ROAD INFRASTRUCTURE AND SAFETY OF POWER TWO WHEELERS

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ABSTRACT

Power Two Wheelers (PTWs) safety risk factors are examined in relation to the road infrastructure characteristics and the extent and magnitude of their influence to the PTW accidentology is discussed. In view of the above, a variety of published articles, European and international research reports and other public studies have been collected and analyzed with respect to specific road infrastructure characteristics such the type of the area and location of the accident, the road geometry and roadside installations, issues of lighting and visibility, collision type and road surface condition. Analysis results indicate a significant number of factors that contribute to the increase PTW accident risk, for example accidents occurring inside urban areas, or at the vicinity of extreme road geometries such as severe bends and high gradients. Moreover, disharmonic alignment design and maintenance defects emerged as critical in the present study. The paper also addresses several interdependencies between different risk factors. Finally, the paper provides a discussion on the importance of each risk factor revealed with respect to the existing literature dedicated to the specific factor, as well as the need for further research.

Keywords: Power Two Wheelers, road safety, infrastructure, risk factors

INTRODUCTION

Power Two Wheelers (PTWs) are distinguished into mopeds and motorcycles. Mopeds refer to PTWs with 50cc engines, restricted top speed (limit 50km/h) and typically are used for short trips and are prohibited in motorways. Legal requirements for riding mopeds differ across EU countries; in general, moped riding has an age restriction (usually riding is allowed with an age of 16), but require less training skills. In many European countries, a separate category of light motorcycles (125cc engines) is also distinguished. In both categories, helmet use is mandatory.

There are currently an estimated 33 million PTWs in circulation in the EU 27 countries, from small 50cc mopeds to powerful motorcycles (ERF 2008). These represent about 14% of the entire European private vehicle fleet (cars and PTWs only), but they account for around 17% of the fatalities. PTW use varies across EU. In Greece, there are more than 150 mopeds and 100 motorcycles per 1000 inhabitants. Trends reveal a systematic decrease of moped use in most European countries, whereas motorcycle use is increasing. Moreover, PTW use is also an international concern. In United States, since the mid-1990's, motorcycle use for commuting and recreational purposes has been on the rise, with motorcycle registrations having increased 61 percent between 1996 and 2005 (NHTSA, 2006).

In the recent years, the PTW community has experienced extraordinary growth with the number of PTWs on European roads more than doubling over the last two decades; and PTW sales are expected to continue to increase over the next decade. This is due, in part, to the re-use of the urban space, which is reducing the space available for cars. In dense urban areas, where traffic density is high, the PTW is a clear challenger for individual trips. In the last 20 years, the average age of PTW riders killed on the roads has been increasing; motorcycling is no longer a youth phenomenon, due in large part to the high cost of insurance and the cost of equipment, clothing, testing and training. Over the last 5 years, there has been a 41 percent increase in the number PTWs in circulation in Europe. Within the EU Member States, there are now more than 27 million in use, including mopeds, scooters and motorcycles, which range from 50cc to over 1000cc in engine displacement. PTW use penetrates all social and professional classes. Moreover, the newly introduced PTW models enhanced with intelligent systems and advanced technologies are considered more environmentally efficient and are, hence, less polluting than those of the past.

PTWs differ from regular vehicles both in driving style and patterns and accident characteristics. At first, they are a more economical means of transport, when compared to cars, and more flexible in manoeuvring and parking due to reduced size and, thus, more appealing to users in metropolitan densely populated areas with significant portion of congested road network.

PTW accidents are potentially more dangerous when compared to car accidents. The relative small size which most times is accompanied by a relatively powerful engine, the missing collapsible zone and often very complex driving manoeuvres increases risk and severity of accidents, due to easiness in stability lose at low speeds (difficulty in controlling and coordinating body), tyre friction loss at poor surface condition and high acceleration capabilities, speeding associated by the difficulty in braking. Riders must focus on coordinating speed and angle of body lean, and managing traction and control, while navigating various surfaces, curves and conditions. The lack of a protected vehicle compartment means that motorcycle riders and passengers are much more vulnerable to injury in crash situations. Furthermore, the task of operating a motorcycle is much more demanding than operating a passenger vehicle. Moreover, the small vehicle silhouette increases the risk of accidents, as car drivers fail to detect them or predict their manoeuvres and speed. In this framework, The present paper addresses the PTW safety risk factors through the prism of road infrastructure characteristics and the extent and magnitude of their influence to the PTW accidentology. For the analysis of interactions between PTW accidents and road infrastructure a comprehensive methodological framework has been developed in the context of EU FP7 project 2-BE-SAFE (www.2besafe.eu). A variety of published articles, European and international research reports and other public studies have been collected and analyzed with respect to specific road infrastructure characteristics such the type of the area and location of the accident, the road geometry and roadside installations, issues of lighting and visibility, collision type, collision type and pavement surface conditions.

PTW SAFETY INDICATORS IN EUROPE

PTW safety indicators possess strong regional and seasonal characteristics. High fatality rates have been observed in Greece, France, Spain and Italy. A significantly higher fatality rate is observed in Portugal. From 2001 and on, a considerable decrease in the fatality rates is observed in most countries (Table I). However, it is to note that the fatality rate should be related to the number of PTWs per inhabitants in order to extract meaningful information.

Table II summarizes the PTW riders' fatalities as a percentage of the total number of road accidents observed by country in the period between 1997 and 2006. The regional differences are evident. Largest share of PTW accidents, higher than 20% of total number of accidents, can be traced in Greece, France and Portugal. Belgium, Malta, Austria and UK exhibit also rather high percentages of fatalities.

Table I: Fatality rate (fatalities per million inhabitants) of PTW riders, 1997-2006 (Source: CARE Database / EC 2008).

Country	Year									
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
PT	67,5	55,0	49,9	42,8	40,2	35,8	35,6	28,8	27,9	22,1
EL	47,1	52,6	51,7	45,5	46,0	36,1	33,0	39,3	41,2	44,7
FR	23,7	23,8	24,5	23,4	25,3	23,6	20,6	19,4	19,9	17,6
ES	22,7	23,4	22,7	21,6	20,5	19,1	18,2	17,9	18,2	18,0
IT	21,5	20,9	20,7	22,5	23,1	22,6	25,1	25,2	-	-
IE	18,6	10,0	11,5	10,6	13,0	11,3	13,9	-	-	-
AT	21,2	15,1	18,9	19,5	18,0	16,7	19,3	17,4	16,9	16,2
BE	19,0	19,5	19,4	18,0	20,5	21,9	16,3	14,7	14,6	15,8
NL	11,6	10,5	11,5	12,4	9,6	11,9	11,7	-	-	-
DK	8,7	11,3	12,6	13,3	10,3	11,5	12,6	12,8	8,3	8,3
FI	4,7	4,9	4,1	3,7	4,4	5,6	6,7	6,9	6,9	7,4
SE	5,5	5,9	5,4	5,5	5,3	5,5	6,3	8,2	6,0	7,7
LU	7,2	16,6	11,7	18,5	13,7	0,0	-	-	-	-
UK*	9,0	8,7	9,5	10,4	10,1	10,6	12,0	10,2	9,7	10,2
CZ	-	-	-	-	-	-	-	-	-	11,3
EE	-	-	-	-	-	-	-	-	5,2	5,2
HU	-	-	-	-	-	-	10,1	9,3	13,9	13,0
MT	-	-	-	-	-	-	-	-	7,5	4,9
PL	-	-	-	-	-	-	-	-	5,5	-
EU-14	20,5	20,0	20,1	19,8	19,9	19,0	18,8	18,1	18,0	17,6

UK (2006) = GB (2006) + NI (2005)

Table II: PTW rider fatalities as percentages of the total number of road accident fatalities by country, 1997-2006 (Source: CARE Database / EC 2008).

%	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
BE	14,1	13,3	14,2	12,5	14,1	17,3	13,9	13,2	14,0	15,5
CZ	-	-	-	-	-	-	-	-	-	10,9
DK	9,4	12,0	13,0	14,3	12,8	13,4	15,7	18,7	13,6	14,7
EE	-	-	-	-	-	-	-	-	4,1	3,4
EL	24,0	26,1	26,5	24,3	26,8	24,2	22,6	26,0	27,6	30,0
ES	16,0	15,6	15,7	15,0	15,1	14,7	14,0	16,0	17,7	19,2
FR	16,8	16,0	17,4	17,6	18,9	18,9	21,1	21,8	23,5	23,5
IE	14,4	8,1	10,4	9,6	12,1	11,6	16,3	-	-	-
IT	18,2	18,9	17,6	19,2	19,7	19,1	23,8	25,9	-	-
LU	5,0	12,3	8,6	10,5	8,6	0,0	-	-	-	-
HU	-	-	-	-	-	-	7,7	7,3	11,0	10,1
MT	-	-	-	-	-	-	-	-	17,6	18,2
NL	15,5	15,5	16,7	18,1	15,5	19,4	18,4	-	-	-
AT	15,3	12,5	14,0	16,0	15,0	14,1	16,8	16,2	18,1	18,4
PL	-	-	-	-	-	-	-	-	3,9	-
PT	27,0	26,2	25,4	23,5	24,7	22,1	24,0	23,3	23,6	24,1
FI	5,5	6,3	4,9	4,8	5,3	7,0	9,2	9,6	9,5	11,6
SE	9,1	9,8	8,3	8,3	8,1	8,8	10,6	15,4	12,3	15,7
UK*	14,0	14,2	15,6	17,1	16,5	17,5	19,5	18,0	17,5	18,5
EU-14	17,2	16,9	17,3	17,4	17,9	17,8	19,3	20,4	21,1	21,9

UK (2006) = GB (2006) + NI (2005)

EU statistics show that the magnitude of fatalities drops during winter and increases during summer (CARE Database / EC 2008). This is evident due to the lack of rider protection against adverse weather and poor road condition, especially in northern European countries. In general, the numbers show that motorcycle fatalities have stronger seasonal characteristics than mopeds.

INTERACTION BETWEEN ROAD INFRASTRUCTURE AND PTW SAFETY

A significant number of projects and papers related to the influence of infrastructure elements to the PTWs behaviour can be traced in literature. However, the papers concerning PTW safety are much fewer. A selective overview of the existing PTW safety research papers and reports, as well as their influence on road design is conducted. The literature findings are presented with respect to:

- The type of the area (inside or outside urban areas)
- Road geometry and roadside installations
- Collision type
- Type of control
- Type of junction
- Pavement condition

Type of area

One of the major influential characteristics of PTW accidents interaction to infrastructure is the type of area. MAIDS (ACEM 2003) reports that most of the accidents (72%) take place in an urban area and approximately 25% take place in a rural area. Pearson and Whittington (2001) also state that approximately 70% of motorcycle injuries occur on local area roads in Australia.

Table III depicts the number of motorcycle and moped rider fatalities by area and road type, 2006. A common observation in most European countries is that fatalities occur with high frequency inside urban areas or in non-motorway networks. This is evident for mopeds, as their circulation is restricted to non-motorway road networks in most EU countries. Regarding overall PTW fatalities, reduced figures in motorways may also be observed due to the smoother and safer geometrical characteristics of motorways (controlled accesses, medians separating opposite traffic flows on motorways). Fatal moped accidents occur more often inside urban areas, whereas the number of motorcycle rider fatalities is higher in rural areas. Results of Table 8 reveal that 53% of moped riders were killed inside urban areas, whereas this percentage drops to 40% in the case of motorcycle riders. These figures are considered high compared to car occupants fatalities (approximately 20%).

Table III: The number of motorcycle and moped rider fatalities by area and road type, 2006 (Source: CARE Database / EC 2008).

	Fatalities Moped			**Fatalities Motorcycle**			**PTW fatalities as percentage of all fatalities by road type**		
	Inside urban area	Outside urban area		Inside urban area	Outside urban area		Inside urban area	Outside urban area	
		Non motorway	Motorway		Non motorway	Motorway		Non motorway	Motorway
BE	18	18	0	49	72	9	25,3%	14,1%	5,5%
CZ	1	2	0	46	66	1	11,0%	11,4%	2,7%
DK	14	10	0	5	16	0	18,8%	13,8%	0,0%
EE	2	0	0	1	4	0	6,5%	2,5%	-
EL	33	18	6	273	137	30	39,5%	21,1%	24,5%
ES	133	172	3	112	347	21	33,2%	16,6%	10,2%
FR	157	158	2	294	453	42	33,6%	19,9%	14,9%
IE* **	0	0	0	17	37	1	19,1%	15,4%	12,5%
IT **	241	147	0	500	508	62	32,1%	24,6%	9,6%
LU ****	0	0	0	0	0	0	0,0%	0,0%	0,0%
HU	30	12	0	34	54	1	12,6%	8,9%	1,8%
MT	0	0	0	2	0	0	18,2%	-	-
NL ***	55	38	1	22	52	21	22,3%	16,9%	14,6%
AT	16	23	0	18	74	3	17,0%	21,3%	4,1%
PL *	23	30	0	94	63	0	4,7%	3,2%	0,0%
PT	56	41	0	74	57	6	29,0%	22,5%	6,8%
FI	3	10	0	5	19	2	8,6%	12,8%	11,8%
SE	7	8	0	14	39	2	20,2%	15,0%	7,1%
UK *	19	10	0	207	355	22	17,1%	20,4%	11,6%
EU-19	808	697	12	1.767	2.353	223	22,1%	16,2%	10,7%
%	53,3	46,0	0,8	40,7	54,2	5,1			

* Data from 2005 UK = GB (2006) + NI (2005) *** Data from 2003 ** Data from2004 ***Data from 2002

Research has also related crash severity with location, road geometry and junction type. Most crashes at intersections occur inside urban areas where the speed is generally lower than outside urban areas. As a consequence, the crash severity is also much lower at these locations. By contrast the percentage of crashes in curves is much higher outside urban areas.

SPORNER (2006) analyses the main aspects and the particular risks for accidents on rural roads in cooperation with TÜV Bayern and some police stations with in the federal states of Bavaria and North Rhine Westphalia. For the first time a global view on vehicle/driving behaviour and layout of roads is presented: If only one of the derived risk elements appears it may be harmless, but in combination with others it can finally cause an accident. The study includes analytical investigated samples concerning the focal reasons that caused the accident, as well as a list of typical distinctive features due to the layout of the roads.

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 the markings. Miller (1997) reports that gravelled (rather than sealed) road shoulders, slippery road markings, slippery manhole covers/steel plates and uneven road surfaces are considered a danger to motorcyclists. Moreover, a German in-depth study has underlying that crests in the vicinity of curves and intersections, a high bendiness and high gradients are characteristics of roads with a high proportion of motorcycle crashes (Kuhn 2008).

At road sections in which a) the angle changing throughout the entire section is more than 200gon/km, b) a maximum of 15 changes in the road direction per km occur, c) at least 50% of the roads are straight and d) the road section is longer than 2.0km there is a higher risk potential for motorcyclists compared to the average potential for risk on comparative road sections (Gerlach 2007). Concerning the gradient, is shown that both ascending and descending gradient has a strong effect on motorcycle safety (Gerlach 2007). On the combined effect of crossfall, gradient and direction of curve, it is found that most motorcycles crashes happen in left curves with descending gradient followed by right curves with descending gradient, whereas, in left curves with descending gradient, a negative crossfall is a major problem (Gerlach 2007). Finally, as 78% of the investigated motorcycles crashes happen on roads with a bendiness of more than 200gon/km (60% of investigated routes), it could be proven, that the bendiness of a road is a very important criterion from the safety point of view (Gerlach 2007).

MAIDS report (ACEM 2003) identified the contributing factors for each accident case study reported. Considering a roadway design defect as a condition which presented a danger for PTW riders (such as failure to install signs, built-in obstructions, curve with decreasing radius or inadequate distance to merge lines), data indicated that roadway design defects were present in 57 cases (6,2%) along the PTW pre-crash path, but did not contribute to the causation of the accident in 47% of those cases. A roadway maintenance defect was reported in 146 cases (15,8%), being a primary or contributing factor in 25 cases (17,1% of cases involving a roadway maintenance defect). Weather made no contribution to the accident causation in 92,7% of the total number of cases, while there were 18 cases (2%) in which weather was identified as the primary contributing factor and weather was also reported to contribute to accident causation in 42 cases (4,6% of all cases).

In relation to infrastructure elements, Elliot et al. (2003) made the following points:

- Parallel longitudinal grooves in the road surface (for example, to avoid aquaplaning) can also induce instability.
- While travelling on a road with markings on the path of travel, a potential leaning angle of 45 degrees on dry tarmac can be reduced to 40 degrees on dry road markings, and reduced further to 25 degrees on wet markings.
- Crossing profiled (markings running in a direction other than parallel to the direction of travel) road markings causes “strong steering impulses leading to deviations of about 100mm” from the motorcycle’s track. Furthermore, road markings cause surface water retention, and can increase the possibility of aquaplaning.

Road markings, manholes and cattle grids can be more slippery than the road surface, especially when wet (NPRA 2004). Moreover, riding is affected by the presence of surveillance cameras; not-at-fault crash involvement at intersection is reduced in such a setting (Haque et al. 2009).

Serious consideration has been focused on the potential for Vehicle Restraint Systems (VRS) to cause injury to motorcyclists. Most researches on the effect of VRS to the PTW safety underline that current standards and specifications for roadside hardware, and the systems themselves, are not designed to take into account impact by motorcyclists (Gibson and Benetatos 2000, McDonald 2002). Moreover, the current European Standard is not necessarily applied to minor roads. There is also a distinction between a safety fence and a safety barrier. The former consists of poles supporting one or more horizontal elements, whereas the latter tend to have a continuous surface. Safety barriers are generally not considered to present the same type of hazard to motorcyclists as fences.

MAG (2005) suggests exposed posts as a major cause of injury when a rider comes into contact with a crash barrier. Morgan and Ogden (1999) suggest that impact forces are not as severe when colliding with a large surface area at a shallow attack angle. Gibson and Benetatos (2000) and Duncan et al., (2000) therefore argue that hitting an exposed post can result in more severe injuries. Impacts with guardrail posts reportedly cause injuries that are five times more severe than those from an average motorcycle accident.

Concerning the use of road safety barrier systems, road safety barriers are an important and effective road safety measure (ATSB 2000). Moreover, an in-depth databases analysis concluded that roadside barriers impact occurred under small angles at high speeds, mostly causing injuries to head and lower extremities (APROSYS 2006). Considering metal barrier impacts, the rail seems to be hit more often than the post. Trees and poles impacts are at least equally hazardous to PTW riders than barrier impacts.

MAG’s position in relation to safety barriers in the UK is summarized below (MAG 2006):

- In 2003, there were 109 slight, serious or fatal motorcycle casualties where the rider hit the central barrier.
- There were 144 collisions where the rider struck the near or offside crash barrier.

- From 1999 to 2003, there were 1271 motorcycle casualties involving a collision with a central, near or offside barrier. 142 fatalities resulted from these collisions.
- In 2003, 5.2% of all fatalities were crash barrier impacts.

Finally Ulleberg (2003) conclude that it is also important to focus on the road side area on locations where there are no fences/barriers, particularly by removing objects in the road side area which the motorcyclists may hit in run-off-road accidents.

Regarding guardrail crashes, Gabler (2007) examined the Fatality Analysis Reporting System (FARS) database to identify guardrail crash trends in cases where a fatality has occurred and showed that, although motorcycles compose only 2% of the vehicle fleet in the US, they account for 42% of fatalities involving a guardrail. In Germany, a significant percent of PTW fatalities involve crashes with guardrails (Koch and Brendicke, 1988, Brailly 1998).

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). Poor sightline visibility and rider/bike 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, 2008).

Motorcyclists are found to be more vulnerable during night time at both intersections and expressways (Haque et al. 2009). Injuries resulting from early morning riding, in general, appear to be the most severe, especially in junctions controlled by stop, and give-way signs and markings (Pai and Saleh 2007). Furthermore, motorcyclists often experience reduced visibility when wearing glasses, visors or wind shields (NPRA 2004). Dew can build up quickly on motorcyclists' visors, windshields and glasses when entering a tunnel.

Type of collision

Concerning the type of collision, a French study (Brailly, 1998) concluded that the rate of fatal injuries per collision is five times higher than the national average if the rider strikes a barrier. Collisions with barriers account for 8% of all motorcycle fatalities and 13% of fatalities on rural roads. At-fault crashes on expressways are found to increase when riding in the median lane, with higher engine capacity and when riding with a pillion passenger (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, Savolaine and Mannering 2007). Motorcyclists were more injurious while motorcycles were overtaking their collision partners and while vehicles made a turn (Pai and Saleh 2008).

Regarding collisions at intersections between cars and motorcycles, the car drivers are usually at fault. A possible explanation for this is that the car drivers do not "see" motorcycles, either because the shape and colour of motorcycles make them blend with the background and hard to see or the car drivers have a strong set to just notice other cars making them overlook motorcycles even though they are clearly visible.

Junction Type

Junction type is a significant influential factor of PTW safety. Table VI shows the number of motorcycle and moped occupant fatalities by junction type for the year 2006. As can be observed, nearly a third of all motorcycle rider and moped rider fatalities occur at a junction, significantly higher than the corresponding percentage for car occupant fatalities that is 16%. Moreover, cross-roads seem to be critical, as 40% of PTW fatalities occur in such setting. These percentages are significant compared to the figures illustrated in Table 11 that shows the fatalities for all transportation modes near or away of junctions; as can be seen most fatalities are not observed not at junction areas. However, the percent of PTW and bicycle accidents at junctions is higher compared to the rest of the transport modes.

Table VI: The number of motorcycle and moped occupant fatalities by junction type, 2006. (Source: CARE Database / EC 2008)

	Not at junction	**At junction**					**Not defined**	**Total**
		cross-road	t or y junction	level crossing	round-about	other junction type/ unknown		
BE	109	0	0	0	3	54	0	166
CZ	86	10	17	3	0	0	0	116
DK	30	3	0	0	2	10	0	45
EE	4	0	2	0	0	1	0	7
EL	430	0	0	0	0	67	0	497
ES	547	85	103	0	30	23	0	788
FR	905	91	64	2	13	31	0	1.106
IE* **	0	6	6	0	0	1	42	55
IT**	905	258	0	1	29	265	0	1.458
LU******	0	0	0	0	0	0	0	0
HU	99	31	0	0	1	0	0	131
MT	0	0	0	0	0	0	2	2
NL***	112	41	34	0	1	1	0	189
AT	77	17	9	0	1	0	30	134
PL*	163	47	0	0	0	0	0	210
PT	135	15	35	1	5	0	43	234
FI	25	0	0	0	0	13	1	39
SE	3	28	0	0	2	1	36	70
UK*	371	32	141	0	12	57	0	613
EU-19	4.001	1.705					154	5.860
%	68,3%	29,1%					2,6%	100%
EU-19At junction		664	411	7	99	524		
% junction type		38,9%	24,1%	0,4%	5,8%	30,7%		

* Data from 2005 UK = GB (2006) + NI (2005) *** Data from 2003 ** Data from2004 ***Data from 2002

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 and Saleh (2007, 2008) provide an extensive study on the interaction of junction type and motorcycle injury severity. In brief, the influential factors to motorcyclist injury severity at uncontrolled junctions are: elderly rider, greater engine size of motorcycle, riding in early morning, on weekend and under fine weather; street lights unlit; riding on uncongested road; collisions with bus/coach or HGV. In the case of signalized intersection, identified critical parameters are the following: heavier engine size of motorcycle; collisions with bus/coach or HGV; riding under fine weather and on non built-up road; and type of collision.

Regarding interactions of junction type with genre and age, it has been reported that male riders, given an accident has occurred, were more likely to be severely injured at signalized than at unsignalized junctions (Pai and Saleh 2007). Moreover, teenaged riders were more prone to be severely injured than those aged 20–59 in accidents where stop, give-way signs or markings controlled the junctions, in contrast to findings regarding accidents at uncontrolled junctions (Pai and Saleh 2007). Collisions where older driver vehicles were making a turn and colliding with motorcycles appeared mostly in unsignalized junctions (Pai and Saleh 2008).

Intersection accidents account for 30% of person injury accidents, and 17% of fatal accidents. These types of accidents are more prevalent in 'moped' users. In 87% of such accidents it was the motorists' obligation to give way, whereas in 13%, it was the motorcyclist who should have yielded. This would suggest that driver behaviour is the main factor in intersection accidents (NPRA 2004).

Unsafe speed greatly affects injury severity (Branas and Knudson 2001, Savolainen and Mannering 2007); the effect of speeding is intensified at unsignalized junctions (Pai and Saleh 2007).

More than half of motorcycle crashes with personal injury occur at intersections respectively t-junctions including entrances and exits (ASSING 2002); however, these crashes are characterized by a relatively low severity. The crash severity is much higher for crashes in curves, especially in combination with slopes.

Pavement surface condition

On the pavement surface conditions, Shankar et al. (1996) emphasize on pavement surface and type of highway impact on 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, riding on wet pavement conditions, near intersections.

In Germany, during 1999, 83% of all motorcycle crashes occurred on dry road surfaces (ASSING 2002). In comparison the percentage of all crashes with personal injury on dry road surfaces was only 66%. This difference could be explained by the fact that most motorcyclists use their bikes only during fair weather conditions. Roadway was found to be dry and free of defect in 84,7% of all accidents, while roadway was found to be wet in 7,9%

in all collected cases (ACEM 2003). Road surface defects were present in 30% of cases (ACEM 2003).

A well known problem caused by an insufficient stiffness of a motorcycle frame is deterioration of the stability (Brorsson and Ifner 1983). Serious injuries have been reported caused by motorcycles which suddenly begin to wobble or weave. 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: i. Surface grip. ii. Surface irregularities and potholes, iii. Loose materials, vi Patch repairs, and v. Road markings. Pearson and Whittington (2001), state that motorcycles are very sensitive to changes in friction level between the road surface and tires.

Type of vehicle and vehicle characteristics

Type of vehicle and vehicle characteristics has an important role on PTW accidents. Greater motorcycle engine size and motorcycle speed resulted in higher injury severity levels regardless of the control measure adopted (Shankar et al. 1996, Quddus et al. 2002, Langley et al. 2000, Lin et al., 2003, Harrison and Christie, 2005, de Lapparent 2006, Pai and Saleh 2007). Moreover, collisions with heavier vehicles result in more severe injuries (Quddus et al. 2002; Lin et al., 2003, Pai and Saleh 2007).

Ulleberg (2003) conclude that there are no studies based on real accidents estimating the preventive effect of ABS-brakes on motorcycles. Moreover, studies demonstrate that the use of daytime running lights reduces the number of accidents which involve a collision with another vehicle. It is expected that additional measures improve motorcycle conspicuity (e.g. fluorescents clothing, additional beams or the use of high beam in daylight) can result in a further reduction in daytime collision accidents. There is, however, a need for further studies in order to estimate the effects of such additional measures. Collision tests indicate that leg protectors may reduce the severity of leg injuries, but increase the risk of head, chest and neck injuries. Tests demonstrate that an airbag can be effective, especially in cases where the motorcycle collides into the side of a car. The airbag may, however, increase the risk of head injuries in some cases. It is uncertain whether the airbag can cause neck injuries while inflating.

PTW RISK FACTORS

The state-of-the-art on the relationship between PTWs risk factors and road infrastructure conducted has revealed various determinants with different degrees of influence to the PTW safety, which might be of interest to be further considered in future PTW behavioural studies. Summarizing the above, it is revealed that infrastructure related PTW accidents, although more easily recorded, are caused by complex roadway conditions encompassing:

1. Roadway design defects (failure in road construction, disharmonic trace geometry, curvature, unevenness, potholes, etc.)
2. Roadway maintenance defects

3. Road surface condition (problems on wet roads, slippery bitumen on hot asphalt, poor skid resistance, etc.)
4. Collision with road side barriers in a run-off accident (very high fatality rate)
5. Critical curve radii (curve radii relations)
6. “Negative” crossfall (crossfall does not match the requirement of driving dynamics)
7. Combined effect of crossfall, gradient and direction of curve
8. Intersections (poor sightline visibility and rider/bike conspicuity are likely to contribute to motorcycle accidents at intersections)
9. Road markings, manhole covers and cattle guards
10. Poor visibility and speeding as common multiplicators of infrastructure related accident risk

From the above factors, some have been systematically treated, whereas others have been either disregarded or poorly treated due to the lack of data. The following Table V summarizes risk factors with respect to their magnitude of influence to PTW accidents, as well as the need for further research.

Table V: Summary of findings concerning risk factors with regards to their influence magnitude and the need for further research.

Risk Factor	***Interaction***	***Magnitude***	***Need for Further Research***
Roadway design defects	Infrastructure	High	Low
Roadway maintenance defects	Infrastructure	High	Low
Road surface condition	Infrastructure	High	Mid
Collision with road side barriers in a run-off accident	Infrastructure	High	Low
Critical curve radii	Infrastructure	High	Mid
“Negative” crossfall	Infrastructure	Mid	Low
Combined effect of crossfall, gradient and direction of curve	Infrastructure	High	Mid
Intersections	Infrastructure	High	Low
Road markings, manhole covers and cattle guards	Infrastructure	Low	Low
Collision type	Infrastructure	High	Low
Drivers’ Perception of motorcycles	Infrastructure/vehicle	Low	Mid

Regardless of the degree of interest in studying specific factors, as well as the gap of knowledge that may arise, there exist several misconceptions and weaknesses in PTW safety literature. A core problem of identifying significant correlations between road infrastructure parameters and accident information is the lack of relevant data. Another reason of not having more detailed investigations on this research question is that official motorcycle accident reports - and the media coverage of motorcycle accidents - do not always give the entire and accurate details of an accident. When a motorist violates a give way sign and hits a motorcyclist, a common explanation is that the rider was speeding, or that the rider was impossible to see, which is now recognized as ‘inattentional blindness’, while in single vehicle crashes, when a rider loses control on a curve, a common explanation is that he was speeding. In-depth studies or specific vehicle-infrastructure-interactionsimulations (VIIS) including the road infrastructure (virtual road generated by measurement data) that could shed light to the factors that cause a PTW accident are very rare.

Moreover, road accident analysis at international level is very often limited not only by the incomparability of the national accident data but also by a number of insufficiencies of the respective exposure data (Golias and Yannis 2001). These insufficiencies refer to poor availability and reliability, to comparability problems and to insufficient or inappropriate disaggregation (Golias and Yannis 2001).

Another 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 are more relevant in frequency and severity. Identifying these settings could lead to a more efficient and rapid manner of distinguishing and ranking the importance of critical infrastructure parameters to the PTW accident risk.

Finally, a serious consideration in studying PTW safety is the lack of exposure data. Exposure data is significant in obtaining risk data in the form of outcome per unit of exposure or describing differences in the road safety situation. Utilizing absolute numbers and trends of values may lead to conclusions on traffic safety, which is, in general, of limited significance due to lack of exposure information (volume, vehicle- and person-kilometres of travel, etc.). Continuous exposure measurements of different road user categories in different modes and different road environments would be required and could provide detailed exposure estimates to the degree of disaggregation of the respective accidents data.

In practice, such measurements are not possible, therefore, road safety analyses need to compromise to some approximations of the actual exposure, which are nearly as accurate and representative as measured traffic volumes. Different exposure measures may be used, according to data availability and quality, as well as the context of the analysis (Yannis et al. 2008). 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). Regardless of whether or not there exist rules and methods to choose and measure the proper exposure data, colleting exposure data, both in concept and in methods, should be among the challenges of every research attempt to model risk and safety of road traffic.

CONCLUSIONS

The main objective of the paper was to identify the road infrastructure elements (road design elements, road geometry, road surface condition, roadside obstacles, etc.) that have an influence on PTW accidents. A comprehensive overview of the existing PTW safety guidelines, projects and papers and their influence on road design has been conducted and interesting results arose. It is evident that roadway design defects (failure in road construction, disharmonic trace geometry, curvature, unevenness, potholes and so on) are critical to the PTW road safety. Specific geometric attributes related to critical curve radii (curve radii relations), cross-fall which does not match the requirement of driving dynamics, as well as the combined effect of cross-fall, gradient and direction of curve are found to significantly affect PTW accidents severity and increase accident risk. It was also revealed that significant fatality rates have been related to collision with road side barriers in a run-off accident. Moreover, adverse road surface condition, such as wet roads, slippery bitumen on hot asphalt, together with poor visibility and speeding as common multiplicators of infrastructure related PTW accident risk.

A critical view of the resulted PTW risk factors reveals that, most attempts to study the causes of PTW accidents with relation to infrastructure issues lack a broader perspective and fail to incorporate a multivariate view of PTW accident risk, as well as integrate other behavioural issues, such as training, age, gender and so on. Moreover, there is a need to adopt a comprehensive methodology for collecting, archiving and standardizing PTW accidents across EU along with exposure data in order to be able to generalize on each analysis result.

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