

From Data to Road Safety Advancing Car-to-Pedestrian AEB Test Scenarios

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ABSTRACT

From 2026, Euro NCAP will expand their assessments, focusing on the robustness of active safety systems such as Autonomous Emergency Braking (AEB). The upcoming changes aim to better reflect real-world traffic situations. The VERDAS project supports the inclusion of robustness layers, with an emphasis on Vulnerable Road Users (VRUs), as studies show AEB effectiveness can be improved for that group. This paper uses real-world traffic data to identify relevant aspects—such as infrastructure elements and visual obstructions—within existing test scenarios.

Incorporating crash data from multiple sources, the study applied descriptive statistics, alignment across datasets, and in-depth analyses of pedestrian and vehicle trajectories, speed profiles, infrastructure elements, and obstructions.

Euro NCAP pedestrian test scenarios are performed under specific environmental conditions, which limit the variety of the real-world crashes covered. The 2026 robustness update has the potential to substantially mitigate this limitation.

The analysis showed that the most common pedestrian conflict situation—Straight Crossing Path (SCP)—accounts for a substantial portion of car-to-pedestrian crashes (52-69%), moderate to severe injuries (57-73%), and fatalities (63-82 %). Case-by-case crash data analyses revealed information about frequent obstructions and infrastructure elements in the road environment. Information extracted from crash data sources enabled identification of key SCP features, for use in enhanced test scenarios. While the findings provide a more realistic basis for test scenario development, limitations in dataset representativeness, technical feasibility and the careful evaluation of false vs. true positive AEB activations remain important considerations. Together, these insights — both findings and constraints — provide a foundation for refining test protocols to better reflect operational conditions and enhance AEB system effectiveness.

Keywords: ADAS, AEB, Pedestrian, Car-to-pedestrian crashes, Straight-crossing path, Pedestrian detection, Euro NCAP robustness, Pedestrian field data

INTRODUCTION

Retrospective Analyses of Effectiveness of AEB Systems in Car-to-VRU Accidents

Retrospective analyses of Car-to-Vulnerable Road User (VRU) accidents show a limited safety effect of Advanced Driver Assistance System (ADAS) [1]–[13]. Tests also indicate that system performance decreases as the traffic environment becomes more realistic, for example in the presence of additional road users and objects, variations in clothing and vehicle colors, as well as lighting and weather conditions [14] [15].

Today's physical rating scenarios are tested in greatly simplified and idealized conditions, which means that details in traffic environment and mechanisms are not captured [16]. These test scenarios only cover a subset of all real-world accident situations, even though the number of different test scenarios has increased substantially since the first ratings of driver assistance systems in 2014 [17]–[20]. Due to the simplifications of test scenarios, the performance of ADAS in these tests may not correspond to its performance in real-world traffic conditions. In order to improve the robustness of ADAS performance in real-life traffic environments, the test scenarios need to reflect real-world accident situations more accurately.

Definition of Test Protocol from Crash Data

Crash data statistics have supported the definition of test protocols for ADAS crash avoidance testing. Different European crash data sources were investigated to identify relevant crash scenarios that involved a passenger car, against VRUs or against other vehicles [21]–[25]. Some of these test protocols were included in assessments, such as Euro NCAP [26], which had periodic protocol updates (in 2014, 2016, 2018, 2020, 2023) reflecting some of these projects proposals.

Euro NCAP 2026 Protocol Update Introducing Robustness

Euro NCAP has identified limitations in its roadmap Vision 2030 [27] and is expanding the assessment of active safety measures, focusing on the robustness of systems such as Autonomous Emergency Braking (AEB). Previous protocol updates introduced new test scenarios based on crash frequency and severity. The upcoming changes in test scenarios aim to better mirror real-world conditions by introducing variability in key parameters, thereby enabling a more robust assessment of system performance and ensuring scenarios are more representative of real-world traffic situations. For the introduction 2026, Euro NCAP will limit it to one selected robustness layer (parameter) change to today's 2023 rating test scenario [28]. Thus, the possibility of covering all important mechanisms is limited. In the next Euro NCAP protocol update in 2029 [27], there is a possibility to include other relevant accident scenarios and the mechanisms behind them more realistically.

VERDAS project

The goal of the VERification methods for RObust DRiver AS sist System performance (VERDAS) project was to propose new or updated car-to-pedestrian test scenarios with robustness layers, to verify ADAS performance in a more real-world traffic environment. For this purpose, real-world traffic data was analysed to identify relevant aspects such as infrastructure/clutter (Euro NCAP definition section 5.2.1.2 in 2026 Crash Avoidance Frontal Collision protocol: Environments cluttered with objects such as urban furniture or secondary road users without fully obscuring the main target) and visual obstructions within existing test scenarios, which can be used for the proposal of new or updated car-to-pedestrian test scenarios with robustness layers. The VERDAS project has supported Euro NCAP with its findings and proposals for the robustness test scenarios in the Technical Bulletin CA 002 Verification Conditions for Robustness Layers [29].

For the VERDAS test scenario proposals towards 2026, the variations of robustness layers were chosen so that it would be technically feasible regarding repeatability and reproducibility assessment on test track. Physical tests were also performed in the project with three different systems on the market, to study the influence on the performance between base SCP test scenarios versus the proposed SCP robustness layer test scenarios. This part of the VERDAS project is not included in this paper, but the VERDAS End-of-project report [30] gives some examples of how the robustness layers affected the performance.

This paper, part of the VERDAS project, presents a real-world analysis of crash and observational data with a focus on the car-to-pedestrian Straight Crossing Path (SCP) pre-crash conflict situations, in which the car and pedestrian cross each other's paths on straight trajectories. The analysis was performed in two parts: descriptive statistics and case studies. The first part provides a general overview of the problem, while the second presents a detailed analysis of elements in SCP cases, which presence could potentially have an influence on the ADAS performance.

METHODS AND DATA SOURCES

This study utilized real-world crash and traffic data as input to the design of updated test scenarios. The study comprised two main components. First, descriptive crash statistics were presented to provide representative and relevant distributions of car-to-pedestrian conflict situations and overall pre-crash factors. Second, detailed case analysis was conducted to identify and exemplify potential crash-contributing factors that are often absent from aggregated crash data. Together, these complementary approaches offer both a broad overview and nuanced insights into underlying car-to-pedestrian crash factors.

The following datasets were used:

- **GIDAS**, the German In-Depth Accident Study, and the accompanying **Pre Crash Matrix (PCM)** cover crashes with at least one personal injury in Germany [31].
- **PAV**, the People Around the Vehicle crash database by If, covers car-to-VRU third-party liability insurance crashes reported in Sweden [32].
- The **Swedish Transport Administration Fatality Database (STA-F)** covers fatal crashes in Sweden [33].
- **STRADA**, the Swedish national accident database, covers police-reported crashes [34].
- **Viscando on-site traffic measurement data** covers details in the traffic flow in selected sites, including measurement and analysis details [35].
- **V_PAD**, the Volvo Cars Pedestrian Accident Database, covers Volvo car-to-pedestrian third-party liability insurance crashes reported in Sweden [36].
- **Volvo Cars fleet on-board data (VCC-Fleet)**, covers a fleet of ADAS-equipped Volvo cars worldwide [37].

Figure 1 provides an overview of the analysis; Table 1 summarizes the datasets used, along with the sample sizes. The presence of SCP situations within all car-to-pedestrian crashes was examined (1.1), and a descriptive analysis of SCP crashes (1.2) was performed. Reconstructed crashes, in-depth crash investigations, traffic measurements, and car fleet measurement data provided information about potential crash-contributing factors that are not consistently represented in aggregated crash data (2).

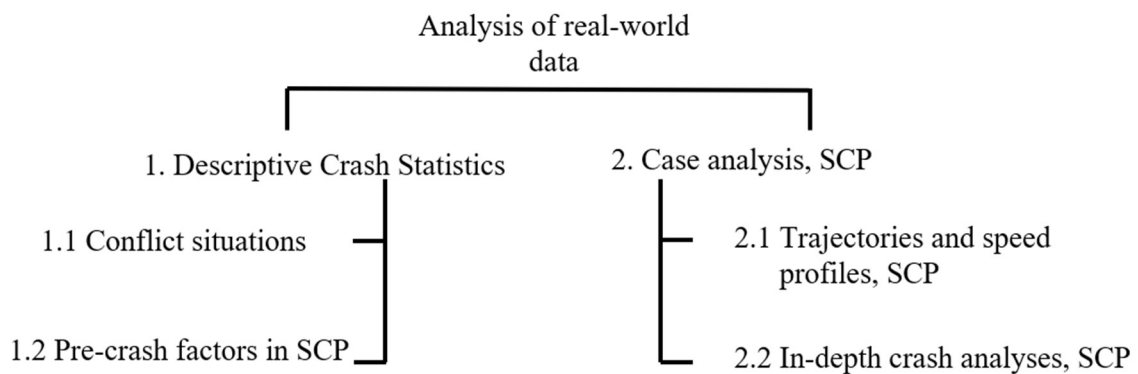


Figure 1. Overview of analysis. Numbers refer to sections in Results and to Table 1.

For the descriptive statistics (sections 1.1 and 1.2 in Figure 1); the data from PAV and STA-F were considered representative of their countries, respectively, due to their data collection process. Weighting factors were used to achieve representativeness for all police reported crashes in Germany for GIDAS [38].

The identification of relevant car-to-pedestrian SCP crashes used the Conflict Situation classification system [39-40] in PAV and STA-F. For GIDAS, SCP crashes were defined by the UTYP variable, so all UTYP 4XX cases were selected (except for specific pedestrian turning situations, defined by UTYPs 481, 482, 483 and 484) [41].

Crashes were grouped into aggregated pre-crash conflict situations: SCP, Car turning, Longitudinal, Reverse, Other/Unknown, see Appendix 1.

The analysis in 1.2 categorized key pre-crash factors that may influence crash occurrence: crash location, the presence of designated crossings, posted speed limits, the direction of the pedestrian, potential obstructions in the roadway, and light conditions. The category *Unknown* refers to cases where the relevant information was not recorded or could not be determined, while *Others* denote values that do not fit into any predefined category.

Detailed case analyses in 2.1 and 2.2 revealed crash-contributing factors that are often missing in aggregated crash data. The analysis of trajectories and speed profiles in 2.1 included GIDAS-PCM, and on-site measurement data from the Viscando dataset. Vehicle and pedestrian average speeds and accelerations from the two datasets were analyzed to understand speed at SCP situations, for pedestrians crossing from right and left, respectively, denoted as SCP-right and SCP-left. Viscando data also provided pedestrians' start position when stepping out on the road, relative to the pedestrian crossing centerline and pedestrians' movement direction over the street. The angle was measured relative to the direction of the pedestrian crossing, which is perpendicular to the road (i.e. pedestrian crossing the road perpendicular is 0 degree).

- From GIDAS-PCM, 471 car-to-pedestrian SCP crashes from accident years 2003-2018 with available pre-crash reconstructions were analyzed.
- To identify relevant traffic measurement sites for the Viscando dataset, a cluster analysis was performed based on crash data in PAV including the following parameters:
 - posted speed limit grouped (30/50/60+ kph),
 - the vehicle position relative to the road network at the time of the crash: approaching, within, or exiting an intersection, or on a road section not associated with an intersection/roundabout,
 - pedestrian direction (from left/right)

The results provided an overview of general locations with car-to-pedestrian SCP crashes, e.g., crashes adjacent to intersections in roads with posted speed limit 50 kph represent ~38% of all SCP car-to-pedestrian crashes, and crashes adjacent to intersections in roads with posted speed limit 30 kph represent ~8% of all SCP car-to-pedestrian crashes. The on-site traffic measurement sites were chosen after availability of measurement data, adjacent to 3- or 4-way intersections with high density of pedestrians and vehicles and without traffic lights or untypical infrastructure elements: the intersection Landøyvejen - Fekjan, Viken, Norway (GNSS coordinates: 59.858934, 10.493785), a pedestrian crossing at a 3-way road crossing with posted speed 50 kph, and intersection Högborgsgatan - Swedenborgsgatan, Stockholm, Sweden (GNSS coordinates: 59.315538, 18.064358), a 4-way intersection in a busy central area, with posted vehicle speed 30 kph. The top-views of the chosen sites with the trajectories of pedestrians and vehicles measured by Viscando, are provided in Figure 2. These sites are further on called Viken site and Stockholm site, respectively.

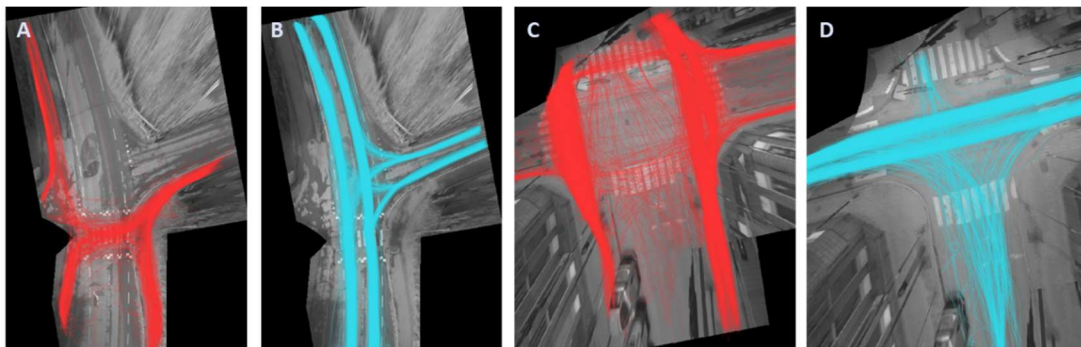


Figure 2.
Pedestrian and vehicle trajectories for the Viken site in Norway (A and B, respectively) and the Stockholm site in Sweden (C and D, respectively)

In-depth analyses of the SCP crashes in 2.2 using GIDAS-PCM, PAV, STA-F, STRADA, V_PAD, and VCC-Fleet provided information about details in the infrastructure and traffic situations that normally cannot be found in high-level crash databases. Cases from different non-random sampling procedures (see Table 1) were analysed. A moderate correlation was observed between the statistical datasets and the in-depth cases regarding pedestrians' approach direction (left versus right) and the presence of visual obstructions. Each case was examined to find parameters that were considered potential factors influencing the ADAS system's object detection and tracking performance. The following parameters were considered:

- Road layout (e.g., lanes, refuges, pedestrian crossings, pedestrian and bike lanes).
- Parking space along the road at pedestrian road entering location.
- Posts (presence, type, location, with or without sign).
- Stationary clutter elements that obstruct the view or form a non-ideal background (e.g., electrical cabinets, garbage bins, bollards, fences, buildings, vegetation).
- Position, speed, and trajectory of dynamic elements (e.g., moving cars, pedestrians, bicyclists).
- Temporary stand-still dynamic elements that obstruct the view or form a non-ideal background (e.g., vehicles stopped at red lights, parked cars and bicycles, stationary pedestrians).
- Glare and low sun.
- Impact location in relation to the above-mentioned elements.

GIDAS-PCM cases, n=35, included dynamic element information, such as trajectories and speed profiles up to five seconds before the crash happened. Additional GIDAS data, including digital images, provided information to elaborate on the context of the scenery, in terms of infrastructure clutter and obstruction elements. For PAV cases, n=28, photographs of the accident site were reviewed alongside information in insurance files, Nationell vägdatabas (NVDB) National Road Database in Sweden [42], and map services. Measurements were taken of a) the road layout, and b) distances from the collision point to nearby objects such as obstacles, buildings, parking areas, and vegetation; see example in Appendix 2.

For the STA-F analysis, n=24, photographs of the accident site were reviewed in conjunction with data reported by the police and detailed on-scene findings from the investigators. For STRADA, n=8, accident site photographs were reviewed alongside the simplified accident descriptions provided by the police. For V_PAD, n=96, the cases were digitized to provide vehicle and pedestrian pre-crash paths. Case summaries were prepared when map data provided additional information about the crash scene, such as road layout and objects present at the location. For VCC-Fleet, a subset of specifically annotated car-to-pedestrian SCP crashes from 2022–2024 was examined. This subset consisted of 33 crashes with stored ADAS camera images captured prior to the crash. No further sensor information has been used for the analysis.

Table 1.
Overview of datasets used and selection criteria with reference to Figure 1 and to sections in Results.

**For in-depth case analysis, different non-random sampling procedures were applied.*

DATASET	DATA SELECTION	DATA FROM (YEAR)	SAMPLE SIZE	ANALYSIS SECTION
GIDAS	Car-to-pedestrian crashes.	2003–2022	1976	1.1
Reconstructed two-participant crashes with known injury severity, December 2022 GIDAS release	Car-to-pedestrian SCP crashes.	2003–2022	1017	1.2
	Car-to-pedestrian SCP crashes.	2003-2018	35*	2.2
GIDAS_ PCM	Car-to-pedestrian SCP crashes.	2003-2018	471	2.1
	Car-to-pedestrian SCP crashes.	2003-2018	35*	2.2
PAV	Car-to-pedestrian crashes.	2008-2024	1573	1.1
	Car-to-pedestrian SCP crashes.	2019-2024	275	1.2
	Car-to-pedestrian SCP crashes, cars equipped with VRU-ADAS	2020-2023	19*	2.2
STA-F	Car-to-pedestrian SCP crashes.	2009-2016	79	1.2
			24*	2.2
STRADA	Car-to-pedestrian SCP crashes.	2010-2020	8*	2.2
V_PAD	Car-to-pedestrian SCP crashes.	2000-2020	21*	2.2
Viscando	Viken, Norway	2022	Cars: 48856, Pedestrians: 2199	2.1
	Stockholm, Sweden	2024	Cars: 38824, Pedestrians: 9089	
VCC-Fleet	Car-to-pedestrian SCP crashes, cars equipped with VRU-ADAS	2022-2024	33*	2.1 & 2.2

RESULTS

The results of the analysis are organized according to the diagram shown in Figure 1 and the column “Analysis Section” in Table 1.

Descriptive Crash Statistics (Section 1)

This section provides an overview of the descriptive statistics for the datasets and uses relevant parameters to summarize their main characteristics.

SCP out of all conflict situations (Section 1.1)

SCP is the situation with a higher share for all types of severities. A slight increase in share is observed when focusing on MAIS2+ injuries, compared to the full sample. This increase is more pronounced when focusing on fatalities where the share of SCP situations range between 63% and 82%.

*Table 2.
Conflict situations share in car-to-pedestrian crashes for SCP in comparison
with the Total for GIDAS, PAV, and STA-F*

			GIDAS (unweighted) n=2696 %	GIDAS (weighted) n=1975 %	PAV n=1573 %	STA-F n=79 %
Conflict situation	SCP	Total	69	52	53	-
		MAIS2+	73	57	61	-
		Fatal	82	63	68	71
	Turning	Total	16	16	12	
		MAIS2+	14	16	11	
		Fatal	4	6	5	
	Longitudinal	Total	2	3	8	
		MAIS2+	2	4	8	
		Fatal	2	3	8	
Reverse	Total	7	17	16		
	MAIS2+	7	14	14		
	Fatal	2	3	8		
Other/Unknown	Total	7	12	12	-	
	MAIS2+	5	9	6	-	
	Fatal	11	25	12	29	

Pre-crash factors in the SCP situation (section 1.2)

The table below (see Table 3) shows descriptive statistics for some pre-crash factors. It was observed that crashes occurred more commonly on roads with posted speed limits between 40 and 50 kph. The proportion of crashes occurring at designated crossings varied significantly between datasets. In GIDAS, more than half of the crashes happened at non-designated crossings, whereas in PAV, the majority occurred at designated ones. The most common VRU direction was from the right, with fatalities representing an even higher proportion in these situations. In the GIDAS dataset, most of the crashes happened in daylight. The PAV dataset shows a more balanced distribution between daylight and night/dusk/dawn. STA-F presents a slight increase in the share of fatalities happening at night, dusk, or dawn compared to daylight. The data also show that most cases (33% in GIDAS and 23% in PAV) occurred from the right without obstruction. Cases from the left without obstruction accounted for 22% in GIDAS and 17% in PAV. Those from the left with obstruction were less common (16% for GIDAS and 11% for PAV), and the shares were similar to those of the cases from the right with obstruction.

Table 3.
Pre-crash factors for SCP car-to-pedestrian crashes for GIDAS, PAV, and STA-F

		GIDAS n=1017 %	PAV n=275 %	STA-F n=79 %
Crash location	Before inters./roundabout	22	24	19
	In inters./roundabout	1	3	3
	After inters./roundabout	14	10	32
	No inters. Nor roundabout	60	47	33
	Other	3	6	0
	Unknown	0	11	14
Pedestrian crossing site (regardless of road segment type)	Designated for the VRU to cross	23	61	55
	Not designated for the VRU to cross	62	34	37
	Unknown	15	5	8
Posted speed limit	<= 30 kph	19	21	5
	40-50 kph	76	59	90
	>=60 kph	1	8	5
	Unknown	4	13	0
VRU direction	From left	39	29	35
	From right	58	42	65
	Unknown	3	30	0
Obstruction (for PAV: when VRU direction known)	From left with obst.	16	11	-
	From left without obst.	22	17	-
	From left, obst. unknown	-	13	-
	From right with obst.	25	26	-
	From right without obst.	33	23	-
	From right, obst. unknown	-	10	-
	Unknown	4	-	-
Light	Daylight	72	48	43
	Night/Dusk/Dawn	28	42	57
	Unknown	0	11	0

Case Analysis (Section 2)

This section presents results from case analyses, where detailed analyses were conducted on cases from different non-random sampling procedures.

Trajectories and speed profiles (Section 2.1)

The kinematics of the crash were studied using two datasets, GIDAS, and Viscando. Detailed information on speeds was divided into SCP cases with the pedestrian crossing from the right (SCP-right) and from the left (SCP-left). Table 4 shows the shares for the datasets.

Table 4.
Number of SCP crashes for GIDAS-PCM, and Viscando

	GIDAS-PCM	Viscando
SCP-right crashes	321	-
SCP-left crashes	150	-
All crossing directions	-	2 measurement locations

Vehicle mean speed profiles were analyzed to understand speed distributions from the GIDAS-PCM dataset's reconstructed time-history data. Table 5 summarizes the results for vehicle mean speeds. Viscando on-site traffic measurement data shows lower mean vehicle speeds (24 and 16 kph for 50 kph and 30 kph locations respectively). Figures with more detailed information can be found in Appendix 3.

Table 5.
Overview of kinematic parameters for the vehicle and the pedestrian in two different datasets, GIDAS-PCM, and Viscando.

		GIDAS-PCM		Viscando
Vehicle speed kph (mean +/-SD)	SCP right	2 s before collision	M=37.4(SD=14.4)	-
		1 s before collision	M=36.9 (SD=13.9)	-
		At collision	M=33.15 (SD=13.8)	-
	SCP left	2 s before collision	M=43.8 (SD=16.1)	-
		1 s before collision	M=43.3 (SD=15.7)	-
		At collision	M=38.7 (SD=16.2)	-
	All crossing directions	2 s before zebra crossing	-	Viken: M=24.0 (SD=8.2) Stockholm: M=16.2 (SD=7.6)
		At zebra crossing center	-	Viken: M=22.2 (SD=7.61) Stockholm: M=16.7 (SD=6.3)
	Vehicle deceleration m/s ² (mean +/-SD)	SCP right	Max deceleration	M=-1.4 (SD=2.1)
SCP left		Max deceleration	M=-1.8 (SD=2.2)	-
Pedestrian speed kph (mean +/-SD)	SCP right	2 s before collision	M=7.0 (SD=4.4)	-
		1 s before collision	M=7.0 (SD=4.4)	-
		At collision	M=7.1 (SD=4.6)	-
	SCP left	2 s before collision	M=7.1 (SD=5.4)	-
		1 s before collision	M=7.3 (SD=5.6)	-
		At collision	M=7.4 (SD=5.7)	-
	All crossing directions	2 s before zebra crossing	-	Viken: M=5.4 (SD=1.6) Stockholm: M=4.7 (SD=1.3)
		At zebra crossing center	-	Viken: M=5.7 (SD=1.9) Stockholm: M=5.3 (SD=1.2)

On-site traffic measurement data: movement direction and position of pedestrians stepping onto the road.

The trajectories of the pedestrians at the Viken site were analyzed, and Figure 3 shows the spread of angles and positions of the pedestrians, moving from left (eastbound) and right (westbound) directions (left and right images, respectively). The distributions demonstrate large spreads in terms of positions (reaching far beyond the extent of the painted pedestrian crossing lines) and directions, with a clear tendency to go from the side of the crossing towards its middle. This tendency is more pronounced for the pedestrians moving from the left (walking eastbound direction). For pedestrians moving from the right (walking westbound direction), there is a sidewalk along the secondary road that aligns with the pedestrian crossing, so they tend to walk closer to the middle of the crossing at a smaller angle.

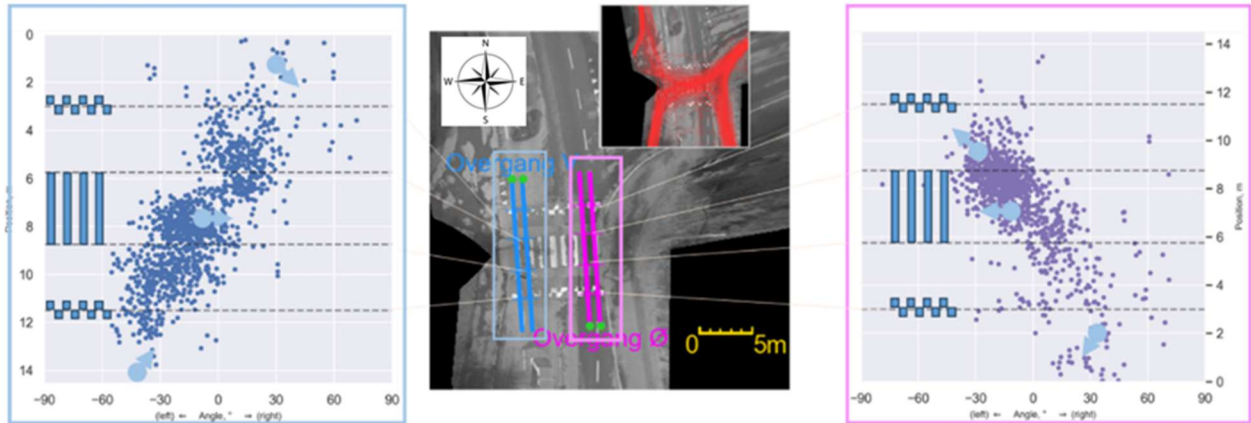


Figure 3.

Pedestrian position and angle distribution at the start of the pedestrian crossing. Middle image: Top-view of the crossing with recorded trajectories. Left and right images: Position vs. angle scatter plots for pedestrians from the left (walking eastbound direction) and from the right (walking westbound direction), respectively.

On-site traffic measurement data: speed profiles for interacting pedestrians and vehicles

At the Stockholm site, detailed dynamics were studied for both pedestrians and vehicles as they approached the crossing, with a focus on how speed varied in the different types of crossing events with and without interactions between car and pedestrian at the crossing. The distributions of approach speed of both pedestrians and cars are shown in Figure 4. The crossing events were sorted into: 1) pedestrian crossing when there were no approaching cars (no interaction, Fig. 4A); 2) car crossing when there were no pedestrians approaching (no interaction, Fig. 4D); 3) interaction between a pedestrian and a vehicle, where the vehicle gives way to the pedestrian (Figs. 4B and E); and 4) interaction where pedestrian waits to let the vehicle pass (Figs. 4C and F).

The speed profiles indicate that:

- pedestrians tend to reduce speed before the intersection. Those who let cars pass reduce the speed most, as expected.
- pedestrians accelerate just before stepping into the intersection, which is different from typical test cases.
- pedestrians tend to cross the road at a constant speed (90% within the interval of 4.5kph–6.5kph), which is slightly higher than normal walking speed.
- when a vehicle gives way to a pedestrian, the latter tends to have a higher speed (median around 6 kph) compared to pedestrians who let the vehicle go first (5.5 kph).
- some pedestrians run across the road when crossing before the car, with speeds reaching 8 kph.

Overall, the speed profiles of both pedestrians and vehicles exhibit location- and situation-dependent dynamics, with pronounced non-uniform speed profiles.

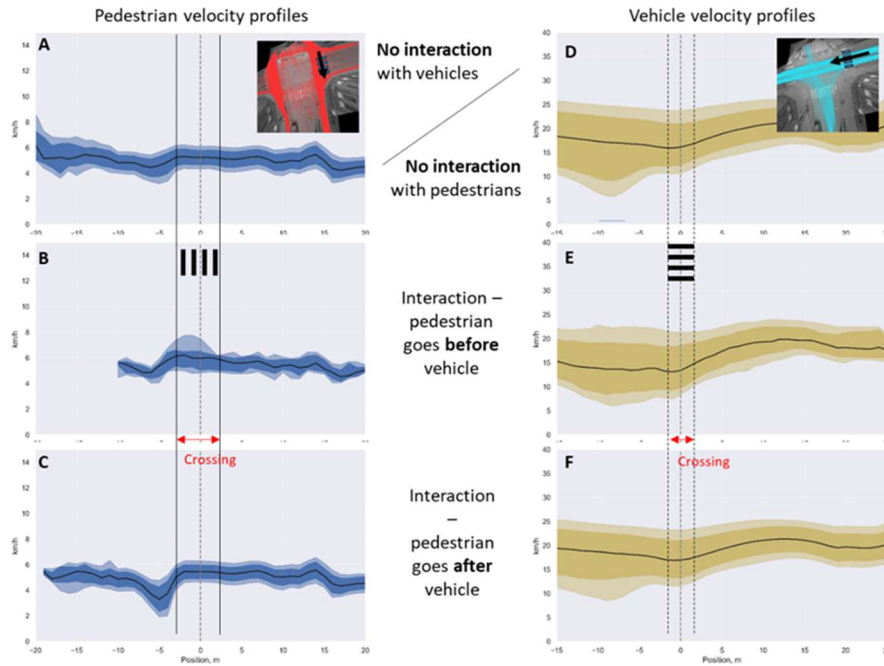


Figure 4

Speed as a function of distance to the middle of the intersection for pedestrians and vehicles at the Stockholm site. Pedestrian and vehicle directions are shown on insets. Black lines: median speed; dark-colored regions: 25th to 75th speed percentile; light-colored regions: 5th to 95th speed percentile.

In-depth analysis (Section 2.2)

Table 6 presents a data summary of the presence of infrastructure/clutter elements and obstructions from the in-depth analyses of crashes. In the few cases with no infrastructure or clutter elements, the accident scenario could be described as similar to current physical verification test scenarios, which are clean and idealized. However, most cases include one or more infrastructure and clutter elements or/and obstructions.

The most common infrastructure and clutter elements were different types of posts, which could be seen in almost all cases. These could be grouped into three categories based on post thickness: streetlight post (diameter approx. 23 cm), traffic light post (diameter approx. 12 cm), and traffic signpost (diameter approx. 7 cm). In almost all cases, there were multiple posts in the field of view for the sensor systems. Other less common elements were fences, guard rails, electrical cabinets, garbage bins, and rows of bollards. In around half of the cases, visibility was totally or partially obstructed, just before the pedestrian stepped out in front of the vehicle, based on witness statement or analysis of the event from the vehicle's ADAS field of view. The most common cases were pedestrians walking out from behind vehicles that were parked or temporarily stopped in adjacent lanes. Buildings and hedges close to the road were also found to obstruct the view, although less frequently.

The presence of other VRUs at the time of the crash was demonstrated by images recorded on camera for the VCC-Fleet dataset and based on witness statements for the other datasets. It can be seen in the VCC-Fleet data that there are other VRUs between 0 to 7 meters from the pedestrian in around one fifth of the accidents.

Table 6.
The presence of infrastructure/clutter elements and obstruction in the in-depth case analyses

Number of cases	GIDAS PCM n=35	PAV n=19	STA-F n=24	STRADA n=8	V_PAD n=21	VCC- Fleet n=33
<u>Infrastructure /Clutter</u>						
Yes	24	18	24	8	18	32
Type of Infrastructure/Clutter <i>(there can be more than one per case)</i>						
<u>On the side the pedestrian crossing from:</u>						
Post (single)	10	0	3	1	1	1
Posts (multiple)	10	18	19	6	16	30
Bollards	3	0	1	0	1	8
Fences & Guard rails	1	4	4	3	1	6
Electrical cabinet, Garbage bin, etc.	2	5	5	1	1	4
<u>Other VRUs 0–7m from the pedestrian:</u>						
VRUs	4	0	3	1	2	6
<u>Obstruction</u>						
Yes	18	12	13	5	9	10
Type of Obstruction						
Moving/Stopped vehicles	10	6	2	2	4	8
Parked vehicles	5	0	3	1	2	1
Building	0	6	1	0	0	0
Vegetation (Trees & Hedges)	3	0	1	0	2	0
Sign posts, Fences	0	0	6	2	1	1

DISCUSSION AND LIMITATIONS

The results aimed first to provide a preliminary understanding of the frequency of different conflict situations in car-to-pedestrian crashes and then to focus on the most relevant category with respect to frequency and injuries. Further details observed from real-world data were then investigated.

The similarities observed between the German and Swedish datasets (Table 2) suggest that key patterns in car-to-pedestrian conflict situations are consistent across national contexts. In particular, SCP scenarios dominate in both datasets. This finding has also been reported in similar figures [43]. The third dataset, STA-F, focuses exclusively on fatal crashes, but the figures for the three datasets are similar. Previous studies have already described the high proportion of fatal crashes in vehicle-to-pedestrian crossing situations [44-45].

The results obtained from GIDAS display both weighted and unweighted values. The unweighted results are aligned with those of previous studies using GIDAS unweighted data [46]; the weighted ones show that car-to-pedestrian SCPs are overrepresented in the dataset while the reversing and other conflicts are underrepresented. The GIDAS weighted data for SCP corresponds better with PAV data than the GIDAS unweighted data.

The SCP car-to-pedestrian crash results displayed in Table 3 indicate that crashes occurring outside intersections represent the largest group for the GIDAS and PAV datasets, while crashes have a higher frequency around intersections for the STA-F dataset. Additionally, crashes where the posted speed limit is 40–50 Kph are also common, which supports findings from previous studies [47-48]. Among the factors for which differences were identified, the presence of a designated crossing was particularly relevant for Swedish datasets; however, in GIDAS this factor appeared to be less relevant. A previous study using GIDAS data has already shown that non-designated crossing areas are more frequently associated with car-to-pedestrian crashes [46].

The analysis of descriptive crash statistics provides a useful overview of which car-to-pedestrian conflict situations are more common, as well as which key factors are most relevant. However, additional details about the context of the

crash are needed, which cannot be obtained in statistical databases but require in-depth analysis. Previous studies have emphasized the fact that detailed analysis of crashes using in-depth data can support a better understanding of the crash situation [49-50]. It has been suggested that national crash statistics should be complemented by in-depth analysis [51]; following this approach, Section 2 focused on a smaller set of cases, which could provide more insights into the crashes.

The descriptive statistics results revealed that designated crossings had a higher share in Swedish datasets, and although they had a smaller presence in GIDAS, a relevant share of cases was still identified. This finding suggests that there is a need to understand further what happens at designated crossings.

The analysis of case-by-case crash data helped identify how infrastructure elements can play a role in these car-to-pedestrian SCP situations, where multiple poles were consistently present in the analyzed cases. Not only were traffic light poles often present, but so was vertical signage used to inform drivers about pedestrian crossing areas. Previous studies [52] suggested various measures such as increasing the number of signs or reinforcing existing ones, including islands or refuges, to highlight the presence of infrastructure elements in designated crossing areas, which still represent a big proportion for pedestrian crashes. Therefore, we suggest the inclusion of such elements in future test protocols, which aim to cover real-world crash situations. Appendix 4 includes some examples of test protocol proposals from the VERDAS project.

Additionally, as descriptive crash statistics showed the importance of obstruction elements in car-to-pedestrian crashes. Further details about these elements could be identified from the case-by-case studies, which showed the importance of moving and stopped vehicles as visual obstructions. This observation is hard to capture, as those vehicles are not usually directly involved in the crash. Some of these stopped/parked vehicles are already captured by existing protocols, such as the Euro NCAP CPNCO (Car-to-Pedestrian Nearside Child Obscured) scenario [53]. However, situations where the vehicles are on the opposite side, or where pedestrians appear between them, also seem relevant, although existing protocols fail to capture them.

The Viscando on-site traffic measurement data from two locations analyzed in this article shows lower mean vehicle speeds (24 and 16 kph for 50 kph and 30 kph locations respectively), which is presumably since all vehicles' speeds were considered - compared to only vehicles involved in critical events in GIDAS-PCM data. The measurement shows (figure 3) also that a considerable number of pedestrians take shortcuts when crossing the road, leading to a large spread of positions and angles, and that this behavior is tightly connected to the layout of sidewalks. Since the measurements are from a limited number of locations. Additional measurements at different locations would limit the influence of possible location- and situation-dependent dynamics and would support an increased understanding of how different factors influence the speed, position, and angle variations.

When adding these elements to future test protocols, it must be understood how challenging the perception of these elements is for current vehicle systems, which need to predict the behavior of pedestrians continuously; these obstructions or infrastructure elements pose a perception challenge that can limit the time available for the system to be triggered.

Limitations

Wide variety of data sources

The datasets in this paper range from detailed case-by-case analyses to descriptive statistics.

The descriptive statistics are based on crash data from Germany and Sweden, providing a solid basis for these two national contexts, but no data from other parts of Europe were included.

The case study was not designed to be representative. Rather, its purpose was to enable an in-depth examination of real-world crash locations and to document context-specific infrastructural and situational details that are typically not captured in aggregate analyses. The cases were chosen to ensure sufficient variability and richness in the observed features. This approach supports hypothesis generation and the identification of potentially relevant parameters. The overall relevance and generalizability should be systematically assessed in future studies. The in-depth case analyses are based on German and Sweden case data except for the VCC-Fleet case data that also include other countries, mainly from Europe.

Using multiple datasets brought additional challenges, since they are generally coded using their own definitions, which makes it hard to find commonalities. For example, in GIDAS the conflict situation is defined from the variable UTYP, and where PAV and STA use the Conflict Situation classification system [39-40].

Technical feasibility of implementing the identified elements

Testing limitations

The elements identified from the case studies include a wide variety of infrastructure/clutter elements. Incorporating these elements and layouts from real traffic environment would support bringing more realism to a test protocol, thereby more accurately identifying the ADAS' actual performance in the real world. However, performing physical testing with all the identified elements would considerably increase the test effort, which raises the possibility of virtual testing. However, since the identified elements could challenge the perception performance of the evaluated systems, sophisticated physical sensor models that can replicate the performance of actual sensors would be required (including combinations such as fusion systems). This approach is still under development, but there are already world-wide initiatives aiming to tackle this challenge, e.g. [54]. While virtual methods are being developed, physical testing remains an intermediate solution; some of the identified elements, such as the ones related to infrastructure and obstruction shown in Table 6, can be realized in test-track environments. Although this approach results in a more simplified definition of real-world traffic environment, it will still contribute more realism to the tested scenarios.

Stepwise approach

Beyond this aspect, the identified elements, alongside other elements not evaluated in this article, such as weather conditions, could be considered. However, the implementation of such elements in a test protocol would require a stepwise approach to quantify the effect of individual elements and make the testing and assessment more efficient.

Evaluation of false vs. true positive activations

Another aspect which needs to be considered with the implementation of the identified elements in a test environment is the expected vehicle performance vs. the driver's intention.

CONCLUSION

This paper presents an analysis of SCP car-to-pedestrian crashes, using datasets with different level of granularity, from two different countries, Germany and Sweden, with the scope to identify enhanced future test scenarios which are closer to real world crashes. While the representativeness among datasets varies, the relevance is first the identification of the relevant conflict situation as well as environmental factors, from the descriptive statistics, ensuring that those situations and elements are representative of real-world crashes in those countries, according to their sampling methods. The usage of case-by-case analysis allows us to understand practical examples of how these environmental factors are like in real-world crashes.

The analysis revealed that car-to-pedestrian straight crossing path situations were the most common in the analyzed datasets. In the German dataset, the crashes most often occurred at non designated pedestrian crossings, with a high proportion of crashes occurring outside defined intersections and a similar distribution of cases regardless of whether an obstruction was present. In the Swedish datasets, crashes were more prone to occur at a designated pedestrian crossing and for the fatal accidents often in or around defined intersections/roundabouts. These findings highlight the need for a deeper investigation into the circumstances of such events. Where case-by-case analysis first provided insights into the kinematics of the participants involved, supported with on-site traffic measurement data about pedestrian behavior. Lastly, a more detailed case-by-case analysis of in-depth datasets allowed to identify relevant infrastructure elements—such as light posts—as well as contextual factors like the presence of multiple pedestrians and types of obstructions, including vehicles, either moving, stopped, or parked.

While this work provides relevant insights, it should be considered that the proposals of test scenarios must always be based on elaborated justification from descriptive statistics and their relevance to real-world, rather than biased by case-by-case selection, that lack significant representation in crash statistics and in the associated injuries.

Based on this analysis, proposals for enhanced test scenarios of car-to-pedestrian crossing situations which reflect the findings from real-world crashes have been elaborated. The proposals have supported Euro NCAP in the creation of Euro NCAP's Technical Bulletin CA002 Verification Condition for Robustness Layers [29]. Contributing to the goal of reflecting a more realistic environment in real-world crash situations more accurately than in existing test protocols. Euro NCAP will continue the development of updating the test scenarios to better mirror real-world conditions for the European market. For the Chinese market CATARC will do a similar update 2027 to its China-NCAP and other NCAPs is likely to follow. Since each NCAPs need to base the updates on the relevant field data, infrastructure, traffic rules etc. for their specific market. The question is how much might be possibly used globally.

Further work on the technical feasibility of implementing the proposed test scenarios is preferably done in a stepwise approach. To better understand the effect of individual environmental elements on ADAS performance, as well as a necessary consideration of test limitations and evaluation of false versus true positive activations.

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REFERENCES

- [1] Kullgren, A. Amin, K, Tingvall, C. (2023) Effects on crash risk of automatic emergency braking systems for pedestrians and bicyclists. Proceedings of the 27th International Technical Conference on the Enhanced Safety of Vehicles (ESV). Paper number 23-0114.
- [2] Amin, K., Kullgren, A., & Tingvall, C. (2025) Effects of automatic emergency braking systems to reduce risk of crash and serious injuries among pedestrians and bicyclists. *Traffic Safety Research*, 9, e000085. doi:10.55329/nbj7880
- [3] Cicchino, J. B. (2023), 'Effects of a bicycle detection system on police-reported bicycle crashes', 27th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Yokohama, Japan, 3–6 April 2023. [40] MICA ref (which can be used as reference?)
- [4] Cicchino, J. B. (2022), 'Effects of automatic emergency braking systems on pedestrian crash risk', *Accident Analysis & Prevention*, 172, 106686.
- [5] Cicchino, J. B. (2022), 'Effects of automatic emergency braking systems on pedestrian crash risk', *Accident Analysis & Prevention*, 172, 106686.
- [6] Lesie, P., F. Léopold, C. Chauvel, V. Hervé, S. Cuny (2015), 'Implication of children in road accidents in France in 2011', 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Gothenburg, Sweden, 8–11 June 2015, https://www-esv.nhtsa.dot.gov/Proceedings/24/files/24ESV_000418.PDF.
- [7] Leslie, A. J., R. J. Kiefer, C. A. Flannagan, S. H. Owen, B. A. Schoettle (2022), 'Analysis of the Field Effectiveness of General Motors Model Year 2013-2020 Advanced Driver Assistance System Features', University of Michigan Transportation Research Institute, <https://deepblue.lib.umich.edu/bitstream/handle/2027.42/171916/UMTRI-2022-2.pdf>. UMTRI 2022-2
- [8] Isaksson-Hellman, I., M. Lindman (2023), 'Estimating the crash reducing effect of Advanced Driver Assistance Systems (ADAS) for vulnerable road users', *Traffic Safety Research*, 4, 000036.
- [9] Isaksson-Hellman, I. Lindman, M. (2019) Real-world evaluations of driver assistance systems for vulnerable road users based on insurance crash data in Sweden. Proceedings of the 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV). Paper number 19-0300
- [10] Maria C. Rizzi, Khabat Amin, Johan Strandroth, Simon Sternlund, Rikard Fredriksson, Anders Kullgren (2024), The safety effect of increased pedestrian protection, autonomous emergency braking for pedestrians and bicyclists on passenger cars, and speed management. *Traffic Safety Research*, 6, e000046
- [11] PARTS, (2022), 'Real-world Effectiveness of Model Year 2015-2020 Advanced Driver Assistance Systems', Partnership for Analytics Research in Traffic Safety, https://www.mitre.org/sites/default/files/2022-11/pr%2022-3734-PARTS-real-world-effectiveness_model-year-2015-2020-advance-driver-assistance-systems_0.pdf. 22-3734
- [12] Spicer, R., A. Vahabaghaie, D. Murakhovsky, G. Bahouth, B. Drayer, S. St Lawrence (2021), 'Effectiveness of Advanced Driver Assistance Systems in Preventing System-Relevant Crashes', *SAE International Journal of Advances and Current Practices in Mobility*, 3(4), 1697–1701.
- [13] Wakeman, K., M. Moore, D. Zuby, L. Hellinga (2019), 'Effect of Subaru eyesight on pedestrian-related bodily injury liability claim frequencies', 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Eindhoven, the Netherlands, 10–13 June 2019, <https://www-esv.nhtsa.dot.gov/Proceedings/26/26ESV-000265.pdf>.
- [14] Charlebois, D. Anctil, B. Dube, S. Saleh, A. Pierre, G. Chirila, V. Nahimana, F. (2023) The ideal vulnerable road user – a study of parameters affecting VRU detection. Proceedings of the 27th International Technical Conference on the Enhanced Safety of Vehicles (ESV). Paper number 23-0104
- [15] Rahman, T. Liu, A. Cheema, D. Chirila, V. Charlebois, D. (2023) ADAS Reliability against Weather Conditions: Quantification of Performance Robustness. Proceedings of the 27th International Technical Conference on the Enhanced Safety of Vehicles (ESV). Paper number 23-0306.
- [16] Euro NCAP (2024) Euro NCAP AEB_LSS VRU Test Protocol version 4.5.1 Feb 2024. <https://www.euroncap.com/en/for-engineers/protocols/vulnerable-road-user-vru-protection/>
- [17] Schram, R. Williams, A. van Ratingen, M. (2013) Implementation of Autonomous Emergency Braking (AEB), The next step in Euro NCAP's safety assessment. In: Proceedings of the 23rd International Technical Conference on the Enhanced Safety of Vehicles (ESV). Paper number 13-0269. FFI Fordonsstrategisk Forskning och Innovation | <https://ffisweden.se/en> 16 Application FFI autumn 2025
- [18] Schram, R. Williams, A. van Ratingen, M. Ryrberg, S. Sferco, R. (2015) Euro NCAP's first step to assess Autonomous Emergency Braking (AEB) for Vulnerable Road Users. In: Proceedings of the 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV). Paper number 15-0277.
- [19] Schram, R. (2019) Euro NCAP's First step towards scenario-based assessment by combining Autonomous Emergency Braking and Autonomous Emergency Steering. Proceedings of the 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV). Paper number 19-0128.

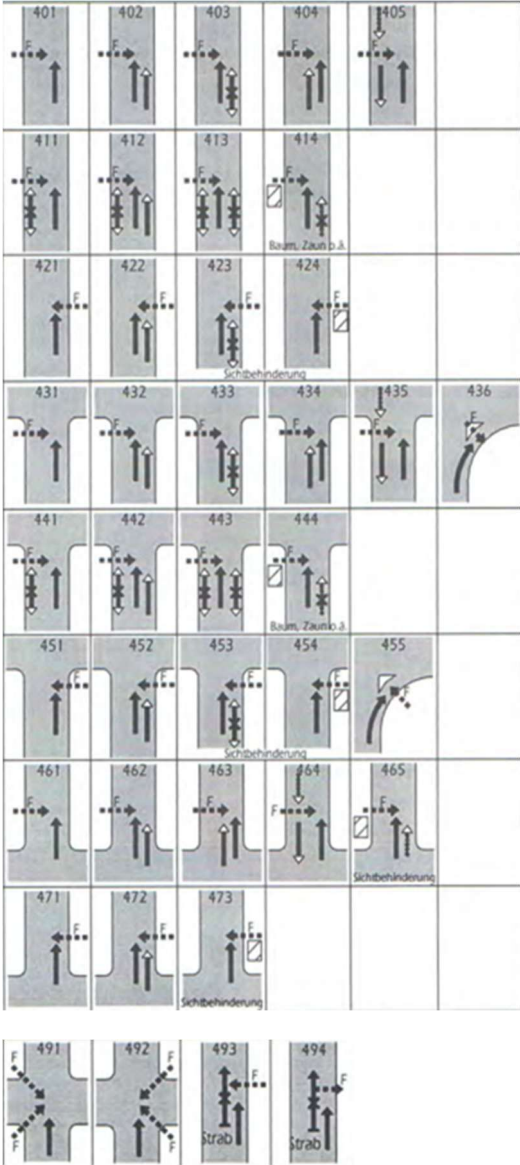
- [20] Damon, P-M. Garcia, A. Palao, A. (2023) Euro NCAP's First step towards rider safety with new Car-to Motorcyclist scenario. Proceedings of the 27th International Technical Conference on the Enhanced Safety of Vehicles (ESV). Paper number 23-0209.
- [21] Edwards et al. 2014. D1.4 Proposal for test and assessment protocol for pedestrian pre-crash systems. AsPeCCS project. European Commission.
- [22] Jeroen Uittenbogaard, Carmen Rodarius, Olaf Op den Camp. 2016. TNO 2014 R11594 CATS Deliverable 1.2: CATS car-to-cyclist accident scenarios.
- [23] Stoll et al. 2016. D3.1 The addressed VRU scenarios within PROSPECT and associated test catalogue. European Commission
- [24] Wish et al. 2019. ESV. Car-to-car accidents at intersections in Europe and identification of Use Cases for the test and assessment of respective active vehicle safety systems
- [25] Brookes et al. 2019. MUSE project Deliverable 1.1 Accident Data Study
- [26] Euro NCAP Assessments Protocols <https://www.euroncap.com/media/80156/euro-ncap-acb-lss-vru-test-protocol-v451.pdf>
- [27] Euro NCAP (2022). Euro NCAP Vision 2023, A safer Future for Mobility. Euro NCAP 2030 Roadmap. <https://cdn.euroncap.com/media/74468/euro-ncap-roadmap-vision-2030.pdf>
- [28] Euro NCAP (2025). Euro NCAP 2026 Crash Avoidance Frontal Collisions Protocol version 1.1 October 2025, section 4.2.2. p.60, <https://www.euroncap.com/media/91710/euro-ncap-protocol-crash-avoidance-frontal-collisions-v11.pdf>
- [29] Euro NCAP (2025). Euro NCAP 2026 Technical Bulletins Crash Avoidance CD 002 Verification Conditions for Robustness Layers. <https://www.euroncap.com/media/91714/ca-002-verification-conditions-for-robustness-layers-v11.pdf>
- [30] Petersson, M et al. VERDAS End-of-project report, Available online at [Verification methods for Robust Driver Assist System performance \(VERDAS\) | Vinnova](#)
- [31] A. Schubert and M. Eng, Standardized pre-crash-scenarios in digital format on the basis of the VUFO simulation, 2013.
- [32] I. Isaksson-Hellman, "A study of bicycle and passenger car collisions based on insurance claims data," *Annals of Advances in Automotive Medicine.*, vol. 56, pp. 3-12, 2012.
- [33] Kullgren, A., Stigson, H., Ydenius, A., Axelsson, A., Engström, E., & Rizzi, M. (2019). The potential of vehicle and road infrastructure interventions in fatal bicyclist accidents on Swedish roads—What can in-depth studies tell us? *Traffic Injury Prevention*, 20(sup1), S7–S12. <https://doi.org/10.1080/15389588.2019.1610171>
- [34] C. Howard and A. Linder, "Review of Swedish experiences concerning analysis of people injured in traffic," VTI notat 7A-2014; Diariennr: 2013/0487-8.3, 2014.
- [35] Viscando, <https://viscando.com/>, 2025. [Online].
- [36] M. Lindman, L. Jakobsson and S. Jonsson, "Pedestrians interacting with a passenger car; a study of real world," in IRCOBI, Krakow, 2011.
- [37] Varghaei, A. Dehghani, S., (2022) Analyzing the override strategy for collision avoidance functions. Matser's thesis [CSE 22-29 Varghaei Dehghani.pdf](#)
- [38] Ding, C., Rizzi, M., Strandroth, J., Sander, U., Lubbe, N., Motorcycle injury risk as a function of real-life crash speed and other contributing factors, *Accident Analysis & Prevention*, Volume 123, 2019, Pages 374-386, ISSN 0001-4575, <https://doi.org/10.1016/j.aap.2018.12.010>.
- [39] Lindman, M., Jonsson, S., Jakobsson, L., Karlsson, T., Gustafson, D., Fredriksson, A., (2015). Cyclists interacting with passenger cars; a study of real-world crashes. International Research Council on the Biomechanics of Injury, 1-12.
- [40] Klug, C., Christoph, L., Schachner, M., Rizzi, M., Grumert, E., Davidse, R., Heinzl, P., Iancovici, S., Wågström, L., Lindman, M., Thomson, R., Linder, A. (2020). Current and future accident and impact scenarios for pedestrians and cyclists, Deliverable 4.1. of the H2020 project VIRTUAL.
- [41] GDV (2016). *Unfalltypen-Katalog, Leitfaden zur Bestimmung des Unfalltyps (in German)*. Available online at <https://www.udv.de/resource/blob/80022/89b4d80028aacf8cab649d3a3c6157a0/unfalltypenkatalog-data.pdf>
- [42] Nationell vägdatabas (NVDB), National Road Database, Swedish Road Administration, <https://www.nvdb.se>
- [43] European Commission (2021) Road safety thematic report – Pedestrians. European Road Safety Observatory. Brussels, European Commission, Directorate General for Transport.
- [44] How safe is walking and cycling in Europe? PIN Flash Report 38, ETSC, 2021.
- [45] ITF (2012), Pedestrian Safety, Urban Space and Health, OECD Published. [Pedestrian Safety, Urban Space and Health \(EN\)](#)
- [46] Balint et al, 2021. D2.6 USE CASE DEFINITIONS AND INITIAL SAFETY-CRITICAL SCENARIOS. SAFE-Up deliverable. European Commission

- [47] Juozėvičiūtė, D.; Grigonis, V. Evaluation of Exclusive Pedestrian Phase Safety Performance at One-Level Signalized Intersections in Vilnius. *Sustainability* 2022, 14, 7894. <https://doi.org/10.3390/su14137894>
- [48] Md Jamil Ahsan, Mohamed Abdel-Aty, Ahmed S. Abdelrahman, Evaluating the safety impact of mid-block pedestrian signals (MPS), *Accident Analysis & Prevention*, Volume 210, 2025, 107847, ISSN 0001-4575, <https://doi.org/10.1016/j.aap.2024.107847>.
- [49] Marianna Imprialou, Mohammed Quddus, Crash data quality for road safety research: Current state and future directions, *Accident Analysis & Prevention*, Volume 130, 2019, Pages 84-90, ISSN 0001-4575, <https://doi.org/10.1016/j.aap.2017.02.022>.
- [50] LN Wundersitz. 2012. An analysis of young drivers involved in crashes using in-depth crash investigation data. University of Adelaide.
- [51] Jonas Krampe, Mirko Junge IRC-24-125. 2024. Enhancing Data in National Crash Statistics using an In-depth Study. IRCOBI conference, 2024.
- [52] Ying Chen 1, Yi Tian 1,* , Zhaoheng Ouyang 1, Jiaxun Zhu 1 Editor: Nik Hisamuddin Nik Ab Rahman2 Influence of road environmental factors on traffic accidents involving vulnerable road users through negative binomial models, 2025 Feb 13;20(2):e0317601. doi: [10.1371/journal.pone.0317601](https://doi.org/10.1371/journal.pone.0317601)
- [53] Euro NCAP Test Protocol – AEB/LSS VRU systems Implementation 2023 v4.5.1 February 2024. <https://www.euroncap.com/media/80156/euro-ncap-aeb-lss-vru-test-protocol-v451.pdf>
- [54] Kuzumaki, S., Inoue, H. Development of Driving Intelligence Validation Platform (DIVP®) for ADS Safety Assurance, January 2023 DOI:[10.1007/978-3-031-11112-9_2](https://doi.org/10.1007/978-3-031-11112-9_2), In book: Road Vehicle Automation 9 (pp.13-22)

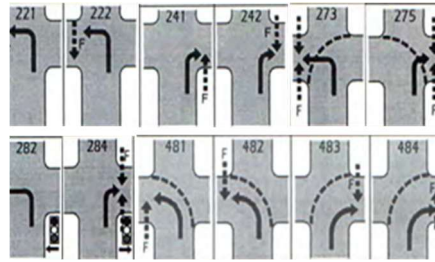
APPENDIX 1.

This Appendix describes how each conflict situation for the used datasets under Table 1 has been categorized. The pictograms correspond to the definitions of UTYP under [39] and for PAV-STA under [37]-[38].

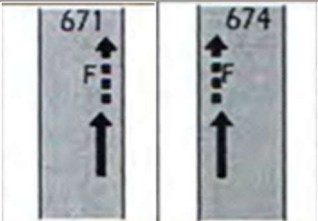






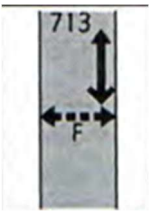




































Table A1. Categorization of conflict situations in the datasets.

Conflict situation	GIDAS - UTYP	PAV-STA																					
<p>SCP (Straight Crossing Path)</p>		<table border="1"> <tbody> <tr> <td data-bbox="959 633 1066 712"></td> <td data-bbox="1070 633 1161 712">SCPvr_{oo}</td> <td data-bbox="1166 633 1390 712">Straight Crossing Path, VRU from right, initially from Opposite Direction</td> </tr> <tr> <td data-bbox="959 719 1066 797"></td> <td data-bbox="1070 719 1161 797">SCPvr_{sd}</td> <td data-bbox="1166 719 1390 797">Straight Crossing Path, VRU from right, initially from Same Direction</td> </tr> <tr> <td data-bbox="959 804 1066 882"></td> <td data-bbox="1070 804 1161 882">SCPvr</td> <td data-bbox="1166 804 1390 882">Straight Crossing Path, VRU from right</td> </tr> <tr> <td data-bbox="959 889 1066 967"></td> <td data-bbox="1070 889 1161 967">SCPvl_{oo}</td> <td data-bbox="1166 889 1390 967">Straight Crossing Path, VRU from left, initially from Opposite Direction</td> </tr> <tr> <td data-bbox="959 974 1066 1052"></td> <td data-bbox="1070 974 1161 1052">SCPvl_{sd}</td> <td data-bbox="1166 974 1390 1052">Straight Crossing Path, VRU from left, initially from Same Direction</td> </tr> <tr> <td data-bbox="959 1059 1066 1137"></td> <td data-bbox="1070 1059 1161 1137">SCPvl</td> <td data-bbox="1166 1059 1390 1137">Straight Crossing Path, VRU from left</td> </tr> <tr> <td data-bbox="959 1144 1066 1223"></td> <td data-bbox="1070 1144 1161 1223">SCPvu</td> <td data-bbox="1166 1144 1390 1223">Straight Crossing Path, VRU from unknown direction</td> </tr> </tbody> </table>		SCPvr_{oo}	Straight Crossing Path, VRU from right, initially from Opposite Direction		SCPvr_{sd}	Straight Crossing Path, VRU from right, initially from Same Direction		SCPvr	Straight Crossing Path, VRU from right		SCPvl_{oo}	Straight Crossing Path, VRU from left, initially from Opposite Direction		SCPvl_{sd}	Straight Crossing Path, VRU from left, initially from Same Direction		SCPvl	Straight Crossing Path, VRU from left		SCPvu	Straight Crossing Path, VRU from unknown direction
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	SCPvl	Straight Crossing Path, VRU from left																					
	SCPvu	Straight Crossing Path, VRU from unknown direction																					

Car Turning



	LT/OD	Left Turn, VRU from Opposite Direction
	LT/OD_{LD}	Left Turn, VRU from Opposite Direction, initially from left direction
	LT/OD_{RD}	Left Turn, VRU from Opposite Direction, initially from right direction
	LT/SD	Left Turn, VRU from Same Direction
	LT/SD_{LD}	Left Turn, VRU from Same Direction, initially from left direction
	LT/SD_{RD}	Left Turn, VRU from Same Direction, initially from right direction
	LT/RD	Left Turn, VRU from Right Direction
	LT/LD	Left Turn, VRU from Left Direction
	LT/UD	Left Turn, VRU from Unknown Direction
	RT/OD	Right Turn, VRU from Opposite Direction
	RT/OD_{LD}	Right Turn, VRU from Opposite Direction, initially from left direction
	RT/OD_{RD}	Right Turn, VRU from Opposite Direction, initially from right direction
	RT/SD	Right Turn, VRU from Same Direction
	RT/SD_{LD}	Right Turn, VRU from Same Direction, initially from left direction
	RT/SD_{RD}	Right Turn, VRU from Same Direction, initially from right direction
	RT/RD	Right Turn, VRU from Right Direction
	RT/LD	Right Turn, VRU from Left Direction
	RT/UD	Right Turn, VRU from Unknown Direction

<p>Longitudinal</p>		<table border="1"> <tr> <td data-bbox="957 168 1069 257"></td> <td data-bbox="1069 168 1165 257">Oncoming</td> <td data-bbox="1165 168 1442 257">Driving Straight Ahead, VRU from Opposite Direction</td> </tr> <tr> <td data-bbox="957 257 1069 387"></td> <td data-bbox="1069 257 1165 387">SD</td> <td data-bbox="1165 257 1442 387">Driving straight ahead, VRU from Same Direction</td> </tr> </table>		Oncoming	Driving Straight Ahead, VRU from Opposite Direction		SD	Driving straight ahead, VRU from Same Direction																																	
	Oncoming	Driving Straight Ahead, VRU from Opposite Direction																																							
	SD	Driving straight ahead, VRU from Same Direction																																							
<p>Reversing</p>		<table border="1"> <tr> <td data-bbox="957 448 1069 526"></td> <td data-bbox="1069 448 1165 526">REVvr</td> <td data-bbox="1165 448 1442 526">Car reversing straight, VRU from Right</td> </tr> <tr> <td data-bbox="957 526 1069 604"></td> <td data-bbox="1069 526 1165 604">REVvs</td> <td data-bbox="1165 526 1442 604">Car reversing straight, VRU standing still</td> </tr> <tr> <td data-bbox="957 604 1069 683"></td> <td data-bbox="1069 604 1165 683">REVvl</td> <td data-bbox="1165 604 1442 683">Car reversing straight, VRU from Left</td> </tr> <tr> <td data-bbox="957 683 1069 761"></td> <td data-bbox="1069 683 1165 761">REVvu</td> <td data-bbox="1165 683 1442 761">Car reversing straight, VRU from Unknown direction</td> </tr> <tr> <td data-bbox="957 761 1069 840"></td> <td data-bbox="1069 761 1165 840">REVRvr</td> <td data-bbox="1165 761 1442 840">Car reversing and turning Right, VRU from Right</td> </tr> <tr> <td data-bbox="957 840 1069 918"></td> <td data-bbox="1069 840 1165 918">REVRvs</td> <td data-bbox="1165 840 1442 918">Car reversing and turning Right, VRU standing still</td> </tr> <tr> <td data-bbox="957 918 1069 996"></td> <td data-bbox="1069 918 1165 996">REVRvl</td> <td data-bbox="1165 918 1442 996">Car reversing and turning Right, VRU from Left</td> </tr> <tr> <td data-bbox="957 996 1069 1075"></td> <td data-bbox="1069 996 1165 1075">REVRvu</td> <td data-bbox="1165 996 1442 1075">Car reversing and turning Right, VRU from Unknown direction</td> </tr> <tr> <td data-bbox="957 1075 1069 1153"></td> <td data-bbox="1069 1075 1165 1153">REVLvr</td> <td data-bbox="1165 1075 1442 1153">Car reversing and turning Left, VRU from Right</td> </tr> <tr> <td data-bbox="957 1153 1069 1232"></td> <td data-bbox="1069 1153 1165 1232">REVLvs</td> <td data-bbox="1165 1153 1442 1232">Car reversing and turning Left, VRU standing still</td> </tr> <tr> <td data-bbox="957 1232 1069 1310"></td> <td data-bbox="1069 1232 1165 1310">REVLvl</td> <td data-bbox="1165 1232 1442 1310">Car reversing and turning Left, VRU from Left</td> </tr> <tr> <td data-bbox="957 1310 1069 1388"></td> <td data-bbox="1069 1310 1165 1388">REVLvu</td> <td data-bbox="1165 1310 1442 1388">Car reversing and turning Left, VRU from unknown direction</td> </tr> <tr> <td data-bbox="957 1388 1069 1547"></td> <td data-bbox="1069 1388 1165 1547">REVO</td> <td data-bbox="1165 1388 1442 1547">Car reversing, Other scenario</td> </tr> </table>		REVvr	Car reversing straight, VRU from Right		REVvs	Car reversing straight, VRU standing still		REVvl	Car reversing straight, VRU from Left		REVvu	Car reversing straight, VRU from Unknown direction		REVRvr	Car reversing and turning Right, VRU from Right		REVRvs	Car reversing and turning Right, VRU standing still		REVRvl	Car reversing and turning Right, VRU from Left		REVRvu	Car reversing and turning Right, VRU from Unknown direction		REVLvr	Car reversing and turning Left, VRU from Right		REVLvs	Car reversing and turning Left, VRU standing still		REVLvl	Car reversing and turning Left, VRU from Left		REVLvu	Car reversing and turning Left, VRU from unknown direction		REVO	Car reversing, Other scenario
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<p>Other</p>	<p>Other car to pedestrian not matching above definitions</p>	<table border="1"> <tr> <td data-bbox="957 1547 1069 1668">DoorL</td> <td data-bbox="1069 1547 1442 1668">Car occupant on driver side is about to leave the car and the VRU crashes into the door being opened</td> </tr> <tr> <td data-bbox="957 1668 1069 1769">DoorR</td> <td data-bbox="1069 1668 1442 1769">Car occupant on passenger side is about to leave the car and the VRU crashes into the door being opened</td> </tr> <tr> <td data-bbox="957 1769 1069 1877">Other</td> <td data-bbox="1069 1769 1442 1877">Other</td> </tr> </table>	DoorL	Car occupant on driver side is about to leave the car and the VRU crashes into the door being opened	DoorR	Car occupant on passenger side is about to leave the car and the VRU crashes into the door being opened	Other	Other																																	
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Other	Other																																								

APPENDIX 2. Illustration of in-depth information collection for crashes in PAV for 2.2, using a fictive crash case.

For each case analysis, the aim was twofold; 1) to anonymize case descriptions and 2) to express details of the infrastructure and surrounding environment as datapoints, in relation to the paths of both vehicles and pedestrians. Photographs of the accident site and information in insurance files were revisited.

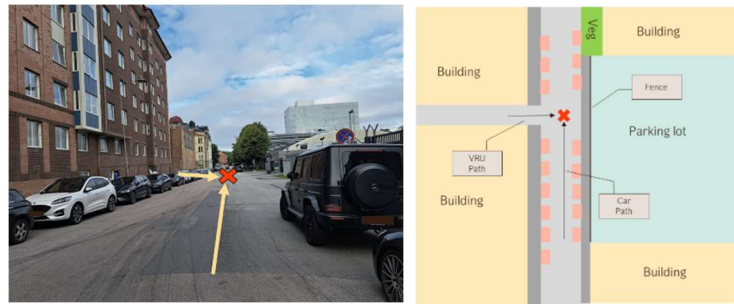


Figure A1. Photo and outline sketch from accident location.

Measurements were taken of
a) the road layout, and
b) distances from the collision point to nearby objects such as obstacles, buildings, parking areas, and vegetation. This approach provided a clear overview of traffic elements and potential view visual obstructions.

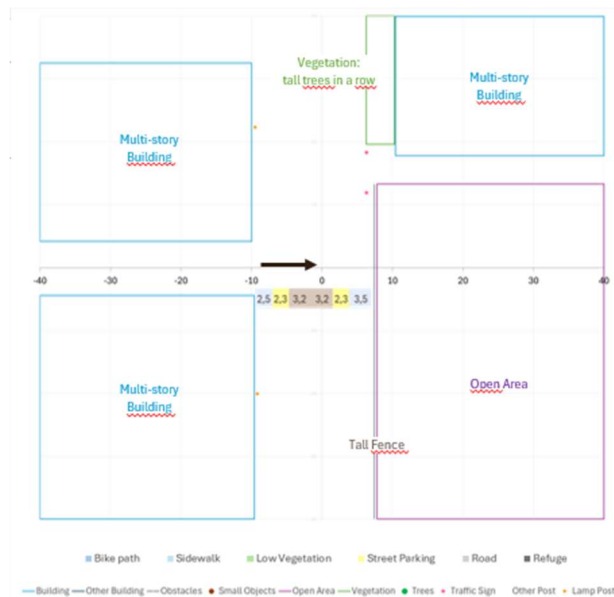


Figure A2. Drawing of the road layout and infrastructure at the accident location.

APPENDIX 3. VEHICLE AND PEDESTRIAN SPEED PROFILE GRAPHS.

In this appendix, instead of the nomenclature of SCP-right and SCP-left, the terms Far-side and Near-side are used, as one of the datasets, containing data from both left hand and right-hand drive vehicles.

Far-side would correspond to SCP-left for left hand driven vehicles and SCP-right for right hand drive vehicles

Near side would correspond to SCP-right for left hand driven vehicles and SCP-left for right hand drive vehicles.

GIDAS-PCM data: Vehicle Mean Speed Profile, Far-side and Near-side.

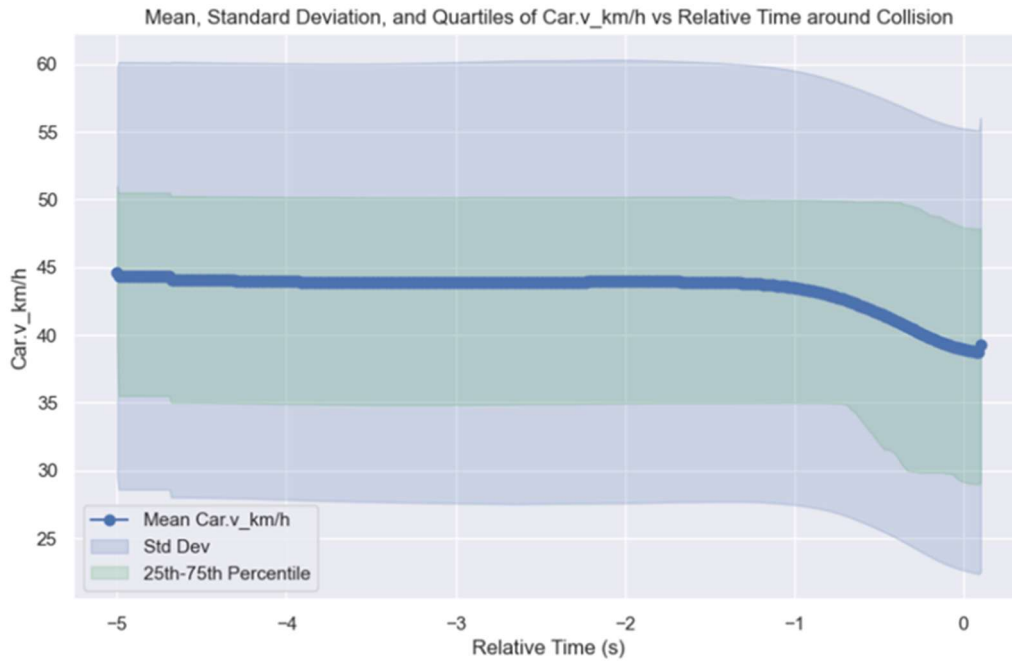


Figure A3. Far-side mean speed profiles from GIDAS-PCM (n=168).

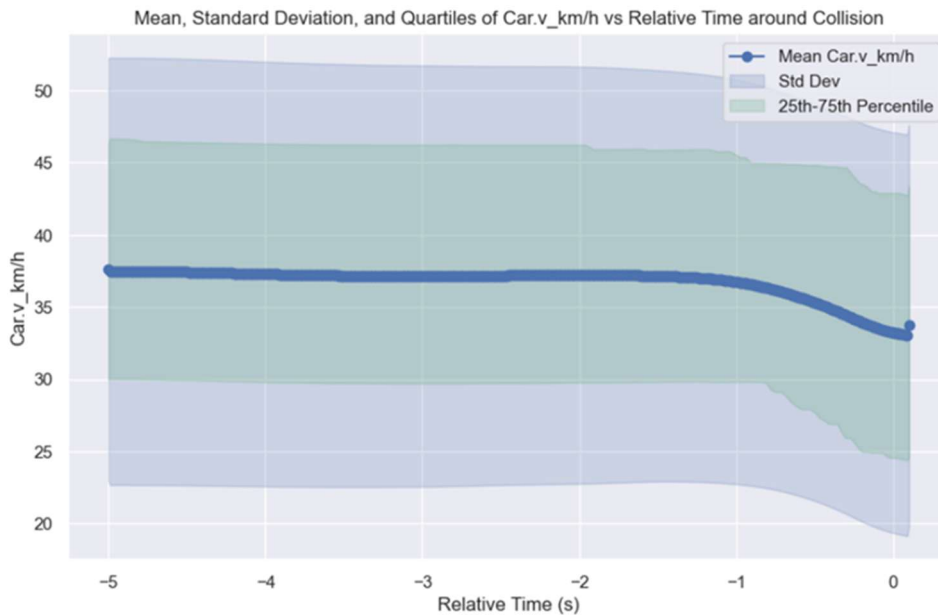


Figure A4. Near-side mean speed profiles from GIDAS-PCM (n=363).

GIDAS-PCM data, Vehicle Mean Deceleration Profile, Far-side and Near-side.

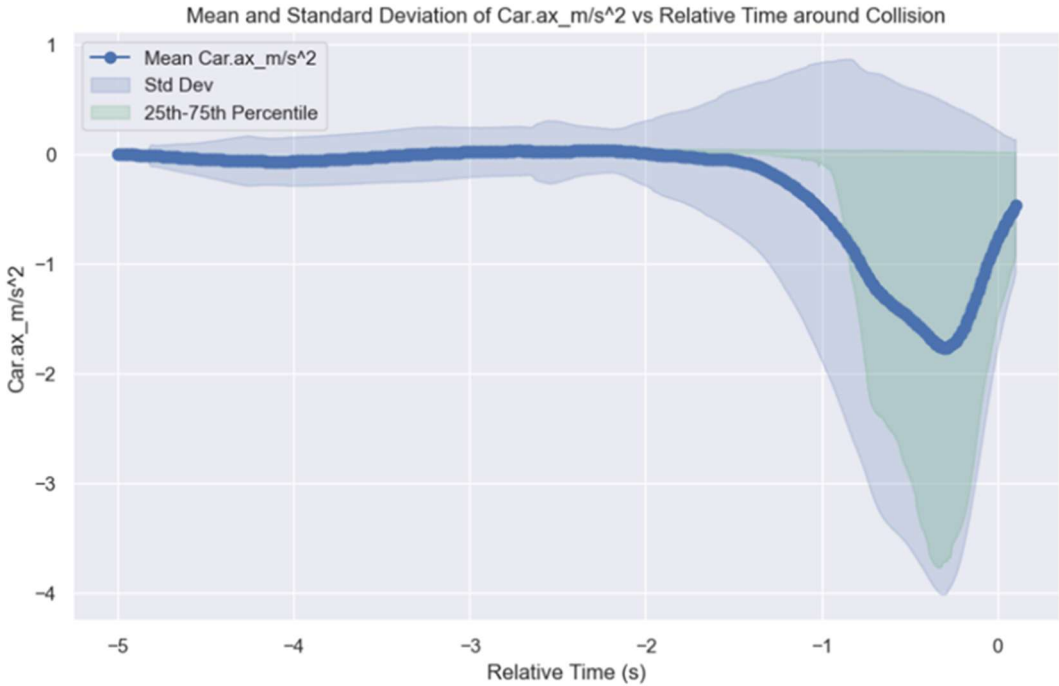


Figure A5. Far-side mean deceleration profiles from GIDAS-PCM (n=168).

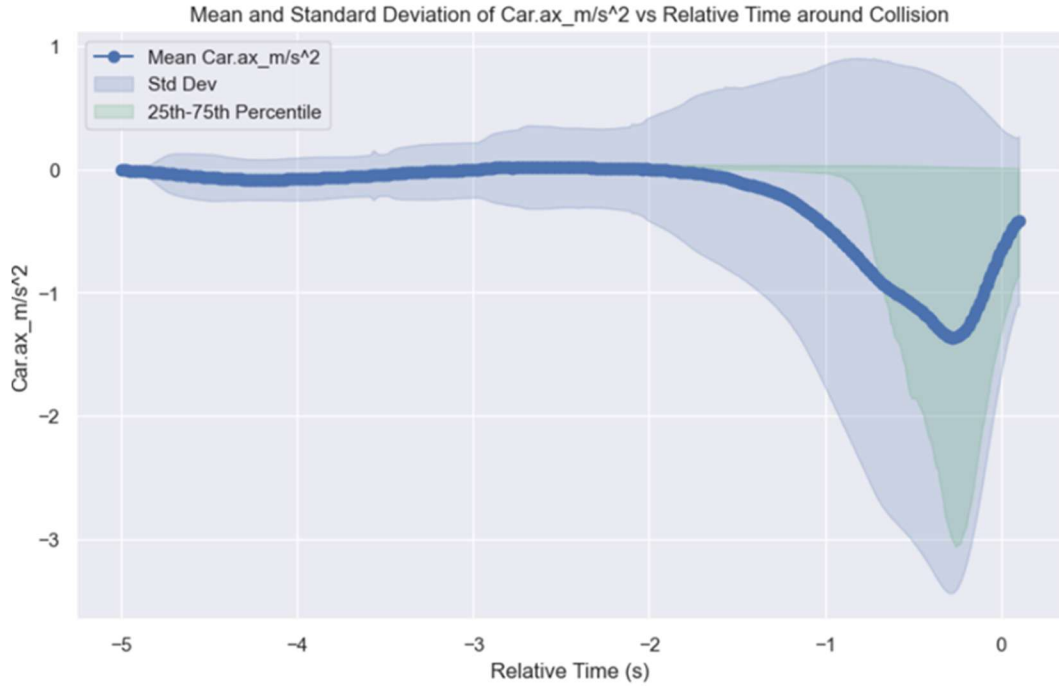


Figure A6. Near-side mean deceleration profiles from GIDAS-PCM (n=363).

APPENDIX 4. EXAMPLES OF TEST SCENARIO PROPOSALS.

Below are two examples of proposals for test scenarios with a robustness layer. Each adds one element to the Euro NCAP 2023 standard test scenario. Figure A8 shows the 2023 Euro NCAP standard CPNA 25% test scenario, and Figure A9 shows the proposal to add a row of bollards according to their normal position in a real traffic environment. Figure A10 shows the Euro NCAP 2023 standard CPFA 50% test scenario, and Figure A11 shows the second proposal: adding a traffic signpost with traffic signs positioned according to their normal positions in real traffic environment.

Proposal 1: Row of bollards in front of pedestrian path

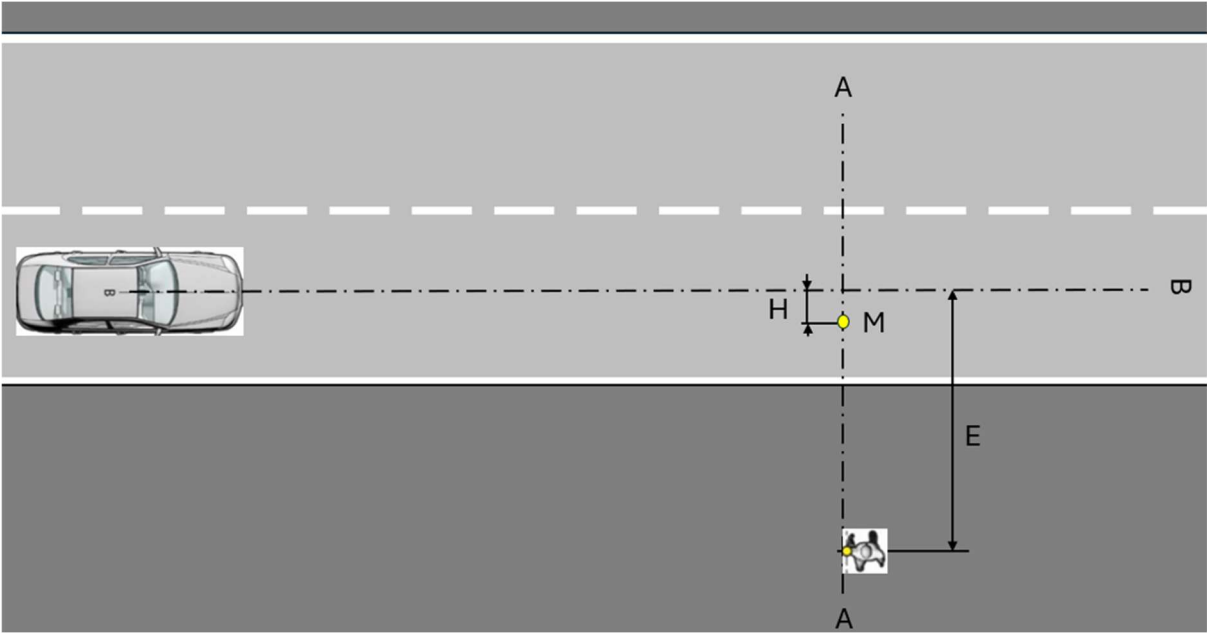


Figure A7. Base scenario Euro NCAP 2023 Car-to-Pedestrian Near-side Adult (CPNA) 25% impact location.

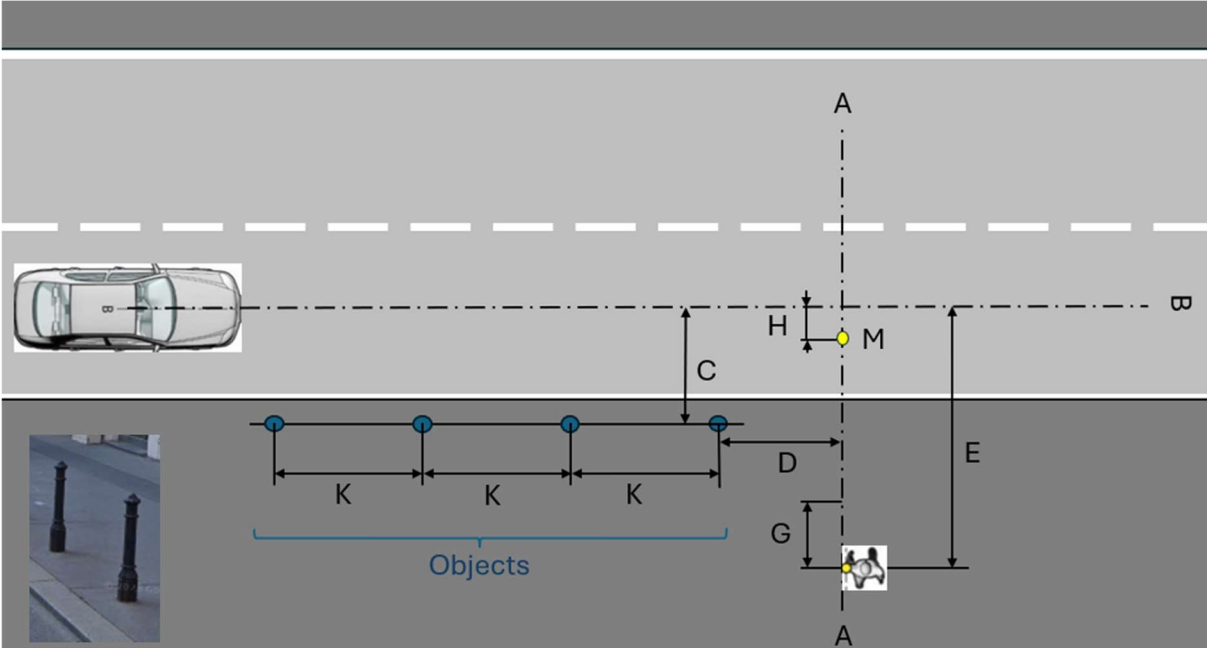


Figure A8. Proposal for a row of four bollards added in front of the pedestrian path.

Proposal 2: Traffic signpost in front of pedestrian path

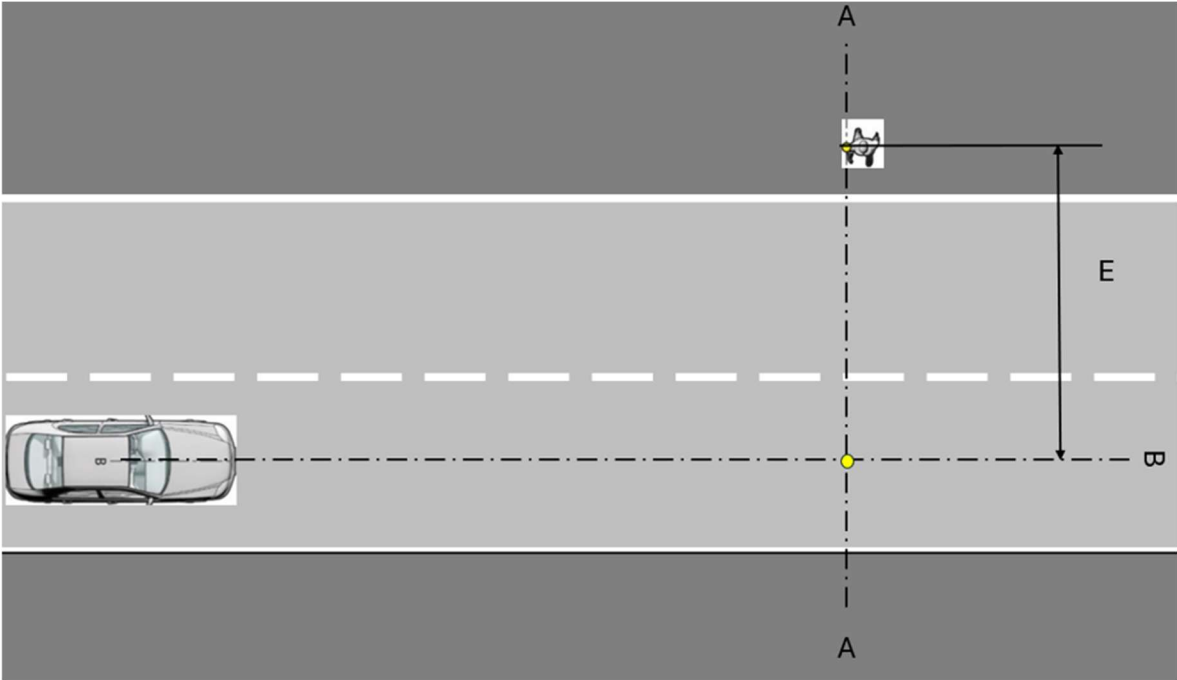


Figure A9. Base scenario Euro NCAP 2023 Car-to-Pedestrian Far-side Adult (CPFA) 50% impact location.

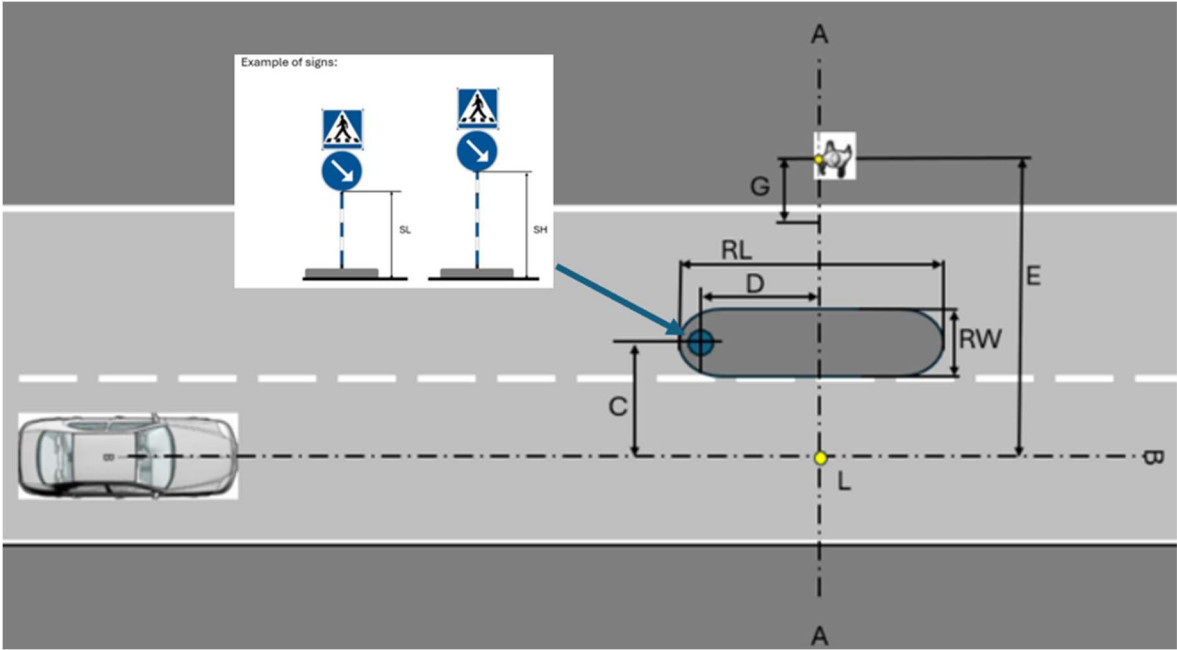


Figure A10. Proposal for a traffic signpost on refuge added in front of the pedestrian path. Post diameter 7 cm, with two traffic signs mounted at two heights.