Power-Two Wheelers Critical Risk Factors: A European Study

George Yannis, Eleni I. Vlahogianni, John C. Golias
National Technical University of Athens,
5 Iroon Polytechniou Str, Zografou Campus, 157 73 Athens, Greece

Phan Vuthy
Centre Européen d'Etudes de Sécurité et d'Analyse des Risques,
132, rue des Suisses, 92000 NANTERRE, FRANCE

Peter Saleh
AIT Austrian Institute of Technology GmbH
Donau-City-Straße 1, 1220 Vienna, Austria

Martin Winkelbauer
KfV -Austrian Road Safety Board
Schleiergasse 18, 1100 Vienna, Austria

Abstract
The paper summarizes the results of a large European project on the critical risk factors for Power-Two-Wheeler (PTW) safety. Analyses conducted in both a macroscopic and microscopic level in Greece, Spain, Italy, Great Britain, Austria, Finland and Germany revealed a set of critical risk factors as well as their ranking of importance. Among the research questions treated are what are the most relevant PTW accident configurations at European level and why accidents of those configurations take place. The identified critical risk factors cover a wide range of interactions and form important knowledge for structuring guidelines dedicated to PTW users. Moreover the analyses conducted add value to the manner future in depth analyses and accidentology studies should be conducted.

1. Introduction

Power Two Wheelers (PTWs) are distinguished into mopeds and motorcycles. Mopeds refer to motorcycles with 50cc engines, restricted top speed (limit 50km/h) and typically are used for short trips and are prohibited in motorways. 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 maneuvering 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 small size which most times is accompanied by a relatively powerful engine increases risk and severity of accidents, due to easiness in stability lose at low speeds (difficulty in controlling and coordinating body), type friction loss in pure surface conditions and high acceleration capabilities, speeding associated by the difficulty in braking. Riders must focus on coordinating speed and 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 size increases the risk of accidents, as car drivers fail to detect them or predict their maneuvers.

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. Regarding usage, the first place takes Greece with 150 mopeds and 100 motorcycles per 1000 inhabitants. Trends reveals a systematic decrease of moped use in most European countries, whereas motorcycle use in increasing. 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, 2007).

A recent research study has summarized the prevailing risk factor of PTW safety as they are depicted in the current literature (Vlahogianni et al. 2012). While there is extended interest focused in PTW safety, a systematic effort to address these on both a macroscopic and microscopic level has not yet been conducted. The paper aims at identifying the factors that contribute to PTW crashes across Europe, including rider factors, driver factors and characteristics of the road environment (road infrastructure and weather conditions). The analysis is conducted at two levels: at the macroscopic level, using accident statistics from national accident databases; and at the microscopic level, using appropriate models, interviews and in-depth accident data. The analysis revolves around three distinct directions: the driver/rider behavior, the road infrastructure and the weather conditions. Regarding the behavioral factors, the aim is to first identify the most frequent PTW road accident types and high risk situations (e.g., at intersections; involving novice riders) from a macroscopic point of view and then to identify, at the microscopic level, the dysfunctions that underlie these accidents- taking into account differences in the personal determinants of the riders, rides/driver interactions, vehicles etc. For the road infrastructure, the research focuses on the investigation of the number and type of road infrastructure elements (road design elements and road surface parameters) that influence PTW accidents. Focus is also given to the extent and the magnitude of influence of infrastructure elements to the PTW safety. Finally, for the weather conditions, the aim is at determining the relationship between weather conditions and PTW accident occurrence and at establishing a framework of procedures to eliminate weather dependent components of PTW accident records. The basic research questions that are addressed are as follows:

- What knowledge has already been obtained for road users?
- What are the most relevant accident configurations at European level?
- Why accidents of those configurations take place?

The first question is answered via a thorough literature review which is conducted on the interactions of rider/driver behaviors, infrastructure and weather conditions with the emergence of PTW accidents. The second question is addressed via a macroscopic analysis of the available national accident datasets, gathered and analyzed by the partners involved. Finally, the third question refers to a pioneer series of in-depth studies using data from selective European countries.

2. Interactions between rider/driver behavior and PTW accidents

The macroscopic analyses of the interaction between drivers/riders and PTW accidents was conducted using data from Finland, France, Greece, Italy and the United Kingdom (Figure 1); all the accident characteristics reported in national databases, mainly descriptive characteristics and not analytic ones – such as the place and the weather during the accident and not the causes of them - give us a large overview of which kind of accidents frequently appears and what are the road safety issues (for instance, 33% of injury accidents are single vehicle accidents but these accidents represent 50% of the fatalities, young drivers and riders are riskier population).

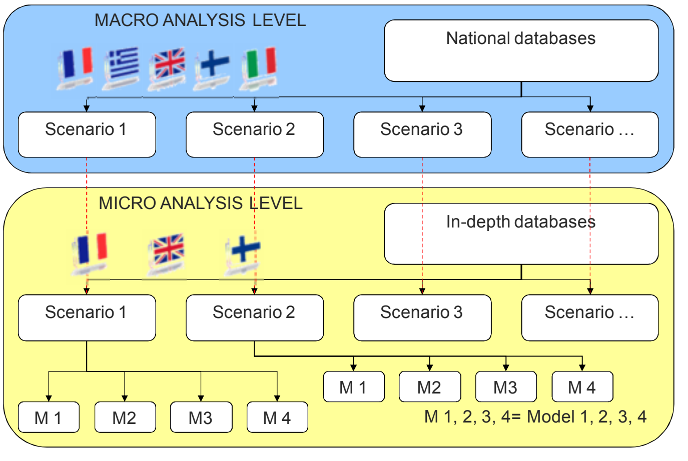

Figure1: Rider / Driver behaviours study methodology

The macroscopic analysis was focused on a 2 years period, from 2006 to 2007. When analyzing the data of the different countries, it was always possible to get full information for the entire period of 2 years. The macroscopic analyses resulted in defining 9 road accident scenarios:

- Scenario 1: Moped / passenger car accident – Inside urban area – No intersection,
- Scenario 2: Moped / passenger car accident – Inside urban area – Intersection,
- Scenario 3: Single motorcycle accident – Outside urban area – No intersection,
- Scenario 4: Single motorcycle accident – Inside urban area – No intersection,
- Scenario 5: Single motorcycle accident – Inside urban area –Intersection,
- Scenario 6: Motorcycle/passenger car accident - Outside urban area - No intersection,
- Scenario 7: Motorcycle/passenger car accident - Inside urban area - No intersection,
- Scenario 8: Motorcycle/passenger car accident - Inside urban area - Intersection,
- Scenario 9: Motorcycle/passenger car accident - Outside urban area - Intersection.

A further in-depth analysis is conducted in order to study the behavioral aspects of the interaction of riders with other drivers at a microscopic level. The methodological framework of analysis encompasses a set of complementary accident analysis models which enable the better understanding of the role of driver and rider behaviors in the accident genesis. In brief, the analysis of the detailed factual information relating to the rider (eg. the rider’s professional status, family status, age, gender, etc), to the other party involved in the crash, to the vehicles involved (eg. vehicle type, vehicle age, vehicle defects, etc) and to the environment (eg. type of road, road geometry, traffic density, etc) per each phase in the evolution of the crash (e.g. the normal driving phase, the precipitating event, the emergency phase, the crash phase and the post-collision phase) was conducted. Moreover, a human functional failure model was applied in order to classify the factors that characterize the state of the system and their interactions, which explain human failures that contribute to crashes.

Finally, a though analysis to systematically classify and record accident causation information was undertaken based on the DREAM model (Driving Reliability and Error Analysis Method (Warner et al., 2008). DREAM is a useful way for analysing the possible causal factors occurring in the "pre-crash" phase of an accident, regarding the interaction between driver, road system and vehicle, as well as the background contributing factors. It enables a systematic classification and storage of information on factors contributing to accidents which have been collected by the conduct in-depth accident investigations. DREAM has three main elements: an accident model; a classification scheme; and a method. The accident model is derived from the Contextual Control model and the Extended Control Model. These models assume that cognition, in the road traffic domain, involves observation, interpretation and planning, and that control in the traffic domain involves working towards multiple parallel goals on different timeframes. The classification scheme in DREAM consists of so-called "phenotypes" and "genotypes" – and the links between them (Warner et al, 2008). Phenotypes are the "observable effects" of an accident and include human actions and system events. Genotypes are the factors that may have contributed to the observable effects – in other words, the contributing factors. The links represent existing knowledge about how different factors can interact with each other. The output of the DREAM analysis is a "DREAM-chart" which shows, from left to right, the genotypes (Inadequate training) that contribute to the phenotype (e.g., too late action or no action) that best describes the observable effects of the accident. Each driver or rider involved in an accident analysed according to DREAM analysis has his own "DREAM-Chart". All of them are then gathered in order to highlight problems for one scenario. The arrows illustrate the link between the phenotypes and the genotypes and between the genotypes. These links are structured according to what is proposed when using DREAM methodology. Colours have been used in "DREAM-Chart" in order to make it easier to read. Links that occur often are represented with proportionally thicker lines. Results are summarized in Table 1.

Table 1: Results of the DREAM analysis for all the scenarios

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
RIDER	Phenotype	Too late action	Too late action	Too high speed No action	Surplus force Too late action	Surplus force Too late action	Too late action Surplus force	Too late action Too fast	Too late action No action	Too late action No action
	Genotypes	Late or false observation Inattention Reduced visibility Insufficient skills / Knowledge	Priority error Expectance of certain behaviours Late observation Insufficient skills / Knowledge	Lack of practical skills or theoretical knowledge Late observation Expectance of certain behaviours Inattention Inadequate road maintenance	Reduced friction Late or false observation Priority error Overestimation of riders' skills	Reduced friction Priority error Expectance of certain behaviours Late observation Overestimation of riders' skills	Expectance of certain behaviours Missed information False information Inattention Priority error	Late observation Inattention Priority error Overestimation of riders' skills Expectance of certain behaviours	Expectance of certain behaviours Late observation Inattention Visibility mask Priority error	Expectance of certain behaviours Priority error Missed observation Late observation
DRIVER	Phenotype	Too late action Too early action	No action Too early action				Too early action No action	Too early action No action	Too early action	Too early aaction No action
	Genotypes	Late or false observation Drugs/Alcohol	Missed observation Priority error Expectance of certain behaviours				Expectance of certain behaviours Missed information False information Inattention Priority error	False observation Inattention Priority error Late observation Expectance of certain behaviours	Late observation Obstruction of view Inattention	Missed observation Expectance of certain behaviours Reduced visibility

The DREAM analysis highlights the facts that for moped users, there are a lack of skills and knowledge about riding. Single motorcycle accidents involved users who do not ride a lot each year comparing to motorcyclists involved in accidents between a motorcycle and another vehicle. Single motorcycle accidents happened either during the day and in a curve, when it is outside urban area or during the night and on a straight road, when it is inside urban area. Single motorcycle accidents, outside urban area happened later after departure than single motorcycle accidents, inside urban area. In the first configuration, a conflict with another vehicle is possible and has caused the accident (even if there is no crash with this "conflict"). The main human functional failures for single motorcycle accidents describe a loss of control when underlying a guidance problem or a poor control of an external disruption because of excessive or not adapted speeds, risk taking, etc.

When the accident involved a motorcycle and a passenger car, at intersection, the motorcyclist is crossing the intersection, has a right of way and he is confronted to a vehicle coming from a side road. This one is generally turning across traffic. Once again, such accidents underline the lack of perception (from the passenger car driver and of the motorcyclists) because whether they neglect the need to search information or they cannot see the riders because of visibility masks. Then, that is why motorcyclists misinterpret the driving situation. They are on a road where they have a right of way status, there is an absence of clues from the other road user and then they do not understand the maneuver from the driver. When the accident involved a motorcycle and a passenger car, not at intersection, the accidents situations are more complex. Whether the rider is realizing a maneuver legal or not (such as overtaking or splitting lanes) and is confronted an oncoming vehicle or a vehicle in a lateral lane or the rider do not perform any maneuver and is confronted with a passenger car driver realizing a maneuver (changing lane, overtaking, turning not at an intersection). In both cases, the drivers do not see the motorcyclist.

3. Interactions between Infrastructure and PTW accidents

The macroscopic analysis of the interactions between mopeds and motorcycles and road infrastructure characteristics refers to data from the Greek, Spanish, British and Italian accident database. Data extracted from national accident databases have been analyzed to identify the accident causation factors and potentially review accident site characteristics (primary road infrastructure parameters).

Results show that most PTW accidents occur inside urban areas, however, accident severity is higher outside urban areas. Most PTW accidents inside urban areas occur at intersections (angle collisions, lateral collisions), outside urban areas the most frequent collision type is a single vehicle accident (run-off the road). Moreover, rear end and head-on collisions are proportionately more common outside urban areas when compared to accidents inside urban areas. Dry road surface conditions dominate the accident figures; injuries and fatalities in accidents involving a PTW are mostly observed in dry weather conditions. Finally, skidding is systematically observed in PTW accidents both inside and outside urban areas.

In Greece, critical interrelationships between curves and descending gradients and PTW crashes have been revealed. Moreover, over a quarter of narrow passage accidents inside urban areas between motorcycles and moving vehicles are head-on collisions. Moreover, lateral collisions inside and outside urban areas are mostly observed in straight roads. In areas outside urban environments, narrow passages are exclusively related to lateral collisions

In Great Britain, roundabouts have a high accident figure given the relative frequencies of these junction types. Older riders are more likely to have an accident at a roundabout. Only just under 6% of accidents involve a carriageway object (not including a moving vehicle) being hit. Moreover, young riders are proportionally more likely to have an accident when the road is wet/damp than older riders.

In Spain, less front to side accidents at roundabout in comparison to other junction types, however more side wipe accidents, while front-to side, run-off-road and rear-end represent nearly 60% of all accidents. Inside urban areas, accidents account for three quarters of all accidents.

In Italy, accidents on wet and slippery roads are less severe than on dry roads. Taking into account the accident type, the most relevant accident case is head-on side on road with one carriageway and two ways, but the most severe is one carriageway and two ways and collision with an obstacle. Finally, uneven paved roads have been found to increase the accident severity in Italian roads.

Analysis at micro-level performed to identify the critical characteristics of road infrastructure that constitute PTW risk factor sis conducted. In-depth data from accident databases and road geometry data and appropriate software tools (MARVin, RoadVIEW) have been employed and used to conduct this detailed analysis. The software tools allow correlating road measurement data together with PTW accident data. Similarities of road design elements and surface conditions and the combination of these data at accident locations will be determined as well as typical crash-causal-circumstances. Moreover, the Spanish databank DIANA that delivers lots of gathered in-depth accident information was used. The studies carried out in Germany (BASt, data by TU Dresden) and Austria (AIT) also used measured road surface data.

Results from Spain show that most of the accidents occurred at left hand bends (72%) - in left hand bends the eyes are fixed in the inner curve therefore possible hazards on the lane do not appear immediately in the field of vision. Three out of four accidents located at bends occurred at roads with descending gradient. Most run-off the road accidents (n=29) occurred in curves with a radii lower than 70m (62.5%). Kerbs are identified as potential safety hazard (objects hit in carriageway). Barriers are identified as most dominant roadside element hit by riders (objects hit off carriageway). Riders are almost twice as likely to impact in an upright position as in a sliding position. Most frequent type of intersection where single vehicle accidents occurred is a roundabout (7 out of 8) and only one of them is located inside urban areas - 70% of these accidents occurred during night time.

Among the critical factors identified from German data are that the curvature change rate [gon/km] is higher on unsafe road sections than on safe road sections. Vast majority of IMDC occurred in curves (86%) usually (83%) characterized by very small curve radii (< 100 m), usually in sections with a bad radii relation (unbalanced ratio of successive radii). Moreover, consecutive curves with very different or with decreasing curve radii - 10/26 locations. Jumps in curve radii within one curve (decreasing radius) - 4/26 locations. Abrupt change from a long straight into a curve - 7/26 locations are critical. Defects concerning the longitudinal unevenness have an impact on injury motorcycle driving crashes. The overall value for road surface condition at the crash scene is much worse than this is the case of the general road network. The overall quality value and hence the road surface condition has therefore an influence on injury motorcycle driving crashes.

In Austria, defects concerning the longitudinal unevenness, the rut depth and the texture seem to have a low impact on PTW accidents, whereas the opposite occurs for the theoretical water depth. Defects concerning the skid resistance have no impact on PTW accidents. A radii relation larger than 1 is more dangerous than a relation smaller than 1. The probability of an occurring PTW accident decreases with an increasing radius. The most accidents happen in relation where the consecutive radius is smaller than 200 m. The relation of a curve with a large radius (or a straight lane) followed by a curve with smaller radius is dangerous.

4. Interaction between weather conditions and PTW Safety

Most of the national as well as international crash data bases give the opportunity to select accidents with participation of PTWs and prepare tabs about the weather and road surface conditions that can be found in the various data sets about accidents. Practically, this can be done in a couple of minutes. Unfortunately, such a result does not say anything about the risk of PTW riding under "bad" weather conditions. It is a generally accepted hypothesis that PTW-riding is heavily influenced by the weather. Many PTW riders, in particular riding as a spare time activity, choose not to go out with the bike in case the weather is bad - or the weather report forecasts bad weather. Weather has been reported to be a less influential factor in 98% of motorcycle accidents in a research conducted in California (Hurt et al. 1981). In MAIDS report (ACEM 2003), weather made no contribution to accident causation in 92.7% of MAIDS cases (854 cases). Rain at the time of the accident was noted in 8% of all cases, whereas dry and free of defect in 85% of all accidents. More than 80% of crashes involving the death of a motorcyclist between 1999-2003, in Australian roads were reported under fine weather conditions (Johnston et al. 2008). Riding under fine weather also appears to result in more severe injuries regardless of what control measure was employed (Pai and Saleh 2007).

Figure 2 describes the relation between weather and PTW accidents may de described by three functions: i. the difference of intrinsic risk of riding under different weather conditions, ii. differences in risk taking behavior of riders under different weather conditions, maybe as a compensation for higher subjective risk on wet roads, iii. the impact of weather on exposure. However, such relations have not been researched so far.

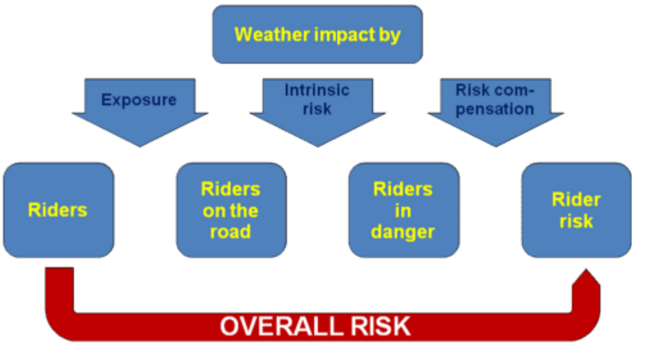

Figure 2: Model of impact of weather on PTW rider risk

The hypotheses tested in the framework of the present paper were the following:

1. PTW accidents correlate with weather conditions. This correlation can be described in mathematical terms.

2. The accident record of a year can be normalized using a correlation between accidents and weather conditions.
3. The correlations between weather and accident numbers differ for weekends and workdays.

Although it was already supposed before, a macroscopic analysis of PTW crashes with respect to weather was carried out using data from the official road accident databases in Austria, Greece and Italy (for 2007) and the CARE database (CARE2006). It was found that a vast majority of PTW accidents (more than 90%) occur on dry roads, but no particular differences could be found between countries based on this data, although the countries strongly differ in typical weather conditions and typical use of PTW. However, this assessment did not discover any other striking results.

To assess the real impact of weather on PTW collisions, it is necessary to have information on weather at any place of the area at any time of a given period included in this assessment. For this purpose, the Institute for Meteorology and Geophysics at the University of Vienna (UNIVIE) extended its existing database. On a grid of 20 km x 20 km, 16 km x 16 km or 10 km x10 km, depending on the parameter, weather information on temperature, humidity, wind and air pressure was already available. This database included weather information from various sources including the approximately 150 weather recording stations all over Austria and slightly beyond its borders. This gives an average of about 500 km² per weather station. These weather stations record the weather with an interval of 3 hours. Other sources could have been used, but neither radar nor automatic recording stations provide weather data of reasonable accuracy for the purpose (Figure 6). The existing weather database mentioned above was extended by data about precipitation, which is considered to be the most important variable of influence on PTW crashes. Finally, UNIVIE provided a database including information on precipitation for 2002 and 2003 based on a grid of 16 x 16 km with a resolution of 3 hours. Precipitation was ranked into 6 categories from 0 (no rain) to 5 (hard rain).

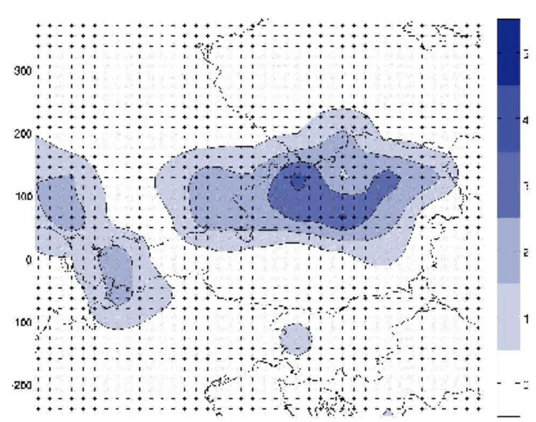

Figure 1: Example of weather data provided by UNIVIE.

Statistical analysis results showed that rain likelihood and accident number correlate very well. The relation can be expressed in an exponential function. Further, it was found that workdays differ from weekend days. On sunny weekend days, eight times more motorcycle accidents happen than on rainy weekend days. On sunny workdays, five times more motorcycle accidents happen than on rainy workdays. On sunny days, six times more motorcycle accidents happen than on rainy days.

With a broader database, more parameters could be included, such as urban vs. rural areas and mopeds vs. motorcycles. This additional information could be used to optimize comparability of data. On the long run, neither time series nor international comparison of accident numbers should be done without correcting the data for weather conditions before, at least for PTW accidents. Research on mobility behavior with respect to weather (in particular precipitation and temperature) is urgently needed to separate the effect of risk taking behavior and intrinsic risk within certain weather conditions from the exposure effect. Once this is done, further research is needed to separate the effect of risk taking behavior from intrinsic risk within certain weather conditions.

5. Discussion and Conclusions

The analyses demonstrated the need to study accident configurations rather than single accident records in order to understand the causal mechanisms of riding/driving behavior influencing PTW risk. Evidently, the PTW accident risk causal factors involving the behavioral characteristics of riders and drivers do not differentiate significantly between motorcycles and mopeds: conspicuity, risk taking behavior, human error and riding experience are the prevailing behavioral characteristics that increase PTW accident likelihood.

Regarding infrastructure, the assessment was quite rich and straightforward in results. From the extensive macroscopic and microscopic analyses several risk factors have been revealed that point towards necessary improvements of road infrastructure and safety treatments such as safe/forgiving roadsides, obstacle free zones, protection of obstacle with motorcycle-friendly protective devices. It was also found that the installation of these systems along sections with curves which have a curve radii lower than 100m, negative sequences (cross fall) of curves, outside of left hand descending curves, as well as signposting of hazardous locations could be proven critical measures. Finally, reconstruction of road sections especially with a bad unevenness in longitudinal direction, improvement of conspicuity of sections like roundabouts outside urban areas (e.g. electric lightening, retro reflect materials), less aggressive curbstones in roundabouts and no obstacles in the central island are some complementary measures that could critically affect PTW safety.

Regarding weather conditions, analysis conducted revealed that precipitation intensity is a critical risk factor. PTW accidents have been found to correlate with weather conditions. It was found that the correlations between weather and accident numbers differ for weekends and workdays. Finally, it was revealed that the yearly PTW accidents should be normalized using the revealed correlation between accidents and weather conditions. Since the impact of weather on PTW and especially on motorcycle accidents might be higher than for other vehicle categories, this research on motorcyclists should be continued first, by assessing more years of weather and accident data, by including temperature and maybe other weather parameters as well.

The revealed critical risk factors are summarized on Table 3. The identified critical risk factors cover a wide range of interactions and form critical knowledge for structuring guidelines dedicated to PTW users. The design of guidelines should act as countermeasures targeting PTW risk factors. However, this is not a straightforward task due to the regional differences in PTW usage in EU countries. For example, in countries in southern Europe the traffic environment in such countries demonstrates completely different characteristics than that in western countries and PTWs comprise a significant proportion of the vehicle population (e.g. Italy, Greece, Spain, Portugal).

Table 3: Summary of critical PTW risk factors.

Element	Macroscopic Analysis	Microscopic Analysis
Rider/Driver Behavior	Prevailing PTW accident scenarios with respect to: • the number of vehicles (including pedestrians) involved in the accident., • the area of the accident (outside or inside urban area), • accident occurring at a junction or not and the type of the opponent (vehicle) in the accident	moped riders: • age, experience • riding frequency • state of moped • PTW apparel • Human errors (looking but not seeing, failure in perceiving the moped) • voluntary risk taking behavior conspicuity • lack skills and knowledge about riding. Motorcycle riders: • age, experience • human functional failures (loss of control when experiencing a guidance problem or the poor reaction to an external distraction due to excessive speeds, risk taking) • the lack of perception (from the passenger car driver and of the motorcyclists) • conspicuity (the driver fails to see the motorcyclist)
Infrastructure	The type of area Carriageway type Road Installations and stationary objects Pavement surface conditions Junction type Geometry specifications	Crossfall and curve radius (radii smaller than 200m) curvature change rate Black spots for passenger cars Deficits (general unevenness for example are road surface waves as well as potholes) friction value accumulation of bituminous binders and ruts Not-predictable road geometry
Weather Conditions	Meteorosensitivity Precipitation intensity Snowfall	PTW accidents correlate with weather conditions. This correlation can be described in mathematical terms. The accident record of a year can be normalized using a correlation between accidents and weather conditions. The correlations between weather and accident numbers differ for weekends and workdays.

Ownership of PTWs is increasing in other countries as well, for several reasons including low travel times in congested areas, being more economical in terms of acquisition, maintenance and usage cost (fuel consumption, road charging fee etc). PTWs are regarded as a vulnerable road user group based on accident statistics that illustrate high risk rates for PTWs. Nevertheless, the majority of designed and implemented guidelines are focused on the passenger car user and specific needs of motorcyclists are neglected.

The presented results may be used to design efficient guidelines that may significantly alleviate the risk of having accidents for PTW users. Moreover the analyses conducted add value to the manner future in depth analyses and accidentology studies should be conducted. In particular, several limitations, such as the need for larger more detailed datasets, the need for exposure data that may help defining risk, as well as the need to adapt current in-depth analysis methodologies to the special characteristics of PTW safety were highlighted.

Acknowledgments
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