CONTRIBUTORY FACTORS OF POWERED TWO WHEELERS CRASHES

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ABSTRACT

The objective of this paper is to discuss factors contributing to powered two wheeler (PTW) crashes. They are described under three main categories: road user (perception and awareness, atypical behaviour etc.), road environment (design, conditions), and vehicle. An exhaustive literature review of existing studies on powered two wheelers risk and contributory factors was carried out, in order to identify and quantify the impact of various factors on PTW crash and injury risk, with emphasis on the association of risk factors. The results reveal that human factors (e.g. driver and rider behaviour) are prevalent in PTW crashes, compared to vehicle and road factors. Road design and environment factors mostly influence accident severity (e.g. roadside obstacles and barriers, traffic calming installations) rather than accident occurrence. There is also a clear over-representation of perceptive problems in PTW crashes, which suggests a specific problem of detectability for these road users. Moreover, PTW are over-represented in impairment and speeding related crashes, and there appear to be specific PTW behaviours that may surprise other road users - although such behaviours are not necessarily traffic-law-violating. Male, young and inexperienced riders are at higher crash risk. A stronger correlation of crash contributory factor is identified among PTW riders, compared to other road users, often resulting in coexistence of several risk factors in PTW accidents, and in multiplication of the related risk in these cases.

Keywords: Pedestrians, Safety, Perceptions, Attitudes, Behaviour

BACKGROUND AND OBJECTIVES

It is well known from the literature that moped and motorcycle riders have significantly higher risk of getting injured in road traffic, compared to the other means of transport. Several risk factors proven to be associated with accident rates can be found in road safety literature. Some examples that can influence the safety conditions of PTW riders (and in general also the other means of transport) are:

- Road users related: age and experience of PTW rider, use of alcohol, speed of travel, etc.
- Infrastructure related: the type of road or traffic environment, the elements of the roads design (i.e. number of lanes, design of junctions, guardrails, etc.), environmental risk factors (e.g. darkness, precipitation, road surface conditions, etc.)
- Vehicles related: power to weight ratio, etc.

The main risk factors for injury severity are related with vehicle mass, impact speed and protective equipment. Motorcycles and mopeds are relatively heavy and are often moving at speeds that are comparable to powered four wheel personal vehicles. They however do not offer the same level of protection to their drivers when compared to personal vehicles. The relatively high kinetic energy and the limited protection results in an increased exposure to injuries for motorcycle and moped drivers. Relating with protection of road users, the use of personal safety equipment (e.g. helmets, protective clothing) is particularly important for the injury risk of PTWs.

The objective of this paper is to discuss factors contributing to powered two wheeler (PTW) crashes. They are described under three main categories: road user (perception and awareness, atypical behaviour etc.), road environment (design, conditions), and vehicle. An exhaustive literature review of existing studies on powered two wheelers risk and contributory factors was carried out, in order to identify and quantify the impact of various factors on PTW crash and injury risk, with emphasis on the association of risk factors. It is noted that the present research focuses on developed countries; the analysis of PTW crashes in “PTW-dependent” countries might yield quite different results, and is beyond the scope of this paper.

PTW DRIVER-RELATED FACTORS IN FATAL CRASHES

Driver-related factors are known to be major PTW crash contributory factors. A review of the 23,322 fatal motorcycle crashes (involving at least one motorcycle occupant fatality per crash) in U.S. Fatality Analysis Reporting System (FARS) data for 2004 through 2008 revealed several motorcycle driver-related behaviours prevalent in fatal crashes (see Table 1).

The five most prevalent motorcycle driver-related behaviours in fatal crashes were:

- driving too fast for conditions or in excess of posted speed limit;
- under influence of alcohol, drugs, or medication;
- inattentive/careless driving;
- and operating vehicle in erratic, reckless, careless, or negligent manner or at erratic or suddenly changing speeds.

During the same period, there were 140,560 fatal crashes of vehicles other than motorcycles (involving at least one non-motorcycle occupant fatality per crash) in the United States. By comparison, the five most prevalent driver-related factors in fatal crashes resulting in non-motorcycle occupant fatalities were the same as for fatal motorcycle crashes, although the most prevalent driver-related factor for non-motorcycle fatal crashes was failure to keep in proper lane.

Table 1. Driver-Related Factors in Fatal Crashes of Motorcycles versus Other Vehicles in the United States, 2004-2008.

Driver-Related Factor	Percentage of Fatal Motorcycle Crashes	Percentage of Fatal Non-motorcycle Crashes
Driving too fast for conditions or in excess of posted speed limit	37.1	29.5
Failure to keep in proper lane	25.7	41.5
Under influence of alcohol, drugs, or medication	15.3	18.9
Inattentive/careless	8.4	9.8
Operating vehicle in erratic, reckless, careless, or negligent manner or at erratic or suddenly changing speeds	6.4	5.8
Non-moving traffic violation	3.5	2.4
Failure to obey traffic actual signs, traffic control devices or traffic officers, failure to observe safety zone traffic laws	2.9	5.0
Making improper turn	2.5	3.9
Operator inexperience	2.5	0.8
Failure to yield right of way	2.1	8.0
Over correcting	1.7	7.9
Following improperly	1.5	0.8
Driver has not complied with physical or other imposed restrictions	1.5	0.5
Passing with insufficient distance or inadequate visibility or failing to yield to overtaking vehicle	1.4	0.8
Improper or erratic lane changing	1.3	1.1
Avoiding, swerving, or sliding due to live animals in road	1.3	0.4
Operating without required equipment	1.2	1.5
Driving on wrong side of road (intentionally or unintentionally)	0.9	1.8
High-speed chase with police in pursuit	0.9	0.7
Passing where prohibited by signs, pavement markings, hill or curve, or school bus warning not to pass	0.8	0.4

Note: Each driver-related factor refers to the driver of a vehicle with at least one fatality injured occupant, and each such vehicle is counted as a fatal crash. The top 20 driver-related factors cited in fatal motorcycle crashes are listed. Some crashes involved two or more driver-related factors. Source: National Highway Traffic Safety Administration Fatality Analysis Reporting System, 2004-2008.

Excessive and inappropriate speed

Speed is one of the main risk factors of PTWs. It mainly concerns motorcyclists (and less moped riders) (Langley et al., 2000). Excessive and inappropriate speed is responsible for around 2/3 of single vehicle fatal crashes (Lardelli-Claret et al. 2005; Shankar et al. 1992). Young riders are more concerned by the speed risk (Lardelli-Claret et al. 2005; Mullin et al. 2000; Wells et al. 2004).

Riding a PTW with an excessive (i.e. over the speed limit) or inappropriate (e.g. not adapted to the circumstances) speed is a common type of inappropriate riding behaviour. Because of their small size and their acceleration capacity PTWs allow overtaking and approaching bends at high speed and quickly inserting into traffic compared to 4-wheel motorised vehicles. The performance of these vehicles can seduce users to adopt deviant behaviour such as the search for speed sensation.

Speed is even more difficult to manage as the acceleration capacity of vehicles becomes higher, which leads to more severe crashes (Gisements de sécurité routière 2008). It is a common observation that the most powerful vehicles tend to go faster than the less powerful ones.

In France, a study (ONISR, 2007) shows that excessive speeds are usually between 10 and 30 km/h above the applicable speed limit, depending on the type of roads. In 2004, nearly half of the PTW casualties were riding above the legal limit (ONISR 2006a). US studies show similar results: In 2006, 37% of motorcyclists involved in a fatal crashes, were above the legal limit when the crash occurred (NHTSA 2006b).

The conclusions from the studies are clear: excessive or inappropriate speed is associated with an increased accident severity (Keng 2005; Lin et al. 2003a; Peek-Asa et al. 1996a; Shibata et al. 1994; Zambon et al. 2006, Lardelli-Claret et al. 2005; Shankar et al. 1992).

It is noted that, on average, motorcyclists ride at higher speeds than cars and PTW crashes usually occur at higher speeds than cars (Horswill et al. 2003). Speed differences between motorcyclists and car drivers are higher on rural roads, as are speed violations (Gisements de sécurité routière 2008). Walton & Buchanan (2012) report that motorcycles and scooters travel through t-junctions around 10% faster than other traffic and were 3.4 times more likely to be exceeding the speed limit than cars. It is thus indicated that speeding is a bigger problem for PTW accidents, compared to other modes.

Non respect of traffic rules (other than speed)

Due to increased flexibility and performance (engine power/vehicle mass), motorcycles may be more appealing for inappropriate or dangerous manoeuvres, especially in regard to overtaking. Overtaking in front of curves, overtaking at intersections and filtering are a few examples of inappropriate motorcycle manoeuvres. These manoeuvres may be the most particular type of motorcycles violating traffic rules. However, no specific quantitative results concerning the compliance of motorcyclists to traffic rules are available.

A recent study in China (Wu et al. 2012) shows that the probability of a rider running through a red light is higher for young and middle-aged riders, when the rider is alone, when there are fewer riders waiting, and when there are other riders already ignoring the red light. It is therefore likely that motorcyclists' tendency to respect traffic rules is strongly correlated with other characteristics (e.g. age, experience, engine power and social influence).

Impaired riding: alcohol, drugs and fatigue

Alcohol

The consumption of alcohol is associated with increased risk of fatal crashes among PTWs (Evans 2004; Kasantikul et al. 2005; Luna et al. 1984; Shibata et al. 1994). In addition, several international studies show that riders with a BAC above the limit have a higher probably of speeding and not wearing a helmet than a rider who doesn't drink (SARTRE4, 2012).

Alcohol related crashes are usually most severe (i.e. lead to a fatalities) for PTW. Villaveces et al. (2003) estimates that in the UK, in 2003, 49% of PTW fatal crashes were alcohol related, while this percentage was only 26% for other road users. In Sweden, on the other hand, the percentage of alcohol related crashes is the same for PTW and car drivers, i.e. around 24%. In France, the percentage or riders having drunk alcohol is higher among moped than motorcyclist for both injury and fatal crashes (Gisements de sécurité routière 2008). In the United States, 43% of PTW fatal crashes are alcohol related (NHTSA 2006a) and 27% of PTW riders involved in a fatal crash have a BAC above the legal limit of 0.8 g/ l. This percentage is higher than for car drivers (23 %) (NHTSA 2006b).

As few studies have been conducted among PTW who did not have a crash; it is difficult to assess the prevalence of alcohol consumption among PTWs. Several studies have shown a higher prevalence of drivers under the influence of alcohol among PTW than car drivers involved in injury or fatal crashes (McLellan et al. 1993; Soderstrom et al. 1993; Soderstrom et al. 1995; Stoduto et al. 1993; Williams et al. 1985).

Studies on PTW patients admitted in hospital showed that alcohol was present in 29 to 75% of cases for fatalities (Drummer et al. 2003; Holubowycz et al. 1994; Hurt et al. 1981; Larsen et al. 1987; Preusser et al. 1995) and between 13 % and 60 % for injuries (Holubowycz et al. 1994; Kasantikul et al. 2005; Luna et al. 1984; McLellan et al. 1993; Soderstrom et al. 1995; Stoduto et al. 1993; Sun et al. 1998).

On average, PTW riders involved in injury crashes have a lower BAC than those involved in fatal crashes (Holubowycz et al. 1994). For PTW, riding under the influence of alcohol tends to result more often in fatal than injury crashes.

PTW alcohol related crashes may affect more often young men (Holubowycz et al. 1994; McLellan et al. 1993; Williams 1979). Studies also show an overrepresentation of alcohol related crashes at night time (; Kasantikul et al. 2005; Peek-Asa et al. 1996a; Williams et al. 1985), during the week-end (Holubowycz et al. 1994; Kasantikul et al. 2005), and at high speed (Colburn et al. 1993; Peek-Asa et al. 1996a; Soderstrom et al. 1993).

Drugs

As for alcohol, the effect of drugs can be amplified for PTWs, as riding a PTW requires more balance, co-ordination and accuracy than driving a car (Van Elslande et al. 2003). The consumption of drugs, in addition to the consumption of alcohol, mainly by young people, during the week ends nights should not be ignored (Assailly et al. 2002).

Very few studies focus on the relationship between drugs consumption and crash risk for PTW; most of them focus on the prevalence of different types of drugs among injured riders (Drummer et al. 2003; Longo et al. 2000; Soderstrom et al. 1993; Soderstrom et al. 1995; Stoduto et al. 1993; Sun et al. 1998; Williams et al. 1985). In these studies, the proportion of drivers consuming drugs is higher among PTW drivers compared to car drivers (Drummer et al. 2003; Longo et al. 2000; Soderstrom et al. 1995; Sun et al. 1998; Williams et al. 1985) and the proportion of drivers positive both to alcohol and drugs can't be neglected (Drummer et al. 2003; Williams et al. 1985). Only one study has assessed the relationship between crash risk of PTW and cannabis consumption and has not found a higher crash risk (Williams et al. 1985)

Results from the European DRUID project, based on the French case study, suggest that, concerning prevalence of alcohol and cannabis, among drivers involved in fatal crashes, drivers of motorised two-wheel vehicles, especially moped drivers, have higher prevalence than other road users. Concerning prevalence of alcohol and cannabis, among drivers involved in fatal crashes, drivers of motorised two-wheel vehicles, especially moped drivers, have higher prevalence than other road users (DRUID, 2010).

Gender, age and experience

Gender

Several factors may explain risk variation between men and women: risk taking, natural fragility, choice of vehicle, travel purposes, etc. The results of related studies are rather heterogeneous; nevertheless, a tendency of male motorcyclists to be at higher risk than females motorcyclists is identified. Because of their more impulsive behaviour and despite their higher physiological resistance, they are more often injured in traffic crashes. (Yannis et al. 2007). The higher risk for men can also be explained by a higher propensity to ride faster (Fergusson et al. 2003). When women have a higher risk, this is more to be explained by their frailty and their lack of experience rather than by a risk taking attitude (Chang et al. 2007).

Age

The increased risk of young motorcyclists, confirmed by numerous studies, can be explained by the combination of a lack of experience, the propensity of youngsters to adopt a risky behaviour (speeding, consumption of alcohol or drugs) (Chesham et al. 1993; Ryan et al.

1998). For the 16-17 riding a moped, the yearly distance travelled is very high reflecting their new autonomy (Yannis et al. 2007). For motorcyclists, distance travelled is higher for the 25-34.

One study showed increased risk for the riders above 60 (Lardelli-Claret et al. 2005). This can be explained by a decrease in their ability and riding performance and difficulty in managing complex riding situation (Ryan et al. 1998). On the other hand, other studies reveal a decrease of risk with higher age (Chang et al. 2006; Harrison et al. 2005; Lin et al. 2003b; Mullin et al. 2000). This is mainly explained by a decrease in the number of kilometers yearly traveled (Yannis et al. 2007).

Lack of experience

Studies which assess crash risk with the number of years of license, showed that crash risk diminishes with the number of years (Harrison et al. 2005; Lardelli-Claret et al. 2005; Lin et al. 2003b; Mullin et al. 2000; Namdaran et al. 1988). However, some studies found the reverse association between experience and the risk of being killed or seriously injured (Lin et al. 2003a; Pang et al. 2000; Shibata et al. 1994). Many studies also found an increased crash risk for riders without a valid licence (Haworth et al. 1996; Hurt et al. 1981; Lardelli-Claret et al. 2005; Lin et al. 2003b; Magazzu et al. 2006; Reeder et al. 1999; Rutter et al. 1996; Wells et al. 2004).

Studies show the importance of experience in traffic, not only as a PTW driver but also as a car driver. The experience of driving a car contributes to a decrease of the PTW crash risk among young people: those who have driven a longer distance by car also have a lower crash risk when riding a motorcycle (Reeder et al. 1995). Experience with riding a PTW also decreases the crash risk: the more distance travelled on a motorcycle, the lower the risk (Mullin et al. 2000).

A recent study (Bellet & Banet, 2012) investigates four populations of motorcycles in terms of experience: professional riders (Policemen), experienced riders, novice riders and beginners. The results showed that cognitive abilities in both hazard detection and situational criticality assessment depend of the riding experience: professional and experienced riders obtained better results than novice and beginners for hazard perception (i.e. shortest reaction time), and beginners underestimate the situational risk and seem overconfident in their abilities to manage the situational risk.

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Age and inexperience

It is important to make a distinction between young drivers and novice drivers: a novice driver is not necessarily young. Crash risk depends on both age and experience: the youngest will have a longer novice period. Some studies showed that the age of driver is a more important contributing factor than the lack of experience (Mullin et al. 2000; Rutter et al. 1996).

After adjustment on age, one study found that the driving experience (measured in the number of years of driving licence) is not associated with a decrease in severe or fatal injuries (Mullin et al. 2000). Only the number of kilometres driven with the same vehicle (familiarity with the motorbike) remains associated with a decrease of fatal or severe crashes. More recently, one study found that the effect of experience remains after adjustment with the age of the driver (Lardelli-Claret et al. 2005).

Inexperience and training

Other factors, combined with experience, may significantly affect PTW road accidents. For example, rider gender, compulsory training, and whether he or she had ‘taken a break from riding’ are among the most critical accident risk factors (Sexton et al. 2004). Moreover, there appears to be a transaction of experience and knowledge from the driving of a vehicle to the riding of a PTW that may increase risk awareness (Lardelli-Claret et al., 2005, Wong et al. 2010). Swezey and Llaneras (1997) suggest that exposure to riding may have a strong positive effect on accident risk, while the improvement in skills may decline with experience or learning trials. In this context, Goldenbeld et al. (2004) report that PTW trainees who improved most in the short term may show a large loss of skill in the long run, whereas trainees who improve less by training may be able to improve their skill in the long run.

Personal protective equipment

It is obvious that helmet use significantly reduces the risk of severe head injury and accident severity in general. Although not directly related to accident risk, not wearing helmet is more common among young males (Yannis et al. 2012) and may be associated with reckless driving behaviour.

Several studies (e.g. see detailed meta-analysis by Elvik & Vaa, 2004) have examined the safety effects of increasing helmet wearing rates among the population of motorcyclists and found a significant reduction of motorcycle fatalities associated with increased helmet use. In a recent study in 70 countries, helmet non-usage percentage, motorcycle per person ratio and the presence of helmet standards were positively associated with motorcycle-related death rates. A simple linear regression model between helmet usage and road traffic death rate has shown that for each 10% increase in helmet usage, one life per 100 0000 inhabitants can be saved per year (Abbas et al. 2012).

Lin and Krauss (2009) reviewed the previous studies on protective clothing and concluded that no advantages in the occurrence of fractures were associated to protecting clothing, except for reduced soft tissue injuries. Moreover, De Rome et al. (2011) report that there is no significant association between riding either unprotected or wearing non-motorcycle pants and other indicators of risk taking. However, limited empirical evidence on the effect of protective clothing to PTW safety is available in the literature (Lin and Krauss 2009).

Atypical Behaviour

By its very nature driving a PTW induces a specific way of behaving on the road which is different from the drivers of 4-wheel vehicles. These specific behaviours are not necessarily "deviant" in regards to the law, but have in themselves the capacity to surprise others road users, as far as they are atypical for them.

This refers first to "normal" behaviours which are common to PTWs riders but atypical for the drivers of other vehicles. It includes all the manoeuvres (overtaking within a small space, overtaking on the right, filtering, positioning on one side of the road, intense accelerations, etc.) that are feasible for PTW. For other road users, these manoeuvres are potentially startling, and confront them with interactions which would not be possible with ordinary vehicles, and are thus disturbing their normal efficient information seeking routines. This also includes "deviant" behaviours, e.g. extreme behaviours by a small segment of the PTWs riders, referenced in the literature as "risk takers". This refers to stunt, wheeling, etc.

PERCEPTION AND AWARENESS (OF MOTORCYCLISTS BY OTHER ROAD USERS)

A large European study (MAIDS, 2004) examines in depth over 900 crashes in five countries (France, Germany, Italy, Spain and the Netherlands) involving a motorized two-wheeled vehicle (motorcycle/moped). The study concludes that in over 36% of the cases, the driver of the other vehicle did not see the two-wheeler; in 12% of the cases, the rider of the two-wheeler failed to see the other vehicle.

In the same vein, Van Elslande (2002, 2009) has shown that independently of the question of responsibility, car drivers involved in a crash with a PTW meet a detection problem in nearly 60% of cases; while these problems of detection represent 45% of failures in car crashes not involving two-wheelers. As a consequence, there is an over-representation of detection problems in two-wheelers vehicle accidents, which suggests a specific problem of detectability for these road users.

Typical situations of perception problems vis-à-vis PTW

Figure 1 shows a graphical presentation of typical situations in which a car driver fails to give way to a PTW rider. It is common in these crashes for the other user to declare that he had looked in the direction of the motorcyclist prior to undertaking his interfering manoeuvre, but did not see him even though he was theoretically visible (Wulf et al., 1989). These crashes are called "looked-but-failed-to-see" crashes (Clarke et al., 2007; Koustanaï et al., 2008) or "motorcycle conspicuity-related crashes" (Radin-Umar et al., 1996; Wulf et al., 1989); and are often characterized by a high level of severity (Pai, 2009).

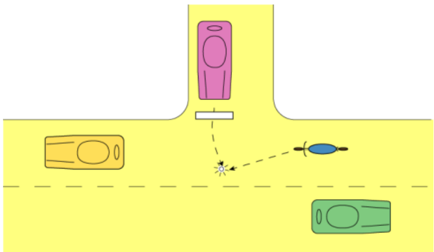	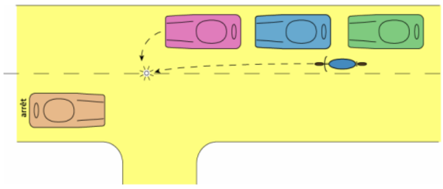	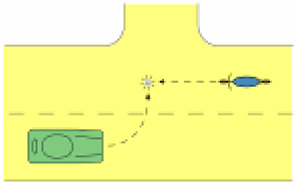
The other driver enters a main road without right of way, despite the arrival of the motorized two-wheelers. The two-wheeler then collides with the car.	The other driver begins a left turn manoeuvre while he is overtaken by a PTW driver who was "lane-splitting"	The other driver makes a left turn manoeuvre, despite the arrival in the opposite direction of a PTW.

Figure 1 Typical situations of detection problems (Guyot et al., 2008)

The problem of PTW perception and its role in traffic crashes

Weaknesses of the human visual perceptive system in driving environment

The human visual system has limited capacities beyond which performance deteriorates. However, it may become adaptive to natural environment, which means at a certain level of speed of movement. The problem is that the traffic environment confronts this adaptive system to far higher speeds, pushing it to its limits of efficiency. This can lead to failing to perceive unexpected, unusual pieces of information, as it is sometimes the case with PTWs. Because they present a different shape, a different behaviour, and they are less spontaneously gathered.

Numerous parameters may contribute to detection problems. These parameters can relate to either the human visual system's capabilities, characteristics of the environment, and specificities of PTW perceptual object itself.

Small size of motorcycle

The smaller dimensions of motorcycles on the road are the most commonly mentioned explanatory element of the specific difficulty to perceive them (e.g. (Hurt et al., 1981; Wulf et al., 1989). Cars, which are wider and have more homogenous contours and colours, are more easily detected by drivers needing to gather information rapidly. PTWs, which are narrower and have more complex contours, provide information with a high spatial frequency and are less easily perceived at a first glance. In any case, physical characteristics of PTW are close to the limits of the human sensorial system, explaining the difficulty to detect it and evaluate its approach.

Environmental impairments on visibility

Environmental impairments on visibility have a negative effect on the detection of every road user, but some road users can be even more sensitive to these defects. By its size, a PTW is more easily hidden by an object than a larger sized vehicle. But the consequences can become very critical in correlation with other crash-prone conditions. A traffic sign slightly impeding visibility, some vegetation on a crossroad, a black spot due to car roof pillars, etc., are parameters that drivers most of the time manage to compensate. But this capacity can be subject to lapses when meeting additional difficulties (attentional factors, traffic constraints, interaction with atypical situations, etc.).

Role of PTW rider behaviour

PTW riders' behaviour can also contribute to the fact that they are not physically perceivable, for example when riding behind the black spots of cars (usually practiced -and sometimes trained- with the purpose to escape easily in case of a difficulty or overtake when possible). As an example of the influence of behaviour on perception,, a study by Brenac et al. (2006) showed a significant relationship between problems of conspicuity and the motorcyclist's high level of speed in crash cases. This relationship can be interpreted as resulting from the particular influence of speed on motorcyclist conspicuity. Conspicuity problems seem to be rare at low speeds given the larger size of the motorcyclist in the protagonist's field of vision for a given time to collision. And vehicles at higher speeds than practiced by the majority of road users can mislead the usually efficient information seeking strategies and perceptual schemes.

In a recent study (Ragot et al. 2012), PTW riders are specifically characterised by car drivers for their speed, considered too fast, and for their driving style, considered as unpredictable. PTW 'atypical' behaviours that consist in weaving between cars, overtaking with an inferred risk, deviate from car drivers' behavioural standards strengthen the perceived unpredictability of PTW riders and the fear of their coming out of nowhere.

Rareness of PTW and experience of interacting with PTW

According to Clarke et al. (2007), this low level of expectation is in part related to the rareness of these users in traffic compared to car drivers (of course depending on the country and the region). (Crundall et al., 2008) found in a questionnaire study that dual drivers (having both car and motorcycle license) have more empathic attitudes and greater understanding of the need to search for motorcyclists, compared to car drivers. Dual drivers are also less prone to cause crashes with motorcycles with respect to drivers with no motorcycle licence (Magazzù, Comelli & Marinoni, 2006).

Difficulties with appraisal (evaluation and decision)

Detection is not the only challenge of the perceptual system: detection alone does not ensure the correct processing of visual information. After a PTW is detected, there are still two more stages (evaluation and decision) were problems can occur. And it is common for PTWs to be detected on the road, but their distance and approach speed are not assessed properly by the observer (Pai, 2011).

On the one hand there are indications that due to the small size of the motorcycle compared to a car there is a so-called size–arrival effect described by (DeLucia, 1991). (Horswill et al., 2005) found that indeed people estimated that motorcycles reached them later than cars when time-to-arrival was actually the same. On the other hand, car drivers may not *expect* motorcycle riders to speed or accelerate as much as they can.

THE ROAD ENVIRONMENT

The contribution of the road and its environment to PTW crashes is limited. MAIDS revealed that the road and its environment are considered as the primary cause for 7.7% of all PTW accidents. Additionally, the road environment was found to contribute to the final outcome of the accident in 14.6% of all analysed accidents. Although they could be considered responsible for only a minority of accidents, specific road environment factors can have an important influence on the accident severity.

Road design

The design of roadway elements influences how a road user interacts with the roadway. These elements include horizontal and vertical curves, intersections, and the roadside.

Horizontal Curves

A horizontal curve's radius (curvature) and superelevation can contribute to PTW crashes. When traveling through a curve, a motorcyclist will lean to remain stable, or also try to reduce the forces by increasing the radius when going through a curve.

- 30% of all PTW crashes include a curve in the pre-crash path. For other vehicles this is 21%. Compared to other vehicles, negative road conditions present in a curve increase the risk for motorcyclists significantly. *(MAIDS, 2009 & MOW, 2008)*
- Curves with small radii are more difficult to handle and require more anticipation from the rider. Deficiencies in the road surface become more critical as curve radius decreases. *(ACEM, 2006 & MOW, 2008)*
- Curves with decreasing radii require a rider to change his position when going through the curve. Such manoeuvres are more difficult and increase the risk for the rider. *(ACEM, 2006)*
- In a curve, riders usually focus on the inner curve. When going to a left curve, this means that their attention is divided between the riding lane and the opposite lane which can

result in the rider having a harder time detecting hazards present in the riding lane. *(ACEM, 2006)*

Moreover, inappropriate (negative) crossfall or superlevation presents the rider with an unpredictable situation that doesn't correspond with driving dynamics. *(2-BE-SAFE, 2009).*

Vertical Curves

Crest curves followed by a sharp downward gradient create a situation where visibility is reduced with oncoming traffic or obstacles behind the crest more difficult to detect in advance. When a crest vertical curve is combined with a horizontal curve, the risk for PTWs increases. *(2-BE-SAFE, 2009)*

Junctions

The severity of a PTW accident at an intersection is higher than for other road users. (CERTU 2010) Different factors make PTWs more vulnerable at intersections; speed, conspicuity, sight distance, complexity of the intersection, unexpected behaviour, etc., all have an influence (MAIDS, 2009).

Moreover, roundabouts that are not sufficiently visible (particularly at night) can present obstacles themselves. Obstacles that are installed on or near a roundabout can reduce visibility (MAIDS, 2009) or increase the severity of accidents (SETRA, 2000). Sufficient skid resistance is crucial on roundabouts (MAIDS, 2009).

Roadside Design

Obstacles (plantings, construction, road equipment, etc.) in the inner curve or at intersections can compromise visibility by either obscuring or limiting sight distance. Road users travelling from different directions will have more difficulties detecting each other. *(MOW, 2008)* Although they contribute only to a minor portion of PTW accidents, obstacles are responsible for a relatively high number of fatalities *(BIVV, 2005).* Obstacles considered as 'safe' or not aggressive for car users, can still be very aggressive for powered two wheelers, resulting in fatalities or severe injuries. *(CROW, 2003)*

Road restraint systems / barriers

Crashes with road restraint systems or barriers contribute to 2,4% - 4% of all PTW fatalities. Impacts to the non-protected posts, particularly exposed sharp parts, of guard rails appear to be critical *(APROSYS, 2006 & 2-BE-SAFE, 2009).* There is no objective, statistical evidence that wire rope barriers cause more severe or lethal injuries than other types of road restraint systems *(SmartRRS, deliverable D1.1.).*

Road delineation / lane separation

In some countries, kerbs and delineation posts are sometimes used to separate lanes or to delineate the side of the road. When hit by vulnerable road users such as PTW, even at relatively moderate speed, there is a high risk for loss of stability. *(BIVV, 2005)*

Joints

Longitudinal joints between lanes present a small zone with different skid resistance or a small irregularity in the road surface. Steel expansion joints, sometimes used on bridges, can destabilize a motorcyclist *(SETRA, 2000 & CROW, 2003).*

Traffic calming measures

Traffic calming to reduce vehicle speeds or divert traffic generally consists of changes to the road surface (installation of speed humps), installation of a local obstacle, or a change of the path of the road (lane shift, locally narrowing lanes that allow only one direction simultaneously). For powered two wheelers however, changes in the road surface can cause a loss of grip to the road surface and destabilize the machine *(ACEM, 2006 & ERF, 2009 & MOW, 2008)*.

Elements on the road surface

Elements in the road surface (gully tops/drainage grates, manhole covers, tram rails, etc.), when installed in the travelways used by the motorcyclist, can be a risk factor for PTWs *(IHIE, 2010 & MOW, 2008 & ERF, 2009 & CROW, 2003),* as they have different skid resistance than the surrounding pavement and can also represent an irregularity in the road surface level.

Road condition

PTWs are more sensitive to roadway conditions then other motorized vehicles. The MAIDS study showed that the road conditions can be considered as acceptable for the majority (70%) of the examined incidents (normal/no defects). For the remaining incidents (30%), road conditions were not optimal. Not all defective roadway conditions end in a crash. In most cases, a proactive rider will be able to deal with such minor road condition deficiencies

Road surface and road markings

In particular in bends and on sections with frequent braking or acceleration, insufficient skid resistance, surface defects or sudden changes in the road surface characteristics can cause a motorcycle to destabilize. Road markings rarely have the same skid resistance as the surrounding road surface *(ACEM, 2006).* The difference in skid resistance between a road marking and the surrounding road surface can be problematic; the reduction of the grip to the road surface can cause loss of stability *(ACEM, 2006 & ERF, 2009 & IHIE, 2010)*, especially in case of water stagnation on the surface of the road marking. Road markings with a good (dry) skid resistance will behave poorly in these circumstances *(MOW, 2008 & ACEM, 2006)*. Moreover, wear caused by traffic, deteriorates the characteristics of the road markings rapidly.

Surface defects, debris and pollution

Defects in the pavement surface can create unsafe conditions for motorcyclists by reducing the amount of friction or creating an unlevel travel surface. These pavement defects include: rutting of bituminous surfaces, corrugation, potholes and other local deficiencies, border damage or unravelling of the pavement edge, pavement swelling due to impurities in the materials used for the foundation layers, roots from trees along the road which push the road surface upwards, fatting up or bleeding of bituminous surfaces, expansion joints of non-continuously reinforced concrete surfaces (BIVV, 2005; MOW, 2008; IHIE, 2010).

Debris, pollution, and fallen cargo on the road can create unsafe conditions for motorcyclists: overhanging trees and other vegetation, falling leaves, gravel, earth, mud and liquids, discharged fuel, can cause local slippery spots or hide local road surface defects. Lost or fallen cargo is problematic for all road users. Motorcyclists will try to avoid larger objects forcing them to execute unexpected and dangerous manoeuvres. (MOW, 2008)

Aquaplaning/Hydroplaning

Water on the road surface can have different reasons; insufficient or blocked drainage, water from the surrounding area not properly evacuated through the sewer system, extreme weather, road surface evenness problems. Independent of the origin of the problem, these spots represent a zone with reduced friction characteristics (IHIE, 2010) and present even more of a problem for PTWs.

Road maintenance

To avoid safety problems however, it is important that defects are detected and appropriate action is taken in a timely manner to bring the quality back to the required level and that regular cleaning and vegetation removal schedules are maintained However, road maintenance operations can represent an additional risk, due to the modified road configuration and work zone activities.

Local spot repairs or surface treatments (surface dressing) that are not properly executed create a risk so that these repaired sections are a (temporary) hazard for PTWs. During resurfacing, the exposed scarified pavement that is left open to traffic before the new surface can be laid can represent an additional hazard for motorcyclists *(CROW, 2003).* Salt residues after winter maintenance can cause skidding problems. *(IHIE, 2010)*

Weather conditions

Weather appears to be a contributory factor of PTW accidents to a minor extent, compared to other contributory factors. Related studies in Europe, Australia and the USA, mostly on the basis of in-depth accident investigations, suggest that adverse weather conditions may be a contributory factor in less than 10% of PTW road accidents (Hurt et al. 1981; ACEM 2003; Johnston et al. 2008).

It is noted that, for PTWs, adverse weather conditions may also refer to high temperatures, which may equally affect riding comfort and safety; however, no research results are available for this particular case. These results may be explained by the fact that adverse weather conditions may have an important effect on PTW mobility, as daily users are more likely to shift to other modes of transport, and occasional users (e.g. recreation users) may postpone their trip.

THE VEHICLE

Vehicle deficiencies are rarely a problem for motorcycle crashes. Vehicle related factors are mentioned in less than 2 % of injury or fatal crashes. In general, vehicle factors are more likely to be an issue with mopeds.

Vehicle age

When comparing new motorcycles with new cars, the odds of fatal or serious injury to a motorcycle rider involved in an injury crash in New Zealand are almost eight times the odds for a car driver (Keal & Newstead, 2012). Similar analyses from Greece reveal that PTW risk decreases with motorcycle age, with new moped (<1 year) riders being 6 times more likely to be killed in than new car drivers, and new motorcycle riders 12 times respectively (Yannis et al. 2005).

Engine displacement

The existing studies are inconclusive as regards the effect of engine displacement on motorcycle crash risk. Two literature reviews were conducted (Mayhew et al. 1989; Ruijs et al. 1997) and highlight the lack of evidence between the engine displacement and the occurrence or severity or a crash. An analysis combining the results of 13 studies found that the association between the vehicle displacement and the occurrence of a crash is lower when adjusted with age, gender and kilometres driven, than when the results do not adjust with these factors (Elvik et al. 2004). Especially as regards, the effects of kilometres driven, a study by Harrison et al. (2005) show that, reported to the kilometre driven by each individual, the crash risk is higher for the 251-500 cc.

It is likely that other criteria, such as the purpose of vehicles (sport, tourism, trails etc.) should be considered. For example, Bjornskau et al. (2012) show that sport bikes (i.e. racing replica bikes) show significantly increased crash risk in Norway.

One study shows a reduction in the number of crashes when restricting the access of the most powerful PTW for novice drivers (Nairn et al. 1993). Further research is however needed to demonstrate the efficiency on this measure in reducing the number of casualties (Mayhew et al. 1989).

ASSOCIATION OF PTW RISK FACTORS

Risky behaviours are often correlated. The combination of low age, low experience, risky behaviour and "unsafe" attitudes seems to be a particular potent risk factor for Norwegian motorcyclists (Bjornskau et al. 2012). Compared to a driver with a valid licence, those without a valid license have a higher probability not to wear a helmet, to drive above the speed limit, to drive under the influence of alcohol and without daytime running light (Peek-Asa et al. 1996a; Reeder et al. 1996). Riders not wearing a helmet have more risk to drive above the speed limit (Shankar et al. 1992). Moreover, individuals who are impaired are more likely not to wear protective equipment. Riders under the influence of alcohol have more risk of driving above the speed limit, not wearing a helmet and not having a valid licence (Hundley et al. 2004; Luna et al. 1984; Nelson et al. 1992; Peek-Asa et al. 1996a; Soderstrom et al. 1993). Drivers aged over 65 showed greater propensity for run-off-the-road crashes in curves (Montella et al. 2012).

Several combinations of factors including nighttime were associated with PTW-pedestrian crashes. As an example, hit pedestrian crashes in nighttime, rainy weather, tangent alignment, and involving a scooter or a light weight motorcycle resulted 9.16 times the number of crashes expected if the above crash characteristics were independent (Montella et al. 2012).

CONCLUSIONS

From the above exhaustive review of road accident risk factors for PTW, it is concluded that driver and rider - related behaviour factors are much more prevalent in PTW accidents, compared to vehicle and road environment factors. More specifically, vehicle-related factors are only a minor proportion of PTW road accident contributory factors, whereas road design and road environment factors can mostly have an important influence on the accident severity (e.g. roadside obstacles and barriers, traffic calming installations) rather than on accident occurrence.

However, there is a clear over-representation of inappropriate perception in PTW crashes, which suggests a specific problem of detectability (conspicuity) for these road users. Moreover, PTW are over-represented in impairment and speeding related crashes, and there appear to be specific PTW behaviours that may surprise other road users; although such behaviours are not necessarily traffic-law-violating, they appear to be unexpected and atypical for other road users, resulting in poor detectability and predictability of PTW behaviour.

Road user behaviour issues constitute the major contributory factors in PTW road crashes. In fact, the five most prevalent driver-related factors in fatal crashes of non-motorcycle occupants are the same as for fatal motorcycle crashes, namely including speeding, driving under the influence of alcohol or drugs, inattention or distracted attention, risk-taking driving behaviour, and failure to keep in proper lane. Moreover, the literature suggests that male, young and inexperienced riders are at higher road accident risk.

Furthermore, a stronger correlation of road accident contributory factor is identified among PTW riders, compared to other road users, often resulting in coexistence of several risk factors in PTW accidents, and in multiplication of the related risk in these cases.

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