A Literature Review on Motorcycle Collisions
Final Report

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Executive Summary

The Transport Studies Unit, University of Oxford, was commissioned by the Association of Chief Police Officers (ACPO), in conjunction with the Police Foundation, to review the literature on motorcycle accidents. This included a review of the data on national motorcycle accidents, motorcycle user demographics and trends in the motorcycle market. It also included a review of the types of motorcycle accidents, their causes and primary and secondary prevention measures.

It is well known that motorcycles have the potential to be a safety hazard. For example, in Great Britain in 2002 the number of people killed or seriously injured (KSI) using two wheeled motor vehicles was 147 per 100 million vehicle kilometres. The comparable casualty rate for car users was 5 per 100 million vehicle kilometres. The all injuries casualty rate for two wheeled motor vehicles was 556 per 100 million vehicle kilometres compared to 50 per 100 million vehicle kilometres for car users. However, there have been some improvements in motorcycle safety. For example, between 1982 and 1996 the number of KSI casualties reduced from 16,281 to 5,640, but by 2002 the number of KSI casualties had increased to 6,686.

This recent increase in accidents seems to be correlated with increased motorcycle ownership and use. In particular, there has been a big increase in the number of high-powered machines (with an engine size of 500cc or above). There were 155,000 such machines in 1992 but by 2002 their number had increased to 482,000. Moreover, there have been significant changes in the demographics of those involved in motorcycle accidents. In 1982 almost half of all KSI casualties were under 20, by 2002 this had decreased to a little over 1 in 10. By contrast 30 to 39 year olds accounted for less than 1 in 10 KSI casualties in 1982 but by 2002 accounted for around a third of such casualties. National data seem to confirm the anecdotal evidence that born-again riders are posing a road safety problem.

Studies carried out in several countries show that between half and three-quarters of motorcycle accidents involved collision with another vehicle. Among these multiple vehicle accidents, the driver of the other vehicle often violated the motorcycle right-of-way. Furthermore, a study of accident typology suggests that five main types account for over 80% of *fatal* accidents in the US: ran off road; ran traffic control; oncoming collision, oncoming right-turn collision; and motorcyclist down. Among them, motorcycle running off road is the most common type, which accounts for 41% of the total. These are often late night, weekend crashes involving a drunken motorcyclist.

The literature suggests two main groups of causes. The first group relates to difficulties in motorcycle detection as a result of the poor conspicuity of motorcycles due to their smaller size (leading to poor sensory conspicuity) and lower frequency (leading to poor cognitive conspicuity) than other road vehicles, as well as the visual limitations of other road users. The second group relates to problems of motorcycle use, including excessive risk taking by certain riders and alcohol impairment. For example, in the US in 1998 over one in three motorcyclists involved in fatal accidents

were intoxicated, although this was an improvement on earlier studies where the figure was more than a half.

Preventative action involves a mixture of education, engineering and enforcement measures. Primary accident prevention involves reducing the number of accidents. The motorcyclist licensing and rider training regimes in the UK are reviewed, including the Police Assessed Ride Programme in Scotland. These regimes are then compared with graduated licensing schemes in New Zealand and parts of Canada and the United States. The other form of primary prevention involves conspicuity improvements including daytime running headlights and the colour and fluorescence of the vehicle (and rider). Secondary measures may not reduce the number of accidents per se, but can reduce the severity of such accidents. The two main types of measures reviewed are motorcycle design, including brakes, airbags and leg protection, and motorcycle helmets and other protective equipment.

Since the mid 1990s there has been an increase in motorcycle casualties in Great Britain, in marked contrast to the previous downward trend. For example, the number of motorcycle related KSI casualties reduced by 65% between 1982 and 1996 but has since increased by almost 19% between 1996 and 2002. This increase is almost entirely due to increased ownership and use of motorcycles. Indeed the KSI casualty rate per motorcycle vehicle kilometre continues to fall (down 12% between 1994/8 and 2002).

However, some important changes in motorcycle ownership and use also seem to have occurred. With respect to motorcycle ownership, the big change has been in machines of 500cc and above, with their numbers trebling over the last ten years (1992-2002). With respect to motorcycle use, the data, and particularly the data on accidents, suggest that this is no longer the domain of young men. For example, in 1982 the under 20s accounted for 49% of motorcycle casualties but by 2002 this had decreased to under 12%. By contrast, the 30-39 age group made up 8% of motorcycle KSI casualties in 1982 but by 2002 this had increased to 33%.

There is thus some statistical support for anecdotal evidence that the born again motorcycle rider is becoming something of a public health problem. Further work is required to quantify the extent and nature of this problem and in particular to determine the extent to which the problem of increased casualties amongst older motorcycle users is due to middle aged men returning to motorcycling or existing motorcyclists upgrading to more powerful machines as they get older. This will be important in framing new policy towards rider training and licensing which to date has focused on younger riders and less powerful machines and has assumed a continuity of motorcycle use.

1 Introduction

Motorcycles, which are a small subset of all motor vehicles, are greatly over-represented in fatal motor vehicle accidents. In the United States, the death rate per registered motorcycle (59 per 100,000) is approximately three times the death rate per registered passenger car (17 per 100,000). Death rate calculated per vehicle, however, do not take into account the substantially lower mileage travelled by motorcyclists. Per mile travelled, the death rate for motorcycles is estimated to be 22 times higher than the comparable death rate for passenger cars (Preusser et al., 1995). In an earlier study, Wulf et al. (1989) estimated the death rate for motorcycle riders of about 35 per 100 million miles of travel compared with an overall vehicle death rate of 2.57 per 100 million miles. In Great Britain in 2002, the “Killed or Seriously Injured” (KSI) casualty rate was 147 per 100 millions vehicle kilometre for two wheeled motor vehicles, whilst for car users the rate was 5 per 100 million vehicle kilometres (DfT, 2003a).

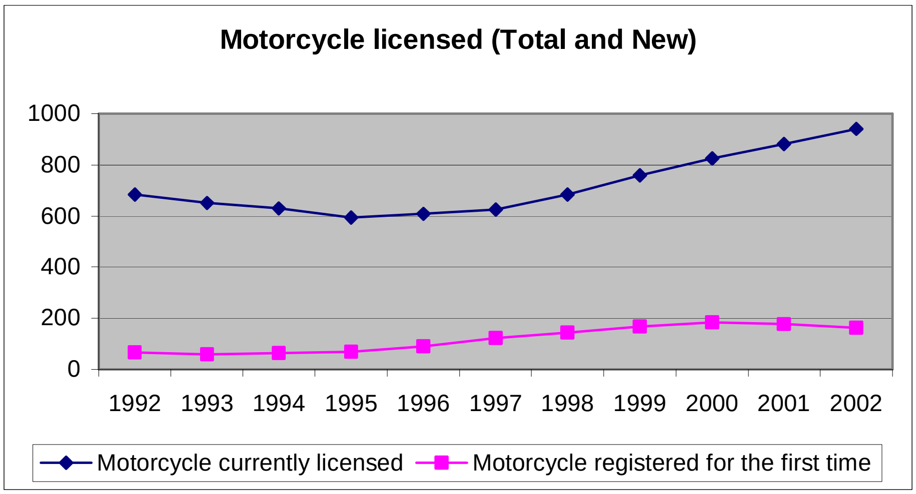
Besides the higher death rate, motorcyclists are more likely to be injured when involved in an accident. Horswill and Helman (2001a) looked at 399 injury accidents in the UK (1999 data) in which either a motorcycle or car was involved in a head on collision with a car (that is, both types of vehicle collided with the same type of object in the same way). Around 97% of motorcyclists were injured or killed in these collisions compared with 50.5% of car drivers (in accidents where the car driver or motorcyclists was not injured, the injured parties were either passengers or the occupants of the other vehicle). To take into account the possibility that motorcycle/car collisions may occur at higher speeds than car/car collisions, they assessed a sample of 109 motorcycle/car head on collisions (that is, the impact speed was the same for the car and the motorcycle) from the same dataset, and found that the motorcyclists involved were 95.4% likely to be injured while the car drivers were 0.9% likely to be injured. The much higher injury rate confirmed that motorcyclists are more physically vulnerable than car drivers. Overall, the casualty rate (all injury types) is 556 per 100 millions vehicle kilometre for two wheeled motor vehicle, compared to 50 for car users in Britain 2002.

2 National Trend in Motorcycle Use and Motorcycle Accident

2.1 Licensed Motorcycle and Motorcycle Traffic

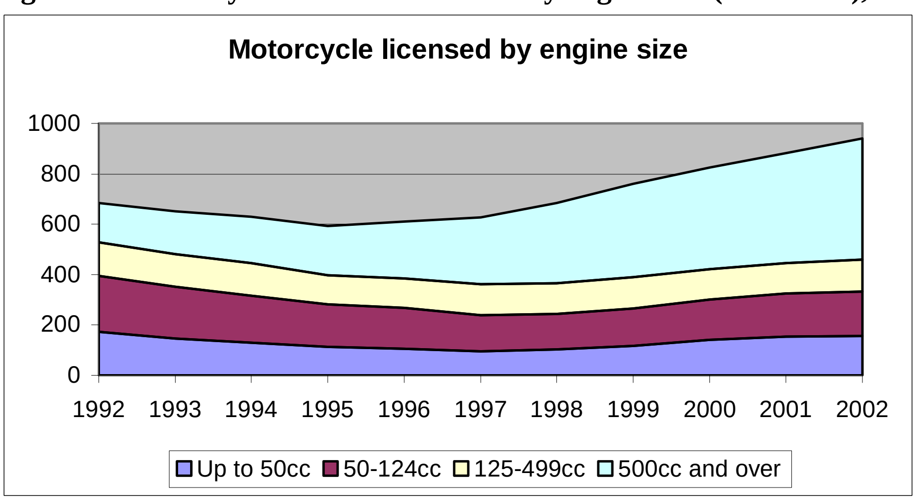
The number of motorcycles (including scooters and mopeds) licensed was 941 thousand at the end of 2002, which accounts for 3.1% of the total vehicles registered in Great Britain (DfT, 2003b). This is well below the 1960 peak of over 1.5 million, when motorcycles accounted for 19% of all registered vehicles. Nevertheless, the total number of licensed motorcycle has gradually increased since 1996, while the number of new motorcycle registration increased for most of the 1990s (Figure 2.1).

Figure 2.1 Motorcycle licensed in Britain (Thousand), 1992-2002



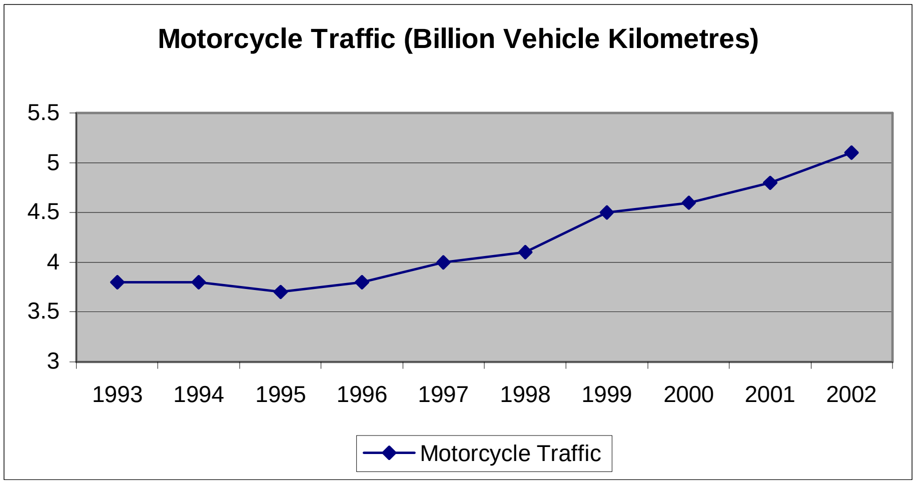
Over the last 10 years there has been a change in the size of motorcycles licensed with over a half of those licensed at the end of 2002 of 500cc and over (482 thousand), compared with only 155 thousand (22.6%) in 1992. In contrast, there is a slight fall in the numbers of smaller motorcycles (under 125cc) from 394 thousand (57.6% of all motorcycles) to 332 thousand (35.2% of total) for the same period (Figure 2.2).

Figure 2.2 Motorcycle licensed in Britain by engine size (Thousand), 1992-2002



The motorcycle traffic has also increased over the ten years period prior to 2002. As the pre-1993 road traffic data were estimated using a different methodology and not directly comparable, Figure 2.3 shows the motorcycle traffic has increased from 3.8 billion vehicle-km in 1993 to 5.1 billion vehicle-km in 2002.

Figure 2.3 Motorcycle traffic in Britain (Billion vehicle-km), 1993-2002



2.2 Motorcyclists and Motorcycle use

The number of active motorcyclists could be estimated in principle from DVLA information on the number of motorcyclist licences. The age and sex of the rider is also given. However, Broughton (1987) found that this significantly overestimated the number of active motorcyclists since large proportions of those with licences do not ride regularly. A better measure of the number of active motorcyclists therefore is the number of motorcycles licensed, as discussed in the previous section. One significant drawback of this measure is that no demographic information of the motorcyclists (age, sex, area, etc.) is available. Another problem of this measure is that some owners fail to license their vehicles to avoid paying Vehicle Excise Duty and some owners may own more than one bike.

An alternative source of information is the National Travel Survey, which collects data on the travel habits of around 3,200 households (around 8,000 individuals) per year. Individuals complete a seven-day (consecutive days) travel diary recording details of travel such as the purpose of the journey, the method, the distance traveled and the time of day as well as personal information. This information is invaluable in linking the motorcyclist demographics, motorcycle information (such as engine size) with motorcycle use. Its major drawback is the small sample of the respondents who ride motorcycles (in line with the small number of active motorcyclists). To get the necessary level of details, several years of data has to be aggregated and thus mask changes over time (Elliott et al., 2003).

One comprehensive study of motorcyclist and motorcycle use based on the NTS data is reported in DfT (2001). The period of 1992 to 1999 is covered in the analysis, as the sample sizes are too small for a shorter period of time. The key results cover motorcycle travel by area, journey purpose, age and sex as well as motorcycle size.

2.2.1 Motorcycle Travel by Area Type

Table 2.1 shows that motorcyclists living in London were the heaviest users of motorcycles, making the most trips and travelling the furthest distance per trip. Those living in rural areas made less trips but travelled further than average. The average trip length was greatest in the London and Metropolitan areas and in rural areas, perhaps owing to the greater distance travelled for commuting, for which motorcycles are mainly used (see next section).

Table 2.1 Motorcycle use by motorcycle users by area type of residence, 1992-99

	London Boroughs	Met Areas	Population >250k	Population 25-250k	Population 3-25k	Rural Areas	All Areas
Trips per person per week	9.7	8.5	9.2	9.2	9.3	9.0	9.2
Miles per person per week	91	73	68	62	72	78	72
Average trip length (miles)	9.4	8.6	7.3	6.8	7.9	8.6	7.8

2.2.2 Motorcycle Travel by Journey Purpose

Of the average 9.2 motorcycle trips per person using a motorcycle made in the travel week, Table 2.2 shows that the main trip purposes were commuting, business and education, which accounted for 57% of trips and 50% of the distance travelled. A further 16% of trips were made to visit friends, the second most important purpose. On average the distance ridden for work or education was 6.7 miles. For leisure purposes (including holidays and day trips) the average was 21.3 miles per trip. By comparison, the average shopping trip was only 4.6 miles in length.

Table 2.2 Motorcycle use by journey purpose, 1992-99

	Work, Business and Education	Shopping	Other personal business and escort	Visit friends	Other leisure	All purpose
Trips per person per week	5.3	1.1	0.7	1.4	0.7	9.2
Miles per person per week	36	5	4	12	16	72
Average trip length (miles)	6.7	4.6	5.5	8.2	21.3	7.8

2.2.3 Motorcycle Travel by Sex and Age

Table 2.3 shows that men were 6 times more likely to register a trip as a motorcycle driver than women. Overall 1 per cent of the sample registered a motorcycle trip. This was more than doubled for men less than 60 years old. Although women were less likely to be motorcycle drivers than men, those who used motorcycles made about the same number of trips as men (9.6 trips in the travel week compared with 9.2 for men). However, the overall distance travelled by women was 42 per cent less than that travelled by men. Women tended to make much shorter trips on average than men, travelling 4.6 miles compared to 8.3 miles. This resulted in males drivers travelling nearly 76 miles in the travel week compared with 44 miles for women. Men aged 16–

29 were the heaviest users of motorcycles in terms of distance ridden averaging 85 miles in the travel week for this age group.

Table 2.3 Motorcycle use by Sex and Age, 1992-99

	Men				Women	All
	16-29 years	30-59 years	60+ years	All 16+years	All 16+years	All 16+years
% of sample making a trip	2.3	2.2	0.6	1.8	0.3	1.0
Trips per person per week	10.2	8.8	8.2	9.1	9.6	9.2
Miles per person per week	85	76	44	76	44	72
Average trip length (miles)	8.3	8.7	5.3	8.3	4.6	7.8

2.2.4 Motorcycle Travel by Size and Journey Purpose

Table 2.4 shows that the average annual distance travelled by a motorcycle increases with motorcycle size, from 2,270 miles for small motorcycles of 50cc and less to 4,290 miles a year for motorcycles of 500cc and above. The proportion of mileage for smaller motorcycles was greatest for commuting, business and education than for other purposes. Over half of the mileage traveled for motorcycles under 125cc was for this purpose, while larger motorcycles over 500cc were used more for leisure purposes than smaller motorcycles, although the main use (in terms of distance) was still for work and education. As leisure includes holidays and day trips, the greater mileage could be explained by larger motorcycles being more used for those purposes which on average have much greater lengths than other journeys.

Table 2.4 Motorcycle use by Size and Journey Purpose, 1992-99

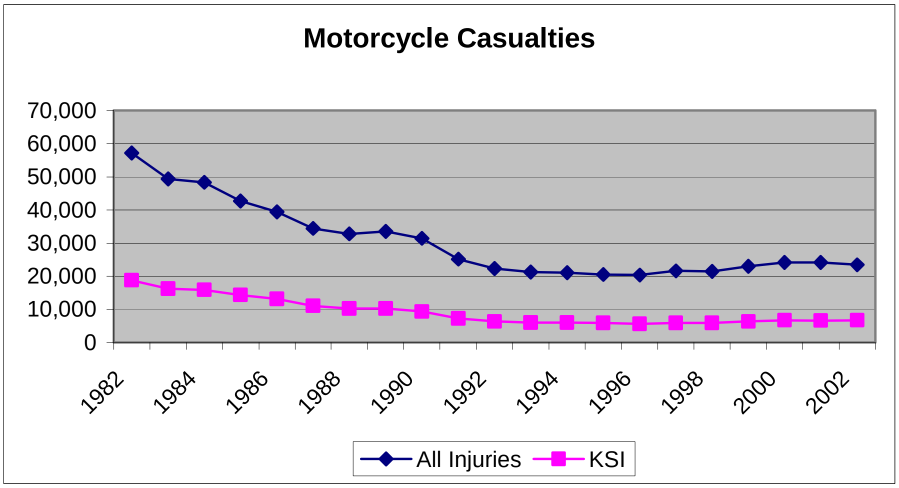
	Work, Business and Education	Shopping	Other personal business and escort	Visit friends	Other leisure	All purpose	Average Annual Mileage
50cc or less	56	8	9	21	7	100	2,270
50-125cc	67	10	4	13	5	100	3,000
125-500cc	46	9	7	20	18	100	3,210
500cc and over	37	6	6	16	35	100	4,290
All size	46	7	6	17	23	100	3,440

2.3 Motorcycle Casualties

2.3.1 Overall Trends in Motorcycle Casualties

From 1982 to the mid-1990s the number of motorcyclist casualties and motorcyclists killed and seriously injured (KSI) fell rapidly (Figure 2.4). In 1982, the number of KSI casualties was 16,281; this had reduced to 5,640 in 1996. Since then, the number of casualties has begun to increase again. As discussed in the previous section, the rise in casualties has been accompanied by a rise in the stock of motorcycles and total motorcycle mileage in recent years. The number of KSI casualties was 6,686 in 2002, an 18.5% increase from the 1996 trough. Nevertheless, the casualty rate is continuing to fall. In 2002, the KSI casualty rate was 147 per 100 million vehicle kilometres, a 12% fall from the 1994-98 average of 167 (DfT, 2003a).

Figure 2.4 Motorcycle Casualties in Britain, 1982-2002

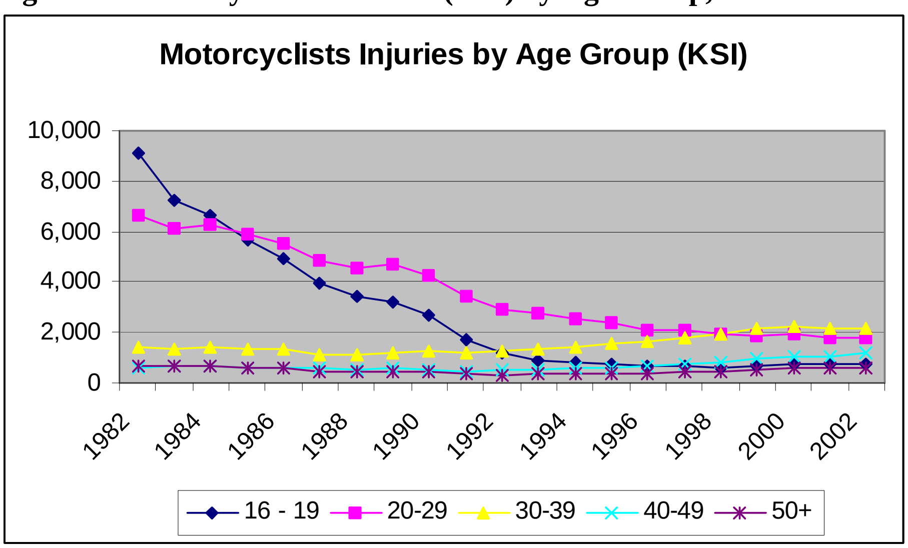


(Source: Data provided by Department for Transport, Transport Statistics Division)

2.3.2 Demographics of Motorcyclist Casualties

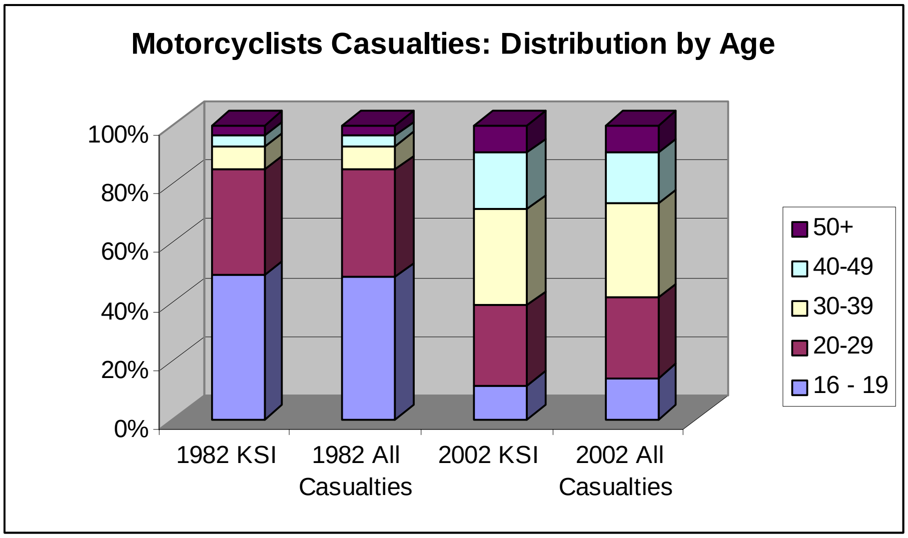
The rapid decline of motorcyclist casualties, especially for the period up to the mid-1990s, could be largely attributed to the decline in casualty numbers amongst young riders. For the 16-19 age group, the number of KSI casualties was 9,117 in 1982, compared to the trough of 619 in 1998. The 20-29 age group experienced a similar decline of casualty number from 6,613 in 1982 to 1,760 in 2002. However, the number of KSI casualties for the 30-39 age group has increased from 1,451 in 1982 to 2,135, while a similar upward trend is also evident for the 40-49 age group (Figure 2.5).

Figure 2.5 Motorcyclist Casualties (KSI) by Age Group, 1982-2002



Over the past 20 years, the composition of motorcyclist casualties by age group has changed dramatically. In 1982, the under-20 age group accounted for 49.3% of KSI casualties and 48.6% of all-injury-types casualties. By 2002, these proportions had declined to 11.5% and 14.1% respectively. On the other hand, the 30-39 age group made up 33% of the KSI casualties in 2002, up from 7.8% in 1982. Similarly, the 40-49 age group accounted for 19% of all KSI casualties, although their share was merely 3.4% in 1982. Figure 2.6 compares the proportion of motorcyclist casualties in each age group in 1982 and 2002.

Figure 2.6 Age of Motorcyclists Injured, 1982 and 2002



2.3.3 Motorcyclist Casualties and Engine Size

The road casualty data in the UK are collected through the STATS19 form. When linking the STATS19 vehicle registration data with the DVLA record, it is possible to analyse the composition of motorcyclist casualties by engine size. Due to the limited time scale of our work, we are not able to explore the original database. Instead, we refer to an earlier study by Elliot et al. (2003).

In 1996, almost two-thirds of all fatalities involved a bike with an engine capacity greater than 500cc. There were almost 4 times as many fatalities involving a machine with a 500cc or over engine as for other groups. This represented a large shift: only a quarter of all fatalities involved this group of bikes in 1984. Furthermore, the proportion of fatalities involving large motorbikes that occurred on non-built-up road had increased dramatically over the same period: from about 15% in 1984 to over 40% in 1996. In fact, Elliot et al.'s study showed that almost two-thirds of the riders killed on the non-built-up roads were aged over 30 and were riding bikes with an engine capacity greater than 500cc.

3 Why are motorcyclists more prone to accident and injury?

What are the possible reasons behind why motorcyclists are more at risk than car drivers? There seem to be two major factors contributing to the higher accident and injury rate: the problem of detecting a motorcycle and the higher levels of risk taking behaviour (including riding under impairment) engaged in by motorcyclists.

3.1 Problem of Motorcycle Detection

Motorcycle crash studies provide ample evidence that motorcyclists are not easily seen by drivers of other vehicles, particularly when traffic is heavy and the visual field is complex. A common claim of motor-vehicle drivers involved in crashes is that they did not see the motorcycles and their riders at all, or did not see them in time to avoid the crash. In roughly half of the cases in which motor-vehicle drivers failed to detect a motorcycle in time to avoid a crash, other obstacles were present, either within the vehicle, as part of the landscape, or in passing traffic, that interfered with the driver's line of sight (Hurt et al., 1981; Bednar et al. 2000). The ability of other road users to see and notice the motorcycle is termed conspicuity. Because motorcycles are less conspicuous than passenger cars or trucks, they are more difficult to detect and their approaching speed is more difficult to determine, and this largely contributes to the high accident rate of motorcycles (Thomson 1980; Wulf et al., 1989; RSC, 1992).

Hancock et al. (1990) described two factors that lead to drivers failing to detect motorcyclists in the first place: sensory conspicuity (the physical qualities of the approaching vehicle that distinguish it from its background) and cognitive conspicuity (the degree to which the observer's experience or intentions affects the salience of the approaching vehicle). Motorcycles have poor sensory conspicuity (due to the smaller size of the motorcycle) but they also have poor cognitive conspicuity (they are less frequent and hence less expected than cars).

3.1.1 Smaller Size of Motorcycles

According to RSC (1992), size is one of the important factors influencing conspicuity. The face-on silhouette area of motorcycle is 30-40% of a passenger car but this is enlarged, on the one hand, by fairings or, on the other, by changing the angle of approach. Under daytime ambient light conditions, even motorcycles are big enough to be seen far enough away to allow execution of avoidance manoeuvres when they are in a driver's visual field. However, motorcycles' small size increases the likelihood that motorcycles will be obscured by traffic and their detection may rely on their being seen in a gap a long distance away.

Moreover, people identify objects on the basis of their size, shape, colour and motion. At a distance motorcycles are similar to pedestrians or bicycles except for their speed. Size is related to judgement of speed and distance so that the speed difference between motorcycles and other road users may not always be enough to enable drivers to discriminate between them at long distances.

These findings are supported by Horswill and Helman (2001). They found that people waiting to pull out at a junction have problems detecting when a motorcycle will reach them. People judged an oncoming motorcycle would reach them later than an oncoming car – despite the actual time to arrival being exactly the same. This is likely to be due to the smaller size of motorcycles, since the increase in their size as they approach – their rate of looming - is less easy to detect.

3.1.2 Lower Frequency of Motorcycles on the Road

The lower frequency of motorcycles on the road is another factor that causes drivers of other vehicles to overlook motorcyclists and subsequently violate their right-of-way. Many drivers do not anticipate routine encounters with motorcyclists in traffic (NHTSA and MSF, 2000).

Hurt et al. (1981) found that drivers involved in crashes with motorcycles were more likely to be unfamiliar with motorcycles. Brooks and Guppy (1990) shows drivers who also ride motorcycles and those with family members or close friends who ride are more likely to observe motorcyclists and less likely to collide with them. This indicates that drivers can see motorcyclists, whom they might otherwise overlook, if they mentally train themselves to do so.

Some experts adduce an "expectancy" phenomenon. They follow research on vigilance and say that road users become conditioned to respond more to the visual cues provided by other vehicles than those of motorcycles because of their greater size and frequency on the road.

3.1.3 Visual Limitation of Drivers

The visual problem is compounded by a variety of visual limitations confronting drivers (RSC, 1992; NHTSA and MSF, 2000). The typical factors are:

- The physiology of the human eye influences the driver’s ability to see the motorcyclists. Blink frequency, direction of eyesight, eye movement, masking and glare are all factors affecting the drivers’ ability to detect the motorcycle in various light and manoeuvre scenarios;
- Automobiles have obstructions and blind spots that can obscure or hide a motorcycle and rider. These include door pillars, passengers’ heads, and areas not visible in the mirrors;
- Other conditions affecting the vehicle—such as precipitation, glare, and cargo—can further impair a driver’s view and obscure motorcyclists;
- Objects and environmental factors beyond the vehicle, including other vehicles, roadside objects, and light patterns can make it more difficult for drivers to identify motorcyclists in traffic.

3.2 The Behaviour of Motorcyclists

Motorcycle accidents can also be caused by the aggressive driving and risk taking behaviour of motorcyclists. Motorcyclist alcohol and other impairments are a prominent factor in serious motorcycle crashes. Early research in the United States has shown that more than half of fatal motorcycle accidents involved alcohol (Hurt et al., 1981).

3.2.1 The Risk Taking Behaviour of the Motorcyclists

Risk taking has been identified as a critical contribution to the occurrence of many health problems such as motor-vehicle crashes (Jelalian et al., 2000).

Horswill and Helman (2001a) analysed the behaviour of the motorcyclists in a laboratory environment. They found that motorcyclists chose faster speeds than the car drivers, overtook more, and pulled into smaller gaps in traffic, though they did not travel any closer to the vehicle in front. The speed and following distance findings were reproduced by two further studies where cars and motorcycles were unobtrusively measured from the roadside.

The risk taking behaviour of motorcyclists are also influenced by demographic factors. For example, Chesham et al., (1993) found that young male motorcyclists are at a higher risk of accident involvement than other motorcyclists. In general, young male drivers as a group behave more riskily than females and older drivers and are also worse at hazard perception than older drivers (McKenna, et al., 1998). Both these factors are likely to influence their accident liability and, indeed, young male drivers have a higher accident liability than either females or older drivers (Maycock, et al., 1991; McKenna et al., 1998).

Moreover, Lin et al. (2003) showed that young motorcyclists with crash experience had higher risk-taking levels during the study period than those without previous crash experience. It seems that motorcyclists who perceive a higher risk after experiencing a crash do not adopt precautionary behaviour or do not reduce their risk-taking levels. This finding is consistent with the results for all motor-vehicle crashes (Begg et al., 1999; Slap et al., 1991).

However, given the extent to which motorcyclists took more risks, the increased risk-taking behavior of motorcyclists was only likely to account for a small proportion of the difference in accident risk between motorcyclists and car drivers. For example, Horswill and Helman (2001a) believed that the difference in speeds would make motorcyclists only 4% more likely to be killed given a crash if the motorcyclists had the same physical protection as a car driver.

3.2.2 Motorcyclist Alcohol and Other Impairment

Alcohol and other substances have been found to be major risk factors in all types of motor vehicle crashes. According to the Traffic Safety Facts (NHTSA, 1998a), these factors appear to weigh more heavily in motorcycle crashes than in crashes of other vehicle types in the United States based on the following:

- In 1998, intoxication (BAC > 0.10 percent) rates for vehicle operators involved in fatal crashes were 36 percent for motorcycles, 29 percent for light trucks, 25 percent for passenger cars, and 3.0 percent for large trucks. An additional 9.0 percent of motorcycle operator fatalities had a BAC of 0.01 to 0.09 percent
- Forty-five percent of motorcycle operators killed in single vehicle crashes, and 62 percent killed in weekend-night, single vehicle crashes, were intoxicated;

- Helmet use rates in the US for intoxicated motorcyclists are lower than for those who are sober. Impaired motorcyclists involved in crashes are more likely to be speeding than those not drinking.

Alcoholic beverages are frequently available and promoted where motorcycles are ridden and at events targeted at motorcyclists. Public information programmes and training programmes currently include information on the dangers of alcohol and motorcycling. The effects of alcohol on judgement and vehicle operation skills have been studied and quantified (Moskowitz, 1988). The number of skills needed to operate a motorcycle is known to be higher than for other motor vehicles (MSF, 1974).

3.3 Other factors

3.3.1 Characteristics of Motorcycles

According to Elliot et al. (2003), there are some inherent characteristics of motorcycles that make the riders more prone to accident and injuries:

- Motorcycles tend to have much higher power-to-weight ratios than cars, and increasing numbers of motorcycles are capable of very high speeds and accelerations.
- Being a ‘single track’ vehicle, a motorcycle can easily become unstable and capsize if braking, accelerating or when a slippery road surface causes a wheel to lose adhesion. This is particularly critical if the machine is leaning (‘banking’) to take a bend. Braking can also cause a motorcycle to change its line on a bend.
- Such characteristics make motorcyclists particularly vulnerable if they take bends too fast to be able to stop in the distance they can see to be clear, and to sudden changes in road surface. The need to avoid wheel-locking also means that riders may find it difficult to make best use of the brakes in other emergency situations.
- Longitudinal ridging or grooving of the road surface, and raised road markings, can produce steering instability (see next section for further details).

The most essential characteristic of motorcycles is being a balanced machine. Hence, the incorrect use of brakes is likely to cause the motorcycle to lose balance. For many types of vehicle, incorrect or inappropriate brake application is not critical under most circumstances. With two-wheeled motor vehicles a mistake by the rider that leads to either wheel being over-braked will cause the machine to skid, become unstable and capsize. The incidence of skidding in personal injury accidents is substantially greater for motorcycles (TWMV) than for other vehicles

It has been shown that many motorcyclists brake incorrectly, and this is thought to be a contributory factor in many motorcycle accidents. A study by Sheppard *et al.* (1985) researched the way in which motorcyclists brake by observing their behaviour at road junctions. They found that when braking normally, 36% of riders used only the rear brake and 11% used only the front brake. Even in an emergency 19% still used only the rear brake and 35% used only the front brake. The characteristics of a motorcycle determine that any incorrect braking will have more severe adverse effects on the riders and motorcyclists with less experience and less advanced riding skills are in greater danger of accident and injuries.

3.3.2 The Road Environment

Being two wheelers, motorcyclists are more susceptible to difficulties and hazards created by the design, construction, maintenance and surface condition of roads. They are particularly vulnerable to

- Changes in the level of friction of road surfaces
- Pot holes
- Uneven surfaces
- Poor repairs to the surface
- Spillages
- Drain covers
- Debris
- Road markings.

Other road surface hazards include leaves, which can appear dry but may be soggy underneath, tram tracks, gravel, melted tar in hot weather which may reduce tyre grip or roads that become greasy and slippery in summer during rainstorms (RoSPA, 2001).

Raised road markings can also cause problems for motorcyclists, either by affecting their stability or by retaining water on the surface, which results in a loss of adhesion between the tyres and the road surface. The use of bitumen for repairs can lead to difficulties, especially when the road surface is wet, as it leads to reduced friction and skid resistance. Furthermore, some traffic calming features can cause additional hazards to motorcyclists.

4 The cause and type of motorcycle collision

To determine if there are additional feasible countermeasures that can reduce motorcycle crashes and crash injuries, a more thorough understanding of the cause and type of crash is needed. Crash type analysis is one important technique for studying how and why crashes occur, and for developing targeted countermeasures.

An early study of motorcycle crashes in America is Hurt et al. (1981), which is regarded as the benchmark of motorcycle crash research (NHTSA and MSF, 2000). It was based on the investigation of motorcycle accidents in the Los Angeles Area during the period of 1976 to 1981 and its findings summarised the causes of motorcycle accidents. RSC (1992), a study based on Victoria, Australia, also includes a detailed discussion of motorcycle crash typology. Finally, Preusser et al. (1995) is a comprehensive study of crash typology, which used the Fatal Accident Reporting System data provided by National Highway Traffic Safety Administration (NHTSA, 1993).

These results show that the most common type of motorcycle accident is collision with another vehicle, usually a passenger car. However, for fatal accidents, motorcycle running off the road is the most common type, accounting for 41% of the total. These are often late night, weekend crashes involving a drunken motorcyclist (Preusser et al., 1995). Overall, it appears that while low conspicuity is the main factor that causes motorcycle accidents, impairment has a much more deadly effect on motorcyclists.

4.1 Hurt et al. (1981) and Studies with Consistent Results

Throughout the accident and exposure data there are special observations which relate to accident and injury causation and characteristics of the motorcycle accidents studied. The findings summarising the cause and type of crashes are presented as follows:

- Approximately three-quarters of motorcycle accidents involved collision with another vehicle, which was most usually a passenger automobile. In the multiple vehicle accidents, the driver of the other vehicle violated the motorcycle right-of-way and caused the accident in two-thirds of those accidents.

- Approximately one-quarter of these motorcycle accidents were single vehicle accidents involving the motorcycle colliding with the roadway or some fixed object in the environment. In the single vehicle accidents, motorcycle rider error was present as the accident precipitating factor in about two-thirds of the cases, with the typical error being a slideout and fall due to overbraking or running wide on a curve due to excess speed or under-cornering.

- The most frequent accident configuration (in countries with right hand drive) is the motorcycle proceeding straight then the automobile makes a left turn in front of the oncoming motorcycle. Intersections are the most likely place for the motorcycle accident, with the other vehicle violating the motorcycle right-of-way, and often violating traffic controls.

- The failure of motorists to detect and recognize motorcycles in traffic is the predominating cause of motorcycle accidents. The driver of the other vehicle involved in collision with the motorcycle did not see the motorcycle before the collision, or did not see the motorcycle until too late to avoid the collision. The view of the motorcycle or the other vehicle involved in the accident is limited by glare or obstructed by other vehicles in almost half of the multiple vehicle accidents.

- Vehicle failure accounted for less than 3% of these motorcycle accidents, and most of those were single vehicle accidents where control was lost due to a puncture flat. Vehicle defects related to accident causation are rare and likely to be due to deficient or defective maintenance.

- Roadway defects (pavement ridges, potholes, etc.) were the cause of 2% of accidents; animal involvement was responsible for 1% of accidents.

Hurt et al (1981)'s results are supported by many other studies, which found that collision with another vehicle is the most common cause of accidents. The European Enhanced Vehicle-safety Committee (EEVC) review of motorcycle safety (1993) identified that the object struck most frequently, in a half to two thirds of collisions, was a car. It also found that a quarter to a third of all motorcycle accidents were solo accidents without collision with another vehicle.

Carre and Filou (1994) studied the TWMV accidents in France found that the great majority of two wheeler injury accidents, 70%, involved another vehicle (1093 out of 1554 accidents in the sample) and this was generally a car.

Otte et al. (1998) has investigated and reconstructed a sample of 402 motorcycle traffic accidents in the Hannover region in Germany. They found that the most frequent occurrences were with the motorcycle running obliquely into the front or rear corner of the car (or other four-wheeled vehicle)—23.7%, the bike and car in frontal impact with each other—16% and the motorcycle impacting the side of the car—5.2%. Accidents not involving a collision with a fourwheeled vehicle were grouped together and include cases where the motorcycle simply lost control; this group accounted for 38% of the total.

4.2 Summary Results of Road Safety Commission (RSC) Report (1992)

The study of RSC (1992) is based motorcycle crashes data in Victoria, Australia. It showed that 65% of motorcycle casualties are injured in accidents involving multi-vehicles and a further 22% involve single vehicle crashes. The report addressed the direction of approach of vehicles involved in motorcycle collisions and the road user movements involved in motorcycle collisions.

4.2.1 The Direction of Approach of Vehicles involved in Motorcycle Collisions

The report showed that 28% of multi-vehicle motorcycle crashes involve vehicles approaching each other from opposing directions, within the drivers' central vision. A further 28% involve vehicles approaching each other at right angles (Table 3.2). When motorcycles are involved, multi-vehicle casualty crashes are more likely to involve vehicles which approached each other from opposite directions or in which the approach is unspecified and changeable, for example U-turns. They are less likely to involve vehicles travelling in the same direction.

Table 3.2 Direction of Approach of Vehicles in Multi-vehicle Casualty Accidents Involving Motorcycles and Other Vehicles

Direction of approach	Crashes involving motorcycles %	Crashes involving car %
Adjacent	27.5	31.7
Opposing	28. 0	21.1
Same	28.3	38.4
Other	16.2	8.7

4.2.2 The Road User Movements Involved in Motorcycle Collisions

Collisions involving motorcycles and other vehicle crashes within the three approach categories also differ in the way the vehicles behaved. When vehicles approach each other from adjacent directions (Table 3.3), motorcycle crashes are less likely than other multi-vehicle collisions to involve cross-traffic road user movements. They are more likely to be involved in collisions which occur when one vehicle attempts to turn right into the direction of travel of the other vehicle (right far) or when one vehicle attempts to turn right across the direction of travel of the other vehicle (right near). The motorcycle had the right of way in 74% of these collisions.

Table 3.3 Road User Movements Involved in Motorcycle and Other Vehicle Multi-vehicle Collisions from Adjacent Directions

Road User Movement	Crashes involving motorcycles %	Crashes involving car %
Cross Traffic	46.0	59.8
Right Far	7.7	4.8
Right Near	38.5	27.7
Other	7.8	7.7

When vehicles approach each other from opposite directions, motorcycles are more likely than other vehicles to be involved in collisions, which occur when one vehicle attempts to turn right across the path of the other vehicle (right through) (Table 3.4). These accidents are concentrated in the metropolitan area, and 78% occur at signalised intersections.

Table 3.4 Road User Movements Involved in Motorcycle and Other Vehicle Multi-vehicle Collisions from Opposing Directions

Road User Movement	Crashes involving motorcycles %	Crashes involving car %
Head-On	23.1	34.4
Right Through	75.3	63.8
Other	1.6	1.8

Rear end collisions comprise 56% of motorcycle crashes in which vehicles are travelling in the same direction (Table 3.5). This amounts to 17% of all multi-vehicle motorcycle crashes. However, rear end collisions are much less frequent in crashes involving motorcycles than in those involving other vehicles. Collisions when another vehicle changes lane or performs other manoeuvres are more important in motorcycle collisions than other collisions involving vehicles travelling in the same direction. These comprise 12% of all multi-vehicle motorcycle collisions.

Table 3.5 Road User Movements involved in Motorcycle and Other Vehicle Multi-vehicle Collisions when Travelling in the Same Direction

Road User Movement	Crashes involving motorcycles %	Crashes involving car %
Rear End	56.2	87.4
Lane Change	10.5	4.1
Other	33.3	8.5

4.3 Summary results of Preusser et al. (1995)

Based on the analysis of computer files of coded FARS data for 1992, Preusser et al. (1995) defined ten fatal crash types plus one category for other and unknown. Of the 10 crash types considered, the most frequently occurring crash type was ran off-road, followed by ran traffic control, oncoming (i.e. head-on), left-turn oncoming, and motorcyclist down. Taken together, these five most frequent types accounted for 86% of the 2074 crashes. Table 3.1 shows the distribution of crashes by type for all crashes and separately for single-and multiple-vehicle events.

Table 3.1 Distribution of motorcycle crash types by single-vehicle and multiple-vehicle crashes

Motorcycle crash type	Single Vehicle Crashes	Multiple Vehicle Crashes	All Crashes	%
Ran off Road	831	26	857	41.3
Ran Traffic Control	-	375	375	18.1
Oncoming	-	225	225	10.8
Left-turn oncoming	-	176	176	8.5
Motorcyclist down	83	69	152	7.3
Run down	-	69	69	3.3
Stopped/Stopping	-	66	66	3.2
Road Obstacle	49	2	51	2.5
Lane Change	-	28	28	1.4
Cut off	-	25	25	1.2
Other/Unknown	33	17	50	2.4
All	996	1078	2074	100

Ran off-road crashes involve situations where the motorcyclist leaves the roadway and overturns or strikes some off-road object. This is the most frequently occurring motorcycle crash type accounting for 41% of the total. These are often late night, weekend crashes involving a motorcyclist who has been drinking. Off-road objects struck include: culvert, kerb, or ditch (24% of the 857 crashes); posts and poles (11%); trees (10%); and guardrails (10%). This crash type, unlike the other crash types, most often occurs on a curve in the road (71% at curves vs 21% for all other crashes). Most are single-vehicle crashes though occasionally the motorcycle, the driver, or debris from some off-road impact, returns to the roadway and some other vehicle becomes involved.

Ran traffic control crashes occur when one vehicle with an obligation to stop, remain stopped, or yield, fails to do so and thus collides with some other vehicle. This was the second most frequently occurring motorcycle crash type accounting for 18% (375) of the total. Most accidents occurred at intersections (72%), driveways and alleys (7%), or interchanges (4%). The traffic control device was most often a stop sign (39%) or traffic control signal (18%).

Oncoming, or head-on, crashes involve a collision between two vehicles travelling in opposite directions. This was the third most common motorcycle crash type accounting for 11% (225) of the total. Few of these crashes occurred at intersections (5% vs 25% for all other crash types) and few occurred on divided highways (7% vs 25%). About half occurred on straight roadways and half occurred on curves. Driver factors, typically failure to keep in proper lane or running off road and/or driving too fast for conditions or in excess of the posted maximum, were most often assigned to the motorcyclist

Left-turn (in the US – equivalent to right turn in the UK) oncoming crashes, as with the oncoming crash type described above, involves vehicles traveling in opposite directions. However, for this crash type, one of the vehicles is in the process of making a left-turn in front of oncoming traffic. This was the fourth most common crash type accounting for 8% (176) of the total. The left-turn was almost always being made by the other vehicle and not the motorcycle (175 of 176 events). That is, the motorcycle almost always had the superior right of way. This crash often occurred at intersections (69%) or at driveways and alleys (7%).

Motorcyclist down crashes cover situations where the motorcyclist loses control of the vehicle and goes down in the roadway. The motorcycles could have struck the roadway or have been struck by some other vehicle after going down. This was the fifth most common crash type accounting for 7% (152) of the total. Generally, it could not be determined why the motorcycle went down. The “loss of control” could have been a deliberate action on the part of the motorcyclist (i.e. putting the bike down) to avoid some perceived threat ahead. These crashes occurred on dry (93%) level (73%) roadways that were straight (56%) or curved (43%).

The five most common crash types accounted for 86% of all crashes studied by Preusser et al. The other types were substantially less common; each accounted for less than 4%. Hence, only a brief definition is given here. Run down crashes (69 crashes) cover situations where one vehicle “runs down” another vehicle travelling in the same direction striking it in the rear. Stop/stopping crashes (66 crashes) are similar to run down except that the lead vehicle struck in the rear was stopped, stopping, or just starting to move immediately prior to the crash. Road obstacle crashes (51 crashes) cover cases where the “first harmful event” involved striking something other than a “motor vehicle in transit” on the road. Lane change crashes (28 crashes) and cut off crashes (25 crashes) both involve a motorcycle and at least one other vehicle travelling in the same direction. In lane change crashes, one of these vehicles swerves or moves into the other’s lane. In cut off crashes, one of these vehicles attempts to make a turn across the other’s lane.

5 Accident Prevention—Primary Prevention of Motorcycle-Related Injuries

Primary prevention of motorcycle injuries focuses on reducing the frequency of motorcycle accidents. This involves enforcement (through licensing systems), engineering (for example to improve conspicuity) and education (through rider training).

5.1 Graduate Driver Licensing System

The graduate driver licensing system phases in on-road driving of motorcyclists, allowing beginners to gain their initial experience under conditions that are less risky. This is accomplished through a multi-stage licensing program that includes two key components: an extended learners stage, during which driving is only permitted under supervision (usually for a period of six months or more); followed by an intermediate stage of unsupervised driving that is restricted to low risk. High risk activities that have been identified and targeted include night-time driving (Williams, 1985; Preusser et al., 1995), driving after the consumption of alcohol (Hingston et al., 1994), and driving with the presence of other young people as passengers (Robertson, 1981; Karpf and Williams, 1983). In this report, we review the motorcyclist licensing system in the UK, New Zealand and North America (Canada and US). Note that the motorcyclists licensing system in the UK places limits only on the size of motorcycle for newly qualified riders.

5.1.1 Motorcyclist Licensing in the UK

Traditionally, motorcycle training in the UK was available on a voluntary basis, with the take-up being as low as 10-15% (Wells, 1982). Since 1981, learner motorcyclists have been limited to a machine of less than 125cc, and riders are required to take and pass both a Part 1 and Part 2 motorcyclist test. Those who pass the Part 1 test are allowed to ride on the road, while passing the Part 2 test gains the rider their full motorcycle licence. A review of the effects of the 1981 Transport Act legislation suggested that positive benefits had been seen, both in an expansion of training facilities throughout Great Britain, and in a sharp rise in the Part 2 Test pass rate from 50% to 75% (Department of Transport, 1986).

In 1990, the government introduced Compulsory Basic Training (CBT) for motorcyclists. It is a one-day course designed to reduce the high accident rate amongst inexperienced riders. The course, which may only be provided by Approved Training Bodies, aims to cover basic skills and knowledge relating to safe motorcycle operation. Since January 1997, CBT is compulsory for all learner drivers. Currently, successful completion of CBT allows the rider to ride on the road with L-plates for a maximum of two years before being required to take and pass the final DSA (Driving Standards Agency) motorcycle test in order to gain a full motorcycle licence.

There are two types of full motorcycle licence that entitle the motorcyclists to ride without L plates (or D plates in Wales), carry a passenger and use motorways:

1. Light motorcycle licence (Category A1): The Category A1 licence entitles the use of any motorcycle up to 125cc with a power output of up to 11kW (14.6 bhp). To obtain this type of licence the motorcyclist must have passed his/her practical test on a motorcycle of between 75 and 125cc.

2. Standard motorcycle licence (Category A): For category A motorcycles there is a two stage graduated licence scheme. After passing the practical test, riders attain stage 1 entitlements. Riders at this stage have a limited motorcycle licence which encompasses machines up to 25kW (33 bhp) and a power to weight ratio not exceeding 0.16 kW/kg. For the motorcyclist to qualify for stage 2 entitlements, he/she must gain two years motorcycling experience. Riders with stage 2 entitlements have a licence with no power restrictions and are allowed to ride motorcycles of all types. To obtain this type of licence the motorcyclist must have passed his/her practical test on a motorcycle of over 120 but not larger than 125cc and capable of at least 100kph.

Furthermore, the applicant is permitted to take an additional test to provide unrestricted category A entitlements if he/she reaches the age of 21 before the two year qualifying period is complete. The additional test must be taken on a motorcycle with a power output of at least 35kW (46.6 bhp). Practice for the test is allowed on motorcycles more powerful than those permitted by a limited motorcycle licence providing the motorcyclist is accompanied at all times by an approved instructor on another motorcycle and in radio contact; wears fluorescent or reflective clothing, has L plates fitted to the motorcycle, and follows provisional licence restrictions.

The applicant is permitted to take one test which allows direct access to the unrestricted category A entitlements if he/she is at least 21 years of age. The test must be taken on a motorcycle of at least 35kW (46.6 bhp) and the applicant is allowed to practice on a motorcycle of any size. However, if practising on a motorcycle which exceeds UK learner specification the motorcyclist must follow the same restrictions as for accelerated access above.

5.1.2 Graduated Driver Licensing System in New Zealand

A three stage Graduated Driver Licensing System (GDLS), comprising learner, restricted and full licence stages was implemented in New Zealand on August 1, 1987 (New Zealand Government, 1987). The GDLS for car drivers is targeted at the 15–24 year age group. In contrast, those who seek a motorcycle driver’s licence must complete all stages of the GDLS, regardless of age or whether they are already licensed to drive a car. This difference is in recognition of the special skills and risks involved in motorcycling. Nevertheless, the greatest impact is likely to be upon the 15–19 year age group, which is the period of life during which most motorcycle drivers obtain their licence (Reeder et al. 1999).

Under the GDLS, a motorcycle learner licence is issued to novice riders who pass tests of eyesight, road code knowledge, motorcycling theory, and basic motorcycle handling skills in an off-road environment. The holder of a learner licence is restricted to riding a motorcycle with a maximum engine capacity of 250cc, must not ride at a speed of more than 70 km/h on the open road (maximum speed 100 km/h), and must carry the licence whenever driving. Pillion passengers must not be carried, there is a curfew on riding between 22:00 and 05:00 hours and a learner (L) plate must be displayed on the rear number plate. In addition, the driver must not have more than 30 mg of alcohol per 100 ml of blood or more than 150 mg per litre of breath. The learner licence is held for 6 months (reducible by 3 months if further approved training is undertaken) after which a practical on-road test is administered before a restricted licence is issued. Apart from the 70 km/h limit, the same restrictions apply to the holder of a restricted licence, except that passengers may be carried in a sidecar. A restricted licence is held for 18 months reducible by 9 months if an approved course is successfully completed) after which a full licence is issued. The GDLS permits a reduction in the minimum time for which training licences must be held, as an incentive to attend additional training courses.

Progression through driver licence stages is, therefore, associated with minimum time constraints and a progressive lifting of restrictions on driving opportunities, in particular, engagement in more risky driving patterns (e.g. night-time driving). Progression from the learner to the restricted licence stage is conditional on meeting practical criteria for driving skills in traffic, as assessed by the passing of a practical on-road driving test. No additional test is required before the issuance of a full licence. There is also no time limit after which learner and restricted licences expire. Provided that other road traffic regulations are not also broken, the only penalty for breaching any of the conditions of the GDLS is an extension of the period of time that the current grade of licence must be held.

While the GDLS was introduced and promoted as a package, targeted mainly at young novice drivers, the key changes that affected all novice motorcyclists were fivefold: (i) a reduction in the maximum alcohol limits (from 80 to 30 mg per 100 ml of blood); (ii) the introduction of a night-time curfew (22:00–05:00 h); (iii) the requirement to carry a driver's licence at all times when riding; (iv) the requirement to pass an off-road basic handling skills test before the issue of a learner's licence; and (v) a rationalisaton, in conformity with the conditions imposed on young car drivers, of (a) the time periods for which licences must be held and (b) the incentives for their reduction.

5.1.3 Graduated Licensing in Canada

Since 1994, the following seven jurisdictions in Canada have implemented some version of graduated licensing for novice drivers of passenger vehicles – Ontario (April 1994), Nova Scotia (October 1994), New Brunswick (January 1996), Quebec (July 1997), British Columbia (August 1998), Newfoundland (January 1999), and the Yukon (September 2000). All these jurisdictions, with the exception of New Brunswick, also implemented a version of graduated licensing for novice motorcyclists. Three jurisdictions – Alberta, Saskatchewan and Manitoba – were currently considering the implementation of graduated licensing for passenger vehicles and motorcycle drivers (Mayhew and Simpson, 2001).

All jurisdictions have adopted or are considering multi-phased graduated licensing comprised of a learner's stage and an intermediate stage. The only exception is Manitoba, where an additional probationary stage is under consideration. The features of each of these stages are summarized below.

Level 1: Learner stage. In all jurisdictions, some form of testing is required to qualify for a learner's motorcycle licence and this includes tests for a learner's driver licence

– knowledge and vision – as well as the motorcycle knowledge test. A few jurisdictions also require the beginner to pass a motorcycle skill test which is administered off-road so that the novice can demonstrate handling skills and ability to maneuver the motorcycle under low speed conditions.

The minimum age for obtaining a learner's licence is 16 years in all jurisdictions except the Yukon where the minimum age has been set at 15 years. The holding period for the learner's licence ranges from 60 days in Ontario to 12 months in Newfoundland and Manitoba (proposed). In three jurisdictions this minimum length of time in the learners stage can be reduced with successful completion of a motorcycle training program.

Six of the nine jurisdictions require supervised driving at all times by a fully licensed motorcyclist. Supervised driving is only required for the first 30 days of the 6-month learner holding period in British Columbia. However, the learner must pass a motorcycle skills test administered off-road on a paved lot before being granted unsupervised driving privileges.

In all jurisdictions, passengers are not allowed on the learner's motorcycle and the learner is subject to a zero BAC limit – i.e., absolutely no drinking and driving. A few jurisdictions also apply a low BAC limit on supervising drivers. In all jurisdictions except Quebec, learner motorcyclists are only allowed to drive during daylight hours – e.g., ½ hour after sunrise, ½ hour before sunset. In the Yukon, a midnight to 5:00 a.m. driving restriction is also applied because of the long periods of daylight during part of the year. Several jurisdictions restrict learners from driving on highways where the speed limit is above 80 km/h. British Columbia imposes a road restriction – i.e. no freeways – as well as a speed restriction – i.e., the learner must drive under 60 km/h.

Three of the nine jurisdictions require learner motorcyclists to display an "L" sign or plate at all times during practice driving – British Columbia, the Yukon, and Manitoba (proposed).

Level 2: Intermediate stage. The mandatory holding period ranges from 12 months to 24 months. Most of the restrictions applied in Level 1 are dropped in the intermediate stage with the exception of the zero BAC limit. Novice motorcyclists are allowed to carry passengers in all jurisdictions during the intermediate stage. However, in the Yukon, the passenger must be aged 13 or older. Four of the nine jurisdictions include a night restriction, typically from midnight to 5:00 a.m. In the Yukon, supervised driving is allowed during these night hours.

Only two jurisdictions require novices to display an "N" sign or plate on their motorcycle – British Columbia and Manitoba (proposed). An advanced, on-road, motorcycle skills test is required to exit the intermediate stage and obtain a motorcycle driver licence in Ontario and British Columbia. Such an exit test has been proposed in Manitoba and is also under consideration in Alberta. Nova Scotia requires novice motorcyclists to complete a motorcycle driver improvement course to graduate to a full motorcycle licence; a motorcycle course has also been proposed in Saskatchewan.

Learner licence holders and intermediate licensed motorcyclists are also typically subject to a more stringent penalty point system for traffic violations than fully licensed motorcyclists – fewer demerit points result in a licence suspension. For example, in Quebec the limit is 4 demerit points for novices as opposed to 15 for a regular licensed driver. The accumulation of 4 demerit points results in a 3-month licence suspension and the lengthening of the learner or intermediate period by that amount of time. In some jurisdictions, breaking any of the conditions of the program will result in a licence suspension – e.g., in Ontario, the suspension period is for 30 days.

5.1.4 Graduated Licensing in the US

Graduated licensing for novice drivers of passenger vehicles has become increasingly popular in the United States – 25 states have already enacted some form of graduated licensing and others are currently planning on doing so. Despite this trend, few states – only California, Maryland and South Dakota – have adopted some version of graduated licensing for motorcyclists. All three U.S. graduated licensing programs include a learner or instruction permit and an intermediate stage.

Level 1: Learner stage. All learner stages have entry requirements – e.g., tests and mandated education/training – and minimum holding periods – 6 months in California, 4 months in Maryland, and 180 days in South Dakota. The minimum entry age ranges from 14 years in South Dakota to 15 years, nine months in Maryland. Although rider training and/or driver education are required in all three states, only South Dakota reduces the minimum holding period for successful completion of courses. Maryland also requires 40 hours of certified driving practice. Restrictions in this stage typically include no passengers, no night driving, and supervision.

Level 2: Intermediate stage. The intermediate stages in all three states also have entry requirements – e.g., on-road skills tests and rider training – and minimum holding periods – 12 months in California, 18 months in Maryland, and until 18 in South Dakota. In California, during the first 6 months of the 12-month minimum holding period, no passengers under 20 are allowed on the motorcycle. All three states have some form of night driving restriction in this stage. Exit requirements are age-based in Maryland and South Dakota. None of these states have an advanced, on-road test to exit their graduated licensing program and obtain a full motorcycle operator licence.

5.2 Conspicuity Improvement

Measures to improve the visibility of motorcycles during the day can reduce motorcycle casualty collisions. When the vehicles approached each other from opposite directions, a daytime running light could have improved conspicuity. When the vehicles approached each other from the side, colour and fluorescence may have improved visibility.

Generally, conspicuity can be improved by two strategies:

1. Selecting the type of measure which is recommended, that is daytime running lights, motorcycle colours, including fluorescence, or modifications and rider clothing; and
2. Voluntary or compulsory implementation procedures.

5.2.1 Daytime Running Headlight

Daytime running lights are effective in drawing other drivers' attention to motorcycles because they increase the contrast between the motorcycle and the background against which he or she is viewed. However, they can only be expected to influence whether the motorcycle is detected by other motorists when it approaches at an angle within 30 degrees of the driver's central vision. Zador (1985) studied the effect of daytime headlight laws in several US States and found a substantial, statistically significant, decrease in the ratio of daytime accidents to nighttime accidents for the US states with daytime light laws. Bijleveld (1997) found that the 1982 Austrian hard-wiring law had "reduced the number of victimised motorcyclists in daytime multiple accidents by about 16%".

Earlier research undertaken by the Transport and Road Research Laboratory (Donne and Fulton, 1985) demonstrated that two lamps and lamps over 180mm diameter have greater influence than single or smaller lamps. More recent American studies have demonstrated that, at ambient light intensities equivalent to dawn and dusk, detection distance and time, noticeability and the size of gaps between vehicles which are accepted by other drivers, are improved by daytime running lights over 1,600cd. These studies did not demonstrate any effect when the ambient light intensity is equivalent to full daylight. One implication from the above finding is that specifications for daytime running lights should have a minimum intensity of 1,600cd for two lamps of greater than 180mm diameter.

5.2.2 Colour and Fluorescence

The colour of the motorcycle and its rider can be used to improve conspicuity. Its effectiveness depends on the contrast between the motorcycle and its background. It is particularly useful to improve detection of a motorcycle approaching at an angle or in combination with measures, which increase the size of a motorcycle's frontal silhouette.

Fluorescent yellow-orange and plain yellow materials are detected faster and further away than other colours, depending on the weather. On clear sunny days white is useful. On overcast days, fluorescent red-yellow is better. Black has no effect on motorcycle visibility.

Similarly, drivers respond more quickly and accept longer safety gaps in the traffic when motorcycle riders wear red and/or fluorescent jackets than when they see low beam headlamps, larger fairings or no extra conspicuity equipment. However, coloured helmets have no effect.

Therefore, motorcycle riders should be encouraged to use yellow, white, red and fluorescent clothing and motorcycles.

5.2.3 Implementation

In the UK, there is no compulsory daytime running headlight law, and a proposal for a law requiring motorcycles to be fitted with twin daytime running lamps was withdrawn by the British Government in 1983. Nevertheless, the Highway Code has been advising motorcyclists to 'wear light-coloured or reflective and fluorescent clothing' since 1978. In 1987 it added that "dipped headlights on larger machines (over 150cc–200cc)" helped others to see them, while it was stated more clearly in 1999 that "dipped headlights might make motorcyclists more conspicuous" (Perlot and Prower, 2002).

However, motorcycle riders in Britain are less likely to use all types of conspicuous equipment than countries like Australia. For example, about 60% of motorcycle riders in Victoria, Australia voluntarily use daytime running lights during fine weather conditions compared with about 28% in England (Road Safety Committee, 1998). The same study reported that that the voluntary use of coloured and fluorescent clothing and daytime running lights can be increased by publicity campaigns though their effect wears off after about 9 months. Further, surveys suggest that motorcycle riders are not opposed to selective use of daytime running lights or, to a lesser degree, brightly coloured clothing.

Besides the voluntary measures to increase conspicuity, there could be compulsory daytime running light measures that include the following(s):

1. A legislative requirement for all motorcycles to use daytime running lights;
2. Hard-wiring of new motorcycles; or
3. Hard-wiring of new motorcycles plus the retro-fitting of existing motorcycles with hard-wiring.

Historically, compulsory daytime running lights have evolved from the Scandinavian experience of changing from left-hand to right-hand drive in 1967, and low ambient light levels in rural areas in winter. They have been extended to Canada and to all seasons of the year, but proposals to extend their general use to Europe and the United States have recently been quashed on the basis of inadequate evaluation and the potential dangers of daytime running lights. Compulsory legislation requiring daytime running lights especially for motorcycles is now confined to France and 23 States of America.

5.3 Rider Education and Training

Rider education and training have important effects on the reduction of motorcycle accident rate.

5.3.1 Training for Novice Riders

As outlined in Section 5.1, current UK legislation requires that all learner motorcyclists must attend and successfully complete a course of Compulsory Basic Training (CBT), before being allowed to ride any motorbike on the road.

The course, which may only be provided by Approved Training Bodies (ATBs), aims to cover basic skills and knowledge relating to safe motorcycle operation, and is in five sections:

- an introduction to the course;
- practical on-site training;
- practical on-site riding;

- practical on-road training; and
- practical on-road riding.

The level of mandatory training within individual countries varies greatly around the world. In Europe, EU directives set out minimum requirements for the *testing* of novice riders, but not for the form or level of *training* required. Consequently, some European countries require riders to attend compulsory training with no unaccompanied on-road riding before the test is taken (e.g. Austria, Germany, Denmark, Luxembourg, Netherlands, Norway and Sweden), whilst others require riders to attend a programme of compulsory training followed by a period of unaccompanied riding before the test is taken (e.g. Belgium, Great Britain and Finland). Other countries have no legal requirement for any training to be completed before taking the licence test.

The DETR Road Safety Strategy (1997) stated that there is 'every reason to assume it (CBT) has played some part in the reduction of motorcycle casualties in the 1990s', although reductions in the numbers of motorcyclists could also have had a major effect. No scientific evaluation of the effects of CBT on accidents has been carried out, and as CBT is compulsory, it would not now be possible to compare the accident involvement of trained and untrained riders. Furthermore, no published evidence existed to demonstrate whether CBT is effective in improving riders' knowledge or skill (Elliot et al, 2003).

One published evaluation of CBT investigated the attitudes and opinions of both trainers and trainees to the course (Thompson, 1994). It found generally positive attitudes towards CBT among both groups, though riders tended to consider it easy and expensive. Another study (Brookes and Arthur, 1997) used qualitative interviews with riders of different age groups and levels of experience to investigate attitudes towards various motorcycling issues, including training. The study found that riders of all age groups viewed existing training as 'not relevant enough'. Although some elements were appreciated as a 'good start', CBT in particular was seen as 'falling short of the mark'.

Driver and rider training, certainly basic pre-test training, tends to emphasise control skills and to neglect higher order cognitive skills such as those related to the anticipation, detection and assessment of hazards. Many studies of car drivers have indicated that there is a link between accidents and hazard perception skills (Currie 1969; Peltz and Krupat 1974; Quimby and Watts 1981; Quimby *et al.* 1986; Hull and Christie 1993; McKenna and Horswill 1999). These studies suggest that enhancing motorcyclists' hazard perception skills could be an effective way to reduce motorcycle collision and casualties, as discussed in the next section.

5.3.2 Enhancing Motorcyclists' Hazard Perception Skills

A significant element of safe road use is the ability to perceive actual or potential danger in order to avoid it. Noticing and perceiving a set of stimuli to represent real or potential danger can be termed 'hazard perception', and must be accomplished quickly and efficiently so that an individual can decide whether their safety is in jeopardy, and correspondingly choose and enact any avoidance behaviour necessary to escape a potential crash (Hawort and Symmons, 2002).

The hazards that car drivers and motorcyclists face are not identical. Indeed it is likely that motorcyclists face the same hazards as car drivers, as well as another set of hazards unique to riding a motorcycle. One source of differences arises from the differences between the vehicles, and therefore the differences in the way the vehicles are operated. Additionally, the potential consequences of undertaking any avoidance manoeuvres and the extent of potential harm associated with any given hazard is likely to be greater for a motorcyclist, given their comparatively lower degree of protection.

Research has noted that the types of hazards reported by motorcyclists differed from those reported by other motorists (Armsby et al, 1989). Over 70 percent of the hazards mentioned by car drivers with no motorcycle riding experience arose from the behaviour of other road users, rather than features of the road environment. Car drivers who also rode (or had ridden) motorcycles, however, were able to identify specific features of the road, and specific actions of other road users as hazards to motorcyclists.

Many driver licence qualification assessments include a test of hazard perception ability. Since November 2002 all car, motorcycle, LGV (vans) and PCV (buses and lorries) candidates shall take a Hazard Perception Test (HPT) when they take a theory test (DSA, 2004). The HPT is a multimedia presentation that incorporates video-footage of traffic scenes. The novice has the driver's view of the scene and touches the screen when they feel that "their" vehicle should change speed or commence a manoeuvre in order to avoid a crash. The situations presented to the candidate currently involve following distance, safe gap and visual scanning.

Drivers with lower scores on the HPT were found to be more likely to be involved in crashes within the first 18 months following their licensing (driving time or distance travelled did not differ between the groups) (Congdon and Cavallo, 1999). In addition, experienced drivers have been found to perform better on the HPT than inexperienced drivers.

The standard HPT is also administered for motorcycle licensing, while it is not known how predictive the HPT is of subsequent motorcyclist crash involvement. Should a relationship be found to exist, then the question of whether there should be a separate motorcyclist HPT arises. There does not seem to be an equivalent of the HPT specifically for motorcycle riders, although the Netherlands uses a slide-based test for moped riders (Wijnolst, 1995). It has been found that a rider's score on the British Motorcycle Operators Skills Test did not predict a rider's crash involvement (Chesham et al. 1993).

New Zealand uses a hazard perception test that should work equally well for motorcyclists and car drivers (Christie et al., 1998). Just prior to manoeuvring through a real traffic situation the tester asks the candidate to note and remember all of the hazards they see as they drive/ride. The candidate then pulls over and describes the hazards and how they responded to them – this must match the tester's assessment of the situation. To improve the execution of the test for motorcyclists the authors suggested the use of voice-activated communications between the candidate rider and the assessor.

5.3.3 Assessed Ride Program and Advanced Training

It is considered that the style of riding or driving adopted at UK Police Driving Schools is sought after by many rider/driver training organisations. The police service over the last four decades has developed driver/rider training to a high level. Students are subjected to the rigours of on-road training and undertake theory examinations in relation to Roadcraft (Police driver/rider's handbook; see, for example, Police Foundation, 1996) and the Highway Code. The training course follows a continuous assessment process. Some centres also require students to undergo a final assessment (Green, 2004).

The concept of police style rider training was launched as a five-year initiative in Scotland in 2000 (Bikesafe Scotland), and to date, the main component has been the Police Assessed Ride Programme. Assessed Ride programme involves a free on-the-road assessment of motorcycling skills from a trained Police motorcyclists in addition to theoretical advice and guidance on motorcycling skills and safety.

Ormston et al. (2003) is a comprehensive evaluation study of the Bikesafe Scotland programme. It shows that approximately 1,769 assessed rides have been carried out in the three years since the launch of Bikesafe Scotland. The vast majority of Bikesafe Scotland participants are male and 67% fall into the 35- 44 and 45-54 year-old age groups. Twenty-nine per cent of respondents to the pre-course survey were aged 35 or older when they obtained a full motorcycle licence, while around a fifth had returned to riding in the last five years after a break in riding of a year or more. This suggests that Bikesafe is attracting some riders who might be classed as 'born again bikers'. Forty-three per cent of respondents had gained their motorcycle licence through the Direct Access scheme, which allows riders aged over 21 years to ride a bike of any size once they pass their test.

The views on the Assessed Ride Programme in Scotland were very positive. According to Ormston et al. (2003), almost 100% of respondents to the 2002 post-course survey and the survey of 2001 participants said that they found the Bikesafe Scotland Assessed Ride programme 'very' or 'fairly useful'. The vast majority 'agreed' or 'strongly agreed' that they would recommend the scheme and that all bikers should be encouraged to go on it.

The same study also shows some positive impacts of Bikesafe Scotland on the behaviour and attitudes of participants. There seemed to be an improvement in the proportion of respondents after the course saying they 'never' or 'hardly ever' "brake too quickly on a slippery road" or "find your back wheel slipping away when you take a bend, almost causing you to lose control". Less than 5% of participants agreed with the statement "Bikesafe did not make any difference to the way I ride my bike" and over three quarters agreed that Bikesafe had taught them to ride more defensively. However, the proportion of post-course participants who say they often exceed the speed limit on motorways and on country roads is higher than the proportion of pre-course participants. As the proportion of serious and fatal motorcycle accidents is much higher in non-built up areas, findings relating to participants' speeds on these roads are cause for concern.

Currently, many police forces across the UK are also promoting the "BikeSafe Initiative". It is being proposed to develop a generic BikeSafe product, which has the same standard and level of training regardless of workshop location. Furthermore, it has been agreed that every BikeSafe workshop must include the following core skills (Green, 2004):

- System
- Observation
- Cornering
- Safe Overtaking
- Safe Positioning
- Hazard perception
- Safety brief
- Braking
- On road riding – observed
- Attitudinal issues
- De-brief
- Use of Gear
- Clothing/safety equipment
- Safe/lawful use of speed

It has also been decided that all workshops will include some theory within the classroom environment. The delivery will be fronted by a police officer in uniform and police liveried machines (sometimes loan machines) will be used for on-the-road sessions.

5.4 Other Primary Prevention Measures

5.4.1 Enforcement and Adjudication

Law enforcement is responsible for ensuring compliance with laws and regulations intended to promote and maintain highway safety, and is an integral component of motorcycle safety.

According to NHTSA and MSF (2000), many prosecutors and judges in the US are unaware of the factors that contribute to motorcyclists' injuries and fatalities. Even though violations, such as riding without a motorcycle operator's license, are associated with a significant increase in crashes and injury, there is little perceived threat for the motorcycle rider of being caught, and even less fear of the consequences.

NHTSA and MSF (2000) put forward a proposal for better enforcement and adjudication. It suggested that judicial and law enforcement agencies and associations should work together to promote motorcycle safety and coordinate with motorcycle safety organizations and working with other traffic safety groups that already work on motorcycle safety. There should be concerted effort to inform and educate law enforcement officers and administrators about other programs designed to address motorcycle safety. Technical expertise in motorcycle safety and crash investigation should be available to crash investigators. Motorcycle-specific crash investigation training should be more widely available to law enforcement investigative personnel. Areas to cover include:

- Existing materials, e.g. cue cards with indicators for detecting impaired motorcyclists that differ from those of other impaired motorists, should be widely distributed and utilized.
- Law enforcement officers need the proper tools to fairly and effectively enforce helmet-use laws, such as information on how to identify helmets not compliant to the Standard.
- Motorists who violate motorcyclists' right-of way should face legal consequences at least as great as if they had violated an automobile operator's right-of-way. The public should be educated about the danger of overlooking a motorcyclist and the serious legal penalties for doing so.
- Motorcycle crash experts should be available as a resource for police crash investigators to aid in accurate analysis of motorcycle crashes.

In the UK, the enforcement of speeding violation for drivers/riders has been strengthened in recent years through the introduction of speed cameras. As research into motorcycle accidents has shown that excessive speed is a cause of casualty accidents (Mannering and Grodsky, 1995; Carroll and Waller, 1980; StBA, 1995), one might expect more enforcement of speeding violation would be effective in reducing motorcyclist casualties. Although there is no specific data available for motorcyclists, research has shown significant positive impact of speed cuts on road casualties, e.g. for every 1% reduction in mean traffic speed, fatalities reduce by about 7% (CfIT, 2001).

5.4.2 Tackling Motorcyclist Alcohol and Other Impairment

Research has shown that a high proportion of motorcycling accidents are alcohol-related (Williams and Hoffmann, 1979; Lacey and Carroll, 1980; Ouellet *et al*., 1987; Iowa Department of Transportation, 1988; Fell and Nash, 1989; Holubowyez *et al*., 1992; Soderstrom *et al*., 1993). In addition, Bednar et al. (2000) show that motorcycle operators involved in fatal crashes have higher intoxication rates than operators of all other motor vehicles in the US (Further details see section 3.2.2).

It is important for the road safety and law enforcement agencies to better understand motorcyclists' alcohol/substance abuse behaviour and to work closely with each other to enforce current laws. Partnership with groups already involved in alcohol/substance abuse issues related to motorcycle crashes (such as the charity Roadpeace) should be encouraged.

Furthermore, intervention must focus on the unique characteristics of motorcyclists and motorcycling. Interventions designed for automobile drivers (e.g., the designated driver program) do not necessarily apply to motorcyclists. Impaired motorcyclists are much less likely than car drivers to accept a ride home, especially if it means leaving their motorcycle unsecured for the night. There have been some interventions for impaired motorcyclists put in place in the US (Bednar et al, 2000). For example, a required module in the MRC/RSS (Motorcycle Rider Course/Riding and Street Skills) course focuses on impairment. Other examples include peer-to-peer programs promoting awareness and responsible use of alcohol, and "dial-a-ride" programs for motorcyclists, designed to get the impaired rider and motorcycle home safely. Specialized training that will enable law enforcement representatives to detect impaired motorcyclists has been implemented nationwide through the Standard Field Sobriety Testing Curriculum.

6 Impact Reduction—Secondary Prevention of Motorcycle-Related Injuries

Secondary prevention measures reduce the severity of accidents (and the related injuries) rather reduce the frequency of accidents per se. Indeed, the risk compensation hypothesis associated with Peltzman (1975) suggests that such measures might even increase the frequency of risk related accidents. These measures are normally engineering based related to the design of motorcycles, motorcycle helmets and other protective equipment. These measures will be examined in turn, along with the related issue of enforcement, which is particularly relevant to the wearing of motorcycle helmets.

6.1 Motorcycle Design

In the past 10 to 15 years, there have been major innovations in motorcycle aerodynamic design, liquid cooling, engine counterbalances, antilock and "linked" braking, fully adjustable suspension systems, and advanced disc braking systems. Both handling characteristics and tyre technology, so crucial to the safe and efficient use of the motorcycle, have improved greatly. Recently, manufacturers have been conducting research on new concepts, including automatic transmissions, fully enclosed rider capsules, and radical chassis designs. The latter involve such ideas as new swing-arm technologies and nontraditional front ends that use flexing technologies to overcome torsion problems. Continued experimentation with improved shaft designs and aerodynamic forms can be expected to increase rider comfort and stability. In addition, improvements of the last decade in such features as fuel injection, braking systems, and engine load mapping will continue to be introduced to a wider selection of motorcycles (Bednar et al, 2000). Three aspects of motorcycle protection design are considered in more detail below: brakes, airbags and leg protection.

6.1.1 Brakes

For many types of vehicle incorrect or inappropriate brake application is not critical under most circumstances. With two-wheeled motor vehicles a mistake by the rider that leads to either wheel being over-braked will cause the machine to skid, become unstable and capsize. The incidence of skidding in personal injury accidents is substantially greater for motorcycles (TWMV) than for other vehicles. In Great Britain in 1997, skidding occurred in 28% of accidents in the wet involving a TWMV compared with 20% for other vehicles (DETR, 1998).

Anti-lock brakes (ABS) are designed to prevent wheel locking and thus provide motorcyclists with the confidence to use the brakes up to the limit of the friction available, without fear of falling to the ground. ABS also reduces stopping distance in wet and icy conditions. A few machines are now offered with anti-lock brakes (Elliot et al, 2003). NHTSA and MSF (2000) called for more studies of the effectiveness of linked and antilock braking system, which would form the basis for more widely deployment if these technologies prove valuable. Furthermore, information from research can be used to implement other braking-related countermeasures.

Although new technologies seem to promise shorter stopping distances and overall safer stopping for motorcyclists, assuring that motorcyclists get maximum braking performance requires additional training and education on proper braking and panic-braking techniques. The BikeSafe programme in the UK could be an ideal venue for this purpose (see section 5.3.3).

6.1.2 Airbag

The first crash tests with airbags on motorcycles were published in 1973 (Hirsch and Bothwell, 1973). The results were not entirely satisfactory but gave a clear indication that an airbag system could be beneficial. In the early 1990s tests were completed in the UK in which three different types of motorcycle were fitted with an airbag (Happian-Smith and Chinn, 1990). The aim was to achieve maximum restraint by the airbag and as great a reduction in the motorcyclist's speed as possible. The results show that full restraint was not possible above a speed of 30mile/h, though reducing the rider's velocity and controlling his trajectory could still be beneficial.

Okello and Chinn (1996) and Chinn *et al*. (1997) examine the effect of the airbag module, purposely designed and built for the Norton Commander. The sled test results showed that the airbag system fully restrained the rider with 100% reduction in rider kinetic energy for all test conditions assessed. A similar study by Iijima of Honda Research (Iijima *et al*., 1998), of airbags mounted in a large touring motorcycle, the Honda Gold Wing, demonstrated that the airbag was beneficial in four cases, harmful in two cases and had little or no effect in three cases.

6.1.3 Leg Protection

Injuries, particularly fractures, to the lower limbs of motorcyclists are common and a considerable amount of research has been conducted in this area. Generally, lower limb protectors incorporate a bar, 'crash bar', and/or other structure-for example a fairing designed to prevent intrusion into the spaces normally occupied by the rider's legs.

Ouellet (1990) investigated 131 crashes involving crashbar equipped motorcycles. He stated that leg protection devices may have the ability to affect favourably those serious leg injuries, which result from direct crushing of the rider's leg against the side of the motorcycle during impact. Nairn (1993) contended that the severity of leg injuries would be reduced in approximately 50% of the crashes which involved serious leg injury if leg protection were to be fitted.

BMW have launched a TWMV, designated the C1, that is a departure from conventional designs. It is based upon a Scooter layout but also has a 'roof' whereby the frame is extended from the rear at the base of the seat base over the rider's head and joins with the front. Kalliske *et al.* (1998) have evaluated the performance of the C1 in a series of impact tests and computer simulations. Specific results are not given but the paper comments that for impacts frontal to the C1, the HIC (Head Injury Criterion) was always well below the human tolerance, the neck momentum was reduced by about 50%. Lower extremities, leg forces, were very low and only about $1/12^{th}$ of the values normally measured for a two-wheeler.

6.2 Motorcycle Helmet

6.2.1 The Effectiveness of Motorcycle Helmet

Although protective helmets have been used to advantage for more than three millennia, the first systematic investigations of helmet function and effectiveness appeared only recently, in England in the 1940's. Cairns in 1941 reported that in a study of over a 100 motorcyclist fatalities, 92% suffered from head injury and 66% had multiple injuries (Cairns, 1941). He also discussed 7 cases of nonfatal injury in which helmets had been worn and in which the injury had been "unusually mild." He discussed the structure of the helmets, noted accident damage and speculated as to how the helmets may have intervened to prevent more serious injury.

Even in the 1940's, motorcycle crash helmets had been available for some time. Dr Cairns did not discover the crash helmet but he demonstrated conclusively that motorcyclists were exposed to a substantial risk of serious head injury and that crash helmets could be used to attenuate this risk. He also began the process of relating the mechanical behavior of crash helmets to the mechanisms of head and brain injury. Before Dr Cairns, helmet effectiveness was anecdotal and helmet design was based on intuition. His 1941 and 1943 (Cairns and Holbourn, 1943) papers established the value of crash helmets as head protection and declared them fit subjects for medical and engineering study.

Epidemiology is now providing strong objective evidence to support the two perceptions so basic to protective helmets: that injury risks exist and that helmets are effective countermeasures (Hurt et al., 1981; Williams, 1991; Rivara and Thompson, 1996; Evans and Frick, 1988, Anderson and Kraus, 1996).

Hurt *et al.* (1981) surveyed over 900 injured motorcycle riders, of which 60% were non-helmet wearers and 40% helmet wearers. The analysis of injuries at the critical to fatal threshold, showed that 3.5% of helmeted riders were above this threshold, compared with 8.2% above this threshold for the non-wearers. It can be concluded from this that the risk of death is more than halved if a helmet is worn. In his conclusions Hurt states that 'helmeted riders and passengers showed significantly lower head and neck injury for all types of injury at all levels of severity'.

Otte *et al.* (1984) studied 272 motorcyclists injured in road accidents around the Hanover area. Non-helmeted riders accounted for 72.5% of the total injuries and yet this group were outnumbered (by how many is not stated) by the helmet wearers. Overall (including figures from a previous study) Otte *et al.* claim that 70% of non-helmeted riders suffer head injuries whereas only 45% of helmeted riders sustain head injuries.

Finally, NHTSA (1998c) showed when involved in a crash, an unhelmeted motorcyclist is 40% more likely to have a fatal head injury and 15% more likely to incur a disabling head injury than a helmeted motorcyclist. Helmets reduce the likelihood of death by 29% for all motorcycle crashes. From 1984 through 1996, it is estimated that helmets saved the lives of more than 7944 motorcyclists.

6.2.2 The Law on Compulsory Helmet Wearing

In Britain, according to *The Motor Cycles (Protective Helmets) Regulations 1998* and *The Motor Cycles (Protective Helmets) (Amendment) Regulations 2000*, anyone driving or riding on a 2-wheeled motorcycle on a road must wear a helmet, although passengers in a side-car don't have to wear one.

In the US, there are 20 states, the District of Columbia, and Puerto Rico which require helmet use for all motorcycle operators and passengers. In another 27 states, only persons under a specific age, usually 18, are required to wear helmets. Three states have no law requiring helmet use (NHTSA, 2001).

There has been much studied and written on the effect of helmet law repeal and reinstatement in various States in the US. Data from Louisiana, the first state to repeal and then readopt a full helmet law, showed a 30 percent reduction in fatalities (40 fewer deaths) during 1982, the first year after helmet law reenactment. The reduction occurred even though motorcycle registrations increased 6 percent during the year. The helmet use rate increased from roughly 50 percent to 96 percent. Since 1989, six states (Oregon, Nebraska, Texas, Washington, California, and Maryland) have enacted helmet use laws that govern all motorcycle occupants. In Oregon, there was a 33 percent reduction in motorcycle fatalities the year after its helmet law was re-enacted; Nebraska experienced a 32 percent reduction in the first year of its law; Texas experienced a 23 percent reduction; Washington experienced a 15 percent reduction; California experienced a 37 percent reduction; and Maryland experienced a 20 percent reduction. Since 1997, five states, Arkansas, Texas, Kentucky, Louisiana, and Florida have weakened their universal helmet laws to mandate coverage to those under the age of 21 years. These became the first states since 1983 to repeal or weaken a universal helmet law.

Helmet use decreased following the Arkansas and Texas law changes. In the first full year following repeal, fatalities in Arkansas increased by 21 percent, compared to the last full year under the helmet use law requiring all riders to wear a helmet. In Texas, motorcyclist fatalities increased by 31 percent over these same periods. Arkansas pre-hospital EMS data showed an increase in the number of injured motorcyclists, the number of motorcyclists with head injuries, and the proportion of all injured motorcyclists with head injuries after the law change. Texas Trauma Registry data showed that the proportion of motorcyclists treated for traumatic brain injury increased and that treatment costs for traumatic brain injury cases also increased following the law change. Treatment costs for other injury cases did not change markedly.

6.2.3 Helmet Standard

That current helmets afford good protection is in no doubt, but it is clear that there is much room for improvement and the route is through improved standards. Efficient energy absorption with the optimum impulse, minimum tendency to induce rotational motion and a comprehensive evaluation of the whole helmet including the chin guard of a full face helmet are features for which standards should require tests. Currently only the British Standard 6658 includes tests for rotation and the chin guard (Elliott et al. 2003).

Hopes and Chinn (1989) investigated the effect of helmet shell and liner stiffness on the ability of a helmet to protect the head. Helmets made to pass British Standard

BS6658 were compared with helmets similar in size and shape, but with liners of different stiffness, ranging from well below to above that of the standard liner: shells with increased stiffness were also tested at stiffnesses 1.5 and 1.8 times that of the standard helmet. All possible combinations were tested. The conclusions were that the stiffer the liner or shell, the higher the peak acceleration and HIC (Head Injury Criterion) from a given drop height.

The standard helmet was considered to be too stiff and too resilient. For example, when impacted at 6.7m/s the peak resultant acceleration was 305g and the HIC was 3351. A helmet with a standard shell but a lower density liner gave results of 189g and 1825 HIC. The standard helmet does not absorb energy efficiently in an impact of the sort of severity that a rider may be able to survive. At an impact speed of 6.7m/s a HIC of 3351 was measured, and yet only 70% of the energy absorbing capacity of the liner was used. It was not until the impact velocity was raised to 12.5m/s that nearly 100% of the energy absorbing capacity was used, but at this velocity the HIC became nearly 9000, almost certainly unsurvivable. Helmet shells are also too resilient, so that they rebound and thereby increase the total acceleration.

In the same study an experimental helmet was made from an aluminium shell, which had little resilience, and a low-density liner. This was tested at 6.7m/s giving a peak acceleration of 102g and a HIC of 602 compared with the 305g and HIC of 3351 of a standard helmet. This experimental helmet has a greatly superior performance, but the materials would be insufficiently durable for a practical helmet. Nevertheless, it indicates the sort of improvement that might be possible. Gilchrist and Mills (1987) have also studied the effect of materials on helmet efficacy and their conclusions are similar to those of Hopes and Chinn. Overall, it seems that helmets are too stiff and too resilient and further improvement would be desirable.

6.2.4 Motorcycle Helmets and Risk Compensation

In its crude form (Wilde (1982)), the risk compensation hypothesis states that individuals have a target (equilibrium) level of risk that they try to maintain. Thus, the implementation of helmet laws will lower the actual level of risk for a group of individuals (non helmeted riders). It is hypothesized that these riders will respond behaviourally by increasing their risk level to its target through other types of risky activity (i.e. higher driving speeds, alcohol consumption, more risky driving patterns, etc.). It is argued that this behavioural response can offset the positive affects of helmet laws on motorcycle safety.

The more sophisticated variant (Peltzman (1975) recognizes that the equilibrium level of risk is variable. In particular, regulatory legislation that lowers risk typically has two competing effects - an income and substitution effect - on an individual's response. Thus, total risk can increase or decrease in response to a regulatory act. In the case of motorcycle helmet laws, the law reduces the probability of a bad state -- injury and lost productivity -- and thus increases the expected income of individuals. The law also reduces the cost or price associated with driving intensity (i.e. high speeds) because of expected reductions in injury. In response, the individual uses the extra expected income (income effect) to buy more of all goods including more safety and more driving intensity but, because the price of driving intensity declines the individual will "buy" an additional amount of driving intensity because it is cheaper (substitution effect). The overall effect on safety depends on the size of the competing safety and driving intensity "purchases".

Thus the risk compensation effect of helmet laws becomes an empirical question. The measurement of such effects is a difficult empirical problem. Graham and Lee (1986) and Adams (1983) attempt to measure this effect. Both studies suggest that a risk compensation effect exists. The former study shows that a 2.5% increase per year in the fatality rate follows the initial 12% decline in the fatality rate from enactment of a helmet law. Thus within 5 years the fatality reducing benefits of helmet laws are eradicated. However, there are concerns that the regression equation they use is affected by misspecification problems. Adams (1983) argues that risk compensation responses could explain some of the stylised facts about motorcycle accidents and he cites other studies on automobile safety equipment and driver response as supporting evidence.

Further statistical evidence is provided by Goldstein (1986). He finds that helmets have no statistically significant effect on the probability of a fatality given that a motorcycle accident has occurred. Instead, the major determinants of fatality are the rider's crash speed (kinetic energy) and blood alcohol level. For the average rider involved in the average accident, it was found that the probability of death increases from 2.1% to 11.3% when the rider's blood alcohol level increases from 0.0 to 0.1 (from sober to legally intoxicated in most states). Similarly, an increase in the crash speed from 40 to 60 mph increases the probability of death from 7.1% to 36.3%

Goldstein also found that helmets have a statistically significant effect in reducing head injury severity but beyond a critical impact velocity to the helmet (approximately 13 mph), helmet use had a statistically significant effect which increases the severity of neck injuries. Past a critical impact speed to the helmet (13 mph), which is likely to occur in real life accident situations helmet use reduces the severity of head injuries at the expense of increasing the severity of neck injuries.

Goldstein concluded that until the injury tradeoff issue is more carefully studied, it cannot be concluded that mandatory helmet use laws are an effective method to reduce motorcycle casualties. A more effective policy approach would be two pronged, including both policies to prevent accidents and policies that effectively reduce the probability of death and the severity of injuries. Policies to prevent accidents include: (1) the education of the general driving public; (2) the education of a younger and more inexperienced population of motorcyclists on the issues of accident avoidance and the proper use and control of high horsepower machines: (3) stricter enforcement of drunk driving laws; and (4) implementation of alcohol awareness programs. Policies to reduce death and injury severity include: stricter enforcement of speed limits and alcohol consumption limits, as well as mandatory driver training and education programs which emphasize the proper execution of evasive action.

This literature is thus sceptical of the epidemiological evidence presented in 6.2.1 and empirical evidence of the type presented in 6.2.2. It also highlights that one of the main impacts of compulsory motorcycle helmet wearing is a reduction in the numer of motorcycle registrations.

6.3 Other Protective Equipment for Motorcyclists

There are other protective equipment for motorcyclists with protective clothing being the most common and important one. According to Elliot et al. (2003), choosing the right clothing can achieve the following protection:

- Prevention of most laceration and abrasion injuries that occur when a rider slides on the road surface after falling off.
- Prevention of contamination of open fractures by road dirt.
- Reduction in the severity of contusions and fractures, with the prevention of some fractures and joint damage.
- Reduction in the severity (or prevention) of muscle stripping and degloving injuries, particularly to the lower leg and hands.
- Prevention of accidents by maximising the conspicuity of the rider.
- Prevention of accidents by maintaining the rider in good physiological and psychological condition by keeping the rider dry, warm, comfortable and alert.

The selection of single items of clothing and their combined use should be based on the following considerations:

- Clothing must be able to protect against, wet, cold and heat even when these occur for long periods.
- If the hazard is a single event such as a collision the likelihood of it occurring should be assessed. Falls and impacts are common in all types of riding (including off-road) except on motorways. The severity of the collisions is dependent on the surface impacted. However because it is not possible to control where a rider will travel at any one time, the clothing must satisfy all requirements.
- As a set of clothing may be bought from different sources, it is therefore important that advice should be given on compatible items. For example there should not be a gap between boots and trousers. The outermost layer should always be of high conspicuity even in wet weather.
- Clothing should be designed to ensure that all tasks required of a motorcyclist are easily accomplished and in particular movement must not be restricted.
- Riders need a way of knowing the conditions for which an item of clothing is suitable, and with which other items it is compatible.

7 Conclusions

A brief review of data on national motorcycle accidents reveals that motorcyclists are a particularly vulnerable group of road users. For example, in Great Britain in 2002 the number of people killed or seriously injured (KSI) using two wheeled motor vehicles was 147 per 100 million vehicle kilometres. The comparable casualty rate for car users was 5 per 100 million vehicle kilometres. The all injuries casualty rate for two wheeled motor vehicles was 556 per 100 million vehicle kilometres compared to 50 per 100 million vehicle kilometres for car users.

Various studies in several countries covering a long period of time show that up to three-quarters of motorcycle accidents involved collision with another vehicle. Among these multiple vehicle accidents, the driver of the other vehicle often violated the motorcycle right-of-way. These results show that low conspicuity is the main factor that causes motorcycle accidents, although other road users especially motorists should also be more alert to the presence of motorcycles.

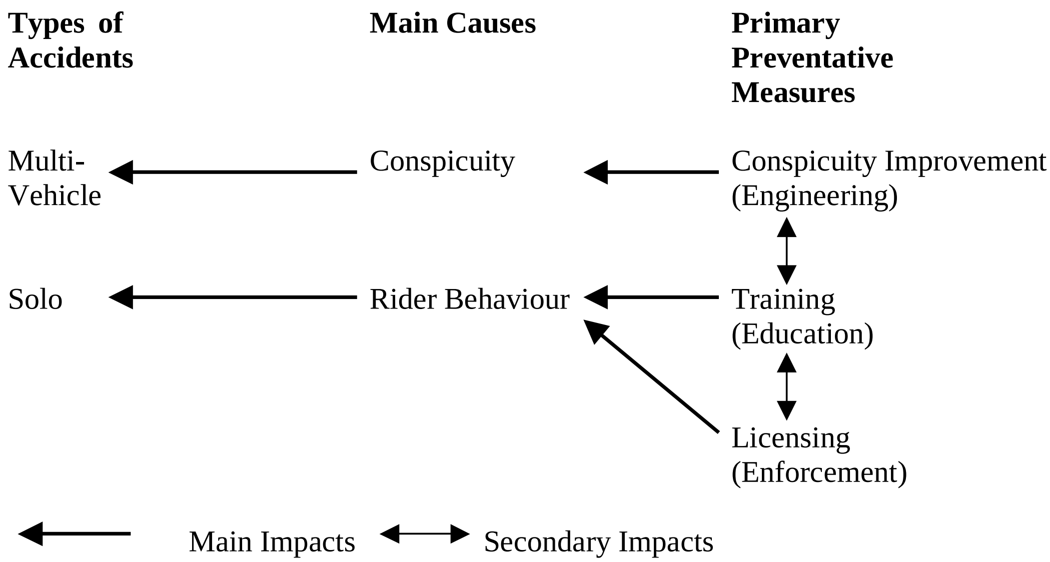
However, for fatal accidents, motorcycle running off the road is the most common type, accounting for 41% of the total. These are often late night, weekend crashes involving a drunken motorcyclist (Preusser et al., 1995). As solo accidents without collision with another vehicle only account for a small proportion of total accidents, it appears that impairment has a much more deadly effect on motorcyclists.

Primary prevention is designed to reduce the occurrence of motorcycle accidents. One important measure is conspicuity improvements including daytime running headlights and the colour and fluorescence of the vehicle (and rider). Other primary prevention measures include educating riders (both learner and qualified) and enforcing traffic regulations. Secondary prevention may not reduce the number of accidents per se, but can reduce the severity of such accidents. The two main types of measures reviewed are motorcycle design, including brakes, airbags and leg protection, and motorcycle helmets and other protective equipment.

Our work suggests that there are important linkages between accident types, accident causes and preventative measures. These linkages are sketched out in Figure 7.1. For example, the main causes of multi-vehicle accidents are related to conspicuity and could be tackled by engineering measures to improve conspicuity. Such measures might be reinforced by appropriate training and education measures and possibly enforcements measures (for example with respect to daytime running headlights). Solo accidents are most likely to be due to rider behaviour, which might be best addressed by education, particularly if that can be reinforced by enforcement through the licensing system.

Since the mid 1990s there has been an increase in motorcycle casualties in Great Britain, in marked contrast to the previous downward trend. For example, the number of motorcycle related KSI casualties reduced by 65% between 1982 and 1996 but has since increased by almost 19% between 1996 and 2002. This increase is almost entirely due to increased ownership and use of motorcycles. Indeed the KSI casualty rate per motorcycle vehicle kilometre continues to fall (down 12% between 1994/8 and 2002).

Figure 7.1. The inter-relationship between motorcycle accidents, causes and preventative measures



However, some important changes in motorcycle ownership and use also seem to have occurred. With respect to motorcycle ownership, the big change has been in machines of 500cc and above, with their numbers trebling over the last ten years (1992-2002). With respect to motorcycle use, the data, and particularly the data on accidents, suggest that this is no longer the domain of young men. For example, in 1982 the under 20s accounted for 49% of motorcycle casualties but by 2002 this had decreased to under 12%. By contrast, the 30-39 age group made up 8% of motorcycle KSI casualties in 1982 but by 2002 this had increased to 33%.

There is thus some statistical support for anecdotal evidence that the born again motorcycle rider is becoming something of a public health problem. Further work is required to quantify the extent and nature of this problem and in particular to determine the extent to which this problem of increased casualties amongst older motorcycle users is due to middle aged men returning to motorcycling or existing motorcyclists upgrading to more powerful machines as they get older. This will be important in framing new policy towards rider training and licensing which to date has focused on younger riders and less powerful machines and has assumed a continuity of motorcycle use.

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