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Investigation of accidents involving powered two wheelers and bicycles – A European in-depth study

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ABSTRACT

Introduction: The number of road fatalities have been falling throughout the European Union (EU) over the past 20 years and most Member States have achieved an overall reduction. Research has mainly focused on protecting car occupants, with car occupant fatalities reducing significantly. However, recently there has been a plateauing in fatalities amongst 'Vulnerable Road Users' (VRUs), and in 2016 accidents involving VRUs accounted for nearly half of all EU road deaths. *Method:* The SaferWheels study collected in-depth data on 500 accidents involving Powered Two-Wheelers (PTWs) and bicycles across six European countries. A standard in-depth accident investigation methodology was used by each team. The Driver Reliability and Error Analysis Method (DREAM) was used to systematically classify accident causation factors. *Results:* The most common causal factors related to errors in observation by the PTW/bicycle rider or the driver of the other vehicle, typically called 'looked but failed to see' accidents. Common scenarios involved the other vehicle turning or crossing in front of the PTW/bicycle. A quarter of serious or fatal injuries to PTW riders occurred in accidents where the rider lost control with no other vehicle involvement. *Conclusions:* Highly detailed data have been collected for 500 accidents involving PTWs or bicycles in the EU. These data can be further analyzed by researchers on a case-study basis to gain detailed insights on such accidents. Preliminary analysis suggests that 'looked but failed to see' remains a common cause, and in many cases the actions of the other vehicle were the critical factor, though PTW rider speed or inexperience played a role in some cases. *Practical Applications:* The collected data can be analyzed to better understand the characteristics and causes of accidents involving PTWs and bicycles in the EU. The results can be used to develop policies aimed at reducing road deaths and injuries to VRUs.

1. Introduction

Road safety remains a major societal challenge within the European Union (EU). In 2016, 25,600 people died on the roads of Europe and 1.4 million people were injured (EC, 2018). Although there are variations between Member States, road fatalities have generally been falling throughout the EU until recent times. During the last few decades, measures to improve road accident prevention have predominantly focused on protecting car occupants to good effect as car occupant fatalities reduced by 44% during the period from 2007 to 2016 (EC, 2018).

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However, at the same time the number of fatalities and injuries amongst other categories of road users has not fallen to the same extent, for example cyclist deaths decreased by only 0.4% on average in the EU between 2010 and 2018 (ETSC, 2020). Vulnerable Road Users (VRUs) are a priority and represent a real challenge for researchers working on accident prevention. Accidents involving VRUs comprised approximately 47% of all fatalities in the EU during 2016. Of these, Powered Two-Wheelers (PTWs) comprised 17% and cyclists 8% of the total numbers of fatalities (EC, 2018), though these proportions do vary between different countries.

Powered two-wheeler is the collective term for motorcycles, mopeds, light mopeds (also called mofas) and speed-pedelecs. PTW use has continued to increase over the years, attracting road users for a variety of reasons such as their lower running costs and ability to easily move in and out of congested traffic (Haworth, 2012). However, there are also disadvantages associated with PTWs, for example they are lightweight and can lose control more easily than a car (Van Elslande & Elvik, 2012). Compared with some other vulnerable road users they can travel at high speeds and mix more closely with other traffic, making them one of the most vulnerable groups of road users and road accidents involving PTW riders are a major social concern.

Bicycle riders are also particularly vulnerable as they travel at lower speeds than motorized vehicles, can be difficult to see, and have little protection if they are involved in an accident. Unlike pedestrians with whom they share these characteristics, cyclists are often on the road mixing directly with other traffic with a higher speed differential, giving them an increased risk of being in an accident with a partner of greater mass.

For these reasons, the SaferWheels study aimed to investigate the causes of accidents involving PTWs and bicycles in Europe. An integral part of this study was that in-depth accident data were collected by trained investigators from six European countries using a common methodology.

The primary objectives of the SaferWheels study were: (1) collection of accident data for at least 500 accidents of which approximately 80% would involve PTWs and the remainder bicycles that collided with a motorized vehicle; (2) in-depth investigations to be carried out using a common established set of protocols based on a systemic approach to risk factor identification; and (3) analysis of the collected data to give an indication of the main accident typologies and causation factors.

It is noted here that the current study only investigated bicycle accidents where a motorized vehicle was involved. Bicycle only, bicycle-bicycle, and bicycle-pedestrian accidents were not in the scope of this study, though research suggests such accidents account for a large number of serious and fatal injuries to cyclists that often go unreported (see for example Schepers, Stipdonk, Methorst & Olivier, 2017, Boele-Vos et al., 2017).

Several previous studies have examined the characteristics of motorcyclist safety. MAIDS (Motorcycle Accidents In-Depth Study), reported in ACEM (2009), carried out in-depth investigations of over 900 accidents involving PTWs in five sampling areas in the EU. The study concluded that the main cause of the majority of PTW accidents was rider or driver error, primarily due to driver inattention, temporary view obstructions or low PTW conspicuity (ACEM, 2009). Other studies have also explored factors affecting injury severity. For example, Albalate and Fernandez-Villadangos (2010) identified gender, excess speed, road width, and alcohol consumption as factors affecting PTW injury severity. Pai and Saleh (2007) determined that junction accidents resulted in more severe outcomes than those not at junctions, and that riding in dark conditions further increased severity. In a recent study, Theofilatos and Ziakopoulos (2018) found that traffic and speed variations increase PTW injury severity, while increased truck proportions in the traffic mix were found to reduce injury severity.

With respect to bicycle accidents, previous literature has identified some common scenarios and causes. Räsänen and Summala (1998) carried out an in-depth analysis of bicycle accidents and found that poor attention allocation and unjustified expectations of the behavior of others were common causes. They also identified a common scenario involving a car driver turning right and coming into conflict with a cyclist on a cycle track. More recently, Wegman, Zhang, and Dijkstra (2012) have explored methods to increase cycling in a population without also increasing fatalities and suggested a safe system approach would best protect vulnerable road users such as cyclists. Tripodi and Persia (2015) further promoted the use of e-safety applications and Information and Communication Technologies (ICT) in enhancing cyclist safety, as well as highlighting that different European countries have varied attitudes to cyclists and so will need different countermeasures.

2. Methodology

Data for the study were collected from sample regions in six EU countries (Table 1) to give a representative view of accidents in Europe. Together the countries accounted for 57% of PTW and 45% of cyclist fatalities in Europe in 2016 (EC, 2018). The sample regions were chosen to be as representative as possible of each country; the relationship between each sample region and the country's national population is described in more detail in Morris et al. (2018).

The objective of the study was to investigate 500 accidents comprising approximately 80% PTW and 20% bicycle accidents; however the proportions would vary for each sample region in order to be more representative of their own accident populations. Table 1 shows the proportion of bicycle and PTW accidents aimed to be investigated by each team to achieve a representative sample. Due to some difficulties in data collection, which are discussed later, these individual proportions were reviewed regularly during the study and adjusted where needed, with some teams collecting more or less PTW / bicycle accidents than originally planned. The numbers that were achieved in practice are shown in the results section in Table 2.

Table 1
Study sampling areas.

Country	Data collection region	Team proportion PTW accidents	Team proportion bicycle accidents
France	Essonne	88%	12%
Greece	Thessaloniki	96%	4%
Italy	Rome	98%	2%
The Netherlands	The Hague	51%	49%
Poland	Mazowieckie	47%	53%
United Kingdom	Midlands	54%	46%

The aim of the study was to investigate the causes of road accidents involving cyclists and PTWs in Europe, therefore only accidents that involved either a PTW or bicycle (or both) were examined. PTW accidents could either be single vehicle or involve a collision partner, however bicycle accidents were only within the sampling criteria if they were in collision with a motorized vehicle. The exception to this was e-bikes (bicycles that provide electrical support even when the cyclist does not pedal at all) and pedelecs (electrically assisted bicycles in which you have to pedal to get assistance), as these could be classified as motorized in their own right and so were included regardless of whether the accident included another motorized vehicle.

For investigation of accidents the study utilized the methodology defined by the DaCoTA project (Atalar, Talbot & Hill, 2012).

The DaCoTA methodology was chosen because: (a) it is a comprehensive guide to conducting in-depth road accident investigations; (b) it has the capability to describe all involved road users in the accident; (c) it has a manual including examples and recommended applications; and (d) it allows all the investigation teams to use a harmonized methodology and thus make the results comparable.

The DaCoTA investigation methodology specifies two primary approaches to gathering information: 'On-Scene' and 'Retrospective.' In the 'On Scene' approach, investigators were notified of an accident by emergency services and attended the scene at the time to collect data. A 'Retrospective' approach was used when attendance at the accident was not possible. In this approach, the vehicles are examined after the accident (e.g., at recovery yards), the scene revisited, and road users approached for interviews. Accident investigation reports (including scene photos, vehicle examinations, driver/rider interviews etc.) from the emergency services are also obtained wherever possible.

The adapted SaferWheels methodology is described fully in Morris et al. (2018). Data were collected during the period of 2015–2017. Investigated accidents usually involved injury to the PTW or bicycle rider; however, a small sample of non-injury accidents were investigated if there were sufficient data available to form a useful case.

A purposive sampling method was adopted. This was based on the concept of saturation, defined as the point at which the data collection process no longer offers any new or relevant data. Case selection was random in all cases, however, there were limitations as not all accidents could be reached in time to investigate thoroughly. Furthermore, barriers such as data privacy issues, legal investigation, explicit refusal by involved parties, etc. prevented the investigation of some accidents. Due to these challenges, some teams relied on investigations of fatal and more serious accidents conducted by specialist police accident investigators ('retrospective' investigations). This did not reflect the true severity distribution of accidents that occur in those regions but was a result of the challenges of collecting in depth accident data.

2.1. Data specification

Approximately 1,500 variables (or fields) per accident were gathered and were entered into a central database. Data were gathered for each element involved in the accident – for example, if the accident involved both a PTW and a passenger car, data were collected for both vehicles and both drivers. The following list illustrates the categories of variables included in the dataset:

- Accident (e.g., date and time, local environment, light and weather conditions)
- Road (e.g., road type, speed limit, road geometry, roadside furniture)
- Road user (e.g., age, gender, injury severity)
- PTW or bicycle (e.g., make and model, motor displacement, mechanical condition)
- Opponent vehicle(s) (e.g., type, make and model, general condition, safety technologies fitted)
- Causation analysis (e.g., speed, distraction, intoxication)
- Reconstruction analysis
- Injury descriptions (coded using the Abbreviated Injury Scale (AIS))
- Road user interviews

2.2. Accident causation classification

Accident causation analysis was carried out using the Driving Reliability and Error Analysis Method (DREAM). DREAM allows investigators to systematically classify and store accident causation information that has been gathered through in-depth investigations by providing a structured method of establishing the causal factors inherent within each accident into a set of formally defined categories of contributing factors.

DREAM originated from the Cognitive Reliability and Error Analysis Model (CREAM) (Hollnagel, 1998), which was used to analyze accidents in process control domains, becoming DREAM when it was adapted for use in road transport accidents (Ljung, 2002, 2007). Warner, Ljung, Sandin, Johansson, and Björklund (2008) developed DREAM further as part of the EC SafetyNet project, and version 3.2, the latest version, was created during the DaCoTA project where additional variables were added specifically relating to PTW accidents (Ljung et al., 2012).

DREAM 3.2 was selected as the preferred method of causation analysis in this study due to the success of previous application, the rigorously established theoretical background, and the structured approach of establishing accident causation specifically for PTWs (Phan et al., 2010).

3. Results

The 500 investigated accidents resulted in a total of 515 'cases;' some accidents involved a PTW and a bicycle so can be considered either a PTW case and/or a bicycle case for analysis purposes. The distribution of PTW and bicycle cases collected by each team is shown in Table 2. in total 77% (385) of the 500 accidents involved a PTW and 26% (130) involved a bicycle.

Table 2
Distribution of cases collected by each investigation team.

Team	PTW cases	Bicycle cases	Total
France	81 (94%)	5 (6%)	86
Greece	78 (92%)	7 (8%)	85
Italy	71 (95%)	4 (5%)	75
The Netherlands	57 (57%)	43 (43%)	100*
Poland	48 (54%)	41 (46%)	89*
United Kingdom	50 (63%)	30 (38%)	80
Total	**385 (75%)**	**130 (25%)**	**515***

*Greater than the total accident number as some accidents involve PTWs and Bicycles.

For the overview analysis e-bikes and pedelecs were grouped with pedal cycles, since they were a small proportion of the sample (14 cases), and share similar characteristics in terms of being able to use cycle lanes, their visibility/conspicuity, and that they generally travel at lower speeds than PTWs.

The distribution of injury severity for the different vehicle types is shown in the Table 3. Teams used the following injury severity classifications:

- Fatal: Death within 30 days of the road accident.
- Serious: Injured (not killed) and hospitalized for at least 24 h.
- Slight: Injured (not killed) and hospitalized for less than 24 h or not hospitalized.
- Not injured: Participated in the accident though not injured.

This classification was applied rather than the national definitions since definitions may vary between countries. The overall distribution comprises 36% (181) slight injury, 30% (149) serious injury, and 17% (84) fatal injury accidents, with the remainder being no injury or unknown severity.

3.1. Accident scenarios

Analysis of the accident scenario was undertaken to look for trends or patterns. The analysis takes into consideration the num-

Table 3
Maximum injury severity of all accidents, PTW cases, and bicycle cases.

Vehicle Type	Non-Injury	Slight	Serious	Fatal	Unknown	Total
PTW cases	22 (5.7%)	134 (34.8%)	103 (26.8%)	69 (17.9%)	57 (14.8%)	385
Bicycle cases	1 (0.8%)	49 (37.7%)	59 (45.4%)	15 (11.5%)	6 (4.6%)	130
All accidents	23 (4.6%)	181 (36.2%)	149 (29.8%)	84 (16.8%)	63 (12.6%)	500

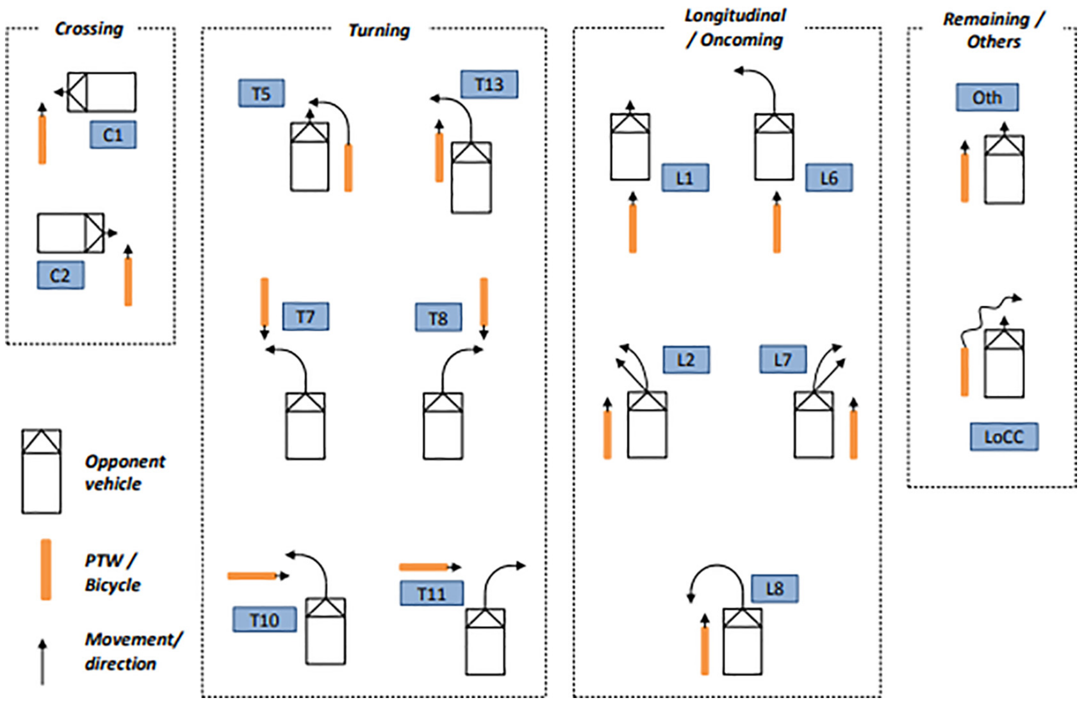

Fig. 1. Grouped accident scenarios for PTW and bicycle accidents (source: Morris et al., 2018).

ber of vehicles/pedestrians involved in the accident, their maneuver, the positions of each road user prior to the accident, and their intended directions. For multi-vehicle accidents, scenario groups were developed for analysis as shown in Fig. 1, which were derived from the 'DaCoTA Accident Type' variable. Further descriptions of these scenarios are included in Appendix A. The main results of the accident scenario analysis are given below.

3.1.1. PTW cases

25% of fatally and seriously injured PTW users were involved in a single vehicle PTW accident. Sixty-four percent of these lost control of their vehicle on a curve. In comparison, only 10% of slight injuries to PTW riders occurred from single vehicle accidents, though it is recognized there may be under-reporting in this area and this figure may not represent the true population.

The three most common accident scenarios for fatally and seriously injured PTW riders involved in a two-vehicle accident were: T7 (16%), C2 (13%) and Loss of Control on a Curve (LoCC – 9%). For slightly injured PTW riders, the two most common accident configurations were T7 (17%) and C1 (16%). The remaining accidents were evenly distributed among the other accident scenarios.

3.1.2. Bicycle cases

The three most common accident scenarios for fatally and seriously injured bicycle riders involved in a two-vehicle accident were C1 (19%), C2 (19%), and T5 (7%). For slightly injured road users involved in a bicycle accident, the three most common accident scenarios differ somewhat; C2 was still the main accident configuration (18%), but the next most frequent were T8 (9%) and T11 (9%).

3.2. Road and environment characteristics

Both PTW and bicycle accidents tended to occur during daylight hours (respectively 78% and 81%). Similarly, most of the accidents occurred under fine dry conditions, with rain, snow, or fog being present in less than 10% of cases. Most of the accidents occurred on urban roads (78% of PTW cases and 83% of bicycle cases), and within a speed limit of 50 km/h or less (79% of all accidents).

Regarding junction-related accidents; 52% of PTW cases and 43% of bicycle cases did not occur at or within 20 m of junctions. When considering all 500 accidents together, 50% occurred at junctions, which was most frequently at a T or Y junction (23%), or crossroads (21%).

3.3. Vehicle characteristics

The sample contains 393 PTW investigations from 385 PTW 'cases' as some accidents involved multiple PTWs. The most common PTW types examined were scooters (47%), followed by road race replicas (19%), standard street bikes (13%), and commuter bikes (7%). The distribution of PTW motor displacement (engine power) is shown in Table 4. Half the sample were lower powered PTWs (250CC or less).

Table 4
Distribution of PTW motor displacement ($n = 393$).

PTW motor displacement	Proportion of sample
50 CC or less	19.8% ($n = 78$)
100–250 CC	29.3% ($n = 115$)
251–500 CC	8.1% ($n = 32$)
Over 500 CC	38.7% ($n = 152$)
Unknown	4.1% ($n = 16$)

The overall PTW condition was coded in the data, ranging from excellent to poor. Excellent or good would indicate the vehicle is in a roadworthy condition, with no obvious signs of defect or poor maintenance. In the majority of cases (80%), the condition of the PTW was found to be good or excellent; only 4% of vehicles were considered to be in poor condition, which would indicate an obvious defect. Defects were observed in 5% of vehicles, most commonly the defects related to the tires, wheel, or brake condition. However, these defects were thought to have contributed to the accident in only 2% of the PTW cases.

Regarding bicycles, 132 bicycles were investigated from 130 bicycle 'cases' as some cases involved two bicycles. Of these, 117 were conventional 'pedal' bicycles and 15 were power assisted (pedelecs). Power assisted bicycles were excluded from detailed bicycle analyses as they have subtle but potentially important differences. Mechanical defects in pedal bicycles were generally limited; when found they were most frequently associated with the tire condition, specifically a worn tread on the tire (11–12% of bicycles). The overall condition of the bicycle was described as good or excellent in 72% of cases. In only 1 case were bicycle defects thought to contribute to the accident.

3.4. Road user characteristics

The 500 investigated accidents involved 1,012 road users, of which 916 (91%) were drivers or riders of the vehicle ($n = 393$ PTW riders, $n = 132$ bicycle riders, $n = 391$ collision opponents). A further 75 (7%) road users were passengers in vehicles, and 21 (2%) were pedestrians; these are generally excluded from analyses unless stated otherwise. PTW riders were highly likely to be male (90%), and two thirds were aged 18–45 (67%). For bicycle riders the gender difference was not as pronounced (68% male), and over half (54%) were over 45 years old.

While most PTW riders used helmets (81%), a non-negligible percentage did not (15%). For bicyclists, only 32% of riders were wearing a fastened helmet; 45% were not wearing one at all. When reading these figures, it is noted that PTW helmets are required by law in all the data collection countries, with an exception that in the Netherlands this only applies to vehicles with an engine displacement over 50 cc. At the time of data collection, light moped riders in the Netherlands were not required to wear helmets, although new laws are being introduced that will change this. Light moped riders in the Netherlands accounted for over half (58%) of the 15% riders who did not wear helmets. In contrast, bicycle helmets are not required by law in any of these countries (apart from in France where they are mandatory only for children under 12 years old), which may in part explain the lower usage observed.

Headlights were used by the majority of PTW riders (72%). However, only 20% of bicycle riders used lights; a further 22% had lights fitted that were not being used and 36% had no lights fitted at all. Reflective and high conspicuity clothing was not often worn by either PTW riders (13%) or bicycle riders (20%). For both headlights and reflective clothing, it should be noted that the figures do not consider the daylight conditions at the time, and the majority of accidents occurred during daylight hours.

3.5. Contributory factors

Contributory factors in more common terminology were derived from the DREAM analyses, which use more specialist terms (e.g., 'attention allocation' became 'distraction'). Through DREAM and other variables in the database nearly 100 possible contributory factors or subfactors were able to be assigned to any given road user. Analyses were carried out for drivers, riders and pedestrians, but not for passengers as they are not in control of the vehicle. Multiple factors were assigned to each road user in each case; in total for the 500 accidents over 4000 factors were assigned with an average of 4.4 factors per road user. Table 5 below shows the results of a selection of 'human' factors commonly related to road accident causation, split by road user type. 'OIRUs' refer to 'other interacting road users' (i.e., drivers of cars/trucks/other vehicles in collision with the PTW or bicycle).

It can be seen that intoxication (alcohol and drug involvement), fatigue, heightened emotions or psychological impairments, medical conditions or physical impairment and risk-taking behavior were not found to be major contributing factors of the investigated accidents. Each of these were thought to be a contributing factor for less than 10% of road users.

Distraction was more prevalent. In particular, for over a third (34%) of the other interacting road users, distraction immediately prior to the accident contributed to its occurrence, compared to 10% of PTW riders, and 16% of cyclists. Distraction could be related to objects/people within the vehicle (e.g. talking to passenger, looking at mobile phone), or outside the vehicle (e.g. focused on road signs, a friend walking past).

Furthermore, errors of observation, typically described as 'looked but failed to see' accidents were a major factor, being a contributing factor for over a third of PTW and bicycle riders (respectively 38% and 39%), and two thirds of interacting road users (66%). Sight obstructions (such as other vehicles, vegetation, or roadside furniture) were also a factor for over a quarter (28%) of interacting road users and may have contributed to some of the errors in observation.

Inexperience as a contributing factor was more prevalent among PTW riders than bicycle riders (respectively 14% and 7%). Inexperience was determined in relation to overall riding experience, familiarity with the specific vehicle ridden, or familiarity with the roads being ridden on. Further analysis was done of the inexperienced PTW riders ($n = 53$). Riders with inexperience as a contributing factor were generally younger, with over half (52%) aged under 25. This is compared with 27% of the total PTW rider sample being in the same age category. Inexperienced riders were also relatively more likely to have speed as a contributing factor compared with all riders (31% compared with 21%).

3.5.1. Speed

Excess speed was rarely observed to be a major factor for cyclists or other interacting road users (respectively 7% and 4%). However, for 22% of PTW riders excess speed was a contributing factor in the accident. The PTW riders that were identified as having speed as a contributing factor ($n = 85$) were further analyzed to determine if there are any trends or commonalities within them.

In the majority of these cases the PTW rider was exceeding the speed limit for the road (71 out of 85 riders), but excess speed was also recorded when the speed was judged to be too fast for the road or weather conditions ($n = 5$ riders speed contributed to the accident but not travelling above the speed limit, $n = 9$ riders speed contributed to the accident but speed limit unknown).

As shown in Table 6, the age profile of riders where speed was a contributing factor is younger than the overall sample, indicating younger people have a higher propensity towards risk taking through speeding. Speed is also correlated with increased injury severities, with PTW accidents where speed was a contributing factor leading to a far higher proportion of fatal/serious injury accidents (81% compared with 45% of all accidents) over slight/no injury accidents (12% compared with 41% of all accidents).

Table 5
Distribution of selected contributory factors according to road user type.

Contributory Factor	Value	Road User		
		PTW Riders (n = 393)	Bicycle Riders (n = 132)	OIRUs (n = 391)
Alcohol*	No	86.8%	84.8%	88.0%
	Yes	4.1%	6.1%	1.5%
	Unknown	9.2%	9.1%	10.5%
Drugs	No	90.6%	92.4%	91.0%
	Yes	3.1%	1.5%	0.5%
	Unknown	6.4%	6.1%	8.4%
Excess Speed	No	54.7%	84.8%	88.5%
	Yes	21.6%	6.8%	3.6%
	Unknown	23.7%	8.3%	7.9%
Fatigue	No	94.9%	89.4%	96.4%
	Yes	2.3%	2.3%	3.1%
	Unknown	2.8%	8.3%	0.5%
Distraction	No	87.5%	75.8%	65.5%
	Yes	9.7%	15.9%	34.0%
	Unknown	2.8%	8.3%	0.5%
Emotional/psychological impairment	No	88.3%	85.6%	93.9%
	Yes	8.9%	6.1%	5.6%
	Unknown	2.8%	8.3%	0.5%
Medical conditions/physical impairment	No	96.2%	88.6%	98.2%
	Yes	1.0%	3.0%	1.3%
	Unknown	2.8%	8.3%	0.5%
Risk-taking behaviour**	No	92.1%	86.4%	98.7%
	Yes	5.1%	5.3%	0.8%
	Unknown	2.8%	8.3%	0.5%
Rider inexperience	No	83.7%	84.8%	95.4%
	Yes	13.5%	6.8%	4.1%
	Unknown	2.8%	8.3%	0.5%
Missed/late observations	No	59.5%	52.3%	33.8%
	Yes	37.7%	39.4%	65.7%
	Unknown	2.8%	8.3%	0.5%
Sight obstruction	No	79.6%	76.5%	71.9%
	Yes	17.6%	15.2%	27.6%
	Unknown	2.8%	8.3%	0.5%

*Note 1: For the Netherlands a large proportion of the data for alcohol involvement were coded as 'unknown', as police in the Netherlands do not regularly check for alcohol involvement.
**Note 2: Factors such as alcohol, drugs and speeding, although also could be considered as risk-taking behaviour, are considered separate to this variable.

Table 6
Age and injury severity of PTW riders for which speed was a contributing factor in the accident (n = 85) compared with all riders (n = 393).

Age	All PTW riders (n = 393)	PTW riders with speed as a contributing factor (n = 85)
0–17	4.6%	7.1%
18–25	21.9%	29.4%
26–35	25.2%	25.9%
36–45	19.3%	14.1%
46–55	15.3%	15.3%
56–65	8.9%	7.1%
>65	3.8%	1.2%
Unknown	1.0%	0.0%
Injury Severity	**All PTW accidents (n = 385)**	**PTW accidents with speed as a contributing factor (n = 85)**
Not injured	5.7%	3.5%
Slight	34.8%	8.2%
Serious	26.8%	31.8%
Fatal	17.9%	49.4%
Unknown	14.8%	7.1%

4. Discussion

4.1. Collection of in-depth accident data

The primary outcome of this study was the collection of in-depth investigation data on 500 accidents involving PTWs or bicycles across six European countries. Many past research studies have raised issues concerning better understanding of the causation of accidents involving VRUs such as PTWs and bicycles, however many of these, for example the MAIDS study (ACEM, 2009), were carried out some time ago. More recently the Motorcycle Crash Causation Study (MCCS) (Nazemetz, Bents, Perry, Thor, & Mohamedshah, 2019) carried out in-depth investigations on 351 PTW accidents in the United States, however there is a lack of more recent large scale in-depth research from a European perspective. The value of the current study therefore is that it will enable researchers to gain a more up to date understanding of the nature and causes of PTW and bicycle accidents in Europe.

The objective of the study was to gather PTW and bicycle accident data from in-depth accident investigations, obtain accident causation and medical data for those accidents, and to store the information according to an appropriate and efficient protocol enabling an accident causation-oriented analysis. The study showed that the DaCoTA protocols for in-depth accident investigations were successful in securing relevant highly detailed data for describing the nature and circumstances of PTW bicycle accidents. Further research could compare the methodology of the current study with other in-depth studies, including the MAIDS and MCCS studies which both utilized adapted OECD investigation protocols.

However, the data collection was not without challenges. Although the target of 500 cases was completed within the time frame of the study, a significant amount of resource was required to achieve this, and some adjustments had to be made to individual team targets and methods of data collection. Ideally an 'on-scene' investigation approach would be used for all cases, as this gives the investigating teams the opportunity to collect more data directly themselves according to the established protocols, supplementing it with additional interview/medical/vehicle examination data later (either directly or through the emergency services). In the current study the on-scene method worked well when utilized and provided accurate data collection, however it was found to have a high cost and time resource associated with it. Teams trying to collect data on-scene faced a variety of challenges, such as; long times 'on-shift' waiting for a suitable accident to occur, not being able to secure data sharing agreements with all emergency services, not being able to reach the accident location before some of the involved parties had already left the scene, being refused permission to interview all involved parties or examine their vehicles, etc. These challenges potentially result in a case not being included in the sample if all the core data could not be collected, in addition to time lost waiting for accidents to occur, so the number of cases collected does not always reflect the amount of effort expended.

Many teams had to instead use the 'retrospective' approach in order to reach their target within the timeframe. Although not able to attend the accident when it occurred, the teams found that it was still possible to gain a large amount of in-depth data by combining data from multiple sources such as police investigation reports and medical examination reports, and that some data could still be collected directly by the investigation teams at a time after the accident (e.g., interviews with road users or examinations of vehicles involved). This method also allowed teams to cover a wider sample area than what they could reach directly from their on-scene base within a short time of the accident occurring, and so increased the sample pool. The drawbacks to this approach include reduction in the amount of data collected, preventing for example a full reconstruction in some cases, and also that investigators often have to rely on interpreting second hand information, which may not have been collected with the same purpose in mind. Overall, however, the retrospective method was found to be more cost-effective, enables better planning and use of staff resources, and does not significantly reduce the quality of the collected data; therefore future studies should consider this method as a good alternative to collecting data directly at the scene if that is not possible.

Finally, issues relating to data protection and privacy, as well as variations in methods or terminology between countries (or different regions within countries) did pose a challenge in collecting harmonized data. The current study highlighted the importance of regular communication between teams through the data collection process to ensure a common understanding was used. Researchers using national datasets to compare accident circumstances between countries face challenges such as incompatible data, missing variables, or unclear definitions. Using a common methodology, in this case the adapted DaCoTA protocols, achieved the aim of generating comparable data between teams, and the output dataset will be valuable in future research to gain insights both within and between countries.

4.2. Data sample

The accident characteristics in the collected sample were in line with those seen in previous in-depth PTW studies such as the MAIDS and MCCS studies, and with similar research on both PTWs and bicycles (e.g., Piantini et al., 2016; Beck et al., 2016). Accidents primarily occurred in urban areas, during daylight hours, and not in adverse weather. Just under half of the accidents investigated occurred at junctions, which is in line with the results reported in the MAIDS study. Compared to the United States, the MCCS study found similar results for single vehicle accidents but reported that over three quarters of multi-vehicle accidents occurred at intersections. Relatively more bicycle accidents occurred at junctions when compared with PTWs, however this could be a function of the sample inclusion criteria as only multi-vehicle bicycle accidents were included, whereas PTWs could be involved in a single-vehicle accident, which often occur outside of junctions.

For both PTWs and bicycles, the characteristics are reported alone and do not consider any exposure data, therefore the results are given solely to describe the sample and do not imply any specific relative risk. Future research could examine this further, considering exposure and comparing with characteristics of all road user types to identify any significant results in the collected data.

4.3. Road user characteristics

In the current study, the PTW rider sample was dominated by males, and over two thirds were aged under 45. This could be explained due to the desires of each age group, as speed, maneuverability and sensation seeking can be said to be the needs of younger people. Conversely, as road-users age, they may seek the comfort of a car, switch to a bicycle or travel on foot, or limit their exposure altogether by taking fewer trips. This was slightly different to the data relating to bicycle riders where two thirds of the sample were male and over half were older than 45. Previous research has found that males are more likely to be involved in a cycling accident (Beck et al., 2016), though this is possibly because of greater use of cyclists by males versus females.

In the accidents investigated, most PTW riders recognized the benefit of helmet use while riding. Haworth and Debnath (2013) found that motorcyclists were more likely to wear a helmet in comparison to cyclists, though this could be related to more legislation being targeted at PTW helmet use. Other research has found that wearing a helmet can reduce injury severity amongst motorcyclists by 70% and reduce the numbers of fatal head injuries by 44% (Elvik, Høye, Vaa, & Sorensen, 2009), which supports the view that continued efforts to improve helmet use by PTW riders will be highly beneficial.

Many of the cyclists investigated in this study did not use a cycle helmet. A recent meta-analysis by Høye (2018) found that in the case of a fall or accident, the use of a bicycle helmet was found to reduce serious head/brain injury by 60% and fatal head/brain injury by 71% on average. However, some studies show adverse effects of bicycle helmets on accident involvement (Robinson, 2006; Phillips, Bjørnskau, Hagmand, & Sagberg, 2011); this is due to 'behavioral adaptation,' as cyclists may feel safer wearing a bicycle helmet and as a result they may show more risky cycling behavior. Other studies indicate that young helmet wearing cyclists take no additional risks (Hagel & Pless, 2006). It is unclear what this could mean for the safety effects of helmet wearing; several studies contradict each other.

4.4. Accident scenarios

A quarter of the serious or fatal PTW cases analyzed involved no other vehicles and two thirds of these were due to the rider losing control on a curve. Loss of control of the PTW was also the third most common accident scenario for multi-vehicle PTW accidents. Combined, these form a large portion of severe outcomes for PTW riders and should be investigated further. Whilst speed is likely to be a factor in a portion of these accidents, it is also recommended to investigate vehicle-based measures to reduce loss of control accidents. See for example Grant et al. (2008), who proposed the implementation of integrated safety systems for a range of PTWs to improve primary safety through handling and stability. Furthermore, Anti-lock Braking Systems (ABS) have been mandatory on European PTWs with engine capacity over 125 cc since 2016 and have been shown to reduce fatal accidents by 31% (Teoh, 2013).

Outside of 'loss of control' accidents, the most common scenarios for multi-vehicle PTW accidents involved another road user turning or crossing in front of the PTW. In most of these cases the PTW rider had the right of way and therefore, although PTW speed was also sometimes a factor, the results show that the actions of the other vehicle drivers are more often the critical factor in the accident than the actions of the PTW rider.

The most common cyclist scenarios also involved other road users crossing in front of them, and as rider speed is highly unlikely to be a factor in bicycle accidents, this suggests failure of other vehicle drivers to either detect them or respond appropriately. More research should be aimed at the other road users involved to better understand why they are committing these right of way violations and to identify how these scenarios can be prevented, for example through the use of in-vehicle intelligent technologies to detect PTWs and bicycles and warn drivers of their presence.

4.5. Contributory factors

The right of way violations may in part be explained by the results seen in the causation analysis. Errors in observation were thought to be a contributory factor for two thirds of the other vehicle drivers analyzed and over a third of PTW and bicycle riders. Interestingly, the MCCS study reported similar results for PTW riders in the United States, but much lower figures for other vehicle drivers (being a cause in less than half of cases). Distraction and sight obstructions were each also prevalent in the current study and are likely to have contributed to the observation errors.

Distraction has long been identified as a common factor in road traffic accidents (e.g., Regan, Lee & Victor, 2013), and it is only expected to increase as both the complexity of the road system increases (e.g., smart motorways, advertising, new vehicle types), and the amount of distractions within vehicles increases (e.g. mobile phones, warnings from driver assistance systems, touchscreen entertainment). The data need to be examined on a case-by-case basis to fully understand the reasons behind the distracted behavior observed, however even from the aggregated analysis it is clear that more measures are needed to combat distraction, potentially through new legislation or targeted awareness campaigns.

However, distraction or obstructions to view did not account for all the observation errors in the analysis, suggesting that 'looked but failed to see' accidents are a large problem for both PTWs and bicycles. Speed of the PTW will have played a role in some cases, as often car drivers can misjudge the speed of an approaching PTW and believe they have time to complete their turn, but a collision occurs when the PTW reaches them sooner than expected (Pai, 2011; Davidse et al., 2019). For non-speed related incidents, particularly those involving crossing or turning scenarios, technology countermeasures might be effective in reducing accidents. Research has shown that vehicle technologies such as advanced forward collision warning would be effective in reducing accidents, including those involving PTWs and bicycles (see e.g. Jermakian, 2011).

Improved conspicuity of riders is also proposed as a countermeasure to this issue. In the investigated accidents use of reflective clothing was low, however De Craen, Doumen, Bos and Van Norden (2011) conclude that it is not so much light or reflective clothing that can increase the visibility of motorcyclists, but particularly the contrast with their environment. Research by Gershon, Ben-Asher, and Shinar (2012) came to a similar conclusion; in an urban environment with a varied and multi-colored background a motorcyclist was more conspicuous in white or reflective clothing, and in a rural setting, where the background mainly consisted of a blue sky, a motorcyclist wearing black was more easily noticed. Clarke, Ward, Bartle and Truman (2004) previously highlighted this problem and calculated that if 'looked but failed to see' errors could be eliminated it could result in a reduction of 25% in the total PTW accident rate. The results of the current study show that this problem is still common over a decade later, so it is clear that more research is required urgently to develop countermeasures to help drivers to recognize PTWs and bicycles and respond appropriately.

Aside from distraction, sight obstructions and errors in observation, the causation analysis did not reveal many other common causes. Intoxication, through alcohol or drugs, and fatigue, whilst traditionally known to be factors in road traffic accidents, did not appear commonly in the current study. Vehicle defects were also not prevalent in the current study and the results show that poor maintenance is not a major cause of PTW or bicycle accidents, being a contributing factor for only 2% of PTW accidents and in only one bicycle accident. Results from both the MAIDS and MCCS studies support that vehicle defects are rarely the primary cause of PTW accidents.

PTW rider inexperience was present in a small but potentially significant amount of cases and was generally associated with younger riders. Lack of experience in driving or riding is a commonly studied factor in road accidents (Groeger, 2006), and accidents can result from a lack of situational awareness, lack of experience in avoiding dangerous situations, or inability to remedy them when they start to occur. Although not analyzed further in the current study, an in-depth review of the cases involving inexperience could give insights into possible countermeasures.

Finally, speed as a contributory factor was analyzed and the results show it was predominately the PTW rider that was speeding, not the bicycle rider or interacting road user. Although only a factor for less than a quarter of cases, preliminary analysis showed that contributory speed was correlated to more severe injury outcomes. The MCCS study similarly reports that excess speed of the PTW was overrepresented in fatal accidents. Much research has been carried out on the benefit of reducing speed on road safety, and the current study supports the view that policies and strategies to reduce speeds would be beneficial in reducing both the number of accidents and their severity. Although the sample was too small to draw statistically significant conclusions, speed being contributory appears to also be correlated with younger inexperienced riders, suggesting that targeted interventions aimed at those groups could be beneficial in reducing accidents.

5. Conclusions

The SaferWheels study collected in-depth investigation data relating to 500 PTW or bicycle accidents within the European Union. These data can be further analyzed by researchers and policy makers to provide insights into how to improve the safety of these vulnerable groups. Accidents involving powered two wheelers and bicycles remain common on European roads and coordinated strategies should be deployed to reduce fatalities and serious injuries. A harmonized dataset containing investigations from six European countries may help towards this, allowing researchers to identify where road safety policies might benefit all member states, and where different countries will need different approaches.

Initial analysis of the 500 investigations reveals that causation factors such as observation errors, distraction, and sight obstructions are particularly prevalent, with 'looked but failed to see' accidents still being a key concern for PTWs and bicycles. Additionally, for PTW riders, there were a small but potentially significant number of cases for which excess speed and/or inexperience was a contributing factor, and these cases could be analyzed further to inform potential countermeasures.

Analysis of the accident scenarios showed that single-vehicle loss of control accidents accounted for a quarter of serious and fatally injured PTW riders, therefore measures to reduce these (through road design, rider behavior or vehicle stability technologies) could result in large benefits for PTW safety. Outside of these, for both PTW and bicycle riders the most common scenarios involved another vehicle crossing or turning in front of them, supporting the view that in many cases, the actions of the PTW or bicycle rider is not the primary factor in the accident.

Whilst the analysis reported here reveals some interesting findings regarding PTW and bicycle accidents, it should be remembered that such findings are based on aggregated analysis of the collective data to look for trends in accident characteristics and causation. Much more can be gained from an evaluation of each individual investigation on a case-study basis to derive more in-depth insight into specific factors that may be relevant to reducing such accidents, as well as how various factors interact with each other to come together and result in an accident.

6. Practical applications

The results of the SaferWheels study have validated the value of a harmonized approach to accident investigation across the European Union, whilst also identifying difficulties in data collection to guide future research methods. The outcome of the study, a dataset of 500 in-depth accident investigations involving PTWs and bicycles, can be analyzed to provide evidence to support policies targeted at reducing road deaths and injuries to vulnerable road users on EU roads.

The SaferWheels dataset is available for analysis upon request from the European Commission.

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Ilona Butler is the lead road safety expert for Poland in many international activities. She represents Poland in the European Transport Safety Council activities and has contributed to national road safety strategy. She has been a research partner in many international programmes including the Road Safety Performance Index (PIN) program and the SEC-Safety Belt program coordinated by the ETSC. She has worked on European projects such as BEST (Benchmarking Professional Road Transport Safety, 2001-2003), DRUID (Driving Under the Influence of Drugs, Alcohol and Medicines, 2006-2010). She was also involved in the DaCoTA project (2010-2012) developing a pan-European accident investigation network.

Apostolos Ziakopoulos is a Civil Engineer, MSc, PhD Candidate and Researcher at the Department of Transportation Planning and Engineering at the National Technical University of Athens (NTUA). In 2014, he received a Master of Science – DIC in Transport from Imperial College London and University College London. He has worked as a researcher for the University of Sheffield through the I.A.E.S. T.E. scheme. His main research interests involve road crash analyses, statistical and spatial modelling and traffic engineering. He has participated in 5 research and engineering projects and studies and has published 29 papers in scientific journals and conferences.

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George Yannis is Professor in Traffic Safety and Management with focus on data management and analysis and is currently Director of the Department of Transportation Planning and Engineering of the School of Civil Engineering at the National Technical University of Athens. For over 30 years, he has contributed extensively in more than 245 research and engineering projects and studies and in several scientific committees of the European Commission and other International Organisations (UNECE, OECD, WHO, World Bank, EIB, CEDR, ERF, IRF, UITP, ETSC, ECTRI, WCTR, TRB). He has published over 560 scientific papers (169 in scientific journals) widely cited worldwide.

Alain Martin is head of branch office of CEESAR (Centre Européen d'Etudes de Sécuritéet d'Analyse des Risques /European Center of Safety Research and Risk analysis) in Essonne. He makes in-depth accident investigation until 2000. For the past 20 years, he has participated in Transport Safety study projects in Europe such as MAIDS (2000-2002), RIDER (2002-2004), Caciauap (2009-2011) and finally Saferwheeks (2015 to 2017). Before this he worked in the commercial field.

Fallou Wadji is an accidentology engineer at CEESAR (Centre Européen d'Etudes de Sécurité et d'Analyse des Risques /European Center of Safety Research and Risk analysis). He makes in-depth accident investigation until 2016. Fallou graduated from the University of Toulouse as an aeronautical mechanics engineer in 2014. He had started working in mechanical calculation and sizing of metal structures between 2014 and 2016.

Appendix A. – Accident Scenario Descriptions

Accident Scenario	Description
C1	• PTW/bicycle driving straight • Opponent vehicle crossing the PTW/bicycle path from the right side
C2	• PTW/bicycle driving straight • Opponent vehicle crossing the PTW/bicycle path from the left side
T5	• PTW/bicycle turning to the left, crossing the (straight) opponent vehicle path • Opponent vehicle is riding straight in the same direction as the heading of the PTW/bicycle before turning
T7	• Opponent vehicle turning to the left, crossing the (straight) PTW/bicycle path • PTW/bicycle coming from the opposite direction, riding straight
T8	• Opponent vehicle turning to the right, crossing the (straight) PTW/bicycle path • PTW/bicycle coming from the opposite direction, riding straight
T10	• Opponent vehicle turning to the left, crossing the (straight) PTW/bicycle path • PTW/bicycle is riding straight, coming from the left side of the opponent vehicle
T11	• Opponent vehicle turning to the right, crossing the (straight) PTW/bicycle path • PTW/bicycle is riding straight, coming from the left side of the opponent vehicle
T13	• Opponent vehicle turning to the left, crossing the (straight) PTW/bicycle path • PTW/bicycle is riding straight in the same direction as the heading of the opponent vehicle before turning
L1	• Opponent vehicle and PTW/bicycle driving in the same direction • PTW/bicycle is riding straight and hit by the opponent vehicle (going straight) from the rear
L2	• Opponent vehicle and PTW/bicycle driving in the same direction • Opponent vehicle is swerving to the left in front of the PTW/bicycle and hit by the PTW/bicycle
L6	• Opponent vehicle and PTW/bicycle driving in the same direction • PTW/bicycle is riding straight and hit by the opponent vehicle (turning left) from the rear
L7	• Opponent vehicle and PTW/bicycle driving in the same direction • Opponent vehicle is swerving to the right in front of the PTW/bicycle and hit by the PTW/bicycle
L8	• Opponent vehicle and PTW/bicycle driving in the same direction • Opponent vehicle is u-turning from the right to the left in front of the PTW/bicycle and hit by the PTW/bicycle
LoCC	• The driver of the PTW/bicycle loses the control of their vehicle, on a curve, and crashes an opponent vehicle
Oth	• All other scenarios that are not covered by any of the previously described scenarios