the weave, after which the driver can reduce speed by reducing throttle and braking until the motorcycle reenters its stabile region for the original seating position of the driver.
These possible dangerous vibrational phenomena are properties of the single-track vehicle and are independent of engine size or power.
These phenomena occur regularly, as has been observed by Brorrson & Ifver [3]. They conducted a mail inquiry among riders of motorcycles with engine size above 239 cc in Sweden. 45% of the riders reported at least one wobble or weave occurrence in 1982 and 8% at least one serious occurrence. The occurrence increases with engine size. According to Brorrson, this information indicates that the dangerous vibrational modes might be involved in the motorcycle accident rate.

The single-track motorcycle is also sensitive to external disturbances or irregularities [26]. Road irregularities such as "cat-eyes", striping, drainage grooves and bumps, and other disturbances such as side wind, etc. can cause an undesired path change or behaviour of the motorcycle. Depending on the actual situation on the road, there may be a risk of a fall or a collision.

Of all accident studies, only Mayhew & Simpson mentioned other motorcycle properties besides engine size with respect to improving motorcycle handling performance and the stability and vibrational behaviour. They did not analyse the papers in detail: "Unlike the previous section, the intent here is not to assess the merits of these measures but simply to identify them. Much of the literature in this area is extensive and beyond the resources and purview of this project as well as their technical expertise of the authors".

The handling properties, stability, and vibrational modes of a motorcycle all have an influence on accident occurrences, and improvements in motorcycle design is promising for accident prevention and reduction of injury levels.
However, the literature does not indicate to what extent these properties influence the accident involvement of motorcycles. With respect to stability and vibrational modes, engine size/power is not the determining influencing parameter.

5 Conclusions

In the last decade, numerous motorcycle accident studies have been conducted to investigate whether motorcycle performance characteristics like engine size, engine power, and power-to-weight ratio are factors in motorcycle accidents. Most of these studies were initiated by the fact that governments proposed the introduction of engine size restrictions for novice motorcyclists or learners. The general idea of the governments is that new riders have a greater accident risk due to the lack of experience of the motorcyclist and the higher maximum speeds and higher accelerations of powerful motorcycles. Both direct and indirect studies have been conducted to determine whether motorcycle performance characteristics like engine size/power are important factors in accidents risks.

Direct studies

One of the direct study types, namely the statistical database studies, gives conflicting results. Those who only use data from officially registered databases find an increasing accident rate with engine size/power, whereas those who also use other kind of data sources and take into account the annual mileage do not find any statistically significant relation. In these latter studies, it has been found that annual mileage is an influential factor in motorcycle accident risk. One of the latter studies observed that engine size only effects accident risk in case of fatal accidents. However, if engine size is a risk factor in fatal accident involvement, then it must also have an effect on other levels of injury severity, especially the serious injury level. This relation has not been found.

Is engine size a major factor in motorcycle accidents according to the statistical database studies? Powerful motorcycles are involved in more accidents, but also have a different pattern of use in which annual mileage increases with engine size. When these two effects are combined, the influence of engine size on accident occurrence diminishes. So, the conclusion that the high number of accidents of powerful motorcycles is caused by engine size is misleading because the amount of exposure to an accident is responsible for this effect.

The following conclusions can be drawn from the statistical database studies:
1. powerful motorcycles are involved in more serious and fatal accidents;
2. accident risk of motorcycles per travelled kilometre has not been proven to be dependent on engine size.

The other type of direct studies which use questionnaires and interviews as data sources and weigh the accident rate with the annual mileage generally conclude that engine size does not emerge as a risk factor in accident involvement. Also, these studies found that powerful motorcycles are involved in more accidents. This can be explained, however, by the different pattern of use (annual mileage) and the rider's characteristics.

The conclusion which can be drawn from the direct studies which use questionnaires as data sources is that there is no relation between engine size and the occurrence of a motorcycle accident; engine size does not emerge as a risk factor. However, (near) fatal accidents are not fully taken into account in these studies.

Both types of direct studies give corresponding results; there is no link between motorcycle performance characteristics like engine size and motorcycle accidents. The accident rate/risk per unit of distance travelled is not dependent on engine size.
The major factors which play a role in motorcycle accidents are:

1. age of the rider;
2. experience of the rider;
3. annual mileage.

Other factors with respect to the rider's attributes and characteristics are: type of road, pattern of use, conditions at the accident site, single/multiple vehicle accidents, and alcohol usage. Many of these factors are strongly correlated (e.g. age and experience, etc.). Some studies suggest that the type of the motorcycle (e.g. touring, standard, race, etc.) might have an effect on the accident rate. However, these conclusions are statistically uncertain and might also result from the rider's behaviour.

Indirect studies

No indirect studies have been found that investigate the effect of high engine power restrictions, not even in France with its restriction of the maximum engine power of 74 kW. The limited indirect studies, which investigate the effect of engine size restrictions for novice motorcyclists, do not make it clear that there is a relation between high-powered motorcycles and accident involvement. The results are weak and even conflicting. It should be mentioned that conclusions of the indirect studies can be regarded at best as a confirmation of the results of the direct studies. The results may become more significant if the accident rates are stabilized several years after the introduction of the engine size restrictions. The conclusions of the indirect studies will not lead to either a change or confirmation of the conclusions of the direct studies.

The conclusion of this literature survey is that there is no scientific evidence that engine size is a major factor in motorcycle accidents; engine size does not emerge as a risk factor. The statistical database studies which find significant relations did not take into account the annual mileage, a measure of risk exposure for accidents, and an influential factor. The results of these statistical data-

base studies indicate that annually more powerful motorcycles are involved in fatal and serious accidents than less powerful motorcycles. The high number of accidents of the powerful motorcycles are explained by the different pattern of use and the rider's characteristics.
It should be mentioned that a two-wheeled, single-track motorcycle is an instable vehicle in which an accident will almost certainly result in a fall.

The following factors are found to be significantly involved in motorcycle accidents:
1. age of the motorcyclist;
2. experience of the motorcyclist;
3. annual mileage.

Accident risk declines with both age and experience. Age and experience may be highly correlated, as most motorcyclists start to ride when young.

The factors used in the studies to describe motorcycle performance characteristics are engine size, engine power, or power-to-weight ratio. All of these factors are related to power, maximum speed, and acceleration. The relation between engine size and (acceleration) power is only generally applicable. However, the difference in engine power of motorcycles with the same engine size can be considerable. It is dependent on the type of motorcycle; touring, street/normal, race, etc.

Are the above factors sufficient to describe the performance behaviour of motorcycles? These are factors which can easily be determined and characterize the power source of the vehicle. Due to the two-wheel, single-track design of a motorcycle, other properties also have a major influence on the overall motorcycle dynamics and handling characteristics.
Another problem with motorcycles is that the rider is not only steering and controlling the machine but also stabilizing it. The motorcyclist is an integral part of the total vehicle system. This makes it difficult to discriminate between the influence of rider characteristics and a single motorcycle performance property on accident risk.

6 References

[1] Albus, C. (1993)
Krafträder der Leistungsklasse über 74 kW.
Bundesanstalt für Straßenwesen, Bergisch Gladbach, Mai 14, 1993

[2] Bragg, B.E.E., Dawson, N.E., Jonah, B. (1980)
Profile of the accident involved motorcyclists in Canada.
In Motorcycle Safety Foundation (Ed.), Proceedings of the International Motorcycle Safety Conference. Linthicum, Maryland: Motorcycle Safety Foundation

[3] Brorsson, B. (1983)
Wobble and weave in motorcycles.
Trafiksaekerhetsverket, Borlaenge, Sweden

[4] Broughton, J. (1987)
The effect on motorcycling of the 1981 transport act
TRRL Research Report 106, 1987

[5] Broughton, J. (1988)
The relation between motorcycle size and accident risk
TRRL Research Report 169, 1988

[6] Broughton, J. (1991)
Safer Motorcycling Part II: The variation of motorcyclists accident risk with age, experience and motorcycle engine capacity.
In safety 91: Papers on Vehicle Safety, Traffic Safety and Road User Safety Research; 1-2 May 1991
Transport and Road Research Laboratory, Crowthorne, 1991

[7] Carré, J-R., & Filou, C. (1994)
Accident risks for tow-wheelers in France: safety of two-wheelers is largely subject to the skill and vigilance of cars drivers.
In 14th International Technical Conference on the Enhanced Safety of Vehicles (ESV), May 23-26, 1994, Munich, paper no. 94 S7 W 15

[8] Filou, C., Noëll, O., & Decamme, C. (Eds.) (1993)
La sécurité des motocyclettes en 1992. Étude sectorielle.
l'Observatoire National Interministériel de Sécurité Routière. La Documentation Française-Paris, 1993

[9] Hull, M.A. (1981)
Age, driving experience and engine capacity and their effects motorcycle accidents.

Traffic Research Circular No. 17. Traffic Research Section, Road Transport Division, Ministry of Transport, New Zealand, Wellington 1, New Zealand

[10] Hurt, H.H., Quellet, J.V. and Thom, D.R. (1981).
Motorcycle accident cause factors and identification of countermeasures. Volume I: Technical report. Final Report.
National Highway Traffic Safety Administration report no. DOT-HS-805-863. Springfield, Virginia: National Technical Information Service.

[11] Ingebrigtsen, S. (1989)
Motorsykler, mopeder og ulykker
Institute of Transport Economics, Norway (TØI), Repport 30/1989, August 1989

[12] Koch, H. (1987)
Zusammenhänge und Einflüsse von Lebensalter, Fahrerfahrung und Motorleistung auf die Unfallentwicklung von Motorradfahranfängern: Ergebnisse multivariater Auswertungen.
In VDI - Gesellschaft Fahrzeugtechnik (Ed.), Aktive und passive Sicherheit von Krafträdern. (pp. 1-14). VDI Berichte 657. Düsseldorf: VDI Verlag

[13] Koch (Ed.), H. (1990)
Motorcycle licensing: evaluation of the effectiveness of a graduated licening scheme.
Forschungshefte Zweiradsicherheit. Bochum: Institut für Zweiradsicherheit

[14] Koch, H., & Hagstotz, W. (1990)
Influencing factors on accidents of motorcyclists: empiric investigation of the suppositions and prerequisits of a graduated driving license model.
In Motorcycle Safety Foundation (Ed.), The Human Element: 1990 International Motorcycle Safety Conference Proceedings. (pp. 13.73-13.103). 2. Irvine: Motorcycle Safety Foundation.

[15] Koch-H, Schulz-U (1991)
Motorcycle accidents: views from psychological accident research and results of multivariate analysis of empirical Investigation.
In VDI-Berichte Nr. * VOL: 875, pp. 347-355????

[16] Koch, H., Schulz, U. (1993)
Factors that influence the involvement of motorcycle riders
In the thirteenth International Technical Conference on Experimental Safety Vehicles, November 4-7, 1991, Paris, France. Volume I, pp. 263-268

[17] Koenen, C. (1983)
The dynamic behaviour of a motorcycle when running straight ahead and when cornering. Doctoral Thesis.
Delft University of Technology, The Netherlands, 1983.

[18] Kroj, G., Stöcker, U. (1986)
Statistische Analyse der Unfall- und Bestandsentwicklung motorisierter Zweiräder.
Der Motorradunfall, Vol. 3, pp. 1-46, 1986

[19] Lynn, P. (1990)
Factors affecting the accident liability of motorcyclists - an analysis of survey data.
Behavioral Studies Unit, Safety and Transportation Group Contract report 146. Crowthorne: TRLL

[20] Lynn, P. (1990).
Factors affecting the accident liability of motorcyclists. Technical report.
Social and Community Planning Research. Report P.979 july 1990.

[21] Mayhew, D.R., & Simpson, H.M. (1989).
Motorcycle engine size and traffic safety.
Ottawa, Canada: The Traffic Injury Research Foundation of Canada

[22] J. Monsrud (1996)
Accidents involving heavy motorcycles in 1993 and 1995.
Statistics Norway (to be published)

[23] Pedder, J.B., Newman, J.A., Mackay, G.M. (1990)
The role of in-depth motorcycle accident studies in the reduction of accident trauma
In proceedings of the 1990 International IRCOBI Conference on the Biomechanics of Impacts, held in Bron-Lyon, 12-14 September 1990

[24] Rogerson, P. (1991)
Accident involvement and exposure by type of motorcycle
Vic Roads. Road Safety Division, Victoria Australia, Report GR/91-5, 1991-02

[25] Rogerson, P., Lambert, J., Allen, P. (1992)
Motorcycle accident involvement by power to weight ratio for novice and experienced riders
Vic Roads. Road Safety Division, Victoria Australia, Report GR92-11, 1992-11

[26] Ruijs, P.A.J., & Pacejka, H.B. (1985)
Recent research in lateral dynamics of motorcycles.
In O. Nordström (Ed.), Proceedings of the 9th IAVSD Symposium "The dynamics of vehicle on roads and on tracks", Linköping, Sweden, June 24-28, 1985

[27] Rutter, D.R., Quine, L. (1996)
Age and experience in motorcycling safety.
Accident Analysis & Prevention, jrg 28, nr 1, pp. 15-21, Jan-1996, GB

[28] Schulz, U. (1990)
Factors affecting different kinds of motorcycle accidents.
In Motorcycle Safety Foundation (Ed.), The Human Element. 1990 International Motorcycle Safety Conference Proceedings. (pp. 1.14-1.33). 1. Irvine: Motorcycle Safety Foundation

[29] Schulz, U. (1990)
Zur Unfallverwicklung von Motorradfahranfängern.
In H. Koch (Ed.), Motorradfahren. Faszination und Restriktion. (pp. 165-186). Forschungshefte Zweiradsicherheit 6. Bochum

[30] Schulz, U., Hagstotz, W. (1990)
Zur Unfallverwicklung von Motorradfahranfängern.
Analyse von Unfalldaten aus der Studie "Motorradfahren in Deutschland: Basisstudie 1988".
In H. Koch (Ed.), Motorradfahren: Faszination und Restriktion. (pp. 187-199). Forschungshefte Zweiradsicherheit 6. Bochum: Institut für Zweiradsicherheit

[31] Schulz, U., Koch, H. (1991)
Factors that influence the involvement of motorbikers in traffic accidents
Safety-Environment-Future. In proceedings of the 1991 International Motorcycle Conference, pp. 89-103, 1991

[32] Scott, C., & Jackson, S. (1960)
Accidents to young motorcyclists - A statistical investigation.
Central Office of Information, Social Survey Division, Montagu Mansions, Baker Street, London, W.1.

[33] Simpson, H.M., & Mayhew, D.R. (1984)
Motorcycle engine size and collision involvement.
Ottawa, Canada: The Traffic Injury Research Foundation of Canada

[34] Statistische Bundesamt
Zweiradunfälle im Straßenverkehr 1994.
Auszug aus Fachserie 8, Reihe 7 "Verkehrsunfälle 1994", Statische Bundesamt, Gruppe Verkehr VC-81

[35] Stöcker, U. (1990)
Situation der stark motorisierten Zweiräder in der Bundesrepublik Deutschland.
Bundesanstalt für Straßenwesen, Bergisch Gladbach, April 9, 1990

[36] Taylor, M.C., Lockwood, C.R. (1990)
Factors affecting the accident liability of motorcyclists - a multivariate analysis of survey data.
Behavioral Studies Unit, Safety and Transportation Group Research report 270. Crowthorne: TRLL

[37] Taylor, M.C., & Maycock, G. (1990)
Factors affecting the accident liability of british motorcyclists.
In Motorcycle Safety Foundation (Ed.): The human element. Proceedings of the 1990 International Motorcycle Safety Conference, Vol. I., Orlando, Florida

[38] Thomson, G.A. (1980)
Motorcycle surveys: Headlights, helmets and engine capacity checks.
Traffic Research Section, Road Transport Division, Ministry of Transport, Wellington, New Zeeland. (Traffic research report 23)

[39] Troup, G.A., Torpey, S.E., Wood, H.T. (1984)
Engine capacity restrictions for novice motorcyclists - the Victorian experience
In proceedings of 12th ARRB Conference, Hobart, Tasmania, 27-31 August 1984. Vol. 12, nr. 7

[40] Vis, A.A. (1995)
De onveiligheid van motorrijden nader bekeken.
Stichting Wetenschappelijk onderzoek Verkeersveiligheid SWOV, rapport R-95-69, 1995 (in Dutch)

[41] Weinand, M. (1994)
Stufenführerschein für motorisierte Zweiradfahrer.
Zeitschrift für Verkehrssicherheit, Vol. 40, nr. 1, 1994