Proactive Safety for
Pedestrians and Cyclists

EUROPEAN COMMISSION
EIGHTH FRAMEWORK PROGRAMME
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European Commission

The research leading to the results of this work has received funding from the European Community's Eighth Framework Program (Horizon 2020) under grant agreement n° 634149.

GENERAL INTRODUCTION

Accidents involving Vulnerable Road Users are still a very significant issue for road safety. According to the World Health Organisation, pedestrian and cyclist deaths account for more than 25% of all road traffic deaths worldwide. Autonomous Emergency Braking Systems have the potential to improve safety for this group of VRUs.

PROSPECT is a collaborative research project funded by the European Commission under H2020 Grant Agreement nº 634149. The goal of the PROSPECT project is to address this problem by developing the next generation active safety systems for protecting Vulnerable Road Users, with an emphasis on two groups with large shares of fatalities: cyclists and pedestrians. The project will focus specially on urban environments, where the large majority of VRU accidents occur.

Compared to first generation AEB-Pedestrian systems currently on the market, PROSPECT will improve the effectiveness by expanding the scope of scenarios for a better understanding of vehicle-VRU accidents and will improve the overall system performance.

The introduction of a new generation safety system in the market will enhance VRU road safety in 2020-2025, contributing to the 'Vision Zero' objective of no fatalities or serious injuries in road traffic set out in the Transport White Paper. Furthermore, test methodologies and tools shall be considered for 2018 and 2020 Euro NCAP test programmes, supporting the European Commission goal of halving the road toll in the 2011–2020 timeframe.

To derive coherent user requirements towards the development of the next generation proactive safety systems, PROSPECT requires an early and in-depth understanding of the prevalence and underlying characteristics of vehicle-VRU accidents within the different countries of Europe.

Newest available accident data combined with results from naturalistic observations are developed within WP2, which together with the development of HMI guidelines represent key inputs for the system specifications, which form the basis for the system development.

The focus of these activities has been made towards the complex, yet significant needs of cyclists and pedestrians. Know-how about VRU accidents and VRU behaviour is also a pre-requisite for the specification of the relevant real-life conditions in which the safety functions developed in the project need to be tested.

In order to understand the traffic safety issues related to VRUs in all parts of the EU, detailed accident data from several European regions has been analysed within task T2.1, including countries in Central and Eastern Europe. Part A of this deliverable includes the information regarding the results from the accident analysis activities. Human factors and behaviour is a major source of accidents. Naturalistic observations developed within task T2.2 provide additional data that will be used first to better understand drivers and VRUs' behaviour and anticipate potential conflicts that could lead to accidents, by quantifying data on drivers and VRUs' attitude, motion, intent and other features. The information about Naturalistic Observations is provided in part B of this document.

PROSPECT

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EXECUTIVE SUMMARY

This report provides an overview and an in-depth understanding of the characteristics of road traffic crashes involving vehicles (here focussing on passenger cars) and vulnerable road users (VRUs, i.e. pedestrians, cyclists, riders of mopeds, e-bikes or scooters), primarily in European countries.
Several crash databases including international, national and in-depth crash information have been analysed. Among them, the CARE database (Europe), the German, Swedish and Hungarian national road traffic statistics, as well as the in-depth databases IGLAD (Europe), GIDAS (Germany), in-depth data from Pest county (Hungary) and the Volvo Cars Cyclist Accident Database (Sweden). Early investigations have shown that the crashes between passenger cars and pedestrians or cyclists are most frequent in Europe, hence these crashes were investigated in greater detail. Further, this report describes briefly the road safety situation of scooter riders in collisions with passenger cars and crashes between trucks and VRUs.
As the structure of the databases was quite different, not all results for different countries could be compared directly. Nonetheless, trends could be identified from the analysis.
Considering cyclists the highest numbers of fatalities per inhabitants can be observed in countries where cycling is very common and the bicycle is used as a daily transportation means like in The Netherlands and in Denmark. Similar to the observation for pedestrians in former projects, elderly people have the highest risk to get fatally injured as cyclist riders in most countries due to their high vulnerability.
Overall, datasets confirmed that older cyclists suffered more often from higher injury severities compared to younger ones, male cyclists were injured more often than females, higher injury severities (in particular fatal crashes) happened more often on rural roads and that crashes occurred most often in fine weather and daylight conditions.
The in-depth understanding of the crashes included the identification of the most relevant road traffic ‘accident scenarios’ and levels of injury severity sustained as well as the transport modes that represent a higher risk for VRUs.
Within PROSPECT, an ‘Accident Scenario’ is described by the type of road users involved in the accident, their movements (e.g., the motion of the cyclist or pedestrian relative to the vehicle) expressed as ‘accident types’ and further relevant contextual factors like the course of the road, light conditions, weather conditions and view obstruction. The wording ‘Target Scenario’ or ‘Use Case’ is often used to describe ‘target groups’. Within PROSPECT, ‘Target Scenarios’ are equivalent to ‘Use Cases’. They are derived from accident scenarios by adding more detailed information about the road layout, right-of-way, as well as manoeuvre intention of the driver. One accident type can be split into several Use Cases.
Regarding car-to-cyclist crashes, it was concluded to consider five Accident Scenarios: (I) “Car straight on, Cyclist from near-side”, (II) “Car straight on, Cyclist from far-side”, (III) “Car turns”, (IV) “Car and cyclist in longitudinal traffic” and (V) “Others”. Focusing on killed and seriously injured (KSI) cyclists, results for Germany, Hungary and Sweden were similar regarding scenarios (I) and (II); around 42%-52% of all casualties were assigned to these scenarios. However, the results varied a lot between the considered countries for Accident Scenarios III and IV. In particular, Hungary seems to have major issues with cyclists in longitudinal traffic compared to

Germany and Sweden, which could also be caused by infrastructural differences. Focusing on killed cyclists in car-to-cyclist crashes, it can be seen that in all countries the accident scenario IV (longitudinal traffic) had the greatest relative frequency of all accident scenarios ranging from 25-64%. This was linked to the higher car impact speeds observed on rural roads.

Use Cases have been derived from these Accident Scenarios for car-to-cyclist as well as for car-to-pedestrian crashes. Major parts of this work have been published in separate PROSPECT papers and deliverables. Detailed crash analyses in PROSPECT focusing on the causation of crashes could also show that the most common contributing factor to the crashes was “disregarding traffic regulations”, seen for both cyclists and car drivers.

Further results show that the drivers’ task and the orientation of cyclist have an influence on the frequency of collisions. For example, the cyclist violated traffic regulations as the wrong driving direction on a bicycle lane was chosen to cross a road. Potentially, the car driver failed to watch out for this unexpected traffic situation, as the cyclist would have to approach from the other side, and thus, drove into the intersection area hitting the cyclist. The analysis of Hungarian crash data confirmed that the primary reasons of car-to-cyclist crashes were the violation of traffic rules and the delay of action.

Regarding crashes between cars and pedestrians, all databases confirmed that the Accident Scenario 1 “Crossing a straight road from nearside; no obstruction” was ranked highest regarding killed or seriously injured pedestrians, and the Accident Scenario 2 “Crossing a straight road from the offside; no obstruction” was ranked highest regarding all pedestrian injury severities. It became also clear that higher injury severities were seen in all databases in crashes occurring at dark light conditions. The analyses of the German and Hungarian data have also shown the importance of accident scenarios on turning (3&4), longitudinal traffic (7) and reversing (8). As the major scenarios (1, 2 and also 5) were largely covered by previous research activities, the PROSPECT consortium decided to focus on the turning scenario as primary Use Case for car-to-pedestrian crashes.

Finally, for a more complete understanding of the road crash data and to provide input to the benefit estimation task in the project, differences between police-reported and hospital-reported injury severities and the extent of road crashes unreported to the police have been investigated based on Swedish crash data.

It was found that males, persons above 60, and rural traffic environments lead to higher odds for different classifications of injury severity by the police and hospitals. A recent study showed that police and hospitals classified the injury equally for 70% of all observed individuals.

Regarding under-reporting of crashes, there was a higher under-reporting rate found for slight than severe crashes, estimated 54% and 11% respectively. The under-reporting was slightly lower for car-to-pedestrian crashes, estimated 35%, than for car-to-cyclist crashes estimated 38%.

CONTENTS

List of Abbreviations

AEB	Automatic Emergency Braking
AIS	Abbreviated Injury Scale
CADaS	Common Accident Data Set
CARE	Community Database on Accidents on the Roads in Europe
CATS	Cyclist-AEB Testing System
GIDAS	German In-depth Accident Study
GDV	German Insurance Association
iGlad	Initiative for the Global Harmonisation of Accident Data
KSI	Killed or seriously injured
V_CAD	Volvo Cars Accident Database
VRU	Vulnerable Road Users

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1 INTRODUCTION

1.1 THE EU PROJECT PROSPECT

The past decade has seen significant progress on active pedestrian safety, as a result of advances in video and radar technology. In the intelligent vehicle domain, this has recently culminated in the market introduction of first-generation active pedestrian safety systems, which can perform autonomous emergency braking (AEB-PED) in case of critical traffic situations. PROSPECT will significantly improve the effectiveness of active Vulnerable Road User (VRU) safety systems compared to those currently on the market. This will be achieved in two complementary ways: (a) by expanded scope of VRU scenarios addressed and (b) by improved overall system performance.

1.2 OBJECTIVES OF THIS REPORT

The primary goal of the Work Package 2 in PROSPECT is to generate the user requirements for next generation proactive safety systems to support their deployment in vehicles considering the specific needs of VRUs.

The main objective of this report is to provide an overview and in-depth understanding of the characteristics of road traffic crashes involving vehicles (here focus on passenger cars) and VRUs (i.e. pedestrians, cyclists, riders of mopeds, e-bikes, scooters) in European countries.

The in-depth understanding of the crashes include the identification of the most relevant road traffic ‘accident scenarios’ and injury severity levels sustained as well as the transport modes that represent a higher risk for VRUs. This knowledge is used to provide the key starting points in the project and to derive safety strategies.

The identified ‘accident scenarios’ will be abstracted into relevant ‘target scenarios’ or ‘use cases’, which are essential for the development of systems as well as for the evaluation of the system performance later in the project. Thus, this report provides mainly input for Work Package 3 where the ‘use cases’ will finally be transferred into ‘target scenarios’ for the system development and ‘test scenarios’.

1.3 STRUCTURE OF THIS DELIVERABLE

This report provides firstly a project and literature review of most relevant PROSPECT familiar activities on crash data analysis and the derivation of Use Cases. Chapter 3 describes the method of the performed crash data analysis including definitions for the road users addressed in this report as well as explains the PROSPECT Accident Scenarios. Chapter 4 provides a general view on the current road safety of Vulnerable Road Users, followed by Chapter 5 that focuses on car-to-cyclist crashes and Chapter 6 looking at car-to-pedestrian crashes. In addition Chapters 7 and 8 report about car-to-scooter crashes and truck-to-VRU crashes, respectively. As injury misclassification and underreporting issues need to be mentioned in the context of Vulnerable Road Users Chapter 9 provides insight to this research area. Finally, Chapters 10 and 11 provide a summary of the work performed as well as discuss the results.

2 PROJECT AND LITERATURE REVIEW

2.1 PREVIOUS EUROPEAN PROJECTS

2.1.1 FP 7 AsPeCSS

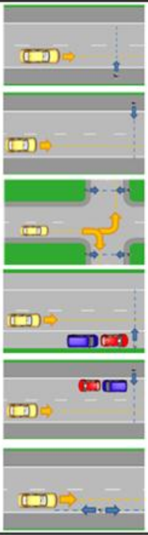
The overall purpose of the AsPeCSS project ("Assessment methodologies for forward looking Integrated Pedestrian and further extension to Cyclists Safety", FP7, SST.2011.RTD-1 GA No. 285106) was to contribute towards improving the protection of vulnerable road users, in particular pedestrians and also cyclists, by developing harmonised test and assessment procedures for forward-looking integrated pedestrian safety systems.

A first estimation for accident scenarios was done by taking advantage of previous work and supplementing this with additional information using current data from Germany and the GB to identify severe crashes between passenger cars and pedestrians. Taking results of previous projects into account and performing additional detailed analysis, available literature was reviewed and summarised into preliminary accident scenarios for AsPeCSS [1].

Pedestrians:

Based on a literature review of results of previous projects (APROSYS, AEB Test Group, vFSS) and further detailed accident data analysis, seven accident scenarios could be identified to be most representative for car-to-pedestrian crashes, see Figure 1. These were compiled mainly by the analysis of German, British and French national accident data for different injury severity levels (slightly, seriously injured and killed pedestrians as well as regarding all pedestrian casualties) and light conditions ('day' and 'dark'). The seven preliminary accident scenarios were confirmed to be relevant for Great Britain and Germany and weighting factors were obtained for each of them. As these weighting factors for accident scenarios 3 and 4 were small (and thus their relevance was low) both were joined together. The final AsPeCSS accident scenarios with weighting factors for killed and seriously injured (KSI) pedestrian casualties were given for GB, Germany and the average for both, and for fatally injured pedestrians only, see Figure 1.

The result of this basic analysis was that more often, collisions with a car in dark light conditions ended up with serious injuries or death of the pedestrian. Figure 1 shows also randomly chosen accident scenes at night from the GIDAS database. Since a majority of accidents occur in urban areas, there was almost never complete darkness, but always a diffuse illumination by streetlights, traffic lights, street furniture or reflections on the wet roadway and / or bright lights from the headlamps. These driver demanding light conditions often occurred combined with obstructions, glare, rain, reflections and thus led to a more complex situation.



Accident Scenarios	Light condition	KSI (84%)	Fatalities (83%)
	Day Night	**15** **10**	8 15
	Day Night	8 12	**7** **23**
	Day Night	5 3	3 1
	Day Night	7 2	1 3
	Day Night	5 2	1 2
	Day Night	8 7	5 14
TOTAL	Day Night	48 36	25 58

National accident data from Germany and GB (averaged) of years 2008-2010

ID	Accident Scenario Description
1 A/B	Crossing straight road, nearside, no obstruction, day / dark
2 A/B	Crossing straight road, offside, no obstruction, day / dark
3 A/B	Crossing at junction, near- or offside, vehicle turning across traffic, day / dark
4 A/B	Crossing at junction, near- or offside, vehicle not turning across traffic, day / dark
5 A/B	Crossing straight road, nearside, obstruction, day / dark
6 A/B	Crossing straight road, offside, obstruction, day / dark
7 A/B	Along straight road, no obstruction, day / dark

Figure 1: Selected results from AsPeCSS accident data analysis; AsPeCSS' Accident Scenarios of car-to-pedestrian crashes in day (A) and dark light (B) conditions (national accident data from GB and Germany of years 2008-2010 regarding killed and seriously injured (KSI) pedestrians) [2]

In summary, accident scenarios 1, 2 and 7 were found as the three highest weighted scenarios for car-to-pedestrian crash configurations (sum of weights concerning KSI is 60% and concerning fatalities is 72%) that may potentially be addressed by forward-looking integrated pedestrian safety systems. However, accident scenarios 3&4, 5 and 6 (KSI: 24%, Fatalities: 11%) also have a significant weighting regarding future active pedestrian protection systems. About 80% of the car-to-pedestrian crashes could be assigned to the seven AsPeCSS accident scenarios. Remaining percentages include other car-to-pedestrian crash configurations, such as crashes while parking or reversing.

Cyclists:

Also within AsPeCSS, car-to-bicyclist accidents have been investigated for the United Kingdom (UK) and the Netherlands. The main differences between car-to-bicyclist and car-to-pedestrian accidents have been pointed out and general test scenarios for cyclist safety systems have been proposed [3].

With regard to common accident scenarios for car-to-cyclist crashes, crossing accidents with both opponents travelling straight forward were very common. Situations where the car hits the cyclist while turning either to the right or to the left were considered also to be from high importance. Longitudinal accidents with both, car as well as cyclist travelling in the same direction are quite common in the UK (and other EU countries), however less prominent in the Netherlands.

In comparison with pedestrians, it can be seen that pedestrians move relatively slow with velocities between roughly 3 km/h and 8 km/h, whereas bicyclists are much faster and can reach speeds of up to 50 km/h (race bike). Note: crash speeds may differ from these reachable speeds.
While in most cases pedestrians contacted with their heads on the car's bonnet or the lower part of the windscreen, cyclists tend to hit higher.
Further, it has to be noted that a significant amount of cyclists got injured in crashes involving no other crash partner or involving a crash partner other than a passenger car.

2.1.2 FP 6 APROSYS

The European project on "Advanced Protection Systems" (APROSYS, 6th Framework Programme) was completed in 2009. One of the main aims was to develop a generic evaluation method for the assessment of adaptive safety devices that employ pre-crash information from vehicle sensor systems. The generic APROSYS method used real-world accident scenarios to develop system-specific test conditions. The method was followed within the project to develop a set of specific tests for an advanced pedestrian safety system. This was used to evaluate the generic method and identify any refinements. As part of this process, de Lange [4] presented accident scenarios for pre-crash pedestrian protection systems. These were derived from an analysis of the GIDAS accident database, which provided 649 front impact collisions with a pedestrian injury level of MAIS≥2. These collisions were assumed to be representative (of the situation in Germany) and were used for further analysis by de Lange. Figure 2 shows the most common accident scenarios derived by de Lange in the APROSYS project.

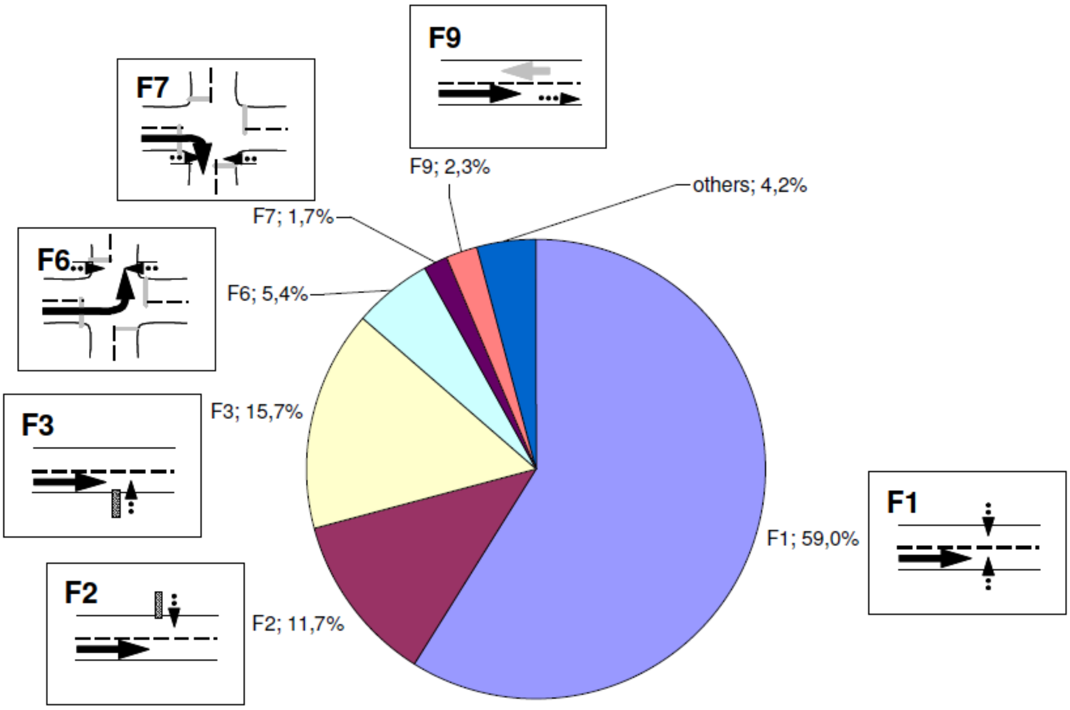
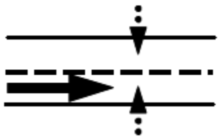
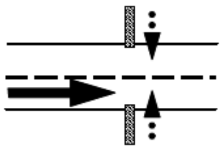
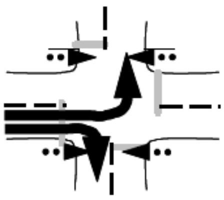


Figure 2: Summary of car-to-pedestrian accident scenarios from APROSYS [4]

The initial scenarios shown in Figure 2 were developed further into three main groups. These groups are shown in Table 1 together with the fourth group 'others'. A range for certain parameters related to the collision is also shown in the table. A more detailed analysis of the three main scenarios was carried out by de Lange, but it did not provide mean or median values. Nevertheless, charts were provided in an appendix, which can be used to highlight trends in pedestrian collisions.

Table 1: APROSYS accident scenario groups and their relevance [4]

Scenario	Schematic view	Relevance	Remark
1. Crossing pedestrian on straight road		59%	<u>Scenario F1</u> Initial speed = 50±20 km/h Impact speed = 35^{+20}_{-10} km/h Pedestrian speed = $5.4^{+10.8}_{-3.6}$ km/h Light = day, night Weather = dry
2. Crossing pedestrian on straight road with occlusion		27.4%	<u>Scenarios F2 and F3</u> Initial speed = 45±25 km/h Impact speed = 35±20 km/h Pedestrian speed = $5.4^{+10.8}_{-3.6}$ km/h Light = day Weather = dry
3. Crossing pedestrian after turn off		7.1%	<u>Scenarios F6 and F7</u> Initial speed = 20±10 km/h Impact speed = 20^{+10}_{-15} km/h Pedestrian speed = $5.4^{+10.8}_{-3.6}$ km/h Light = day, night Weather = dry
4. Others	-	6.5%	

2.1.3 CATS

In anticipation of the introduction of cyclist-AEB systems and their corresponding consumer tests, a consortium (CATS: Cyclist-AEB Testing System) was formed to prepare a test setup and test protocol that covers the most relevant accident scenarios for Cyclist-AEB systems and to develop the test tools necessary for such tests. Data on accidents between cyclists and passenger cars has been collected covering as many different EU countries as possible. In addition to the CARE database, accident data has been collected specifically for Belgium, France, Germany, Hungary, Italy, the Netherlands, Spain, Sweden and the United Kingdom. Some data sources did not provide sufficient information about the accident configuration, and for this reason, data from Belgium, Spain and Hungary were not included. [5]

CATS highlighted that the overall number of fatalities in road traffic accidents in Europe decreased, but the number of fatalities among cyclists did not follow this trend with the same rate. The project identified the most relevant scenarios for car-to-cyclist collisions using the approach to analyze accident type classifications of each available database and to assign the derived cases with a severity of at least being seriously injured to 10 pre-defined accident scenarios (plus one scenario including the remaining crashes). Hereby, the road layout was removed, basic trajectories of the cyclist and car were considered and the cyclist could be either on the road or on a bicycle lane. The result can be seen in Figure 3.

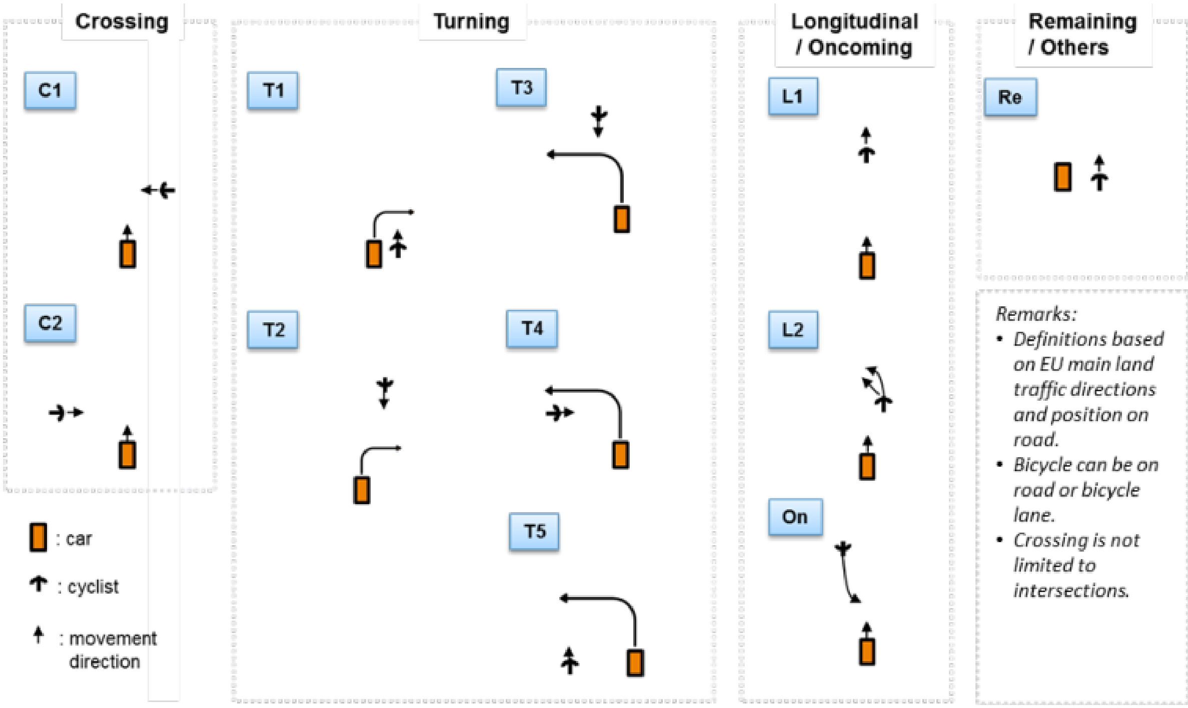
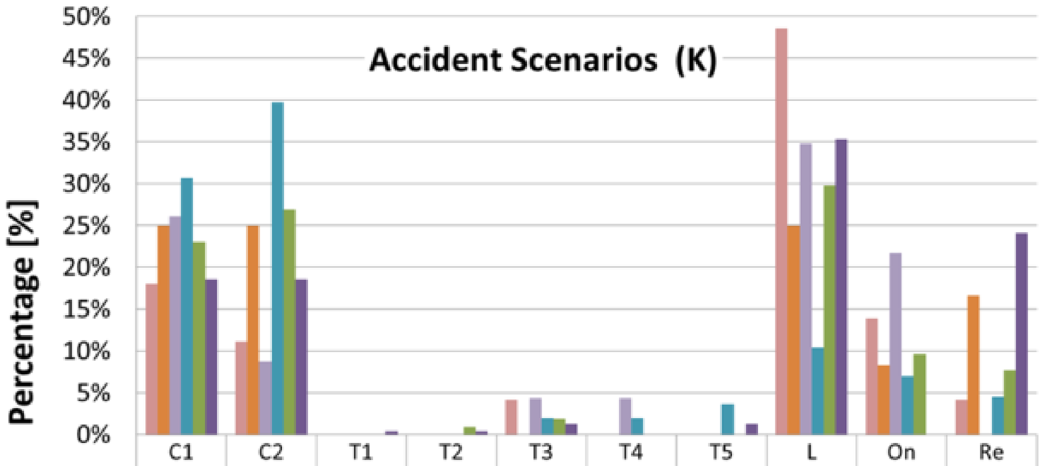


Figure 3: Overview of distinguished car-to-cyclist scenarios [5]

The CATS analyses showed that scenarios in which the cyclist crossed the road in an approximately perpendicular direction towards the passenger car were most relevant in all studied countries. Longitudinal scenarios in which car and cyclist were driving in the same direction and the cyclist was hit at the rear end by the car also covered a significant portion of serious accidents. Figure 4 shows the distribution of fatally injured cyclists in crashes with passenger cars over nine accident scenarios (plus the accident scenario ‘others’) analyzed for six different European countries.



	C1	C2	T1	T2	T3	T4	T5	L	On	Re
France	18%	11%	0%	0%	4%	0%	0%	49%	14%	4%
Germany	25%	25%	0%	0%	0%	0%	0%	25%	8%	17%
Italy	26%	9%	0%	0%	4%	4%	0%	35%	22%	0%
Netherlands	31%	40%	0%	0%	2%	2%	4%	10%	7%	5%
Sweden	23%	27%	0%	1%	2%	0%	0%	30%	10%	8%
UK	19%	19%	0%	0%	1%	0%	1%	35%	0%	24%

Figure 4: Distribution of fatally injured cyclists over 10 accident scenarios for six European countries [5]

2.1.4 Analysis of the German Insurance Association (GDV)

The structure of the official German statistics does not permit in-depth analyses to be carried out for the entire country, so the UDV (German Insurers Accident Research) built up a set of representative case material in order to examine crashes between cars and cyclists in more detail and to derive effective measures to improve the safety of cyclists [6]. GDV's database (UDB) is based on the contents of insurers' claim files and the data collected is conditioned for interdisciplinary purposes to facilitate research in the fields of vehicle safety, transportation infrastructure and behaviour on the roads. The data analyzed contained cases from years 2002 to 2010 which were covered by motor third-party insurance and involved injury and damage costs of at least 15,000 €.

The cyclist accident material consisted of a total of 407 accidents between cars and cyclists. In GDV's study it was described how and under what circumstances cyclist-to-car accidents occur, the maximum levels of injury severity sustained by the cyclists and the impact categories that occurred most frequently. In 84% of the cases, the impact between the bicycle and the car occurred at the front part of the vehicle (the front of the car plus the left- and right-hand front wings). In 42% of these cases, the bicycle was coming from the right (from the driver's point of view), and in 34% of the cases from the left. Further, 13% of the cyclists approached longitudinally against and 11% longitudinally in the car's driving direction.

Moreover, the analysis of the cyclist-to-car crashes revealed that the "average speed of the cars by impact constellation" was 24 km/h. The speed of the cyclists often could not be derived from the available documents. However, it is known from the UDV's measurements of the speeds of 20,000 cyclists that they travel at an average speed of 18.6 km/h.

When analyzing the most frequent crash constellations four typical scenarios A-D were identified. Category A - "The car is travelling straight ahead or turning left or right, and the bicycle is coming from the right" - was most prominent, accounting for 42% of all considered cases. Within this category, three sub-scenarios were identified as: A1 "The car is turning left, and the bicycle is coming from the right", A2 "The car is travelling straight ahead, and the bicycle is coming from the right" and A3 "The car is turning right, and the bicycle is coming from the right", see Figure 5. The lower part of Figure 5 sets out distinct situations for each of the three accident scenarios (A1, A2 and A3) showing the circumstances of the cyclist-to-car collisions in more detail. These 'distinct situations' can be already understood as Use Cases, see Section 3.6.

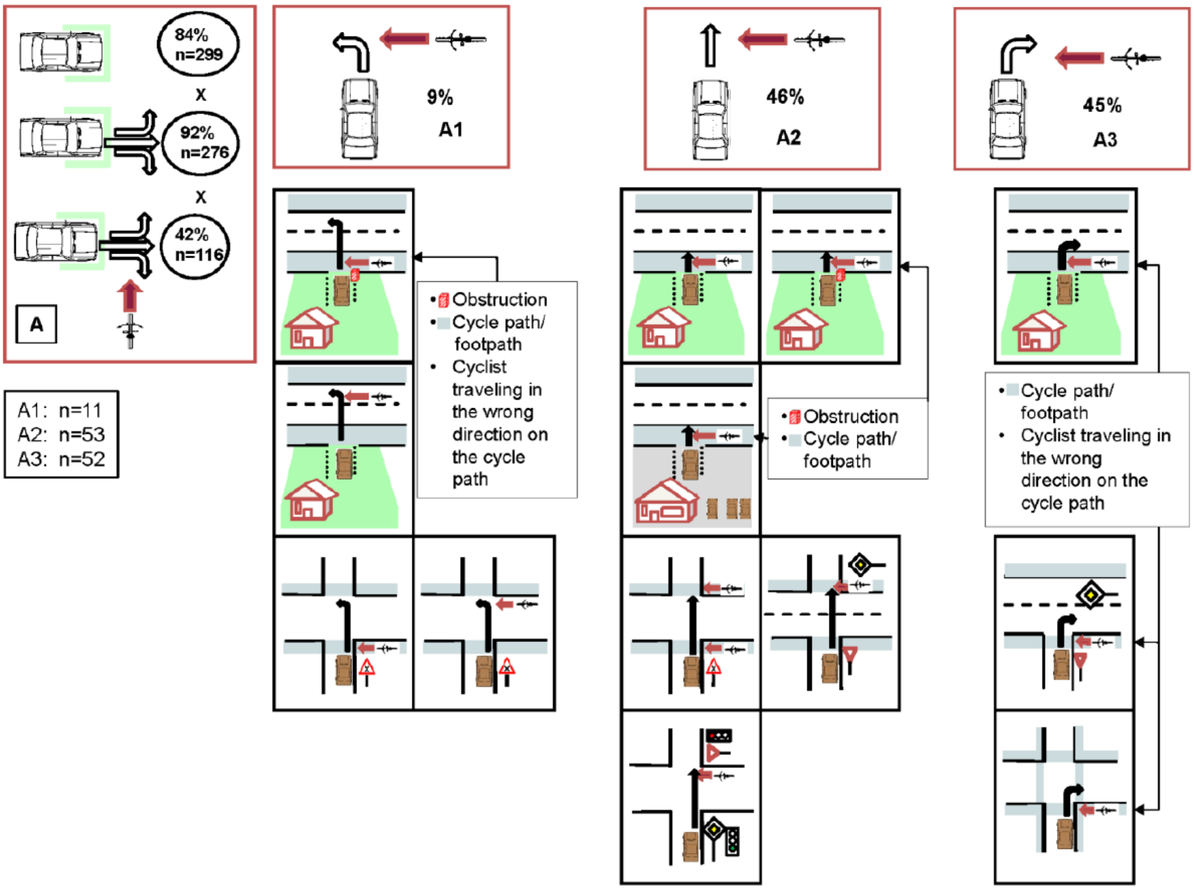


Figure 5: GDV analysis - Distribution of accident scenarios A1 - A3 and illustration of typical cases [6]

Overall, the three most important scenarios were "car travelling straight ahead, cyclist coming from the right" (15%, scenario A2), "car turning right, cyclist coming from the right" (15%) and "car travelling straight ahead, cyclist coming from the left" (12%). Another key finding is that the collisions in these three scenarios often (in 47% to 85% of the cases) took place at the entries to or exits from properties or parking lots and at junctions.

2.2 SCIENTIFIC PAPERS

It is estimated that over 500,000 pedestrians and bicyclist are killed annually in traffic worldwide [7]. Approximately 27% of all fatalities annually in European Union are pedestrians and bicyclists (6,004 and 1,994 respectively) [8]. In urban areas in the EU [9], pedestrians and bicyclists contribute to the half of the traffic fatalities.

More details regarding car-to-cyclist crashes are investigated in several other studies. Fredriksson et al [10] found that four scenarios represented 70% of all crashes for both AIS2+ and fatally injured bicyclists in Sweden. The fatal cyclist crashes from the Swedish Transport Administration (Trafikverket) in-depth database were analysed in detail. This data includes comprehensive on-site information of road and surrounding conditions, detailed vehicle data including photo documentation and all available medical and forensic records about the casualty. 104 fatal cases met the inclusion criteria within the time period 2005-2014 (no information available about total numbers within this time frame). AIS2+ accidents were obtained from STRADA which includes both police and emergency hospital records. Fatalities were excluded in this analysis. The sampling period was 1 January 2010 - 31 January 2014 which resulted in a total number of AIS1+ crashes of 1,569 and a total number of AIS2+ crashes of 552 (this is the number of cyclists not specifying if there were several cyclists on the same bike). Each case in STRADA includes a simplified sketch and an accident summary. From the variables mentioned above, the sketch, the text and the CATS scenarios were coded manually for 435 crashes (79% of all AIS2+). The scenarios that represented 70% of all crashes for both AIS2+ and fatally injured bicyclists were: 1) car driving straight, bicyclist crossing from left, daylight and dry conditions, urban area (AIS2+ and fatal); 2) car driving straight, bicyclist crossing from right, daylight and dry conditions, urban area (AIS2+ and fatal); 3) bicyclist turning in front of passing car in same lane, daylight and dry conditions, rural areas (fatal) and car turning left and bicyclist crossing the road the car intended to turn into from right, daylight and dry conditions, urban junctions (AIS2+).

These results differ from car-to-pedestrian crashes which occur more frequently in dark and rainy conditions [11] [12]. Another difference is that car-to-cyclist crashes occur at a higher rate at junctions compared to car-to-pedestrian crashes. Missing in the Swedish study by Fredriksson et al. [10] are the travelling and impact speeds of the bicyclist and the car and these need to be further studied from other databases. The results were similar to the ones from the CATS project, which studied data from six countries in Europe [5], see also Section 2.1.3. CATS did not consider the road layout and considered basic trajectories derived from accident types only. These accident types defined the conflict triggering event but do not always give information about the turning intention of the car.

Other analysis that includes the road layout in the definition of accident scenarios, for Swedish data, is reported in [13]. The data within the study came from 'If' insurance company (collection period 2005-2012), which insures about 25% of all cars in Sweden including many different makes and models, but only 50% of these accidents are covered in the official data reported by the police in Sweden (STRADA). On the other hand, 'If' insurance data is more detailed compared to both hospital and police reported data and more detailed accident scenarios are defined.

A total of 32 detailed scenarios were defined including both cyclist riding on the road and on bicycle path, separated from the roadway.

More specifically, the frequency from the crossing scenarios were: road crossing, cyclist came from a bicycle path (53.4%); road crossing, cyclist rides on the road (21.5%); driveway crossing, cyclist came from a bicycle path (15%); driveway crossing, cyclist rides on the road 4.8%; cyclist rides in the roundabout (4.8%). Note that driveway in the study was defined as entrance/exit to parking lot, petrol station, path to private garage, house etc. The scenario in which cyclist and driver shared the same roadway and moved in the same or opposite direction represented 10.7% of all collisions.

Concerning injury severities, the risk of a severe to fatal injury (Maximum AIS level 3 or greater, MAIS3+) was found to be significantly higher for collisions in the same/opposite direction situations compared to crossing situations ($\chi^2(1) = 23.1$, $p < .001$). Moderate injuries (MAIS2) were more frequent in the crossing situations, 17%, compared to 10% in the same/opposite direction.

Comparing road crossing situations, higher MAIS3+ risk was found for the cyclist riding on the road than riding on a bicycle path, but this was not statistically significant ($\chi^2(1) = 2.7$, $p = .100$). The number of fatal injuries was highest in the same/opposite direction situation, although the total number of crossing situation accidents was more than seven times higher. In the same/opposite direction accident situations, the median impact speed was higher compared to the crossing situations: in 50% of the cases the impact speed was below 22km/h vs. 7km/h, respectively. In the same/opposite situations 25% of the situations occurred with a speed limit higher than 50km/h. In crossing situations 50% of the drivers reported that they did not see the cyclist before the collision occurred in comparison to same/opposite direction situations in which only 30% of the drivers stated not to have seen the cyclist before the collision.

In addition to the cyclist, other VRU are also studied using V_PAD database which contains extensive information about the pedestrian accidents in Sweden involving Volvo Cars [14]. The results from the study show that 85% of the pedestrians were impacted at speeds below 40 km/h. The most frequent moving patterns for adult (15-64 years old) pedestrians were "MP2-Car moving forward and pedestrian crossing from the right" (34.7%), followed by "MP1-Car moving forward and pedestrian crossing from the left" (21.4%) and "MP10-Car moving rearward" (18.4%). For the junior (up to 14 years old) pedestrian accidents the frequency differs from the adult group: the most frequent pattern is MP2 (58.8%), followed by MP1 (20.6%) and MP10 (11.8%). Senior (65 years or older) pedestrians on the other hand were mostly involved in crashes in which the car was reversing – MP10 (37%), followed by MP2 (26%), and MP1 (16%). When considering the impact speed it was found that for car-moving-forward accidents, the mean impact speed is 30.3 km/h (S.D. 20.7) for the whole group (n=186) and 33.3 km/h (S.D. 20.0) for pedestrians sustaining a MAIS2+ injury (n=99).

The VRU fatality risk as a function of impact speed is of particular importance in the estimation of the potential benefits of new safety countermeasures. These functions have been analyzed previously in [11], [12] and [15]. Pedestrian risk curves for fatal and severe injury (AIS3+F) are provided in [11] and [12] respectively: P_{fatal} =

1/(1+exp(6.9-0.090v)), P_{severe} = 1/(1+exp(4.6-0.078v)), where v is the car impact speed in km/h. Risk curves for bicyclists struck by the front of a car or van using weighted GIDAS data are provided in [12]: P_{fatal} = 1/(1+exp(8.8-0.098v)), where v is the car impact speed in km/h. The risk curve for severe or fatal (AIS3+F) injury are P_{severe} = 1/(1+exp(4.7-0.065v)). The risk functions are derived by using the data for ages above 15.

The analysis of accident data on EU level is found in two reports by the EU [8] [16]. The following statistics are reported by analyzing the CARE database for bicyclist and pedestrian fatalities. Bicycle fatalities made up 6.8% of the total number of road accident fatalities in 2010 in the EU-20 countries. Pedestrian fatalities in 2010 EU-24, made up 20% of all fatalities.

In Hungary, there is a forensic expert training on crash analysis only at the Faculty of Transportation Engineering and Vehicle Engineering (KJK) of the Budapest University of Technology and Economics (BME). With that, several publications on crashes involving VRU are available.

The statistical analysis of car-to-pedestrian and car-to-cyclist accidents was in the focus of the study from Glász and Juhász [17]. Firstly, main crash causes and circumstances which led to car-to-pedestrian and car-to-cyclist accidents in Hungary were statistically investigated. The basis of the research was raw accident data (in chart form) provided by the Hungarian Central Statistical Office (KSH). This data was systematized by a data managing system and processed. 56.6% of crashes involving cyclists were car-to-cyclist crashes and 66.1% of crashes involving pedestrians were car-to-pedestrian crashes. Most of the analysed accidents occurred in built-up areas (92.1%). Nonetheless, crashes that occurred on the rural road can’t be ignored, because these accidents have more serious outcome due to the typically higher impact speed: 44.9% of all analysed fatal accidents occurred on the open road. Despite the fact that the number of car-to-pedestrian accidents are typically 10-20% lower than the car-to-cyclist accidents, fatal cases in car-to-pedestrian accidents happened twice as much.

In recent years, because of the significantly increased cyclist traffic in Budapest the validity of the “Safety in Numbers” theory was examined in [18]. Between 2011-2014, although the cyclist traffic significantly increased the number of accidents has risen but to a smaller degree.

The examination of cyclist accidents in Budapest included the types, the primary reason and the supposed party of fault (causer) of the accident, shown in [19]. The party of fault of cyclist crashes were mostly the cyclists (54%) followed by car drivers (37%) and pedestrians (3%) besides other participants (6%).

Investigating the age of cyclists involved in road accidents, it could be seen that in all age groups men suffer more often from fatal injuries compared to women. The number of accident distribution by age is the same regarding both men and women. The maximum number of accidents happened with a cyclist rider age of 60 compared to other age groups. The injury severity is the highest between the ages 41 and 75 whereas the injury severity increases sharply from the ages 56-60 onwards [20].

The investigation of pedestrian behaviour was based on a questionnaire of 500 pedestrians [21]. According to the answers 54 % of pedestrians never crossed the road at the red traffic light, 37% did sometimes, when in a hurry and 9% violated frequently the rule. Mostly pedestrians between the ages 17-25 violated the rule. Two third of the respondents (65%) knew that pedestrians have priority at a zebra crossing, compared to one fifth of the pedestrians having only priority at zebra crossing with traffic lights. Only 20% of the pedestrians were aware that they have priority at an intersection when the car is turning. 81% of the pedestrians answered to always look around when they start crossing a road, 17% usually look around and 2% cross without looking at all. More than half (60%) of the pedestrians asked usually felt safe at a zebra crossing, but more than one tenth (12%) never felt safe at a zebra crossing [22].

The SIMPAS model used to analyse the human actors' behaviour of road traffic is based on fuzzy logic and neural network theory [23]. This SIMPAS model aims, among others, to support collecting data of actors' behaviour, accident risk (real and near miss) and characteristics of traffic flow. The principle of the SIMPAS model is how momentary traffic situations develop according to interactions of actors. Traffic actors communicate with each other and make their own decision based on their personality and the information coming from the environment. Analyses showed that 63% of all considered road crashes were caused by pedestrians. Further, it was shown that the innocent rate increases parallel with the pedestrian's age. The majority of accidents caused by pedestrians happens because of sudden, careless step to the road or behind of a parking vehicle, at the red traffic light or crossing at a forbidden area.

3 METHOD AND APPROACH OF CRASH DATA ANALYSIS

3.1 FOCUS OF THE ANALYSES

The focus of the project and this report is on crashes with two participants. Regarding the injury severity of the vulnerable road users two groups were considered: first “slightly, seriously injured and killed VRU” and second “killed and seriously injured (KSI) VRU”.

As result of the discussions within the entire consortium, Table 2 shows the priorities for accident data investigation set within the Task 2.1 activities that go along with the amount of information gathered. It was decided to focus on crashes with exactly two participants as this allowed to gain more precise results than including crashes with three or more participants and unclear interactions. Further, crashes with two participants represent the majority of cases, see Section 3.4

Table 2: Priorities for accident data analysis based on crashes with two crash participants

against	Car	Truck
Cyclist	1st priority	General statistics
Pedestrian	2nd priority	General statistics
Pedelec rider	3rd priority	General statistics
Scooter / Moped rider	4th priority	General statistics

3.2 DESCRIPTION OF ACCIDENT DATABASES

In order to get a current comprehensive overview on the accident situation of vulnerable road users several databases from various countries have been analysed. This included official road accident data sources on European and national level and also in-depth accident databases.

3.2.1 European databases (IRTAD / CARE)

IRTAD - International Road Traffic and Accident Database – Source: IRTAD/ITF

In 1988, the OECD Road Transport Research Programme established the International Road Traffic and Accident Database (IRTAD) as a mechanism for providing an aggregated database, in which international accident and casualty as well as exposure data are collected on a continuous basis. The ambition of IRTAD is to include as many countries as possible and to build and maintain a high quality database on road safety information.

Coverage
The database includes aggregated data on injury accidents, road fatalities, injured and hospitalised road users, as well as relevant exposure data, in relation to factors such as population, motor vehicle fleet, road network length, vehicle-kilometres travelled and seatbelt wearing rates from 31 countries, covering every year since 1970. Key road safety indicators are compiled on a monthly basis. Data on serious injuries based on MAIS3+ definitions are being progressively included.

The database includes more than 500 data items, aggregated by country and year and shows up-to-date accident and relevant exposure data, including:

- Injury accidents classified by road network;
- Road deaths by road usage and age, by gender and age or by road network;
- Car fatalities by driver/passengers and by age;
- Hospitalised road users by road usage, age groups or road network;
- Accident involvement by road user type (e.g. HGVs, LGVs) and associated casualty data;
- Risk indicators: fatalities, hospitalised or injury accidents related to population or kilometrage figures;
- Monthly accident data (three key indicators);
- Population figures by age groups;
- Vehicle population by vehicle types;
- Network length classified by road network;
- Kilometrage classified by road network or vehicles;
- Passenger kilometrage by transport mode;
- seat belt wearing rates of car drivers by road network;
- Area of state.

The IRTAD database includes accident and traffic data and other safety indicators for 40 countries: Argentina, Australia, Austria, Belgium, Cambodia, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Jamaica, Japan, Korea, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States.

Course of reporting
Data in IRTAD comes directly from relevant national data providers in member countries. The data are provided in a common format, based on definitions developed and agreed by the IRTAD Group. This requires a clear understanding of national definitions in order to enhance international comparability and, where needed, the use of an appropriate correction factor.
All IRTAD members have full access to the online IRTAD Database.

CARE - Community Database on Accidents on the Roads in Europe

CARE is a Community database on road accidents resulting in death or injury (no statistics on damage - only accidents). The major difference between CARE and most other existing international databases is the high level of disaggregation, i.e. CARE comprises detailed data on individual accidents as collected by the Member

States. The purpose of CARE system is to provide a powerful tool which would make it possible to identify and quantify road safety problems throughout the European roads, evaluate the efficiency of road safety measures, determine the relevance of Community actions and facilitate the exchange of experience in this field.

Legal Basis

The Council decided on 30 November 1993 the creation of a Community database on road accidents (Council Decision 93/704/EC, Oj No L329 of 30.12.1993, pp. 63-65). National data sets should be integrated into the CARE database in their original national structure and definitions, with confidential data blanked out. The Commission provides a framework of transformation rules allowing CARE to provide compatible data.

Coverage

The CARE database comprises detailed data on individual accidents as collected by the Member States (all EU-28 countries plus Iceland, Liechtenstein, Norway and Switzerland), using a flexible data structure.

Course of reporting

Disaggregated accident data is provided by the member states due to their national accident database. In 2012 the CADaS-Protocol (Common Accident Data Set) was introduced and can be implemented by the member states on a voluntary basis. The transformation of the national accident data (based on the CADaS protocol) will be performed at the national level and the derived CADaS variables and values will be transmitted to the EC, where they will be included in a more automatic way into the CARE database. This process will allow for more common variables and values but also for higher quality, given that the national authorities better perceive any particularities related to national data collection, thus they can better identify the interrelation between the collected and the CADaS variables. Thus, progressively, more and more common road accident data from the various countries will be available in a uniform format.

CADaS-Structure

The CARE database currently contains 55 common road accident variables in CADaS. The CADaS variables are divided into four basic categories. The category in which each variable is included can be identified by a unique letter (code) at the beginning of the name of the respective variable. The categories and the relevant codes used to describe each category are the following:
A, for Accident related variables,
R, for Road related variables,
U, for Traffic Unit (vehicle and pedestrian) related variables,
P, for Person related variables

Several variables include two distinct types of values, referring to different level of detail:

1. Detailed values: concern information at the highest level of detail.
2. Alternative values: concern information at a more aggregate level of detail, when more detailed values are not available.

Alternative values do not differ from detailed values apart from their level of detail. These values are complementary and can be used when more detailed data are not available (for example concerning the “Traffic Unit type” variable, if a country does not collect the values “car” and “taxi” separately, it can provide this information through the “car or taxi” alternative value).

The CARE database contains the number of accidents, road users involved and casualties as they are reported in the national statistics. Due to comparability the number of fatally injured and the number of seriously injured as they are reported in the several national statistics are corrected by correction factors to provide comparable numbers of fatalities and seriously injured (limited comparability) due to the following definitions:

- Fatally Injured (at 30 days): Total number of persons fatally injured corrected by correction factors when needed. Death within 30 days of the road accident, confirmed suicide and natural death are not included.
- Seriously Injured (at 30 days): Total number of persons seriously injured corrected by correction factors when needed. Injured (although not killed) in the road accident and hospitalized at least 24 hours.

3.2.2 National databases

DESTATIS - German Official Road Accident Data

Legal basis
The legal basis for the German Official Road Accident Statistic is the law on the statistics on road traffic accidents. Pursuant to this, federal statistics are compiled on accidents due to vehicular traffic on public roads or places, with persons killed or injured or involving material damage.

Coverage
According to the law, the police authorities whose officers attended the accident are liable to report. This implies that the statistics cover only those accidents which were reported to the police. These are primarily accidents with serious consequences. Especially traffic accidents involving only material damage or slight personal injuries are to a relatively large extent not reported to the police. Pursuant to Art. 1 of the Law on Statistics of Road Traffic Accidents only those accidents are recorded which are due to vehicular traffic, i.e. accidents involving only pedestrians are not covered by these statistics.

Course of reporting
Survey records for the statistics of road traffic accidents are the copies of the standard traffic accident notices (Verkehrsunfallanzeige) as used for the entire Federal Republic, which are completed by the police officers attending the accident. After its transfer to data recording media, the information included in the accident notices is tabulated on a monthly and annual basis at the statistical offices of the federal states ("Bundesländer"). The federal states (Bundesländer) results are compiled to the federal result.

Accidents

Accidents are subdivided the following:

- traffic accidents involving personal injury
- severe accidents involving material damage
- other accidents under the influence of intoxicating substances and
- other accidents involving material damage.

The criterion for the allocation is in each case the most serious consequence of the accident. Accidents with personal injury imply that irrespective of the amount of the material damage persons were killed or injured. Severe accidents involving material damage are accidents whose cause of accident is an irregularity or an offence concerning participation in road traffic. At the same time the motor vehicle has to be towed away from the accident scene because of a damage (motor vehicle not ready to drive). This includes accidents under the influence of intoxicating substances. With full details recorded are all other accidents with material damage where a road user involved was under the influence of intoxicating substances (other accidents under the influence of alcohol or other intoxicating substances). All other accidents involving material damage are only numerically recorded by the locality of accidents (in town/village, out of town/village, on motorways).

For each accident registered in the official German Road Accident Statistic detailed information is available on:

- Time and place of accident, road class
- Light conditions
- Type and kind of accident
- Number of road users involved
- Consequences of accident
- Cause of accident (weather condition, road surface condition, obstacles)

Vehicles and pedestrians involved in the accident

Accident involved vehicles and pedestrians are recorded even if the vehicle driver or the pedestrian is not injured in the accident. For involved road users detailed information is available on:

- Age and sex
- Blood alcohol content
- Cause of accident (improper action of road user and technical defects)
- Means of transport
- Age and technical specification of motorized vehicles

Casualties

Casualties due to road traffic accidents are subdivided in:

Fatalities:	all persons who died within 30 days as a result of the accident
Severely injured:	all persons who were immediately taken to hospital for inpatient treatment (of at least 24 hours)
Slightly injured:	all other injured persons

For casualties information is available on age, sex, consequence of accident and if the person was a driver or a passenger.

STRADA – Swedish TRaffic Accident Data Acquisition

STRADA is a national information system in Sweden which contains all police reported road crashes and emergency hospital admission data related to road crashes. The police and hospital reports are linked based on the persons' civic number, the crash time and the crash location. The Swedish Transport Agency manages the data collection and storage. Since 2003 the Swedish national statistics is based on the police records stored in STRADA. In 2016 all emergency hospitals are linked to STRADA and the database can thereby be considered representative for Swedish conditions even with respect to injury data. By law [24], the Swedish police is obliged to report every road crash with at least one personal injury while hospitals report data voluntarily. The hospital records are collected from emergency hospitals and consist of information on person, hospital care and specific injuries sustained.

The police reports crashes including at least one fatality within five days and crashes with other severities within seven days. If a road traffic accident involving personal injury has occurred, the police authority shall report it to the transport agency as soon as possible and no later than seven days after the police authority learned of the accident. If a death has occurred as a result of a road traffic accident, the police authority shall report it to the transport agency as soon as possible and not later than five days after the police authority was informed of the death. Reporting shall be traffic accidents where someone died in the accident or as a result of an accident within 30 days of the accident [24].

The definition of a road crash is provided in the guidelines by the Swedish Transport Agency to the police: "A road crash is a crash which occurs in traffic on a road, involves at least one vehicle in motion and involves at least one personal injury" [25]. A vehicle is defined as a "device on wheels, continuous track, skids or similar means which is mainly meant to be driven on the ground and does not run on rails. Vehicles are differentiated into motor vehicles, trailers, side-cars, bikes, a vehicle towed by horses and other vehicles" [26].

Casualties due to road crashes are subdivided in:

- Fatalities: death within 30 days as a result of the crash.
- Severely injured: according to the police at the crash scene.
- Slightly injured: according to the police at the crash scene.

The data available for the crashes includes information regarding the circumstances of the crash, such as: date, location, weather and road conditions, type of accident and a police sketch describing the course of events, person's age and gender. The hospital reports include information on a person's medical state and measures of injury severity such as AIS, MAIS, ISS, ICD and injury position.

Database of accidents with personal injury from the Hungarian Central Statistical Office (KSH)

In Hungary, the database of accidents with personal injuries is handled by the Hungarian Central Statistical Office (KSH).
Police investigation on the spot is obligatory at accidents with personal injuries. During the investigation the police record the traces, the attestations of the witnesses and the photos on the spot, followed by creating a report and a drawing of the crash scene. The police send the accident statistical form to KSH 30 days after the accident. KSH collects, checks and summarizes the statistical data from the police, then makes it available to the public in June annually. The KSH database includes only accidents with personal injuries.
In Hungary around 15,000 accidents with personal injuries happen per year on average, from this 4-5 thousand are serious and 5-6 hundred are fatal. In Budapest 3,200-3,500 accidents with personal injuries happen per year on average, from this 550-750 accidents are serious and 25-50 are fatal.
The KSH database is not connected to the record of accident injuries of hospitals, so in the statistical database there are only three categories: fatal, seriously injured and slightly injured.
Many times the reason and the causation of crashes are uncertain because the police investigator cannot always identify them on the spot. The statement of responsibility is in the scope of authority or the court and their decision is not included in the KSH database. Therefore, the investigation of cause by the KSH database may be imprecise.
The KSH database contains three tables, such as accident data, participant data (vehicle or pedestrian) and data of persons involved, see Appendix A.1 – Details on the KSH Database - Attributes. Accident types and primary reasons of accidents can be seen in the Appendix A.2 – Details on the KSH Database - Accident Types.

For the PROSPECT project BME purchased the database of road traffic accidents involving injured persons between 2011 and 2014 from KSH for statistical analysis of accidents in Hungary.

3.2.3 In-depth databases

GIDAS

The German In-Depth Accident Study (GIDAS) was founded in 1999 and is a cooperation between the Federal Highway Research Institute (BASt) and the German Automotive Research Association (FAT). Investigation teams record data of road traffic accidents involving personal injury in two regions of Germany (cities of Hanover and Dresden and their surrounding regions). The traffic accident research team of the Medical School of Hanover (MHH) is funded by BASt, whereas the team Verkehrsunfallforschung an der TU Dresden GmbH (VUFO) is commissioned by the FAT. Data is collected on a daily basis in two 6 hour shifts per day per team which are changing weekly in an alternating manner according to a statistical sampling plan.

The investigation teams document all relevant information on vehicle equipment, vehicle damage, injuries of persons involved, the rescue chain, as well as the accident conditions, at the scene. Individual interviews of persons involved are followed by detailed surveying of the accident scene based on existing evidence. In addition to documentation at the scene of the accident, all information available retrospectively is collected in close collaboration with police, hospitals and rescue services. Each documented accident is reconstructed in a simulation program. The entire course of the accident is reconstructed, starting with the pre-crash phase and the reaction of the involved vehicles, to the collision and finally vehicle end position. Characteristic variables such as deceleration, initial speed and collision speed, as well as angle-changes are determined. The documentation scope obtained in GIDAS reaches up to 3,000 coded parameters per accident.

By mid 2015, GIDAS contained a number of about 26,380 cases (years 1999 to 2014) of which data from the years 2013 and 2014 are not yet fully fed into the database. This number corresponds to about 2,000 recorded road traffic accidents per year.

<u>iGlad</u> - Initiative for the Global Harmonisation of Accident Data

IGLAD was initiated in 2010 by European car manufacturers and is an initiative for harmonisation of global in-depth traffic accident data to improve road and vehicle safety [27]. The database contains accident data according to a standardised data scheme that enables comparison between datasets from different countries is every year extended with around 800 cases. The first phase of the project was funded by the European Automobile Manufacturer's Association (ACEA). Phase II started 2014 and is based on member fees to the IGLAD consortium. The Phase II data contains 93 variables regarding the accidents, roads, participants (vehicles or VRUs), occupants and safety systems. IGLAD Datasets from Phase I and Phase II includes data from 2,150 accidents from 11 countries in years 2007 to 2013.

<u>Hungarian In-Depth Data</u>

In the PROSPECT project 100 car-to-cyclist crashes were thoroughly investigated. The in-depth analysis was executed on the sample based on a selection of accident types. In Hungary there is no public database for in-depth analysis. Therefore the researchers need to collect data from different sources, such as the police, KSH and data acquisition on the spot. The most frequently used data for in-depth analysis are the police records made on the spot, the sketch (1:200 scale), the attestations of the witnesses, the photos on the spot, the forensic expert report (if available) and KSH statistical data.
The above documents include personal data, so they are not public. An ad hoc exclusive permission is needed to access these documents and after the investigation the used data has to be destroyed.
These documents can be found at the regional police departments. However, the access is difficult as most documents are not digitalized. After three years of process termination all documents (reports, attestations, photos) are destroyed, therefore later the in-depth analysis cannot be carried out. For the in-depth analysis of the

movement and visibility of the participants involved in the accident specialized crash software was used.

The tasks of this research process were in the following order

1. Statistical analysis
2. Identifying dominant accident types
3. Stratified sampling
4. In-depth analysis

The criteria used during the stratified sampling (100 accidents) are the accident types according to statistical database, built-up area in Budapest or Pest county.

Volvo Cars Cyclist Accident Database

Volvo Cars Cyclist Accident Database (V_CAD) contains information on car-to-cyclist crashes in Sweden including information about the pre-crash scenario, the crash, the car, the driver and the cyclist and is further described in [28].

Basic information on car-to-cyclist crashes was provided by Volvia (IF P&C Insurances) to Volvo's Traffic Crash Research Team and stored in the V_CAD database. Car-to-cyclist crashes were identified using motor insurance claims reported by the third party liability insurance that cover damage to property and personal injuries. Hence, the data include crashes of all severity levels from minor damage to crashes with fatal outcome, both crashes with and without personal injury were collected. In most crashes, though, the cyclist suffered a personal injury. Each case was anonymized before being stored in the database. The information provided by the insurance company came from several sources; the vehicle claim report, the cyclist claim report, the police report and from interviews with the drivers, cyclists and other eyewitnesses. A vehicle crash claim report was available for every case and in most cases a crash report was filed by the cyclist as well. The vehicle report contains information about the course of events from the driver’s perspective. Also, estimated speed at impact, traffic environment (often described in a sketch), cyclist impact points, car damage, driver distraction elements and a description of injuries sustained were described.

For cases where the police were present at the accident scene, a police report including a sketch of the crash scene and witness statements from the driver, the cyclist and any additional observers were available as well.

Additionally, further information such as notes from conversations with the cyclist and the driver were collected by the insurance company during the insurance claim handling process. When relevant, this information was included in the database as well. Vehicle specification data were used to add additional car information, such as equipment and optional safety systems. Map data provided further information of the crash scene, such as road geometry and roadside objects.

Conflict situations describing the way the car and the cyclist were moving in relation to each other before the crash were coded according to the table in Appendix B.1.

3.3 Definitions

3.3.1 Road users

It is interesting to note that there are different definitions of road users within Europe. Since the PROSPECT project focuses on pedestrians, bicycles / pedelecs, scooters, cars and trucks this section describes their official definition in Germany [29], Hungary [30] and Sweden [26].

Table 3: Official definitions for 'pedestrians' in Germany, Hungary and Sweden

	Pedestrians
Germany	**Pedestrian** also with dogs or baby-carriages, as well as children in baby-carriages. **Pedestrian with sports and play equipment** skiers, inline-skaters, children with scooters, sledges or roller skates etc.
Hungary	**Pedestrian** - also baby-carriages, as well as children in baby-carriages, - vehicles with human power or engine, which are intended for people with physical disabilities and with a maximum speed of 10km/h, - wheelbarrow
Sweden	Pedestrian Also In-line skater, skateboarder, foot biker, kicksledder.

Table 4: Official definitions for 'bicycles / pedelecs' in Germany, Hungary and Sweden

	Bicycles / pedelecs
Germany	**Bicycle** without electronic assist **Pedelec** Motor-assisted pedal cycle with electronic assist up to 0.25 kW maximum power and not more than 25 km/h. **E-Bike** Motor-assisted pedal cycle with electronic assist with more than 25 km/h but not more than 45 km/h.
Hungary	**Bicycle** at least two wheels, driven by human power, max. 300W power **No separate definitions for pedelecs or e-bikes.**
Sweden	**Bicycle** Without electronic assist **Electric bicycles** -electric vehicles with pedals; max 250W which can only amplify the pedalling up to 25km/h. -electric vehicles without pedals with a maximum speed of 20km/h per hour; (A) max 250W or (b) self-balancing (e.g., Segway). -electric vehicles without pedals, which are intended for people with physical disabilities. They have no power limit but a maximum speed of 20km/h (e.g., powered wheelchair, electric scooter). Note: Electric bicycles cannot be differentiated by STRADA variables.

Table 5: Official definitions for 'scooters (two-wheelers)' in Germany, Hungary and Sweden

	Scooters (two-wheelers)
Germany	**Mofa 25** Bicycle fitted with an auxiliary motor (incl. Leichtmofa) with an engine capacity not exceeding 50 cc and a maximum design speed not exceeding 25 km/h. **Leichtkraftrad** Motorcycle/motor scooter with an engine capacity of over 50 up to 125 cc piston capacity and a power not exceeding 11 kW.
Hungary	**Moped** max. 50 ccm cylinder capacity, max. 45 km/h speed, max. 4 kW engine power
Sweden	**Moped** Motor vehicle on two, three or four wheels and divided into two classes: **Class I moped** - max 45km/h (EU moped). **Class II moped –** max 25km/h and the power does not exceed 1kW.

Table 6: Official definitions for 'passenger cars' in Germany, Hungary and Sweden

	Passenger cars
Germany	**Passenger car** seating not more than 9 persons (including the driver)
Hungary	**Passenger car** seating not more than 9 persons (including the driver)
Sweden	**Passenger car** A car equipped with maximum 8 seats in addition to the driver's seat. Note: A car is a motor vehicle that is equipped with three or more wheels or runners or with the band and not a motorcycle or a moped. Cars are divided into passenger cars, trucks and buses.

Table 7: Official definitions for 'trucks' in Germany, Hungary and Sweden

	Trucks
Germany	**Delivery van and motor lorry** **with a total weight up to 3.5 t including** - without followers, with followers **with a total weight more than 3.5 t** - without followers, with followers **Delivery van and motor lorry** with a standard body with which on the loading area a container is put on for dangerous goods. - without followers, with followers **Semi-trailer truck** - with or without trailer **Other tractor** **Motortruck with a special body** used e.g., as Tank trucks, silo trucks, stock carriers, trucks designed to carry long materials, etc., i.e. all special vehicles designed to carry goods
Hungary	**Truck** All vehicles excluding passenger car, bus or coach, trolley bus and tractor.

	Trailer truck The truck carries the major part of the weight of the trailer. **Tractor** Vehicle for pulling a trailer without loading area. **Heavy truck** Truck has a maximum gross vehicle weight exceeding 7.5 tonnes.
Sweden	**Truck** A car adapted primarily to carry goods. **Light** truck has a gross vehicle weight of 3.5 tonnes. Light truck may drive at the posted speed for the road. **Heavy** truck has a maximum weight exceeding 3.5 tonnes. Heavy truck may run a maximum of 90 km/h on the highway or expressway, 80 km/h in another way or if the truck has a trailer.

3.3.2 Accident Scenario and Target Scenarios / Use Cases

The wording ‘Accident Scenario’ is quite prevalent in the field of accident research but often used in different manners, which can be seen for instance in Chapter 2.

Within PROSPECT, an ‘Accident Scenario’ is described by the type of road users involved in the accident, their motions (e.g., the motion of the cyclist or pedestrian relative to the vehicle) expressed as ‘accident types’ and further most contextual factors like the course of the road, light conditions, weather conditions and view obstruction. As an example, “vehicle goes straight, cyclist crosses from the near-side behind an obstruction” represents an accident scenario.

The wording ‘Target Scenario’ or ‘Use Case’ is often used to describe ‘target groups’ and becomes more and more common in the development of active safety systems. Within PROSPECT, ‘Target Scenarios’ are equal to ‘Use Cases’. They are derived from accident scenarios, adding more detailed information about the road layout, right-of-way, as well as manoeuvre intention of the driver. One accident type can be split into several Use Cases. For example, the accident scenario “cyclist crossing from the right” can be split into “Driver approaching an intersection with the intention to turn right, while cyclist is crossing from the right on the sidewalk against travel direction” or “Driver approaching an intersection with the intention to go straight, while cyclist is crossing from the right on the sidewalk in travel direction”, as well as others. For every use case, additional information about relevant parameters is analysed (sight obstruction, daytime, age of the cyclist, initial and collision speed of both, cyclist and passenger car). Use Cases allow for a deeper understanding of the background and causation of the corresponding accidents. Furthermore, they can be used to identify specific parameters influencing the performance of active safety systems (e.g., affecting sensor type selection, sensor ranges and fields of view as well as timing of warnings and interventions).

3.3.3 Injury severity

The injury severity level of a casualty in a road traffic accident describes the severity of the outcome for this person as a consequence of this crash. In order to record these information objectively, several definitions have been met regarding the injury severity on national and international levels.

In the German national road traffic accident statistics, the following definitions are used for casualties suffering damages. Hereby, casualties are persons (incl. passengers) injured or killed in the accident. There are classified as killed (all persons who died within 30 days as a result of the accident), seriously injured (all persons who were immediately taken to hospital for inpatient treatment (of at least 24 hours)) and slightly injured (all other injured persons) [29].

In national accident statistics the terms “slightly injured”, “seriously injured” and “killed” are often used in contrast to the more specific “Abbreviated Injury Scale” (AIS) that describes the likelihood of the person’s mortality by a distinct injury classified in seven AIS levels (from “not injured” to “not treatable anymore”) and is often used for in-depth accident investigations [31] [32].

3.3.4 Type of accident

The coding “type of accident” (or accident type) can offer a meaningful insight to the situation before the collision occurred.
For example, in the German statistics there are seven main types of accidents (coded as type 1 to type 7). Each of these main types can be further detailed into sub-types that range up to three levels (e.g., accident type “372”). However, in the German accident statistics this 3-digit accident type information is not available for all federate states of Germany.
In Hungary, the accident type also defines the situation before the collision. There are 10 main categories, all together 87 types on two levels, see Appendix A.2 – Details on the KSH Database - Accident Types.

3.4 General Data Query

Several project partners contributed to the analyses reported in this deliverable. The aim was to produce results using an agreed common method on the data analysis that firstly can be fulfilled by the partners and secondly feeds the needs of the other Work Packages. It has to be noted that not all results could be compared directly with each other as the databases were regarded as quite different (e.g., due to their case inclusion criteria, number of relevant cases, the level of detail and different definitions behind the parameters). Nevertheless, it was tried to preserve the possibility of comparison regarding some of the same key crash characteristics such as the limitation to two crash participants, the VRU’s injury severity, accidents of latest years (2009-2014) and basic trajectories.

3.4.1 Two crash participants

As introduced in Section 3.1 the focus of the project and this report is on crashes with two participants. This approach allows to compare more precisely crashes with each other which were assigned to the same crash configuration but still differ e.g., in the crash opponent, their collision sequences, resulting personal injuries or material damages. In particular in in-depth crash investigations it is expected to gain highest quality in the linkage to injury causing vehicle parts when focusing on two crash participants only. Another aspect is that regarding crashes involving VRUs, the share of crashes with three or more participants is relatively low, which can also be seen in the data from Germany and Hungary as presented in the following paragraphs.

Germany

Figure 6 provides an example for crashes involving pedestrians in Germany for different numbers of crash participants for the years 2012-2014 and separated for urban and rural areas. Note: by definition pedestrian cannot be involved in single accidents in road traffic.

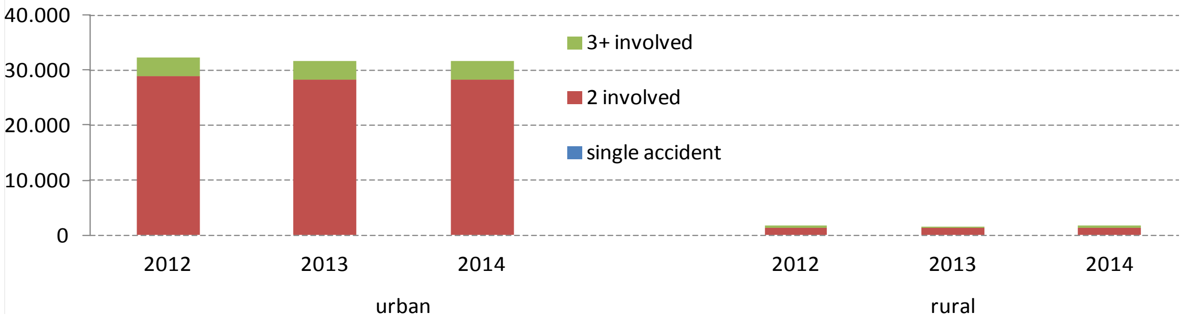


Figure 6: Number of crashes involving pedestrians in Germany with different numbers of participants

Figure 7 and Figure 8 show analogous information for accidents involving cyclists and pedelecs, respectively. It has to be noted that the definition of a pedelec is provided in Section 3.3.1, that the registration of this transport mean has been started in the German national accident statistics in all sixteen federal states of Germany in 2014 and that the share of single accidents is comparatively high.

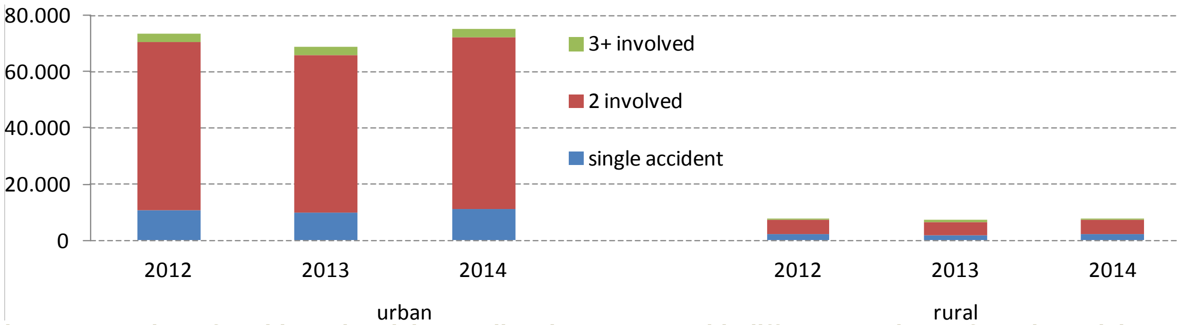


Figure 7: Number of accidents involving cyclists in Germany with different numbers of crash participants

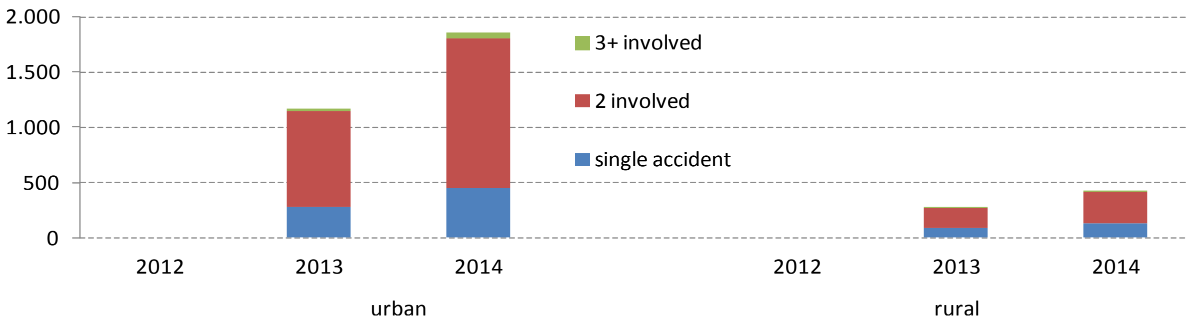


Figure 8: Number of crashes involving pedelecs in Germany with different numbers of participants

Hungary

The percentage of pedestrian accidents with two participants involved in urban areas is more than 90%, as can be seen in Figure 9 that shows also the shares for rural areas.

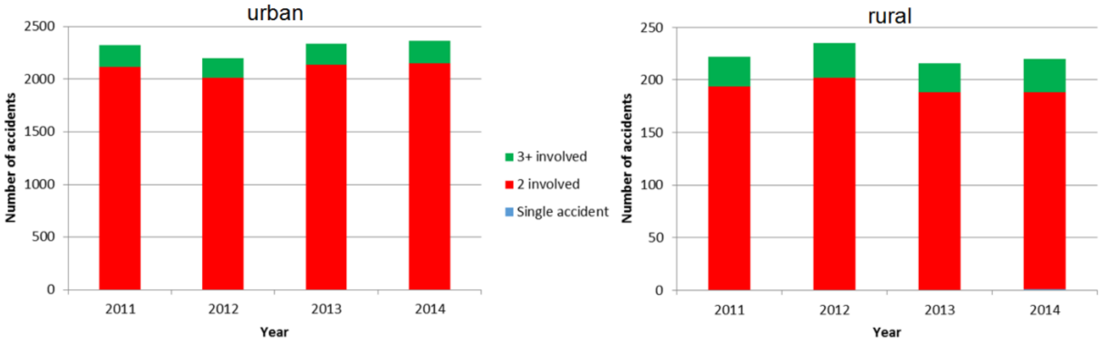


Figure 9: Number of accidents involving pedestrians in urban and rural areas with different numbers of participants in the crash (Hungary, 2011 – 2014)

The percentage of cyclist crashes with two participants involved in urban areas is > 80%, as can be seen in Figure 10 that shows also the shares for rural areas.

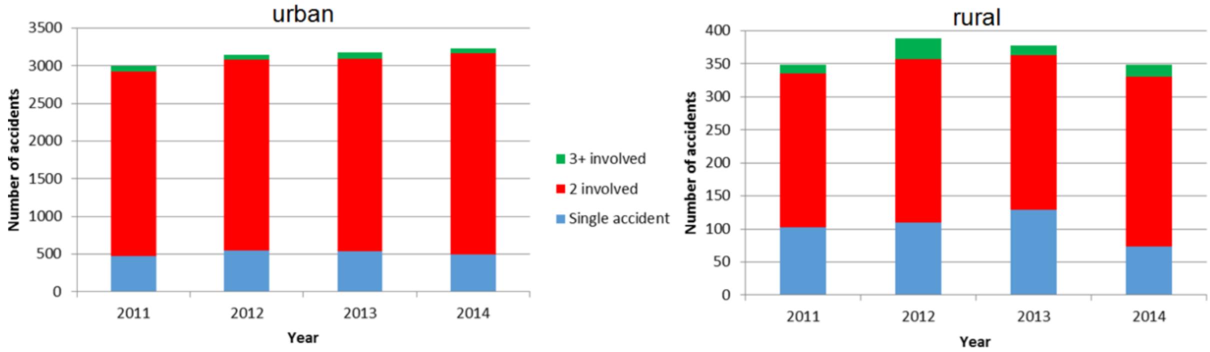


Figure 10: Number of accidents involving cyclists in urban and rural areas with different numbers of participants in the crash (Hungary, 2011 – 2014)

Sweden

The number of crashes involving pedestrians in Sweden for a different number of crash participants for the years 2009-2013 and separated for urban and non-urban areas are shown in Figure 11. A similar figure is observed when considering the number of crashes involving cyclists with different number of crash participants, see Figure 12. The crashes with three and more traffic participants involving pedestrians are more frequent compared to the accidents with three and more traffic participants involving cyclists.

The majority of accidents involving cyclists were with two traffic participants, 90% and 82% in urban and non-urban areas respectively. However the large majority of single cyclist crashes (which also constitute the largest proportion of cyclist accidents in general) are unreported by the police, see Section 9.1.

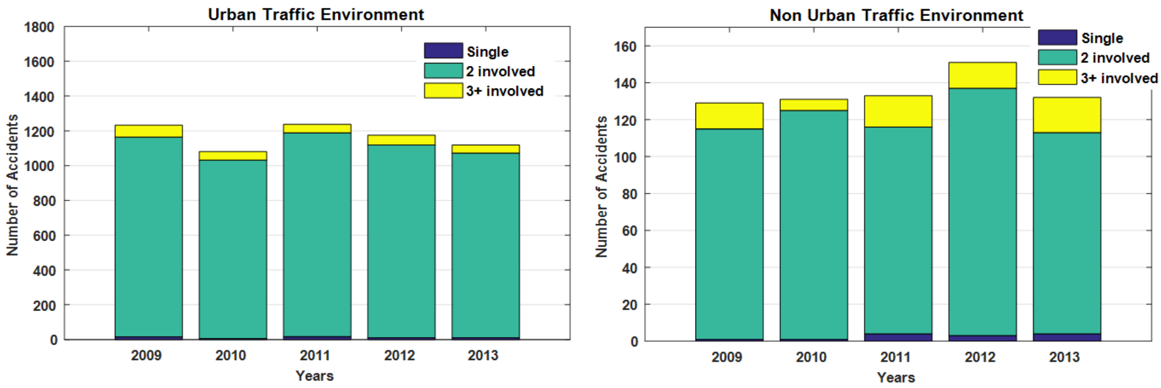


Figure 11: Number of accidents in Sweden involving pedestrians with different numbers of crash participants for years 2009-2013.

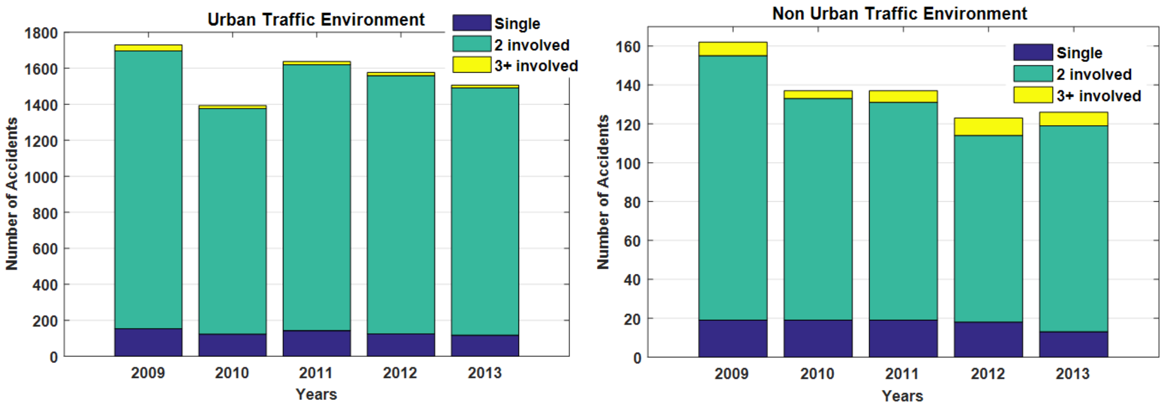


Figure 12: Number of accidents in Sweden involving cyclists with different numbers of crash participants for years 2009-2013.

3.4.2 Injury Severity

Within the project it was concluded that results will be provided for both the target group "killed and seriously injured (KSI) VRU" and the target group "slightly, seriously injured and killed VRU".

The first mentioned target group can be assumed as the one with the highest potential of reducing high injury severities of VRUs by future AEB systems. This is because of the closer focus on the characteristics of the cases with severe outcome only and thus, by addressing i.e. higher average car impact speeds.

The second mentioned target group including slightly injured achieves to provide meaningful results for the later AEB system benefit analysis in PROSPECT. However, it needs to be noted that there is generally less information available on crashes with an outcome of slightly injured casualties and the underreporting rate is higher for slightly injured than for seriously injured traffic participants, see Chapter 0.

3.4.3 VRU's impact on the car and Reversing

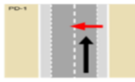
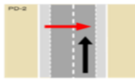
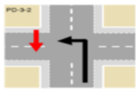
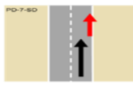
As AEB technologies become more and more advanced it was expected to be able to cover more crash scenarios than in the past. Consequently, PROSPECT needs to analyse a wider range of the VRU's impact location on passenger cars than previous projects. In particular, while the AsPeCSS project considered widely impacts on the car front only (see also Section 2.1.1.), in PROSPECT only reversing passenger cars were excluded, and the VRU's impact location on the car could be anywhere around the car except at the rear.

3.5 PROSPECT Accident Scenarios

Different approaches were taken to find an aligned set of Accident Scenarios on which statistical and comparable results can be produced out of the databases introduced in Section 3.2.

Regarding car-to-cyclist crashes, it was concluded to consider five Accident Scenarios: (I) "Car straight on, Cyclist from near-side", (II) "Car straight on, Cyclist from far-side", (III) "Car turns", (IV) "Car and cyclist in longitudinal traffic" and (V) "Others", see also Table 8. Note: the exemplary pictograms show straight roads except for accident scenario (III), but crashes could also occur at an intersection.

Table 8: PROSPECT Cyclist Accident Scenarios

	Exemplary pictograms
(I) Car straight on, Cyclist from near-side	
(II) Car straight on, Cyclist from far-side	
(III) Car turns	
(IV) Car and cyclist in longitudinal traffic	
(V) Others	

Regarding car-to-pedestrian crashes, the recently completed work from the European project AsPeCSS, see also Section 2.1.1, was considered as being still valid and therefore the approach and thus, the Accident Scenarios were adopted. However, the Accident Scenario "Driving backwards" has been added (and thus extracted from the Accident Scenario "Others") as this was deemed to reflect the importance of this scenario, see Table 9.

Table 9: PROSPECT Pedestrian Accident Scenarios (based on AsPeCSS [2])

ID	Accident Scenario Description
1 A/B	Crossing straight road, nearside, no obstruction, day/dark
2 A/B	Crossing straight road, offside, no obstruction, day/dark
3 A/B	Crossing at junction, near- or offside, vehicle turning across traffic, day/dark
4 A/B	Crossing at junction, near- or offside, vehicle not turning across traffic, day/dark
5 A/B	Crossing straight road, nearside, obstruction, day/dark
6 A/B	Crossing straight road, offside, obstruction, day/dark
7 A/B	Along straight road, no obstruction, day/dark
8 A/B	Driving backwards

3.6 USE CASES

As the Accident Scenarios mentioned in Section 3.5 can only provide a limited amount of information on the causation of the crashes and their features and this was not sufficient for further system development steps in PROSPECT, Use Cases, see Section 3.3.2, have been derived from these Accident Scenarios for car-to-cyclist as well as for car-to-pedestrian crashes.

In a first step, German traffic crash data (GIDAS) has solely been used for the development of PROSPECT's Use Cases. This work has separately been published in Deliverable 3.1 "The addressed VRU scenarios within PROSPECT and associated test catalogue" [33] and the paper "Car-to-cyclist accidents from the car driver's point of view" [34].

4 OVERVIEW ON ROAD TRAFFIC ACCIDENTS IN EUROPE INVOLVING VRUS

4.1 FATALLY INJURED VRU'S IN EU-28 AND OTHER COUNTRIES (CARE / IRTAD)

International crash databases were analysed to obtain an overview of road traffic crashes involving VRUs. To examine the situation and assess the development in the European Union the analysis is based on the CARE Database, see also Section 3.2.1. To compare these figures with other countries in the world additionally the IRTAD database was analysed.
Comparable figures can only be shown when focussing on the number of fatalities, as only for these figures a common definition underlays (death due to consequences of the crash within 30 days). However, not all European countries offered related data for all considered years. To complete this picture of the development of the number of fatalities in EU-28, these gaps were filled by the number of the next or the previous available year. These tables on fatally injured pedestrians and cyclists can be found in Appendix C.1, whereas the artificially added figures were marked in red.

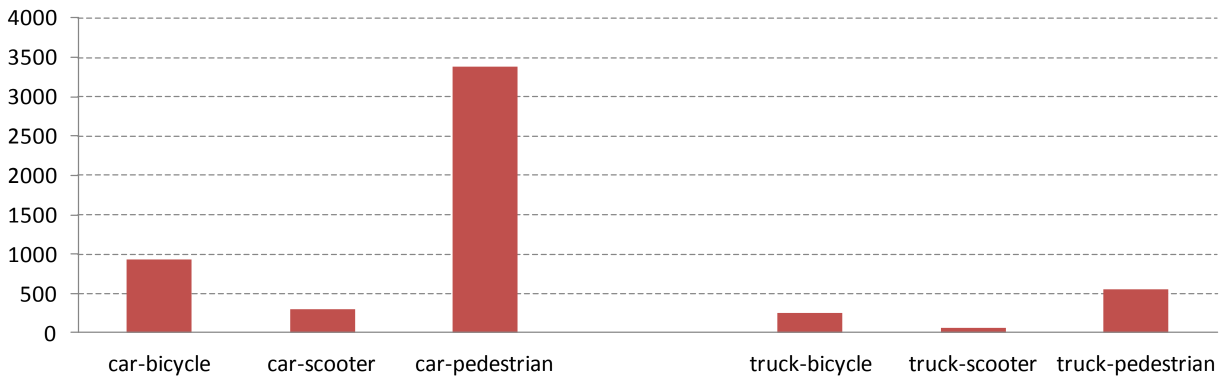


Figure 13: CARE analysis on fatally injured VRUs in crashes with two participants in Europe (year 2013)

In 2013 in the EU 6,810 pedestrians were fatally injured in road crashes. The number of fatally injured pedestrians reduced nearly by 50 % since 2000, see Figure 14.

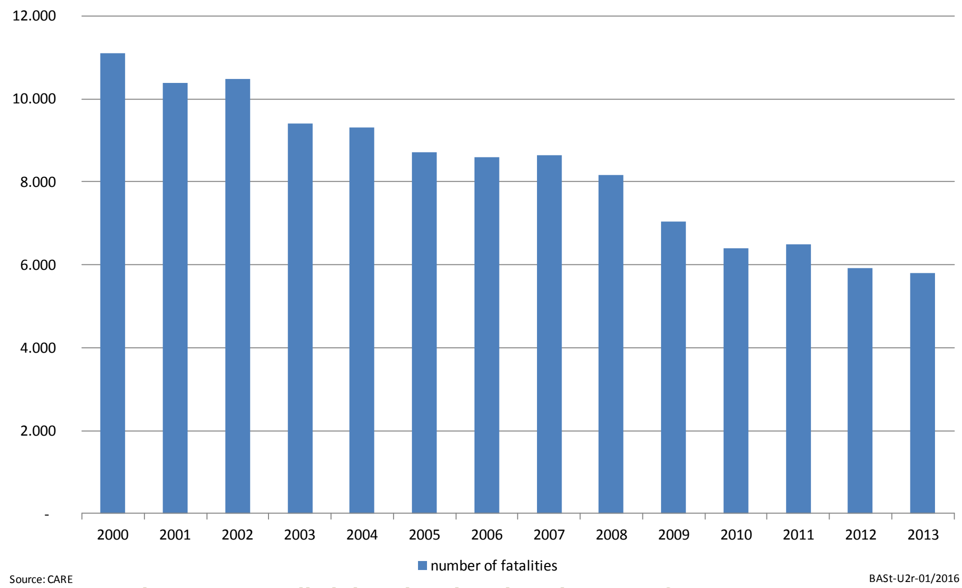


Figure 14: Fatally injured pedestrians in EU-28 from 2000-2013

In the same year (2013) in the EU 2,028 cyclists were fatally injured in road accidents. The number of fatally injured cyclists decreased by 43% since 2000, see Figure 15.

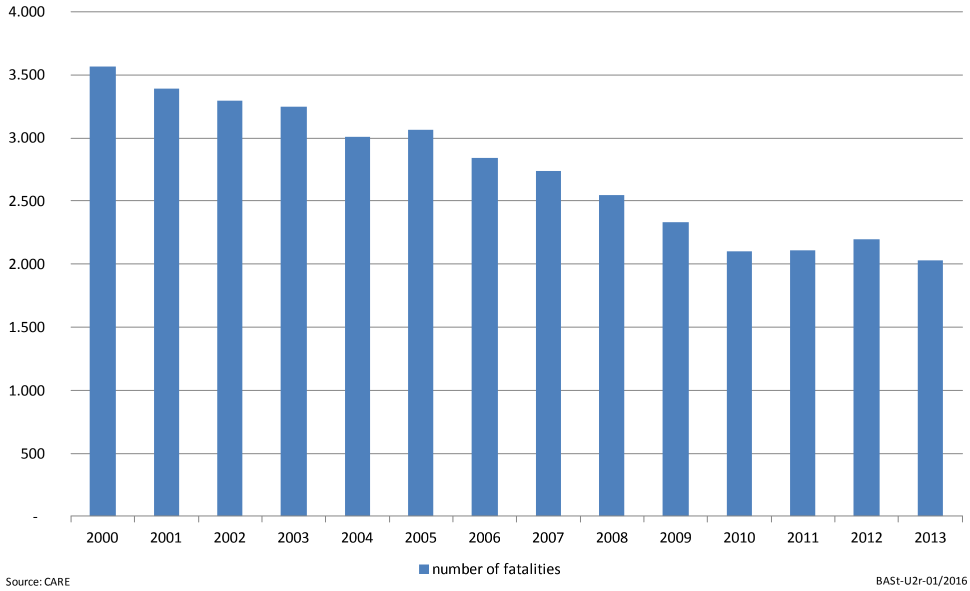


Figure 15: Fatally injured cyclists in EU-28 from 2000-2013

4.1.1 Fatally injured VRUs in 2013 - rate per 100,000 population

For comparison of fatality figures between countries it is useful to use the fatality rate per hundred thousand population. Additionally to EU-28 countries the countries included in IRTAD were used for comparison, see Figure 16 and Figure 17.

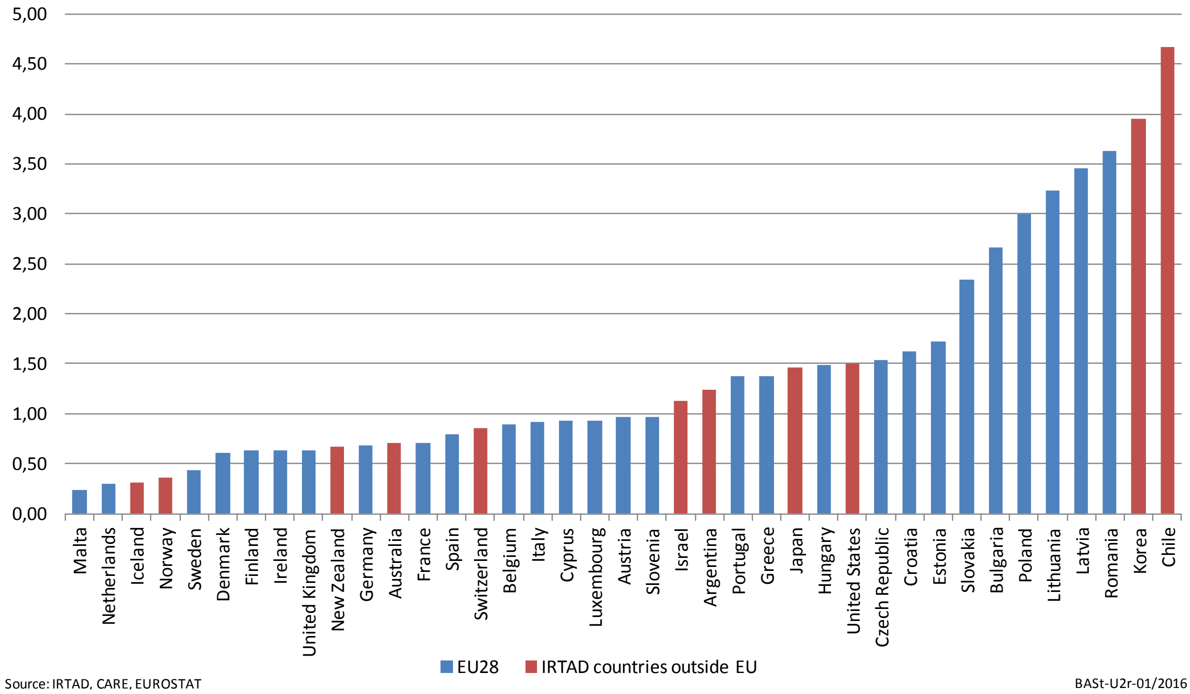


Figure 16: Fatally injured pedestrians in 2013 – rate per hundred thousand population

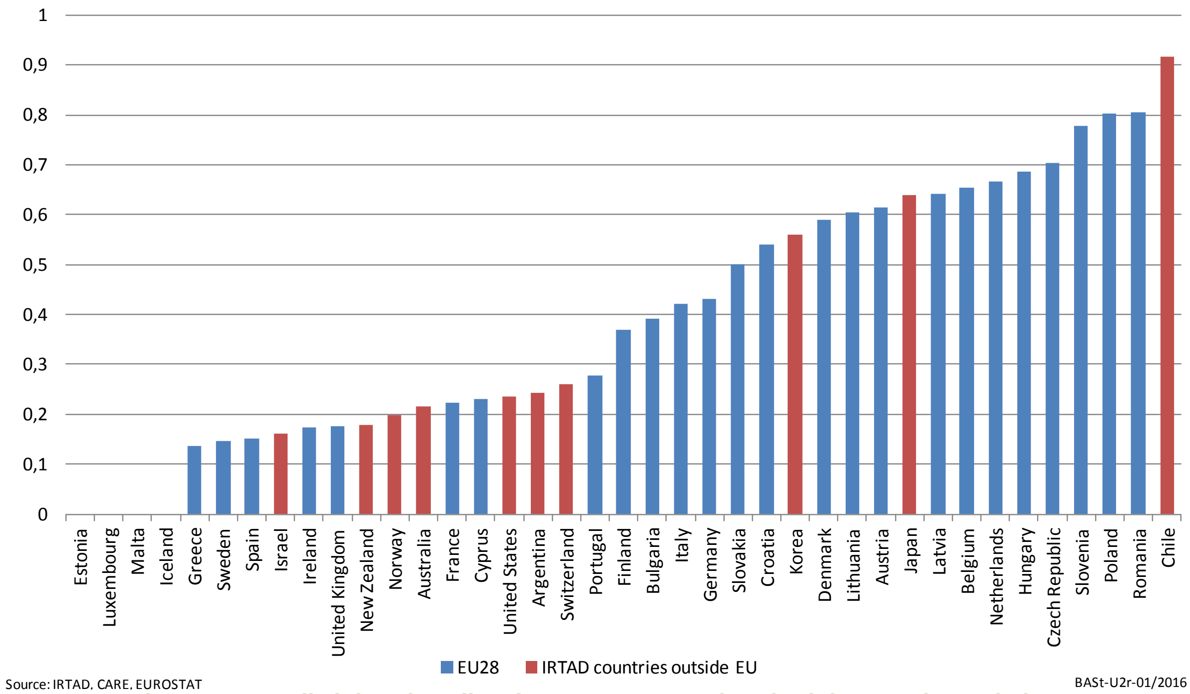


Figure 17: Fatally injured cyclists in 2013 – rate per hundred thousand population

4.1.2 Fatally injured VRUs by age groups in 2013 - rate per 100,000 population

The different kinds of traffic participation do have different relevances as well as different safety levels in various countries. To get an impression on this kind of information the fatality rate per hundred thousand population for different age groups were analysed for selected countries and regarding killed pedestrians, see Figure 18, as well as regarding killed cyclists, see Figure 19.

It is obvious that in most countries older pedestrians (age of 65 and higher) have the highest risk to get fatally injured.

Considering cyclists, the highest numbers of fatalities per inhabitants can be observed in countries where cycling is very common and the bicycle is used as a daily transportation means like in The Netherlands and in Denmark. Similar to the observation for pedestrians, elderly people have the highest risk to get fatally injured as cyclist riders in most countries due to their high vulnerability.

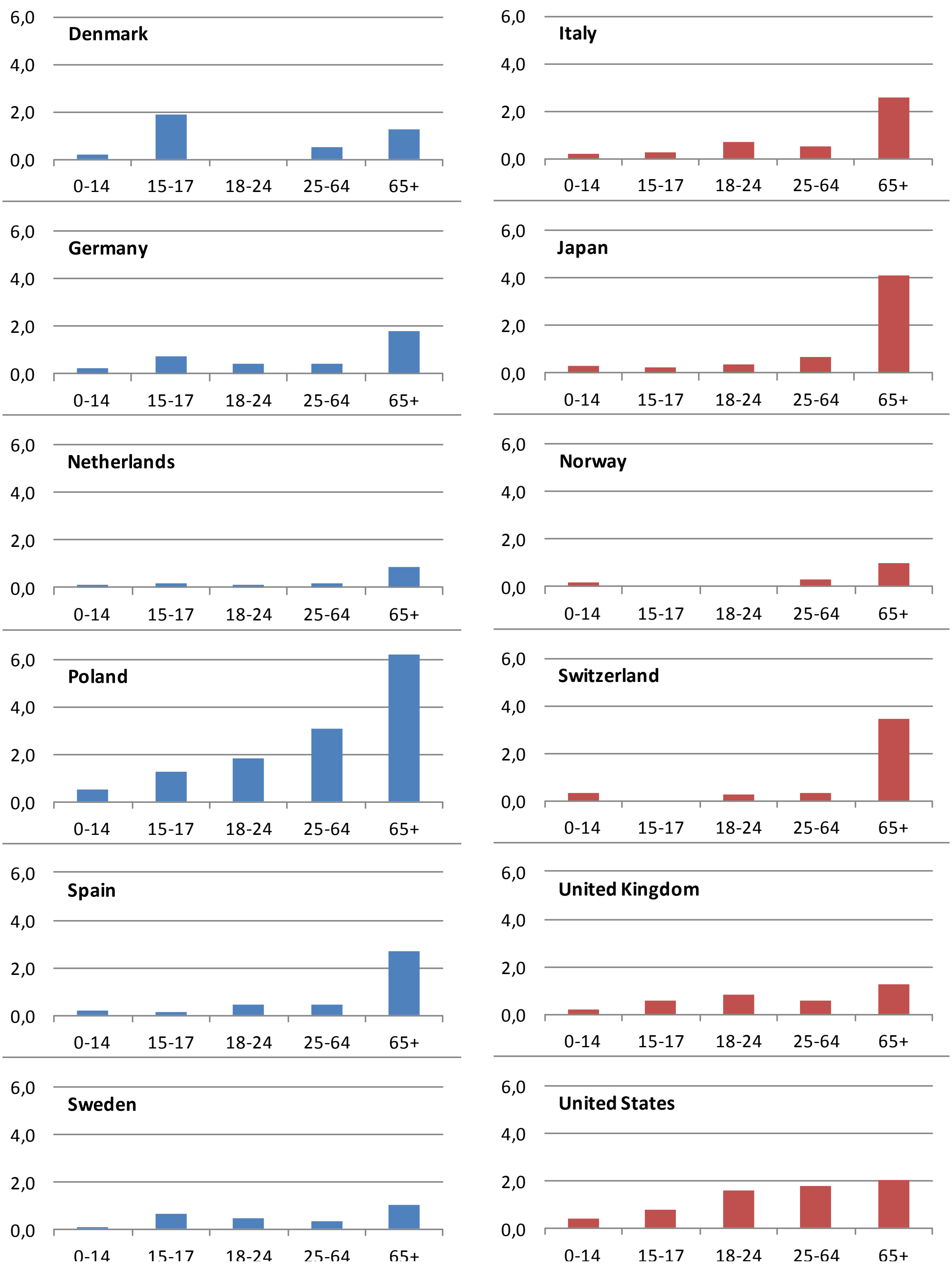


Figure 18: Fatally injured pedestrians by age groups in 2013 - rate per 100,000 population (Source: IRTAD)

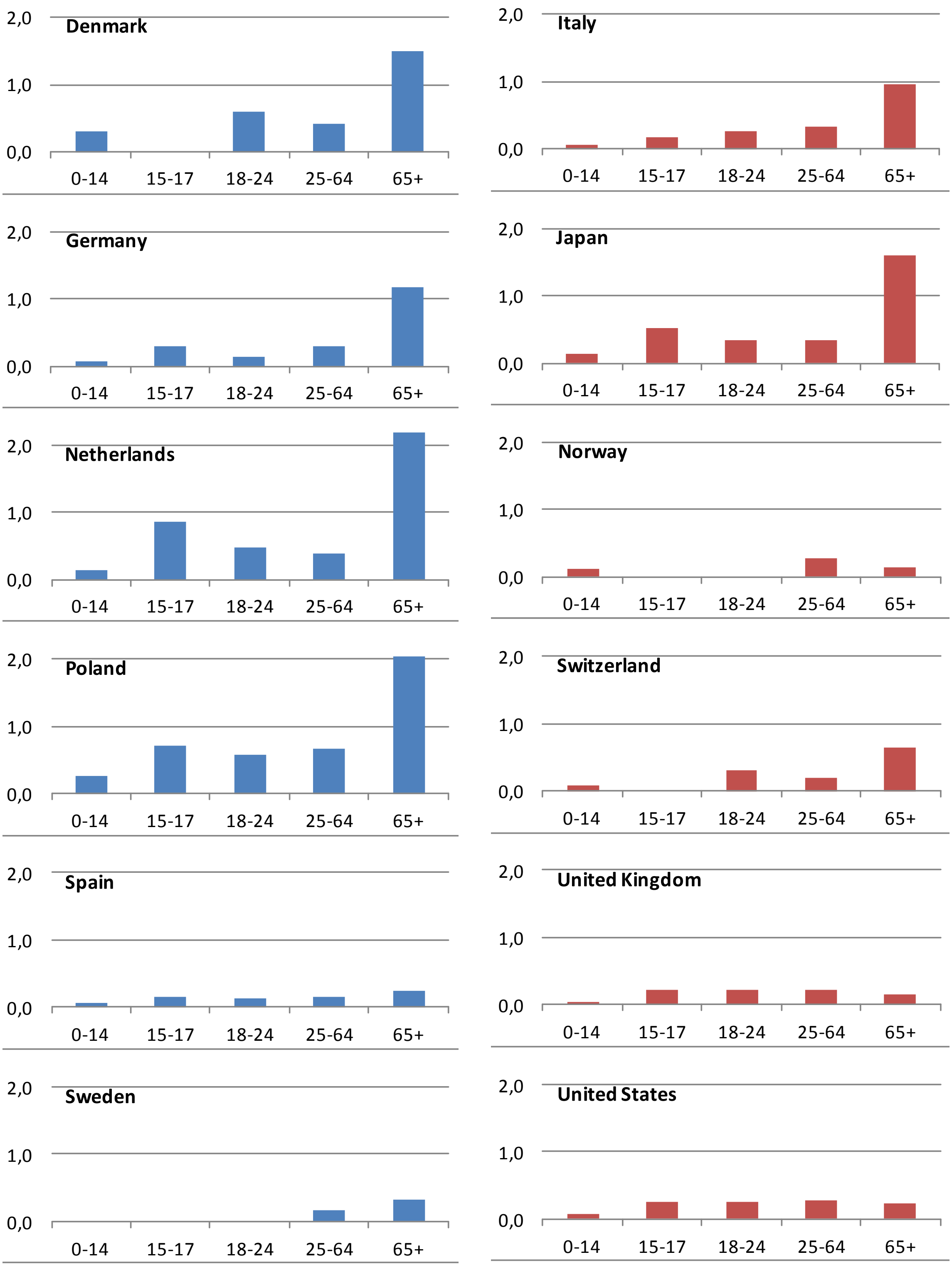


Figure 19: Fatally injured cyclists by age groups in 2013 - rate per 100,000 population (Source: IRTAD)

4.2 GERMAN NATIONAL ROAD TRAFFIC STATISTICS

In 2014 there were 3,377 fatalities in crashes on German roads. Most of them were car occupants (1,575; 47 %), but nearly one third of them were VRU participating as pedestrians, by bicycle or by scooter (motorized two-wheelers with less than 50 ccm and up to 45 km/h). Figure 20 shows the numbers of fatally injured persons in 2014 by traffic participation and age group. Especially the age distribution of fatally injured pedestrians and cyclists is showing a significant high number for the older age groups.

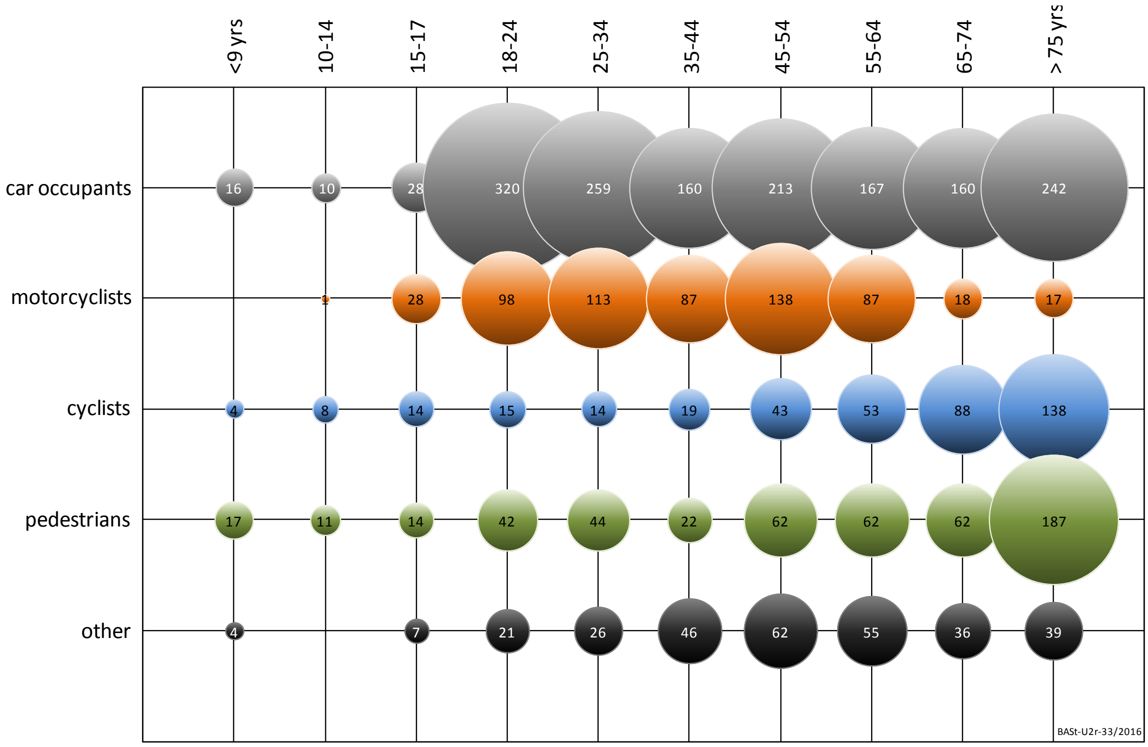


Figure 20: Fatalities in Germany 2014 by age and traffic participation

Most of fatally injured VRUs died in car-to-pedestrian crashes followed by car-to-bicycle crashes. Compared to fatal accidents of cyclists and pedestrians, the number of fatally injured scooter riders is comparatively low, see Figure 21.

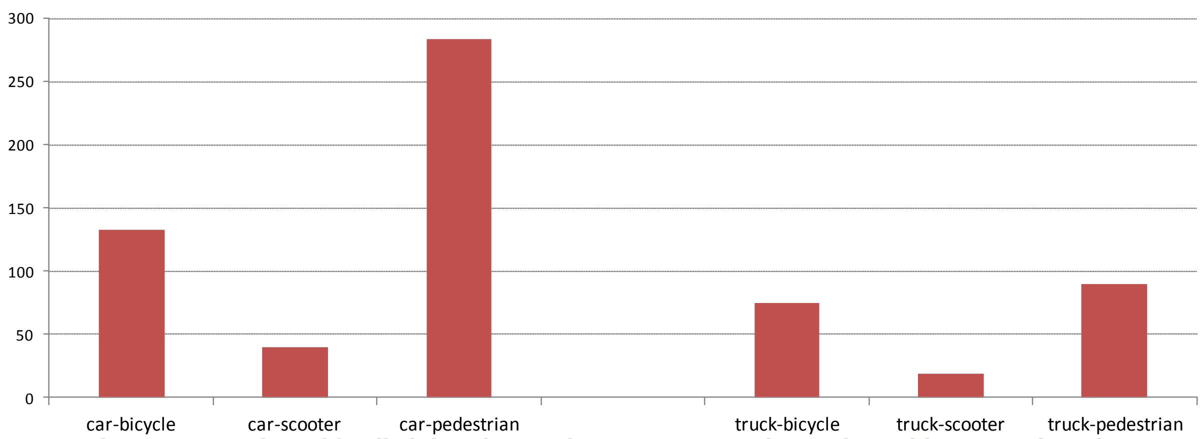


Figure 21: Number of fatally injured VRUs in Germany 2014 in crashes with cars and trucks (crashes with two participants only)

Analysing crash opponents of fatally injured VRUs, Figure 22 shows that most VRUs were killed in crashes with cars. Further, there are more cyclists and scooter riders being killed in single vehicle accidents than in crashes with trucks.

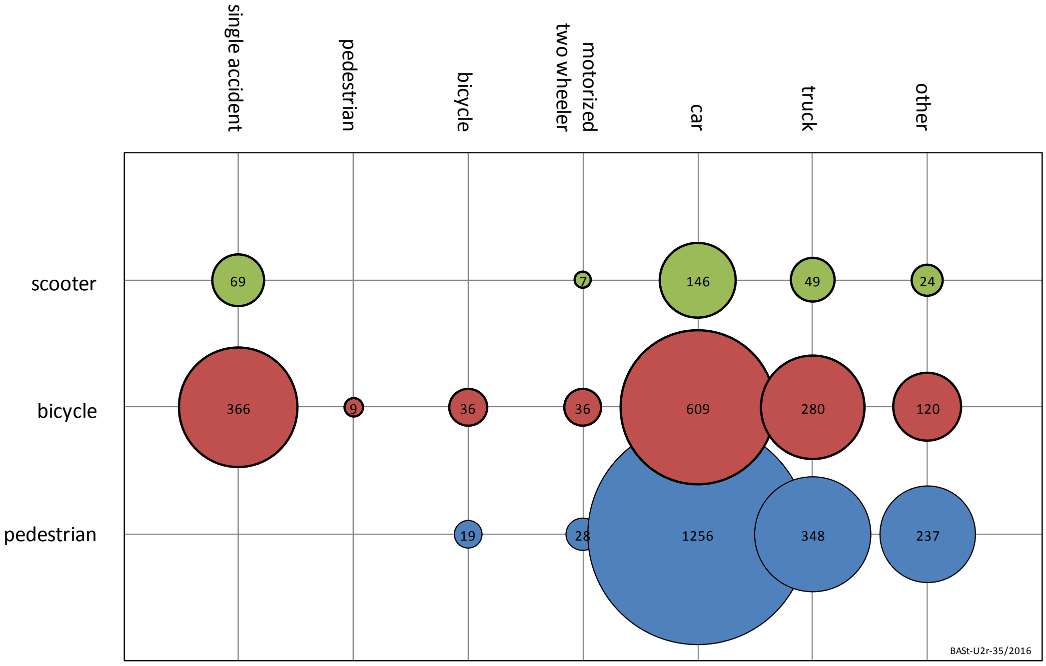


Figure 22: Fatally injured VRUs by crash opponent in Germany 2011-2014 (crashes with two participants)

4.2.1 Bicycles

Figure 23 shows an overview on fatally injured cyclists by crash opponent and age group. It becomes clear that older cyclists correspond to the largest group being killed in crashes against cars.

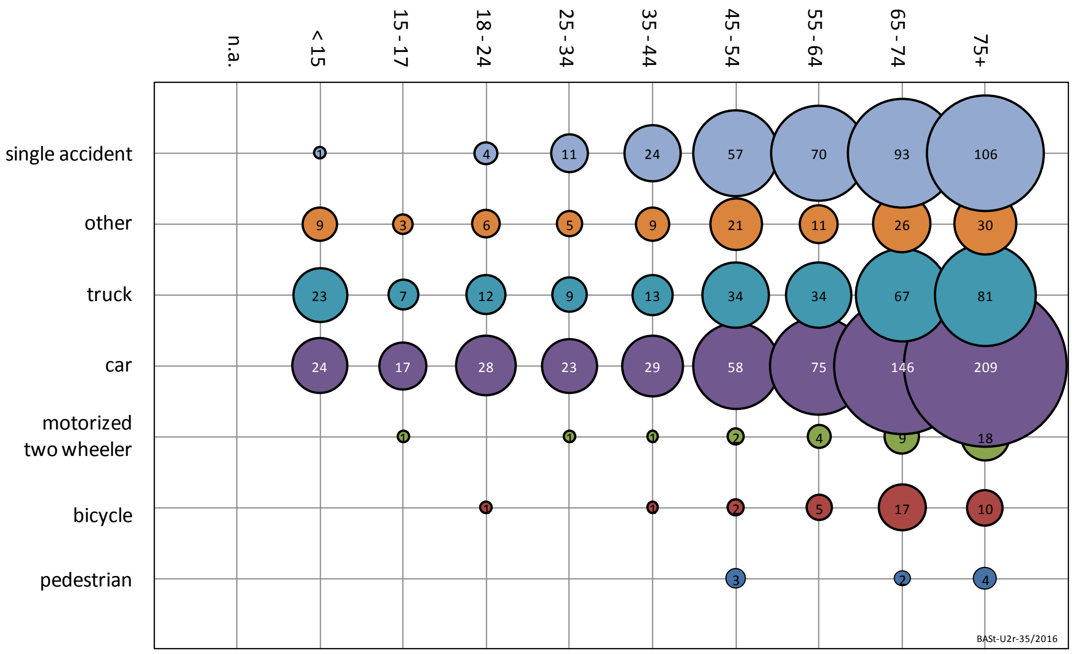


Figure 23: Fatally injured cyclists by crash opponent and age group in Germany 2011-2014 (crashes with one or two participants involved)

Figure 24 provides an overview on the sum of the number of killed and seriously injured cyclists by crash opponent and age group. Clearly, the incorporation of seriously injured casualties influences largely this picture compared to Figure 23.

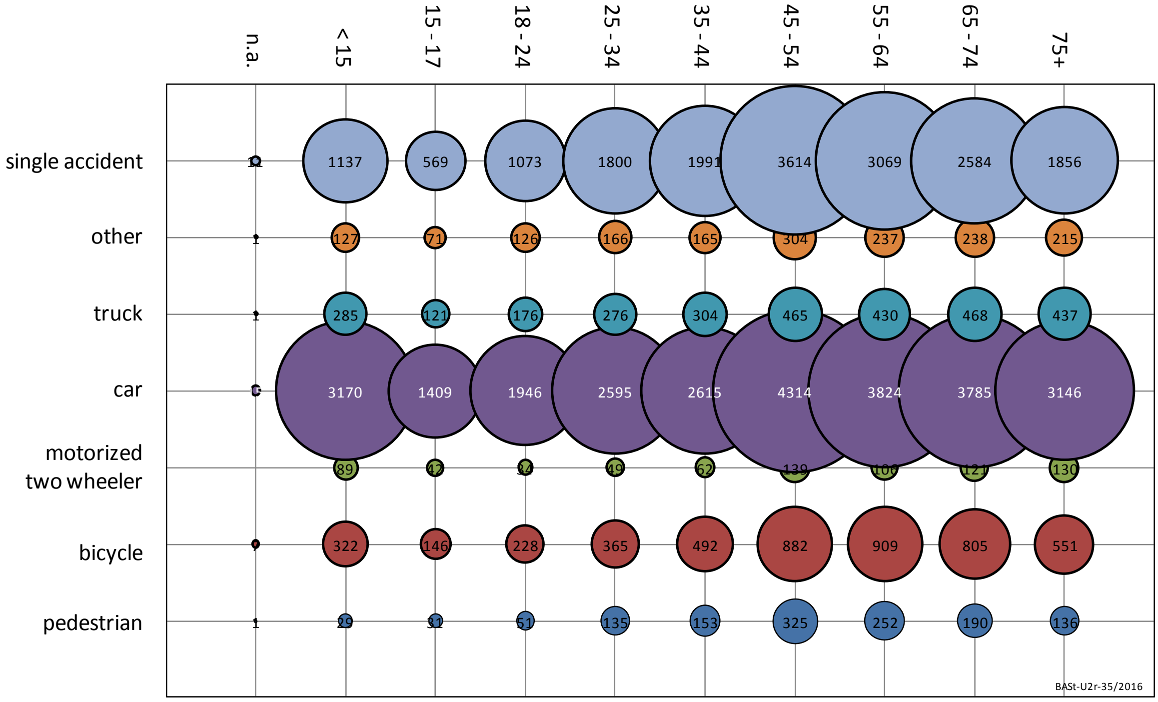


Figure 24: Killed and seriously injured cyclists by crash opponent and age group in Germany 2011-2014 (crashes with one or two participants involved)

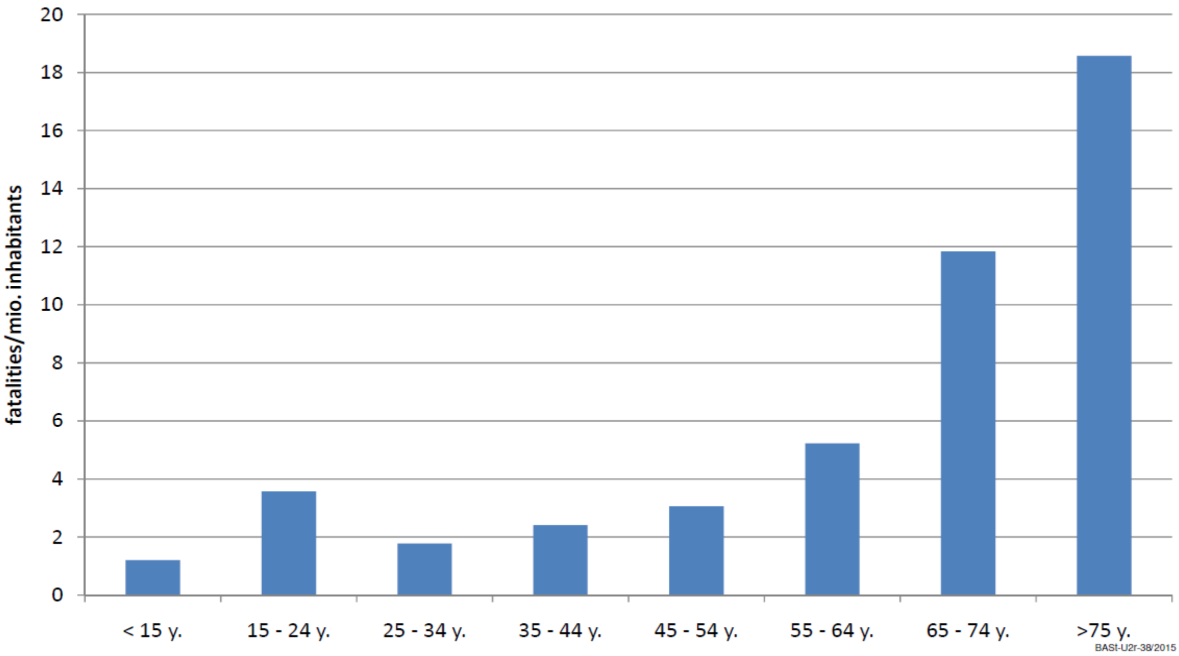


Figure 25: Fatally injured cyclists per 1 million inhabitants of age group in car-to-cyclist crashes in Germany (2012-2014)

4.2.2 Pedelecs

Since 2014 the German road accident statistics enable the distinction between bicycles and pedelecs (up to 250 W, up to 25 km/h). For definitions see Section 3.3.1. In 2015 approximately 4 % (2014: 3 %) of all bicycle accidents were accidents with an involved pedelec, but nearly 10 % of all killed bicyclists were driver of pedelecs, see Figure 26.

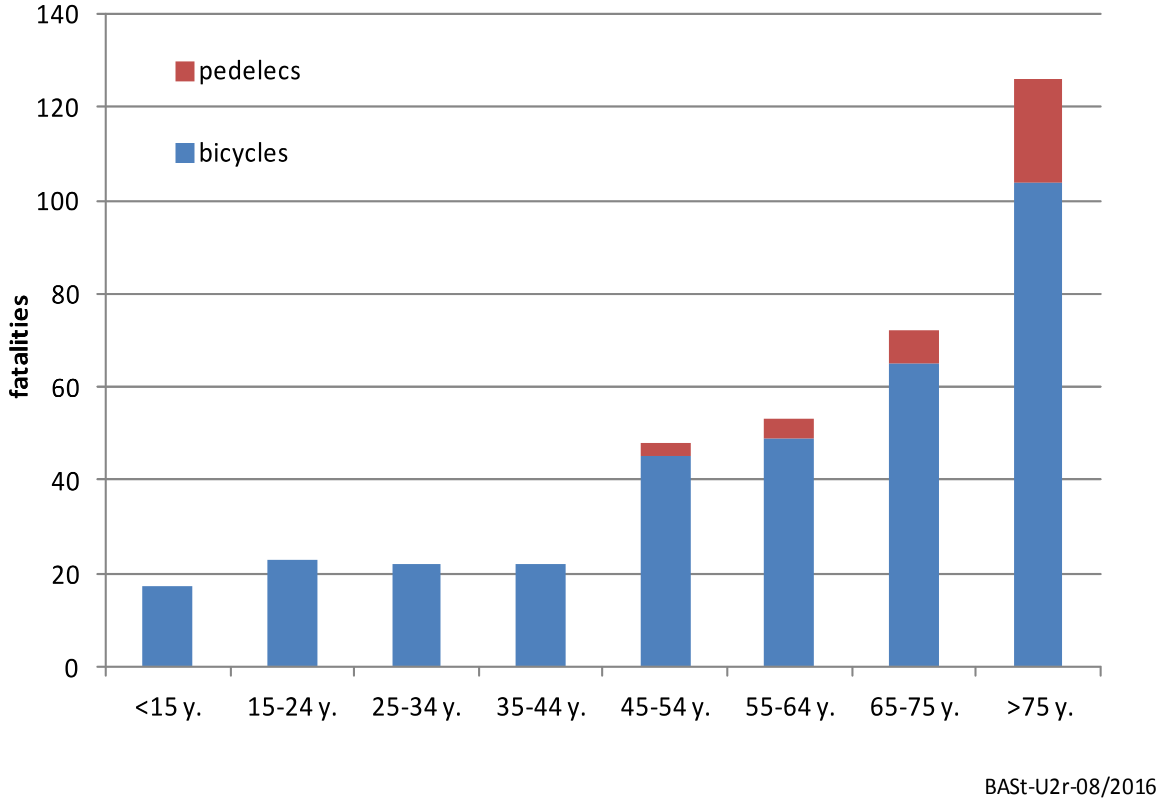


Figure 26: Fatally injured cyclists by age group in Germany (2015) – bicycles and pedelecs

All fatally injured pedelec riders were 45 years and older. This is mainly due to the usage pattern of pedelecs, which is in Germany to a high percentage related to elderly people.
While only 9 % of the accidents with conventional bicycles occured on rural roads, the share of rural roads on all pedelec accidents was double (18 %). More than half of the crashes with pedelec involvement and fatal outcome of its rider occurred on rural roads, compared to 37% for conventional bicyclists.
Analysing the accident opponent shows, that the share of single vehicle accidents is higher for pedelecs (25 %) than for conventional bicycles (18 %). 52 % of the pedelec accidents were against cars, while for conventional bicycles this value is 59 %.

4.2.3 Pedestrians

Figure 28 shows an overview on fatally injured pedestrians by crash opponent and age group. It becomes clear that older cyclists correspond to the largest group being killed in crashes against cars whereby the age group of 75 years and older stands out.

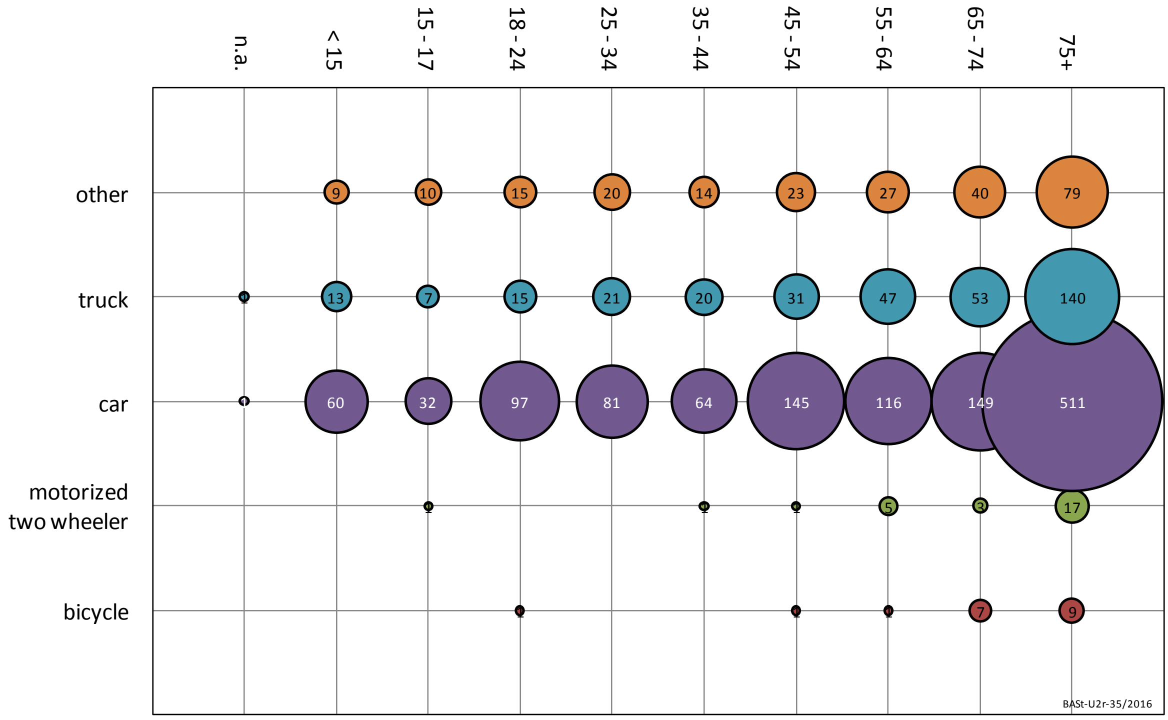


Figure 27: Fatally injured pedestrians by crash opponent and age group in Germany 2011-2014 (crashes with two participants only)

Figure 28 shows the sums of the number of killed and seriously injured (KSI) pedestrians by crash opponent and age group. Clearly, the incorporation of seriously injured casualties influences largely this picture compared to Figure 27. Besides older road users young pedestrians were often seriously injured in crashes with cars.

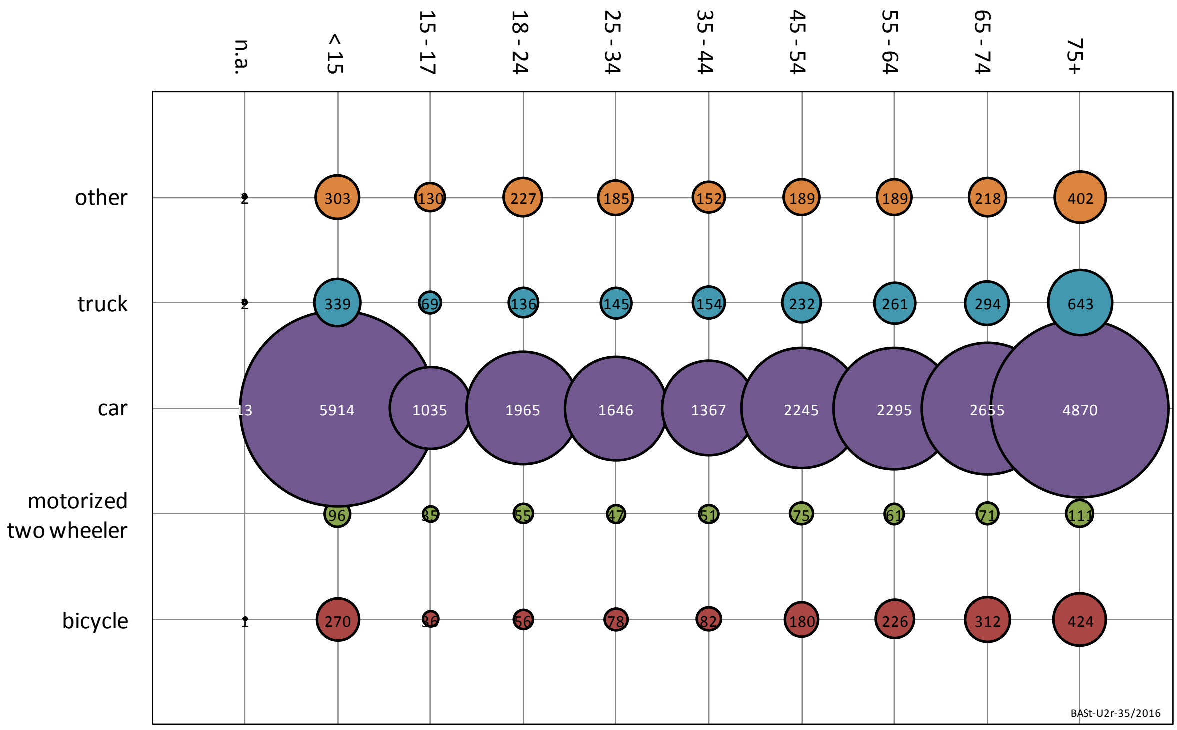


Figure 28: Killed and seriously injured pedestrians by crash opponent and age group in Germany 2011-2014 (crashes with two participants only)

4.2.4 Scooter

Figure 29 shows an overview on fatally injured scooter riders by crash opponent and age group. Compared to other road user types the absolute number of killed scooter riders was low in the years 2011-2014 and the distribution is more balanced towards the different age groups. However, the age groups "15-17 years" and "45 years and older" could be assigned to the ones with highest fatal crash outcome in particular with passenger cars as crash opponent.

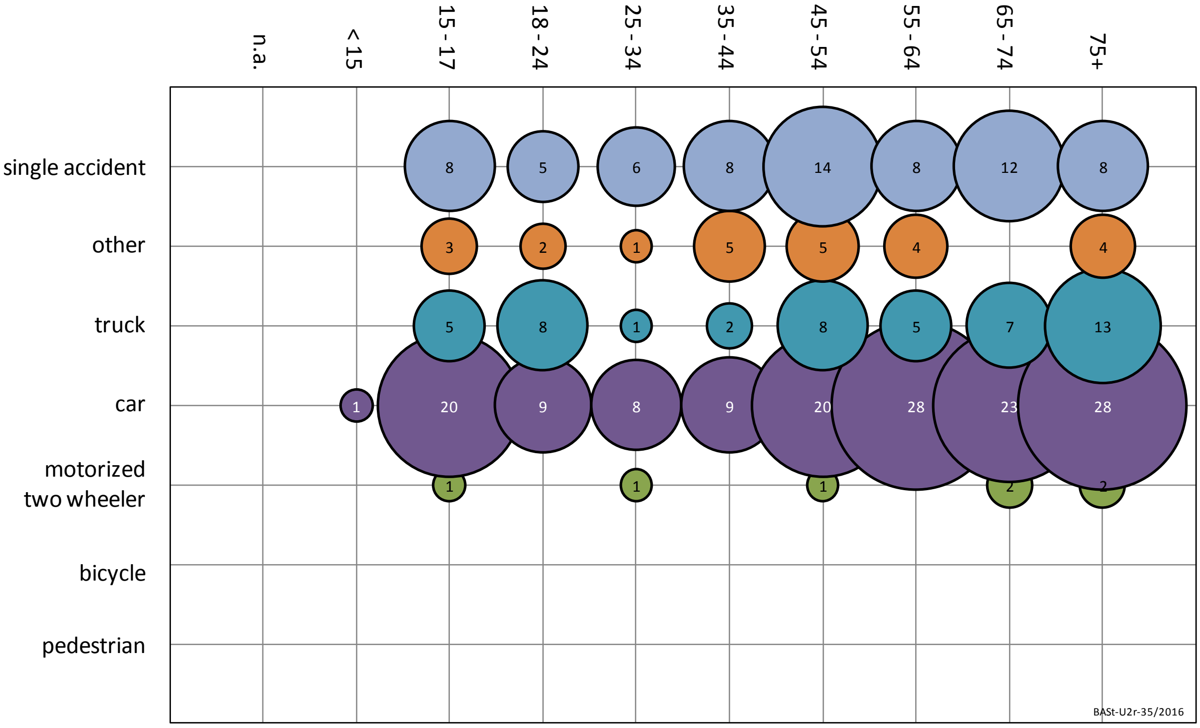


Figure 29: Fatally injured scooter riders by crash opponent and age group in Germany 2011-2014 (crashes with one or two participants involved)

Figure 31 shows the sums of the number of killed and seriously injured (KSI) scooter riders by crash opponent and age group. Clearly, the incorporation of seriously injured casualties influences largely this picture compared to Figure 29. It can be seen that most often young riders (15-17 years) and riders about mid-age (35-64 years) were involved in respective crashes.

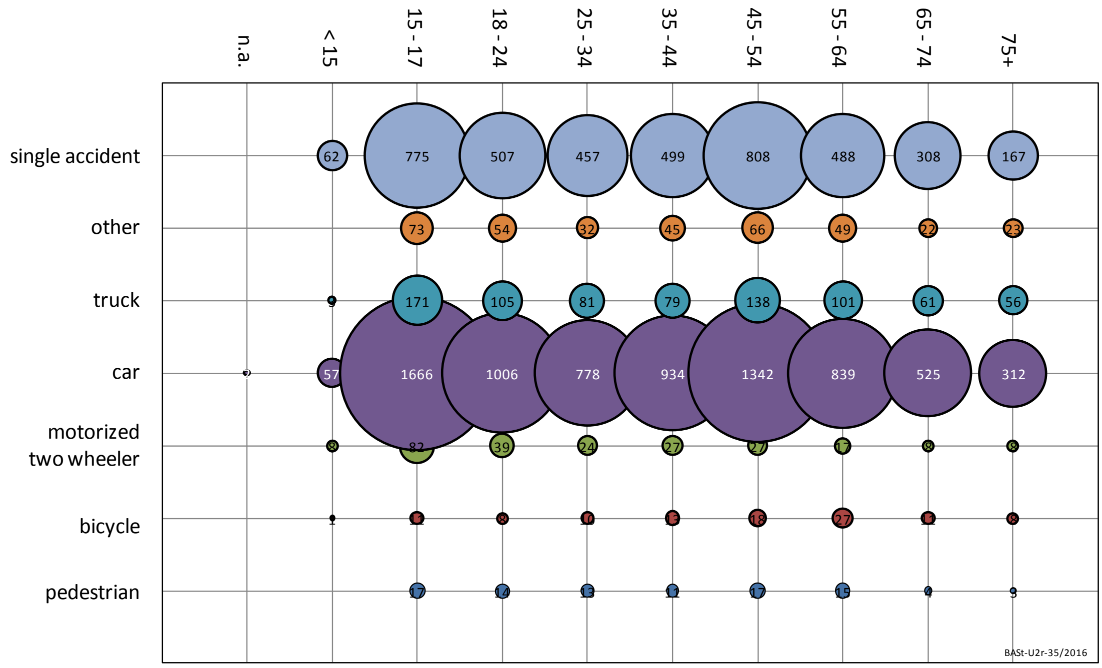


Figure 30: Killed and seriously injured scooter riders by crash opponent and age group in Germany 2011-2014 (crashes with one or two participants involved)

4.3 HUNGARIAN NATIONAL ROAD TRAFFIC STATISTICS

In Hungary, between 2007 and 2013 the number of persons killed in road accidents decreased by about 50%. Unfortunately, this tendency was interrupted in 2013.

The following investigation focused on road traffic accidents in Hungary between 2011 and 2014 recorded in the Hungarian Central Statistical Office database. The number of crashes and persons injured were constant in this period, see Table 10.

Table 10: Number of accidents and persons killed or injured (Hungary, 2011 – 2014)

		2011	2012	2013	2014	total
number of accidents	fatal	563	541	540	573	2217
	serious	4527	4355	4687	4713	18282
	slight	10737	10278	10464	10561	42040
	total	15827	15174	15691	15847	62539
number of persons killed or injured	fatal	638	605	591	626	2460
	serious	5154	4921	5369	5331	20775
	slight	15051	14064	14729	14795	58639
	total	20843	19590	20689	20752	81874

Figure 31 shows absolute numbers of killed casualties by age group and traffic participation in Hungary in years 2011-2014. It can be seen that cyclists and pedestrians killed were in average older than other road users. The most endangered cyclist and pedestrian age group seen in the database is between 55 and 64 years old not considering the population size of this specific age group in Hungary.

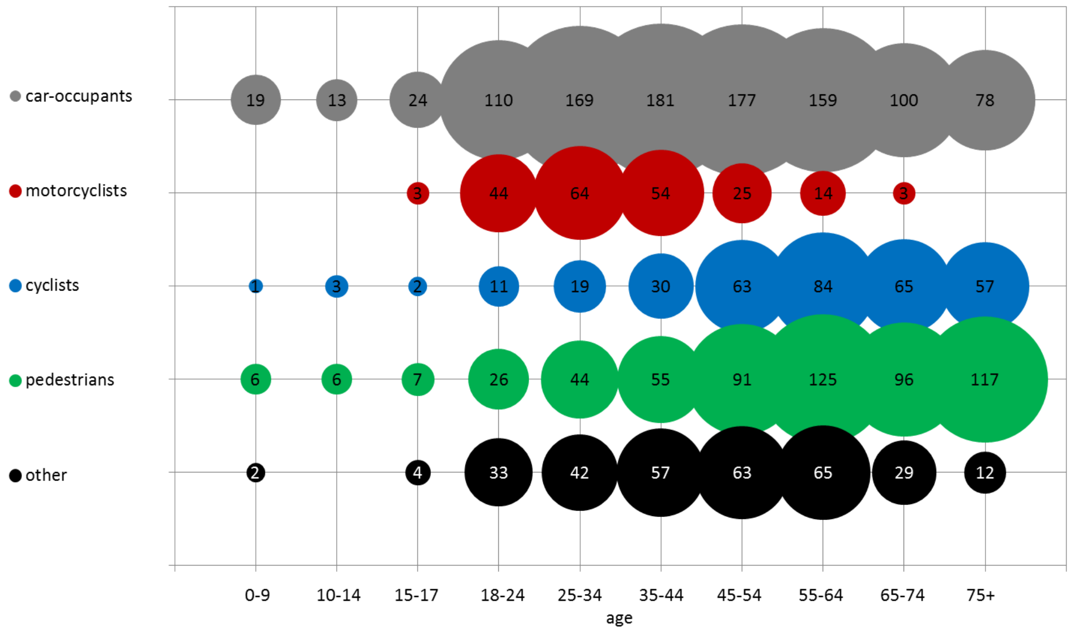


Figure 31: Fatalities by age and traffic participation (Hungary, 2011 – 2014)

Of all accidents involving persons injured, the rate of cyclist accidents was in average 22% and of all persons killed or injured the rate of cyclists was in average 17%. The rate of pedestrian accidents was in average 16% and the rate of pedestrians killed or injured was in average 13%, see Figure 32 and Figure 33.

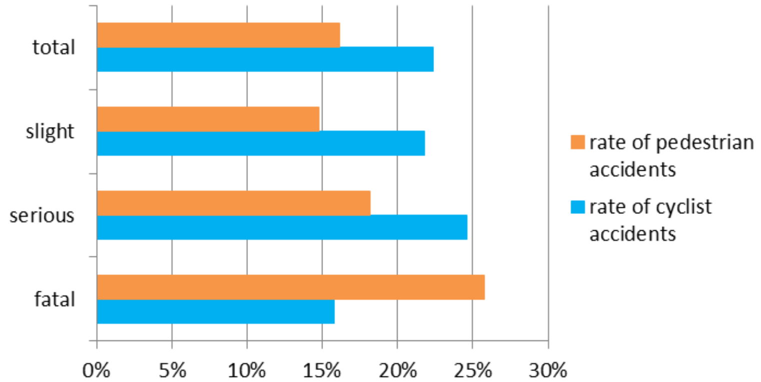


Figure 32: Rate of cyclist and pedestrian accidents (Hungary, 2011 – 2014)

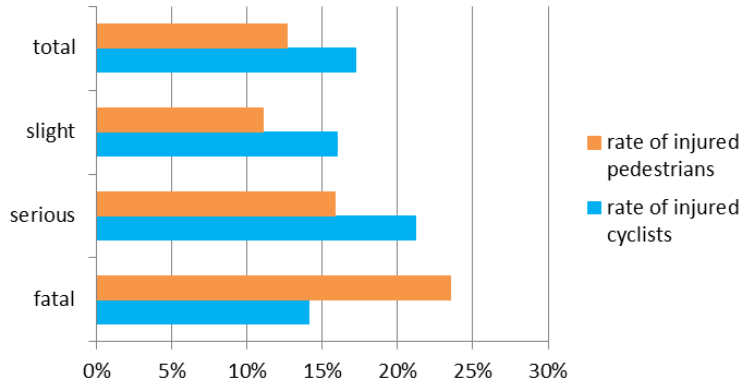


Figure 33: Rate of cyclists and pedestrians killed or injured (Hungary, 2011 – 2014)

About 10 million people live in Hungary, of which 2 million people live in Budapest and its suburbia. Focussing on the region of Budapest, the absolute numbers and percentages of persons injured or killed in road traffic between 2011 and 2014 is presented in Table 11 by road user type. It can be seen that pedestrians accounted for more than half of all persons killed in road traffic accidents and for about one third of all seriously injured casualties.

Table 11: Number and percentage of cyclists and pedestrians injured (Budapest, 2011 – 2014)

Person	Killed	Serious	Slight	Total
Cyclist	13	388	1435	1836
	8%	14%	11%	11%
Pedestrian	86	911	2454	3451
	52%	33%	19%	22%
All	164	2764	13108	16036
	100%	100%	100%	100%

4.4 SWEDISH NATIONAL ROAD TRAFFIC STATISTICS

From 2009-2013, there were 1,489 fatalities recorded in STRADA, see Figure 34. Over this five year period, 7% of the fatally injured were cyclist, more than double pedestrians (15%), and 55% car occupants. The majority of the car occupant fatalities (20%) were in the age of 18-24. More than two-thirds (67%) of the cyclist and pedestrian fatalities were above 55 years, with peak in ages above 75 for the pedestrians (35%). 8% for both, cyclist and pedestrian fatalities were children in ages 17 and under. However, when crashes with fatalities and seriously injured traffic participants were considered together then from the total number of casualties, 16,830, 57% were car occupants, 10% were cyclist and 11% were pedestrians, see Figure 34. The majority of the car occupant KSI (25%) were in the age of 18-24. Most of the KSI pedestrians were older than 75 (18%), compared to most KSI cyclists that were in age group 45-54 (18%), see Figure 35.

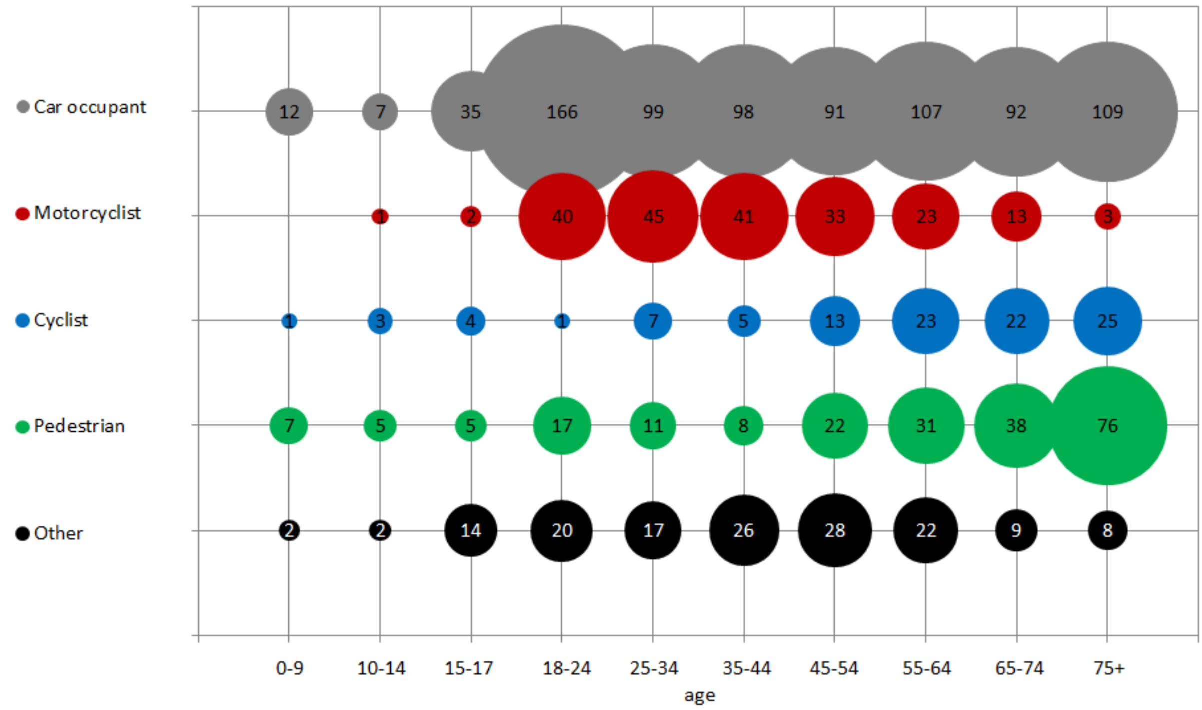


Figure 34: Fatalities in Sweden 2009-2013 by age and traffic participant.

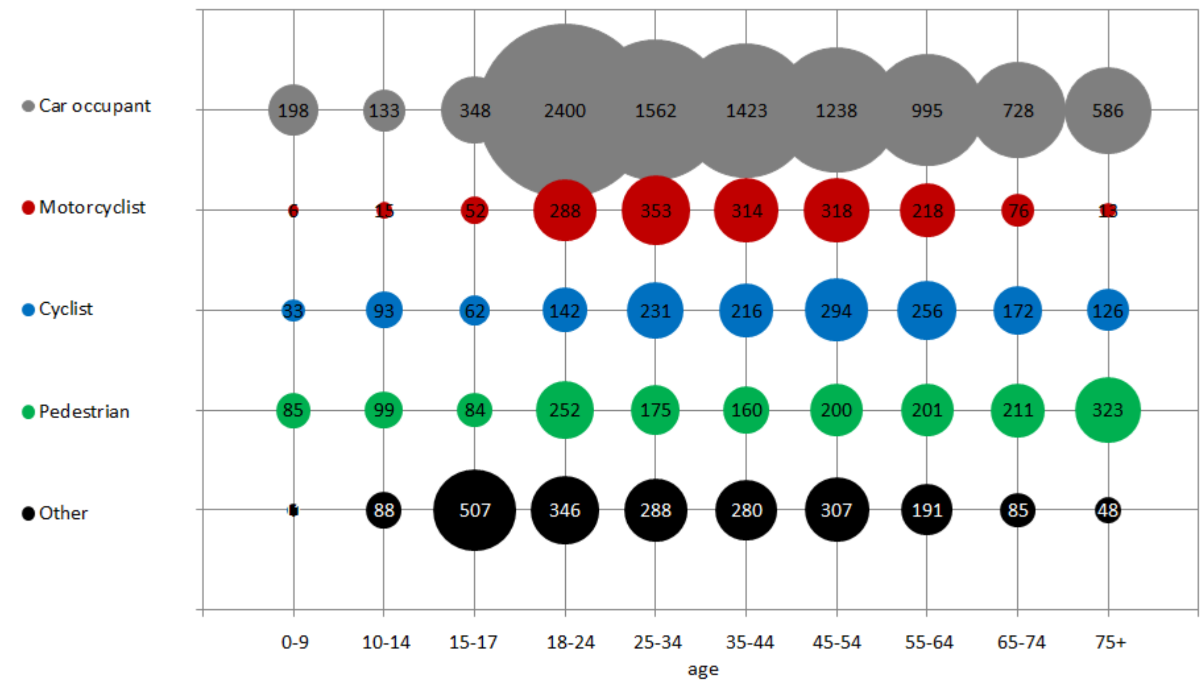


Figure 35: Killed and seriously injured traffic participants by age group in Sweden 2009-2013.

5 CAR-TO-CYCLIST CRASH DETAILS AND SCENARIOS

5.1 ANALYSIS OF IGLAD

IGLAD datasets from Phase I and Phase II 2014 contain data from 11 countries. Phase I includes 1,550 crashes from years 2007 to 2012, while Phase II includes 600 crashes from 2012 to 2013. During this 7 year period, cyclist crashes accounted for 7% (156) of all crashes. Cyclist crashes from Australia, China, India and US are excluded from the analysis to restrict the analysis to European countries whereas the cases from Germany are not included due to separate analysis on GIDAS, Section 5.2. This led to 36 cyclist crashes from which 27 are crashes with two participants, car-to-cyclist. The distribution of cyclist crashes, injuries and accident types are shown in Table 12 and Figure 36. As the majority of the analysed crashes is from Italy (16 crashes), the IGLAD analysis separately considers crashes from Italy, crashes from other EU countries in IGLAD data except Germany (9) and these two sets of crashes combined (27).

There are more urban crashes than rural, but the difference is smaller in Italy than in rest of the EU. The majority of the crashes (around 90%) occurred in bright/dry weather (10% in cloudy) and more than 95% on dry road surface. 15-25% of the cyclist crashes occurred during non-daylight conditions: dawn/twilight (not complete daylight or darkness); electric light (night time but lighting present); and a sudden change of light conditions (e.g. exiting a tunnel). Children aged 7-14 years and adults of 65 years and older accounted for 22% and 28% of cyclist crashes respectively for the combined EU data, but the cyclists older than 75 years were more frequent in Italy than in the rest of the EU. Most common contributing factor to the crashes was “disregarding traffic regulations”. The collision speed of the cyclist was typically between 10-20 km/h while vehicle collision speed was between 0-60 km/h.

Table 12: Distribution of cyclist – car crashes a) per country and b) per injury level using iGLAD cases, 2007-2013.

a)		**b)**	
Country	**Number of cyclist-car crashes**	**Cyclist Injury Level**	**Number of cyclist**
Austria (AT)	3	Not injured	0
Czech Republic (CZ)	4	Slight	7
France (FR)	4	Severe	5
Italy (IT)	16	Fatal	15
	27		**27**

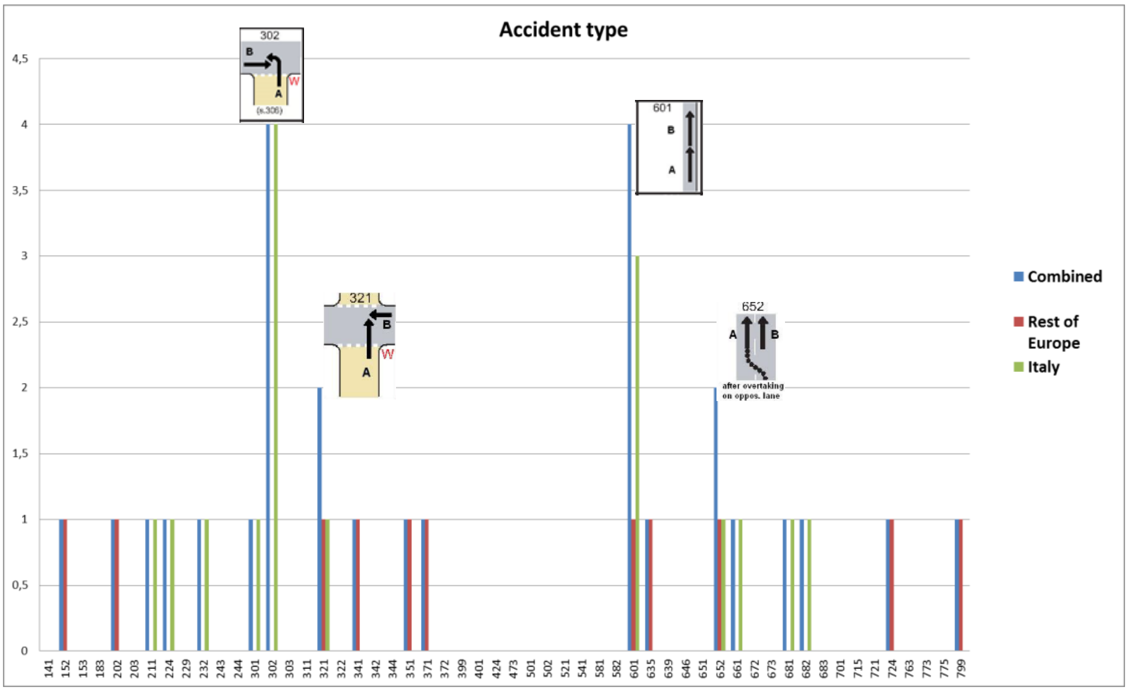
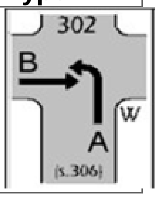


Figure 36: Distribution of car-to-cyclist crashes by three-digit accident type. For Italy, Rest of Europe (AT, CZ, FR) and Combined (IT, AT, CZ, FR). Total of 27 car-to-cyclist crashes in years 2007-2013, iGLAD.

The iGLAD accident types (three-digit-type) were matched to the PROSPECT Accident Scenarios, see Section 3.5, showing that for the combined EU data the most common accident scenario is “Car and cyclist in longitudinal traffic”, followed by “Car straight on, Cyclist from near-side” and “Car turns”. Note that this result is based on a relatively small number of crashes and excluding data from Germany, and another ranking of these accident scenarios was observed in Germany.

A use case was derived from the most common iGLAD accident type “302” (4 car-to-cyclist crashes which all occurred in Italy), by reading the descriptions of the corresponding crashes, see Table 13.

Table 13: Car-to-cyclist use case derived from accident type ‘302’, iGLAD cases 2007-2013.

Description	Vehicle Speed	Collision Speed	Cyclist speed	Acc. Type
A cyclist is turning left onto a priority road. A car is going straight and hits the cyclist on the left side with the front of the car. The Use Case occurs in dry road, clear weather and daylight in urban area. The cyclist is typically a man older than 50 years.	50-90 km/h	55-65 km/h	0-15km/h	

5.2 Analysis of German Data

5.2.1 Car-to-cyclist road traffic accidents of selected states of Germany

In the German statistics there are seven main types of accidents (coded as type 1 to type 7). Each of these main types can be further detailed into sub-types that range up to three levels (e.g., accident type "372"). However, in the German accident statistics this 3-digit accident type information is not available for all federate states of Germany. An analysis of the integrity of the data from the years 2009-2014 showed that this information level is provided to nearly 100% by 5 (out of 16) federate states (Lower Saxony, Northrhine-Westphalia, Rhineland Palatinate, Saxony-Anhalt and Saarland) which by random, represent the German accident occurrence quite well, as non-published studies have shown. It was concluded that only data from these 5 federate states were used for the following analysis.

The German national accident data analysis involved crashes between two participants only (here: exactly one passenger car and one cyclist) and was conducted for urban and rural areas of the accident years 2011-2014, see Table 14 where highest figures for KSI and Fatalities only were highlighted. Consequently, the dataset included 118 cyclist fatalities, 9,275 seriously and 60,592 slightly injured cyclists. Another distinction was made towards the PROSPECT Accident Scenarios as defined in Section 3.5.

Table 14: German national statistics – Analysis of Accident Scenarios (car-to-cyclist crashes 2011-2014)

	Urban areas					Rural areas				
Group	KSI	Killed	Serious	Slight	Total	KSI	Killed	Serious	Slight	Total
V	20%	23%	20%	21%	21%	12%	7%	12%	11%	11%
I	26%	27%	26%	27%	27%	28%	24%	28%	34%	33%
II	16%	17%	16%	14%	14%	22%	27%	21%	16%	17%
III	28%	14%	28%	28%	28%	19%	10%	19%	24%	23%
IV	8%	18%	8%	8%	8%	20%	32%	19%	15%	16%
Parking	1%	1%	1%	2%	2%	0%	0%	0%	1%	0%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

5.2.2 Use Cases

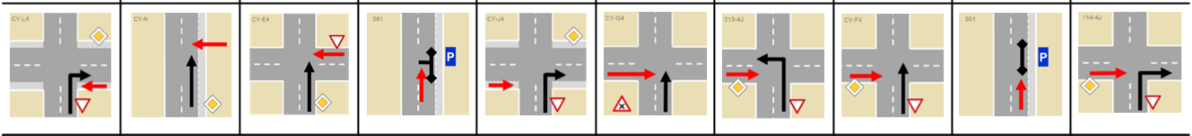
Based on German in-depth crash data (GIDAS) several Use Cases have been derived by case-by-case analyses of 3,550 car-to-cyclist crashes in urban environments (4,272 crashes before setting of primary filters). The method of gathering these car-to-cyclist crash Use Cases was described in [34] and [33].

The results of the crash data analysis confirmed findings of previous studies showing that crossing scenarios play a predominant role in car-to-cyclist crashes. Moreover, the results show that both the orientation of the cyclist and the driver's task (in terms of the driver's manoeuvre intention, road layout, traffic regulations) have an influence on the distribution of those scenarios in so far as certain combinations lead to a

higher or lower distribution. Considering on the one hand the group of “slightly, seriously injured and killed cyclists” and the group “seriously injured and killed cyclists” 35 and 29 Use Cases have been identified, respectively.
Regarding the group including “slightly, seriously injured and killed cyclists” the ten most relevant Use Cases are summarized in Table 15. Hereby, the positions of the Use Cases differ between the ranking and their frequencies found in the crash data. This is because of the method used which applied weighting factors (considering socio-economic costs) to the number of casualties of all injury severity groups (slightly, seriously and fatally injured) and thus, influences the final ranking.

Table 15: Car-to-cyclist Use Cases based on German crash data (GIDAS) including slightly, seriously injured and killed cyclists (cyclist riding direction marked with red arrows, car’s direction with black)

Ranking position									
1	2	3	4	5	6	7	8	9	10



Cumulative relative frequency* [%]									
15.19	18.33	20.13	24.18	28.35	30.25	31.49	32.50	34.51	35.61

*with regard to all car-to-cyclist accidents (n=4,272)

Overall, these first ten Use Cases accounted for 36% of all car-to-cyclist crashes. It can also be seen that crossing scenarios play a predominant role. Another key finding was that car drivers collided more often with a cyclist from the nearside in those situations, in which the cyclist violated road traffic regulations or behaved unexpectedly, see Figure 37. Further main findings were summarized and discussed in [34].

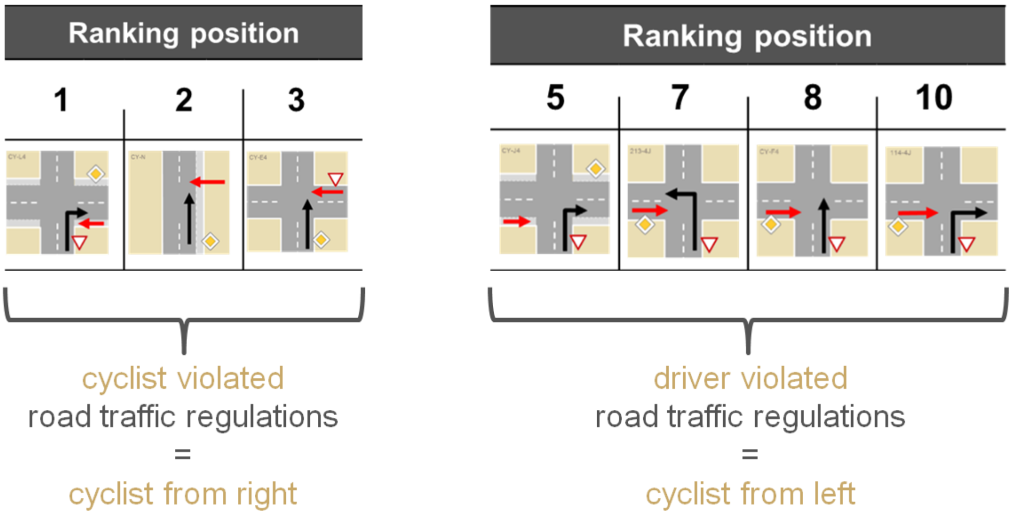


Figure 37: Car-to-cyclist Use Cases based on German crash data (GIDAS) separated for the violation of road traffic regulations by either the cyclist or the car driver (cyclist driving direction marked red)

5.3 ANALYSIS OF HUNGARIAN DATA

5.3.1 Hungarian Central Statistical Office (KSH)

Regarding cyclists, the number of car-to-cyclist crashes has increased by 8% in Hungary between 2011 and 2014. The amount of crashes with outcome of serious injuries to the cyclists increased in the same time by 17%, see Figure 38.

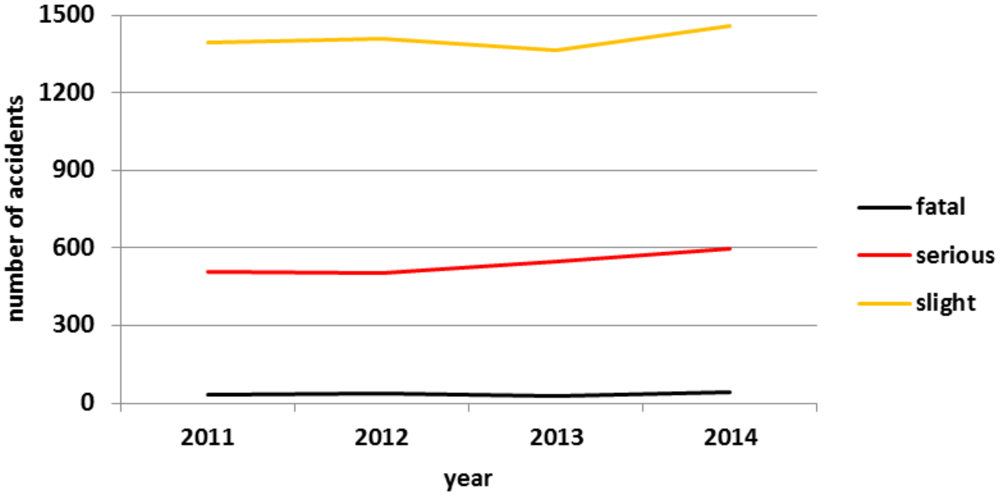


Figure 38: Number of car-to-cyclist accidents (Hungary, 2011-2014)

The most frequent types of crashes involving cyclists accounted for the types “collisions of crossing (but not turning) vehicles at intersections” (20%, 2,862 crashes), followed by “collisions of crossing and turning vehicles at intersections” (19%, 2,620 crashes) and “single vehicle” and “other crashes” (18%, 2,567 accidents), see Figure 39.

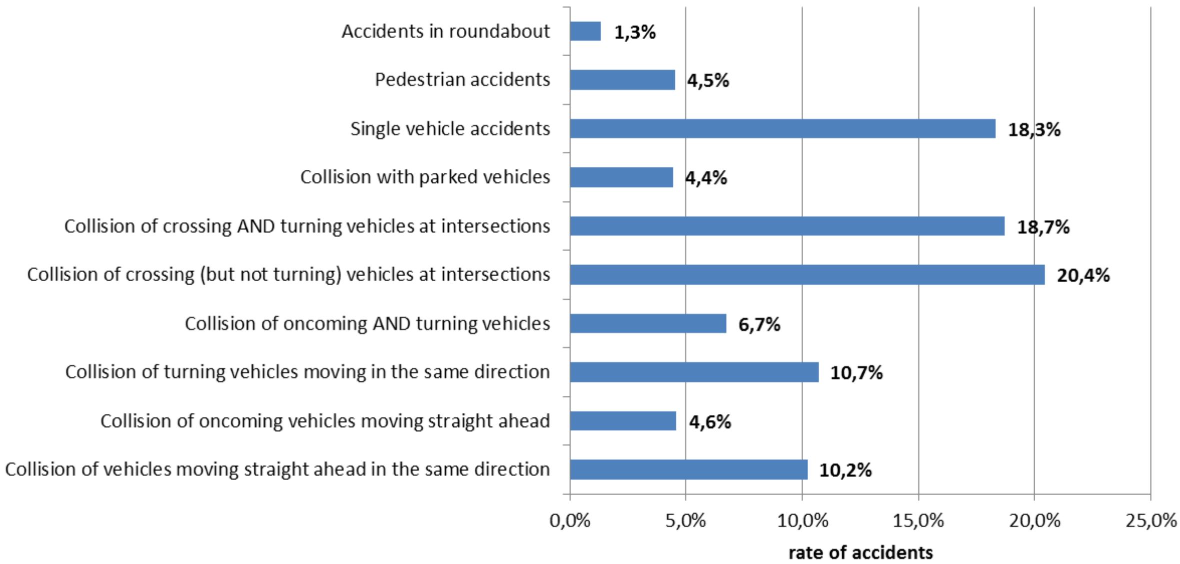


Figure 39: Type of cycling accidents (Hungary, 2011 – 2014)

Figure 40 illustrates the number of injured cyclists in car-to-cyclist crashes by age group and injury severity ranging from slight to fatal injuries. It can be seen that mid-aged and older cyclists were killed most often.

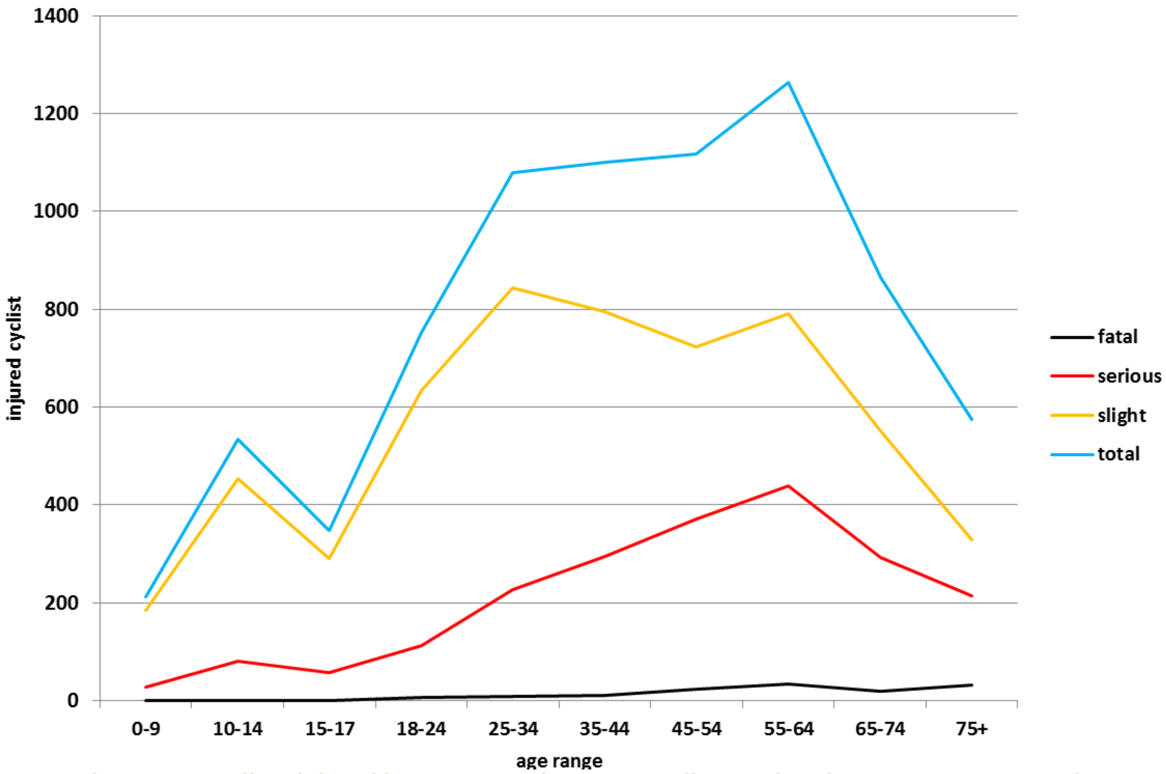


Figure 40: Cyclists injured by age group in car-to-cyclist crashes (Hungary, 2011 – 2014)

Rural areas have been identified as being linked to higher cyclists' injury severities as the impact speeds of the vehicles were in average highest on these roads. In built-up areas, about 25% of the cyclists were injured seriously and more than 70% slightly, see Figure 41.

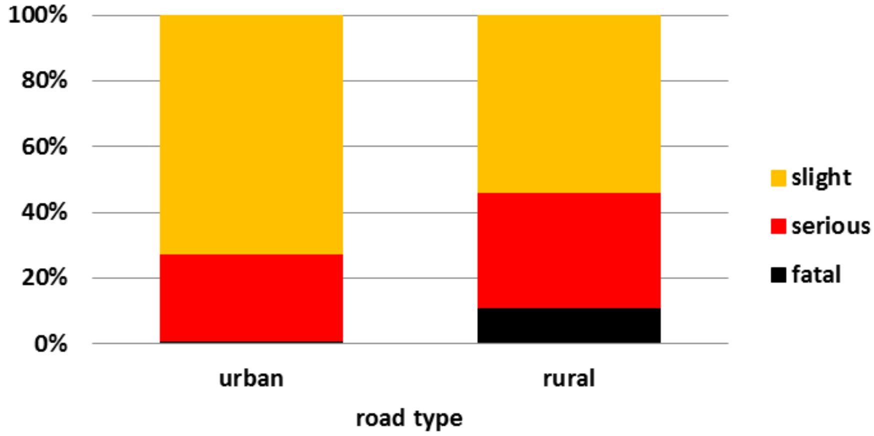


Figure 41: Injury severity in car-to-cyclist crashes by road type in Hungary (2011-2014)

The KSH database offers the distinction into 8 major crash types that were listed and analysed for car-to-cyclist crashes in Figure 42. Two crash types were identified as dominating the statistics: "collision of crossing (but not turning) vehicles at intersections" (29%, 2,264 crashes) and "collision of crossing and turning vehicles at intersections" (26%, 2,078 crashes).

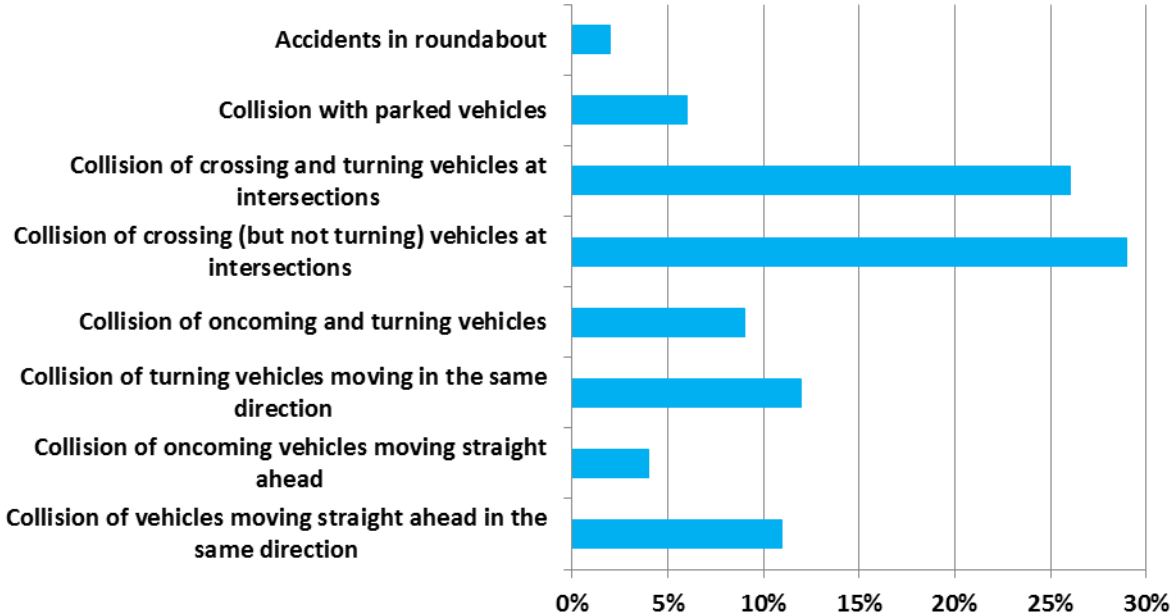


Figure 42: Distribution of car-to-cyclist crashes by accident type (Hungary, 2011-2014)

Regarding the car driver's main fault, it was investigated that the "priority rule violation" (48%, 3,777 crashes) and the "inappropriate changing of lanes" (26%, 2,086 crashes) in car-to-cyclist crashes were seen most often in Hungary, see Figure 41.

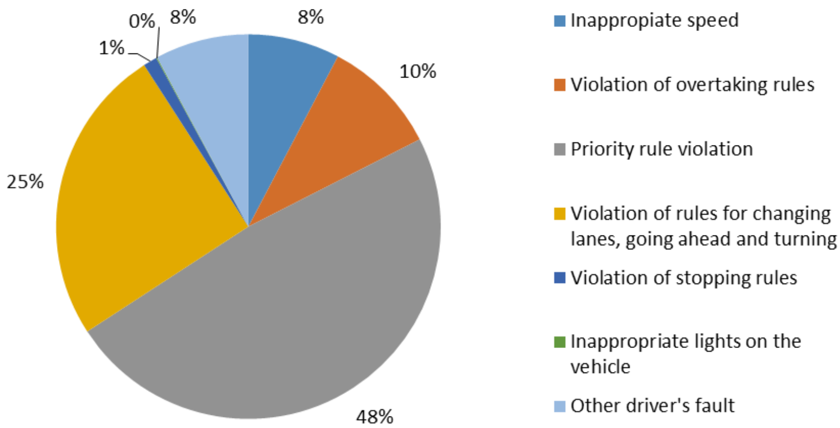


Figure 43: Driver's fault in car-to-cyclist crashes (Hungary, 2011-2014)

A similar pattern was observed when considering the cyclist's faults in car-to-cyclist crashes, see Figure 44.

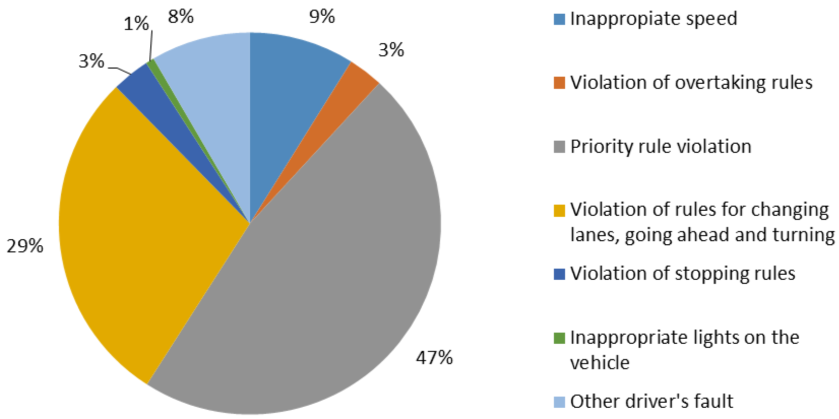


Figure 44: Cyclist's fault in car-to-cyclist crashes (Hungary, 2011-2014)

74% of car-to-cyclist crashes occurred in fair weather conditions, see Figure 45.

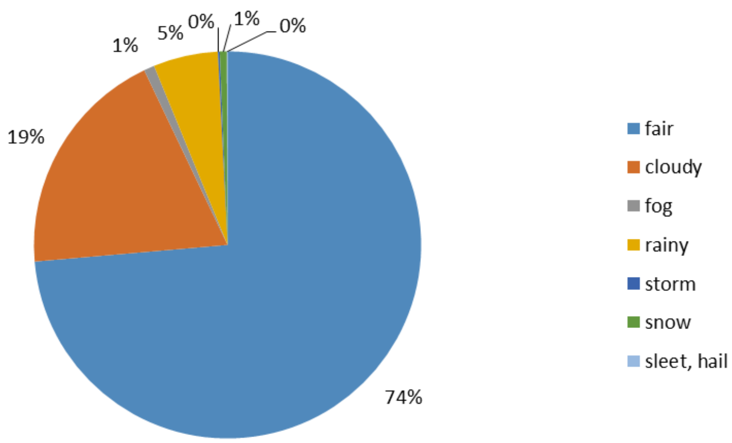


Figure 45: Weather conditions in car-to-cyclist crashes (Hungary, 2011-2014)

82% of car-to-cyclist crashes occurred in natural daylight conditions, see Figure 46.

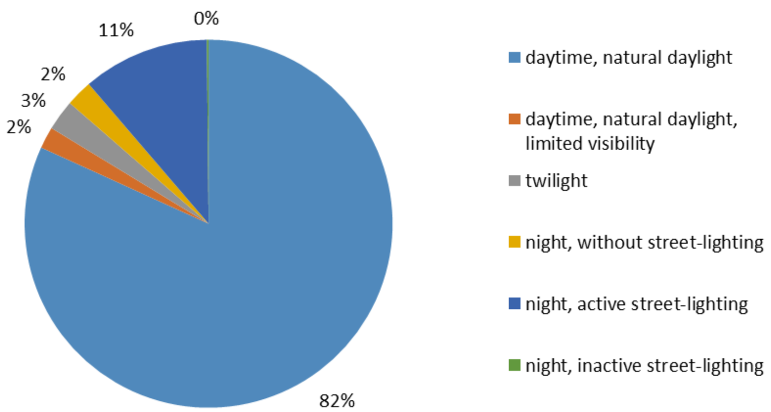


Figure 46: Lighting conditions in car-to-cyclist crashes (Hungary, 2011-2014)

Focusing on car-to-cyclist crashes in Budapest happened in average 16% of total urban crashes, see Table 16.

Table 16: Number of car-to-cyclist crashes in Hungary and the region of Budapest, 2011-2014

		Hungary				Budapest				Budapest			
number of crashes		2011	2012	2013	2014	2011	2012	2013	2014	2011	2012	2013	2014
urban	fatal	26	15	21	20			1	2	0%	0%	5%	10%
	serious	465	472	507	541	44	49	75	62	9%	10%	15%	11%
	slight	1354	1357	1338	1404	239	256	250	255	18%	19%	19%	18%
	total	1845	1844	1866	1965	283	305	326	319	15%	17%	17%	16%

5.3.2 In-depth analysis of car-to-cyclist collisions in Hungary

The advantage of the dataset from Budapest is the availability of the information on the exact crash location which was used to generate heat maps highlighting hot spots (frequently affected crash location on main roads and intersections) in the road network regarding crashes involving cyclists. In Budapest, between 2011 and 2013, 8 fatal, 280 serious and 1,071 slight cyclist crashes occurred that were included in the heat map shown in Figure 47. This figure was primarily used to select the naturalistic observation spots of other PROSPECT activities.

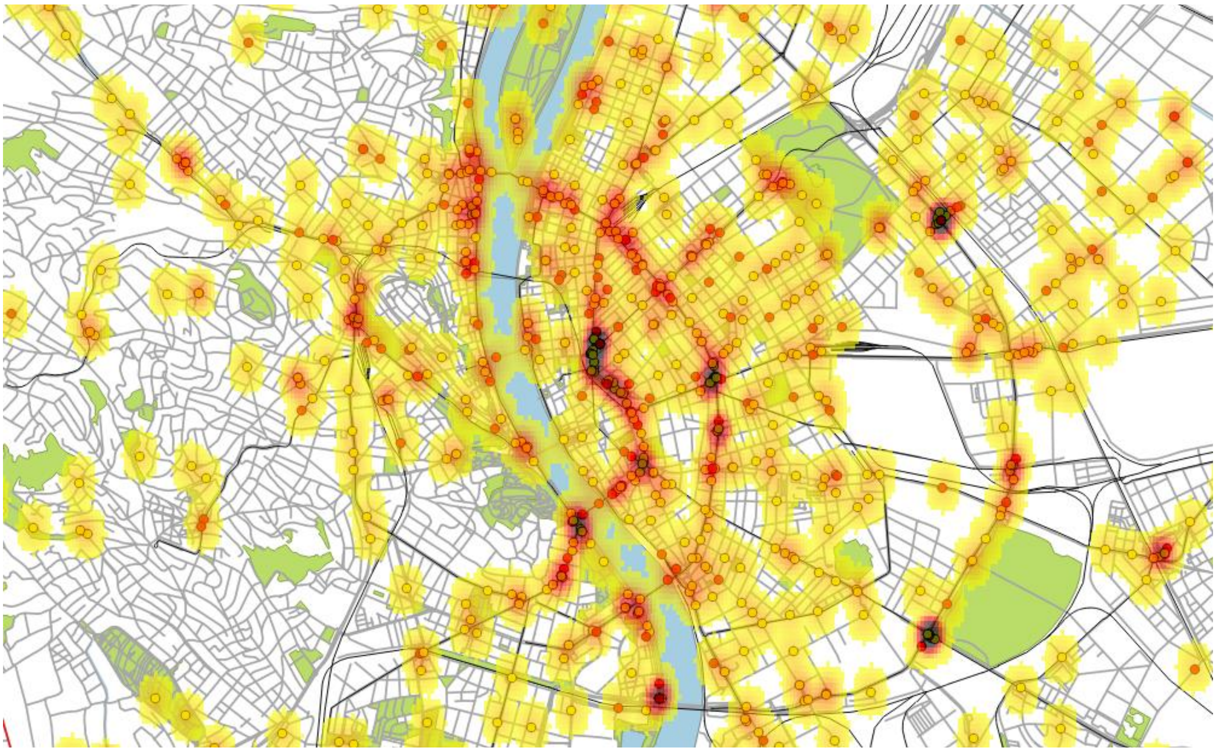


Figure 47: Cyclist accidents heat map (Budapest, 2011-2013)

The selection of crashes that were examined in the in-depth analysis was based on the following criteria: 1) Car and cyclist were in motion, 2) Cyclist was fatally or seriously injured and 3) Crashes in urban areas (Budapest or Pest County). Further, seven crash categories were used to identify leading accident types, see Table 17.

Table 17: Car-to-cyclist crashes by accident type category in the Hungarian in-depth crash database

Type set	Total of personal injured accidents	Fatal or serious accidents	
		Number	Percentage
Collision of vehicles moving straight ahead in the same direction	205	57	15%
Collision of oncoming vehicles moving straight ahead	80	21	5%
Collision of turning vehicles moving in the same direction	309	71	19%
Collision of oncoming and turning vehicles	201	45	12%
Collision of crossing (but not turning) vehicles at intersections	530	97	25%
Collision of crossing and turning vehicles at intersections	421	89	23%
Accidents in roundabout	22	3	1%
Total	1,768	383	100%

Out of these 1,768 crashes summarized in Table 17, 100 crashes have been randomly selected for further investigations keeping the proportions per accident type. Table 18 shows the resulting sample.

Table 18: Number of crashes by accident type in the sampling

Accident type	Set
Collision of vehicles moving straight ahead in the same direction	**15**
101 Collision from behind, vehicle is overtaking from left	1
103 Collision from behind, vehicle is changing lane from right to left	1
105 Rear-end collision with at least two moving vehicles	5
108 Collision with starting vehicle from right side	1
109 Collision between side by side moving vehicles	2
110 Other accident between moving vehicles going ahead co-directional	3
111 Collision from behind, vehicle is overtaking from right	2
Collision of oncoming vehicles moving straight ahead	**6**
201 Collision of oncoming vehicles on straight road, one is overtaking or changing lane	1
202 Collision of oncoming vehicles in curve, one is overtaking or changing lane	1
206 Collision of oncoming vehicles in curve (no overtaking, no lane changes)	1
210 Other collision of oncoming vehicles	3
Collision of turning vehicles moving in the same direction	**19**
301 Collision of co-directional vehicles at crossing, one is turning to right	5
302 Collision of co-directional vehicles at crossing, one is turning to left	2
304 Collision of co-directional vehicles at crossing, both are turning to left	1
310 Other collision of co-directional vehicles	10
Collision of oncoming and turning vehicles	**12**
401 Collision of oncoming vehicles at intersection, one is turning to left	9
404 Collision of oncoming vehicles, at least one is turning or u-turning	1
410 Other collision of oncoming and turning vehicles	2
Collision of crossing (but not turning) vehicles at intersections	**24**
501 Collision of crossing vehicles	24
Collision of crossing and turning vehicles at intersections	**23**
601 Accident between co-directional moving vehicles at crossing, one is turning to right	6
602 Accident between oncoming vehicles at crossing, one is turning to right	2
603 Accident between co-directional moving vehicles at crossing, one is turning to left	10
610 Other accident between crossing and turning vehicles	5
Accidents in roundabout	**1**
2001 Collision with entering vehicle	1
Total	**100**

This sample of 100 crashes was analyzed towards the PROSPECT Accident Scenarios introduced in Section 3.5 and summarized in Table 19.

Table 19: Case numbers of the Hungarian In-Depth Accident Analysis per Accident Scenario

Group	Scenario	Intersection	Vehicle driving direction	Cyclist driving direction	Cyclist used lateral roadside areas	KSI [%] 100 accidents = 100%	
	0	Other				1	1
I	1	yes	Straight on	From right	Yes, before intersection	4	16
	2				No, on normal road	9	
	3				Yes, after intersection	2	
	4	no			n/a	1	
II	5	yes	Straight on	From left	Yes, before intersection	5	16
	6				No, on normal road	7	
	7				Yes, after intersection	3	
	8	no			n/a	1	
III	9	yes	Turn into, NOT crossing oncoming traffic	Longitudinal	No, on normal road	8	37
	10				yes	8	
	11		Turn into, crossing oncoming traffic		No, on normal road	15	
	12				yes	6	
IV	13	yes	Longitudinal	Same or opposing direction	yes	0	29
	14				No, on normal road	9	
	15	no			yes	0	
	16				No, on normal road	20	
	17	no	Parking (forward and backwards driving) from lateral lineup	From side	n/a	1	1

In three quarters (75%) of the crashes examined in detail the primary reason of crashes was assigned to the violation of traffic rules and a quarter (25%) of the cases was linked to the driver's fault, see Figure 48.

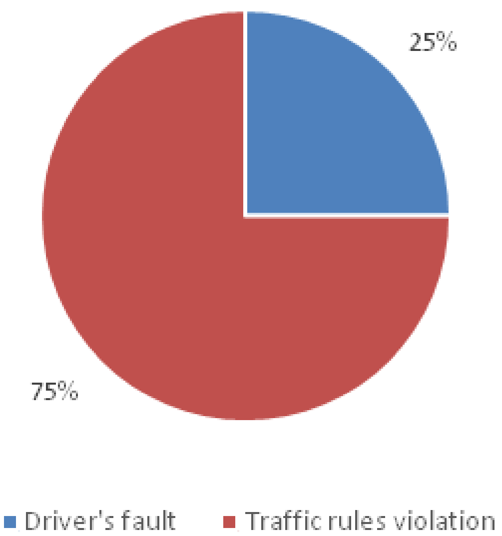


Figure 48: Rate of the primary reasons

Among the violations of traffic rules, the most frequent recorded type was the "violation of priority rules at priority signs" (33%) and the "violation of turning priority rules" (23%), see Figure 49.

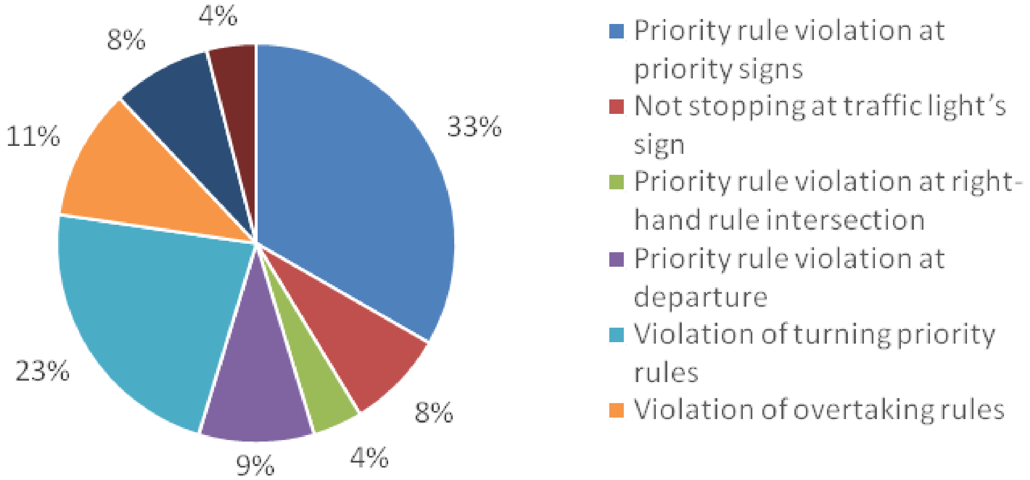


Figure 49: Rate of car driver's traffic rules violation

Among driver's faults, "inappropriate speed" and "following distance" and "other driver's faults" had highest shares with each 20%. Further, "obstruction of straight-ahead moving vehicle" accounted for 16% of the cases, see Figure 50.

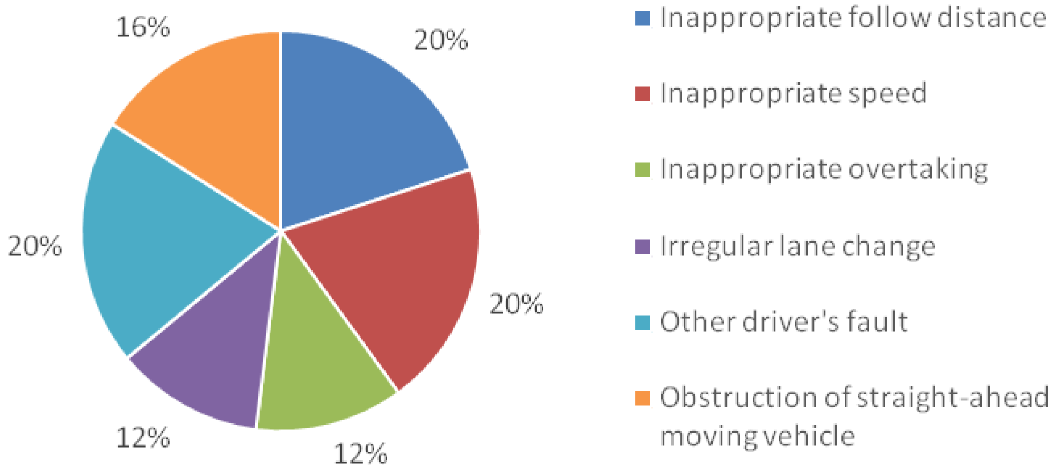


Figure 50: Rate of the driving faults

Another investigation was made on the cyclist's visibility by the car driver's point of view examining the visibility of the cyclists five seconds prior to the collision per accident type, see Figure 51. Based on this analysis it can be stated that visibility was very limited in the case of collisions assigned to "crossing (but not turning) vehicles at intersection".

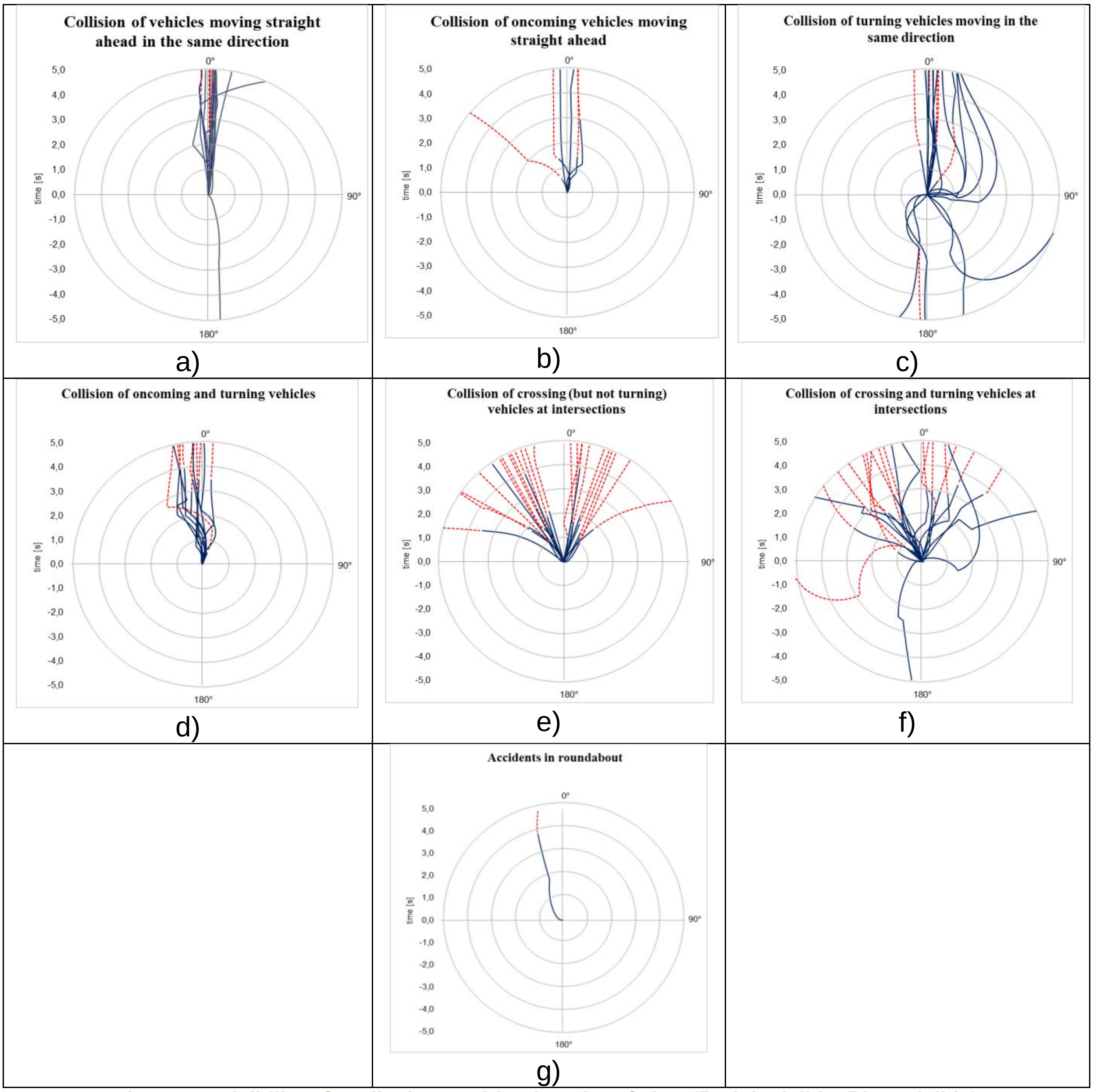


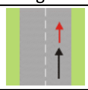
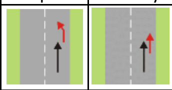
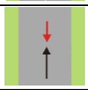
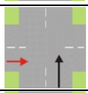
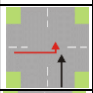
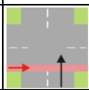
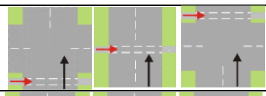
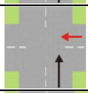
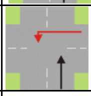
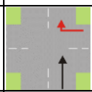
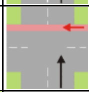
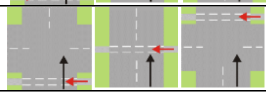
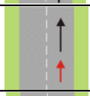
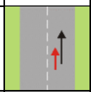
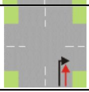
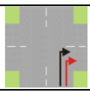
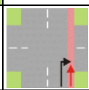
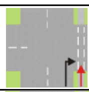
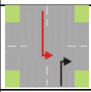
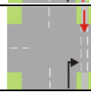
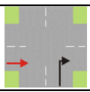
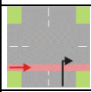
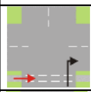
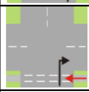
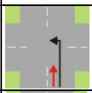
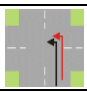
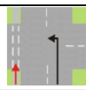
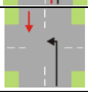
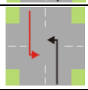
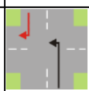
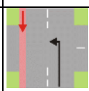
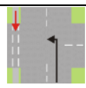
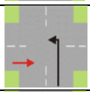
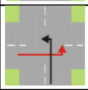
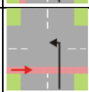
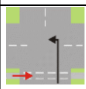
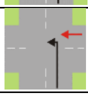
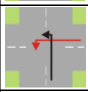
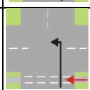
Figure 51: visibility of cyclist by car driver's point of view (Red: invisible, Blue: visible)

5.3.3 Use Cases

The Hungarian KSH database does not include distinguishing appropriately between the crash participants' moving directions in all cases. Therefore, it was decided to use the sample of the 100 crashes from Budapest and Pest county for the analysis of the Use Cases. However, as this sample was small it was not possible to apply the same method from [34] to the Hungarian dataset. Thus, Use Cases were derived for Hungary, but cannot be compared directly to the Use Cases in [33].

The categorization was determined by two factors; firstly, by the content of the available database and secondly, by the aims of the study. Following the basic approach from [34], the car-to-cyclist crash Use Cases classification was conducted focusing on the car driver's point of view. Consequently, 14 categories have been identified considering the relative direction and motion of the cyclist, see Table 20. This classification allows detailed visibility assessments of both, car drivers and cyclists.

Table 20: Categories of Hungarian Use Cases for car-to-cyclist crashes

	Car	Cyclist								
		Relatve direction	Roadway					Bicycle lane	Sidewalk/bikeway before/in/after intersection	
			Straight ahead	Turn left	Turn right	Depart	Sideways			Visibility
AS		Same direction								-90° - 90°
AO		Opposite direction								-90° - 90°
AL	Straight ahead	From left								-90° - 0°
AR		From Right								0° - 90°
AB		From behind								90° - 270°
RS		Same direction								0° - 180°
RO	Turn right	Opposite direction								0° - 180°
RL		From left								0° - -180°
RR		From Right								0° - 180°
LS		Same direction								0° - 360°
LO	Turn left	Opposite direction								0° - -180°
LL		From left								0° - -180°
LR		From Right								0° - 180°
PB	Parking	From behind								90° - 270°

5.4 ANALYSIS OF SWEDISH DATA

5.4.1 Swedish national road traffic statistics

In this section, data from the national crash database STRADA in Sweden is described. The extracted dataset contained in total 6,825 car-to-cyclist crashes with exactly two traffic participants (one car and one bicycle) during the years 2009-2013, an average of 1,365 crashes per year. In these crashes 6,825 bicycles were involved, with 43 of them, carrying two persons on the bicycle, which led to 6,868 persons injured on the bicycle. The following paragraphs are focusing on the distribution of the injury extent, crash factors and cyclist characteristics of these 6,868 persons.

During this five year study period, the injury severity distribution of cyclists in car-to-cyclist crashes was as follows: 1% fatally injured, 13% severely and 85% slightly injured cyclists (1% were assigned to an unknown injury severity). The car-to-cyclist crashes involving older cyclists with an age of 75 years or higher accounted for one third of the fatalities while more than two-thirds of the severely and slightly injured were cyclists aged 18-64, see Figure 52. 53% of cyclists involved in these crashes and 65% of cyclists fatally injured were male.

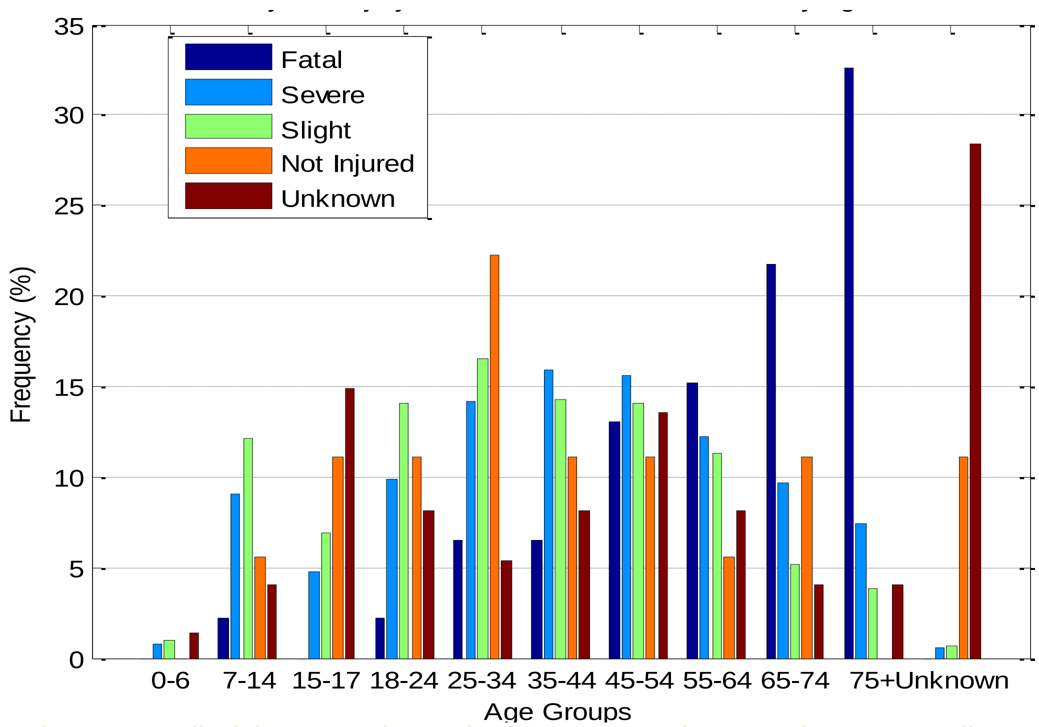


Figure 52: Cyclist injury extent in Sweden by age groups (2009-2013). N=6,868 cyclists.

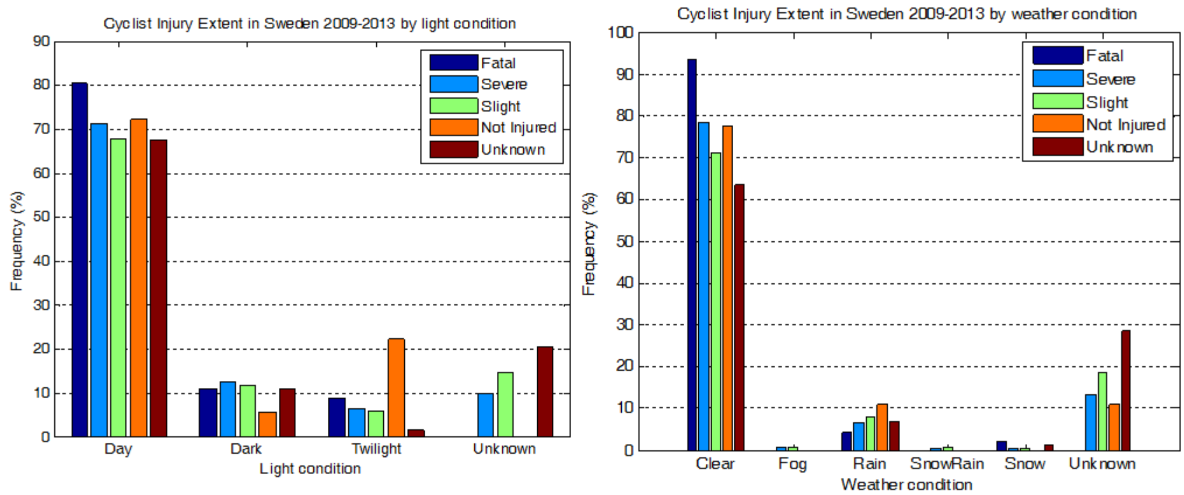


Figure 53: Cyclist injury extent in Sweden (2009-2013) by light (left) and weather conditions (right).

The majority of crashes occurred during daylight and in clear weather conditions, see Figure 53.

Most crashes where the cyclist was slightly or severely injured occurred in urban traffic environment (around 80%). However, the cyclist fatality rate was reported to be half and half regarding urban and non-urban environments, see Figure 54.

Posted speed limit, used as a proxy for vehicle speed, showed that more than 30% of all crashes occurred at 50km/h, see Figure 54.

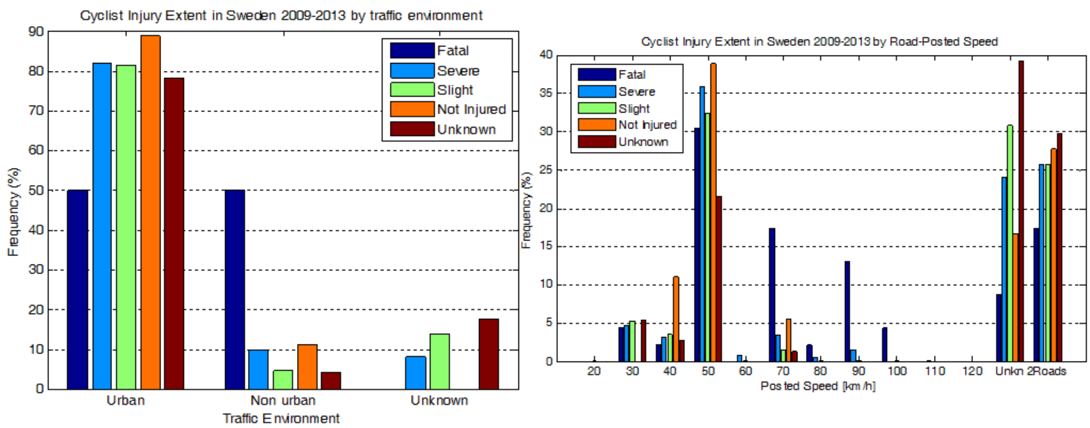


Figure 54: Cyclist injury extent in Sweden (2009-2013) by traffic environment (left) and posted speed limit (right).

The PROSPECT Accident Scenarios (see Section 3.5) could not be derived directly from STRADA variables, therefore the following two-step procedure was applied:

1) CATS classification of accident scenarios [5] and the accident scenario distributions for the fatalities and AIS2+ was used based on [10].
2) Manual classification of a random sample from the AIS1 crashes according to the CATS accident scenarios was performed (reading a simplified sketch and crash summary for each case in STRADA). The random sample was based on the same selection criteria as used in the paper (i.e. the sampling period is 1 January 2010 - 31 January 2014) and contained 30 cases per year for 2010-2013 and 3 cases for January, 2014, altogether 123 cases.

This allows compatibility with the rest of the analysis from STRADA, although with a slightly different sampling period and using results from [10] in which manual classification on STRADA is performed by taking into account AIS2+ injuries per accident scenario. In this way, the analysis covered all AIS2+ and fatal cases and a sample of AIS1 cases in Sweden in the period 1 January 2010 - 31 January 2014. The CATS accident scenarios were then transformed into the PROSPECT Accident Scenarios (I-V) and the result of the analysis is shown in Table 21. Most frequent PROSPECT Accident Scenarios for Sweden were:

- Straight crossing scenarios – groups I and II for AIS1 and AIS2+ injuries, and
- Longitudinal scenario – group IV for fatalities.

In the group Others (V) 56% of the crashes occurred on roundabouts. If AIS2+ and fatal injuries are grouped together then most frequent Accident Scenarios for Sweden were Straight crossing scenarios – groups I and II.
In urban areas Accident Scenario groups I and II contributed to 68% for both AIS2+ and fatal injuries together and 68% for AIS1 injuries, but in rural areas groups III and IV are most common and contribute to 66% of AIS2+ and fatal injuries and 50% of the AIS1 injuries.

Table 21: Distribution of Accident Scenarios for Sweden. N=123 crashes with cyclist AIS1 injury; N=435 crashes with cyclist AIS2+ injury; N=104 crashes with cyclist fatality.

Group	Urban and rural areas				
	AIS2+ and Fatal	Fatal	AIS2+	AIS1	All
V – Others	10%	8%	11%	13%	11%
I - Car straight on, Cyclist from near-side	28%	23%	29%	34%	29%
II - Car straight on, Cyclist from far-side	33%	27%	34%	33%	33%
III - Car turns	13%	3%	15%	12%	13%
IV - Car and cyclist in longitudinal traffic	17%	40%	11%	7%	15%
Total	100%	100%	100%	100%	100%

5.4.2 Volvo Cars Cyclist Accident Database

The sample from V_CAD used for the study of accident characteristics consisted of 311 car-to-cyclist crashes. Due to small sample size, all crashes occurring between 2005-2013 were included. For the injury analysis, detailed injury information was available for 308 cyclists with a total of 786 injuries.

The conflict situation classification scheme from V_CAD, see also Appendix C.1 was used to aggregate the figures to PROSPECT Accident Scenarios according to Table 22.
Based on the crash investigator's compilation of all information of the pre-crash phase, each case was digitalized in order to provide vehicle paths in relation to vehicle velocities and to the surroundings.
Medical records and/or autopsy reports for cyclists involved were collected using an informed consent procedure, and injuries were coded by a physician within Volvo

Cars Traffic Accident Research Team, according to the Abbreviated Injury Scale (AIS). No attempt was made to assign a cyclist injury to a specific impact area; all injuries were regarded as sustained in the car-to-cyclist crash from either impact against a part of the car, the ground or the surroundings. In cases where photos of the car damage were available, experts within the Volvo Cars crash investigation team coded the car deformation following SAE recommended practice, along with cyclist impact point x-, y- and z-coordinates.

Table 22: Comparison of the Conflict situation classification in V_CAD and the PROSPECT Accident Scenarios

PROSPECT Accident Scenarios		Conflict situation classifications in V_CAD
(I)	Car straight on, Cyclist from near-side	SCPcr, $SCPcr_{OD}$, $SCPcr_{SD}$
(II)	Car straight on, Cyclist from far-side	SCPcl, $SCPcl_{OD}$, $SCPcl_{SD}$
(III)	Car turns	LT/OD, LT/OD_{LD}, LT/OD_{RD} LT/SD, LT/SD_{LD}, LT/SD_{RD} LT/RD LT/LD RT/OD, RT/OD_{LD}, RT/OD_{RD} RT/SD, RT/SD_{LD}, RT/SD_{RD} RT/RD RT/LD
(IV)	Car and cyclist in longitudinal traffic	Oncoming, SD
(V)	Others	Reversing, Dooring, Other

Also, according to the sample size, the distribution of crashes per Conflict situations, see Appendix C.1 and Figure 55, and per PROSPECT Accident Scenarios, Table 23, are presented for MAIS2+ injured cyclist crashes (n=70) accompanied by a reference of all (MAIS0+) car-to-cyclist crashes. A majority of crashes are SCP situations with 34% of all MAIS2+ injured cyclists. LT/OD and RT/OD, the car turning and cyclist approaching from opposite direction situations, accounted for 17% of MAIS2+ crashes. In 10% of the crashes with injured cyclists, the cyclist hit the car door that was being opened by the car driver or a passenger. Situations in longitudinal traffic, including the Oncoming and the SD situations, comprise 9% of MAIS2+ injury crashes. In LT/LD, 8% of MAIS2+ cyclists were found. RT/RD held 6% of MAIS2+ causalities. The same share of MAIS2+ cyclists was found when grouping LT/SD and RT/SD situations. There was 4% of the MAIS2+ injured cyclists in both crashes where the car was reversing and the car was standing still. The smallest portions of injured cyclists were found in merging path situations; RT/LD and LT/RD. Two out of the 70 reported MAIS2+ injured cyclists suffered from fatal injuries. They were both involved in 'front to front' crashes in Oncoming situations.
Accordingly, for PROSPECT Accident Scenarios*, (IV) Car turns* is the most common type of crash followed by *(III) Car straight on, Cyclist from far-side* and *(V) Others* where the latter one includes situations with cars standing still, dooring, and car reversing crashes. This is different from the results seen in the Swedish national data where (I) and (II) were most frequent. One reason for this could be the issue of underreporting in the official data. According to [35], only about 50% of data from the

insurance company was covered in national statistics. The subset of non-reported crashes was on average less severe than police reported crashes, but a substantial proportion had AIS2 injuries to the head and the extremities. Another reason could be the data available to perform conflict situation classification that is rather limited in official data. In (28), it was noted that using a less detailed version of the conflict classification scheme, the SCP share of conflicts was somewhat larger than in the current classification. This was due to not considering turning manoeuvres by drivers involved in crashes in intersections in the previous conflict situation coding. A substantial share of SCP situations was moved to the LT/LD and RT/RD situations when using the more detailed coding scheme. This shows the importance of precise conflict situation interpretation and coding from the crash data collected.

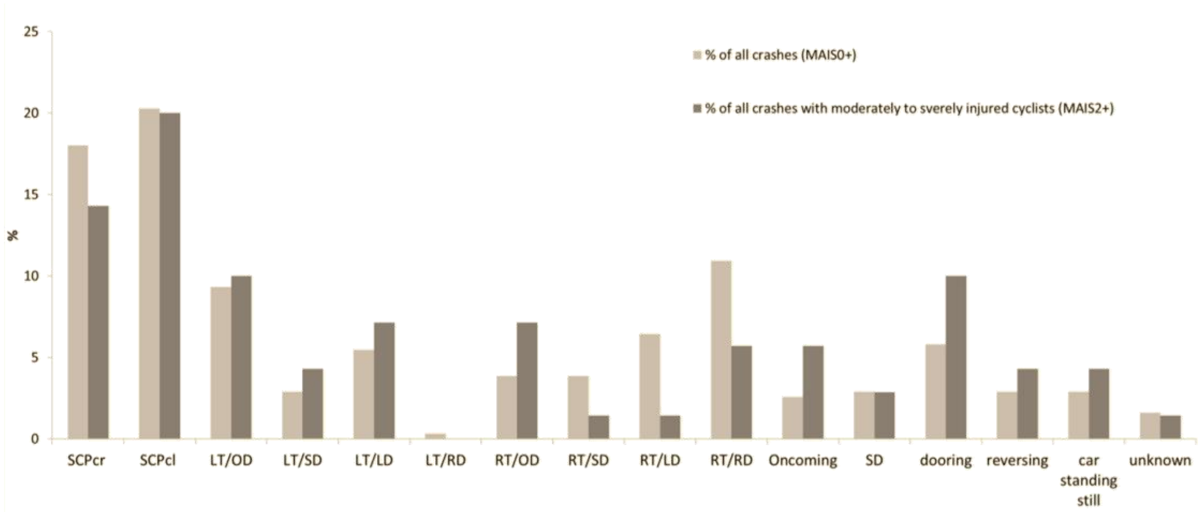


Figure 55: **Distribution of Conflict Situations for all crashes (MAIS0+) and MAIS2+ injury crashes.**

Table 23: Distribution of PROSPECT Accident Scenarios for all crashes (MAIS0+) and MAIS2+ injury crashes.

PROSPECT Accident Scenarios		MAIS2+	MAIS0+
(I)	Car straight on, Cyclist from near-side	14%	18%
(II)	Car straight on, Cyclist from far-side	20%	20%
(III)	Car turns	37%	43%
(IV)	Car and cyclist in longitudinal traffic	9%	5%
(V)	Others	20%	13%

In Table 24 pre-crash factors are presented for conflict situations where the car was moving forward. Impact speed estimations for the car were available in 245 cases. Highest mean impact speed was found in *(IV) Car and cyclist in longitudinal traffic*. The lowest impact speeds were found in *(III) Car turns* crashes. In 20% of the car moving forward crashes, a sight obstruction was hindering the driver from detecting the cyclist prior to the crash. The majority of car-to-cyclist crashes occurred in daylight or in street light. Dry road conditions were present in more than 50% of the cases in most conflict situations. Senior cyclists were most common in RT/RD and in SCPcl. The most common crash configuration was car front to cyclist side in 45% of crashes when the car was moving forward.

Table 24: Descriptive statistics for pre-crash factors and crash configuration in the Volvo Cars Cyclist Accident Database for all crashes (MAIS0+) in conflict situations where the car was moving forward; juniors (up to 14 years old), adults (15-64 years old) and seniors (65 years or older).

	SCPcr	SCPcl	LT/OD	LT/SD	LT/LD	LT/RD	RT/OD	RT/SD	RT/LD	RT/RD	Oncoming	SD	total
	n=56	n=63	n=29	n=9	n=17	n=1	n=12	n=12	n=20	n=34	n=8	n=9	
car impact speed													
mean (km/h)	21 (S.D. 12)	20 (S.D. 10)	14 (S.D. 5)	11 (S.D. 5)	11 (S.D. 5)		15 (S.D. 6)	12 (S.D. 5)	15 (S.D. 6)	7 (S.D. 4)	29 (S.D. 12)	44 (S.D. 27)	**17**
75th percentile (km/h)	30	25	18	15	15		19	16	19	10	36	70	**20**
50th percentile (km/h)	20	20	15	10	10	10	15	15	16	5	30	43	**15**
25th percentile (km/h)	10	10	10	5	6		10	8	11	5	19	23	**10**
unknown	4	7			2			4	7			1	**25**
sight obstruction													
yes	32%	19%	7%	0%	12%	0%	0%	0%	15%	50%	13%	0%	**20%**
no	68%	81%	93%	100%	88%	100%	100%	100%	85%	50%	88%	100%	**80%**
light condition													
light	91%	83%	66%	33%	71%	100%	83%	75%	55%	88%	75%	89%	**79%**
dark with street lights	5%	5%	14%	67%	6%	0%	17%	0%	25%	6%	13%	0%	**10%**
dark	0%	5%	7%	0%	6%	0%	0%	0%	10%	3%	0%	0%	**3%**
unknown	4%	8%	14%	0%	18%	0%	0%	25%	10%	3%	13%	11%	**8%**
road condition													
dry	75%	62%	55%	22%	65%	100%	58%	50%	55%	65%	88%	67%	**63%**
wet	2%	19%	10%	56%	12%	0%	17%	8%	10%	12%	0%	0%	**12%**
snow/ice	2%	0%	3%	0%	0%	0%	0%	0%	5%	6%	0%	0%	**2%**
unknown	21%	19%	31%	22%	24%	0%	25%	42%	30%	18%	13%	33%	**23%**
cyclist age													
junior	23%	16%	7%	0%	0%	0%	0%	8%	0%	15%	38%	0%	**13%**
adult	68%	65%	72%	78%	76%	100%	92%	83%	80%	62%	63%	89%	**71%**
senior	7%	16%	10%	11%	12%	0%	8%	0%	0%	18%	0%	0%	**10%**
unknown	2%	3%	10%	11%	12%	0%	0%	8%	20%	6%	0%	11%	**6%**
crash type													
car front to cyclist front	5%	6%	24%	0%	6%	0%	25%	8%	10%	9%	100%	0%	**12%**
car front to cyclist side	39%	60%	34%	44%	35%	100%	50%	8%	45%	74%	0%	0%	**45%**
car front to cyclist rear	2%	2%	0%	0%	0%	0%	0%	0%	10%	0%	0%	33%	**3%**
cyclist front to car side	45%	30%	38%	56%	53%	0%	25%	67%	30%	15%	0%	0%	**34%**
car side to cyclist side	2%	2%	3%	0%	0%	0%	0%	0%	5%	3%	0%	56%	**4%**
unknown	7%	0%	0%	0%	6%	0%	0%	17%	0%	0%	0%	11%	**3%**

5.5 SUMMARY AND DISCUSSION

Crash databases from Germany, Hungary and Sweden have been analyzed regarding car-to-cyclist crashes of recent years. Although basic crash configurations had been chosen to form the PROSPECT Accident Scenarios, see Section 3.5, different methods had to be applied to calculate respective figures for the different countries.

Table 25 shows a comparison of the results of the accident scenario analysis using the groups (I) “Car straight on, Cyclist from near-side”, (II) “Car straight on, Cyclist from far-side”, (III) “Car turns”, (IV) “Car and cyclist in longitudinal traffic” and (V) “Others”.
Focusing on killed and seriously injured (KSI) cyclists in car-to-cyclist crashes it can be seen that results were similar regarding the accident scenarios car is going straight on and cyclist crosses either from near- or far-side. Around 42%-52% of all casualties were assigned to them. However, the results vary a lot between these countries looking at Accident Scenarios III and IV. In particular Hungary seems to

have major issues with cyclists in longitudinal traffic compared to Germany and Sweden which could also be caused by infrastructural differences.
Focusing on killed cyclists in car-to-cyclist crashes it can be seen that in all countries the accident scenario IV (longitudinal traffic) made up the biggest shares of all accident scenarios ranging from 25-64%. This was linked to the higher car impact speeds observed on rural roads.

Table 25: Comparison of shares of the PROSPECT Accident Scenarios in Germany, Hungary and Sweden

		I	II	III	IV	V	Parking	Total
Germany	KSI	27%	17%	27%	10%	19%	1%	100%
	Killed	25%	23%	12%	25%	14%	0%	100%
	Serious	27%	16%	27%	10%	19%	1%	100%
	Slight	27%	14%	28%	9%	20%	2%	100%
Hungary	KSI	42%		6%	29%	23%	0%	100%
	Killed	33%		1%	64%	2%	0%	100%
	Serious	42%		7%	26%	24%	0%	100%
	Slight	42%		8%	24%	26%	0%	100%
Sweden	KSI	28%	33%	13%	17%	10%		101%
	Killed	23%	27%	3%	40%	8%		101%
	Serious	29%	34%	15%	11%	11%		100%
	Slight	34%	33%	12%	7%	13%		99%

Having a deeper look into the data all datasets confirmed the following points:

- Older cyclists suffer more often from higher injury severities compared to younger ones.
- Male cyclists are injured more often than females.
- Higher injury severities (in particular fatal crashes) happened more often on rural roads.
- Crashes occurred most often in fine weather conditions.
- Shares of Accident Scenarios vary a lot between European countries.

Many of the previous analyses found in literature were based on a higher level of aggregation, e.g., naming basic trajectories of both crash participants. Detailed crash analyses in PROSPECT focusing on the causation of crashes could also show that the most common contributing factor to the crashes was “disregarding traffic regulations” seen for both cyclists and car drivers.
Case-by-case analyses took the drivers’ specific task in a given environment-infrastructure into account by determining typical scenarios which were then summarized to Use Cases. Results show that the drivers’ task and the orientation of cyclist have an influence on the frequency of collisions. As example, the cyclist violated traffic regulations as the wrong driving direction on a bicycle lane was chosen to cross a road. Potentially, the car driver failed to watch out for this unexpected traffic situation, as the cyclist would have to approach from the other side, and thus, drove into the intersection area hitting the cyclist.
The analyses on the Use Cases for car-to-cyclist crashes based on German and Hungarian data have shown several challenges and due to the different data inclusion criteria, it was not possible to harmonize these Use Cases.

Further, it needs to be noted that exposure data, required to estimate risks, was missing. This is a general issue valid for nearly all European countries.

6 CAR-TO-PEDESTRIAN CRASH DETAILS AND SCENARIOS

6.1 ANALYSIS OF GERMAN DATA

In analogy to the accident analyses performed in the FP7 project AsPeCSS, see [2] and [1], it was aimed to identify most important scenarios of crashes between cars and pedestrians based on larger datasets, in best case on national road traffic accident statistics from several European countries.

The official German road traffic statistics cover only those accidents which were reported to the police. These are primarily accidents with serious consequences. Especially traffic accidents involving only material damage or slight personal injuries are to a larger extent not reported to the police. Casualties are persons (incl. passengers) injured or killed in the accident. They are assigned to “killed” (all persons who died within 30 days as a result of the accident), “seriously injured” (all persons who were immediately taken to hospital for inpatient treatment; of at least 24 hours) and “slightly injured” (all other injured persons).

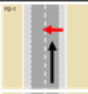
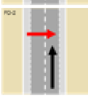
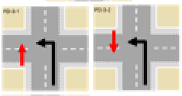
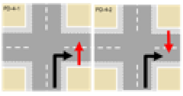
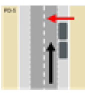
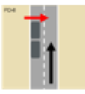
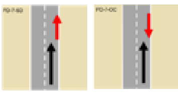
To specify a certain characteristic of a crash, the variables “type of accident” and “kind of accident” are often used. Here, the type of accident coding can offer a meaningful insight to the situation before the collision occurred. In the German statistics, there are seven main types of accidents (coded as type 1 to type 7). Each of these main types can be further detailed into sub-types that range up to three levels (e.g., accident type “372”). However, in the German accident statistics this 3-digit accident type information is not available for all federate states of Germany, see also Section 5.2.1, but the dataset could be used for the following analysis.

The accident data analysis involved crashes between two participants only (here: exactly one passenger car and one pedestrian) in urban areas of the accident years 2009-2014. Consequently, the dataset included 54,241 crashes with 526 pedestrian fatalities, 13,183 seriously and 40,440 slightly injured pedestrians. Table 26 shows the results classified into 9 accident scenarios, the light condition and the pedestrians’ injury severity. The accident scenarios 1-7 are the same as already defined by the AsPeCSS project. Accident scenario 8 describes crashes in which a pedestrian was injured by a backwards driving car. Accident scenario 0 covers all remaining crashes.

In summary, accident scenarios 1 and 2 were found as the two scenarios of highest relevance for car-to-pedestrian crash configurations in Germany (sum of weights concerning KSI is 45% and concerning fatalities is 62%) that may potentially be addressed by forward-looking integrated pedestrian safety systems as they are already under testing and in the market. The analysis also showed that in these both scenarios most severe crashes between cars and pedestrians occurred in dark light conditions.

However, accident scenarios 3-8 also have significant weightings as regards future active pedestrian protection systems. Whereas accident scenarios 1, 2, 5 and 6 are widely addressed by today's Euro NCAP and research tests, accident scenarios 3, 4 and 7 run into the focus of near-term development activities. The accident scenario 3 "Pedestrian crosses at a junction from the near- or off-side whereas the vehicle is turning across the traffic" is the next highest weighted scenarios and thus, was selected to be addressed in further PROSPECT activities as a Use Case to raise the safety of pedestrians. Details on this Use Case are provided in [33].

Table 26: Overview of accident scenarios of car-to-pedestrian crashes in urban areas of 5 federate states of Germany, 2009-2014, 54,241 crashes with 526 pedestrian fatalities, 13,183 seriously and 40,440 slightly injured pedestrians; Pedestrians' injury severity in percentage terms; "KSI" includes "killed and seriously injured"; dark light condition includes twilight

Accident Scenarios	ID	Description	Light condition	Fatalities	KSI	All
	1	Crossing a straight road from near-side; No obstruction	All (day/dark)	23 (9/14)	23 (14/9)	19 (13/6)
	2	Crossing a straight road from off-side; No obstruction	All (day/dark)	39 (6/33)	22 (10/12)	16 (9/7)
	3a, 3b	Crossing at a junction from the near (a)- or off-side(b); vehicle turning across traffic	All (day/dark)	5 (3/2)	11 (5/6)	11 (5/6)
	4a, 4b	Crossing at a junction from the near (a)- or off-side (b); vehicle not turning across traffic	All (day/dark)	1 (0.5/0.5)	4 (2/2)	5 (3/2)
	5	Crossing a straight road from near-side; With obstruction	All (day/dark)	6 (4/2)	10 (8/2)	8 (6/2)
	6	Crossing a straight road from off-side; With obstruction	All (day/dark)	3 (1/2)	7 (5/2)	5 (4/1)
	7	Along the carriageway on a straight road; No obstruction	All (day/dark)	6 (2/4)	3 (2/1)	6 (4/2)
No picture by now	8	Driving backwards	All (day/dark)	6 (5/1)	6 (5/1)	7 (6/1)
	0	Others	All (day/dark)	11 (6/5)	14 (10/4)	23 (17/6)
Urban only		TOTAL	All (day/dark)	100 (36/64)	100 (61/39)	100 (67/33)

6.2 ANALYSIS OF HUNGARIAN DATA

The total numbers of car-to-pedestrian crashes per year were nearly constant in Hungary between the years 2011 and 2014. The number of crashes with serious injury outcome increased by about 10%, see Figure 56.

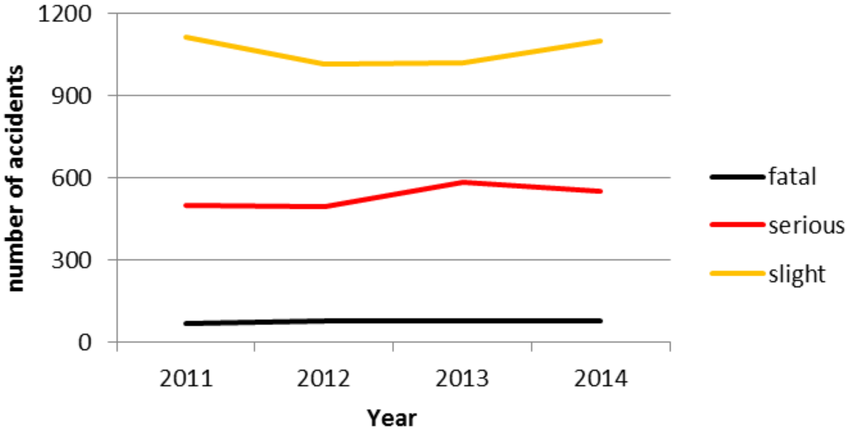


Figure 56: Number of car-to-pedestrian crashes (Hungary, 2011-2014)

In urban areas, about 30% of pedestrians were seriously and more than 65% slightly injured. In rural areas about 40% of crashes ended up with a serious and about 35% of crashes ended up with a slight injury outcome, see Figure 57. This higher injury severity level on rural roads is presumably connected with the observed higher impact speeds.

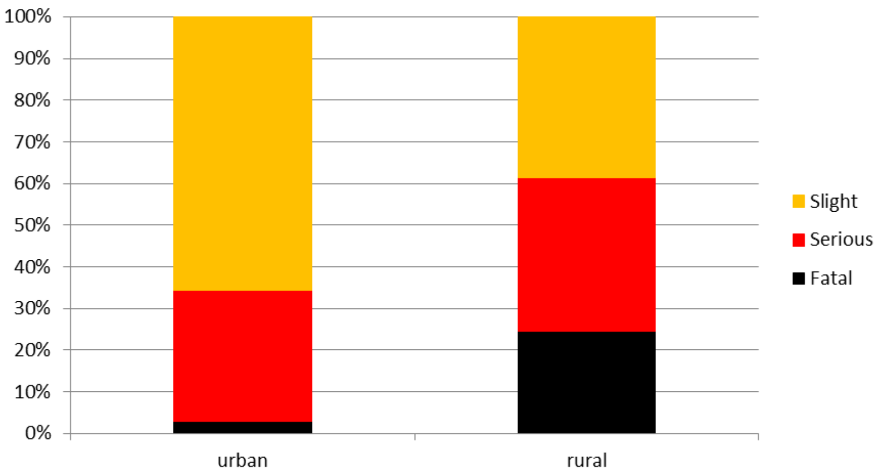


Figure 57: Rate of injury severity by road type in car-to-pedestrian crashes (Hungary, 2011-2014)

In case of car-to-pedestrian crashes the most common fault of car drivers was the denied priority (56%), followed by the denied rules for changing lanes, going ahead and turning (16%). Thus, these two faults caused more than two-thirds of all car driver's faults, see Figure 58.

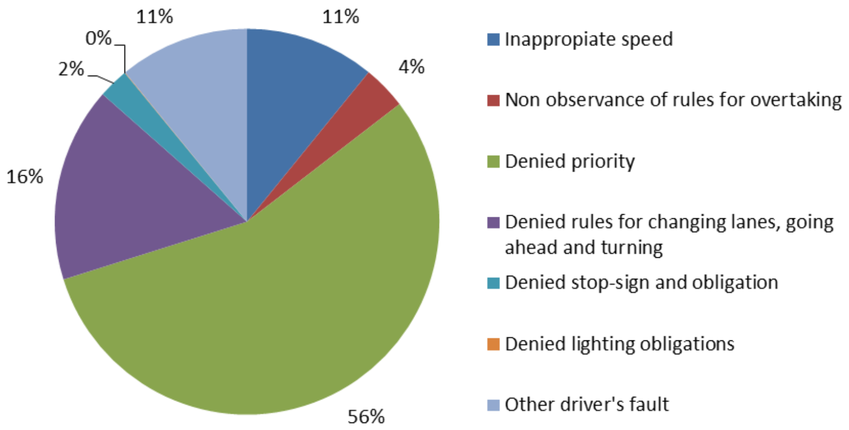


Figure 58: Car driver's fault in car-to-pedestrian accidents (Hungary, 2011-2014)

In 46% of all cases the pedestrian's fault was the incautious, sudden down-step off the pavement. The crossing behind obstruction, illegal crossing and crossing during red light offences were also significant. These four types of faults amounted to 87% of all car-to-pedestrian crashes which were caused by pedestrians, see Figure 59.

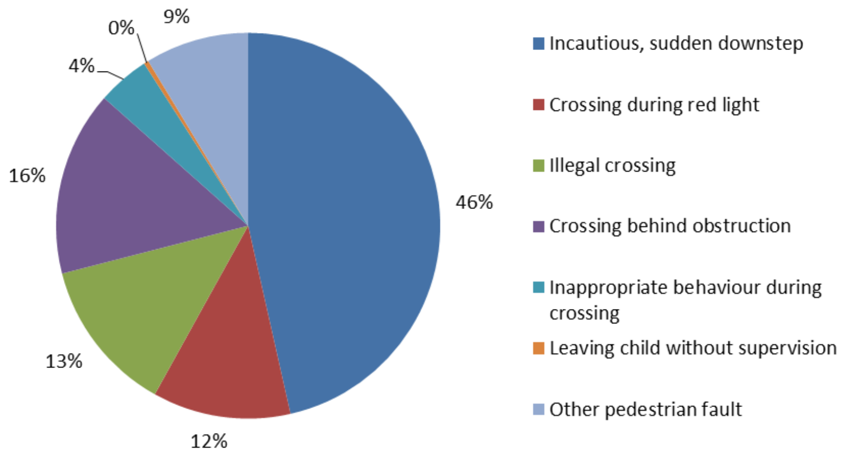


Figure 59: Pedestrian's fault in car-to-pedestrian crashes (Hungary, 2011-2014)

The car-to-pedestrian crash typically occurred in fair or cloudy weather conditions (86%), see Figure 60.

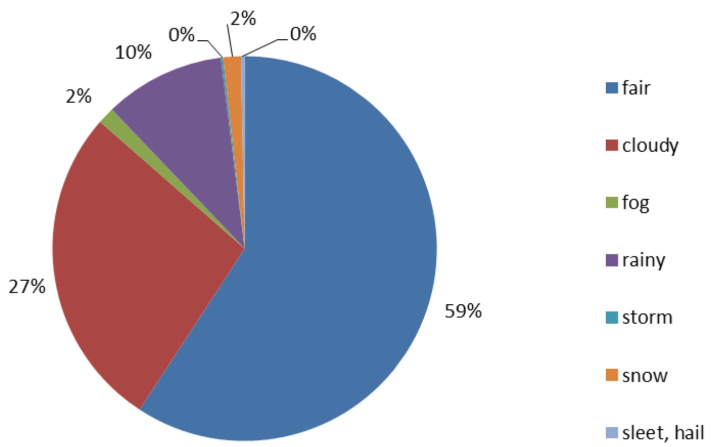


Figure 60: Weather conditions in car to pedestrian accidents (Hungary, 2011-2014)

Further, 60% of accidents were recorded to be taken place at natural daylight conditions and 29% at night with active street lighting. The accidents happened at other lighting conditions were rare, see Figure 61.

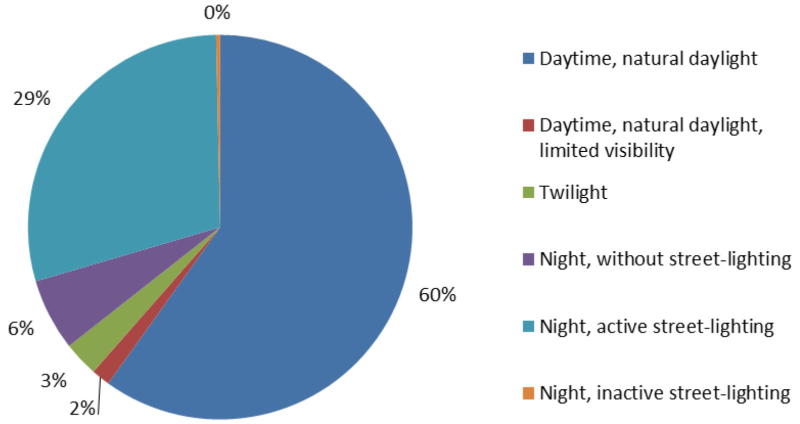


Figure 61: Lighting conditions in car-to-pedestrian crashes (Hungary, 2011-2014)

In contrast to the German crash database the national Hungarian accident database did not allow for grouping the car-to-pedestrian crashes into the categories defined in the AsPeCSS project [1]. However, an in-depth analysis was performed, comparable to the one introduced in Section 5.3.2, to calculate the required figures for Accident Scenarios 1-7 plus for Accident Scenario "Driving backwards" and "Others", see also Section 3.5. As it could not be determined from which direction the pedestrian entered the road, accident scenarios 1 and 2, as well as 3 and 4 had to be merged. Finally, it was found that the most typical car-to-pedestrian crashes belong to the accident scenarios 1 and 2, in that the pedestrian crossed a straight road not behind obstruction, see Table 27.

Table 27: Car-to-pedestrian accident scenarios (Hungary, 2011-2014), A: daylight; B: darkness; KSI: killed or seriously injured

		Rate of accidents		
No.	Description	Killed	KSI	Total
1 and 2 A	Crossing a straight road from the near- or off-side; no obstruction	19%	29%	32%
1 and 2 B		32%	24%	20%
3 and 4 A	Crossing at a junction from the near- or off-side; vehicle turning or not turning across traffic	1%	7%	9%
3 and 4 B		0%	3%	4%
5 A	Crossing a straight road from the near-side; with obstruction	1%	2%	2%
5 B		1%	0%	0%
6 A	Crossing a straight road from the off-side; with obstruction	1%	1%	1%
6 B		1%	0%	0%
7 A	Along carriageway on a straight road; no obstruction	1%	2%	3%
7 B		22%	8%	5%
Reversing A		1%	8%	7%
Reversing B		0%	1%	1%
Other A		4%	7%	8%
Other B		14%	7%	5%
n/a		2%	1%	2%

The advantage of the dataset from Budapest is the availability of the information on the exact crash location which was used to generate heat maps highlighting hot spots (frequently affected crash location on main roads and intersections) in the road network regarding crashes involving pedestrians. In Budapest, between 2011 and 2013, 43 fatal, 369 serious and 847 slight pedestrian crashes occurred, Figure 61. This figure was primarily used to select the naturalistic observation spots of other PROSPECT activities.

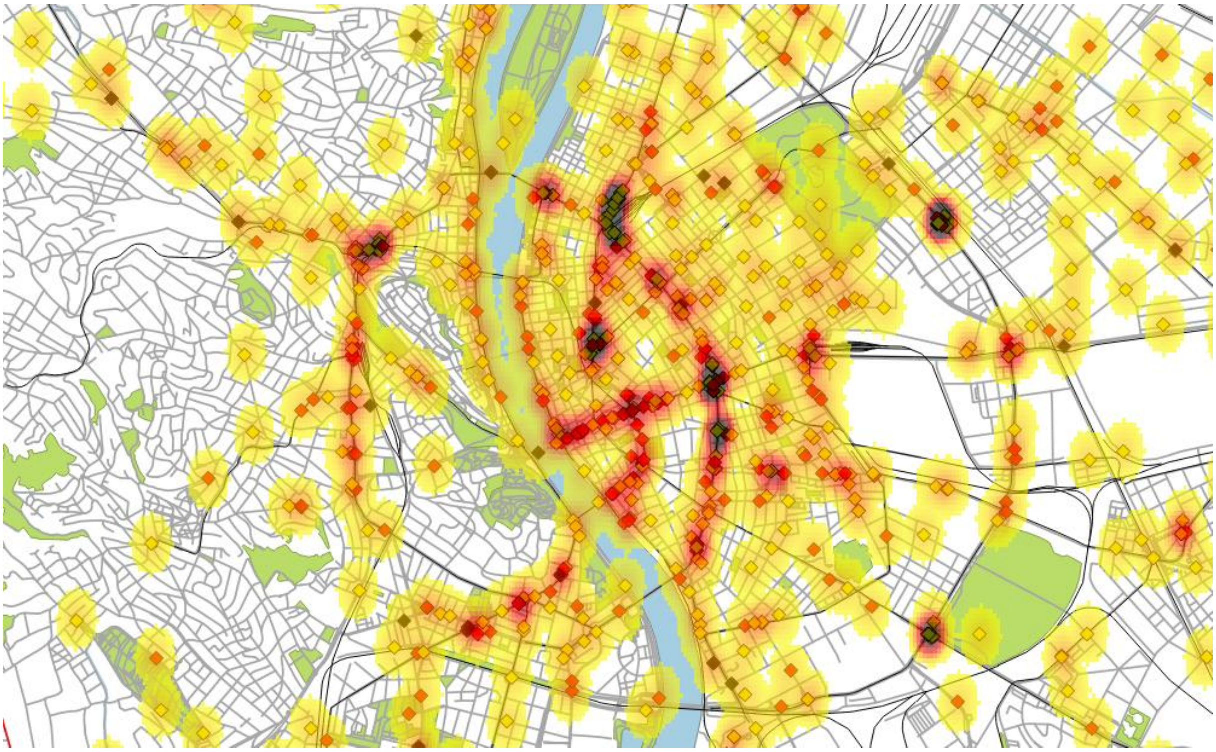


Figure 62: Pedestrian accidents heat map (Budapest, 2011-2013)

6.3 EUROPE: IGLAD

Data were also extracted from the iGLAD dataset for years 2007-2013. Car-to-pedestrian crashes from Australia, China, India and US were excluded from the analysis to restrict the analysis to European countries whereas the cases from Germany were not included due to separate analysis, see Section 6.1. This led to 188 crashes with 78 fatally, 39 severely, 69 slightly and 2 uninjured pedestrians from the following countries Austria, Czech Republic, France, Italy, Sweden and Spain.
The most frequent accident types in iGLAD were identified as “401 – Pedestrian crossed the street from farside”; and “421 - Pedestrian crossed the street from the nearside”, see Figure 63.

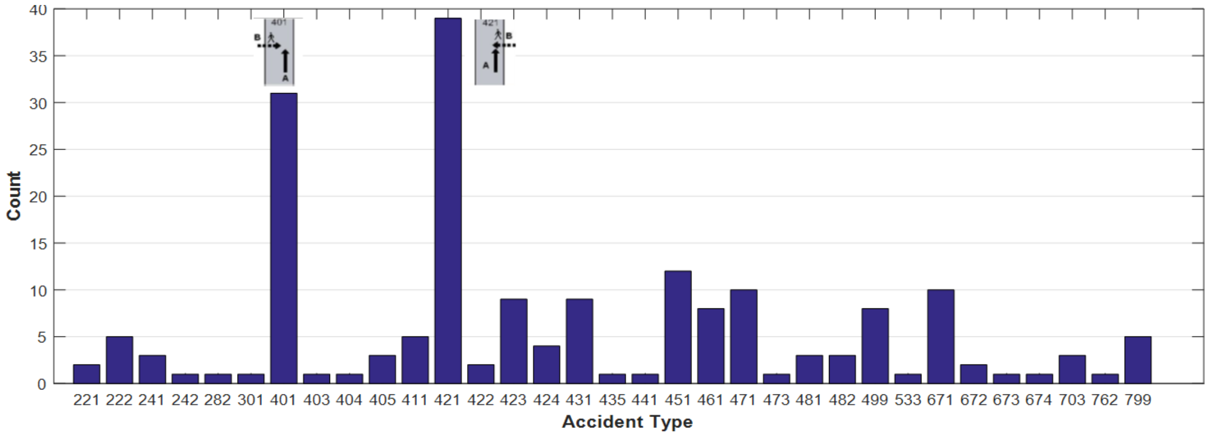
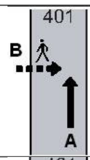
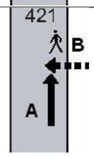


Figure 63: Distribution of car-to-pedestrian crashes in iGLAD, 2007-2013, by three-digit Accident type. N=188 crashes. Countries: AT, CZ, FR, IT, SE, SP.

From these frequent accident types two Use Cases were derived, where the car is driving straight and the pedestrian is crossing the road either from far or near side, Table 28. Both use cases occur in daylight, dry weather, urban area and without obstruction of driver view. The major difference of both Use Cases concerns the pedestrian's injury severity distribution. As 30% of the pedestrians were fatally injured when crossing from nearside, this was increased to more than 60% in Use Case 1.

Table 28: Car-to-pedestrian Use Cases derived from iGLAD dataset, 2007-2013.

Description	Vehicle Speed	Pedestrian speed	Acc. Type
UC1: A car is traveling on a straight road and hits a pedestrian with the front. The pedestrian is crossing the road from the **far** side. The UC occurs in daylight, dry weather, **urban** area and without sight obstruction.	40-60 km/h	Walking	
UC2: A car is traveling on a straight road and hits a pedestrian with the front. The pedestrian is crossing the road from the **near** side. The UC occurs in daylight, dry weather, **urban** area and without sight obstruction.	10-50 km/h	Walking	

Further, the IGLAD accident types were matched with PROSPECT Pedestrian Accident Scenarios, see Section 3.5. For the cases classified as "Others" (accident types 499 and 799), the crash description was read and assigned accordingly.
Results were summarized in Table 29. Most common were accident scenario 1 "Crossing a straight road from nearside; no obstruction" for KSI pedestrians, and accident scenario 2 "Crossing a straight road from the offside; no obstruction" for the pedestrian fatalities. Together, both scenarios account for 65% of the pedestrian severe and fatal injuries. At rank 3 stands the accident scenario 7 "Along carriageway on a straight road; no obstruction" occurring often in dark light conditions. Scenarios 6, 8 and 9 are present only in daylight conditions.

Table 29: Distribution of accident scenarios of car-to-pedestrian crashes in iGLAD, 2007-2013. N=188 crashes; Killed and severely injured (KSI); Day (daylight), Dark (darkness, twilight, electric light and sudden change). Countries: AT, CZ, FR, IT, SE, SP.

Accident Scenario	Light conditions	Fatalities %	KSI %	Total %
1 Crossing a straight road from nearside; no obstruction	Day	15	21	23
	Dark	14	13	11
2 Crossing a straight road from the offside; no obstruction	Day	13	13	16
	Dark	23	18	13
3 Crossing at a junction from the near- or-offside; vehicle turning across traffic	Day	1	3	6
	Dark	0	0	2
4 Crossing at a junction from the near- or-offside; vehicle not turning across traffic	Day	1	2	2
	Dark	1	1	1
5 Crossing a straight road from nearside, with obstruction	Day	8	6	6
	Dark	1	1	1
6 Crossing a straight road from the offside, with obstruction	Day	3	2	3
	Dark	0	0	0
7 Along carriageway on a straight road; no obstruction	Day	5	6	4
	Dark	8	8	5
8 Reversing	Day	0	1	2
	Dark	0	0	0
9 Door opening	Day	1	1	1
	Dark	0	0	0
Other	Day	3	3	3
	Dark	3	3	2
	Total % (N)	100 (78)	100 (117)	100 (188)

6.4 Summary and Discussion

Crash databases on a European level (IGLAD) and on national / in-depth level (Germany and Hungary) have been analyzed towards car-to-pedestrian crashes. In these analyses the Accident Scenarios introduced in the European project AsPeCSS were considered as basis for updated figures. In addition, Accident Scenario 8 “Driving backwards” was added.

In general, all databases confirmed that for car-to-pedestrian crashes the Accident Scenario 1 “Crossing a straight road from nearside; no obstruction” for KSI pedestrians, and the Accident Scenario 2 “Crossing a straight road from the offside; no obstruction” are ranked highest for all pedestrian injury severities. It became also clear that higher injury severities were seen in all databases in crashes occurring at dark light conditions.

The analyses of the German and Hungarian data have also shown the importance of accident scenarios on turning (3&4), longitudinal traffic (7) and reversing (8). As the major scenarios (1, 2 and also 5) were largely covered by previous research activities, the PROSPECT consortium decided to focus on the turning scenario as primary Use Case for car-to-pedestrian crashes.

Biggest differences were seen comparing the results from Germany, Hungary and the IGLAD database (limited to countries AT, CZ, FR, IT, SE and SP) with regard to the Turning Accident Scenarios 3 and 4. Whereas Germany and Hungary show similar distributions for at least seriously injured pedestrians for these both scenarios compared to all Accident Scenarios, the IGLAD analysis did not confirm this finding which is perhaps more due to the different database characteristics and rather than actual differences.

7 Car-to-scooter Crash Scenarios

7.1 Analysis on German Data

Considering the definition of scooters in Germany, see Section 3.1, and analogue to the PROSPECT Cyclist Accident Scenarios, see Section 3.5, the national crash statistics of Germany were analyzed regarding car-to-scooter crashes in the years 2011-2014, see Table 30.

Focusing on KSI and urban areas the accident scenario III “Car turns” made up 37% of all casualties, followed by accident scenario IV “Car and scooter in longitudinal traffic” with 16%. Both scenarios were also identified as being most important for rural areas; however, with a changed order.

It is interesting to note that there are substantial differences for urban and rural roads focusing on killed scooter riders. Whereas on urban roads for killed scooter riders, the longitudinal scenario was seen most frequently (33%) followed by the car turning scenario (29%), this trend changed for rural roads to 39% for the accident scenario 1 “Car straight on, Scooter from near-side” followed by the longitudinal scenario (30%).

Table 30: Scooter casualties in car-to-scooter crashes in Germany, 2011-2014

	Urban Areas					Rural Areas				
Group	KSI	Killed	Serious	Slight	Total	KSI	Killed	Serious	Slight	Total
V	24%	13%	24%	28%	28%	13%	9%	13%	17%	16%
I	10%	4%	10%	8%	8%	19%	39%	18%	13%	14%
II	11%	21%	11%	9%	9%	11%	18%	11%	10%	11%
III	37%	29%	37%	31%	32%	27%	5%	28%	27%	27%
IV	16%	33%	16%	21%	20%	29%	30%	29%	33%	32%
Parking	2%	0%	2%	2%	2%	1%	0%	1%	0%	1%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

7.2 Analysis on Hungarian Data

In Hungary scooters are officially called “mopeds”. The number of car-to-moped crashes showed a decrease by 10% in the years 2011-2014, see Figure 64. This change is proportional to the number of slight crashes. The number of crashes with serious injury outcome has not changed significantly; and the number of fatal accidents is so low that there is no change from the statistical point of view.

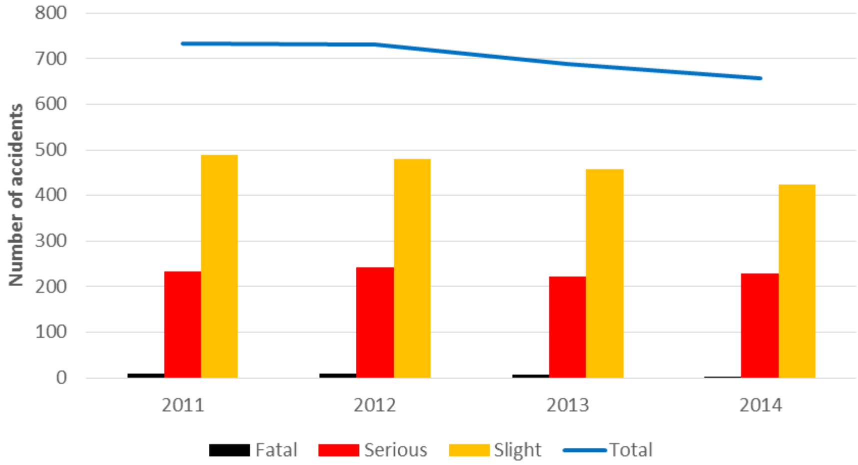


Figure 64: Number of car-to-moped crashes in Hungary, 2011-2014

More than 9 out of 10 crashes with the outcome of slight or serious injuries outcome happened in urban areas, see Figure 65. In contrast, half of the fatal crashes occurred on rural roads, which is likely due to higher collision speeds.

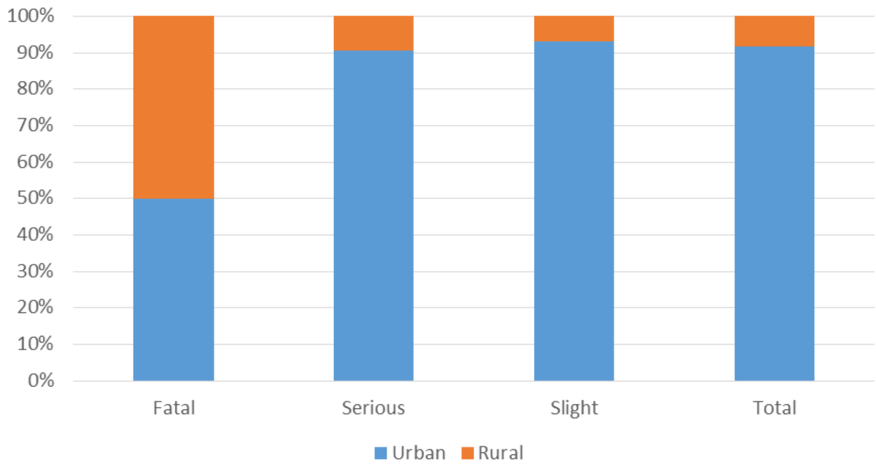


Figure 65: Injury severity of moped riders in car-to-moped crashes by accident location in Hungary, 2011-2014

Regarding accident types in crashes with scooters in urban areas the most frequent type is the “collision of crossing and turning vehicles at intersections” (20%) and on rural roads it is the “collision of vehicles moving straight ahead in the same direction” (24%), see Figure 66.

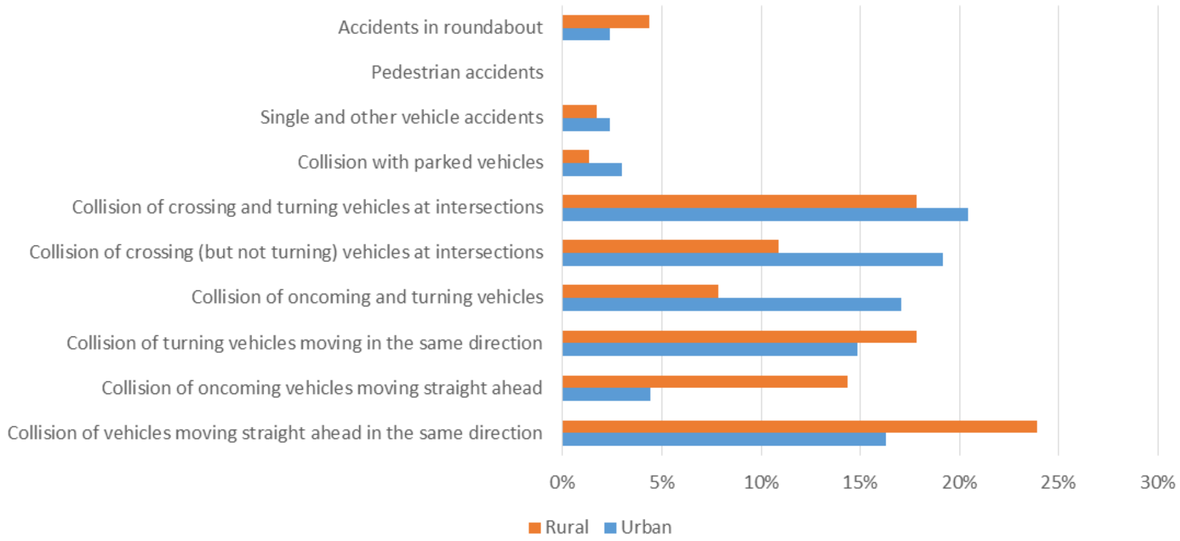


Figure 66: Type of car-to-moped crashes in Hungary, 2011-2014

The two primary reasons of crashes both in rural and urban areas were "denied priority" and "denied rules for changing lanes, going ahead and turning", see Figure 67. These two types of violation are responsible for 4 out of 5 crashes in urban areas and 2 out of 3 crashes in rural areas.

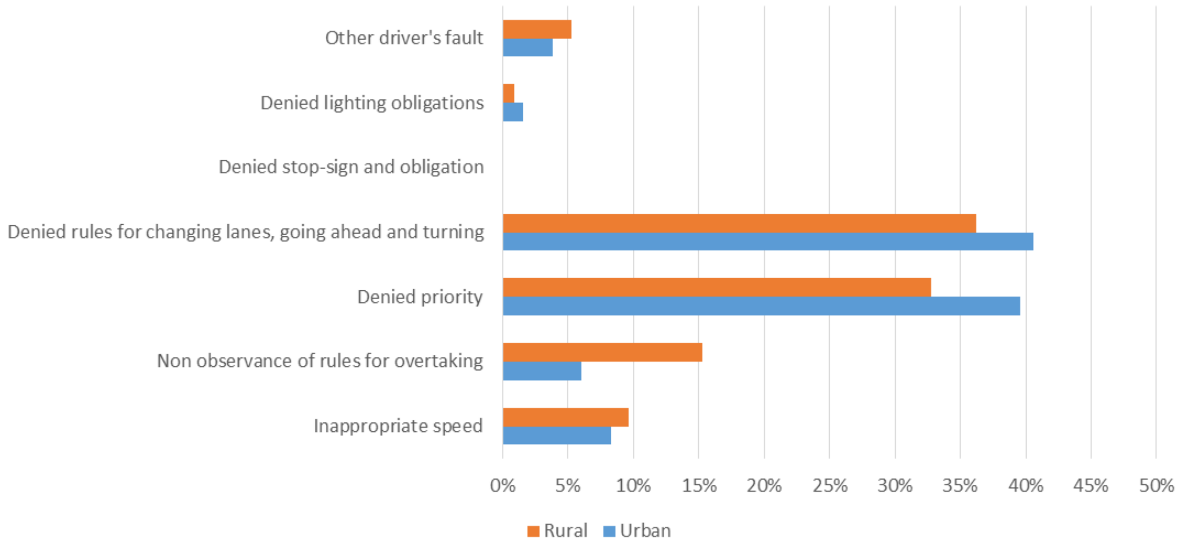


Figure 67: Shares of car-to-moped crashes by the car driver's fault in Hungary, 2011-2014

7.3 Analysis of Swedish Data

Data were extracted from the national crash database STRADA in Sweden in this section for car-to-moped crashes. "Moped" includes classes I and II, but also mopeds that are not assigned any of these categories in the dataset, but are marked as 'unknown moped', see definitions for Sweden in Section 3.3.1.

The extracted dataset contained in total 2,684 car-to-moped crashes with exactly two traffic participants (one car and one moped) during the years 2009-2013 with an average of 537 crashes per year. In these crashes 3,157 moped riders were involved, since in 9 crashes three persons were sitting on a moped and in 455 crashes two persons were sitting on a moped. The distribution of the riders' injuries and characteristics are shown in Figure 68.

During the five year study period, fatally injured riders in car-to-moped crashes accounted for 0.5%, 14% were severely injured and 82% were slightly injured compared to 3.5% that were recorded as uninjured and unknown injury.

Mostly, injured persons on the moped were at an age between 15 and 17 years with 59% of all injuries, but 31% of the fatal, 54% of severe injury and 63% of slight injury outcome. Besides this group of young riders, a second group of mid-aged and older riders (45 years and older) were identified as being involved in many crashes with serious or fatal injury outcome. A peak in these numbers was seen in the age group 45-54 years with 19% of the fatalities.

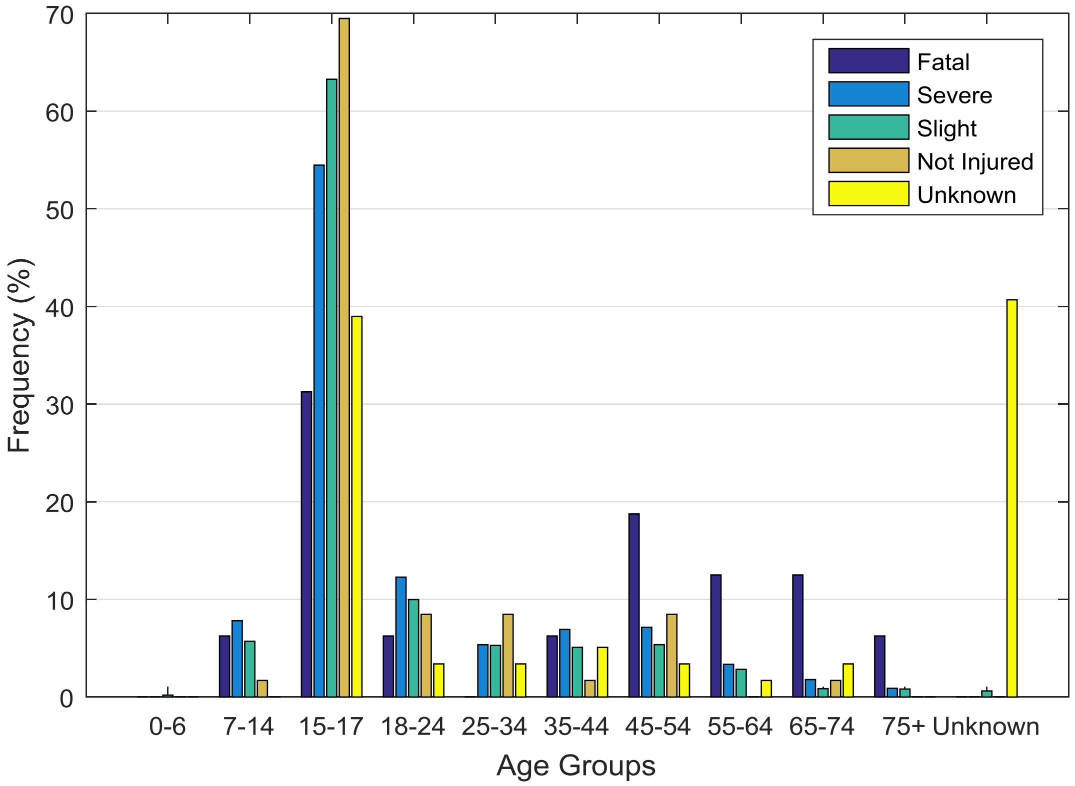


Figure 68: Distribution of injuries for moped riders in car-to-moped crashes in Sweden, 2009-2013, by age. N = 3,157 persons.

Further, there were more than twice as many male riders involved in the car-to-moped crashes than females (69% vs. 30%). The majority of the persons injured were in crashes at daylight (76%) and clear weather (84%) conditions. However, half of the fatalities occurred in daylight and 37% in dark light conditions. Regarding the traffic environment, 80% of all casualties occurred in urban area; for fatalities, 37% occurred in urban and 50% in non-urban area.

8 TRUCK-TO-VRU CRASH SCENARIOS

8.1 ANALYSIS OF GERMAN DATA

Figure 69 shows the age distribution of fatally injured VRUs respectively of fatally and seriously injured VRUs in crashes with trucks in Germany in the years 2011-2014. More than half of the fatalities were older than 65 years. Looking on fatalities and seriously injured showed also a high share of younger people being involved in truck-to-VRU crashes (16 %). The share of seniors aged 65 years and older dropped to one third.

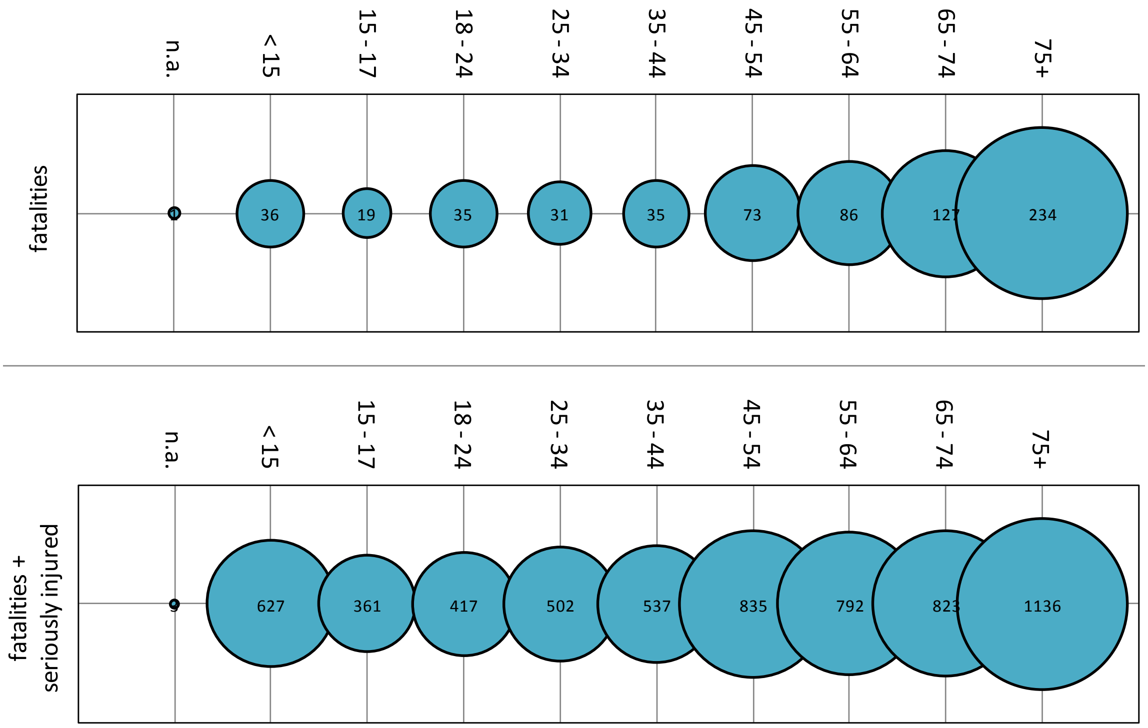


Figure 69: Number of fatally injured and seriously injured VRUs in truck-to-VRU crashes by age groups in Germany in 2011-2014 (only crashes with exactly two involved)

8.2 ANALYSIS OF HUNGARIAN DATA

The number of truck-to-VRU crashes increased by 10.5% during the four year examination period, 2011-2014. This change was proportional to the number of fatal and serious crashes. The number of crashes with slight injury outcome did not change significantly, see Figure 70.

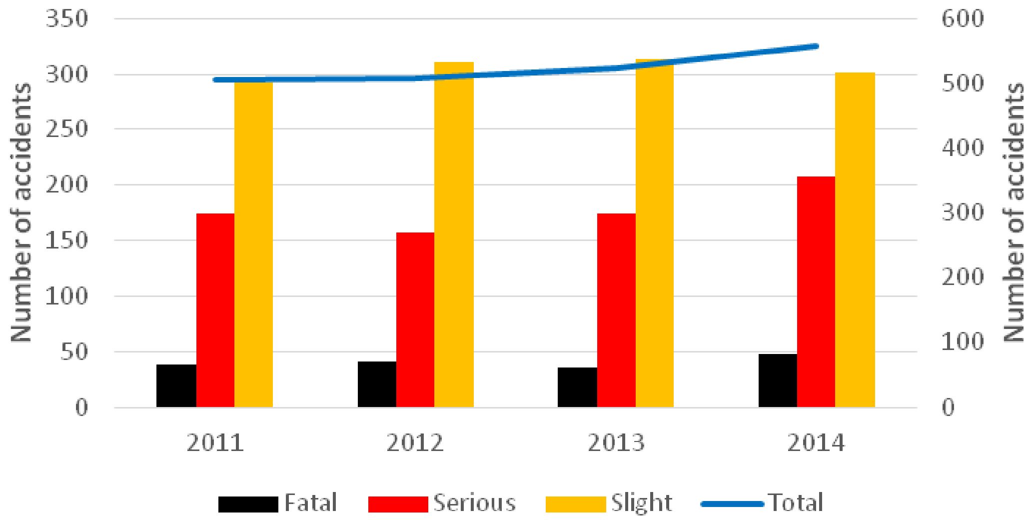


Figure 70: Number of truck-to-VRU crashes (Hungary, 2011-2014)

More than 4 out of 5 (81%) truck-to-VRU crashes happened in urban areas. 88% of the crashes with slight injury outcome and 78% of those with serious injury outcome occurred in urban areas. However, 55% of the fatal accidents happened in rural areas which were probably linked with higher collision speeds, see Figure 71.

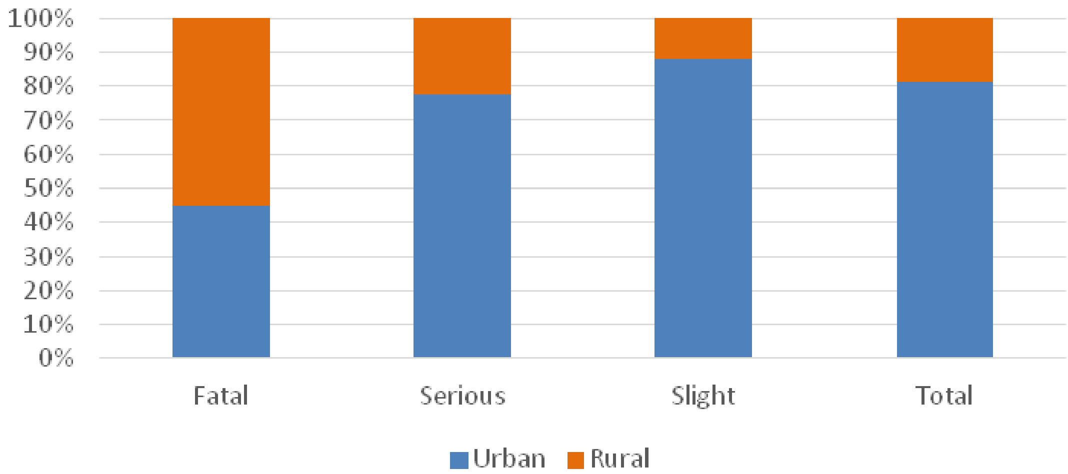


Figure 71: Proportions of truck-to-VRU crashes by road type (Hungary, 2011-2014)

Regarding frequent crash types of Truck-to-VRU crashes the “collision of crossing (but not turning) vehicles at intersections” (20%) and the “collision of crossing and turning vehicles at intersections” (19%) were recorded most often in urban areas, see Figure 72. In rural areas, the “collision of vehicles moving straight ahead in the same direction” (33%), the “pedestrian accidents” (25%) and the “collision of turning vehicles moving in the same direction” (14%) were most frequent.

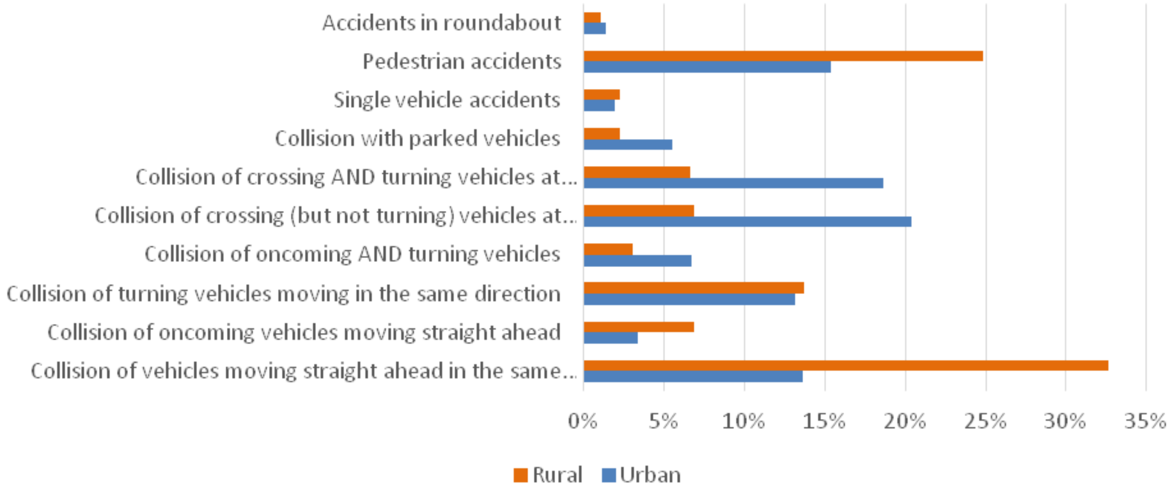


Figure 72: Type of truck-to-VRU crashes (Hungary, 2011-2014)

Focusing on pedestrians and on urban areas, “incautious, sudden down-step” (49%) and “crossing behind obstruction” (19%) were the most common pedestrian’s faults in Truck-to-pedestrian crashes, see Figure 73. In rural areas, “other pedestrian faults” (40%) and “incautious, sudden down-step” (38%) were the most frequent recorded pedestrian’s faults.

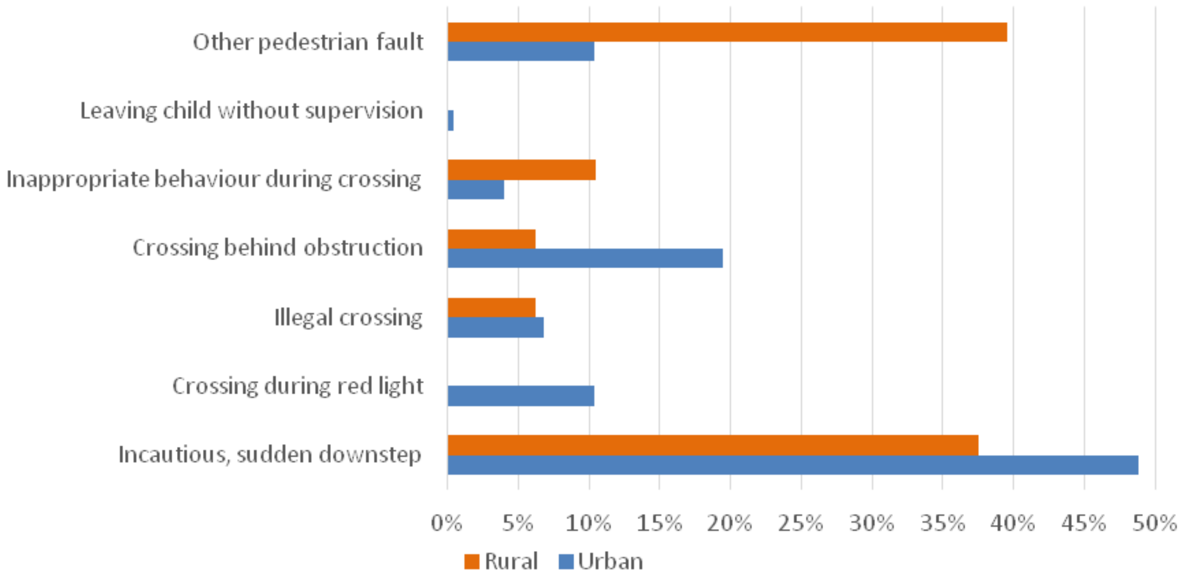


Figure 73: Rate of truck-to-VRU crashes by pedestrian’s fault (Hungary, 2011-2014)

8.3 Analysis of Swedish data

Data were extracted from the national crash database STRADA in Sweden in this section. “Truck” includes light and heavy truck but also trucks that are not assigned any of these categories in the dataset, but are marked as ‘unknown truck’, see definitions for Sweden in Section 3.3.1.

8.3.1 Truck-to-cyclist crashes

The extracted dataset contained in total 382 truck-to-cyclist crashes with exactly two traffic participants (one truck and one bicycle) during the years 2009-2013 with an average of 76 crashes per year. In these crashes 382 bicycles were involved and 384 persons (two bicycles carried two passengers each). The distribution of the cyclist injury outcome and the cyclist's age are shown in Figure 74. One cyclist was not injured and one was with unknown injury severity in ages 35-44 and 'unknown' respectively (not shown in the figure).

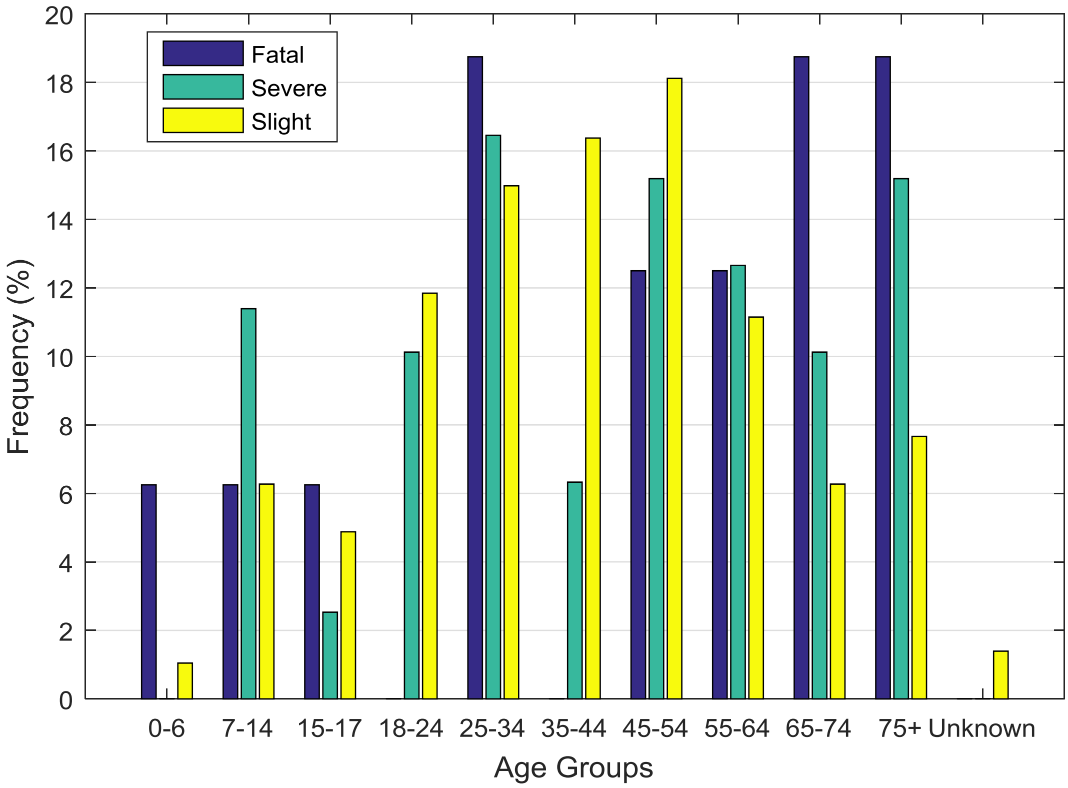


Figure 74: Distribution of injured cyclists in truck-to-cyclist crashes in Sweden, 2009-2013, by age. N=384 cyclists.

During this five year study period, the dataset contained 4% cyclist fatalities, 21% severely injured and 75% slightly injured cyclists.
The truck-to-cyclist crashes involving cyclists above an age of 54 years accounted for half of the fatal crashes while the cyclists in ages 18-54 years accounted for more than half of the slightly and severely injured casualties.
In addition, there were slightly more male cyclists involved in the truck-to-cyclist crashes than females (55% vs. 45%). The majority of the crashes were in daylight (76%), clear weather (75%) conditions and in an urban environment (77%).

8.3.2 Truck-to-pedestrian crashes

The extracted dataset contained 439 truck-to-pedestrian crashes with exactly two traffic participants (one truck and one pedestrian) during the years 2009-2013 with an average of 88 crashes per year. 9% were pedestrian fatalities, 24% severely and 62% slightly injured pedestrians, see Figure 75. Further, 5% accounted for an unknown injury severity.
A similar number of male and female pedestrians were involved in the truck-to-pedestrian crashes (51% vs. 49%). 62% of the crashes occurred in daylight while 19% in dark, 5% in twilight and 14% in unknown light conditions. Looking at pedestrian fatalities 31% of these crashes occurred in dark light conditions compared

to 14% in the case of severely injured pedestrians. More than two-thirds of the crashes occurred in urban traffic environment (69%) and in clear weather (69%) conditions. As for crashes with passenger cars, it could be seen that the older the pedestrian the higher the injury severity.

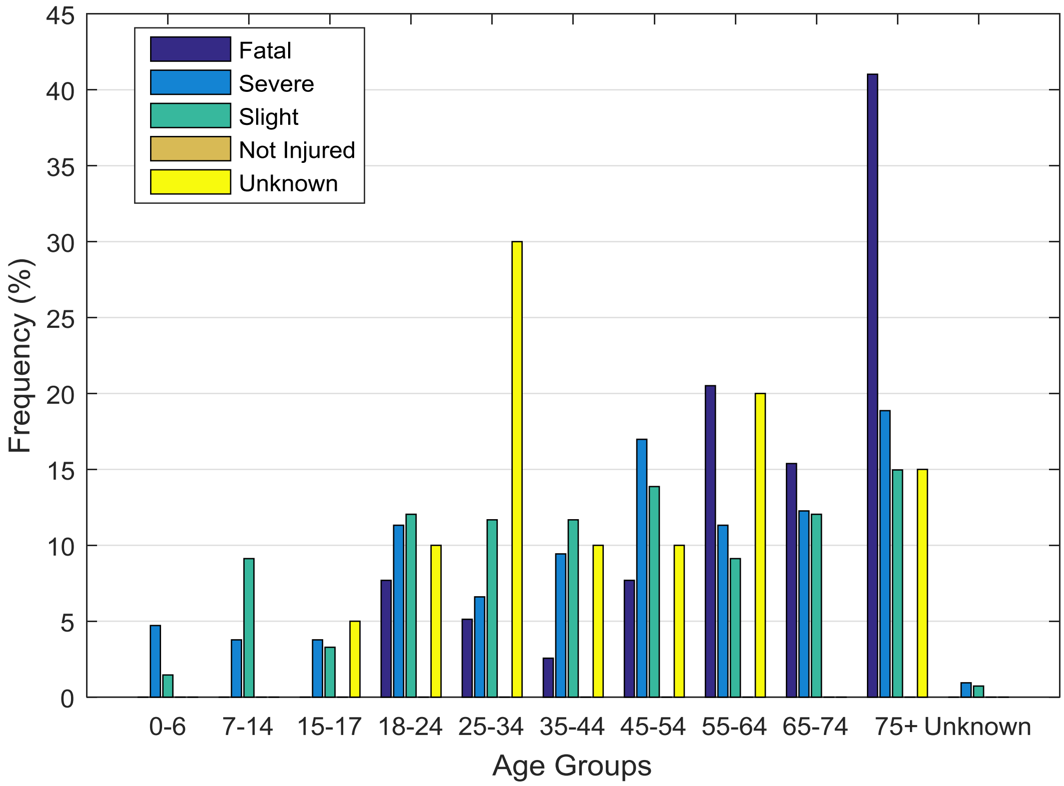


Figure 75: Distribution of pedestrian injuries in truck-to-pedestrian crashes in Sweden, 2009-2013, by age. N = 439 pedestrians.

9 UNDERREPORTING / MISCLASSIFICATION

9.1 UNDERREPORTING AND MISCLASSIFICATION ISSUES IN SWEDEN

Underreporting refers to road crashes not recorded by the police. Several studies have investigated the extent of underreporting of road crashes in police data. In a study from France it was found that underreporting increases with lower injury severity, younger age and female gender [36] [37]. Furthermore, factors as road user type, involvement of a third party, light conditions or crash environment influence the probability of reporting the crash. The report from Watson [38] shows that the probability of underreporting increases for motorcyclists, cyclists, males, young people and rural areas. Similar results have been reported by Janstrup et al. [39], namely that underreporting is increased with the involvement of motorcyclist and cyclists but it declines with helmet and seat belt use, alcohol involvement, injured females, higher speed limits and number of motor vehicles involved in the crash.

The underreporting of police data in STRADA have been investigated in the study of Larsson and Björketun [40]. They compared directly police reports with hospital reports for time interval 2003-2005 and found about 53% of underreporting in the police data. The majority of underreporting, 90% in urban and 95% in rural areas was found for crashes with bicycles and mopeds but without the involvement of motor vehicles. The underreporting of crashes with slight injuries was higher than crashes with severe injuries, 46% vs. 32% in urban areas.

Misclassification of injury severity in police data refers to the consistency of a person’s injury severity, involved in the crash, between police and hospital records. It is termed misclassification because hospital reports are considered to have a greater validity due to better resources and more time in assessing injury severity. The largest misclassification, for STRADA data during the years 2003-2005, was found for injuries classified as ‘severe’ by the police [40]. In this report the ‘severe’ injury reported by police was compared to injures with ISS>=9 (i.e. Injury Severity Score of 9 or greater) reported by the hospital, and only one third of the cases could be matched. However, the authors did not investigate which factors influence this misclassification.

The following crashes from Sweden were selected for analysis of underreporting crashes that occurred in 2003-2013 on public roads, involved at least one personal injury but no fatality and at least one car, bicycle, truck, bus, motorcycle or moped. The crashes reported from police and hospitals were extracted (for hospitals were the county achieved complete hospital coverage). This led to 184,953 road crashes, including 93,217 police reported and 137,214 hospital reported crashes. 25% of the total number of crashes were reported by both sources. In the period 2003-2006, emergency hospital data was unavailable for large regions in Sweden; therefore, analysis was restricted to the period 2007-2013.

The following criteria were used for analysis of misclassification:

1) The crash is registered both in police and hospital records (quality parameter ‘Q’ is greater or equal than 90),
2) Crash occurred in 2007-2013,

3) The person had ISS recorded by the hospital in [0, 75] and was not killed, and the injury level recorded by the police is uninjured, slight or severe.

This led to 64,283 persons who were available both in police and hospital data. A lower bound for underreporting in police data is given by:

1-((P+B)/(P+B+H)),

where P, H and B are the numbers of crashes only known by **P**olice, only by **H**ospitals, and by **B**oth respectively. The capture-recapture method was used to estimate the total amount of crashes which in turn was used to calculate the actual underreporting [41] [42].

The comparison between injury level reported by police and hospital was done by translating the ISS values reported in hospital records into three categories uninjured (ISS 0), slightly injured (ISS 1-8), and severely injured (ISS>=9). More details about the method and results were described in the report by Held [43].

In the analysis of underreporting, the results were presented for the period of 2010-2013 and excluded bicycle single crashes. For these crashes the underreporting was at least 33% and estimated to 49%.

There was a higher underreporting for slight than for severe crashes. While the underreporting of severe crashes was at least 8% and estimated to be 11%, for slight crashes it was at least 36% and estimated to be 54%.

Considering light conditions there was no difference in the underreporting. For severe crashes underreporting was at least 8% and estimated to be 11% during daytime and 13% for night-time. For slight crashes, there was an increase in the estimate of under-reporting, 52% in daytime vs. 57% in night-time conditions.

The crashes involving at least one car were underreported at least 28% and estimated to be 43%. The underreporting for car-to-bicycle crashes, with two participants, was at least 22% and estimated to be 38%. The underreporting was slightly lower for car-to-pedestrian crashes, at least 18% and estimated at 35%. For truck-to-bicycle crashes the underreporting was lower 19% and estimated at 32%. The truck-to-pedestrian crashes had the lowest underreporting rate of 8% and were estimated of 18%.

In this analysis of misclassification only persons who were alone in the vehicle, or were pedestrians involved in a crash with a vehicle had been considered.

The combinations for police/hospital injury classification were occurring with the following frequencies: slight/slight occurred most often (65%), followed by severe/slight (13%) and slight/uninjured (12%), while the combination uninjured/uninjured occurred least (1%). Police and hospital classified the injury equally for 70% of all observed individuals.

How different crash factors influence the injury classification by the police and hospital was tested for statistically significant differences with odds ratios. The odds for a woman to be classified equally by the police and a hospital are greater than those for a man (OR = 1/0.92 = 1.09). Injured persons older than 60 were more likely to be classified differently by the police and a hospital compared to any of the other age groups (odds ratios between 1.08 and 1.65). People in age group 0-17 were more likely to be classified equally by police and hospitals compared to any other age group (odds ratios between 1.45 and 1.65). For crashes that occurred in rural traffic environment, the person involved was more likely to be classified differently by the police compared to a crash in an urban traffic environment (OR = 1/0.72 = 1.39). Regarding cyclists, it was more likely to be classified equally by police and hospitals compared to individuals in cars, trucks, or as pedestrians (odds ratios between 1.24 and 1.64). The light conditions were not found as being significant in the equal or different classification by police and hospital.

9.2 ISSUES WITH INJURY SEVERITY CODING

The definitions of a road traffic crash as well as of casualties in road traffic crashes differ between countries which over the years have developed their own data collection system. The introduction of the IRTAD-Database (1988) and following the European Road Accident Database CARE were attempts to introduce harmonized variables for comparing the accident situation in different countries. The first and still the most reliable variable for the comparison on accident situation between countries is the number of fatalities in road crashes. Therefore, it is important to have a common definition for “road traffic crashes” and for “fatalities in road traffic crashes”:

The definition of an “Injury Road Accident” in CADaS (Common Accident Data Set)[1] concerns an incident on a public road involving at least one moving vehicle and at least one casualty (person injured or killed). It is noted however, that the definition of "injury" varies considerably among the various EU countries affecting thus the reliability of cross country comparisons.

For the definition of “fatalities” it was agreed to use the 30-days definition, which includes all people who died within 30 days of the road accident. Suicide and natural death are not included. As not all countries used that 30 day-definition, for some countries the number of fatalities has to be corrected by correction factors. Applying a correction factor for fatalities also needs to correct the number of serious injured persons, so that the total number of casualties remains constant.

The calculation of corrected measurements for "Fatally Injured (at 30 days)" and for "Seriously Injured (at 30 days)" in CARE has been as following:

[1] CADaS Glossary V 3.5 (08.03.2016)

Table 31: Correction factors applied in CARE (Source: CADaS Glossary V 3.5 (08.03.2016)) with K= number of persons killed and SI: number of persons seriously injured

Member State	Correcting factors	Outside urban area	Inside urban area
Spain	1997 up to 2000:		
	Driver	K(30)=K+SI*2.44%	K(30)=K+SI*1.93%
	Passenger	K(30)=K+SI*2.17%	K(30)=K+SI*1.80%
	Pedestrian	K(30)=K+SI*4.76%	K(30)=K+SI*5.71%
	2001 up to 2010		
	Driver	K(30)=K+SI*2.41%	K(30)=K+SI*2.17%
	Passenger	K(30)=K+SI*2.24%	K(30)=K+SI*2.15%
	Pedestrian	K(30)=K+SI*6.17%	K(30)=K+SI*4.34%
France	1994 up to 2004	K(30) = K * 1.057	
Italy	up to 1998	K(30) = K * 1.078	
Portugal	1998 up to 2009	K(30) = K * 1.14	

The CADaS-Glossary also gives definitions for injured persons. “Seriously injured” are all injured (although not killed) in the road crash and hospitalized at least 24 hours. Similar to fatalities the number of persons seriously injured is corrected by correction factors when needed. “Slightly Injured” are defined as all injured (although not killed) in the road accident and hospitalized less than 24 hours or not hospitalized. Even if the definition of injured gives a precise description of which persons should be counted as injured in the member states, the definitions of injured in the member countries vary widely and several member countries only can give the number of injured persons without differentiation between seriously and slightly injured.
Table 32 shows exemplary the variation of injury definitions in selected EU-member states.

Table 32: Definition of casualties in selected European countries (source: IRTAD, road safety annual report 2016)

	fatalities	serious injury	slight injury
Austria	30 days	suffering an injury resulting in an inability to work or health problems for more than 24 days	all other injured persons
Denmark	30 days	any person marked in police report as injured, apart from "minor injuries"	any person suffering from minor injuries
Germany	30 days	24 hours hospital	Any other injury, also without medical treatment (self declaration)
Hungary	30 days	48 hours hospital within 7 days of crash or fracture or serious cuts, muscle or tendon injuries or injury of inner organs or burn of second/third degree or affecting more than 5% body surface"	Other than serious
Iceland	30 days	Fractures, concussion, internal lesions, crushing, severe cuts and laceration, severe general shock requiring medical treatment and any other serious lesions entailing detention in hospital.	secondary injuries. Persons complaining of shock but not receiving any medical treatment shall be excluded.
Ireland	30 days	either in-patient in hospital or fracture, concussion, internal injury, crushing, severe cuts and lacerations, severe general shock requiring medical treatment"	injury of minor character, e.g. sprain or bruise
Italy	30 days	injured persons are not differentiated by degree of severity	

Luxemburg	30 days	24 hours hospital	Injury requiring less than 24 hours of hospitalization
Netherlands	30 days	MAIS2+ and hospital admission	Other injury, not admitted or admitted with a Maximum Abbreviated Injury Scale score of one (MAIS1)
Poland*	30 days	serious disability, incurable disease or chronic life threatening disease, permanent mental disease, complete or substantial permanent incapacity to work in current occupation, permanent or substantial scarring or disfiguration of the body, other injuries that incapacitate them for longer than seven days	loss of health for less than seven days
Slovenia	30 days	temporary or permanent health damaged or temporary or permanent reduced ability to work	injured, but not seriously injured or killed
Switzerland	30 days	hospitalized for at least 24 hours or be incapable of resuming his or her daily activity for 24 hours	casualty can leave the crash site unaided. An outpatient treatment in a hospital or by physicians may still be required
United Kingdom	30 days	in hospital as in-patient or any specific injury: fracture, concussion, internal injury, crushing, burns, sever cuts, severe general shock requiring medical treatment or injury causing death after 30 days"	injury of minor character, e.g. sprain or bruise, includes injuries not requiring medical treatment

The overview shows for all countries identical definition for fatalities but a wide variation of definitions for seriously and slightly injured persons. Apart from different definitions, different health care systems, different organizational issues of rescue services and alert chains, different organizations of police, different insurance-practice and -culture, different traffic laws and also the different definitions of injury severity make it impossible to compare currently the number of injured persons among the European countries. But not only the absolute numbers, but also the relation of injuries to fatalities, especially the number of seriously injured per fatally injured person is subject to considerable uncertainty predominantly due to the different definitions, see Figure 76.

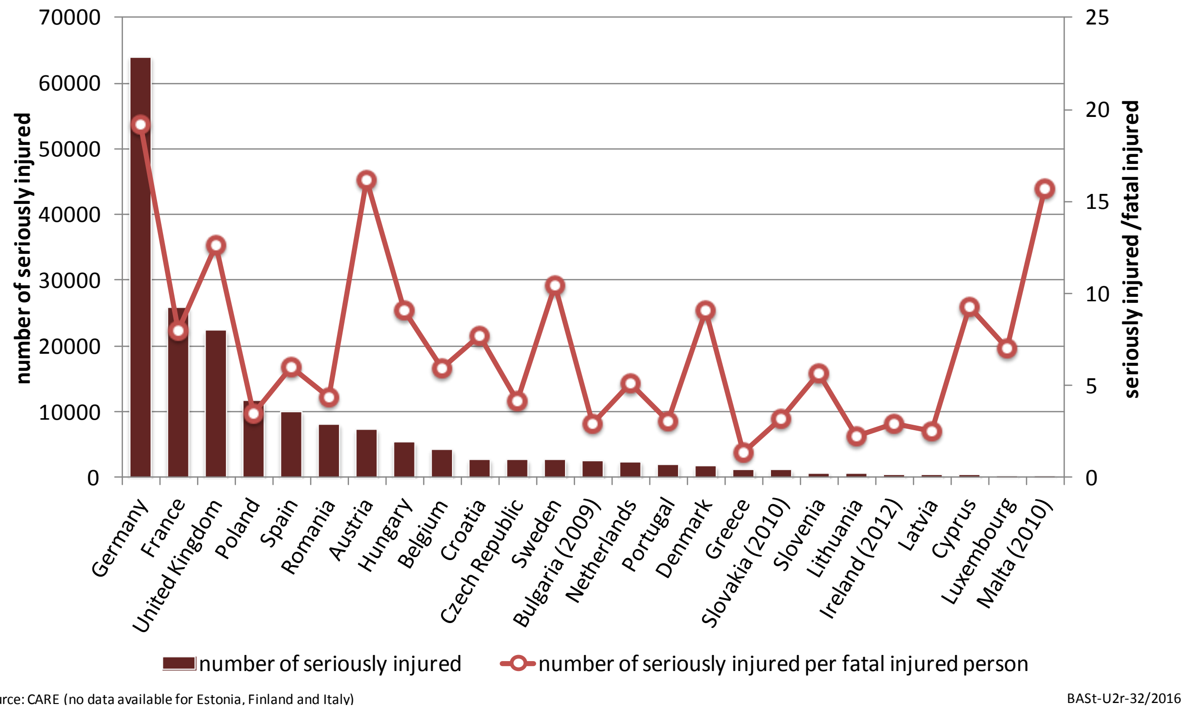


Figure 76: Total number of seriously injured and seriously injured per fatally injured person in EU-28 in 2013

As definitions of seriously injured and also the data collection methods vary widely between counties, the comparison of the number of injured persons between countries is not feasible. Therefore a new category of injured based on the Abbreviated Injury Scale (AIS) was introduced. The aim was to give a more precise picture on the most severe accident consequences and to be able to compare between countries. The new category of a “serious injury” has been defined as one with a Maximum AIS score of 3 or more (MAIS3+).

The member states of the European Union have agreed to report MAIS3+ data to the European Commission (EC) for inclusion in the Community Database on Accidents on the Roads in Europe (CARE). The number of MAIS3+ has been reported the first time for 2014 by some countries up to now.

As another example the injury severity definition used in Germany compared to the CARE definition is as follows:

- Fatalities (30 days – CARE compatible)
- Severe injuries (hospitalized – not CARE compatible)
- Slight injuries (all others with injuries – not CARE compatible)

World-wide definitions vary even more as the summary table created by the International Transport Forum shows, see Table 33.

Table 33: Road injuries – ITF-Eurostat-UNECE definition and application in IRTAD countries (source: International Transport Forum, Reporting on Serious, Road Traffic Casualties, OECD, IRTAD)

	Injured					Seriously Injured			Slightly Injured
Criteria / Country	All injured road users (including death >30 days)	Normally needing medical treatment	lesser wound, such as minor cuts and bruises	Attempted suicides	Inabiliy to work	Hospitali-sation	Hospitalisa-tion or serious injuries	Inability to work	Other than seriously injured
ITF-Eurostat-UNECE classification	Yes	Yes	No	No	-	> 24 hours	-	-	Yes
Australia	-	-	-	-	-	Admitted to hospital			-
Austria	Yes	Yes	No	No				Inability to work or health problem > 24 days	
Belgium	Yes	Yes	No	Yes		> 24 hours			Yes
Canada	Yes	Yes	No	No		> 24 hours			Yes
Czech Republic	Yes	Yes	Yes	Yes			Yes		Yes
Denmark	Yes	Yes	No	No			Yes		Yes
Finland	Yes		No	Yes		> 1 day			
France	Yes					> 24 hours			Yes
Germany	Yes	Yes	Yes	No		> 24 hours			Yes
Great Britain	Yes	Yes	Yes	Yes			Yes		Yes
Greece	Yes		Yes	No		> 24 hours			
Hungary	Yes	Yes	No	No			Yes		Yes
Iceland	Yes								
Ireland	Yes	Yes	No	No			Yes		Yes
Israel	Yes	Yes	Yes			> 24 hours			
Italy	Yes								
Japan	Yes	Yes	No	No					Yes
Netherlands	Yes	Yes	No	-	-	> 1 night	-	-	Yes
New Zealand	Yes		Yes	Yes			Yes		Yes
Poland	Yes	Yes	Yes	No	Yes	> 7 days			-
Slovenia	Yes	Yes	Yes			> 24 hours			Yes
Spain	Yes	Yes	Yes	Yes		> 24 hours			Yes
Sweden	Yes	Yes	No	No					Yes
Switzerland	Yes	Yes						> 24 hours	Yes
United States	Yes								

10 SUMMARY AND KEY FINDINGS

The primary goal of the Work Package 2 in PROSPECT is to generate the user requirements for next generation proactive safety systems to support their deployment in vehicles considering the specific needs of VRUs. Therefore, this report provides an overview and an in-depth understanding of the characteristics of road traffic crashes involving vehicles (focusing on passenger cars) and VRUs (i.e. pedestrians, cyclists, riders of mopeds, e-bikes or scooters) primarily in European countries.

The in-depth understanding of the crashes includes the identification of the most relevant road traffic ‘accident scenarios’ and injury severities sustained as well as the transport modes that represent a higher risk for VRUs. This knowledge can be used to provide the key starting points in the project and to derive safety strategies.

Within PROSPECT, an ‘Accident Scenario’ is described by the type of road users involved in the accident, their motions (e.g., the motion of the cyclist or pedestrian relative to the vehicle) expressed as ‘accident types’ and further relevant contextual factors like the course of the road, light conditions, weather conditions and view obstruction. As an example, “vehicle goes straight, cyclist crosses from the near-side behind an obstruction” represents an accident scenario.

The wording ‘Target Scenario’ or ‘Use Case’ is often used to describe ‘target groups’ and becomes more and more common in the development of active safety systems. Within PROSPECT, ‘Target Scenarios’ are equal to ‘Use Cases’. They are derived from accident scenarios by adding more detailed information about the road layout, right-of-way, as well as manoeuvre intention of the driver. One accident type can be split into several Use Cases. For example, the accident scenario “cyclist crossing from the right” can be split into “Driver approaching an intersection with the intention to turn right, while cyclist is crossing from the right on the sidewalk against travel direction” or “Driver approaching an intersection with the intention to go straight, while cyclist is crossing from the right on the sidewalk in travel direction”, as well as others. Use Cases will be used to establish requirements for improved active vehicle safety systems.

Several crash databases including international, national and in-depth crash information have been analysed. Among them the CARE database (Europe), the German, Swedish and Hungarian national road traffic statistics as well as the in-depth databases IGLAD (Europe), GIDAS (Germany), in-depth data from Pest county (Hungary) and the Volvo Cars Cyclist Accident Database (Sweden).

Early investigations have shown that the crashes between passenger cars and pedestrians or cyclists are of the highest relevance for Europe. For example, in Germany, most of the fatally injured VRUs died in car-to-pedestrian crashes followed by car-to-bicycle crashes. As this was also verified for other European countries, the data analysis work has been concentrated on these two crash configurations.

Based on the available data sources it was aimed to produce results using an agreed common method on the data analysis that firstly, can support the available data and secondly, feeds the needs of the other Work Packages.

To achieve the greatest potential for comparison, the same key crash characteristics were used in the analysis of all databases, such as the limitation to two crash participants, the VRU's injury severity, accidents of latest years (2009-2014) and basic trajectories. As far as possible VRU impact locations on all sides of a vehicle were considered, except the rear, for in-depth analyses. As the structure of the databases was quite different, not all results for different countries could be compared directly (e.g., due to their case inclusion criteria, number of relevant cases, the level of detail and different definitions behind the parameters). Nonetheless, trends could be identified from the analysis.

Considering cyclists, the highest numbers of fatalities per inhabitants can be observed in countries where cycling is very common and the bicycle is used as a daily transportation means like in The Netherlands and in Denmark. Similar to the observation for pedestrians made in previous projects elderly people have the highest risk to get fatally injured as cyclist riders in most countries due to their high vulnerability.

Regarding car-to-cyclist crashes, it was concluded to consider five Accident Scenarios: (I) "Car straight on, Cyclist from near-side", (II) "Car straight on, Cyclist from far-side", (III) "Car turns", (IV) "Car and cyclist in longitudinal traffic" and (V) "Others". Focusing on killed and seriously injured (KSI) cyclists in car-to-cyclist crashes it can be seen that results were similar regarding the accident scenarios (I)-(II): car is going straight on and cyclist crosses either from near- or far-side. Around 42%-52% of all casualties were assigned to (I) and (II), see also Table 25. However, the results vary a lot between Germany, Hungary and Sweden for Accident Scenarios III and IV. In particular Hungary seems to have major issues with cyclists in longitudinal traffic compared to Germany and Sweden which could also be caused by infrastructural differences.
Focusing on killed cyclists in car-to-cyclist crashes it can be seen that in all countries the accident scenario IV (longitudinal traffic) made up the greatest shares of all accident scenarios ranging from 25-64%. This was linked to the higher car impact speeds observed on rural roads.

Having a deeper look into the data all datasets confirmed the following points:

- Older cyclists suffer more often from higher injury severities compared to younger ones.
- Male cyclists are injured more often than females.
- Higher injury severities (in particular fatal crashes) happened more often on rural roads.
- Crashes occurred most often in fine weather and daylight conditions.
- Shares of Accident Scenarios vary a lot between European countries.

As the Accident Scenarios mentioned above could only provide a limited amount of information on the causation of the crashes and their features and this was not sufficient for further system development steps in PROSPECT, Use Cases have been derived from these Accident Scenarios for car-to-cyclist as well as for car-to-pedestrian crashes. In a first step, German traffic crash data (GIDAS) has solely been used for the development of PROSPECT's Use Cases. This work has separately been published in Deliverable 3.1 "The addressed VRU scenarios within PROSPECT and associated test catalogue" [33] and the paper "Car-to-cyclist accidents from the car driver's point of view" [34]. Data from Hungary was also investigated towards Use Cases of car-to-cyclist crashes. Both datasets have provided several challenges and due to the different data inclusion criteria, it was not possible to harmonize these Use Cases. Nevertheless, the major conclusions were the same.

Many of the previous analyses found in literature were based on a higher level of aggregation, e.g., determining basic trajectories of both crash participants. Detailed crash analyses in PROSPECT focusing on the causation of crashes could also show that the most common contributing factor to the crashes was "disregarding traffic regulations" seen for both cyclists and car drivers.

Case-by-case analyses of GIDAS data took the drivers' specific task in a given environment-infrastructure into account by determining typical scenarios which were then summarized to Use Cases. Results show that the drivers' task and the orientation of cyclist have an influence on the frequency of collisions. As example, the cyclist violated traffic regulations as the wrong driving direction on a bicycle lane was chosen to cross a road. Potentially, the car driver failed to watch out for this unexpected traffic situation, as the cyclist would have to approach from the other side, and thus, drove into the intersection area hitting the cyclist.

The analysis of Hungarian crash data confirmed that the primary reasons of car-to-cyclist crashes were the violation of traffic rules and the delay of action.

Regarding crashes between cars and pedestrians crash databases on a European level (IGLAD) and on national / in-depth level (Germany and Hungary) have been analyzed. In these analyses the Accident Scenarios introduced in the European project AsPeCSS were considered as basis for updated figures. In addition, Accident Scenario 8 "Driving backwards" was added.

In general, all databases confirmed that for car-to-pedestrian crashes the Accident Scenario 1 "Crossing a straight road from nearside; no obstruction" for KSI pedestrians, and the Accident Scenario 2 "Crossing a straight road from the offside; no obstruction" are ranked highest for all pedestrian injury severities. It became also clear that higher injury severities were seen in all databases in crashes occurring at dark light conditions.

The analyses of the German and Hungarian data have also shown the importance of accident scenarios on turning (3&4), longitudinal traffic (7) and reversing (8). As the major scenarios (1, 2 and also 5) were largely covered by previous research activities, the PROSPECT consortium decided to focus on the turning scenario as primary Use Case for car-to-pedestrian crashes.

Biggest differences were seen comparing the results from Germany, Hungary and the IGLAD database (limited to countries AT, CZ, FR, IT, SE and SP) with regard to the Turning Accident Scenarios 3 and 4. Whereas Germany and Hungary show a similar trend for at least seriously injured pedestrians compared to all Accident Scenarios, the IGLAD analysis did not confirm this trend. This is perhaps due to the different database characteristics rather than actual differences.

With regard to car-to-moped crashes there were more male moped / scooter riders injured than females and the injuries were mostly in ages 15-17. For the severe and slight injuries, there was drop in injuries with older ages, while half of fatalities were riders older than 45 in the car-to-moped crashes.

In the analysis of misclassification of the injury severity by police in comparison to hospital data, it was found that males, persons above 60, and rural traffic environments lead to higher odds for different classifications by the police and hospitals. A recent study showed that police and hospitals classified the injury equally for 70% of all observed individuals.

Regarding under-reporting of crashes there was a higher under-reporting rate found for slight than severe crashes, estimated 54% and 11% respectively. The under-reporting was slightly lower for car-to-pedestrian crashes, estimated 35%, than for car-to-cyclist crashes estimated 38%.

11 Discussion

Several crash databases from Europe have been analyzed regarding crashes between passenger cars or trucks and VRUs. It has been shown that car-to-pedestrian, followed by car-to-cyclist crashes result in the greatest number of fatalities or seriously injured road traffic casualties. Nevertheless, also car-to-scooter crashes and in particular truck-to-cyclist crashes need to be considered in future as mobility trends show an increase in these types of two-wheelers.

Use Cases with all their details were required as due to the intended improvement of active vehicle safety systems additional information like the “right of way” of a certain crash participant or the layout of an intersection, e.g. via digital maps, are needed.

Usually, crash databases are analyzed in a descriptive way. However, to calculate the risks of getting injured or killed requires also information on uninjured casualties (but involved in a crash), information on under-reporting and exposure data (e.g. mileage) which is rarely available. For instance, the large majority of single cyclist crashes (which also constitute the largest proportion of cyclist crashes in Sweden) are unreported by the police. Under-reporting and misclassification of injury severity in police data are addressed in this document. These are general issues, presumably valid for all European countries.

Historically, the first and still the most reliable variable for the comparison on accident situation between countries is the number of fatalities in road crashes. Comparing the number of slightly or seriously injured people among European countries yields less reliable results as such comparisons are affected by a large number of factors, including different definitions, different health care systems, different organizational issues of rescue services and alert chains, different organizations of police, different insurance-practice and -culture, different traffic laws and also the different definitions of injury severity. Therefore, it would be important to have a common definition for “road traffic crashes” and for injury severities in order to remove part of the uncertainty.

The harmonization of road accident database collection (ex. classification of accidents by different aspects) including data from East and South European countries is required and would be effective in the EU to determine road traffic safety priorities.

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DISCLAIMER

APPENDIX A.1 – DETAILS ON THE KSH DATABASE - ATTRIBUTES

The KSH database contains three tables, such as accident data, participant data (vehicle or pedestrian) and data of persons involved.

Attributes of accidents
Main groups of accident data are

- identifiers of the accident and the police
- date
- place
- infrastructure, traffic control
- environment (surface and weather conditions, visibility)
- accident attributes (type, the severity of injuries, causer)

Description of accident table fields

- **Identifier of accident**
- **Data collection period (month)**
- **County of data collection**

Date

- **Date of accident**
- **Day of accident**

Place

- **County of accident**
- **Municipality ID**
- **Name of public place 1**
- **Type of public place 1**
- **Name of public place 2**
- **Type of public place 2**
- **Street number**
- **Route number**
- **Road section km**
- **Road section m**
- **Crossing route number**
- **Crossing road section km**
- **Crossing road section m**
- **Place of accident:** built-up area / On the open road
- **GPS LAT (y)**
- **GPS LON (x)**

Infrastructure

- **Category of road:** Motorway / Highroad / Highway / Minor road / Other / Unknown or not road
- **Speed limit**
- **Speed limit at the crossroad**
- **Road type:** Vehicle road / Bicycle road / Bicycle way and pedestrian walkway / Pedestrian walkway or other road
- **Road shape:** Straight road / Curve / Winding road / Hump / Intersection / Other or not road
- Intersection type: T or Y intersection / Four-legged intersection / More-legged intersection / roundabout / Other / Not intersection or unknown
- **Traffic type:** One-way / Two-way, undivided / Two-way, divided / Temporary traffic control / Other or unknown
- **Number of lanes in the same direction:** One / Two / Three or more / Off-road or unknown
- **Road markings:** Pavement markings / Abraded, hardly visible markings / Pavement markings and other signs (e.g. prism) / No pavement marking, just traffic sign and/or obstacle / Without signs or off-road
- **Traffic control:** Manual (policeman, signalman) / Traffic lights, functioning / Traffic lights for trams / Traffic sign (Stop, Priority sign) / Temporary traffic control / No traffic control / Not intersection or unknown

- **Gradient:** Flat / Downhill / Uphill
- **Pavement condition:** Perfect / Fragmented, uneven, wavy / Potholed / Rutted / Unpaved or not roadway

Conditions

- **Surface condition:** Normal (dry) road / Wet / Snowy / Oily / Other contamination (e.g. dirt, slob) / Not roadway
- **Weather conditions:** Fair / Cloudy / Fog / Rainy / Storm / Snow / Sleet, hail
- **Visibility:** Daytime, natural daylight / Daytime, natural daylight, limited visibility / Twilight / Night, without street-lightning / Night, functioning street-lighting / Night, inactive street-lighting

Accident

- **Accident type**
- **Primary reason of accident**
- **Severity of injury (after 48 hours):** Fatal / Seriously injured / Slightly injured
- **Severity of injury (after 30 days):** Fatal / Seriously injured / Slightly injured
- **Number of dead after 48 hours**
- **Number of seriously injured persons after 48 hours**
- **Number of slightly injured persons after 48 hours**
- **Number of dead after 30 days**
- **Number of seriously injured persons after 30 days**
- **Number of slightly injured persons after 30 days**
- **Number of vehicles involved**
- **Number of pedestrians involved**
- **Number of killed or persons injured**
- **Causer of the accident**
- **Alcohol influence of causer:** Under 0.5 ‰, under 0.2 mg/l / Between 0.51 and 0.80 ‰ / Between 0.21 and 0.5 mg/l / Between 0.81 and 1.50 ‰ / Between 0.51 and 0.76 mg/l / Up to 1.51 ‰, up to 0.76 mg/l / Hasn't drunk alcohol / Unknown or not examined

Attributes of participants

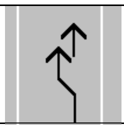
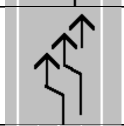
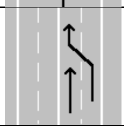
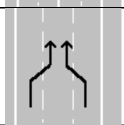
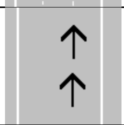
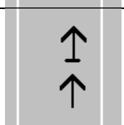
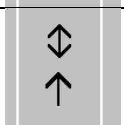
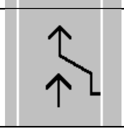
- **Identifier of accident**
- **Causer:** Yes / No
- **Vehicle ID**
- **Role in the traffic:** Motorcycle / Car / Bus / Vehicle for freight transport / Truck and trailer / Tractor-trailer / Truck / Special purpose vehicle / Tram / Trolleybus / Suburban rail / Rail / Bicycle / Mopeds / Animal driven vehicle / Other vehicle / Pedestrian / Passenger / Other person / Animal / Other
- **Manufacturer**
- **Year of production**
- **Dangerous goods code:** Explosives / Condensed, dissolved or deep-frozen gas / Tinderly fluid / Tinderly solid substances / Tent to self-ignition / Tinderly gas generative substances / Oxygenate / Organic peroxide / Toxic substances / Virulent substances / Radioactive substances / Corrosive substances / Other dangerous substances
- **Permanent park of vehicle (county ID or country)**
- **Motion of vehicle:** Departing / Moving / Turning / Waiting for turn / Overtaking / Lane changing / Reversing / In-/Out-parking / Parking
- **Direction according to street number or road section:** Same / Reverse
- **First collision with:** None / Parking vehicle / Animal on roadway / Tree / Other object / Unknown
- **Leaving the spot:** Yes / No

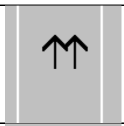
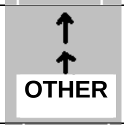
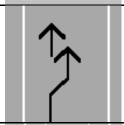
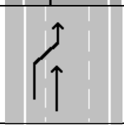
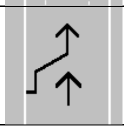
Attributes of persons involved

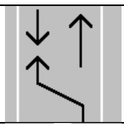
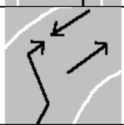
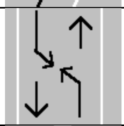
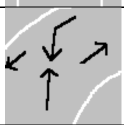
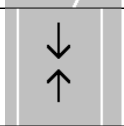
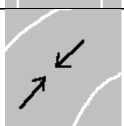
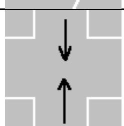
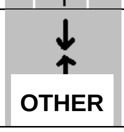
- **Identifier of accident**
- **Identifier of person involved**
- **Vehicle identifier**
- **Role in the accident**: Causer / Participant / Unknown
- **Age**
- **Sex:** Male / Female / Unknown
- **Nationality**

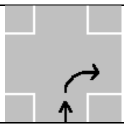
- **Role in the traffic:** Driver / Front seat passenger / Rear seat passenger or other / Pedestrian
- **Airbag:** Yes, opened / Yes, not opened / No
- **Injury severity after 48 hours**: Killed / Seriously injured / Slightly injured / Not injured
- **Injury severity after 30 days:** Killed / Seriously injured / Slightly injured / Not injured
- **Hospitalization:** Medical care on spot / Hospitalized
- **Safety devices used:** Seat belt used / Seat belt not used / Helmet used / Helmet not used / Child restraint system used / Child restraint system not used / Not obligatory by law
- **Driver license:** Possess / Not possess / Not obligatory by law
- **Acquisition of driver license**
- **Do not have driver license:** Yes (he/she does not any driver license) / No (he/she has driver license but it is not necessarily valid)
- **Alcohol influence:** Under 0.5 ‰, under 0.2 mg/l / Between 0.51 and 0.80 ‰, between 0.21 and 0.5 mg/l / Between 0.81 and 1.50 ‰, between 0.51 and 0.76 mg/l / Up to 1.51 ‰, up to 0.76 mg/l / Hasn't drunk alcohol / Unknown or not examined
- **Drug test:** Positive / Negative / Unknown
- **Position of pedestrian:** On the roadway / Crossing at pedestrian crossing / Crossing at non-marked pedestrian crossing / Off-roadway (sidewalk, public transport stop, etc.) / Other (standing, lying) / Non-pedestrian
- **Trajectory type of cyclist:** Roadway / Bicycle way, pedestrian walkway-bicycle way / Bicycle lane, open bicycle lane / Oncoming, marked one-way / Oncoming, non-marked one-way / Sidewalk / Unknown or non-cyclist

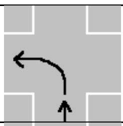
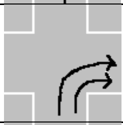
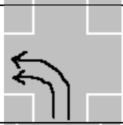
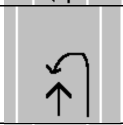
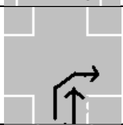
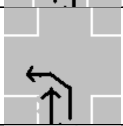
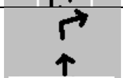
APPENDIX A.2 – DETAILS ON THE KSH DATABASE - ACCIDENT TYPES

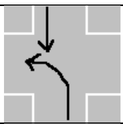
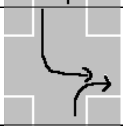
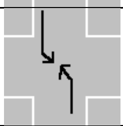
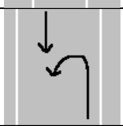
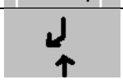
COLLISION OF VEHICLES MOVING STRAIGHT AHEAD IN THE SAME DIRECTION		
101		Collision from behind, vehicle is overtaking from left.
102		Collision from behind, more vehicles are overtaking.
103		Collision from behind, vehicle is changing lanes from right to left.
104		Collision of two vehicles, both are changing lanes.
105		Rear-end collision with at least two moving vehicles.
106		Rear-end collision with at least two vehicles, one stopped.
107		Collision with reversing vehicle.
108		Collision with departing vehicle from the right.

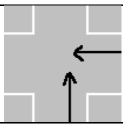
109		Collision between vehicles moving side by side.
110		Other accident between vehicles going ahead co-directional.
111		Collision from behind, vehicle is overtaking from right.
113		Collision from behind, vehicle is changing lanes from left to right.
118		Collision with departing vehicle from the left.

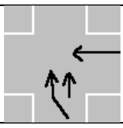
COLLISION OF ONCOMING VEHICLES MOVING STRAIGHT AHEAD		
201		Collision of oncoming vehicles on straight road, one is overtaking or changing lanes.
202		Collision of oncoming vehicles in curve, one is overtaking or changing lanes.
203		Collision of oncoming vehicles on straight road, at least two vehicles are overtaking or changing lanes.
204		Collision of oncoming vehicles in curve, at least two vehicles are overtaking or changing lanes.
205		Collision of oncoming vehicles on straight road (no overtaking, no lane changing).
206		Collision of oncoming vehicles in curve (no overtaking, no lane changing).
207		Collision of oncoming vehicles at intersections, no overtaking, no lane changes, no turn.
210		Other collision of oncoming vehicles.

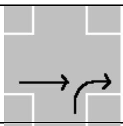
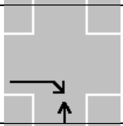
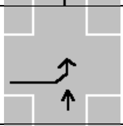
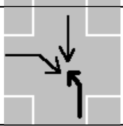
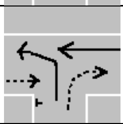
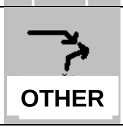
COLLISION OF TURNING VEHICLES MOVING IN THE SAME DIRECTION		
301		Collision of co-directional vehicles at crossing, one is turning right.

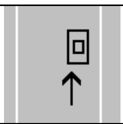
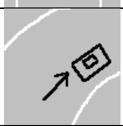
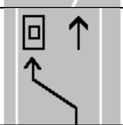
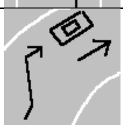
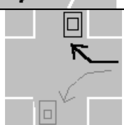
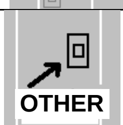
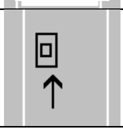
302		Collision of co-directional vehicles at crossing, one is turning left.
303		Collision of co-directional vehicles at crossing, both are turning right.
304		Collision of co-directional vehicles at crossing, both are turning left.
305		Collision of co-directional vehicles, one is u-turning.
306		Collision of co-directional vehicles at crossing, one is turning right from offside lane.
307		Collision of co-directional vehicles at crossing, one is turning left from nearside lane.
310	 **OTHER**	Other collision of co-directional vehicles.

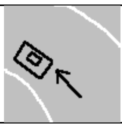
COLLISION OF ONCOMING AND TURNING VEHICLES		
401		Collision of oncoming vehicles at intersection, one is turning left.
402		Collision of oncoming vehicles at intersection, one is turning right, second is turning left.
403		Collision of oncoming vehicles at intersection, both are turning left.
404		Collision of oncoming vehicles, at least one is turning or u-turning.
410	 **OTHER**	Other collision of oncoming AND turning vehicles.

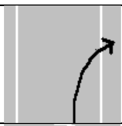
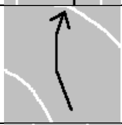
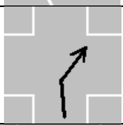
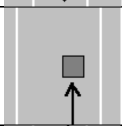
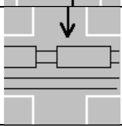
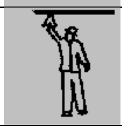
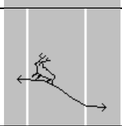
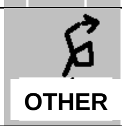
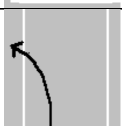
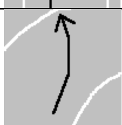
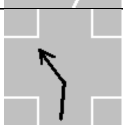
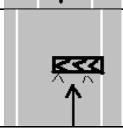
COLLISION OF CROSSING (BUT NOT TURNING) VEHICLES AT INTERSECTIONS		
501		Collision of crossing vehicles.

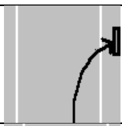
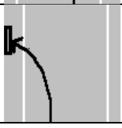
502		Collision of crossing vehicles, one is overtaking/changing lanes.

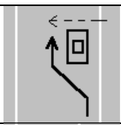
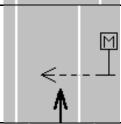
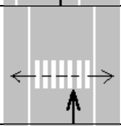
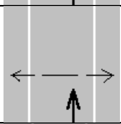
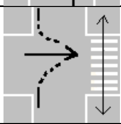
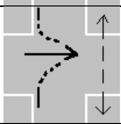
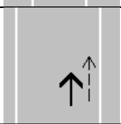
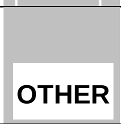
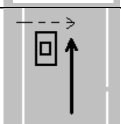
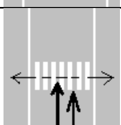
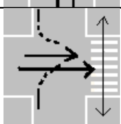
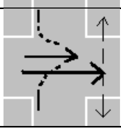
COLLISION OF CROSSING AND TURNING VEHICLES AT INTERSECTIONS		
601		Accident between vehicles moving co-directional at crossing, one is turning right.
602		Accident between oncoming vehicles at crossing, one is turning right.
603		Accident between vehicles moving co-directional at crossing, one is turning left.
607		Accident between more than two vehicles at intersection.
608		Accident between crossing vehicles not at crossing (parking lot, garage, etc.).
610		Other accident between crossing and turning vehicles.

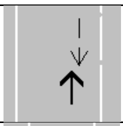
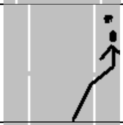
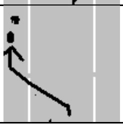
COLLISION WITH PARKED VEHICLES		
701		Collision with parked vehicle on the right.
702		Collision with parked vehicle on the right in curve.
704		Collision with parked vehicle on straight road, at least two participants, at least one vehicle is overtaking or changing lanes.
705		Collision with parked vehicle in curve, at least two participants, at least one vehicle is overtaking or changing lanes.
708		Collision with parked vehicle at crossing, vehicle is turning.
710		Other collision with parked vehicle.
711		Collision with parked vehicle on the left.

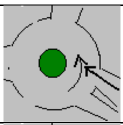
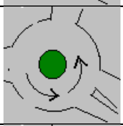
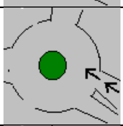
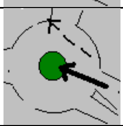
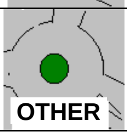
712		Collision with parked vehicle on the left in curve.

SINGLE VEHICLE AND OTHERS ACCIDENTS		
901		Single vehicle accident, vehicle is leaving the line on the right.
902		Single vehicle accident, vehicle is leaving the line on the right in curve.
903		Single vehicle accident, vehicle is leaving the line on the right at intersection.
904		Collision with obstructions on the road.
905		Collision with train, suburban train or tram.
906		Collision with vehicles hauled by animal power.
907		Passenger accident.
908		Collision of animals.
910		Other single vehicle or other accident.
911		Single vehicle accident, vehicle is leaving the lane to the left.
912		Single vehicle accident, vehicle is leaving the lane to the left in curve.
913		Single vehicle accident, vehicle is leaving the lane to the left at intersection.
914		Collision with temporary traffic sign.

921		Single vehicle accident, on straight road, vehicle is leaving the lane to the right, collision with obstruction outside road.
931		Single vehicle accident, on straight road, vehicle is leaving the lane to the left, collision with obstruction outside road.

PEDESTRIAN ACCIDENTS		
1001		Pedestrian accident, pedestrian is crossing behind parked vehicle or obstruction on the right.
1002		Pedestrian accident on the road at public transport station.
1003		Pedestrian accident at pedestrian crossings not at intersections.
1004		Pedestrian accident outside pedestrian crossings not at junctions.
1007		Pedestrian accident at pedestrian crossings at junctions.
1008		Pedestrian accident at junctions outside pedestrian crossings.
1009		Pedestrian accident, pedestrian is walking on the road co-directional with the vehicle.
1010		Other pedestrian accident.
1011		Pedestrian accident, pedestrian is crossing behind parked vehicle or obstruction on the left.
1013		Pedestrian accident at pedestrian crossing not at intersections, vehicle is moving next to parked vehicle.
1017		Pedestrian accident at pedestrian crossing at intersections, vehicle is moving next to parked vehicle.
1018		Pedestrian accident at intersections, vehicle is moving next to parked vehicle.

1019		Pedestrian accident, pedestrian is walking on the road opposite the vehicle.
1020		Pedestrian accident with vehicles outside the road on the right.
1021		Pedestrian accident with vehicles outside the road on the left.

ACCIDENTS IN ROUNDABOUT		
2001		Collision with entering vehicle.
2002		Collision with leaving vehicles.
2003		Collision with co-directional vehicles in roundabout.
2004		Collision with side by side vehicles in roundabout.
2005		Collision between vehicles in front of roundabout.
2006		Single vehicle accident in roundabout.
2010		Other accident in roundabout.

APPENDIX B.1 – VOLVO CARS ACCIDENT DATABASE

Table 34: Conflict situation classification scheme in V_CAD

$SCPcr_{OD}$	Straight Crossing Path, cyclist from right, initially from Opposite Direction	LT/OD	Left Turn, cyclist from Opposite Direction
$SCPcr_{SD}$	Straight Crossing Path, cyclist from right, initially from Same Direction	LT/OD_{LD}	Left Turn, cyclist from Opposite Direction, initially from left direction
SCPcr	Straight Crossing Path, cyclist from right	LT/OD_{RD}	Left Turn, cyclist from Opposite Direction, initially from right direction
$SCPcl_{OD}$	Straight Crossing Path, cyclist from left, initially from Opposite Direction	LT/SD	Left Turn, cyclist from Same Direction
$SCPcl_{SD}$	Straight Crossing Path, cyclist from left, initially from Same Direction	LT/SD_{LD}	Left Turn, cyclist from Same Direction, initially from left direction
SCPcl	Straight Crossing Path, cyclist from left	LT/SD_{RD}	Left Turn, cyclist from Same Direction, initially from right direction
		LT/RD	Left Turn, cyclist from Right Direction
Oncoming	Straight, cyclist Oncoming	LT/LD	Left Turn, cyclist from Left Direction
SD	Straight, cyclist Same Direction	RT/OD	Right Turn, cyclist from Opposite Direction
		RT/OD_{LD}	Right Turn, cyclist from Opposite Direction, initially from left direction
Reversing	Car reversing accident	RT/OD_{RD}	Right Turn, cyclist from Opposite Direction, initially from right direction
Dooring	Car occupant is about to leave the car and the cyclist crashes into the door being opened	RT/SD	Right Turn, cyclist from Same Direction
Car standing still	Parked car, or car standing still in traffic	RT/SD_{LD}	Right Turn, cyclist from Same Direction, initially from left direction
		RT/SD_{RD}	Right Turn, cyclist from Same Direction, initially from right direction
Other	Other	RT/RD	Right Turn, cyclist from Right Direction
		RT/LD	Right Turn, cyclist from Left Direction

APPENDIX C.1 – FATALLY INJURED PEDESTRIANS AND CYCLISTS IN EU-28

Not all European countries offered information on killed casualties for all considered years. To complete this picture of the development of the number of fatalities in EU-28, these gaps were simply filled by the number of the next or the previous available year and were marked in red.

In 2013 in the EU 6,810 pedestrians were fatally injured in road accidents. The number of fatally injured pedestrians reduced nearly by 50% since 2000.

Table 35: Fatally injured pedestrians in EU-28 from 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Austria	140	117	160	132	132	97	110	108	102	101	98	87	81	82
Belgium	142	158	127	113	101	108	122	104	99	101	106	113	104	99
Bulgaria	278	278	278	278	278	278	278	278	278	198	198	198	198	198
Croatia	124	124	124	124	124	124	124	124	136	103	105	71	72	69
Cyprus	23	23	23	23	23	23	19	17	16	9	13	13	10	8
Czech Republic	362	322	308	290	281	298	202	232	238	176	168	176	163	162
Denmark	99	49	63	49	43	44	60	68	58	52	44	33	31	34
Estonia	50	50	50	50	50	50	64	38	41	23	26	26	29	23
Finland	62	62	40	59	49	45	49	48	53	30	35	41	29	34
France	838	822	866	626	581	635	535	561	548	496	485	519	489	465
Germany	993	900	873	812	838	686	711	695	653	591	476	614	527	561
Greece	375	338	279	257	293	234	267	255	248	202	179	223	170	151
Hungary	299	299	299	299	326	289	296	288	251	186	192	124	156	147
Ireland	85	89	86	64	66	72	72	81	49	40	44	47	29	29
Italy	982	1.032	1.226	871	810	786	758	627	646	667	621	589	576	551
Latvia	197	197	197	197	197	174	153	158	105	82	79	60	62	70
Lithuania	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Luxembourg	11	11	6	7	12	2	10	7	6	12	1	6	6	5
Malta	6	6	6	6	6	6	4	3	1	1	1	1	1	1
Netherlands	106	106	97	97	68	83	66	86	56	63	62	65	64	51
Poland	2.256	1.866	1.987	1.879	1.987	1.756	1.802	1.951	1.882	1.467	1.236	1.408	1.157	1.140
Portugal	384	337	339	280	233	214	156	156	155	148	195	199	159	144
Romania	1.110	1.088	1.101	944	1.059	978	1.034	1.113	1.067	1.015	868	747	728	726
Slovakia	174	174	174	174	174	174	214	217	204	113	126	126	126	126
Slovenia	60	42	41	38	35	37	36	32	39	24	26	21	19	20
Spain	899	846	776	786	683	680	614	591	502	470	471	380	370	371
Sweden	73	87	58	55	67	50	55	58	45	44	31	53	50	42
United Kingdom	889	858	808	802	694	699	697	663	591	524	415	466	429	405
number of fatalities	**11.113**	**10.378**	**10.488**	**9.409**	**9.306**	**8.718**	**8.604**	**8.655**	**8.165**	**7.034**	**6.397**	**6.502**	**5.931**	**5.810**

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In 2013 in the EU 2,028 cyclists were fatally injured in road accidents. The number of fatally injured cyclists decreased by 43 % since 2000.

Table 36: Fatally injured cyclists in EU28 from 2000-2013

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Austria	62	55	80	56	58	47	48	37	62	39	32	42	52	52
Belgium	134	130	105	110	79	71	92	90	86	89	70	70	69	73
Bulgaria	35	35	35	35	35	35	35	35	35	29	29	29	29	29
Croatia	28	28	28	28	28	28	28	28	47	29	28	28	21	23
Cyprus	1	1	1	1	1	1	2	3	6	2	2	2	1	2
Czech Republic	151	141	160	159	131	115	110	116	93	84	80	63	78	74
Denmark	58	56	52	47	53	41	31	54	54	25	26	30	22	33
Estonia	7	7	7	7	7	7	13	13	9	7	7	-	-	-
Finland	53	59	53	39	26	43	29	22	18	20	26	19	19	20
France	270	256	223	201	177	180	181	142	148	162	147	141	164	147
Germany	659	635	583	616	475	575	486	425	456	462	381	399	406	354
Greece	22	29	14	21	24	18	21	16	22	15	23	13	21	15
Hungary	178	178	178	178	183	152	153	158	109	103	92	85	84	68
Ireland	10	12	18	10	11	10	9	15	13	7	5	9	8	8
Italy	401	366	326	355	322	335	311	352	288	295	265	282	292	251
Latvia	30	30	30	30	30	31	33	18	15	26	13	15	18	13
Lithuania	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Luxembourg	1	1	1	-	-	1	-	-	-	2	1	2	-	-
Malta	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Netherlands	198	195	169	188	157	151	179	147	145	138	119	144	145	112
Poland	692	610	681	647	691	603	509	498	433	371	280	314	300	306
Portugal	56	50	58	63	47	48	40	34	42	29	33	45	32	29
Romania	157	145	132	156	130	206	198	179	179	157	182	140	154	161
Slovakia	56	56	56	56	56	56	52	61	46	22	27	27	27	27
Slovenia	26	16	18	-	22	19	15	17	17	18	17	16	12	16
Spain	84	100	96	78	88	82	72	90	59	57	67	48	74	70
Sweden	47	43	42	35	27	38	26	33	30	20	21	21	28	14
United Kingdom	131	140	133	116	136	152	147	138	117	104	111	109	120	113
number of fatalities	**3.564**	**3.392**	**3.297**	**3.250**	**3.011**	**3.062**	**2.838**	**2.739**	**2.547**	**2.329**	**2.102**	**2.111**	**2.194**	**2.028**

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PROSPECT
Proactive Safety for Pedestrians and Cyclists

EUROPEAN COMMISSION

EIGHTH FRAMEWORK PROGRAMME

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EXECUTIVE SUMMARY

Deliverable D2.1 “Accident Analysis, Naturalistic Observations and Project Implications” is issued in the scope of WP2 “Accident analysis and user needs” from the PROSPECT project. The objective of WP2 is to generate the user requirements for next generation proactive safety systems, with a focus on the specific needs of vulnerable road users (VRUs).

Part A of deliverable D2.1 (Accident data analyses) provided results from task T2.1 “Characteristics of vehicle to VRU accidents”. Within this task, an in-depth accident analysis involving Vulnerable Road Users was carried out in Europe, focusing mainly on pedestrians and cyclists.

The output already obtained from task T2.1 has provided information about the current safety situation and the identification of the most relevant car-to-cyclist and car-to-pedestrian accident scenarios where safety improvements are necessary. This data has been used to define the use cases of PROSPECT, and the system development will focus on the most relevant of these. The overall process of use case definition for PROSPECT and the associated test catalogue derived from the accident analysis data is provided in deliverable D3.1 “The addressed VRU scenarios within PROSPECT and associated test catalogue”, available in May 2016.

This report corresponds to Part B of deliverable D2.1, which seeks to provide additional knowledge to the project through naturalistic observations within selected European cities in order to establish how vehicles and VRUs interact in real traffic situations. This work has been developed in task T2.2.

Naturalistic observations facilitate a better understanding of potentially dangerous traffic situations with VRUs. In particular, it includes the identification of motions, behaviours and interactions that lead to such situations, from both VRU and driver perspective.

Additional to the information provided from the accident databases, it is necessary to identify the parameters that signal VRU intent in order to enable earlier and more precise reactions by safety systems. Naturalistic observations are therefore crucial for the development of advanced algorithms integrated in next generation PROSPECT-like systems, and must be also taken into account as relevant factors for the definition of test scenarios.

An introduction and specific objectives of the task are presented in this part, as well as the methodology for data acquisition and extraction of conflicts regarding VRUs in real-world traffic from infrastructure-mounted and/or vehicle-based sensors and cameras in Lyon, Budapest and Barcelona.

An additional study made on Helmond on cyclist behaviour is also described.

The parameters considered for the analyses of conflicts are provided, as well as analysis of the conflicts.

Finally, this part of the document offers a general conclusion about the results obtained from the naturalistic observations.

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1 INTRODUCTION

1.1 BACKGROUND

Accident data bases provide a lot of information useful to understand the causation chain of the accidents. However they generally lack information about behavioural aspects in the seconds before the accident and then cannot fully explain the process that lead to an accident.

Compared to other experimental approaches, the naturalistic observation approach is quite new. It refers to studies undertaken using unobtrusive observation when driving in a natural setting.

The so-called naturalistic driving studies (NDS) have been developed since the early 2000s, starting with the American project called 100-car study and then on a larger scale through the SHRP2 program. The method has been used in European projects such as PROLOGUE, DaCoTa, UDRIVE, InDev etc and even adapted for bicycle or motorcycle observations [1] and within European projects such as 2BESAFE, XCYCLE etc. Under this approach, road user behaviour is monitored for long periods of time which results in a reliable picture of everyday driving behaviour. The naturalistic observation approach allows for analysing interactions between drivers, other road users, vehicle, and environment in situations ranging from normal driving to conflicts and even accidents. The main objective of such studies is to quantify safety critical events and related risk for road users. An ISO standard is currently developed in the ISO TC22/SC39/WG8 to define terms and variables to be used in the annotating video that are collected in the NDS.

The approach followed in the PROSPECT project differs from the NDS itself, as the study is not intended to observe totally free driving by different drivers. Even if PROSPECT drivers drive in a natural setting, without the presence of an experimenter, they are asked to drive in hotspot areas, where conflicts have a high probability to occur. Recorded data focuses on the road environment rather than on the driver himself.

In another naturalistic approach, test sites are equipped with cameras that continuously record traffic data during long periods of time. The road traffic observations have been used for decades to evaluate road safety of the infrastructure. Different protocols have been designed such as the Doctor technique [2] or the Swedish technique [3] which focuses mainly on serious conflicts. Such techniques are based on observer judgements. For this reason, protocols are designed to also train the observers to recognize conflicts. This is also the reason why caution is required when being used as they rely mainly on human subjective evaluation. However, the possibility nowadays to include video analysis to the subjective data brings back interest to the approach. Such observations can provide very useful information like location, distance, speed of surrounding traffic, time to collision, post encroachment time, etc.

In the PROSPECT project, naturalistic observations and coding of natural traffic scenes are used to provide a deeper understanding of potential conflicts between vehicles and vulnerable road users and especially to give information on how and why drivers and VRUs' react when they are in conflict. Complementary information to accident analysis is particularly sought such as VRUs and vehicles' motion. A focus is also pointed out on VRU's attitude to gain information about their intents. For example, pedestrians' head position or cyclists' arm movements are potential indicators that signal VRU intent and that are generally not included in accident data. Quantifying such information should play an important role in the development of system safety functions, enabling the system to react quicker and in a more accurate way.

1.1.1 Conflict definition

In the literature, different definitions of a conflict can be found. According to Kraay et al.'s 2013 literature review (Doctor Technique manual, [2]), the notion of conflict has been evolving since the late 1960's. These authors report several definitions ranging from Perkins & Harris [4] to their own one. The first characteristics evoked in the definitions of conflict are related to "sudden" and "uncontrolled actions" of the road users in order to avoid the crash. Another important aspect of these definitions is the "close proximity" between road users on both space and time dimension. The fact that a crash will occur if none of the involved road users rapidly attempt an action to mitigate the situation appears to be particularly relevant to qualify an encounter as a conflict.

Other important aspects are also evoked by Laureshyn et al. [5] to define a conflict. Indeed, they emphasize the continuous relationship between normal encounters and crashes, revealing here the ideas of frequency of occurrence and severity of the encounters. They present a pyramidal / diamond shaped representation of both frequency and severity of conflicts in the global frame of encounters ranging from common ones to accidents. This way of representing conflicts shows the relationship between the severity and the frequency of problematic encounters. The notion of severity is reported by both Kraay et al. [2] and Laureshyn et al. [5] as a very important aspect of what makes an encounter a conflict. The latter indicates that severity is related to various factors namely: "Type of road users", "collision angle", "collision speed" and "potential damages". These questions have been reviewed within the InDev project [6], D2.1 – Appendix 6 focused on site-based road traffic observations.

Evaluating the severity of conflict is an important issue and a key point of conflict identification and analysis. Different parameters are generally considered. Initially the notion of severity was described as being related to "both the probability of collision and the extent of the consequences if a collision would have occurred" [1]. The type of involved road users is also described as influencing the conflict severity through the potential consequences in case of collision [5]. The probability of collision can be related to objective values such as TTC, speed and proximity. Involved road users evasive manoeuvers and control over it may also influence the severity criteria.

1.2 OBJECTIVES

It is important to note that except for the cyclist's behaviour study made in Helmond, see section 5, the analysis of non-conflict situations is not under the scope of this deliverable, and is not included in the naturalistic observations performed in Lyon, Budapest and Barcelona. Additionally, these observations do not focus on free driving by different people. The study is done in areas identified as hotspots with the objective of finding conflicts or near-miss situations.

Results of the study on cyclist's behaviour in non-conflict situations in Helmond will be delivered as an outcome to investigate i.e. cyclist's pose during system modelling.

Use cases that are investigated through naturalistic observations have been defined within WP3 from accident analyses. Naturalistic observations aim at illustrating these use cases by providing information that is not included in accident reports, such a kinematic data (precise trajectory, speed, TTC…) and also information about the intents of the road users that could help to anticipate the evolution of the situation.

The main objectives of this task are:

- To investigate how vehicles and VRUs interact in real traffic when they are in conflict, and to provide a general understanding of these dangerous situations.
- To identify factors (motions, behaviours and interactions) that lead to conflicts from both VRU and driver perspectives.
- To provide both qualitative and quantitative description of VRU-vehicle motion, behaviours & interactions.
- To study various versions of a same use case, that will be differentiated in terms of speed, trajectory, TTC… and conflict severity.
- To identify indicators that signal VRU intent (VRU's plan in the near-future), such as positional data, torso- and head-orientation (e.g. pedestrian head-turning), hand gestures (e.g. cyclist hand-extension).

Moreover, this task will allow for investigating situations where conflicts are correctly managed by a driver and/or a VRU. In most cases, either an accident has been avoided thanks to an evasive manoeuvre, or a very close proximity between the road users is observed. Such situations are interesting for system development as they can lead to sensor false alarms.

Furthermore, the behavioural parameters investigated in the naturalistic studies will provide results that should allow for a more realistic testing, being based on real observations. In this regard, it is important to highlight that regardless differences between observations performed in Lyon, Budapest and Barcelona, a common coding grid has been defined within the task and the same parameters are considered for the analysis of conflicts in the three cities. The intention is to provide an outcome of the study that is as homogenous as possible.

1.3 Outputs

The current development work made in the project is based on the Use Cases derived from the accident analysis done in Task T2.1. However, the development of advanced algorithms will be improved by information provided by the naturalistic observations regarding human factors such as VRU intent, trajectories, behaviour that will be available from task T2.2.

The main output of this activity will be provided towards the development of image-based algorithms, which aims to include path prediction. There are several parameters that can help predict VRU motion:

- Head and torso orientation with respect to the vehicle for instance, are of particular relevance for sensor systems to extract intent related features
- Pedestrians' head position, cyclists' arm movements are also potential indicators that signal VRU intent. This data will play a major role in enabling quicker system reaction.

Such information is delivered in the common data coding sheets filled by each team. These annotating sheets include all variables of interest (i.e. the most relevant ones for sensor specifications) that have been previously discussed and validated with WP3 partners to describe conflicts. Encoded data will then be shared with project partners and will enable for sensor developing.

Additionally, the naturalistic observation campaigns made available a large amount of videos where lots of situations can be extracted. This part of the project focused on conflict situations between vehicles and VRUs. New analyses will be done using these videos, to provide information about typical situations. Kinematic data will be computed for example regarding cruise speeds for VRUs (pedestrians, cyclists) under normal traffic situations in WP5. The individual analysis of conflicts, the in-depth study of the most severe situations, and conclusions about the most relevant parameters will be provided. This work should allow for identifying the most important features of influence in the investigated scenarios.

Finally, recordings from several partners participating in the activity will be available for the partners responsible for the development under the existence of a Non-Disclosure Agreement if needed.

2 METHODOLOGY FOR CONFLICT OBSERVATIONS

Two kinds of naturalistic observations have been carried out in 3 different countries: France, Hungary and Spain in order to collect conflicts between vehicles and VRUs.

- A first data set has been collected from on-site observation. Cameras have been installed in the infrastructure to observe vehicles and VRU interactions from the outside. These observations were conducted in Lyon and Budapest.
- A second data set was collected from in-vehicle to observe interactions from an equipped vehicle with surrounding VRU(s). These observations were conducted in Budapest and in Barcelona.

In both cases, only conflicting interactions between VRU(s) and vehicle(s) were analysed.

2.1 AUTHORISATIONS

Conducting such observations requires having first authorisations considering private life of road users.

Regarding observations in France

A normal declaration has been made to the French data protection authority CNIL (Commission Nationale de l'Informatique et des Libertés - National Commission on Informatics and Liberty), which aims at protecting personal data and preserving individual liberties. Then a request was sent to the City of Lyon - OTEP (Occupation Temporaire de l'Espace Public - Temporary Occupation of Public Space), which gave an authorisation, to the condition that:

- Shootings do not cause discomfort to residents.
- It complies with the laws relating to image rights.
- Agreement from house owners was obtained.

Data storage: videos are stored on a secured data server in IFSTTAR premises, until the end of the project. Videos are only accessible by authorized IFSTTAR personnel.

Regarding observations in Hungary

Personal data recordings in Hungary are regulated by Act 1992/LXIII (Protection of personal data and disclosure of public data). Data recordings for BME are performed with the following conditions:

- Videos stored on dedicated storage device protected by password.
- Access being restricted to authorised persons of the project (BME staff), who sign a confidentiality agreement.
- Conflicts encoded by authorized persons of the project (BME staff only) and not subject to dissemination.
- Videos being destroyed at the end of the project.
- Encodings allow for creating database in which all individuals being anonymous.

- Only encoded databases will be shared with project partners. No images will be transmitted.
- Video recordings are performed in Budapest from October 2015 to September 2016, to the condition that:
    - Shootings do not cause discomfort to residents;
    - It complies with the laws relating to image rights.

Regarding observations in Spain

Data has been recorded during this activity according to personal information data protection regulations “Ley Orgánica de Protección de Datos”, LOPD 15/1999”.

The data will be analysed to obtain statistical information on pedestrians and cyclist interactions in urban area. The camera will be recording complete journeys, then the sections of videos where a pedestrian or cyclist appear in front the vehicle in movement will be saved. The remaining part of the videos will not be processed.

Data storage: the videos are stored on a secured data server inside IDIADA’s headquarter installations for a total durations of 5 years in the case the videos need to be processed with an upgrades algorithm. Those videos will only be accessible by authorized IDIADA personnel.

In the eventuality a video has to be published the following process will be applied:

- Pixelization of recognizable pedestrians faces.
- Pixelization of vehicles identification plates.

A request was sent to Barcelona Film Commission, which gave an authorisation, to the condition that:

- It complies with the laws relating to image rights.
- Filming is done with non-lucrative purposes.

2.2 Experimental design

Two IFSTTAR teams have been involved in this task. The LESCOT team was in charge of collecting video data, selecting relevant conflicts, analysing and categorizing conflicts, while the LEOST team developed algorithms to extract relevant epochs from continuously recorded videos in order to provide kinematic data and trajectories where relevant.

2.2.1 On-site observations in France

Two sites have been selected regarding the following criteria:

- Selected areas are of high concentration of bikes as identified by the local authority Grand Lyon Metropole.
- Accident and fatalities reported: Maps of accident were used. On both sites was observed a concentration of accident between cyclists and vehicles.

- Investigation among neighbourhood was also carried out to check for the occurrence of conflicts on the areas.
- Roadside observations (without cameras) confirmed the intersection interest: experimenters spent several time periods in different places foreseen to be observed. Such observations helped to decide if the place was relevant or not. Special care was taken to observe pedestrian and cyclist behaviour, frequency of obstruction, complexity of the surrounding…

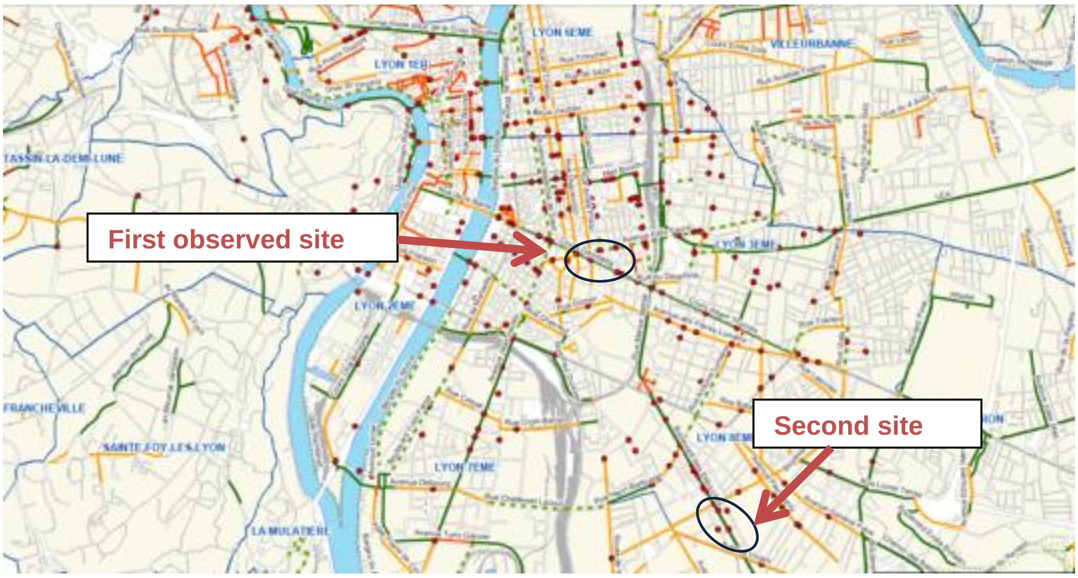


Figure 1: Accident map (2009-2015) from Grand Lyon city

2.2.1.1 Data collection format, size, period of acquisition

Cameras that targeted the roadway have been installed in private premises. Inhabitants where they were installed were compensated for the installation, and received 100€ for each camera per month installed in their home.

Cameras recorded continuously during long period of time (at least one month) to allow for a complete recording of conflicts between vehicles and vulnerable road users.

The films were shot from an elevated viewpoint (16-17th floor for the 1st site and 13th floor for the second one). In each area, two cameras filmed the same scene from two points of view to enable an optimized image processing and allow 3D reconstitution necessary to obtain vehicle and VRU's trajectories.

Figure 2: Site 1 - View from camera 1

Figure 3: Site 1 - View from camera 2

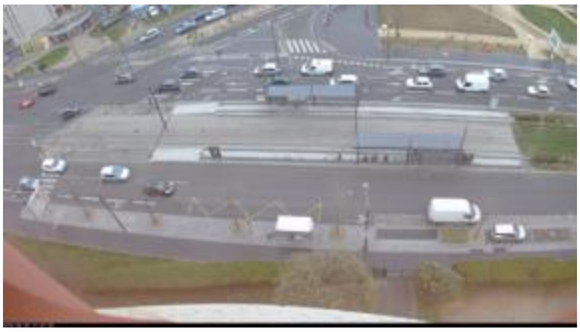


Figure 4: Site 2 - View from camera 1

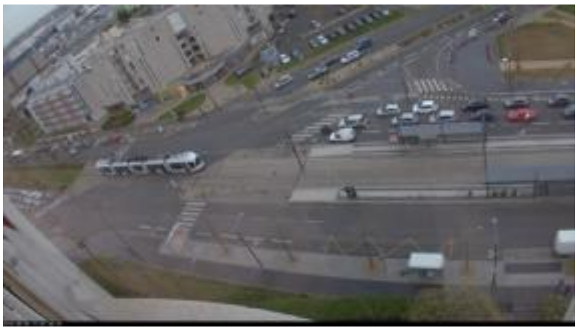


Figure 5: Site 2 - View from camera 2

The choice to enclose the 2 cameras in private premises was, firstly to prevent them from being degraded or stolen and, secondly to ensure that access to stored data would strictly be restricted to authorized persons of the project (IFSTTAR agents only). Inhabitants in whose premises the cameras were installed did not have access to the records.

To ensure the security of the collected data, all the devices were protected by complex randomly generated passwords (12 passwords generated). Each camera and storage devices used were given a different 30 character length password. We used dedicated software to manage and encrypt these passwords.

- **Periods of recordings**

The first data collection was undertaken in September-October 2015, while the second data collection took place in April-May 2016.

2.2.1.2 Recording system

The video recording systems consisted in one Axis IP camera plugged on a Synology server to store the video data. The camera, an AXIS P1428-E, provided 8.3 MP/4K Ultra HD resolution image (H264 encoding format) at 25 frames per second through network protocol to the server. This type of cameras, designed for video surveillance was equipped with day and night auto switch functionality.

Due to the high video recording resolution, an adapted storing system with large storage capacity and high speed network compatibility was required (i.e. Synology

Disk Station DS1815+ RAID5 NAS). The total amount of data collected was approximately 40TB duplicated. The recording systems were monitored through secured internet connection to check the recording status. To ensure the data integrity, all the collected videos were duplicated on a second set of similar storage servers (80TB in total).

2.2.1.3 Data extraction

- **Automatic pre-selection of conflictual situations**

The video sequences represent about 1,440 hours of acquisition. Unfortunately, due to the growth of vegetation in May, 15 days of recording could not be processed: moving leaves in the trees make image automatic process impossible. In the end a total of 1,080 hours have been processed. Because it was not conceivable to look at all the sequences to extract the potential conflictual situations we aimed to describe and code, an automatic pre-selection tool has been used to provide a quite large set of relevant situations. This tool was developed by IFSTTAR-LEOST and operates in the following manner.

The first step extracts foreground objects (car, bicycle, pedestrians etc.) by modelling the urban background. The urban background is defined as an image of the empty scene i.e. without object. This background model is updated to take into account the variability of the lighting conditions and the density of the traffic. Figure 6 is an illustration of the detection results yielded by the implemented technique. The second step classifies the detected objects in two classes that include respectively the VRU (bicycles and pedestrians) and the cars. The classification process is based on the size and the geometry of the detected shape. Figure 7 shows the quality of the classification process.

Figure 6: Object detection results

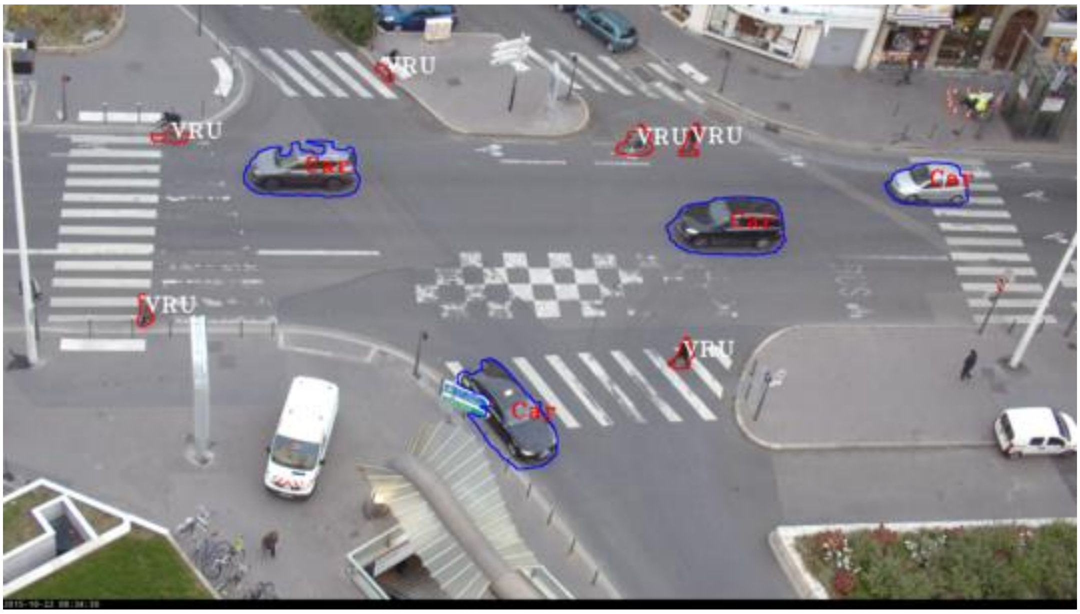


Figure 7: VRU/car classification results

The detection of a conflictual situation is based on the analysis of the distance between the VRU and the car objects. When a VRU is close to a car, the situation is retained. To reduce the number of false positives i.e. false critical events, objects have to be close for a certain period. Only relevant parts of the scene have been studied, pavements being excluded from the analyses for example. Figure 8 shows the mask used to exclude non relevant parts of the scene for the first site of acquisition.

Figure 8: Mask applied to exclude non relevant areas of the scene

All detected events are gathered in a XML playlist compatible with VLC player (as illustrated in Figure 10). Thanks to this solution, it is possible to browse all the “potential” critical situations and reject the irrelevant ones. Each detected events is located in a specific area in the scene. Each area is coded by a particular colour and integrated in a visual mask. This mask is overlapped to the video sequence thanks to the VLC interface to speed up the human rejection task (Figure 9).

Figure 9: Colour mask overlapped to the video to ease human selection task


```xml
<?xml version="1.0" encoding="UTF-8"?>
<playlist xmlns="http://xspf.org/ns/0/" xmlns:vlc="http://www.videolan.org/vlc/playlist/ns/0/" version="1">
    <title>Playlist</title>
    <trackList>
    <track><title>track0_Zone blanche</title><annotation>Zone blanche</annotation>
        <location>file://PROSPECT4/recordings_prospect4/axis-ACCC8E430F7E/20160404/16/20160404_161851_8081_ACCC8E430F7E/20160404_18/20160404_183858_1A78.mkv</location>
        <extension application="http://www.videolan.org/vlc/playlist/0"><vlc:id>0</vlc:id><vlc:option>start-time=113</vlc:option><vlc:option>stop-time=128</vlc:option></extension></track>
    <track><title>track1_Zone bleue</title><annotation>Zone bleue</annotation>
        <location>file://PROSPECT4/recordings_prospect4/axis-ACCC8E430F7E/20160404/16/20160404_161851_8081_ACCC8E430F7E/20160404_18/20160404_183858_1A78.mkv</location>
        <extension application="http://www.videolan.org/vlc/playlist/0"><vlc:id>1</vlc:id><vlc:option>start-time=23</vlc:option><vlc:option>stop-time=38</vlc:option></extension></track>
    <track><title>track2_Zone bleue</title><annotation>Zone bleue</annotation>
        <location>file://PROSPECT4/recordings_prospect4/axis-ACCC8E430F7E/20160404/16/20160404_161851_8081_ACCC8E430F7E/20160404_18/20160404_183858_1A78.mkv</location>
        <extension application="http://www.videolan.org/vlc/playlist/0"><vlc:id>2</vlc:id><vlc:option>start-time=28</vlc:option><vlc:option>stop-time=44</vlc:option></extension></track>
    <track><title>track3_Zone bleue</title><annotation>Zone bleue</annotation>
        <location>file://PROSPECT4/recordings_prospect4/axis-ACCC8E430F7E/20160404/16/20160404_161851_8081_ACCC8E430F7E/20160404_18/20160404_183858_1A78.mkv</location>
        <extension application="http://www.videolan.org/vlc/playlist/0"><vlc:id>3</vlc:id><vlc:option>start-time=40</vlc:option><vlc:option>stop-time=55</vlc:option></extension></track>
    <track><title>track4_Zone bleue</title><annotation>Zone bleue</annotation>
        <location>file://PROSPECT4/recordings_prospect4/axis-ACCC8E430F7E/20160404/16/20160404_161851_8081_ACCC8E430F7E/20160404_18/20160404_183858_1A78.mkv</location>
        <extension application="http://www.videolan.org/vlc/playlist/0"><vlc:id>4</vlc:id><vlc:option>start-time=46</vlc:option><vlc:option>stop-time=61</vlc:option></extension></track>
    <track><title>track5_Zone rouge</title><annotation>Zone rouge</annotation>
        <location>file://PROSPECT4/recordings_prospect4/axis-ACCC8E430F7E/20160404/16/20160404_161851_8081_ACCC8E430F7E/20160404_18/20160404_183858_1A78.mkv</location>
        <extension application="http://www.videolan.org/vlc/playlist/0"><vlc:id>5</vlc:id><vlc:option>start-time=46</vlc:option><vlc:option>stop-time=62</vlc:option></extension></track>
    </trackList>
</playlist>
```


Figure 10: XML Playlist

The pre-selection task has been applied on 1.080 hours of video and has selected about 1.400 potential conflictual situations.

- ### Trajectography computation

The 1,400 potential conflictual situations have been reviewed for validation (see manual coding below). 126 have been retained as of interest and manually coded as presented in the following section. To help at filling all the required information for each retained sub-sequence, we have developed and used software that aims at automatically computing the trajectory of each actor of the conflict.

The trajectories are computed thanks to the tracking process of each detected object. To compute accurate positions, a semi-automatic method is proposed. For one critical situation, one part of the objects is manually selected and a template matching based algorithm is applied to track this part all along the subsequence. Tracking is achieved by an expert that is able to choose the better part to track of the objects. For a car, a headlight is often chosen. For a pedestrian, the head or a backpack is generally retained as a template to track. A (2D+) track is defined in the floor plane of the scene. An obtained (2D+) track is illustrated in the Figure 11.

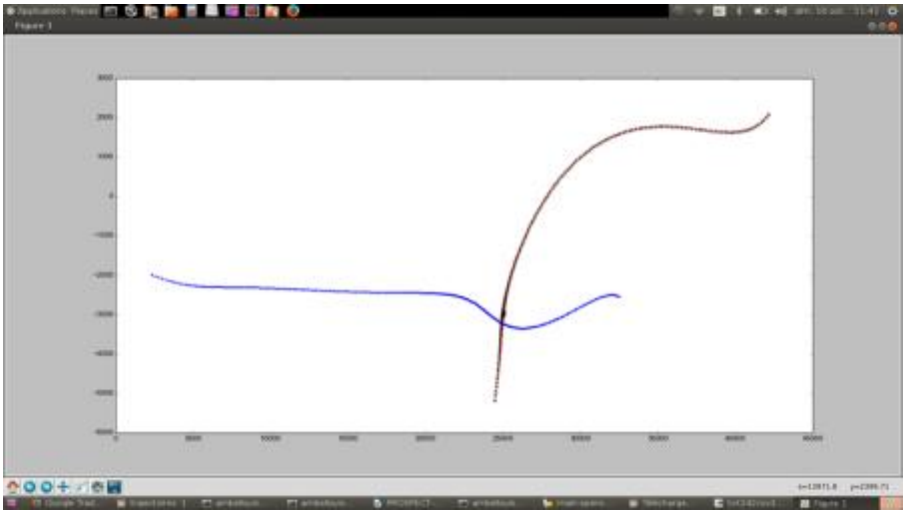


Figure 11: 2D+ trajectories of a car (red points) and a pedestrian (blue points).

Vertical and horizontal scales defined in millimetres. Point (0,0) is the origin of the coordinate system

The (2D+) track is obtained thanks to the image to world coordinate system projection. This inverse projection matrix is estimated during the calibration step.

Calibration is applied as follows. Firstly, some points are collected and located in the real scene by 3D coordinates. Then, the same points are extracted from the acquired image. The intrinsic and extrinsic parameters are finally calculated by optimizing the geometrical relation between the 2D and the 3D coordinates. Intrinsic parameters describe the camera and his optical lens. Extrinsic parameters define the pose of the camera in the world coordinate system. We used the formalism proposed by the ETISEO project (http://www-sop.inria.fr/orion/ETISEO/), which presents calibration parameters as an XML file.

Because 3D raw points obtained from the 2D tracking and after a 3D re-projection are noisy, we applied a filtering step to yield smoothed trajectory curves. Our filtering is based on a polynomial estimation from the 3D raw points. We chose to estimate the parameters of a 6^{th} order polynomial functions. One or more polynomial functions could be estimated depending on the profile of the trajectory. More polynomial functions are important to take into account the abrupt change in direction and speed and to avoid poorly conditioned problem in case of high order function.

Because one trajectory is described by a set of polynomial functions, it is easy to estimate the speed (amplitude and direction) and the acceleration by derivating the functions.

- **Manual coding**

Experimenters who previously signed a written undertaking of confidentiality viewed all extracted potential conflict situations and split them into 3 categories: not a conflict, maybe a conflict and conflicts. The conflicts and maybe conflicts were then reviewed by all coders in order to decide which of them were finally considered as conflicts. A severity level (low-medium-high) was then given to each conflict.

In order to code the video, combine and visualize all data in each specific conflict situation, we used a home-made software internally developed at IFSTTAR-LESCOT: the BIND platform. This platform is based on MATLAB's object-oriented development layer and allows scripting, GUI development and is interoperable with formal databases called "TRIP". All data of a situation are synchronized and imported into a trip file and grouped by categories. The video, after conversion to MJPEG format, is linked and synchronized to the trip database. The video coding part has been achieved through two coding interfaces: a static one and a dynamic one. The static coding interface has been developed specifically for the PROSPECT project to encode non-dynamic (non-evolutive) features of the situation. Figure 12 shows an example of the coding interface (GUI).

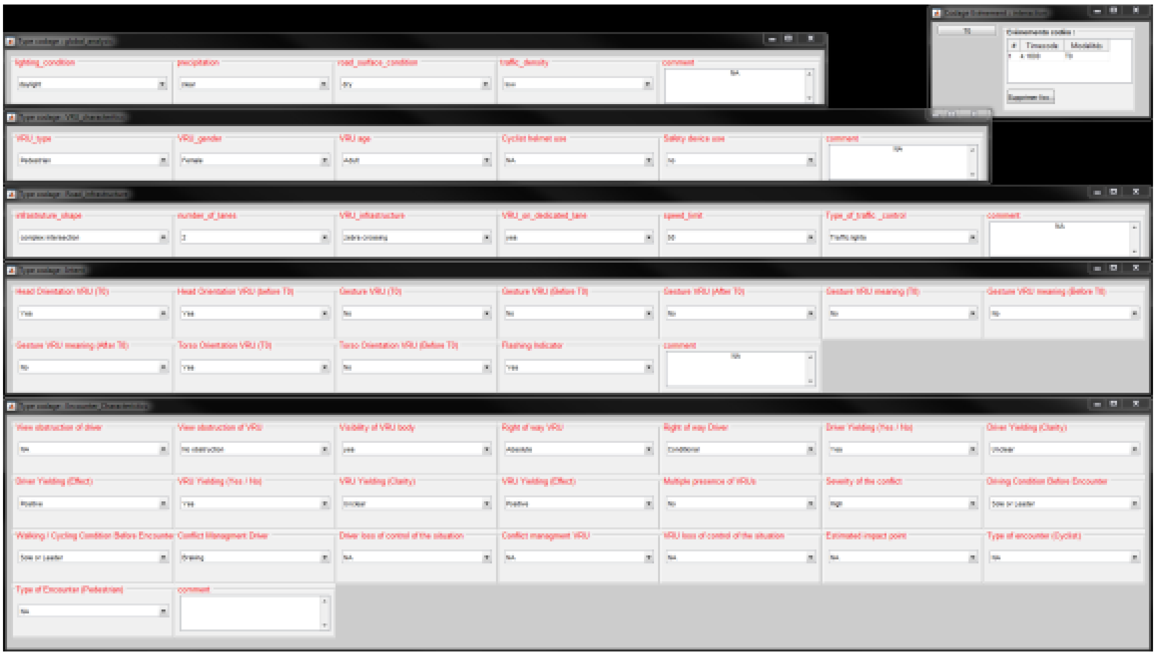


Figure 12: Example of the coding interface

From the 1,400 situations examined, 124 have been selected as conflicts and encoded.

The conflicts were then encoded using the common annotating sheet. For medium and highly severe conflicts, precise trajectories were used to compute all kinematic parameters (trajectories, speed, TTC and or PET).

2.2.2 On-site observations in Hungary

2.2.2.1 Data acquisition system

BME used three cameras (GoPro Hero 3+/GoPro Hero 4 Silver/ GoPro Hero 4 Black) for data collection. Synchronisation of the cameras is automatic with GoPro Smart Remote and verified manually with the recorded videos. Two or three cameras were used in every location, which were mounted to infrastructure elements (lamp post, back of traffic sign, etc.), see Figure 13 and Figure 14. The resolution of the videos is 720p (1280x720 pixel), with 30 FPS (30 Hz) image capture frequency, to ensure adequate detailing with optimal data size (100 hours of recordings on 700 GB).

Figure 13: Camera mounted to lamp post

Figure 14: Camera mounted to back of traffic sign

(Data recording at Szent Gellért tér, Budapest)

Data acquisition locations were selected according to accident analysis and previous experience of traffic conflicts. Pedestrian and cyclist accidents were digitalised and marked on map to define hot-spots and to generate heat-maps (Figure 15 and Figure 16).

2.2.2.2 Location

25 locations with different infrastructure layout, traffic control, etc. were selected, to ensure the diversity of conflict situations. During on-site observations many of the crucial locations of the heat map were covered (red stars on the map). Approximately 1-1.5 hours of data was recorded in each session, where the time and length depended on expected conflict frequency.

Recordings were carried out between the middle of October 2015 to the end of August 2016, therefore VRU and driver behaviour in different weather conditions can be analysed as well.

Figure 15: Pedestrian and cyclist accident map of Budapest for 2011-2014

(Black points – fatal; red points – seriously injured; yellow points – slightly injured)

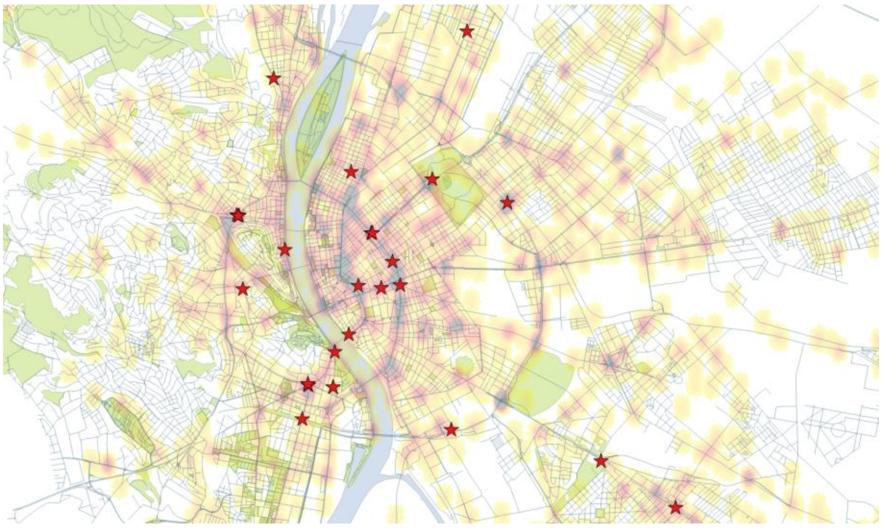


Figure 16: Pedestrian and cyclist accident heat-map of Budapest for 2011-2014 – and on-site observation locations

(No weighting between fatal-serious-slight injuries – darker colours indicate higher accident frequency)

Video processing was carried out manually with dedicated software (PROSPECT Digitizer, developed by BME) which allows synchronised scrolling of videos, tracking of transport users (cyclists, pedestrians, vehicles), and describing situations. The software is connected with a dedicated database which stores three types of data:

- Static – parameters which do not change during the measurement process, e.g. location layout, traffic control, etc. – added directly to database;
- Semi-static – parameters which do not change during a processing unit (usually 10-15 min of video), e.g. weather conditions, traffic density, etc. – added directly to database;
- Semi-dynamic and dynamic – parameters which describe the transport users, e.g. gender, accessories, etc. or parameters which can change frame by frame, e.g. trajectories, activities, etc. – recorded with software, stored coded in the DB.

The labelling process starts with the recording of base data of transport users and continues with the drawing of trajectory boxes (rectangle) frame by frame for all transport users involved in coded situations. Time-dependent activities are added manually with a start and an end time-stamp. In conflict situations more detailed information is added, indicating the attributes of the encounter.

2.2.2.3 Kinematics

The 2D trajectories of transport users are calculated from videos by other dedicated software. The software uses the pinhole camera model as it is widely used in photogrammetric engineering. Firstly the calibration of the cameras was solved to eliminate the distortion of the fish-eye lens. Secondly the position of the camera was calculated with defining multiple control points on each camera-picture (Figure 17).

The last step is the projection of trajectory points (the middle of the trajectory rectangles) onto the road surface level to get the path of transport user in 2D (Figure 18). The result of this calculation is an X-Y dataset with 30 Hz for each transport user, which allows calculating velocity and acceleration as well.

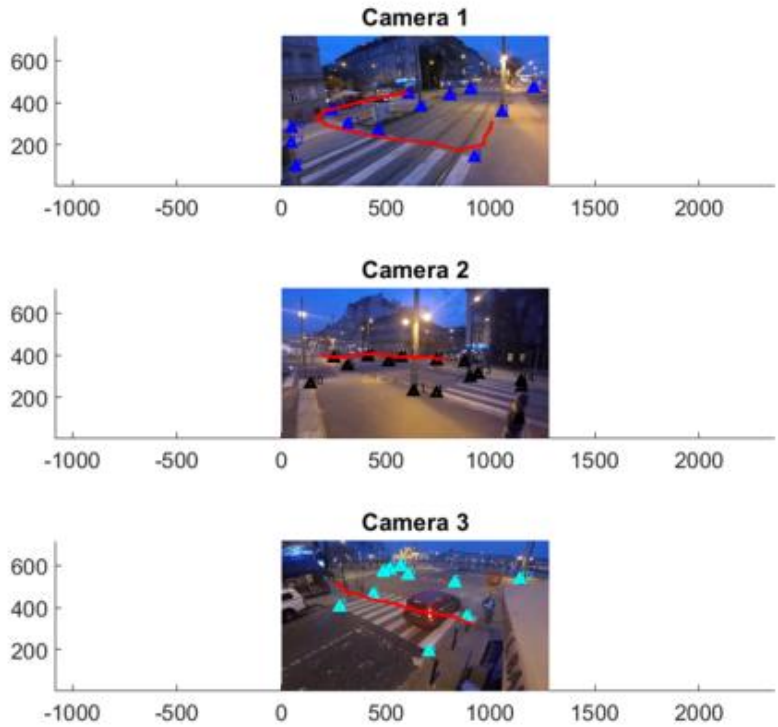


Figure 17: Trajectories and control points on undistorted camera pictures

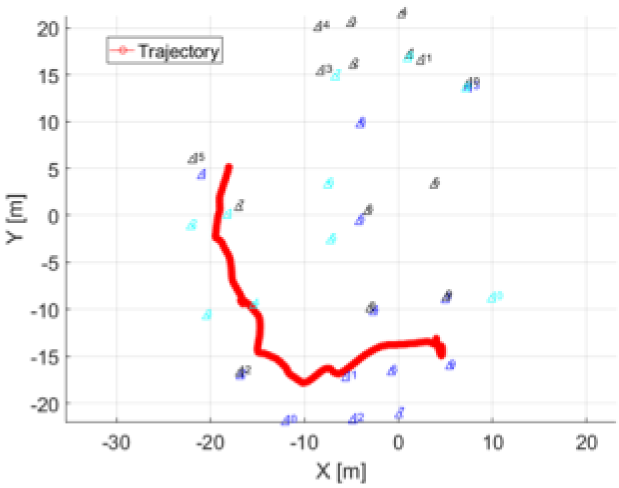


Figure 18: Trajectories and control points in 2D (road surface)

2.2.3 In-car observations in Hungary

BME used three cameras (GoPro Hero 3+/GoPro Hero 4 Silver/ GoPro Hero 4 Black) and special CAN data acquisition software (WeCAN) for data collection. Synchronisation of the cameras is automatic with GoPro Smart Remote and verified manually with the recorded videos. CAN data is synchronised with events appearing in videos and in CAN recordings as well (e.g. flashlight).

The three cameras recorded front, back/side and the driver. (Figure 19). The resolution of the videos is 720p (1280x720 pixel), with 30 FPS (30 Hz) image capture frequency, to ensure adequate detailing with optimal data size (50 hours of recordings on 700 GB).

Figure 19: Camera positions for BME's on-board observations (front – back/side – driver)

Recordings were carried out on 7-10 kilometres long (25-80 min) routes through accident hot-spots according to accident analysis heat-maps and previous experience of traffic conflicts – covering as many hot-spots as possible.

The survey was taken between the middle of October 2015 to the end of August 2016, therefore VRU and driver behaviour in different weather conditions were analysed as well, total distance covered is 964 km.

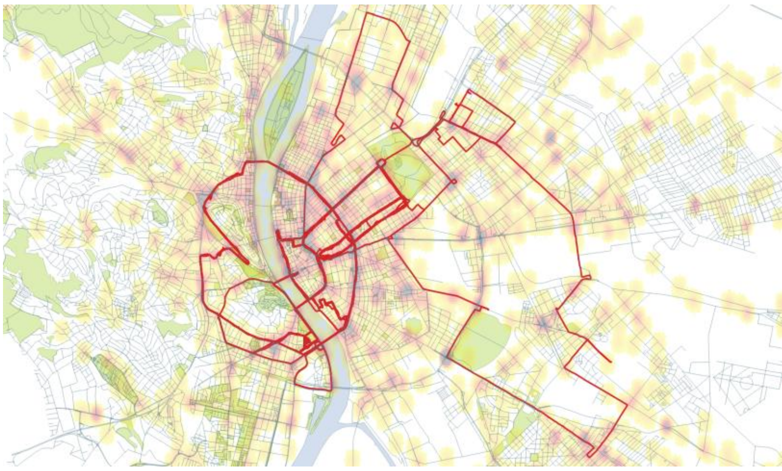


Figure 20: Pedestrian and cyclist accident heat-map of Budapest for 2011-2014 – and in-car observation routes (the widths of red lines are proportional to the number of trips on particular links) (No weighting between fatal-serious-slight injuries – darker colours indicate higher accident frequency)

As for on-site observations, video processing was carried out manually with dedicated software (PROSPECT Digitizer, developed by BME) connected with a dedicated database which stores the same three types of data (static, semi-static, semi-dynamic and dynamic).

During the process the whole length of videos are not labelled, only the important events for PROSPECT project. These events contain the same information as for on-site observations.

The labelling process starts with the recording of base data of transport users and continues with the drawing of trajectory boxes (rectangle) frame by frame for all transport users involved in coded situations. Time-dependent activities added manually with a start and an end time-stamp. In conflict situations more detailed information is added, indicating the attributes of the encounter. CAN data is connected with labelling procedure results in the database using synchronisation-points.

BME's in-car observations allow only basic kinematic data extraction as every transport user appears in just one camera at a time and no other sensor (e.g. LIDAR) was used. However the kinematic data of the car are quite accurate as they are derived from CAN.

2.2.4 In-car observations in Spain

2.2.4.1 Data acquisition system

The equipment used by IDIADA consists of a data fusion and object detection system based on one LIDAR sensor, a GPS data logger, a laptop and two cameras. Together with this, a keypad device has been mounted for manual registration of interesting cases by a triggering event. The entire equipment was connected to the vehicle's 12V battery instead of an external power supply.

This equipment is further described below:

- LIDAR IBEO Lux 4 (model 2010): The laser scanner detects the surroundings and the objects located within its field of view allowing the measurement of the distance, velocity and direction of the detected bodies.
- Camera Logitech Webcam C930 (FOV: 90º and 30 fps): Two cameras have been continuously recording the whole field test. One has been pointing towards the front view and another has been placed inside the vehicle pointing towards the driver's position to record his reactions and/or his interactions with pedestrians.
- Vehicle CAN BUS.
- GPS data logger Video VBOX from Racelogic: To record the vehicle's current position.
- vADASDeveloper: Data fusion and object detection. This software combines the information from the laser and CAN data from the vehicle and builds a virtual representation of the scenes.

The rest of the equipment is formed by:

- Laptop, Vector CAN, ethernet box, synchronization box, battery switch and feeding box.

Some pictures of the equipment on the test vehicle:

Figure 21: LIDAR sensor

Figure 22: Interior view – Drivers interface

Figure 23: Keypad for the trigger

Figure 24: Rear trunk - Recording equipment layout

2.2.4.2 Location

The Naturalistic Driving Study has been conducted in Barcelona. The driving has been focused on some reference areas based on interesting hotspots for pedestrians and cyclists. The next maps show the main areas where the vehicle was driven:

Figure 25: Major tourist zones

Figure 26: Cycling network

2.2.4.3 Data collection format, size, period of acquisition

The route commenced the 7th of April and ended on the 12th of August, 2016 with around 1,000 hours of recording. In terms of data storage, around 8 TB were collected. The daily work consisted on 12 hours of driving and 2 shifts (6 hours per shift).

To ensure the security of the collected data, the HDD devices used for data storage were protected by a password.

Later, the information was stored duplicated in NAS drives kept at IDIADA's facilities, only dedicated for this purpose, and removed from the in-vehicle HDD device.

2.2.4.4 Data extraction

Automatic pre-selection of situations of conflict

Professional drivers were initially trained for the purposes of the activity. Conflicts were defined as situations in which the driver has to take an action over the vehicle in order to avoid situations that could potentially lead to a collision with a pedestrian or a cyclist.

The data collection has been done continuously and this data is available.

For the recording of pre-selected conflicts, the drivers were requested to drive normally and activate a trigger whenever a conflict was identified. On the event of trigger activation, synchronized data from the different sensors (LIDAR, camera, vehicle CAN BUS, GPS) was extracted.

Manual coding

At the end, researchers viewed all extracted potential conflict situations and made a final selection of the conflicts to be considered within the study.

Finally selected situations were later analysed and annotated using the coding grid.

Kinematic data

IDIADA's in-car observations allow the calculation of kinematic data by the use of kinematics of test vehicle provided by the CAN bus, and kinematics of the VRU provided by the LIDAR.

For all conflicts, precise VRU trajectories were derived to compute all kinematic parameters (relative position and speed of VRU with respect to vehicle, TTC and or PET, vehicle acceleration).

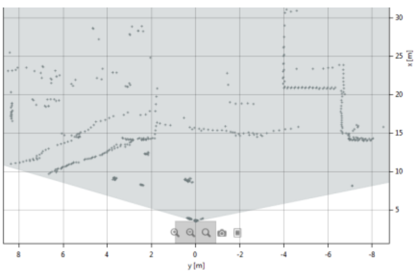



Figure 27: video data

Figure 28: data from LIDAR

2.3 ANNOTATING GRID

2.3.1 Common annotating grid

An annotating grid has been elaborated by WP2 T2.2 partners. The grid was also discussed during joint meetings with partners from WP3 in charge of selecting the use cases. After tests on the data from all sites, improvements of the grid were made both in terms of content and way of use. Precisions on how to homogenise the annotations were given when needed. Finally, after final version being submitted and accepted by WP3 partners, a training session has been organised to finalise the data collection.

This gird provides information on how to encode important parameters for analysing the conflicts. For example it gives clues about intent of the VRU toward the vehicle that should allow for anticipating their future trajectory. Such clues are generally interpreted by the driver and will be used to improve the sensors.

2.3.2 Categories of parameters to consider

Six sub-groups of parameters have been validated for annotation. They describe (1) the general environmental conditions of the conflict (light, precipitation, road surface, traffic density, etc.), (2) the infrastructure (layout, dedicated lanes, speed limit, etc.), (3) the characteristics of the VRU (type, equipment, etc.), (4) the encounter characteristics (visibility, right of way, yielding, conflict management, estimated impact point, etc.), (5) the intents of the VRU (head/torso orientation, gesture, flashing indicator), (6) kinematics and trajectories of both car and VRU.

Start and end timestamps were recorded for time dependent parameters such as yielding, head movements, etc.

2.3.2.1 General environmental conditions

In this part, data indicates the basic environmental conditions of the conflict.

Table 1: Parameters regarding environmental conditions

Parameter name	Description	How to be reported / Options
Identification	Observation number or name of the video file corresponding to the event	Observation number / Videofile name
Date	Date and time of the encounter (Date and precise timecode)	GPS time
T0 – time of the conflict	Specify the time of encounter as t0 and consider 10 sec before and 10 sec after (when possible)	GPS time

	t0 is defined as the time when TTC is the smallest or when PET starts to exist or the most critical moment	
Lighting condition	Lighting condition on the basis of daylight	Daylight / Dark / Transition / Electric light / Other
Precipitation	Precipitation conditions at the time of the encounter NB: as rain is not easy to see on video (especially for infrastructure mounted cameras), to be checked with online weather reporting at corresponding dates	Clear / Fog / Rain / Snow / Other
Road surface condition	Condition of road surface for the considered vehicle	Dry / Wet / Snow-ice / Slippery (other reason) / Other-not relevant-not a roadway / Unknown
Traffic density	Density of traffic flow at the time of the encounter (only regarding the immediate surrounding of the interacting road users) Assess whether the traffic flow has an impact on the considered situation; does not take into account car running in another lane or that does not directly interfere with the studied conflict,	- High (impact of the traffic density on road users' speed and/or on the manoeuvres) - Medium (other road users around; may have an impact on driver behaviour, but not on surrounding road user speed) - Low (only one or two moving car(s) in the studied area)

2.3.2.2 Road infrastructure characteristics

The following parameters describe the road infrastructure characteristics and the location of the conflict. Such parameters are static, as they do not change during the measurement process.

Table 2: Parameters regarding road infrastructure

Parameter name	Description	How to be reported / Options
Configuration, infrastructure shape	Description of the infrastructure	T intersection / Y intersection / X intersection / Complex intersection (intersection with more than 2 roads, cannot be described only by T, Y, X) / Roundabout / Not intersection straight / Not intersection curve
Number of lanes	Number of lanes in the same direction on the road used by the vehicle	Number of: - straight lanes; - merging lanes (if there are any) - other lanes (dedicated lane for VRU not included)
VRU infrastructure	Presence of a dedicated way for the VRU in conflict	None / Zebra crossing / Side walk / Bicycle way / Bicycle contraflow lane / Cyclist lane shared with bus
Speed limit	Speed limit on the road used by the vehicle	Number XX km/h / Unknown
Type of traffic control	Traffic signs and regulation devices at the location of conflict	Not intersection / Right-hand rule / Traffic signs / Traffic lights / Roundabout / Unknown

2.3.2.3 VRU characteristics

In this section, the main attributes of the pedestrian/cyclist are specified.

Table 3: Parameters regarding VRU characteristics

Parameter name	Description	How to be reported / Options
VRU type	Specification of the VRU	Pedestrian / Cyclist / Alternative modes for pedestrian (segway, skate, scooter, etc.) / Pedestrian carrying something (stroller, trolley, animal, etc.)
VRU gender	Gender of the VRU (when possible)	Male / Female / Group of persons / Unknown
VRU age	The age of the VRU (when possible)	Child / Adult / Elderly / Group of persons / Unknown
Cyclist helmet use	The cyclist uses a helmet	Yes / No / Unknown
Safety device use	Indication whether the cyclist uses safety devices or visibility devices (yellow clothes, light, reflectors, etc.)	Yes / No / Unknown

2.3.2.4 Encounter characteristics

Encounter characteristics specify the main attributes and the circumstances of the encounter. Some of the following parameters are time dependent as their state evaluate during the conflict. For example, an obstruction can occur only at the beginning of a conflict then disappear. However, as the process is very consuming, time line data is investigated for the most severe conflicts only.

Start and end timestamps are recorded for time dependent parameters, while with others only a fixed value is provided.

Table 4: Parameters related to the encounter

Parameter name	Description	How to be reported / Options
View obstruction of driver (time dependant)	Type of obstruction from the driver's perspective. Considered only if occurs during the 3 last seconds before t_0	No obstruction / Another vehicle static / Another vehicle moving / Infrastructure element / Sun blinding / Other VRUs / Other
View obstruction of VRU (time dependant)	Type of obstruction from the VRU's perspective. Considered only if occurs during the 3 last seconds before t_0	No obstruction / Another vehicle static / Another vehicle moving / Infrastructure element / Other VRUs / Other
Visibility of the VRU	First visibility of the VRU from sensor point of view (even partially visible) in case of obstruction	Time of first visibility
Visibility of VRU body (time dependant)	Whether the VRU movements (leg and arm) can be perceived or not during the 3 last seconds before t_0	Yes / No / Partially / Unknown
VRU on dedicated lane	VRU in conflict is using the dedicated lane	Yes / No
Right of way VRU	Level of right of way the VRU has, assessed according to traffic laws	Absolute (can run without condition) / Conditional (has the right of way if there is no other road user having an absolute right of way) / Not permitted (right of the way violation) / Not permitted and risky
Right of way driver	Level of right of way the driver has, assessed according to traffic laws	Absolute (can run without condition) / Conditional (has the right of way if there is no other road user having an absolute right of way) / Not permitted (right of the way violation) / Not permitted and risky

Type of encounter	Categorisation of the conflict according to **PROSPECT Use Cases** (*see below*)	Use Case code
Driver Yielding (time dependant)	Driver's yielding behaviour	Yes / No / Unknown
	Clarity of the driver's yielding behaviour	If yes: Clear / Unclear / Unknown
	Effect of the driver's yielding behaviour on the situation	If yes: Positive / Negative/ Unknown
VRU Yielding (time dependant)	VRU's yielding behaviour	Yes / No / Unknown
	Clarity of the VRU's yielding behaviour	If yes: Clear / Unclear / Unknown
	Effect of the VRU's yielding behaviour on the situation	If yes: Positive / Negative/ Unknown
Multiple Presence of VRUs	Presence of other VRUs in the encounter area	Yes / No / Crowd
Severity of the conflict	Indicates how severe the conflict is Three subjective options for pre-categorisation, exact categorisation with kinematic data (TTC and/or PET)	Low (not a normal situation but no severe accident risk) / Medium (accident risk but well controlled, without brutal intervention) / High (strong evasive manoeuver – strong braking or swerving – obvious emergency reaction, management of the situation, very short TTC/PET or VRU fall down)
Driving condition before encounter	The driving condition reflects the driver's role in traffic especially the influence of surrounding vehicles in his lane.	Sole or leader / follower
Walking/cycling condition before encounter for	The walking/cycling condition reflects the VRU's role in traffic especially the influence of surrounding	Sole or leader / follower

VRU	VRUs around.	
Conflict managment driver (time dependant)	Evasive manoeuvre which was taken by the driver to resolve the conflict.	None / Steering / Accelerating / Braking / Other (Multiple choice possible)
Driver's loss of control of the situation	Indicates if the driver loss the control to handle the conflict.	Yes / No
Conflict managment VRU (time dependant)	Evasive manoeuvre which was taken by the VRU to resolve the conflict.	**Pedestrian**: Walk / Wait / Go back / Run / Hesitate (go back and forth in a short amount of time) / Turn about / Fall / Other **Cyclist:** Stop and hesitate / Stop with at least one foot on the ground / Steer / Accelerate / Brake / Pedalling / Stop pedalling / Fall / Skid (without falling) (Multiple choice possible)
VRU's loss of control of the situation	Indicates if the VRU loss the control to handle the conflict.	Yes / No
Estimated impact point	Impact point at t_0 if the movements of road users remained unchanged.	Frontward / Sideward left / Sideward right
Estimated impact point - Front	Predicted impact point with respect to the front of the vehicle (only in case of impact point at the front)	Distance (from 0 point = centre of the car, where positive X is forward, positive Y is to the right)

2.3.2.4.1 PROSPECT Use Cases

Use cases covering different encounter configuration have been identified in WP3.

Aggregations of use cases concerning cyclists have been done, as from a sensor perception viewpoint only the relative positions between car and bicycles are of main interest. Infrastructural conditions, road geometry and right of way rules are only secondary and mainly influence the vehicle control and HMI behaviour, if at all.

Among all use cases, 12 have been more specifically selected to be implemented in the demonstrators: 9 for cyclists and 3 for pedestrians. Even reduced, this number still addresses around 80% of all cyclist accidents investigated in deliverable 3.1.

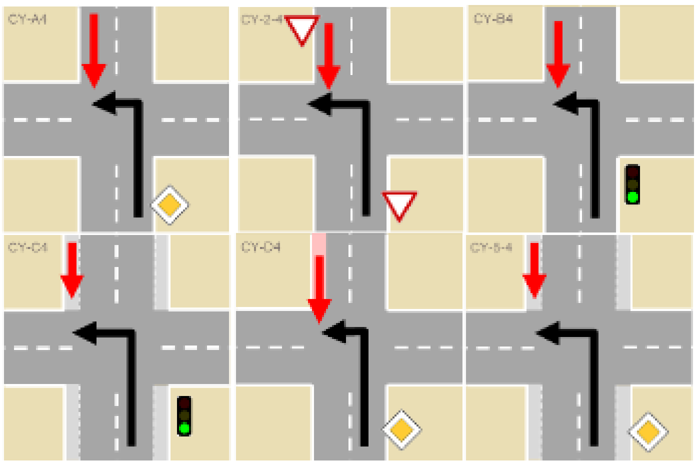
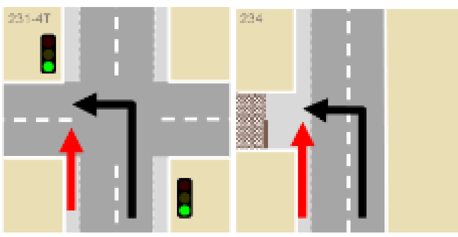
Deeper analyses of these 12 use cases (UC_DEM in the tables below) are provided through the naturalistic observations in order to provide additional information to enhance the demonstrator developing process.

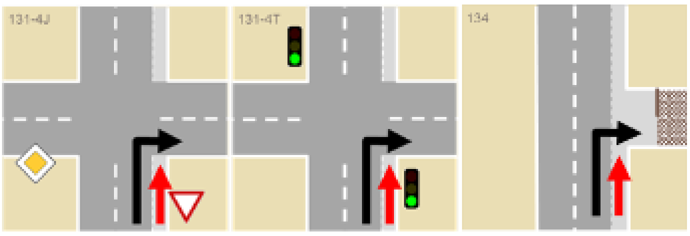
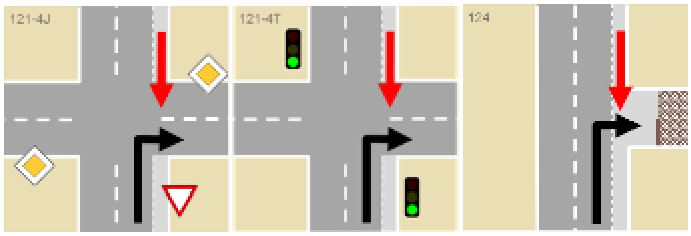
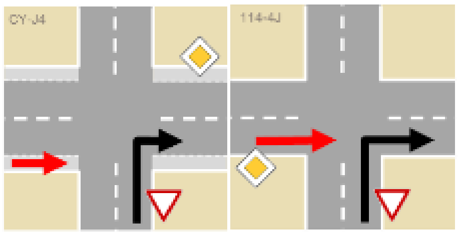
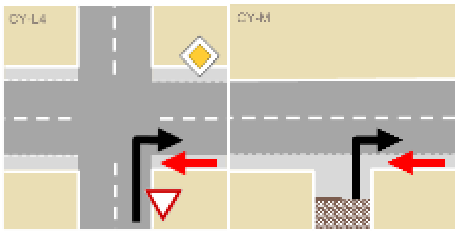
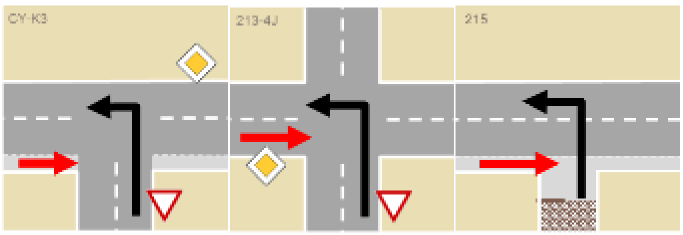
Only pictograms are given below. For a complete description see Deliverable D3.1 and D3.2.

Vehicle turning with cyclist

The turning scenarios cover conflicts when the vehicle is turning and the bicycle is coming from the right or the left, from the same or the opposite direction. The use cases identified within WP3 for being implemented in the demonstrators (UC_DEM) stand in green.

Table 5: Cyclists – turning Use Cases

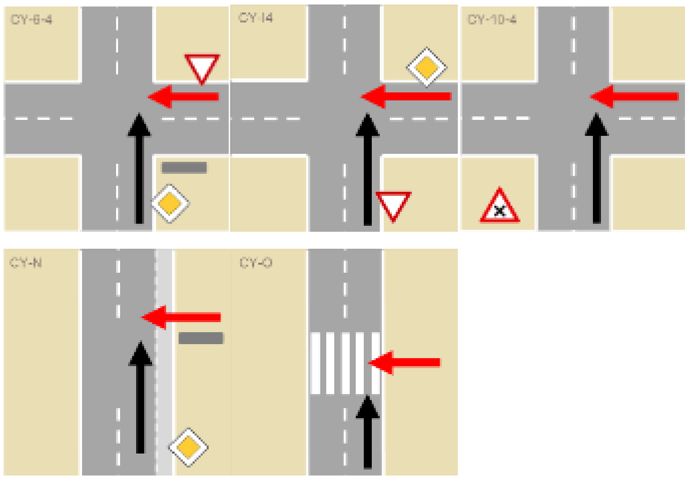
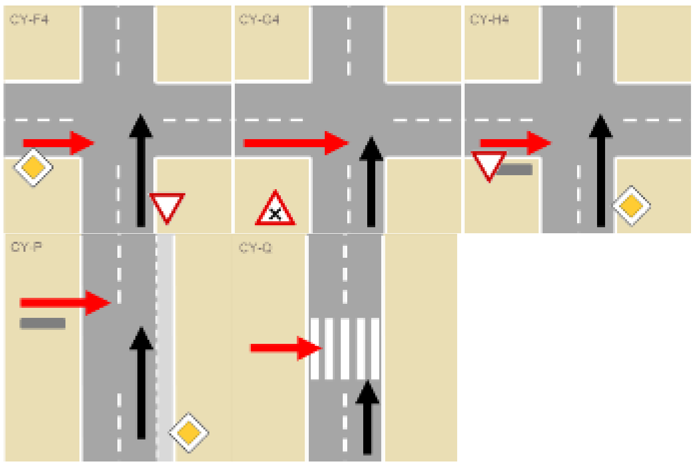
UC_DEM_1	T1_A/T2_1 T2_2 T1_B/T2_3 T1_C/T2_4 T1_D T2_5	
	T1_U/T2_25 T1_V/T2_26	

UC_DEM_2	T2_29 T1_R/T2_20 T1_S/T2_21	
	T2_22 T1_T/T2_23 T2_24	
	T1_J/T2_11 T1_X/T2_29	
UC_DEM_5	T1_L/T2_13 T1_M/T2_14	
UC_DEM_6	T1_K/T2_12 T1_W/T2_27 T2_28	

Vehicle crossing with cyclist

The crossing scenarios include conflicts when the vehicle is going straight and the bicycle is coming either from the right or from the left.

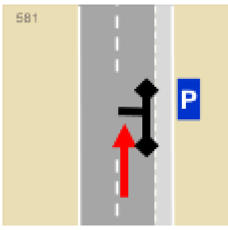
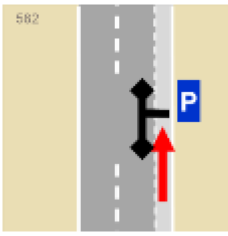
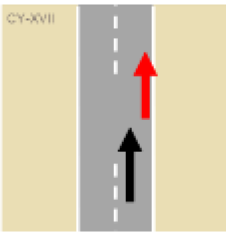
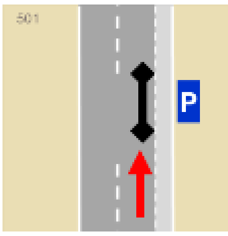
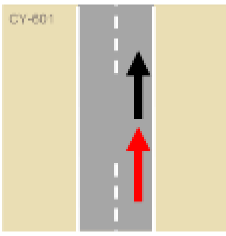
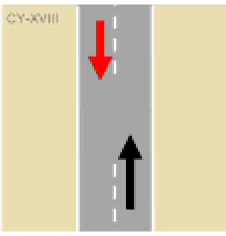
Table 6: Cyclists – crossing Use Cases

UC_DEM_3	T1_E/T2_6 T1_I/T2_9 T2_10 T1_N/T2_15 T1_O/T2_16	
UC_DEM_4	T1_F/T2_7 T1_G/T2_8 T1_H T1_P/T2_17 T1_Q/T2_18	

Longitudinal with cyclist

Longitudinal scenarios for cyclists include scenarios when a driver opens his/her door when the cyclist passes the car, and cyclist riding in the same direction as a car or in the opposite direction.

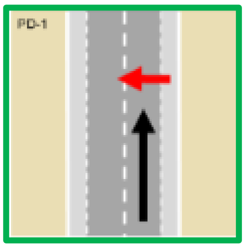
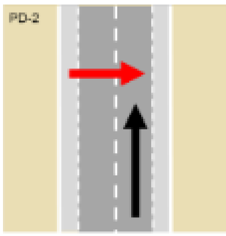
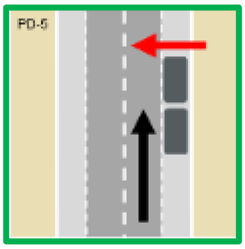
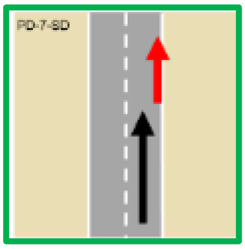
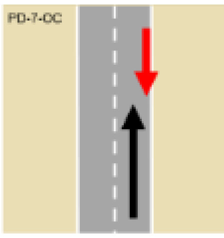
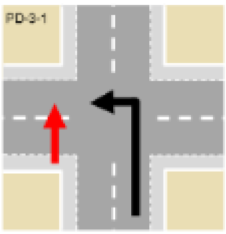
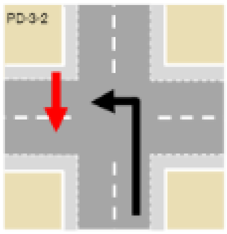
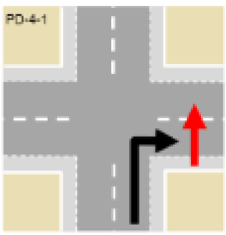
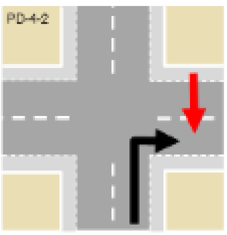
Table 7: Cyclists – longitudinal Use Cases

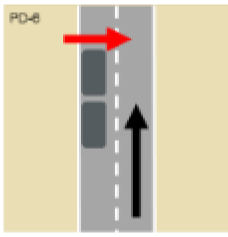
UC_DEM_7	T1_Y/T2_30	
UC_DEM_8	T1_Z/T2_31	
UC_DEM_9	T1_AB/T2_33	
	T1_AA/T2_32 T1_AC/T2_34	 
	T1_AD/T2_35	

Use cases for pedestrians

The number of use cases for pedestrian is reduced compared to cyclists, and only 3 of them will be used for system development. They include scenarios when the pedestrian comes from the right with or without obstruction or from the left with and without obstruction. They also include scenarios when car and pedestrian are coming in the same or opposite direction.

Table 8: Pedestrian Use Cases

UC_DEM_10	**PD_1** (PD_2)	 
UC_DEM_11	**PD_5**	
UC_DEM_12	**PD_7a** PD_7b	 
	PD_3a PD_3b	 
	PD_4a PD_4b	 

	PD_6	
	PD_8	Driving backwards (no pictogram)

2.3.2.5 Intents

Intents contain dynamic data which describe the behaviours of VRUs and drivers in detail. Most of the following parameters are time dependent as their state evaluates during the conflict. Like for the previous ones, time line data is investigated for the most severe conflicts only.

Start and end timestamps are recorded for time dependent parameters.

Table 9: Parameters regarding intents

Parameter name	Description	How to be reported / Options
Head orientation VRU (time dependant)	Head orientation of the VRU towards the centre of the car (sensor point of view). Head orientation is coded at t_0, and before t_0)	16 steps (0º, 22.5º, 45º ... 337,5º) – clockwise (See Figure 30)
Gesture VRU (time dependant)	Gesture expressed by the VRU during a conflict situation. Gesture is coded at t_0, and before t_0)	Description / Yes / No
Gesture VRU meaning (time dependant)	The meaning of the expressed VRU gesture	No / Give the way / Ask for yielding / Thanks / Repremand / Unkown
Torso-orientation VRU (time dependant)	Orientation of the VRU's upper torso relative to the vehicle (angle of the torso towards the line of sight between the center of the car and the VRU).	8 steps (0º, 45º, 90º ... 315°) – clockwise (See Figure 29)

Flashing Indicator	Whether the driver has used the flashing indicator to indicate the change of his driving direction.	Yes / No / Unnecessary / Unknown

The following figures illustrate how head and torso orientations are coded. When the VRU is facing the car the position is 0. Then angular position is incremented clockwise.

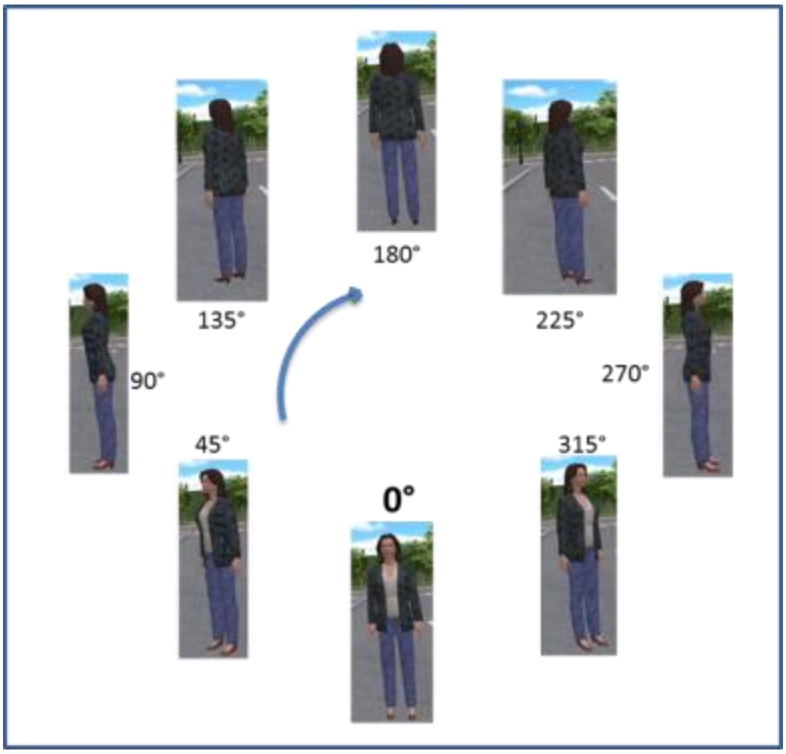


Figure 29: Angle values to code the VRU torso orientation

Figure 30: Angle values to code the VRU head orientation

2.3.2.6 Kinematics

Kinematics data contains the detailed trajectories (with timeline) of VRUs and drivers and describe the conflict with calculated indicators. Calculation are made in the following steps:

1. The basis of kinematic data is the trajectories (coordinate-timelines) of VRUs and vehicles, from which actual speeds and accelerations are calculated. Then all data are transformed to a vehicle-based coordinate system (regarding in-car observations, data from in-car measurements are recorded in this way initially, so do not need to be transformed).

2. Based on the actual relative position and speed of VRU the estimated times are calculated for each moment when the VRU reaches and leaves the path or the front line of the vehicle (see TTC_i, TTC_e and TTC_x on Figure 31). From these times it can be decided whether the VRU or the car will reach the conflict zone first (TTC_i is larger or TTC_x).

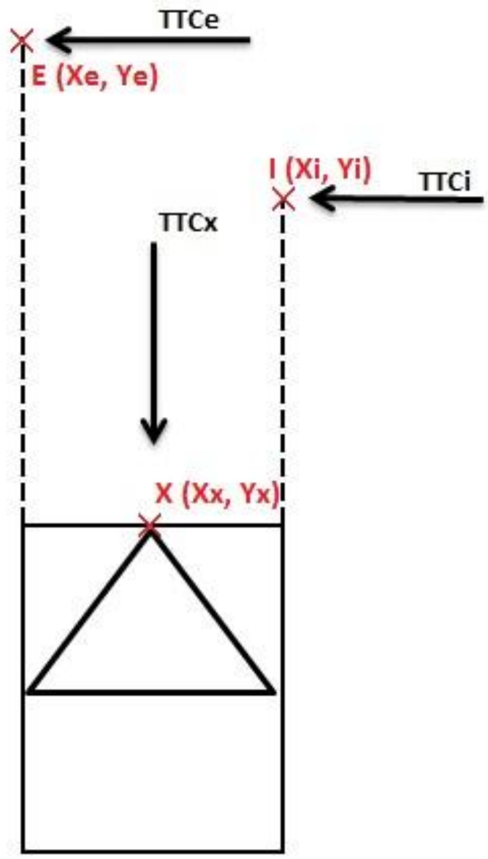


Figure 31: Key points and times of TTC calculation

3. Relative positions are also calculated where the VRU will cross the borders of vehicle's path (see X_i, and X_e on Figure 31) and the front line (Y_x) of the vehicle. From these points it can be decide whether they may collide or not. When the relevant coordinate (if the vehicle arrives first then X_i; if the VRU arrives first then Y_x) is smaller than the vehicle's size, car and VRU are in collision course and TTC is calculated, otherwise PET is calculated.

4. BME also calculates TTCZ (time to conflict zone) which is the maximum of TTC_i and TTC_x (i.e. the time when the second road user arrives to the conflict zone). When car and VRU are in collision course, TTC=TTCZ. However,this value can be given even in case of PET calculation. TTCZ. is continuous for both situations.

Cyclists are modelled by a line (instead of a point), so both front and back of the bicycle are examined. In these cases it is also examined which point of the cyclist would be hit by the vehicle. (For example, a vehicle can hit the cyclist with its corner, as well.)

Table 10: Kinematic parameters

Parameter name	Description	How to be reported / Options
Acceleration / deceleration VRU	The acceleration or deceleration of the VRU at specific times during the encounter.	XY relative acceleration / deceleration with respect to the vehicle (m/s^2) – at t_0 and the maximum in the 5 s before t_0
Acceleration /deceleration driver	The acceleration or deceleration of the vehicle at any time during the encounter.	XY acceleration / deceleration (m/s^2) – at t_0 and the maximum in the 5 s before t_0
Relative speed	The relative speed between the vehicle and VRU at any time during the encounter.	XY relative speed with respect to the vehicle (m/s) – – at t_0 and the maximum in the 5 s before t_0
Absolute vehicle speed	The absolute speed of the vehicle at any time during the encounter.	XY speed (m/s) – at t_0 and the maximum in the 5 s before t_0
Absolute VRU speed	The absolute speed of the VRU at any time during the encounter.	XY speed (m/s) – at t_0 and the maximum in the 5 s before t_0
Relative position	The relative position between the vehicle and the VRU at any time during the encounter.	XY relative position with respect to the vehicle (m) – at t_0 and 5 s before t_0
Trajectory VRU	The actual path of the VRU.	XY position
Trajectory driver	The actual path of the vehicle.	XY position
TTC	Time to collision at t_0.	Time (s)
PET	Post encroachment time at t_0.	Time (s)

3 GLOBAL ANALYSIS OF CONFLICTS

From the 1,080 hours of videos recorded at IFSTTAR, 1,000 hours recorded at IDIADA and 150 hours at BME, naturalistic observations allow for extracting 602 conflicts analysed in terms of severity. Each of them is annotated using the common annotating grid using all parameters described in section 2.3. The full descriptions are available on the website in the partner area.

Severity as shown in

All conflicts are analysed according to the use cases identified in WP3 (see Deliverable 3.1), deeper analyses being provided for those selected for demonstrator development (see Deliverable 3.2 and section 2.3.2.4).

The number of conflicts involving pedestrians is greater than the number of conflicts that involve cyclists. This can be explained first because in all observed areas, pedestrians were much more numerous than cyclists. Also, many conflicts extracted from the videos show road users adopting a risky behaviour and maybe such attitude is more frequent from pedestrians than from cyclists.

Table 11 has been evaluated by human judgement.

All conflicts are analysed according to the use cases identified in WP3 (see Deliverable 3.1), deeper analyses being provided for those selected for demonstrator development (see Deliverable 3.2 and section 2.3.2.4).

The number of conflicts involving pedestrians is greater than the number of conflicts that involve cyclists. This can be explained first because in all observed areas, pedestrians were much more numerous than cyclists. Also, many conflicts extracted from the videos show road users adopting a risky behaviour and maybe such attitude is more frequent from pedestrians than from cyclists.

Table 11: Summary of analysed conflicts

Severity	IFSTTAR			IDIADA			BME			**Total**
	Low	Med.	High	Low	Med.	High	Low	Med.	High	
With cyclists	23	15	0	22	4	0	33	17	3	117
With pedestrians	66	18	2	260	20	1	105	13	0	485
No. of conflicts	89	33	2	282	24	1	138	30	3	602
Total	124			307			171			**602**

Most of the conflicts extracted from the videos are at a low level of severity. Only 2 or 3 have been found by each team at a high level of severity.

As shown in the following section, most of the use cases that have been identified within WP3 as being worth to be implemented in the demonstrators (UC_DEM) can be illustrated by conflicts, except 2 of them. Unfortunately, no occurrence of conflict has been met for UC_DEM_7 and UC_DEM_8 which depict a cyclist passes a car while the driver/passenger opens the door.

Table 12: Number of conflicts by UC_DEM

Use case	No. of conflicts
DEM_1	27
DEM_2	10
DEM_3	11
DEM_4	14
DEM_5	4
DEM_6	10
DEM_9	13
DEM_10	133
DEM_11	33
DEM_12	24

Very few conflicts have been extracted during night periods. Most of them occurred during the day. However, at least regarding IFSTTAR data, automated extraction of relevant epochs was complex during these periods because of the difficulty to discriminate car headlights from relevant objects of the scene. It is then possible that some conflicts have been missed for this reason.

Regarding IDIADA data, the driving sessions were realized during the day, making difficult the possibility to encounter conflicts during the night.

Table 13: Time of the conflicts

Severity / Day/Night		IFSTTAR			IDIADA			BME			Total
		Low	Medium	High	Low	Medium	High	Low	Medium	High	
Cyclist	Daylight	23	12	0	25	4	0	31	16	3	114
Cyclist	Transition	1	2	0	0	0	0	0	1	0	4
Cyclist	Elect. light	0	1	0	0	0	0	2	0	0	3
Pedestrian	Daylight	55	15	2	258	19	1	93	10	0	453
Pedestrian	Transition	3	2	0	0	0	0	9	0	0	14
Pedestrian	Elect. light	7	1	0	0	0	0	3	3	0	14
Nb of conflicts		89	33	2	283	23	1	138	30	3	602
Total			124			307			171		602

Various conditions of traffic flow have been covered, but most of the conflicts occur at a free traffic flow in French data and when traffic is at a medium level (conflicts with cyclist) or medium and high level (conflicts with pedestrians) in Hungarian data. The density of traffic is considered as

- high when it impacts road users' speed and/or manoeuvres,

- medium when other road users are around and traffic may have an impact on driver behaviour, but not on speed;
- and low when only one or two moving car(s) is in the studied area.

Table 14: Traffic density at the moment of the conflicts

Severity / Traffic density		IFSTTAR			IDIADA			BME			Total
		Low	Medium	High	Low	Medium	High	Low	Medium	High	
Cyclist	Low	16	10	0	23	4	0	3	0	0	56
Cyclist	Medium	8	3	0	2	0	0	16	15	1	45
Cyclist	High	0	2	0	0	0	0	14	2	2	20
Pedestrian	Low	55	12	2	219	14	1	31	3	0	337
Pedestrian	Medium	9	6	0	37	5	0	33	6	0	96
Pedestrian	High	1	0	0	2	0	0	41	4	0	48
No. of conflicts		89	33	2	283	23	1	138	30	3	602
Total			124			307			171		**602**

The number of time a pedestrian or a cyclist makes sign or hand gesture toward the car in conflict was investigated. Unfortunately very few are registered.

Such gesture has different meaning according to when it occurs:

- Generally before T0, a hand gesture corresponds to a request for yielding or on the contrary to give the way.
- At T0, a hand sign expresses either a thank or a reprimand (in French data) or a request for yielding or to give the way (Hungarian data).
- After T0, most of the signs express either a thank or a reprimand in both French and Hungarian data.

Table 15: VRU's gesture before T0

Gesture before T0		IFSTTAR			IDIADA			BME			Total
		Low	Medium	High	Low	Medium	High	Low	Medium	High	
Cyclist	Yes	0	0	0	0	0	0	0	0	0	0
Cyclist	No	24	15	0	25	4	0	33	17	3	121
Pedestrian	Yes	3	1	0	3	0	0	3	0	0	10
Pedestrian	No	59	17	2	255	19	1	102	13	0	468
Total gesture			4			3			3		10

Table 16: VRU's gesture at T0

Gesture at T0		IFSTTAR			IDIADA			BME			Total
		Low	Medium	High	Low	Medium	High	Low	Medium	High	
Cyclist	Yes	0	2	0	0	0	0	1	0	0	3
Cyclist	No	24	13	0	25	4	0	32	17	3	118
Pedestrian	Yes	2	4	0	5	0	0	8	0	0	19
Pedestrian	No	63	14	2	253	19	1	97	13	0	462
Total gesture		8			5			9			22

Table 17: VRU's gesture after T0

Gesture after T0		IFSTTAR			IDIADA			BME			Total
		Low	Medium	High	Low	Medium	High	Low	Medium	High	
Cyclist	Yes	1	1	0	0	3	0	4	0	1	10
Cyclist	No	23	14	0	25	1	0	29	17	2	111
Pedestrian	Yes	1	2	1	13	6	1	23	4	0	51
Pedestrian	No	64	16	1	245	13	0	82	9	0	430
Total gesture		6			23			32			61

3.1 VEHICLE TURNING WITH CYCLIST

3.1.1 Global analysis

Four use cases involving a vehicle turning have being identified for being implemented in the demonstrators (DEM_1 & 2 and DEM_5 & 6). However, other situations that correspond to the use cases derived from accident analyses are also described.

Table 18: Turning vehicle with cyclist by severity DEM_1 & 2

Severity		IFSTTAR			IDIADA			BME			Turning
UC_DEM	Use Case	Low	Med.	High	Low	Med.	High	Low	Med.	High	**Total**
1	CY_T1_A	0	0	0	0	0	0	3	0	0	3
	CY_T1_C	16	6	0	0	0	0	0	0	0	22
	CY_T1_D	0	0	0	0	0	0	1	0	0	1
	CY_T2_2	0	0	0	0	0	0	1	0	0	1
None	CY_T1_U	0	0	0	3	1	0	0	0	0	4
	CY_T1_V	0	0	0	0	0	0	2	3	0	5
2	CY_T1_R	1	0	0	0	1	0	2	0	0	4
	CY_T1_S	0	0	0	0	0	0	5	1	0	6
None	CY_T2_24	0	0	0	0	0	0	1	0	0	1
	CY_T1_J	0	0	0	0	0	0	5	6	0	11
	CY_T1_X	0	0	0	0	0	0	1	0	0	1
	Total	17	6	0	3	2	0	21	10	0	**59**
		23			5			31			

Table 19: Turning vehicle with cyclist by severity DEM 5 & 6

Severity		IFSTTAR			IDIADA			BME			Turning
UC_DEM	Use Case	Low	Med.	High	Low	Med.	High	Low	Med.	High	**Total**
5	CY_T1_L	0	0	0	0	0	0	1	2	0	3
	CY_T1_M	0	0	0	1	0	0	0	0	0	1
6	CY_T1_K	0	0	0	1	0	0	1	2	0	4
	CY_T1_W	0	0	0	0	0	0	4	0	2	6
	Total	0	0	0	2	0	0	6	4	2	**14**
		0			2			12			

3.1.2 1.1.2 Behavioural analysis by use case

In some circumstances, it is possible that a conflict does not fully match a pictogram description. Such cases are considered as “assimilated” to use cases”. They generally correspond to situations where the pictogram corresponding to the pre-conflict time is different to the pictogram that fits at the moment of the conflict.

For example, a pedestrian walking along the carriageway suddenly crossing the street is assimilated to a pedestrian crossing situation and not to a longitudinal situation as long as the conflict occurs while the pedestrian crosses. Complementary explanations are given in such situations.

Identification numbers of the conflicts are given to allow for accessing to all annotated information about parameters that could be relevant in the encoding sheets.

CY_T1_A => UC_DEM_1

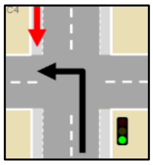
A cyclist travels on a preference road approaching a 3- or 4-arm junction, with the intention to go straight. A car traveling in the opponent direction intends to turn left at the junction into a minor road.

From BME data: **n=3 cases**

Three cases belong to this use case, recorded in the same (3-arm) intersection. Cyclist is approaching on a common bus-cycle lane in all cases, which slopes.

- The cyclist realizes the situation when the car turns and slows down in all cases (170, 171, 172[1]); the car slows down in two cases (170, 171).
- In one case (172) the car and cyclist realize each other in the very last moment, because a bus is between them (it lets the car turn).

CY_T1_C => UC_DEM_1



A cyclist travels on a bicycle lane approaching a traffic light controlled intersection, with intention to go straight while green. A car traveling in the opposite direction intends to turn left at the junction, while green as well.

In this situation the cyclist has two options: to bypass by the left or by the right. Such a decision is actually hard to anticipate, but a good predictor of the trajectory can be the part of the car where the bicycle trajectory heads to:

- If the cyclist projected trajectory cuts the left half of the car, then the cyclist will likely workaround the left side of the car.
- If the cyclist projected trajectory cuts the right half of the car, then the cyclist will likely workaround the right side of the car.

This simple rule helps to predict a good part of the observed cases, but other factors have also to be considered such as the amount of the facing car which encroaches the cyclist path, the presence of incoming traffic (for the cyclist), the presence of a previous car etc. Generally, the cyclist bypasses on the left when the vehicle is not engaged on the cycling path and/or when the cyclist is on the right side of the bicycle path (i.e. closer to the sidewalk).

It can be noticed that in such situations the cyclist often rides fast and does not need to make gesture to indicate a changing of direction.

[1] Each number corresponds to the identification number in the BME coding sheet. This allows for accessing to all annotated information about other parameters that could be relevant.

From IFSTTAR data: **n= 21 cases + 1 assimilated**

- In 16 cases the cyclist bypasses the vehicle on the left:
  - 15 cases follow the previous rule
  - But in one case the cyclist bypasses on the left while should have done by the right side. The cyclist deliberately wants to force the car to stop by looking at the driver and rushes to the car.
  - In 2 cases the vehicle almost hit the cyclist. (24, 25[2])
  - In 2 cases the vehicle also deviates to avoid the cyclist. (26, 27)
- In 2 cases the cyclist bypasses the vehicle on the right according to the previous rule. (11, 15)
- In 3 cases, the cyclist gives way to the vehicle, slowing down and almost stopping.
  - In 2 cases, the car drives quite fast (almost 30 km/h) and does not give the way to the cyclist (16, 21).
  - In the last case, the driver is following a truck, which obstructs the cyclist view and seems to see the cyclist at the last moment only (23).

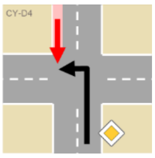
In 2 cases, view obstruction prevents the car driver to see the cyclist arriving, obliging the latter to slow down. (11, 21)

In 2 cases the vehicle is following another vehicle and the driver seems to not pay enough attention to the surrounding. He/she looks surprised and brakes suddenly. (9, 21)

- One more case can be assimilated to this use case: a cyclist rides straight on and decides to turn right at the last moment, without any gesture notification, while the vehicle in conflict stops to give the way. (30)

CY_T1_D => UC_DEM_1

A cyclist travels on a separate bicycle lane (on the street) on a preference road approaching a 3-arm junction with the intention to go straight. A car traveling in the opponent direction intends to turn left at the junction into the minor road.



[2] Each number corresponds to the identification number in the IFSTTAR coding sheet. This allows for accessing to all annotated information about other parameters that could be relevant.

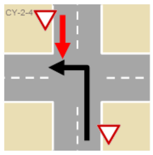
***From BME data:* n=1 assimilated**

Only one case can be assimilated to this use case. Layout is a bit different: bicycle lane is not on the street, but on another - close, parallel - road's sidewalk.

- Turning car realizes the cyclist late, both participants brake. Speeds are low. (36)

CY_T2_2 => UC_DEM_1

A cyclist travels on a minor road (yield or STOP) approaching a 4-arm junction with the intention to go straight. A car traveling in the opponent direction intends to turn left at the junction into the preference road.



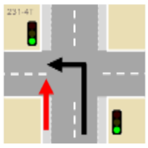
***From BME data:* n=1 assimilated**

Only one case can be assimilated to this use case. Layout is different: cyclist arrives on a bicycle way which crosses the main road (he does not have priority).

- Participants realize the situation late, both of them brake. Speeds are low. (120)

CY_T1_U

The vehicle is approaching a traffic light controlled 3- or 4-arm intersection with the intention to turn left. A cyclist approaches from behind on the cycle lane/sidewalk



***From IDIADA data:* n=2 + 2 assimilated**

There are two cases (one low and one medium) related to this use case. On the other hand, two low cases can be assimilated to this use case.

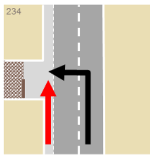
- In one case the cyclist is in a bicycle way and he has priority. The vehicle brake in order to let the cyclist go on.(6[3])
- In the second case, the vehicle needs to stop when turning left because the cyclist is crossing zebra with red light. (65)
- In the third case, the vehicle needs to stop suddenly when it starts to turning left because a cyclist is crossing on a bicycle way and he has priority. Medium severity. (83)

[3] Each number corresponds to the identification number in the IDIADA coding sheet. This allows for accessing to all annotated information about other parameters that could be relevant.

- In the fourth case, the vehicle is on a pedestrian street and suddenly needs to brake because a cyclist appears in front of the vehicle. Low severity due to low speed. (115).

CY_T1_V

The vehicle intends to turn left into a driveway/parking lot. A cyclist approaches from behind on the cycle lane/sidewalk.



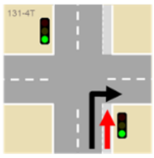
From BME data: **n=5 cases assimilated**

Five cases can be assimilated to this use case (from the same intersection). Layout is different: the car turns on a road, not to parking lot, and the bicycle lane is on another - close, parallel - road's sidewalk

- Turning car realizes the cyclist late, driver brakes, cyclist steers in all cases to avoid the crash. Speeds are low. (37, 75, 78, 99, 157)
- In one case (37) cyclist also brakes; in another (99) cyclist accelerates.
- In two cases (78, 157) cyclist also turns left.

CY_T1_R => UC_DEM_2

The vehicle is approaching a traffic light controlled intersection with the intention to turn right. A cyclist approaches from behind on the cycle lane.



From IFSTTAR data: n=1 assimilated

Only one case can be assimilated to this use case.

- The cyclist realizes the situation before the car turns. Then the cyclist slows down and bypasses the car by the rear (on the left) just before the intersection to avoid it. However the conflict is of low severity due to the low speed of the road users. It is noticeable that the car is driving is in infraction in a lane dedicated to buses (38)

From IDIADA data: n=1

There is one case with medium severity related to this use case.

- Cyclist riding straight at a curve while vehicle follows the turn to the right. The vehicle needs to brake. The cyclist does not check the traffic before go straight.(121)

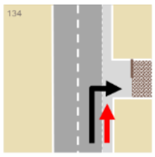
From BME data: **n=2 assimilated**

Two cases can be assimilated to this use case. In one case (3) cyclist is approaching on a common lane with the car; in the other (62) intersection is not signalized.

- In the first case (3) the driver steers, in the second (62) the cyclist steers to avoid the conflict.

CY_T1_S => UC_DEM_2

The vehicle intends to turn right into a driveway/parking lot. A cyclist approaches from behind on the cycle lane/sidewalk.



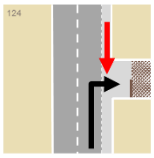
From BME data: **n=1 case + 5 assimilated**

One case (119) belongs, and 5 others (77, 121, 155, 156, 159) can be assimilated to this use case. In these 5 cases the layout is different: the car turns on a road, not to parking lot, and the cyclist arrives on a bicycle lane, which is on another - close, parallel - road's sidewalk.

- In two cases (77, 155) the car brakes, the cyclist brakes and steers.
- In two cases (119, 156) both participants brake.
- In one case (121) only the cyclist brakes and steers.
- In one case (159) the car brakes, the cyclist steers.

CY_T2_24

The vehicle intends to turn right into a driveway/parking lot. A cyclist approaches from the opposite direction on the cycle lane/sidewalk.

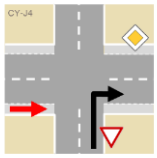


From BME data: **n=1 case assimilated**

Only one case can be assimilated to this use case. Layout is different: the car turns on a road, not to parking lot, and the bicycle lane is on another - close, parallel - road's sidewalk.

- The cyclist stops with one leg on ground. After the driver realizes the situation, lets the cyclist pass. (19)

CY_T1_J



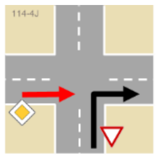
A passenger car travels on a minor road (yield or STOP) approaching a 3- or 4-arm junction, with the intention to turn right. He does not give priority to the cyclist crossing from the left, traveling on the sidewalk/cycle lane.

From BME data: n=2 + 9 case assimilated

Two cases (48, 102) belongs, and 9 others (23, 47, 63, 67, 72, 73, 74, 97, 158) can be assimilated to this use case. In the latter 9 cases the layout is different: car has priority against other cars in the intersection (but not against VRUs); the bicycle lane is on another - close, parallel - road's sidewalk.

- In three cases (23, 67, 73) the driver does not change his/her movement, the cyclist has to brake to avoid crash.
- In three cases (47, 74, 158) the driver brakes, and the cyclist brakes and steers.
- In three cases (48, 72, 97) both participants brake.
- In one case (63) only the driver brakes.
- In one case (102) the driver brakes, and the cyclist steers.

CY_T1_X



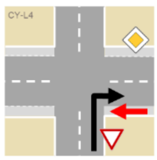
The vehicle is approaching a 3- or 4-arm intersection on a minor road with the intention to turn right in a priority road (yield or STOP). A cyclist approaches from the left on the street.

From BME data: n=1 case

Only one case belongs to this use case.

- The car arrives first to the conflict zone at low speed, but the cyclist has to steer to avoid crash. The car turns after the cyclist passed. (60)

CY_T1_L => UC_DEM_5



A passenger car travels on a minor road (yield or STOP) approaching a 3- or 4-arm junction, with the intention to turn right. He does not give priority to the cyclist crossing from the right, traveling on the sidewalk/cycle lane.

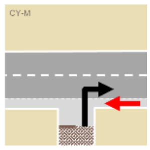
From BME data: **n=1 + 2 assimilated**

Only one case belongs (110) and 2 others (64, 71) can be assimilated to this use case. In one (64) of the latter two cases, the layout is different: car has priority against other cars in the intersection (but not against VRUs), and the bicycle lane is on another - close, parallel - road's sidewalk; while in the other one (71) cyclist goes on a oneway bicycle lane, but in the opposite direction to the traffic.

- In the first case (64) both participants brake.
- In the second case (71) the driver brakes, while the cyclist steers.
- In the third case (110) the driver steers, while the cyclist brakes.

CY_T1_M => UC_DEM_5

The vehicle exits a driveway with the intention to turn right. While crossing the sidewalk/cycle lane he does not give priority to the cyclist approaching from the right side.



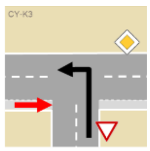
From IDIADA data: n=1 assimilated

Only one case can be assimilated to this use case.

- The vehicle is turning right when a cyclist appear longitudinal against vehicle on right side and opposite direction. The vehicle needs to steer and avoid the cyclist. (256)

CY_T1_K => UC_DEM_6

The vehicle travels on a minor road (yield) approaching an intersection with the intention to turn left. While turning/entering the intersection, he does not give priority to the cyclist, crossing from the left traveling on the sidewalk/cycle lane.



From IDIADA data: **n=1 assimilated**

Only one case can be assimilated to this use case.

- The vehicle crosses a traffic light (green light) when a cyclist crosses far side before X intersection on bicycle way. The cyclist has red light. Low severity due to distance between cyclist and vehicle. (48)

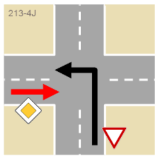
***From BME data:* n=3 assimilated**

Three cases can be assimilated to this use case. Layout is different: car has priority against other cars in the intersection (but not against VRUs); the bicycle lane is on another - close, parallel - road's sidewalk.

- In all cases (70, 76, 98) the driver brakes after he/she realize the situation. In two of these (70, 98) the cyclist brakes, and in the third one (76) the cyclist brakes and steers also.

CY_T1_W => UC_DEM_6

The vehicle is approaching a 3- or 4-arm intersection on a minor road with the intention to turn left in a priority road (yield or STOP). A cyclist approaches from the left on the street.



***From BME data:* n=6 cases**

Six cases belong to this use case, recorded in the same (3-arm) intersection. Cyclist is approaching on a common bus-cycle lane in all cases, which slopes.

- In three cases (161, 164, 165) both participants brake after realizing the situation, but in of them (164), cyclist does not have enough time to slow down and crashes to the car; and in another one (165) the cyclist tries to decelerate too quickly and falls. (The latter two has high severity.)
- In one case (166) the driver brakes while the cyclist steers.
- In one case (168) the cyclist brakes and steers, the car goes back to let the cyclist go.
- In one case (173) the driver accelerates while the cyclist brakes and steers.

3.2 VEHICLE CROSSING WITH CYCLIST

3.2.1 Global analysis

Two use cases involving a vehicle crossing have being identified for being implemented in the demonstrators (DEM_3 & 4).

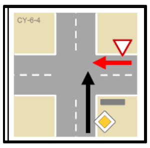
Table 20: Crossing vehicle with cyclist by severity DEM 3 & 4

Severity		IFSTTAR			IDIADA			BME			Crossing
UC_DEM	Use Case	Low	Med.	High	Low	Med.	High	Low	Med.	High	**Total**
3	CY_T1_E	0	2	0	5	0	0	0	0	0	7
	CY_T1_I	0	0	0	0	0	0	0	1	0	1
	CY_T1_N	0	0	0	1	0	0	0	0	0	1
	CY_T1_O	0	0	0	1	0	0	1	0	0	2
4	CY_T1_F	0	0	0	0	0	0	1	1	0	2
	CY_T1_G	0	0	0	0	2	0	0	0	0	2
	CY_T1_H	1	2	0	0	0	0	0	1	0	4
	CY_T1_P	0	0	0	1	0	0	1	0	0	2
	CY_T1_Q	1	1	0	2	0	0	0	0	0	4
	Total	2	5	0	10	2	0	3	3	0	**25**
		7			12			6			

3.2.2 Behavioural analysis by use case

CY_T1_E => UC_DEM_3

A passenger car travels on a preference road approaching a junction with the intention to go straight. A cyclist approaching from the right side intends to cross the junction, not giving priority to the car.



***From IFSTTAR data:* n= 2**

- In the 2 cases, the cyclist runs a red light and forces deliberately the way to cars coming from his left.

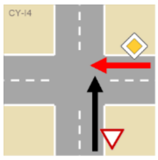
  The 2 cases involve the same cyclist, who generates 2 conflicts with 2 different vehicles. In both cases the traffic is heavy and the vehicles, which have a green light, have to slow down to avoid the cyclist. (31, 32).

  - In one case the cyclist also deviates to avoid the vehicle. (31)

From IDIADA data: **n= 1 + 4 assimilated**

- In one case, the cyclist is on a bicycle way with red light and the vehicle has green light. (10)
- Two cases are on a pedestrian street and the cyclist appears from right side in front of the vehicle. The vehicle needs to brake and steer. (35, 82)
- The other cases are on an X intersection and the vehicle needs to brake when a cyclist appears from the right side. (172, 246)

CY_T1_I => UC_DEM_3



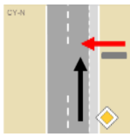
A passenger car travels on a minor road (yield or STOP) approaching an intersection with the intention to go straight. While crossing, he does not give priority to the cyclist coming from the right traveling on the preference road.

From BME data: **n= 1**

Only one case belongs to this use case. Cyclist arrives on a bicycle lane.

- The car arrives first to the conflict zone and accelerates. The cyclist has to brake. (103)

CY_T1_N => UC_DEM_3



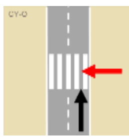
A passenger car is traveling on a preference road. A cyclist coming from the right sidewalk/cycle lane crosses the street in front of the car.

From IDIADA data: **n= 1**

There is one case related to this use case.

- The vehicle needs to brake when a cyclist appears from the right side. The cyclist cross the street without checking traffic. (178)

CY_T1_O => UC_DEM_3



A passenger car is traveling on a preference road approaching a cross walk. A cyclist, traveling on the right side walk /cycle lane crosses the cross walk (cycling, NOT pushing the bike).

From IDIADA data: **n= 1**

There is one case related to this use case.

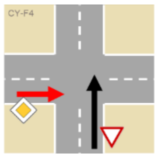
- The vehicle needs to brake when a cyclist appears from the right side. The cyclist cross the (186)

From BME data: **n= 1 case**

Only one case can belongs to this use case.

- The vehicle could not pass through the intersection during green sign due to high traffic, while cyclist starts to go when he gets green. The driver lets the VRUs pass through, but the cyclist has to steer. (55)

CY_T1_F => UC_DEM_4



A passenger car travels on a minor road (yield or STOP) approaching an intersection with the intention to go straight. While crossing, he does not give priority to the cyclist coming from the left traveling on the main road.

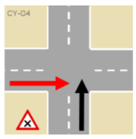
From BME data: **n=2 cases**

Two cases belong to this use case. Cyclist arrives on a bicycle lane in both cases.

- In the first case (35) the driver does not changes his/her movement, so the cyclist has to stop.
- In the second case (46) the driver brakes while the cyclist steers.

CY_T1_G => UC_DEM_4

A passenger car approaches a priority-to-right intersection, with the intention to go straight. A cyclist coming from the left side does not give priority to the passenger car.



From IDIADA data: **n=2**

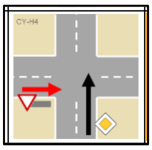
There are two cases related to this use case. In both, the cyclist and the vehicle suddenly brake hard.

- In one case, one cyclist crosses the street in front of the vehicle and a second cyclist starts to cross but he needs to brake hard. Also, the vehicle brakes suddenly. Medium severity due to hard braking (7)

- The second case is on a Pedestrian Street. The cyclist appears suddenly from the left side and the vehicle and the cyclist brake hard. Medium severity due to hard braking. (249)

CY_T1_H => UC_DEM_4

A passenger car travels on a preference road approaching a junction, with the intention to go straight. A cyclist coming from the left side does not give priority to the passenger car.



From IFSTTAR data: **n=3**

The cyclist does not stop at a red light.

In all the following cases, the cyclist behaviour can be predicted:

- In one case, the cyclist makes a hand gesture to ask the incoming vehicle to slow down in order to pass first. The vehicle has to brake suddenly to yield (speed 17 km/h). The conflict is at a medium severity level (35).
- In one case, the cyclist stops pedalling arriving at the crossroads and slows down to give way to the vehicle, then passes after. The driver cannot see the cyclist' pedalling behaviour due to the presence of vehicle that obstructs his/her view, but the swerving manoeuvre of the cyclist is sufficient to indicate to the driver that he gives the way. (33)
- In the last case the rider stops pedalling arriving at the crossroads and then deviates to get behind the vehicle. (34)

In all the cases the cyclist looks to the right before crossing.

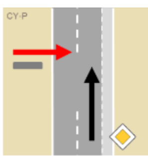
From BME data: **n=1 case**

Only one case belongs to this use case. In that, geometry is different, because the car turns right and the cyclist goes straight, but the car has priority.

- The driver brakes when he/she realizes the situation, while the cyclist continues pedalling. (147)

CY_T1_P => UC_DEM_4

A passenger car is traveling on a preference road. A cyclist coming from the left sidewalk/cycle lane crosses the street in front of the car.



From IDIADA data: **n=1**

There is one case related to this use case.

- Cyclist decides to cross near the vehicle and without bicycle way or pedestrian street. Low braking of the vehicle. (188)

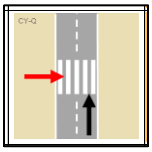
From BME data: **n=1 case**

Only one case belongs to this use case. In that, cyclist appears from standing cars (which waits due to heavy traffic on the opposite lane).

- The driver brakes when he/she realizes the situation, while the cyclist steers and continues pedalling. (148).

CY_T1_Q => UC_DEM_4

A passenger car is traveling on a preference road approaching a cross walk. A cyclist, traveling on the left side crosses the cross walk (cycling, NOT pushing the bike).



From IFSTTAR data: **n= 2 assimilated**

- 2 cases can be assimilated to the use case. In both of them a cyclist crosses the road on a pedestrian crossing, and meets a car turning to the left.
  - In one case the cyclist looks to the right before crossing then slows down and near passes the car while giving way (37).
  - In one case, it is the opposite. The cyclist does not look to the right before crossing and the vehicle has to slow down to give way to the cyclist (36).

From IDIADA data: **n=1 + 1 assimilated**

There is one case related to this use case and one case assimilated.

- In one case, a cyclist crosses on a crosswalk far side from the vehicle. Low severity due to low speed. (14)
- The second case is on a pedestrian street. While the vehicle is entering to the pedestrian street, on cyclist appears from left side. Low severity due to low speed. (50)

3.3 LONGITUDINAL WITH CYCLIST

3.3.1 Global analysis

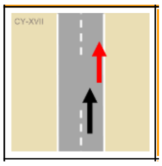
One use case involving a longitudinal encounter has being identified for being implemented in the demonstrators. However, other situations that correspond to the use cases derived from accident analyses are also described.

Table 21: Longitudinal conflicts with cyclists

Severity		IFSTTAR			IDIADA			BME			Longitudinal
UC_DEM	UseCase	Low	Med.	High	Low	Med.	High	Low	Med.	High	**Total**
9	CY_T1_AB	4	3	0	4	0	0	1	0	1	13
	CY_T1_AC	0	0	0	0	0	0	2	0	0	2
	CY_T1_AD	0	1	0	3	0	0	0	0	0	4
	Total	4	4	0	7	0	0	3	0	1	**19**
		8			7			4			

3.3.2 Behavioural analysis by use case

CY_T1_AB => UC_DEM_9



Bicycle and passenger car travel along a road. Vehicle and cyclist are traveling in the same direction.

***From IFSTTAR data: n*=6 + 1 assimilated**

This use case can be split into two sub-categories:

- In 4 cases, the cyclist's behaviour influences the vehicle's behaviour. The cyclist deviates from his/her trajectory without any gesture notification and never looks behind to see if cars are coming. Consequently, the following vehicle has to deviate as well.

  In all cases, the cyclist behaviour is predictable, because the driver can see what happens in front.

  - In one case the cyclist has to overtake a stopped vehicle (6).
  - In two cases the cyclist overtakes another cyclist (4, 5)
  - In one case the cyclist overtakes a bus (3).
- In 2 cases, the vehicle's behaviour influences cyclist's behaviour. In both cases the cyclists look behind to see if cars are coming behind.
  - In one case, the vehicle passes near the cyclist at high speed making the cyclist deviating toward the sidewalk (1). The conflict is rated at a medium level of severity (speed; 67 km/h).

  - In one case, the cyclist shows the intention to turn left: he stops pedalling and extends the arm. Despite this, the car overtakes forcing the cyclist to slow down and give the way. The cyclist bypasses the vehicle on the left after (2).
- 1 case can be assimilated to this use case. The vehicle is a bus. While bus and cyclist are side by side, the bus moves to the right obliging the cyclist to stop avoiding to be trapped between the bus and the sidewalk. This case is presumably due to a blind spot problem (7).

***From IDIADA data: n*=0 + 4 assimilated**

There are four cases assimilated related to this use case.

- In three cases, the cyclist rides towards the vehicle on the right side. There is no bicycle way. In all cases the cyclist is approaching to the vehicle in opposite direction. (108, 158, 266)
- The last case is related to one cyclist stopped on the street on the left side. The vehicle needs to brake and steer in order to avoid him. (298)

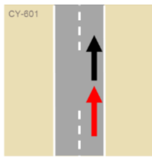
***From BME data:* n=2**

Two cases belong to this use case. In both, cyclists use bicycle lane on the side of the road.

- In the first case (149) the driver steers, while the cyclist continues pedalling.
- In the second case (151) the car starts to change lane (to the turning lane) and crosses bicycle lane on which two cyclists arrive. All participants brake to avoid crash. Severity is high, because vehicle speed is medium and VRUs has very short time to react.

CY_T1_AC

Bicycle and passenger car travel along a road in the same direction. Bicycle rear ends a passenger car.

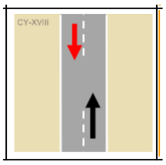


***From BME data:* n=2 cases**

Two cases belong to this use case.

- In both cases, the driver does not change his/her movement, while the cyclist steers. (80, 138)

CY_T1_AD



Passenger car, travelling on inter-urban road at inter-urban speeds loses control and suddenly pulls to the left where a bicycle travels in the opposite direction.

From IFSTTAR data: **n=1**

- The cyclist was crossing an intersection and first faced a left turning car. While swerving to avoid it, he ends riding on the opposite lane facing incoming traffic. (8)
    - The facing vehicle consequently slows down to leave the cyclist safely going back to his dedicated path. The cyclist thanks with a hand gesture.

From IDIADA data: **n=2 + 1 assimilated**

There are two cases related to this use case and one case assimilated.

- In two cases, a cyclist rides towards the vehicle on the left side. There is no bicycle way. The cyclist is approaching to the vehicle in opposite direction. The vehicle needs to steer in order to avoid the cyclist. (102, 247)
- In one case, the cyclist rides towards the vehicle on the right side. There is no bicycle way. The cyclist is approaching to the vehicle in opposite direction. The vehicle needs to steer in order to avoid the cyclist. (267)

3.4 Conflicts with pedestrians – Car goes straight

3.4.1 Global analysis

Three use cases involving pedestrians have been identified for being implemented in the demonstrators. However, other situations that correspond to the use cases derived from accident analyses are also described. In all following cases, the vehicle is going straight or backwards.

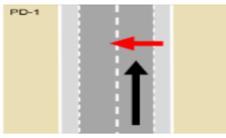
Table 22: Conflicts with pedestrians. Vehicle going straight/backwards & crossing

Severity		IFSTTAR			IDIADA			BME			Pedestrian
UC_DEM	Use Case	Low	Med.	High	Low	Med.	High	Low	Med.	High	**Total**
10	PD_1	12	0	0	80	5	1	33	3	0	133
	PD_2	26	7	0	82	7	0	33	4	0	159
11	PD_5	0	0	0	20	2	0	9	2	0	33
	PD_6	0	1	0	16	2	0	6	0	0	24
12	PD_7a	0	0	0	24	0	0	0	0	0	24
	PD_7b	1	0	0	23	1	0	1	0	0	26
	PD_8	0	0	0	0	0	0	1	1	0	2
	Total	39	8	0	245	17	1	83	10	0	**403**
		47			263			93			

3.4.2 Behavioural analysis by use case

PD_1 = UC_DEM_10

The vehicle goes straight, the pedestrian crosses from the right hand of the vehicle.



From IFSTTAR data: **n=10 + 2 assimilated**

In most cases, the driver has an absolute right of way (green light) while the pedestrian has no right (red light).

Three types of pedestrian behaviour are observed

- The pedestrian looks around and towards the car before crossing which could mean that he/she has taken into account the presence of the car and think having the time to cross (40, 46 & 47).
  - 2 pedestrians can cross without modifying their behaviour (trajectory and speed), but in one case the car slightly adapts its speed.

- The third one seems dreaming during the end of his crossing.
- In the 3 cases the vehicle passes near the pedestrian.

- o The pedestrian looks around while crossing, realizing late that a car is coming quickly. As a consequence he/she must speed to avoid the vehicle (39, 41, 42, 43 ,45).
  - One woman makes big steps to pass in front of a bus,
  - Three pedestrians walk, then accelerate,
  - One accelerates progressively.

  In 2 cases the pedestrian does not look before crossing and is forced to accelerate when he/she realizes the presence of the car. (41, 43)
  - In other cases the pedestrian looks before crossing but seems to underestimate the car' speed (39, 42, 45).
- o The pedestrian adopts a risky behaviour: does not take into account the presence of the ambient traffic, does not look around before crossing and forces the way to the cars. As a consequence, the coming vehicles must brake to avoid him/her (44, 48).
  - In one case a schoolboy tries to escape from another one following,
  - in another case a pedestrian runs and crosses the road to take a tram.
- o 2 other cases can be assimilated to this use case.
  - o Pedestrians end crossing by continuing up the road on the pavement, facing a car at the end. The conflict begins with a configuration (close to PD_1) and ends with a longitudinal configuration (close to PD_7b) (49, 50). In both cases, we are in the limits of the video image, thus cannot fully analyse these pedestrian behaviour.

***From IDIADA data:* n=64 +22 assimilated**

One case related to this use case has high severity.

- o In this case, the pedestrian is walking forward and suddenly he crosses longitudinally the street. There is contact between pedestrian and car. He crosses without checking for the traffic. (116)

Five cases related to this use case have a medium severity.

- o In three of the cases, pedestrians are crossing a crosswalk with red light. (40, 78, 91)
- o In two cases, pedestrians are crossing without crosswalk or Pedestrian Street. (87)
- o In one case, the pedestrian is crossing a crosswalk with red light. Also, she is using a camera and she does not see the vehicle. (125)

In most cases, the driver has an absolute right of way (green light) while the pedestrian has no right (red light).

Common pedestrians behaviour are observed:

- The pedestrian looks around but decided to run in order to cross the street.
- The pedestrian crosses the street longitudinally (cases assimilated)
- The pedestrian crosses the street without zebra or crosswalk and without checking for the traffic.
- The pedestrian crosses on Pedestrian Street and he has priority. Low severity due to low speed.
- The pedestrian crosses the street thinking that the vehicle will stop.

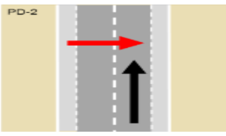
From BME data: **n= 36**

36 case belongs to this use case.

- In 21 cases the vehicle had the right of way, while in the other 15 cases the pedestrian had.
- In only 2 cases the pedestrian did no react (2, 131)
- In 6 cases the pedestrian hesitated during the conflict, before they went back (49, 163), waited (107) or the conflict situation was over before the reaction (6, 95, 154)
- In 9 cases the pedestrian chose to step back to their initial point (29, 42, 49, 83, 86, 135, 136, 160, 163) from which once they turned back as well (42) – in 7 cases the vehicle had absolute right of way.
- In 13 cases the pedestrian managed the conflict with changing either their speed or walking direction – in 7 cases the vehicle braked as well
- In 11 cases the driver did not change his behaviour (did not manage the conflict), therefore the pedestrian had to run (in 3 cases, where the vehicle had the absolute right of way – 9, 26, 27), go back (in 4 cases – 29, 136, 160, 163), or changing either their speed or walking direction (in 4 cases – 4, 66, 115, 129).
- In 1 case the vehicle had the absolute right of way and accelerated to manage the conflict, while the pedestrian stepped back (86)
- In 21 cases the vehicle braked – even in the 12 cases where they had the absolute right of way
- In only 1 case the vehicle braked and steered as well (42)

PD_2

The vehicle goes straight, the pedestrian crosses in from the left of the vehicle.



From IFSTTAR data: **n=28 + 5 assimilated**

Nearly half of these cases (n=11) are annotated as medium severity level.

Generally, the driver has an absolute right of way (green light) while the pedestrian has no right (red light). In one case only, the light is green for both of them.

Here also, three types of pedestrian behaviour are observed

- Pedestrian looks around and towards the car before crossing which seems to show that he/she has taken into account the presence of the car and thinks having the time to cross (16 cases).
  - In 1 case, the pedestrian makes a sign to give the way to a first vehicle and begins to cross then runs to avoid another car arriving (51).
  - In 7 cases, the pedestrian begins to cross in walking then runs to avoid vehicle(s) coming fast (52, 63, 66, 69, 70, 73, 77).
  - In 2 cases, the vehicle forces the way making the pedestrian upset (makes a sign) against the too close vehicle (56, 64).
  - In 5 cases, the pedestrian stops while crossing and is forced to retreat to avoid the vehicle, which passes close (59, 60, 67, 68, 78).
  - In 1 case, the pedestrian doesn't see another car behind a slow vehicle. Consequently, the vehicle brakes and swerves to avoid him (62).
- Pedestrian looks around while crossing, and realizes the arriving of a fast car; he/she speeds to avoid the fast vehicle (4 cases).
  - Pedestrian realizes that stopping cars start to go (traffic light turns green) and runs to finish crossing (53)
  - The pedestrian runs with the goal of taking a bus, cars passes close to him (61)
  - The vehicle brakes to give the way to the pedestrian (71, 72)
- Pedestrians adopting a dangerous behaviour: they seem not taking into account the ambient traffic, do not look around before crossing and force the way to cars. Surrounding cars must brake to avoid them (74, 75, 76)
  - In 3 cases the vehicle brakes to give way to the pedestrian (54, 57, 58)
  - In one case the pedestrian runs to take a bus and the vehicle swerves to avoid her (55)
  - In one case the pedestrian runs to meet somebody at the other side of the street (65)

- 5 cases can be assimilated to this use case, but in each of them the pedestrian does not use crosswalks and crosses the street in diagonal.

  In all these cases the vehicle passes near the pedestrian.

  - In one case, the pedestrian looks around, crosses on the crossroad and he realizes that a vehicle is going from behind (79).
  - In 3 cases, the pedestrian runs to catch a bus or a tram and the vehicle brakes to give the way (80, 81,82).
  - In 1 case, the pedestrian slows down and stops to avoid the vehicle (83).

From IDIADA data: **n=65 + 24 assimilated**

Seven cases related to this use case have medium severity.

- In three cases, pedestrians are crossing crosswalk with red light. One of these goes back when see the car and the other go on to the right side. (20, 46, 72)
- In one case, the pedestrian is stopped on the street, and when he sees the car starts to cross the street to the right side. (85)
- In other case, a pedestrian is crossing on a X intersection without crosswalk. He goes on when see the car. (86)
- Sixth case is important because the pedestrian crosses longitudinally without check traffic and without checking behind him. Suddenly she sees the car near and she gets scared. She goes back to the left side. (139)
- The last case is related to a pedestrian entering to the street without checking traffic but just a second, in order to avoid other pedestrians. The medium severity is due to the dangerousness action and the vehicle's speed. (146)

Analysing other cases, the driver has an absolute right of way (green light) while the pedestrian has no right (red light).

Common pedestrian's behaviours are observed:

- The pedestrian looks around but decided to run in order to cross the street.
- The pedestrian crosses the street longitudinally (cases assimilated)
- The pedestrian crosses the street without zebra or crosswalk and without check the traffic.
- The pedestrian crosses are on Pedestrian Street and he has priority. Low severity due to low speed.
- The pedestrian crosses the street thinking that the vehicle will stop before crash.

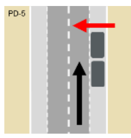
From BME data: **n= 37**

37 cases belong to this use case.

- In 23 cases the vehicle had the right of way, in 13 cases the pedestrian had and in 1 case (143) none of them was allowed to be in the conflict area
- None of the pedestrian reacted.
- In 12 cases the pedestrian hesitated during the conflict, before they went back (112, 133), run through (85, 137) or the conflict situation was over before the reaction (12, 65, 108, 109, 116, 134, 146, 162)
- In 4 cases the pedestrian chose turn and go back to their initial point (10, 111, 112, 133) – in all cases the vehicle had absolute right of way.
- In 21 cases the pedestrian managed the conflict with changing either their speed or walking direction – in 11 cases the vehicle braked as well, in 1 case the vehicle braked and steered (153) and in 1 case the vehicle accelerated slower than originally wanted (54)
- In 15 cases the driver did not change his behaviour (did not manage the conflict), therefore the pedestrian had to run (in 6 cases, where the vehicle had the right of way – 39, 40, 58, 113, 143, 150), go back (in 4 cases – 38, 133, 144, 145), or changing either their speed or walking direction (in 5 cases – 5, 12, 94, 125, 134).
- In 1 case the vehicle did not have the right of way but accelerated to manage the conflict, while the pedestrian hesitated (146)
- In 19 cases the vehicle braked – even in the 10 cases where they had the absolute right of way
- In only 1 case the vehicle braked and steered as well (153)

PD_5 = UC_DEM_11

The pedestrian crosses a straight road from right side with obstruction.



From IDIADA data: **n=20 + 2 assimilated**

Two cases related to this use case have medium severity.

- In two cases, pedestrians are crossing without crosswalk. Checking traffic done once they are in front of the vehicle. They run and go on. (77, 154)

Common pedestrian's behaviours are observed:

- The pedestrian looks around but decided to run or go on in order to cross the street.
- The pedestrian crosses the street longitudinally (cases assimilated)

- The pedestrian crosses the street without zebra or crosswalk.
- The pedestrian crosses the street thinking that the vehicle will stop before crash.

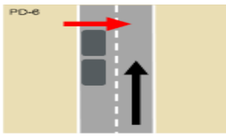
From BME data: **n= 11**

11 cases belong to this use case.

- In 9 cases the vehicle had the right of way and in 2 cases (22, 101) the pedestrian had
- In only 1 case (34) the pedestrian did not react, therefore the vehicle had to steer
- In 2 cases the vehicle braked, and the pedestrian get the opportunity to walk (101) or run (22) through the road
- In 8 cases the vehicle did not react to the conflict, forcing the pedestrian to wait. In all of these cases, the vehicle had the absolute right of way.

PD_6

The pedestrian crosses a straight road from left side with obstruction.



From IFSTTAR data: **n=1**

- In this case the pedestrian has no right (red light) while the driver has an absolute right of way (green light). The pedestrian attempts crossing in front of a slow vehicle. By doing so, she is masked to another faster car, coming from the same direction. The fast car cannot see her as she is also hidden by the previous car.

  Although the pedestrian slows down and even stops to give the way to the car, she forces it to swerve to avoid an accident, resulting in a very close proximity between the two involved road users. However, head orientation of the pedestrian indicates that she looks toward the car and that she finally takes it into account (123).

From IDIADA data: **n=13 + 5 assimilated**

Two cases related to this use case have medium severity.

- In two cases, the obstruction is a vehicle on left side. The pedestrians are crossing without crosswalk. Checking traffic done once they are in front of the vehicle. One of them tries to go back, but finally goes on. In the other case a group of person goes on and crosses a T intersection diagonally. (114, 254)

Common pedestrian's behaviours are observed:

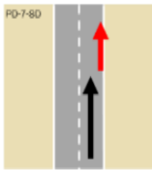
- The pedestrian looks around but decided to run or go on in order to cross the street.
- The pedestrian crosses the street longitudinally (cases assimilated)
- The pedestrian crosses the street without zebra or crosswalk.
- The pedestrian crosses the street thinking that the vehicle will stop before crash.

From BME data: **n= 6**

6 cases belong to this use case.

- In 3 cases (52, 82, 84) the vehicle had the right of way and in 3 cases (61, 88, 89) the pedestrian had
- In only 1 case (88) the pedestrian did not react.
- In only 1 case (84) the vehicle did not brake, therefore the pedestrian had to run

PD_7a = UC_DEM_12



The pedestrian walks along the carriageway on a straight road away from vehicle. The vehicle passes very close to the pedestrian.

From IDIADA data: **n=11 + 13 assimilated**

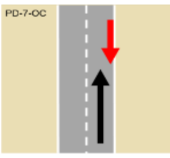
Just low severity cases related to this use case. Most of them are on the left side. For this reason these cases are assimilated to this use case.

The pedestrian's behaviours observed are:

- The pedestrian is walking longitudinally away from vehicle at left side.
- The pedestrian walks out from far side longitudinal to the vehicle
- The pedestrian starts crossing diagonal from far side and ends crossing longitudinal on nearside.
- In all of cases, the pedestrian does not check behind him.

PD_7b

The pedestrian walks along the carriageway on a straight road towards vehicle. The vehicle passes very close to the pedestrian.



From IFSTTAR data: **n=1**

- This conflict happens in the limit of the video field of view, data is missing then to see what happens before (124).

From IDIADA data: **n=12 + 12 assimilated**

Just one case has medium severity related to this use case. Half of them are on the left side. For this reason these cases are assimilated to this use case.

- In the case with medium severity, the pedestrian enter suddenly in the left side of the street in from of the vehicle, walking in opposite direction. Quickly she goes back. (98)

In other cases, the pedestrian's behaviours observed are:

- Walking straight to the vehicle and distracted by phone
- Walking straight to the vehicle on the left side.
- Walking straight to the vehicle in the middle of pedestrian way.
- Walking longitudinal towards the vehicle at left side

From BME data: **n= 1**

- In this case (139) the vehicle had the right of way
- The conflict was of low severity, therefore serious intervention did not happen to manage the conflict

PD_8

The vehicle drives backwards (no pictogram).

From BME data: **n= 2**

2 cases belong to this use case.

- In both cases (28, 87) the vehicle was prohibited to reverse.
- In 1 case the vehicle braked (28) and in 1 case it did not (87). In both situations the pedestrian had to wait.

3.5 TURNING WITH PEDESTRIAN

3.5.1 Global analysis

The following situations involving pedestrians are derived from accident analyses and have not been identified for being implemented in the demonstrators.

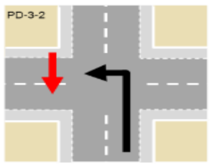
Table 23: Turning with pedestrians

Severity		IFSTTAR			IDIADA			BME			Pedestrian
UC_DEM	UseCase	Low	Med.	High	Low	Med.	High	Low	Med.	High	**Total**
Turning	PD_3a	13	9	2	5	2	0	4	1	0	36
	PD_3b	11	1	0	1	1	0	4	0	0	18
	PD_4a	0	0	0	8	0	0	6	1	0	15
	PD_4b	3	0	0	1	0	0	8	1	0	13
	Total	27	10	2	15	3	0	22	3	0	**82**
		39			18			25			

3.5.2 Behavioural analysis by use case

PD_3a

A car traveling in the opposite direction intends to turn left at the junction, a pedestrian comes (from the) right at a crosswalk.



***From IFSTTAR data:* n=24**

In most cases, the pedestrian has an absolute right of way (green light) while the driver has only a conditional right (i.e. can turn left (green light) but must yield if pedestrians).

In 4 cases only, the pedestrian does not cross on the pedestrian crossing; therefore doesn’t have an absolute right of way.

Here also, three types of pedestrian behaviour are observed

- Pedestrian looks around and towards the car before crossing which seems to show that he/she has taken into account the presence of the car and seems having the time to go
    - In 4 cases the vehicle brakes to yield to the pedestrian (85, 100, 103, 106). In 2 of these cases, he/she makes a gesture to thank for yielding (84, 94). And in 2 other cases the pedestrian makes a gesture of irritation to the vehicle which arrives at high speed (99, 105).
    - In one case the pedestrian deviates to avoid the vehicle and steps back (86).

- In two cases the pedestrian speeds to avoid the vehicle. The vehicle turns left and abruptly slows while the pedestrian runs to cross. In one of these cases the pedestrian makes a gesture to ask for yielding (87, 98).
- In one case, the vehicle passes near the pedestrian and almost hits him/her, the pedestrian jumps to avoid it, then reprimands the driver (90).
- In 2 cases the pedestrian doesn't have any particular behaviour. The vehicle passes behind quite fast (91, 92, 96).
- In 3 cases, the pedestrian slows down to yield to the vehicle. In 2 cases he even stops completely and made a gesture of irritation to the vehicle (97, 95, 104).

o Pedestrian looks around while crossing, then realizes that a car is arriving fast.
- In one case the pedestrian forces the vehicle to brake and makes a sign to ask for yielding (88).
- In case the pedestrian deviates to avoid the vehicle which must slow down (101, 102).

o Pedestrian adopts a dangerous behaviour. He/she seems not taking into account the ambient traffic: don't look around before crossing and forces the way to cars. Vehicle must brake to avoid him/she.
- In one case the pedestrian seems to be dreaming (89)
- In one case the pedestrian is talking with another pedestrian (93)
- In one case the pedestrian must speed to avoid the vehicle (107)

From IDIADA data: **n=4 + 3 assimilated**

There are two cases with medium severity (73, 207).

All cases have common pedestrian's behaviours observed:

o The pedestrian looks around but decided to run or go on in order to cross the street.
o The pedestrian crosses the street without zebra or crosswalk.
o The pedestrian crosses the street with red light.
o The pedestrian see the car while arriving in the middle of the street.

From BME data: **n= 5**

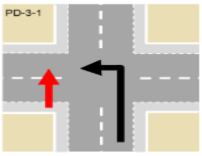
5 cases belong to this use case.

o In all 5 cases the pedestrian had the right of way
o None of the pedestrian did not react– 1 of them walked through (124), 1 of them run (114), 2 of them waited for the car to cross (90, 141) and 1 of them hesitated then changed their walking directions (169)

- In 1 case the vehicle did not have the right of way but accelerated to manage the conflict, while the pedestrian had to wait (90)

PD_3b

A car intends to turn left at the junction, a pedestrian comes left at a crosswalk.



From IFSTTAR data: **n=12**

Generally, the pedestrian has an absolute right of way (green light) while the driver has a conditional right (right to turn left (green light) but must yield if pedestrians).

In 3 cases only, the pedestrian does not cross on the pedestrian crossing then doesn't have an absolute right.

- Pedestrian looks around and towards the car before crossing which seems to show that he/she has taken into account the presence of the car and think having the time to cross.
  - In one case the vehicle passes very close to the pedestrian after crossing (109, 113, 117)
  - In 3 cases the vehicle brakes to give way to the pedestrian, maybe a bit late. And the pedestrian makes gestures to ask for yielding or to reprimand (110, 112, 119).
  - In one case the pedestrian stops completely to give way to the vehicle, which passes very close to him/she (111).
  - In one case the pedestrian walks at the beginning then accelerates slightly because of the vehicle proximity (114).

- Pedestrian looks around while crossing, and then realizes a car is coming fast.
  - In 2 cases the pedestrian crosses normally so the vehicle brakes to give way to the pedestrian .(115, 118)
  - In one case the pedestrian on a push scooter is surprised in the middle of the crosswalk. He stops and the car brakes to yield; then he start crossing again (116).
- Pedestrian having a dangerous behaviour: seems not taking into account the ambient traffic, don't look around before crossing and forces the way to cars, the vehicle must brake to avoid.
  - In 1 cases the vehicle brakes to give the way to the pedestrian (108)

From IDIADA data: **n=2**

One case related to this use case has medium severity.

- The pedestrian crosses a crosswalk running although she sees the vehicle before crossing. (137)

The other case is in a crosswalk. The pedestrian has red light but she tries to cross. When she sees the vehicle, she goes back.

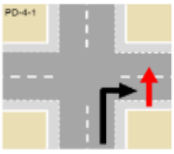
From BME data: **n= 4**

4 cases belong to this use case.

- In 3 cases the pedestrian had the right of way and in 1 cases the vehicle had
- None of the pedestrian did not react– 1 of them run (7 – which did not have the right of way) and 3 of them waited for the car to cross (123, 126, 167)
- In all 4 cases the vehicle did brake

PD_4a

A car intends to turn right at the junction, a pedestrian comes from the right at no crosswalk.



From IDIADA data: **n=6 + 2 assimilated**

Related this use case, there are only low severity cases. In all of them, the pedestrians behaviour observed are:

- The pedestrian crosses a crosswalk with red light.
- The pedestrian crosses without crosswalk or Pedestrian Street.
- Some pedestrian crosses near side from zebra but out of crosswalk.

From BME data: **n= 7**

7 cases belong to this use case.

- In all 7 cases the pedestrian had the right of way, in 5 cases the conflict happened in intersection with traffic lights where the involved vehicle and pedestrian had greens in the same time
- None of the pedestrian did not react– 1 of them run (45), 4 of them hesitated and/or waited for the car to cross (44, 50, 51, 59) and 1 of them hesitated then stepped back to the pavement (31)
- In 2 cases the vehicle did not brake and forced the pedestrian to not cross (31, 44)

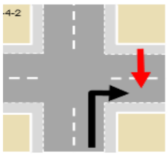
PD_4b

A car intends to turn right at the junction, a pedestrian comes from the left at a crosswalk.

From IFSTTAR data: **n=3**

In the 3 cases the vehicle slows down to give way to the pedestrian. The pedestrian has an absolute right of way (green light) while the driver has only a conditional right (green light but must yield if pedestrian).

In all cases the pedestrian looks towards the car before crossing and seems having taken it into account the car.



- In one case the pedestrian must speed to avoid the vehicle and even crosses in diagonal on the crosswalk to escape (121).
- In one case the pedestrian tows a trolley case on the crosswalk and has to deviate to avoid the vehicle which forces the passage. The pedestrian makes a gesture of irritation toward the vehicle, which passes too close (120).
- In the other case the pedestrian crosses in front of the vehicle without modifying his marching rhythm (122).

From IDIADA data: **n=1**

Just one case related to this use case.

- In this case the pedestrian crosses on a crosswalk but the light is red. The vehicle has absolute priority. (140)

From BME data: **n= 9**

9 cases belong to this use case.

- In 7 cases the pedestrian had the right of way, in 4 cases the conflict happened in intersection with traffic lights where the involved vehicle and pedestrian had greens in the same time
- None of the pedestrian did react nothing – 2 of them run (14, 43), 2 of them waited for the car to cross (92, 93), 2 of them hesitated then stepped back to the pavement (53, 132) and 2 of them changed their walking directions (30, 33)
- In 3 cases the vehicle did not brake and forced the pedestrian to not cross (92), to step back to the pavement (53) or to change the direction of walking (30)

4 CONCLUSION ON CONFLICT ANALYSIS

Conducting naturalistic observations in limited time is challenging, as these studies are time consuming at each step of the work.

The first objective was to collect and analyse a large amount of relevant conflicts between vehicles and VRU (pedestrians and cyclists). More than 2,000 hours of videos were recorded in Lyon, Barcelona and Budapest and allowed for extracting 602 conflicts. Nearly half of them belong to the use cases that have been identified within WP3 as being worth to be implemented in the demonstrators (UC_DEM).

Each of these conflicts was then fully annotated according to six sub-groups of parameters. They describe (1) the general environmental conditions of the conflict (light, precipitation, road surface, traffic density, etc.), (2) the infrastructure (layout, dedicated lanes, speed limit, etc.), (3) the characteristics of the VRU (type, equipment, etc.), (4) the encounter characteristics (visibility, right of way, yielding, conflict management, estimated impact point, etc.), (5) the intents of the VRU (head/torso orientation, gesture, flashing indicator), (6) kinematics and trajectories of both car and VRU.

Analyses performed on each use case provide descriptions of a battery of VRUs' behaviour when involved in a specific conflict that will help to identify the clues that can predict VRUs' behaviour in the near future.

Moreover this large range of information can be used to contribute to the specification of the use cases, and to calibrate the most representative cases that will be used for the test development.

Finally, the naturalist observation campaigns made available videos where lots of more situations could be extracted. This part of the project focused on conflict situations between vehicles and VRUs. New analyses are planned to provide information about typical situations. Kinematic data will be computed for example regarding cruise speeds for VRUs (pedestrians, cyclists) under normal traffic situations in WP5.

It is important to add that all descriptions of the conflicts and videos from some partners are available to partners who develop the demonstrator under the existence of a Non-Disclosure Agreement.

5 ANALYSES OF CYCLIST BEHAVIOUR PARAMETERS FROM INTENTION PREDICTION AND INFLUENCE OF ENVIRONMENT AND SCENARIO (TNO)

5.1 Introduction

For the acceptance of active safety systems that are being developed to prevent collisions with vulnerable road users it is important to have a minimum of false positives and false negatives in the collision prediction. In this project algorithms are developed and/or validated that contribute to this by means of adding movement pattern recognition to the detection of vulnerable road users, since not all detected vulnerable road users in a wide range of view will get in the collision risk zone of the car. Movement patterns should be selected that are consistent in the prediction of the intention of the vulnerable road user (stop, straight on, turn left, turn right) independent of the car-VRU scenario (VRU walking/cycling in front of car, VRU coming from right, VRU coming from left, etc.) or the environment (type of crossing), or the scenario and environmental influence should be taken into account as well.

The objective of TNO in T2.2 is to determine the influence of scene context on certain cyclist behaviour parameters based on available data sets. The following research questions were defined:

- How are behaviour parameters related to the intention of the cyclist?
- How does the environment affect the cyclist behaviour parameters?
- How does the car-cyclist scenario affect the cyclist behaviour parameters?

5.2 Methods

5.2.1 Dataset selection

In order to obtain the required information, datasets were selected that satisfied the following criteria:

- To determine the relationship between behaviour parameters and the intention of the cyclist, datasets should provide information about the same cyclist behaviour parameters for various cyclists.
- To determine the effect of the environment on the cyclist behaviour parameters, datasets should include the same car-cyclist scenario in different environments.
- To determine the effect of the car-cyclist scenarios, datasets should include different car-cyclist scenarios in the same environment.

Based on these criteria, two datasets were selected. These datasets both included information about the cyclist behaviour parameters velocity and pedalling. The two datasets are described in the subsections below.

5.2.2 Naturalistic cycling tests from the project CATS:

CATS is a project with many partners, coordinated by TNO, in which an assessment method for Cyclist AEB systems was developed, aiming at a EURO NCAP test protocol. One dataset of the CATS project includes naturalistic tests at a crossing with the cyclists coming from behind an obstruction entering a road with cars coming from the left side, the so called city crossing scenario. Figure 32 describes the naturalistic tests used in this study. These tests are further referred to as 'CATS tests'.

<table>
<tr>
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Tests from CATS project

Scenario: City crossing

Obstruction: Hedge

Cyclist lane: Exclusively for cyclists

Cyclists: Real, unaware of the tests

Location: Son, NL, crossing connects living area with busy village center

Traffic situation:

- Naturalistic
- Non-prioritised intersection
- Cyclist from right have right of way
- Cyclist give yield to traffic from right

Behaviour parameters:

- Velocity measured by means of a hidden radar at the opposite side of the road
- Stop pedalling recorded by a hidden camera

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Cyclist's direction indicated by yellow arrow

Cars direction indicated by red arrow

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Figure 32: Description of naturalistic cycling tests from CATS project.

5.2.3 Cycling tests from TNO internal project:

The TNO internal project aimed to get insight in behaviour parameters that can predict the cyclists' intention to be used for the development of future cyclist safety systems. The data from this project contains two car-cyclist scenario's; city crossing and city turning. Volunteer cyclists were asked to cycle at 15 km/h towards the crossing, and would meet the car at the crossing. Per test the volunteer cyclists got instructions to either stop, turn right, or go straight on before they started cycling. Because of safety reasons, the car driver always stopped before crossing the cyclist's way. Figure 33 describes the tests from the TNO internal project that were used in this study. These tests are further referred to as 'TNO tests'.

Tests from TNO internal project

Scenario's: City crossing and City turning

Obstruction: No

Cycling lane: On road, no separate cycling lane

Cyclists: 4 volunteers, aware of the situation

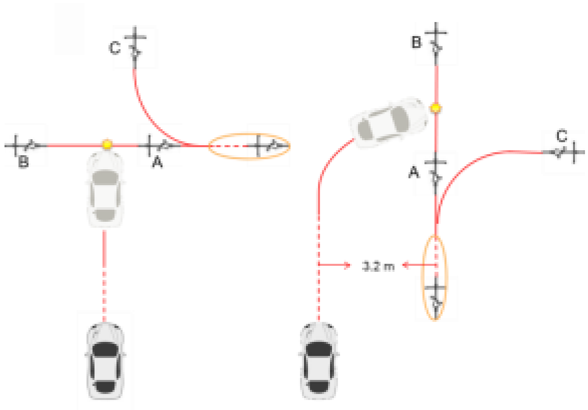
Location: TNO parking place, Helmond, NL, created crossing without traffic lights

Traffic situation:

- Non-prioritised intersection rules counted, but cyclist was always in the situation to have priority
- Cyclist instructed to stop, turn right, or go straight on before they left, but in their own way
- Car driver instructed to always stop before the cyclist's way

Behaviour parameters:

- Velocity measured by means of OXTS
- Pedalling frequency measured at the pedals



City crossing City turning

Figure 33: Description of cycling tests from TNO internal project.

5.3 Analyses

For the current study, the cyclist behaviour parameters velocity and pedalling and their relation to the cyclist's intention, as well as the effect of the car-cyclist scenario and of the environment on these behaviour parameters were analysed. Since the test data used for this study originated from different test set-ups of earlier performed tests, the datasets were not optimal for a full comparison. The scene of the CATS tests and the TNO tests vary in various ways (see Figure 32 and Figure 33), due to which it is not possible to exactly point the cause of differences in the behaviour parameters between the tests. Nevertheless, all comparisons that provided insight in the relationship between behaviour parameters (velocity and pedalling) and the intention of the cyclist (stop, turn right, go straight), the effect of the environment (with obstruction and naturalistic, without obstruction and predefined) as well as the effect of the car-cyclist scenario (city crossing, city turning) on the cyclist behaviour parameters were taken into account.

Before, the test data of the CATS tests could be compared to that of the TNO tests, the coordinates needed to be made similar. In the set-up of the CATS test, the point of interest was located at the point where the cars meet the cyclists at the intersection. Therefore, the origin of the coordinates was chosen at the middle of the intersection. In the TNO tests, the point of interest was at the point where the cyclist enters the crossing, with t=0s manually determined at this point. In order to make a correct comparison, data from the CATS project had to be adjusted to locate the point of interest at the beginning of the intersection, instead of in the middle. For this, an offset was defined as the distance from the beginning of the intersection to the middle of it, which corresponded to the width of the car lane, 1.5m. Once the offset was subtracted from all the CATS tests, t=0s corresponded with the beginning of the intersection, like in the TNO tests. Further, in the TNO tests, the frequency of pedalling was recorded at the bike. However, in the CATS tests the pedalling frequency was not measured at the bike, however from video analyses it was registered whether the cyclist stopped pedalling before the crossing or not. Therefore, in this study only the locations where stopped pedalling were compared in order to analyse the relationship with the intention of the cyclist.

To determine the relationship between behaviour parameters and the intention of the cyclists, the parameters velocity and pedalling from the TNO tests were analysed, and that of the city crossing scenario also compared to that of the CATS tests. The effect of the environment on the cyclist behaviour parameters was analysed by means of comparing the velocity and pedalling cyclist behaviour of the CATS tests to that of the TNO tests, both in the city crossing scenario. The main difference in the environments is that in the CATS tests there was an obstruction for the cyclists to see the cars coming from the left. Another difference in the CATS and TNO tests was that the CATS tests the situation was naturalistic, and in the TNO tests it was not. The effect of the car-cyclist scenario on the cyclist behaviour parameters was analysed by means of comparing the velocity and pedalling behaviour of the cyclists before entering the crossing in the city crossing scenario to that of the city turning scenario, both of the TNO tests.

5.4 RESULTS

The cyclist behaviour parameters velocity and pedalling measured in the CATS tests and in the TNO tests for the cyclists' intentions turning right, going straight on, and stopping are shown in Figure 34 to Figure 37. These figures show that the velocity as well as the position where they stopped pedalling before entering the crossing has a relationship with the cyclists' intention. In the TNO tests, it can be seen that the velocity typically decreases before turning right, the velocity does not change when going straight on, and the velocity considerably decreases when stopping. In the TNO tests, when turning right, cyclists mostly stop pedalling 16-1 m before entering the crossing, the distribution is rather spread. When going straight, cyclists mostly stop pedalling 5-1 m before entering the crossing. When stopping, cyclists stop pedalling 13-5 m before entering the crossing. Unlike in the TNO test, the figures of the CATS test show that the velocity decreases when turning right or when going straight in a similar way. This is probably caused by the blocked view, due to which the cyclists decreased their velocity to get a better view on the cars before turning right or crossing. In the CATS tests no data on the velocity was available for cyclists that stopped before crossing, since the data was lost because of the car passing in front of the radar. The position where stopped pedalling was not measured in the CATS tests. However, in the CATS tests it was recorded that 11 out of 13 stopped peddling when turning right, 23 out of 25 stopped peddling when going straight, and

15 stopped (and stopped pedalling). In the TNO tests all cyclists stopped pedalling before entering the crossing.

The effect of the environment in a city crossing scenario on the cyclist velocity is shown in Figure 34 for turning, and in Figure 35 for going straight on, when comparing the blue signals with the red signals. For turning right a similar decrease in cyclist velocity before entering the crossing is seen in both environments, however the CATS tests only contained data of 4 cyclists. For going straight on a decrease in cyclist velocity is seen in the CATS tests, but not in the TNO tests. The cyclists probably decreased their velocity, because of the obstructed view to the cars coming from left, although the cyclists had right way like in the TNO tests. In the TNO tests the cyclists had a good overview of the intersection.

The effect of the car-cyclist scenario on the cyclist velocity is shown in Figure 34 for turning, in Figure 35 for going straight on, and in Figure 36 for stopping when comparing the blue signals with the green signals. When turning, the velocity in general decreases more in the city turning scenario than in the city crossing scenario. This difference in behaviour might have been caused by the cyclists being more cautious, when a car is following the cyclist in the turn in the city turning scenario. When going straight on, the velocity in the city crossing scenario as well as in the city turning scenario didn't change. When stopping, the velocity in the city crossing scenario as well as in the city turning scenario decreases considerably in both car-cyclist scenarios. It looks like that for stopping the cyclist velocity decreases a bit faster in the city turning scenario than in the city crossing scenario, however there is also a lot of overlap in the cyclist velocity responses between the two scenarios.

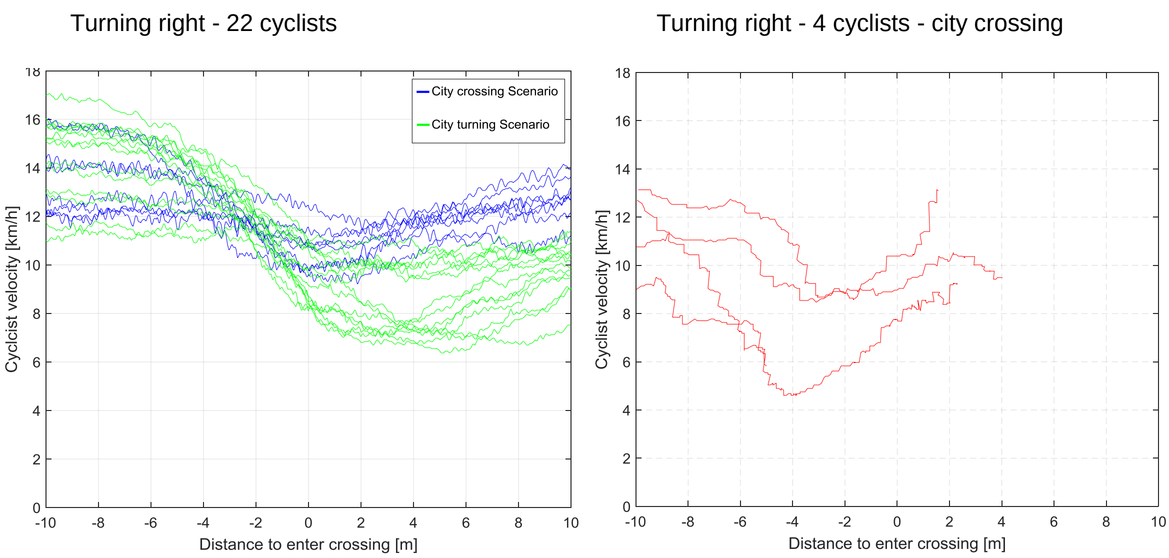


Figure 34: Cyclist velocity in TNO tests (left) and CATS tests (right) of cyclists that turn right.

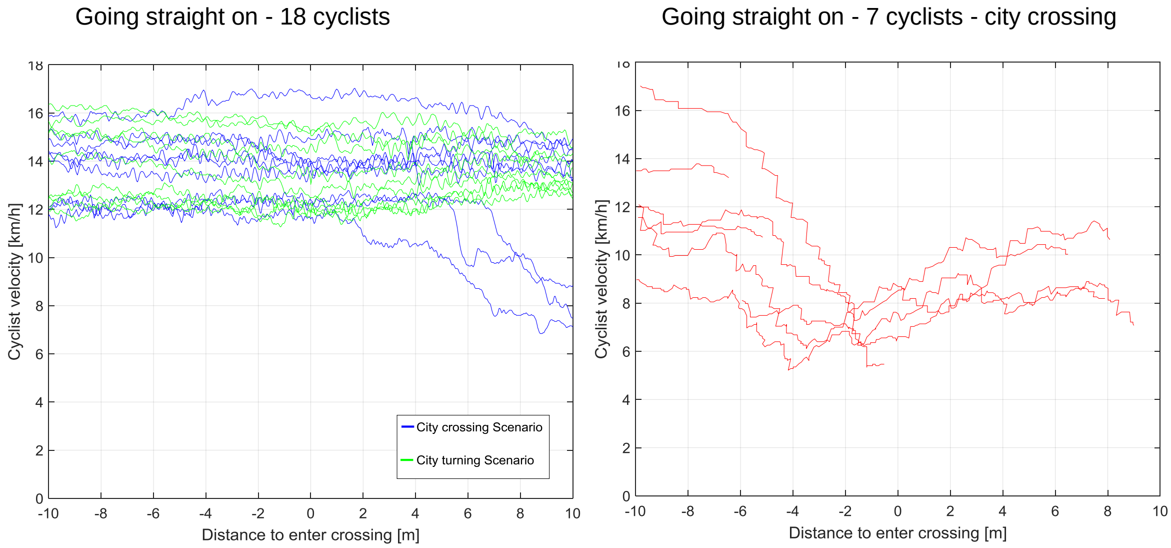


Figure 35: Cyclist velocity in TNO tests (left) and CATS tests (right) of cyclists that go straight on.

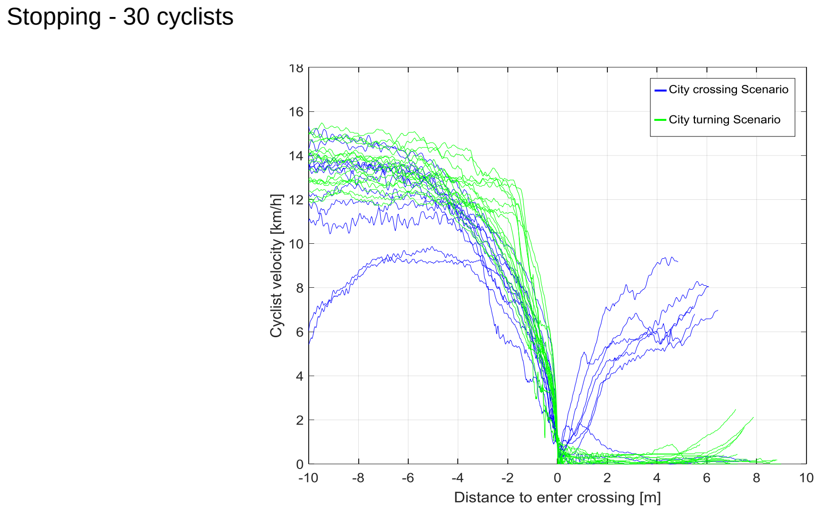


Figure 36: Cyclist velocity in TNO tests of cyclists that stop before the crossing.

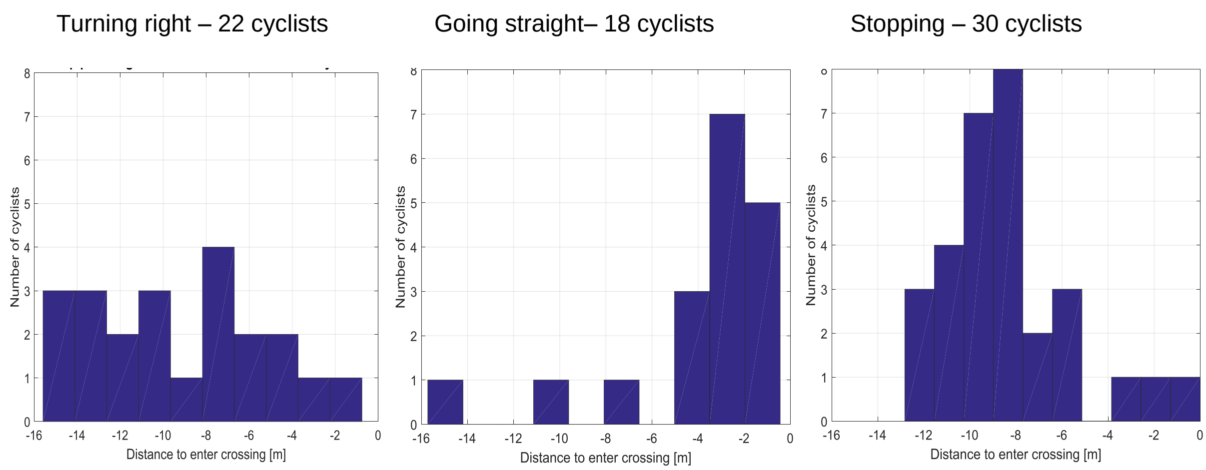


Figure 37: Cyclist position where stopped pedalling before entering the crossing in TNO tests.

5.5 Conclusions & Recommendations

The objective of this study was to determine the influence of scene context on certain cyclist behaviour parameters based on available data sets. The relationship between cyclist behaviour parameters velocity and pedalling and their intention was analysed as well as the effect of the environment and the car-cyclist scenario on these cyclist behaviour parameters using two existing data sets. From the analyses it was concluded that the cyclist velocity as well as the distance where they stopped pedalling before the crossing can give an indication for the cyclists' intentions (turn right, straight on, or stop). However, these parameters seem to be slightly affected by the car-cyclist scenario's, i.e. when turning right or stopping the cyclist velocity decreased more in a city turning scenario than in a city crossing scenario. Also, the environment can affect the cyclist behaviour, i.e. when going straight in a city crossing scenario with an obstruction at the left side, the cyclist velocity decreased before crossing, although the cyclists having right way, while they kept the same velocity when there is no obstruction.

It must be noted here that the cyclist behaviour in the test series of which the car-cyclist scenarios were predefined might be different from a naturalistic situation, although the cyclists were asked to stop, turn right or go straight on in their own way. However, we believe that their behaviour was not affected by the predefinition of the scenario, since all cyclists showed similar behaviour. For a thorough analysis of cyclist behaviour parameters for the prediction of their intention more data is needed, especially data measured at the bicycle in a natural environment.

6 CONCLUSION ON NATURALISTIC OBSERVATIONS

The Naturalistic Observations performed in the PROSPECT project include the data collection and analysis using observations from either infrastructure-mounted cameras at critical spots or from deployed on-board vehicles. Monitoring of hotspots for VRUs has been performed in different European cities (i.e. Barcelona, Lyon, Budapest). An additional study on cyclist's behaviour has been performed in Helmond.

The development of these studies will contribute to the improvement of the state-of-art knowledge about accident causation and facilitate a better understanding of potentially dangerous traffic situations with VRUs. In particular, it includes the identification of behavioural patterns that lead to such situations, from both VRU and driver perspective.

Additional to the accident analysis data on national and European level, Naturalistic studies will enable realistic modelling of VRU behaviour, including the identification of indicators that signal VRU intent. These results will provide important input to safety system development, to testing methodologies and tools in PROSPECT, as well as to future research projects.

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DISCLAIMER

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