Overview of Critical Risk Factors in Power-Two-Wheeler Safety

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Abstract

Power-Two-Wheelers (PTWs) constitute a vulnerable class of road users with increased frequency and severity of accidents. The present paper focuses of the PTW accident risk factors and reviews existing literature with regard to the PTW drivers' interactions with the automobile drivers, as well as interactions with infrastructure elements and weather conditions. Several critical risk factors are revealed with different levels of influence to PTW accident likelihood and severity. A broad classification based on the magnitude and the need for further research for each risk factor is proposed. The paper concludes by discussing the importance of dealing with accident configurations, the data quality and availability, methods implemented to model risk and exposure and risk identification which are critical for a thorough understanding of the determinants of PTW safety.

Key-words: power two wheelers safety, risk factors, road safety, road accidents,

INTRODUCTION

In the recent years, the Power-Two-Wheelers (PTWs) community has experienced extraordinary growth. Over the last 5 years, there has been a 41 percent increase in the number PTWs in circulation in Europe (CARE 2008). The notable increases in motorcycling activities since the mid-1990s have been reported in a number of countries worldwide (Jamson and Chorlton 2009). This growth may coincide with a systematic decrease in the space available for cars, especially in densely populated areas. In 2005, PTW rider fatalities accounted for the 15% of all traffic fatalities in EU (ERSO 2006). The number of motorcycle fatalities in the EU has increased by 7% between 1999 and 2008, whereas the total number of fatalities has decreased by 30% during the same period (ERSO 2010).

PTWs differ from regular vehicles both in driving style and patterns and accident characteristics. They are a more economical means of transport, when compared to the rest of motorized vehicles, and more flexible in maneuvering and parking due to reduced size and, thus, more appealing to users in densely populated areas with significant portion of congested road network (Lin and Kraus 2009). Moreover, PTW use penetrates all social and professional classes (ERSO, 2006). The newly introduced PTW models enhanced with intelligent systems and advanced technologies are also considered more environmentally efficient and are, hence, less polluting than those of the past (ERSO, 2006).

PTW accidents are potentially more serious when compared to car accidents (Preusser et al. 1995, Chen 2009, Wong et al. 2010). The relative small size which most times is accompanied by a relatively powerful engine, the lack of protection of the rider and often the complex driving maneuvers increase risk and severity of accidents, due to easiness in stability lose at low speeds, tire friction loss at poor surface condition, as well as high acceleration capabilities and speeding associated to the difficulty in braking (Pearson and Whittington 2001). Riders must focus on coordinating speed and body angle and managing traction and control, while navigating various surfaces, curves and conditions. Moreover, the small shape of most PTWs increases the risk of accidents, as automobile drivers fail to detect them or predict properly their maneuvers and speed.

Recent results support that the implementation of road safety regulation, improvement in the quality of political institutions, and medical care and technology developments may affect PTW safety and contribute to reduced motorcycle fatalities (Paulozzi et al. 2007, Law et al. 2009). Identifying the main characteristics of the PTW safety and especially those that may increase the risk of having an accident is a complex task, since, in almost all cases, a single contributing factor that caused an accident cannot be easily distinguished. Different studies have been carried out in the past where the specific problems of PTW drivers have been addressed.

In this paper, the majority of these studies are reviewed in order to identify the critical factors in PTW accident causation. Focus is given on the factors that dominate the interaction between PTW drivers' and automobile drivers' behavior on the road, the interaction of PTW drivers with the road infrastructure, as well as those sourcing from weather conditions and the vehicle-related characteristics. The consulted sources in this literature review vary from public research studies performed by governments to published scientific papers.

BEHAVIORAL ACCIDENT RISK FACTORS

PTW drivers' attitudes and driving patterns

Significant variability is observed in the motorcyclists' attitude towards safety. Most times PTWs pay attention to safety issues, but there are age groups and other driver/rider classes that, either - intentionally or unintentionally - seem to disregard them. Risk taking, as well as sensation seeking are typical riders' behaviors (Wong et al. 2010). This behavior is usually reflected on activities such as speeding, disobeying traffic signals, give-way or stop sign, non-compliance to overtaking restrictions or pedestrian crossing, making illegal turns, maintaining short gaps with the following vehicles and so on. Mannering and Grodsky (1995) state that, because motorcycle riding is well known to be a dangerous activity, it 'may tend to attract risk-seeking individuals, in all age and socio-economic categories', which may have a corresponding effect on the total motorcycle accident figures.

Moreover, PTW drivers have a unique perception of hazard different than the one of automobile drivers. Horswill and Helman (2003) conducted a comparative study between a group of motorcyclists and a matched group of automobile drivers and found that motorcyclists travel faster than a matched group of car drivers and may exhibit a better hazard perception - faster in detecting and responding to hazards - than the automobile drivers. Recently, Rosenbloom et al. (2011) also reported evidence on the higher hazard perception ability of PTW drivers over the automobile drivers.

PTW drivers' behavior is related to age and riding exposure; a period of absence from riding might lead to a decline in safety related motorcycle skills, whereas high exposure appears to moderate crash risk (Harrison and Christie 2005). Harrison and Christie (2005) identify three high-risk groups of riders based on accident data from Sydney with respect to the frequency and type – recreational or not – of trips they conduct. Sexton and al. (2006) analyzed the levels of risk acceptance by motorcyclists, their attitudes to risk and their perceptions of personal risk, and divided PTW drivers to: (a) risk deniers who deny the statistical risk levels and did not worry about risk), (b) optimistic accepters who are aware of or willing to believe the statistical risk but were not worried about it and tended to believe it did not apply to them), and (c) realistic accepters who are aware or willing to believe the statistical risk, they worry more about the risks than the other groups, they are more aware that their own skills do not protect them from this risk.

Personality diversities have significant impacts on driving behaviors and can explain various risky riding behaviors (Wong et al. 2010). Clarke et al. (2005) suggest overconfidence as a primary cause for risky riding behavior of young PTW drivers. Watson and al. (2007) determined the following six major types of behavior that characterize both safer and riskier riding as identified by riders: handling the motorcycle skillfully, maintaining concentration and focus on the road environment, not riding whilst impaired, obeying the road rules, not pushing the limits, not performing stunts or riding at extreme speeds. Wong et al. (2010) demonstrated that personality attitudes, such as sensation seeking, amiability and impatience may influence risky driving behaviors especially for young riders; sensation seeking or impatient riders think of unsafe riding intrinsically, whereas amiable riders think of unsafe riding largely due to their worry or concerns about traffic risks.

PTW driving attitudes are greatly affected by socio-cultural factors and socio-economic factors (Preusser et al. 1995, Njå and Nesvåg 2007, Li et al. 2009). Njå and Nesvåg (2007) state that any attempt to reveal causalities related to factors, such has speed, gender, age, lack of concentration etc., in PTW accident risk may be efficient if only associated to social and cultural factors. Literature indicates that socio-cultural factors are difficult to quantify and assess, due to diversity in views of purposes, values, social contexts, and influencing factors that affect the PTW drivers (Njå and Nesvåg 2007, Chen and Chen 2011). Some studies have underlined the subjective norm and perceived behavioral control as critical to speeding behavior (Elliott, 2010, Wong et al. 2010), whereas other studies emphasize the significance of the perceived enjoyment, the personality traits and past experience (Chen 2009, Chen and Chen 2011). Finally, Law et al. (2009) provided evidence that motorcycle deaths follow an inverted U-shape relationship with per capita income and suggested that the implementation of road safety regulation, improvement in the quality of political institutions, medical care and technology developments have contributed to the reduced motorcycle deaths.

Errors and Violations

Several European studies have highlighted the most frequent errors regarding PTW accidents (ACEM 2003, TRACE 2008). PTW accident involvement has been also associated with the willingness to commit traffic violations (Rutter and Quine 1996). Speeding is a frequent violation which has been analyzed in many studies and may result to accidents due to the complex dynamics comparing to passenger cars (Hurt et al. 1981, Horswill and Helman 2003, Elliott et al. 2007, Steg and van Brussel 2009). Steg and van Brussel (2009) found that moped riders were more likely to speed, and had a stronger intention to disobey speed limits when they have a positive attitude towards speeding, and when they think that others expect them to speed. Speeding greatly affects the injury severity (Branas and Knudson 2001, Savolainen and Mannering 2007). The effect of speeding is intensified at unsignalized junctions (Pai and Saleh 2007). Recently, Elliott et al. (2007) provided a methodology to distinguish between traffic errors, control errors, speed violations, stunts, and use of safety equipment; they concluded that reducing riding violations related to speed will increase PTW safety, since, by eliminating such situations, advanced skills in order to avoid accidents would be less frequently required. It should be noted that traffic law violations are usually higher than reported by the police as people tend to under-report their bad behavior (Dandona et al. 2006); under-reporting is a serious consideration in accidentology and may vary according to injury severity, road user type and road type (Amoros et al. 2006).

Conspicuity and Perception of Automobile Drivers for PTWs

Due to their size, PTWs may be difficult to be detected by other users (conspicuity). “Look but fail to see” and poor drivers’ perception is among the most important contributing factor to PTW accidents in UK (Huang and Preston 2004, Clarke et al. 2007). Conspicuity is related to the ‘expectation’ factor of automobile drivers; if the driver does not expect to encounter a motorcycle or a pedestrian he or she will most likely fail to see it (Simons 2000, Clarke et al. 2007). Most right-of-way accidents involving PTWs are attributed to conspicuity (Pai et al. 2009). Pai (2011) provides a thorough review of the conspicuity issues and automobile driver’s decision errors affecting the right-of-way accidents. Horswill and Helman (2003) emphasized on a three-step process for describing the perception of automobile drivers while approaching a motorcycle in junctions: looking, processing and appraising the risk. Labbett and Langham (2006) demonstrated automobile drivers’ propensity to fixate at the focus of expansion, and suggested that novice automobile drivers might fixate an oncoming motorcycle sooner than their more experienced counterparts. Moreover, the failure to correctly appraise the risk is mainly due to size arrival effect (the size of an approaching vehicle can influence the perception of its speed and the time it will arrive at the junction) (DeLucia 1991). Crundall et al. (2008) found that automobile drivers have difficulties in perceiving the motorcycles that were particularly at far distances. Conspicuity is usually addressed via reflective or fluorescent clothing, headlight operation and the color of the helmet (Wells et al. 2004).

Age, Gender and Experience

Age, gender and experience may influence both PTW drivers' attitudes and behavior. Risk taking behaviors are associated with young and inexperienced riders which increase their risk of being involved in a collision (Yeh and Chang 2009). Rutter and Quine (1996) showed that the highest number of injured persons is typically found in age groups close to the lowest legal age limit for use of the vehicle and identified specific patterns of youth behaviors, such as a willingness to break the law and to violate the rules of safe riding, which had a much greater role in accident involvement than inexperience. Older motorcyclists are more likely to be involved severe injury crashes due to (i) decreased physical resiliency to motorcycle crashes and (ii) slow reaction time and reduced sensory and perceptual ability (Savolainen and Mannering 2007, Pai and Saleh 2007, Nunn 2011). Clarke et al. (2002) has shown that younger PTW users tend to make more 'attitudinal' errors. Recently, Rathinam et al. (2007) studied the traffic accidents among underage users of motorcycles and concluded that aggressive behavior and previous encounter with the police are the two strong predictors of PTW accidents.

Young and male motorcycle riders have a stronger propensity for risky behaviors, and these behaviors have been shown to be associated with increased risks of accidents and at-fault crashes, higher tendency towards negligence of traffic regulations and motorcycle safety checks (Mannering and Grodsky 1995, Lin et al. 2003, Rutter and Quine 1996, Sexton et al. 2004, Chang and Yen 2007, Haque et al. 2009). Berg et al. (2008) studied young moped riders, in Sweden, and concluded that there is a connection of trimming with riding in higher speeds and traffic violations. Njå and Nesvåg (2007) underline the importance of socio-cultural factors, for example espoused values, norms and beliefs, assisted by the lack of experience, to the accident proneness of adolescent PTW riders.

Riding experience seems more important for motorcyclists than for automobile drivers (Haworth and Mulvihill 2005, Hosking et al. 2010). Sexton et al. (2004) found that motorcyclist gender, compulsory basic training, or whether he or she had 'taken a break from riding' are among the most critical accident risk factors. Liu et al. (2009) concluded that, under certain conditions, experienced riders exhibited superior responses to hazards compared to inexperienced or novice riders. Moreover, there is a transaction of experience and knowledge from the driving to the riding state that may increase risk awareness (Lardelli-Claret et al., 2005, Wong et al. 2010). Limited experience and poor driving skills, due to a loose motorcycle licensing system, are critical for young riders, particularly young female riders, in increasing accident risk (Chang and Yeh 2007), while, for motorcycle accidents, the highest risk was found in the age group of 20 to 29 years (Barsi et al. 2002).

Education and learning

Education and licensing are considered to be popular PTW risk countermeasures. Literature has for long demonstrated the benefits of an effective rider's education system to the alleviation of PTW accident risk (Chesham et al. 1993). Nevertheless, Baldi et al. (2005) underlined that although motorcycle rider education and licensing play key roles in reducing motorcycle crashes and injuries, little is known about what constitutes effective rider training and licensing. Students affiliated with a vocational senior high school, male students, and students in districts with a higher motorcycle ownership rate had a greater chance of experiencing unlicensed riding and thus had an earlier riding age (Yeh and Chang 2009).

Training is usually suggested as a way to increase awareness of negative behavior, encouraging the rider to behave safely. Elliott et al. (2003) indicate that law and rule breaking behavior is mainly habitual and needs tackling at the early stage of riders. The challenge for training is likely to be made more difficult by the facts that sensation-seeking motives are important for some riders, and that training concentrating on control skills may lead to more accidents if riders become over-confident (Elliott et al. 2003). Sexton et al. (2008) focused on the training provided to motorcyclists, identified current core training competencies in motorcycle training and revealed the ‘best’ practices. Swezey and Llaneras (1997) suggest that the change in skill declines with experience or learning trials, while exposure to riding may have an ongoing effect on crash risk that is similar to the effect of learning. Hosking et al. (2010) found a significant monotonic decrease in hazard response times, as PTW drivers’ experience increases and underlined the potential benefit of training hazard perception and visual scanning. However, literature states that it remains unclear whether the training of riding skills can reduce the incidence of motorcycle accidents and, for this, caution must be taken with educational efforts aimed at expanding motorcyclists’ skill set (Savolainen and Mannering 2007). Goldenbeld et al. (2004) undertook a study in order to examine the effect of training with time and found that trainees who improved most in the short term actually showed the largest loss of skill in the long run, whereas trainees who improved less by training were able to improve their skill in the long run.

Fatigue, Alcohol and other Impairments

PTW or automobile drivers’ fatigue can be defined as (NTC 2001): a. Impaired performance (loss of attentiveness, slower reaction times, impaired judgment, poor performance on skilled control tasks and increased probability of falling asleep) and subjective feelings of drowsiness or tiredness, and b. Long periods awake, inadequate amount or quality of sleep over an extended period, sustained mental or physical effort, and so on. Factors that appear to increase the likelihood of fatigue in motorcycling include the physical effort to control the motorcycle, concentration on the road surface, adverse weather, alcohols and other impairments (Horberry et al. 2008).

Alcohol is an important risk factor of PTW accidents directly related to the decrease in riding skills (Soderstrom et al. 1993, Huang and Preston 2004, Kasantikul et al. 2005, Lin and Kraus 2009). In the US, alcohol is more frequently involved in fatal motorcycle crashes than in fatal crashes of other types of vehicles (NHTSA 2008). Creaser et al. (2009) developed a test track and examined the riding skills of a set of motorcyclists under the influence of alcohol and found that alcohol affected the riders’ weaving skills, the attention allocation and the hazard perception of riders. Haworth et al. (2009) found that the tendency for alcohol may be associated to speeding, non-use of helmets and unlicensed riding for in both moped and motorcycles drivers.

Personal Safety Equipment and Apparel

The effectiveness of safety equipment use has been supported in numerous studies (Branas and Knudson 2001, Keng 2005, Majdzadeh et al. 2008). PTW users can only rely on their protection equipment in case of accident (ACEM 2003, RIDER 2005). A typical protection measure is the helmet use whose importance has for long been supported in literature. However, the use of helmet in PTW riders remains low in smaller cities in developing countries or countries of hot climate (Dandona et al. 2006, Li et al. 2008). Research on assessing the effect of mandatory helmet laws generally indicates that these laws enhance motorcycle safety (Morris 2006, Kyrychenko and

McCartt 2006, Houston 2007, Mayrose 2008). Ferrando et al. (2000) and Houston (2007) suggested that the proportion of fatalities with severe head injuries was also reduced after the establishment of the helmet law in the USA. Little evidence was found to suggest that the effect of helmet use varied with age or gender (Norvell and Cummings 2002). Nevertheless, Kyrychenko and McCartt (2006) and Houston (2007) underlined the negative effect of any downgrading of universal helmet laws to young riders. Recent evidence has suggested that legislation may be a more efficient strategy than education to increase helmet use, as not always helmeted PTW drivers believe that helmets are not protective and impair sight/hearing, but will use them if forced by law (Ranney et al. 2010).

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. The usage of protective clothing may be associated to the purpose of the trip and driver's education (De Rome et al. 2011). De Rome et al. (2011) found no evidence of an association between riding either unprotected or wearing non-motorcycle pants and other indicators of risk taking. It is to note that limited empirical evidence on the effect of protective boots, jackets, leg protectors etc to PTW safety is available in the literature (Lin and Krauss 2009).

ROAD INFRASTRUCTURE RELATED ACCIDENT RISK FACTORSW

Type of road network

One of the major influential characteristics of infrastructure that affect the probability of PTW accidents is the type of area. In European countries, most accidents involving PTWs occur in urban areas (ACEM 2003). In Australia, approximately 70% of motorcycle injuries occur on local area roads (Pearson and Whittington 2001). In the US, the urban and suburban PTW accidents have been found to be the 80% of all PTW accidents observed (Hurt et al. 1981). The prevalence of death on rural roads and at intersections was relatively higher for motorcycle drivers compared to automobile drivers (Lin et al. 2009). Bridges can be problematic for motorcyclists; safety issues of increased accident risk arise in case of bridges that are placed on bends or if they have a surface friction lower than that of the approach road (e.g. concrete or wood after an asphalt road) (NPRA 2004).

Road geometry and roadside installations

A serious consideration in PTW safety is the influence of road geometry, roadside installations, such as barriers, posts and so on, as well as markings (ACEM 2003). Elliott et al. (2003) suggested that parallel longitudinal grooves in the road surface (for example, to avoid aquaplaning) as well as inefficient marking can also induce instability to the PTW riders. Road markings, manholes and cattle grids can be more slippery than the road surface, especially when wet (NPRA 2004).

Literature has systematically underlined the risk associated to curves. Hurt et al. (1981) highlighted the high frequency of right of way violations and single vehicle accidents on bends. A high portion of motorcycle accidents that involve going out of control on a curve was also identified in Preusser et al. (1995), Sexton et al. (2004), Clarke et al. (2007). Schneider et al. (2010) assessed the impacts of horizontal curvature and other geometric features on the frequency of single-vehicle motorcycle crashes along segments of rural two-lane highways; they concluded that the radius and length of each horizontal curve, along with the shoulder width, annual average daily traffic, and the location of the road segment in relation to the curve significantly influence the frequency of motorcycle crashes, as do shoulder width, annual average daily traffic, and the location of the road segment in relation to the curve.

Crash barriers have a significant contribution to the PTW accident risk. Gabler (2007) found that the fatality rates of PTW drivers were high accounting for 42% of all fatalities resulting from guardrail collisions, and 22% of the fatalities from concrete barrier collisions; in cases of crashes with guardrails PTW fatality rates were approximately 80 times higher than for other vehicles. Recently, Danillo and Gabler (2011) found that motorcycle collisions with guardrail were 7 times more likely to be fatal than hitting the ground. Gibson and Benetatos (2000) found that the majority of fatal impacts with barriers were at a relatively shallow angle (between 15° and 45°); such conditions occur when the rider is sliding into the barrier at a bend. The typical barrier impact location is a curve, and in about half of the cases the rider impacts in upright position (APROSYS 2006). The major cause of injury when a rider comes into contact with a crash barrier is exposed posts (Gibson and Benetatos 2000, Duncan et al. 2000, MAG 2005). Moreover, riding has been found to be affected by the presence of surveillance cameras; not-at-fault crash involvement at intersections is reduced in such a setting (Haque et al. 2009).

In recent years, extensive debate has focused on the material of barriers and the general philosophy of their design. The results obtained from simulated concrete barrier tests indicate that motorcyclists impacting in an upright position will experience low deceleration and sustain survivable injuries, unless they are catapulted over the barrier and strike the objects around which the barriers were built, whereas the results on the simulated wire rope barrier tests showed that riders are likely to get caught and decelerate very quickly (Berg et al. 2005). The wire rope barrier system is viewed by motorcyclists as the most aggressive form of Vehicle Restraint Systems causing the most injuries to riders (MAG 2005). It should be noted that the current standards and specifications for roadside hardware, and the systems themselves and rarely designed to take into account the impact by motorcyclists (ATBS 2000, MacDonald 2002, Ibitoye et al. 2006, Tan et al. 2008).

Lighting and Visibility

A significant concern in PTW safety is visibility. Poor visibility (horizontal curvature, vertical curvature, darkness) is responsible for increased motorcycle injury severity (Savolainen and Mannering 2007, Wanvik 2009). Poor sightline visibility and rider conspicuity are likely to contribute to motorcycle accidents at intersections (NPRA 2004). Moreover, riding in darkness without street lighting was related to severe motorcyclists' injury (de Lapparent 2006, Pai and Saleh 2007, 2008a, 2008b). Motorcyclists often experience reduced visibility when wearing glasses, visors or wind shields that may decrease in cases of riding inside tunnels (NPRA 2004). Injuries resulting from after midnight night riding (0:00-07:00), in general, have been found to be the most severe, especially in junctions controlled by stop, and give-way signs and markings (Pai and Saleh 2007). Motorcyclists are found to be more vulnerable during night time at both intersections and expressways, perhaps because of increased speeds and stronger impacts (Haque et al. 2009).

Type of collision

Preusser et al. (1995) found that ran off-road and head-on collisions are predominantly the result of one or more errors on the part of the motorcyclist. At-fault crashes on expressways are found to increase when riding in the median lane, with higher engine capacity (Haque et al. 2009). Head-on collisions with other vehicles while negotiating a curve make up 6% of person injury accidents, and 13% of fatal accidents (NPRA 2004). Collisions with stationary objects result in more severe injuries (Quddus et al. 2002, Lin et al. 2003, Keng 2005, Savolaine and Mannering 2007). Motorcyclists were likely to be engaged to a severe accident during overtaking or while vehicles – either PTW or automobile - made a turn (Pai and Saleh 2008b). At collisions at intersections between cars and motorcycles the automobile drivers are usually at fault; the automobile drivers do not "see" motorcycles, due to either the shape and color of motorcycles or the automobile drivers have a strong set to just notice other cars making them overlook motorcycles even though they are clearly visible (Glad 2001).

Junction Type

Junction type is a significant influential factor of PTW safety. More than half of motorcycle crashes with personal injury occur at T-junctions including entrances and exits. Hurt et al. (1981) and de Lapparent (2006) note that the probability that a severe/fatal accident occurs at intersections is higher than the same probability at non intersections. The most common of accident has been found to be the right of way violation (ROWV), where a vehicle pulls out from a side road onto a main carriageway into the path of an approaching motorcycle (Hurt et al. 1981, Haworth et al. 2005, de Lapparent, 2006, Crundall et al. 2008, Pai et al. 2009); Pai (2011) provides a thorough review of such crash settings and underlines the impact of the lack of motorcycle conspicuity and automobile driver's speed/distance judgment error.

Pai and Saleh (2007, 2008a) provide an extensive study on the interaction of junction type and motorcycle injury severity and identify the following factors contributing to motorcyclist injury severity at non-signalized junctions: elderly rider, greater engine size of motorcycle, riding in early morning (0:00-07:00), on weekend and under fine weather, street lights unlit, riding on uncongested road, collisions with bus/coach. In the case of signalized intersection, Pai and Saleh (2007, 2008) identified the engine size, the collisions with bus/coach, riding under fine weather and on rural road and type of collision as being critical to PTW safety. Very similar findings were also demonstrated by Yannis et al. (2005).

Pavement surface conditions

Most PTW crashes occur on dry road surfaces (ACEM 2003); this could be explained by the fact that most motorcyclists use their bikes only during fine weather conditions. Shankar et al. (1996) emphasize on the impact of the pavement surface and type of highway to sideswipe collisions between motorcycles and other motorized vehicles at junctions. Wet pavement surface is found to cause at-fault motorcycle accidents at non-intersections (Haque et al. 2009). However, Savolainen and Mannering (2007) suggest that in certain circumstances, risks could be mitigated by motorcyclists; for example, maintaining lower speeds on wet pavement conditions, near intersections.

Road surface actively contributed to 15% of crashes examined by the Victorian Motorcycle case control study (Haworth et al. 1997); the authors suggested that the important factors in these collisions were the surface grip, surface irregularities and potholes, loose materials, patch repairs and road markings. Pearson and Whittington (2001), state that motorcycles are very sensitive to changes in friction level between the road surface and tires; once a tire loose friction with the terrain the centrifugal force and the weight force, which are centred in the centre of gravity, create a momentum that leads the motorcycle to an sudden rotation (Cossalter et al. 2007). Bitumen used in the repair of road surfaces have much lower skid resistance than for wet tarmac causing steering problems when riders cross wet bitumen, particularly whilst leaning or braking in an upright position (Elliott et al. 2003).

VEHICLE RELATED ACCIDENT RISK FACTORS

The type and characteristics of PTW have an important role on accidents likelihood and severity. Great motorcycle engine size may increase the injury severity levels regardless of the control measure adopted (Quddus et al. 2002, Langley et al. 2000, Lin et al., 2003, Sexton et al. 2004, Harrison and Christie, 2005, de Lapparent 2006, Pai and Saleh 2007, Savolainen and Mannering 2007). Brorsoon et al. (1984) reported a clear-cut relationship of engine displacement and power to wobbling (unrestricted oscillation of front wheel flutter and high-speed weave). Moreover, collisions with heavier vehicles result in more severe injuries (Quddus et al. 2002; Lin et al., 2003, Keng 2005, Pai and Saleh 2007).

The recent emergence of in-vehicle technologies should be also considered in PTW safety. These technologies refer to systems for collision avoidance, electronic stability control, lane departure warning / lane keeping support, automatic stopping of the vehicle etc. The aim of such systems is to increase the awareness of PTW drivers of their own location, traffic incidents on the road, anticipated weather conditions, as well as any potentially dangerous situations around (e.g. interactions with the rest of the traffic, obstacles etc). Such systems may interact with Infrastructure-based Intelligent Transportation Systems (ITS) to increase information flow and increase safety (Regan 2004).

The research on the effect of in-vehicle technologies and other ITS systems to the PTW safety are still at infancy (Bayly et al. 2006). Passive safety systems, as reflected on vehicle architecture, airbags, leg protectors etc., as well as active safety systems, which deals with technologies aiming at improving stability control, such as braking systems, traction, electronic suspension etc., are reviewed in Di Tanna et al. (2007). Braking technologies have been also largely considered. Over-braking and resulting loss of control are major risk factors in PTW accidents (Hurt et al. 1981, ACEM 2003, Roll et al. 2009). In recent studies, it has been found that anti-blocking systems (ABS) may reduce motorcycle stopping distances; however, these studies have been conducted in closed test tracks (Green 2006, Vavryn and Winkelbauer 2004). In MAIDS project, no meaningful results based on real accidents estimating the preventive effect of ABS brakes on motorcycles may be traced in literature (ACEM 2003). Other studies have underlined the potential effectiveness of ABS in cases of wheel’s block or light PTWs (Lu and Shih 2005). Recently, Teoh (2011) underlined the inability of anti-blocking systems to mitigate all types of crashes, as well as the inability to deduce safe results due to the small sample of ABS equipped PTWs and the lack of pre-crash information.

Moreover, daytime running lights (DRLs) aiming at addressing the key safety issue of motorcycle conspicuity have been largely considered. Paine et al. (2005) suggested that DRLs have the potential to reduce fatal motorcycle crashes in Australia. Finally, Huth et al. (2011) evaluated the use of curve warning systems via a riding simulator experiment and concluded that these systems may enable an earlier and stronger adaptation of the motorcycle dynamics to the curve than when the riders do not use the system. Although the need to shift the focus of

ITS developments onto motorcycles, as well as the market potential of such technologies, have been largely recognized, there are still concerns on the automation of the riding process and its safety implication (Bayly et al. 2006).

WEATHER CONDITIONS RELATED ACCIDENT RISK FACTORS

Intuitively, PTW riding is heavily influenced by the weather. However, literature has recently demonstrated some contradictory results. Weather has been reported to be a less influential factor in 98% of motorcycle accidents comparing to other prevailing factors related to helmet use, type of collision, age and gender etc. in a research conducted in California (Hurt et al. 1981). In a European and Australian large scale study, weather made no contribution to accident causation in 92.7% of accident cases (ACEM 2003, Johnston et al. 2008). Quellet et al. (2003) conducted on-scene, in-depth accident investigations of 1082 motorcycle crashes in Thailand in 1999 and 2000 report weather factors to be rarely a contributing factor. Riding under fine weather also appears to result in more severe injuries regardless of what control measure was employed (Pai and Saleh 2007).

The above contradictions with the basic intuition may be understood considering two distinct issues. First, in many countries, riding is mainly a recreation activity, purely influenced by adverse weather. Even PTW users, which use the vehicle as a means of transport on a daily basis, change to other modes (e.g. car, public transport) when they expect bad weather conditions. Second, the PTW is not an all-weather vehicle and it does not share similar accident characteristics like automobiles concerning the effect of weather (Hurt et al. 1981). Finally, both low and high temperatures should be considered as bad weather conditions for riding a PTW, as they both affect comfort and safety.

CRITICAL APPRAISAL, CAUTIONS AND LIMITATIONS

The available literature is summarized in Table 1 with respect to the general categorization of the study (behavioral, infrastructure related, weather related or vehicle related), the study area (urban, rural, highway), the type of vehicle (motorcycle, moped or both), the available data (police reports, survey and so on), the modeling approach (regression, principal component analysis and so on) and the identified risk factors.

From the analysis conducted, it is evident that the behavioral issues in PTW safety have attracted the larger portion of the research. However, there still exist several behavioral issues, such as the traveling patterns and the risk perception of riders with relation to different riding situations that are only qualitatively treated so far and need further research. Towards this direction, detailed data on the microscopic (individual speed, acceleration features, maneuvering as described by steering angle etc) or cognitive characteristics (e.g. eye fixation) of riders just before, during and after a critical riding situation seem to be imperative.

Regarding road infrastructure risk factors, research is limited mainly due to the lack of relevant accident and exposure data (Yannis et al. 2010b). The use of the popular police reports of accidents rarely provide detailed information on the infrastructure setting (curvature change rate or unbalanced ratio of successive radii, pavement conditions etc.) and its exact specifications that may increase PTW accident likelihood. Furthermore, weather conditions have not yet been systematically treated in relation to PTW accident likelihood; weather is mainly introduced to the modeling PTW accident risk via a qualitative scale (fine, wet, dry etc.) and not in the form of quantitative indicators with spatio-temporal aspects.

Current research for the identification of critical risk factors in Power-Two-Wheeler Safety has to deal with a number of open issues. Firstly, an important open issue for PTW safety investigation is the lack of exposure data. Utilizing absolute numbers and trends of values may lead to interesting general conclusions on traffic safety, which are however of limited significance due to lack of exposure information (traffic volume and speed, vehicle- and person-kilometres of travel, etc.). Despite some availability of passenger car exposure, data on PTW traffic are very rarely available making thus very difficult the extraction of reliable conclusions on PTW accident risk. Furthermore, the research on PTW safety critical risk factors requires the combined examination of the joint effect of weather, traffic volume and speed parameters and consequently sufficient disaggregation of these data should be aimed. The use of severity indices overcomes the need for exposure data but corresponding results are obviously limited only to accident severity characteristics (Golias and Yannis 2001). PTW traffic data are.

The second open issue refers to the need for different analyses for the different PTW traffic environments. Results of PTW risk factors analysis may vary considerably for inside and outside urban areas traffic, for heavy and light PTW traffic, for commuters and recreational riders with varying impact on PTW accident frequency, severity and risk. These traffic environment variations are more important for the PTW interaction with the other road users. This need for segmentation of PTW risk analysis is very critical for the identification of the countermeasures, which should be suitable for each traffic environment.

Another open issue is the need to develop a more holistic view of the PTW accident investigation that will include the entire accident setting characteristics in order to clearly identify more clearly the critical risk factors, as well as the manner PTW drivers may react to the emergence of a critical incident. A serious weakness in most research efforts on PTW risk factors refers to the lack of identifying the characteristics of the accident setting. Prior to studying the critical risk factors, it is of significance to define the PTW accident configurations. Current practice stresses that some accident scenarios, such as losing control on corners and curves with excess speed, PTW at intersection having the right of way, right of way violations most commonly caused by a road user other than the PTW, emergency braking on a straight road and so on, are more relevant in frequency and severity (RIDER 2005, TRACE 2008). Further investigating these settings could lead to a more efficient manner of distinguishing and ranking the importance of critical factors of PTW accident risk.

An additional open issue refers to data availability and quality. Several studies have shown that police reports data, which are the basis for safety research in most countries, may be incomplete and biased (Amoros et al. 2006). Moreover, even if police reports are accurate, they have limited representational power in terms of the entire picture of risk (Njå and Nesvåg 2007). The quality of most studies, especially the behavioral ones, is linked to the availability of data on the riding parameters. Until recently, PTW accident risk has been largely studied through macroscopic and in-depth data analyses (Thomas et al. 2005, Yannis et al. 2010a), as well as through behavior analyses such as questionnaire based surveys, guided discussions, video-based methods (Savolainen and Mannering 2007, Haque et al. 2010). These analyses are inherently destined to qualitatively assess the factors that increase accident risk or causalities involved mainly from a general social representation point of view, without being able to extract accurate and detailed information on how road users may interact with PTWs and how PTWs may behave on the road and especially before, during and after critical situations.

The recent shift to more efficient ways of PTW driving data collection by developing a least intrusive - naturalistic - environment employing advanced sensor technologies has provided a significant number of aspects of automobile drivers' or PTW drivers' behavior and their interactions (Reagan et al. 2006, NHTSA 2006, FESTA 2008, Baldanzini et al. 2009, Creaser et al. 2009). However, special attention should be given to the extent of PTW instrumentation not to exceed certain limits and compromise the validity of experiments, as well as the maneuverability of vehicles. Furthermore, the link between PTW driver behavior and accident risk (possibly through incidents and near misses investigation) requires a considerable research effort before sound conclusions could be drawn.

As for the methods implemented to PTW accident risk modeling, classical statistical modeling seems to dominate the specific research field. Ordered probability models (Quddus et al. 2002) and unordered probability models (multinomial and nested logit) (Shankar and Mannering 1996, Savolainen and Mannering 2007), or structural equation modeling (Chen 2009, Wong et al. 2010, Chen and Chen 2011) have been systematically applied to PTW accident studies. The lack of applications of computational intelligence methods, such as Bayesian methods, neural networks and so on, is more than evident. This may be attributed to the fact that PTW accident risk studies are more focused on explaining the phenomena investigated rather than on providing an efficient - in terms of accuracy and development time - representation of the underlying properties of the data. In this framework statistics seem more suitable than popular computational intelligence models (Karlaftis and Vlahogianni 2011). However, in view of the in-vehicle instrumentation and novel data collection techniques, researchers should consider using advanced computation intelligence approaches to deal with the computational and inferential implications of working with large datasets that may often contain noise or missing values and great deal of uncertainty.

Furthermore, an open issue to be tackled within PTW accident modeling is risk identification and quantification. Njå and Nesvåg (2007) underline that risk refers to anticipated actions; "*it is contextual and based on several assumptions*". Most times, what is being identified is the perception of risk of the one who analyzes the data and not the actual risk. Risk is difficult to be identified and modeled because it encompasses not only measurable parameters but also the social and cultural representations of the rider as reflected on their riding behavior. The last may be a reason for questioning the generalization power of PTW accident risk models.

CONCLUSION

PTW drivers are among the most vulnerable road users encompassing an increased level of risk during critical driving situations, as a result of the nature of their traffic and their interaction with the other road users. In this paper, literature on PTW accidents was reviewed and a synthesis of critical risk factors of PTW safety is proposed with respect to behavioral, infrastructure, vehicle and weather parameters. Behavioral factors concern PTW drivers' attitudes and driving patterns, errors and violations, conspicuity and perception of automobile drivers for PTWs, age, gender and experience, education and learning, fatigue, alcohol and other impairments and personal safety equipment and apparel. Road infrastructure related PTW risk factors refer to the type of road network, the road geometry and roadside installations, lighting and visibility, type of collision, junction type and pavement surface conditions. Vehicle related factors concern engine size, PTW and opponent vehicle size, in-vehicle technologies and day-time running lights and weather related factors concern temperature and precipitation.

Several critical risk factors are revealed with different levels of influence to PTW frequency, risk and severity. A broad classification based on the magnitude and the need for further research for each risk factor is attempted as presented in Table 1. This synthesis of PTW risk factors revealed a number of current challenges, like the need for PTW exposure data and for separate examination of PTW risk factors in the various traffic environments, the need to develop a more holistic view of the PTW accident that will include the entire accident setting characteristics, the importance of accident configurations and the methods implemented to model risk and exposure. Further, discussion was established on the accident, exposure and behavioural data availability and quality, as well as the advantages and limitations of operating instrumented PTWs in order to collect, process and analyse real-time high resolution data.

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Table 1: Summary of literature on PTW accident risk factors.

Author(s)	Date	Category	Area	Vehicle	Modeling	Data	Risk factors
Daniello and Gabler	2011	I	U/R	MC	D	PR	collisions with roadside objects (guardrail, signage etc)
de Rome et al.	2011	B/V	U/R	MC	R	Survey(Q)	experience, helmet and protective clothing, age, PTW type
Huth et al.	2011	I	H	MC	ANOVA	simulator	curve warning system, reaction time
Nunn	2011	B/I	U/R	MC	R	PR	collisions with roadside objects, risky behavior, speed, alcohol and drugs, lighting, age
Rosenbloom et al.	2011	B	U/R	MC	ANOVA	Survey(Q/V)	license, age
Teoh	2011	B/V	U/R	MC	D	PR	antilock braking systems, age, speed, alcohol
Chen and Chen	2010	B	U/R	MC	SEM	Survey(Q)	sensation-seeking and riding experience, perceived enjoyment, concentration, perceived behavioral control, speeding behavior intention actual speeding behavior
Elliott	2010	B	U/R	MC	P	Survey(Q)	affective attitude and perceived controllability, self-identity and perceived group norm and group identification
Haque and Chin	2010	I	U/R	MC	R	PR	collision type, nighttime, curbs, lane and road type, signalization, passenger onboard, red light cameras
Haque et al.	2010	I	U	MC	R	PR	type of intersection, control, red light camera, exposure
Hosking et al.	2010	B	U	MC	ANOVA	Simulator	experience, hazard perception
Ranney et al.	2010	B	U/R	MC	D	Survey(Q)	helmet use, training, age, gender, attitudes, norms, behaviors
Schneider et al.	2010	I	R	MC	R	PR	radius and length of horizontal curve, shoulder length, average daily traffic
Wong et al.	2010	B	U/R	MC	SEM	Survey(Q)	age, sensation seeking, amiability and impatience, violations
Barsi et al.	2009	B/V	U/R	PTW	D	Survey(Q)	age, engine size
Broughton et al.	2009	B	U/R	MC	ANOVA	Survey(Q)	violation/speeding daytime riding on rural roads
Chen	2009	B	U	MC	SEM	Survey(Q)	anxiety, anger, sensation seeking, risky driving attitude
Creaser et al.	2009	B	Other	MC	ANCOVA	Sensors	alcohol impairment, response time, experience
Haque et al.	2009	I	U	MC	R	PR	intersections, errors, speed, pavement surface, lighting, speed limit, pillion passenger, engine capacity, age
Haworth et al.	2009	B	U/R	PTW	D	PR	alcohol involvement, excessive speed, non-use of helmets and unlicensed riding
Lardelli-Claret et al.	2009	B	U/R	PTW	R	PR	inappropriate or excessive speed, alcohol, age, gender, license, helmet use
Law et al.	2009	B	U/R	MC	R	PR	motorization, technical, policy and political countermeasures, helmet laws, medical care and technology improvements, quality of political institutions
Li et al.	2009	I/B	U/R	MC	R	PR	type of area, speed, type of intersection, alignment

Liu et al.	2009	B	U	MC	D	Simulator	experience hazard perception and risk perception
Pai et al.	2009	I	U	MC	R	PR	collision type, area type, light conditions, age, gender
Steg and Brussel	2009	B	U/R	M	F	Survey(Q)	speeding violations, attitudes, subjective norm, and perceived behavior control, age
Wanvik	2009	I	U/R	M	R	PR	road lighting, weather, surface conditions
Yeh and Chang	2009	B	U/R	MC	R	Survey(Q)	age, gender, experience, license
Crundall et al.	2008	B	U/R	MC	ANOVA	Survey(Q/V)	junctions, perceptual and appraisal errors
Haque et al.	2008	I	U	MC	R	PR	intersections, control, errors, exposure
Li et al.	2008	B	U/R	MC	R	PR/I	helmet use, gender, age, engine size, road type, time period, police enforcement
Majdzadeh et al.	2008	B/I	U/R	MC	R	Survey(I)	type of collision, gender, weather conditions, road conditions, age
Mayrose	2008	B	U/R	MC	D	PR	helmet law, helmet use, Age, sex, injury severity
Pai and Saleh	2008a	I	U	MC	R	PR	engine size, crash type, crash partner, gender, age, exposure, speed limit, control, light conditions, weather
Pai and Saleh	2008b	I	U	MC	R	PR	engine size, crash type, crash partner, gender, age, exposure, speed limit, control, light conditions, weather, overtaking or changing lanes
Chang and Yeh	2007	B	U	MC	R	Survey(Q)	age, gender, violation, negligence of potential risk and vehicle examination
Clarke et al.	2007	B/I	U/R	MC	D	PR	collision type, loss of control, curves, conspicuity, age, experience
Elliott et al.	2007	B	U/R	MC	PCA	Survey(Q)	age and experience, control errors and speed violations, perceptual traffic errors
Gabler	2007	I	H	MC	D	PR	guardrail crashes, helmet
Houston	2007	B	U/R	MC	R	PR	helmet, age, speeding, alcohol,
Njå and Nesvåg	2007	B	U/R	PTW	In-depth	Survey(I)	speed, gender, age, lack of concentration, social and cultural factors
Pai and Saleh	2007	I	U	MC	R	PR	collision type, control, engine size, age, speed limit, light condition, gender
Rathinam et al.	2007	B	U/R	MC	R	Survey(Q)	aggressive behavior, age
Savolainen and Mannering	2007	B/I	U/R	MC	R	PR	collision type, roadway characteristics, alcohol consumption, helmet use, unsafe speed
Dandona et a,.	2006	B/V	U/R	PTW	D	Survey(I)	drivers licenses, use of a helmet, and condition of vehicles
de Lapparent	2006	B/I	U	MC	R	PR	gender, age, type of crash, weather, helmet engine capacity daylight intersection
Ibitoye et al.	2006	I	Other	MC	Simulation	Simulated	guardrail
Kyrychenko and McCartt	2006	B	U/R	MC	R	PR	helmet law, age, gender
Morris	2006	B/I	U/R	MC	R	PR	helmet law, temperature and precipitation, alcohol, speed limit engine power, age
Baldi et al.	2005	B	U/R	MC	D	Survey(Q)	program administration, rider education, licensing

Harrison and Christie	2005	B	U/R	MC	R/C	Survey(Q)	riding patterns, age ,gender, riding exposure, skill acquisition and learning
Kasantikul et al.	2005	B/I	U/R	MC	D	PR	alcohol, control, type of intersection
Keng	2005	I	U/R	MC	R	PR	helmet use, age, gender, weather, lighting, speed limit
Lardelli-Claret et al.	2005	B	U/R	MC	R	PR	age, sex, nationality, license, alcohol, speeding, helmet use
Yannis et al.	2005	B/V	U/R	PTW	R	PR	driver age, engine size
Goldenbeld et al.	2004	B	Other	M	I	Survey(Q)	training and experience
Horswill and Helman	2003	B	U/R	PTW	MANOVA	Survey(Q/V)	speed, hazard perception skill, sensation seeking, attitudes to riding/driving
Lin et al.	2003	B	U/R	MC	R	Survey(Q)	crash history, exposure, risk-taking level, alcohol, traffic violations, age, experience
Norvell and Cummings	2002	B	U/R	MC	R	PR	helmet use age, gender, and seat position
Quddus et al.	2002	I	U	MC	R	PR	nationality, engine capacity, headlight , collisions with pedestrians and stationary objects
Branas and Knudson	2001	B	U/R	MC	R	PR	helmet law, temperature
Ferrando et al.	2000	B	U	MC	R	PR	helmet law, age, gender
Mullin et al.	2000	B	R	MC	R	Survey(Q)	age, experience
Reeder et al.	1996	B	U/R	MC	D	Survey(Q)	age, license, experience, helmet, protective clothing, conspicuity, alcohol, daytime headlight
Shankar and Mannering	1996	B/I	U/R	MC	R	PR	environmental factors, roadway conditions, vehicle characteristics, and rider attributes
Mannering and Grodsky	1995	B/I	U/R	MC	R	Survey(Q)	exposure speed limit, passing behavior
Preusser et al.	1995	I/B	U/R	MC	D	PR	Alcohol and excessive speed, crash type,
Sodestrom et al.	1993	B	U/R	MC	D	PR	alcohol use, driving records, and crash culpability
Bronsson et al.	1984	V	U/R	MC	D	Survey(Q)	wobbling, engine power, age, speeding, road-markings, bumps or pot-holes
Muller	1984	I	U/R	MC	R	PR	daytime headlight use
Jonah et al. 2001	1981	B	U/R	MC	R	Survey(I)	age, exposure, riding skills

Category: Behavioral factors(B), Infrastructure related factors(I), weather related factors (W), vehicle-related factors (V)
Study Area: Urban (U), Rural (R), Other
Vehicle: Motorcycle (MC), moped (M), all categories of Power-Two Wheelers (PTW)
Modeling: Regression (R), Structural, equation model (SEM), Descriptive Statistics (DS), Principal Component Analysis (PCA), Factor Analysis (F), Power Analysis (P), Cluster Analysis (C), Item Analysis (I)
Data: Police Reports (PR),Survey (S), Questionnaire (Q), Video (V), Interview (I)