ANALYSIS OF THE EUROPEAN CAR ROAD CRASHES FOR THE IDENTIFICATION OF THE MAIN USE CASES FOR A SIGNIFICANT ROAD SAFETY IMPROVEMENT THROUGH V2X

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Paper Number 23-0213

ABSTRACT

Research question

In pursuit of Vision Zero towards traffic-related fatalities and injuries in Europe, the SECUR project (Safety Enhancement through Connected Users on the Road) was initiated in a Euro NCAP context. SECUR aims to study the potential of V2X communications to improve road safety. This paper illustrates the main European crash cases involving Passenger Cars as ego vehicles and their parameters. The following opponents were considered: Passenger Cars, Powered Two-Wheelers, Bicyclists and Pedestrians.

Methods and Data Sources

An initial study of crashes at a high level was done to draw a general picture based on German (DESTATIS), French (BAAC) and European (CARE) crash databases. Then, an in-depth study was performed to select and define the SECUR crash cases and their characteristics. As part of this in-depth analysis a generic scenario catalog was developed, covering traffic crash situations, that the driver of a passenger might encounter. The most relevant scenarios regarding accidentology were determined providing the baseline to develop a test environment for a useful V2X-system. Based on the German Insurance Association crashes classification (GDV) and the German in-depth crash database (GIDAS), this catalog clusters all the GDV crash types in 28 categories, each crash being analysed from the perspectives of both participants and considering all different opponent types. The data of the most relevant 15 crash scenarios were provided through a GIDAS-based in-depth study, considering a set of 16 parameters.

Results

According to the in-depth crash analysis, 15 out of 112 crash scenarios were identified as the most relevant ones regarding the number of Killed and Severely Injured (KSI) and the relevance of V2X. These 15 scenarios consider the 4 types of road users and cover 71% of all the KSI crashes from the catalog. Among them Straight Crossing Paths, Left Turn Across Path and Rear-End crash situations. The parameters study has shown that the most significant crash blackspot is at intersections with structural view obstruction.

Discussion and Limitations
This study is subject to certain limitations. First, it is expected to be European representative, so the study was based on GIDAS and complemented with analyses of CARE and the in-depth database (IGLAD). However, the European representativity is still limited by the GIDAS-weighting upon CARE.

Moreover, it is complex to draw conclusions for new vehicles as the current databases naturally include old information and are representative of a past context (vehicle without state-of-the-art safety systems). Therefore, in order to have a dataset more representative of the current context, crashes involving a vehicle without ESC were filtered out.

Conclusion
The main crash cases to be ruled out for a significant road safety improvement through V2X are illustrated in this paper. The results have shown that significant white spots that are not addressed by ADAS due to physical sensor limitations (e.g., obstruction) remain. And it is precisely where V2X benefits sit, standalone or fused with current systems. SECUR results will feed Euro NCAP V2X introduction into the protocols and also further NCAP developments in other regions.

INTRODUCTION

SECUR project resume

Through its 2030 roadmap, the European New Car Assessment Programme (Euro NCAP) aims at encouraging, by a consumer approach, even more safety on the roads, in particular thanks to the use of new inter-vehicle communication solutions.

The aim of the SECUR project is to study the potential of communication to improve the safety of different road users. SECUR ensures technological neutrality in a complex and multi-faceted context. Coordinated by UTAC, the SECUR project outlines a coherent proposal for V2X testing and assessment protocols to Euro NCAP. To this end, an industrial consortium brings together about twenty international stakeholders, from the automotive and V2X ecosystem – automotive OEM, Tier1 manufacturers, V2X-market-stakeholders, and automotive test systems providers.

First, the most common crash situations on European roads were studied. Then, the current knowledge on V2X communication systems was summarized. Thereafter, the potential of V2X systems was studied, either alone or combined with ADAS systems. Finally, multi-technologies connected targets and protocols for evaluating these V2X systems, were developed. The results of this paper are coming from the SECUR crash data study (WP1).

Research questions

This paper aims at answering the two following research questions:

> Question 1: What are the main crash scenarios leading to severely injured or killed persons described by road configuration, types of opponents, pre-crash manoeuvres and their relative frequencies?
> Question 2: What are the main other criteria linked to V2X that characterise each of these injury crash scenarios?

To complete them the following question will be discussed:

> What are the important characteristics of these injury crashes that could be addressable by V2X technology solutions in addition to conventional ADAS sensors?

To answer these questions this paper will go through the following sections: notes on V2X, method and data sources, results, discussions, limitations and conclusion. [1] [2]

Crash study scope

The geographical scope of the SECUR Project is Europe. Considering that vehicle connectivity is relatively recent, offering a wide range of possibilities and benefits to all road users the following actors were considered as opponents: Passenger Car, Power Two-Wheelers (PTW), Bicyclist and Pedestrian. However, in this study the ego vehicle is always a Passenger Car.

General view on road traffic crashes in Europe

According to the SECUR high level analysis [1] on the European crash database CARE, severe injury and fatal crash occupants decreased between 2012 and 2018. Most died as occupants in passenger cars. While generally the numbers of killed pedestrians and bicyclists are decreasing, the proportion of these kind of road users in the accident scenarios are getting more important. Most people were injured in a crash in urban areas. About one third of the injured people had a crash in rural area. However, the percentage of injured people in crashes on motorways increased since 2012 and decreased in urban areas. The highest percentage of all killed and severely injured people can be found in rural areas crashes.

NOTES ON V2X

V2X can be seen as a new type of sensor for perceiving the environment. Unlike conventional sensors where it is required to actively sense and obtain information from the environment, a V2X station passively receives the information from other V2X stations. Hence, V2X could be a reliable source of information in situations where other sensors may not be able to function properly. For example, conventional sensors, including cameras and radars, rely on a line of sight between the vehicle and other objects. They fail to detect hazards and objects which are invisible to the driver, e.g., objects at an intersection or vehicles blocked by other vehicles. V2X is not only able to “see” the objects in such situations but can also provide much more detailed information impossible to be obtained by other sensors. For instance, in harsh weather conditions where the camera may not be able to determine the state of the traffic light, such information with much more detail, including traffic light state change time, can be obtained from V2X messages. [3] [4]

Communication forms

There are different forms of communications for a V2X station, The main ones are as follows

- **V2V - Vehicle-To-Vehicle**: Direct communication between vehicles.
- **V2VRU - Vehicle-To-Vulnerable Road User:** Direct communication between a vehicle and a VRU, e.g., pedestrian and bicyclist.
- **V2I - Vehicle-To-Infrastructure**: Direct communication with connected infrastructure, e.g., road gantries and traffic lights.
- **V2N - Vehicle-To-Network**: Indirect communication between V2X stations via a mobile network using cloud-based services.

V2V and V2VRU can address all types of use cases, even safety-critical ones that require low latency communications. Today V2N, due to the latency of current mobile networks, has less or partial applications in safety and delay critical use cases [5]. This may change in the upcoming years. The main benefit of V2N is its large coverage area. Unlike direct communications, e.g., in V2V, that, depending on the situation, may have a coverage area of a few hundred meters, the coverage of V2N can be unlimited if a connection to the mobile network is established. This makes V2N especially suitable for long range communication. For instance, informing the V2X station over a large distance about a crash, traffic jam or road blockage can help the station in making or updating its plan.

V2X-related crash countermeasures

Based on ETSI [6] and defined by SECUR in [7] V2X could be involved in six different crash countermeasures to reduce the frequency and severity of crashes:

Driver information, to provide static (or semi-static) information about the In-Vehicle Signage (IVS) for a safe and comfortable drive (e.g., dynamic speed limit and dynamic lane management). No driver action required.

Driver awareness, to point the driver’s attention to a situation ahead on its vehicle trajectory (e.g., local hazards and Vulnerable Road User (VRU) presence) that has the potential to become dangerous or critical if overlooked by the driver. No driver immediate action required other than to be attentive and to adapt driving behaviour to the situation.

Driver warning, to issue alerts to the driver requiring an immediate action to avoid a crash (e.g., emergency braking and lane keeping). V2X could be used as an additional sensor.

Vehicle action. V2X could be used as an additional sensor for mitigation and crash avoidance by active safety systems. This category could be divided into non-safety-critical and safety-critical actions. Today V2X cannot provide Automotive Safety Integrity Level (ASIL) [8]. Non-safety-critical Vehicle Action is not subject to ASIL requirements due to the low consequence severity (e.g., speed reduction, acceleration limitation, system parameter/sensitivity update, etc). Safety-critical Vehicle Action is subject to ASIL requirements due to the high consequence severity. V2X should ensure enough safety confidence (ASIL level) before data fusion with those applications like Autonomous Emergency Braking (AEB).

Pre-crash countermeasure, to bring additional information to the vehicle active systems in case of an upcoming crash.

Post-crash countermeasures, triggered by passive safety systems after a crash to bring information to the surrounding road users to reduce the risk of another crash.

METHODS AND DATA SOURCES

The method consists in two mains steps which answer research question 1 and 2 respectively:

1. Generic crash scenario catalog: creation of a generic scenario catalog considering all types of crashes and all main road users (Passenger Car (PC), Powered two wheelers (PTW), Bicyclist (BC) and Pedestrian (PD))
2. In-depth crash scenarios study: deep study of selected parameters for the most frequent and severe crash scenario to build SECUR use cases.

To define the SECUR test scenarios and their parameters, a generic crash scenario catalog was created based on the German Insurance Association (dt. Gesamtverband der Versicherer; GDV) crash classification. The latter clusters all crashes involving a passenger car by categories. Thus, it is possible to determine the most frequent and severe crash scenarios and create a foundation to develop a test environment for a useful V2X-System via an in-depth crash study of a selection.

Definitions

In the following analysis, the terms category, crash scenario, use case and test scenario are used as defined in Table 1.

Table 1.
Definition table

Key words	Definition
CATEGORY	Described by the crash-causing conflict situation regardless of the participant.
CRASH SCENARIO	Described by road layout and basic motion parameters of vehicles participating in an injury road traffic crash. A crash scenario is a combination of a category with a kind of road user.
USE CASE	Derived from crash scenarios by adding detailed information for example about road layout, right-of-way and vehicle trajectories prior to the collision. Note: Use Cases serve as an intermediate step between the Crash Scenarios and the Test Scenarios.
TEST SCENARIO	Final testing conditions.

Crash datasets for the analysis

For the development of the SECUR generic crash scenario catalog [1], the data of the German In-depth Crash Study (GIDAS) were used. GIDAS is a collaborative project of the Federal Highway Research Institute of Germany (BASt) and The Research Association of Automotive Technology of Germany (FAT). Each case is encoded with about 3,400 variables. Following the documentation, most of the crashes are reconstructed by an experienced engineer. For all the analyses the GIDAS database with a status of June 2021 was used.

For this analysis it was necessary to create at first a target-oriented master dataset, which is a filtered version of the whole GIDAS dataset. The following selection criteria have been applied:

1) Only completely coded and reconstructed crashes were considered
2) The ego vehicle had to be a passenger car

3) The ego vehicle had to be equipped with an Electronic Stability Control system (ESC)
4) The crash severity had to belong to the following two injury severity groups:
    a. Killed and/or Seriously Injured (KSI)
    b. Injured

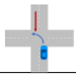
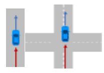
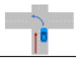
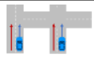
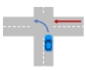
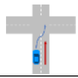
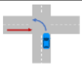
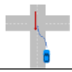
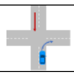
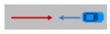
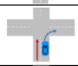
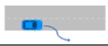
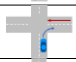
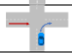
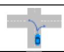
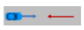
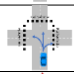
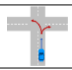
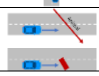
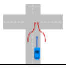
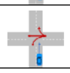
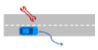
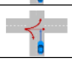
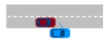
The two first criteria are explained by the need of complete crashes and by the scope of the project which is focus only on a passenger car as the ego vehicle. The third criteria, limits the number of vehicles that are too old in the master dataset. Indeed, the fact to eliminate vehicles without Electronic Stability Control (ESC) allows results that are more in line with the current car market. Two injury severity groups were studied separately. However, all the selection and decisions were done based on KSI crashes. Injured road users should be considered as a complementary information.

Generic crash scenarios catalog

This catalog was developed to group all possible injury crash scenarios into well summarized categories with the main road users with the aim to select the main ones in a second step. The approach was based on a method described by Feifel and Wagner to create harmonized scenarios based on the crash pre-crash description [9]. The method is based on GDV crash types that identify the conflict situation of the traffic participants leading to the crash. The crash types are also used for specifying the causer and non-causer in each crash. Only the first two conflicting partners such as vehicles or vulnerable road users are defined in each crash even if further participants are involved. The proposed scenario catalog contains all degrees of freedom for the ego and opponent participants, such as longitudinal, crossing or turning. All crashes are considered from the causer and non-causer perspectives; therefore, the number of scenarios is twice the number of crashes. This allows for developing a holistic picture of the traffic crash distribution between two participant types, such as car versus car. The catalog provides for a description of the target population in question, in research projects as well as throughout all phases of system development.

Two sources were used to define the categories of the catalog, MUSE project [10] and the scenario catalog in [9]. Additional categories were defined by accidentology experts. These ones are content-related based on the crash type. The crash types of the German Insurance Association (GDV) were mapped to those categories. The crash type is defined as the crash-causing situation. The overall catalog is described in [1].

Table 2.
Category list of the generic crash scenario catalog

Category					
1		Left Turn Across Path – Opposite Direction	15		Rear End - Previous Vehicle
2		Left Turn - Same Direction	16		Parallel Driving
3		Left Turn - Right Direction	17		Lane Change - Same Direction
4		Left Turn Across Path – Left Direction	18		Lane Change - Opposite Direction
5		Right Turn - Opposite Direction	19		Reverse
6		Right Turn - Same Direction	20		Loss Of Control in Straight Line
7		Right Turn - Right Direction	21		Loss Of Control in CUrve
8		Right Turn - Left Direction	22		Loss Of Control - Turning
9		Oncoming	23		Rail Vehicle
10		Straight - Same Direction - Turning	24		Animals / Objects
11		Rear End - Following Vehicle	25		Break Down
12		Straight - Same Direction - Lane Change	26		Inability
13		Straight Crossing Path – Right Direction	27		Sudden Vehicle Damage
14		Straight Crossing Path – Left Direction	28		Dooring

To address all the crash cases included in the GDV classification, the perspectives of all participants (participant A and participant B) were considered in each case. Therefore, a safety measure will not only assist one participant but both and the crash could also potentially be addressed form both sides. Table 3 show the total numbers by occupants and severity considered in the catalog.

Table 3.
Numbers considered in the catalog by occupants and severity (from GIDAS)

Total number of … (in GIDAS)	**Passenger Car**	**Powered Two-Wheelers**	**Bicyclist**	**Pedestrian**	**Other kind of participants**	**Total**
Injured persons	13.140	1.248	3.575	1.121	245	19.329
KSI persons	2.091	421	690	497	21	3.720

To validate the results coming from the catalog at the EU level, a target population study was done. The objective was to estimate for each catalog category the number of KSI occupants, who could be potentially saved thanks to system. For this the catalog categories were estimates based on CARE database 2020 with the methodology describe in [11]. CARE dataset 2020 is extrapolated from CARE 2018. This extrapolation ensures that the covid did not disrupt the data.

Detailed analysis of crash scenarios

Analysing all the 28 categories in combination with all four types of possible opponents would have meant to analyse 112 combinations. This detailed analysis was performed on the most frequent and severe crash scenarios of the catalog. The selection contains 15 crash scenarios selected by the number of KSI.

The 16 parameters chosen are listed in Table 4. However, not all the parameters were analysed for each scenario as not relevant in that case [2]. Those parameters were studied based on GIDAS database.

Table 4.
Parameters description

Parameter	Description
Weather condition [NIED]	E.g., rain, hail or snow
Road surface [STROB]	E.g., dry, damp, wet or hoarfrost
Light condition [LICHT1]	Daylight, darkness and dawn/twilight
Illumination of the road [STRABEL]	Illumination status of the road in the darkness and dawn/twilight cases
Percentage of view obstruction [SICHTBV]	Yes/No
Kind of view obstruction [SICHTV]	E.g., driving vehicle or structural circumstances
Topology of road / intersection [FSTREIF1]	E.g., straight road or intersection one lane
Radius of curve [KRADIUS]	E.g., 101-200m
Kind of traffic regulation [VKREG]	E.g., Traffic lights or observe right-of-way
Traffic density [VSTUFE]	E.g., light traffic, dense traffic or traffic jam
Crash cause [HURSU]	E.g., ability to drive or speed
Human failure [EINFKAT1]	Influence of the driver on the crash (e.g., distraction)
Initial speed [V0]	Ego and opponent speed driven prior the first crash critical situation
Deceleration [BV]	Ego and opponent deceleration prior to the crash

RESULTS

The results of the previously presented methodology are divided between two parts, one by research questions.

Research question 1: what are the main crash scenarios leading to severely or killed persons described by road configuration, types of opponents, pre-crash manoeuvres and their relative frequencies?

Figure 1 shows the frequency of severely or fatally injured people by the categories considered in the catalog.

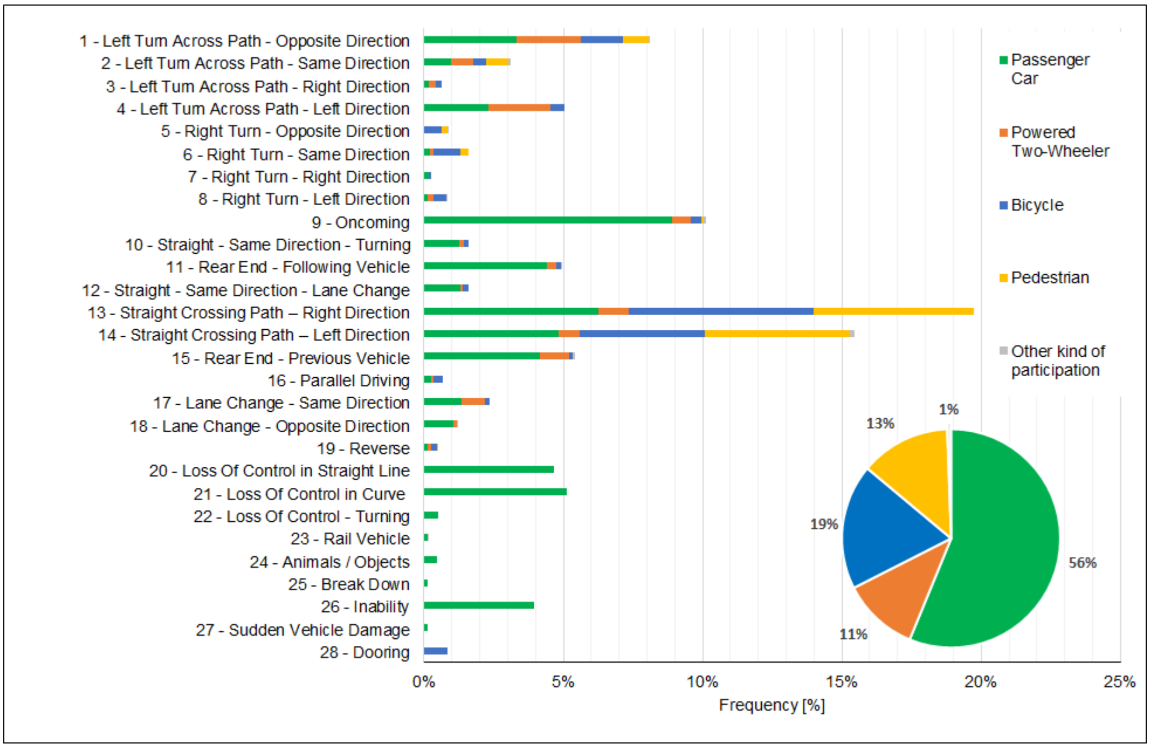


Figure 1. Frequency of severely or fatally injured people by catalog categories.

Table 5 provides a ranking on the 15 most frequent crash scenarios identified through the catalog. Crash scenarios describe a combination of category and road user type (e.g., “Reverse” is a category and “Reverse for bicyclist” is a crash scenario). The category “26 – Inability” contains all the situations, where the driver of the ego vehicle had a physical problem. This category got removed because of V2X systems would not provide assistance in case of inability. With these 15 crash scenarios, 71% of all the KSI occupants are covered and 84% of all injured occupants of the catalog.

This table also the EU target population results based on CARE database. Please note that because of the similarity of the categories 20 and 21 (LOC in Straight Line / LOC in Curve) they got combined to one category “Loss Of Control”, see “*” in the table. Example of interpretation for the column “EU target population (CARE)”: With a countermeasure which addresses the SCP-RD BC scenario, potentially 8% of the KSI bicyclists could be saved.

In addition, the EU project OSCCAR led to an estimation of reduced casualties and an identification of future accident configurations which ADAS equipped vehicles would be exposed to in 2025. It can be seen in [12], [7], how the selected scenarios of the SECUR analysis are aligned with the findings in OSCCAR project.

Table 5.
Main crash scenarios sorted by KSI frequency

KSI Ranking	Catalog category	Crash scenario name	Description	Opponent	Crash scenario catalog coverage (GIDAS-2020)				EU target population (CARE-2020)	
					KSI [n]	KSI [%]	Injured [n]	Injured [%]	KSI [%]	Injured [%]
1	9	Oncoming	Face to face impact between two passenger cars.	Passenger car	332	9%	1326	7%	6%	5%
2	13	Straight Crossing Path – Right Direction (SCP-RD)	Crossing bicyclist from right side at an intersection.	Bicyclist	248	7%	1162	6%	8%	9%
3	13	Straight Crossing Path – Right Direction (SCP-RD)	Crossing passenger car from right side at an intersection.	Passenger car	233	6%	1598	8%	4%	6%
4	13	Straight Crossing Path – Right Direction (SCP-RD)	Crossing pedestrian from right side.	Pedestrian	214	6%	497	3%	9%	10%
5	14	Straight Crossing Path – Left Direction (SCP-LD)	Crossing pedestrian from left side.	Pedestrian	194	5%	360	2%	9%	7%
6	21	Loss Of Control in CUrve (LOC-CU)	/	Ego single	190	5%	493	3%	6% *	3% *
7	14	Straight Crossing Path – Left Direction (SCP-LD)	Crossing passenger car from left side at an intersection.	Passenger car	179	5%	1230	6%	3%	5%
8	20	Loss Of Control in Straight Line (LOC-SL)	/	Ego single	174	5%	393	2%	6% *	3% *
9	14	Straight Crossing Path – Left Direction (SCP-LD)	Crossing bicyclist from left side at an intersection.	Bicyclist	167	5%	747	4%	5%	6%
10	11	Rear End - Following Vehicle (RE-FV)	Rear-end braking crash between two passenger cars.	Passenger car	164	4%	2051	11%	3%	8%
11	15	Rear End - Previous Vehicle (RE-PV)	Rear-end braking crash between two passenger cars	Passenger car	154	4%	2382	12%	3%	9%
12	1	Left Turn Across Path – Opposite Direction (LTAP/OD)	Passenger car turning left across the path of another vehicle coming from the opposite direction.	Passenger car	123	3%	828	4%	2%	3%
13	1	Left Turn Across Path – Opposite Direction (LTAP/OD)	Passenger car turning left across the PTW path coming from the opposite direction.	PTW	87	2%	188	1%	4%	3%
14	4	Left Turn Across Path – Left Direction (LTAP/LD)	Crossing passenger car from left side at an intersection.	Passenger car	86	2%	583	3%	1%	2%
15	4	Left Turn Across Path – Left Direction (LTAP/LD)	Crossing PTW from left side at an intersection.	PTW	82	2%	218	1%	4%	4%
				TOTAL	2627		14056			

Research question 2: What are the main other criteria linked to V2X characterising each of these injury crash scenarios?

The in-depth analysis was performed on the 15 crash scenarios identified before. As example, two relevant use cases are presented in this work. Full results are available in the SECUR Deliverable D1.2 [2] and the summary table in the appendix.

Straight Crossing Path – Right Direction (SCP-RD) Passenger Car

The SCP-RD PC crash scenario is a collision in which a vehicle travels forwards along a straight path across a junction, towards a vehicle crossing the junction on a perpendicular path, from the right direction.

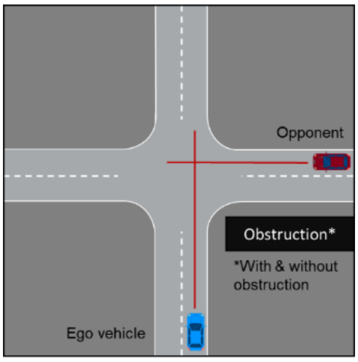


Figure 2. SCP-RD PC pictogram.

Table 6.
Detail analysis results for SCP-RD PC

Parameter	**Description**
Weather condition	In 13% of the cases, the crash happened during rainy conditions.
Light condition	26% of the crashes happened in the darkness or during dawn/twilight.
Illumination of the road	In those cases, 75% of the roads were illuminated with street lighting.
Percentage of view obstruction	in 30% of the crashes there was a view obstruction for the ego participant.
Kind of view obstruction	In the cases with an existing view obstruction, it was due to structural circumstances in 50% of the cases. And in 46% of the cases the view obstruction was due to vehicles. Most of them were parking (33%) during the time of the crash.
Topology of road / intersection	In the majority of the cases, the ego vehicle drove on a road towards an intersection, which had one lane for all directions (46%). In nearly every fifth crash the lane was for straight and right direction only.
Kind of traffic regulation	In 52% of the crashes, the ego had to observe the right-of-way.
Traffic density	During nearly four out of five crashes the traffic density was either light or only sporadic vehicles. Stop-and-go traffic or traffic jams are very uncommon for this type of crashes.
Crash cause	In more than 86% of the crashes one participant failed in observing the right-of-way.
Initial speed ego	In the majority of the cases (58%), the initial speed of the ego vehicle was between 36 kph and 65 kph (81% between 21 kph and 70 kph). The initial speed of the opponent vehicle was most frequently between 0 kph and 50 kph (86%). The ego vehicle was most of the times faster than the opponent before a critical situation was recognised.
Initial speed opponent	

Figure 3 shows the distribution between the different types of obstruction under the condition that a visual obstruction was present at the crash site. Structural circumstances are the main type of obstruction. Obstruction by vehicles is also an important factor; however, it is spread between several driving status.

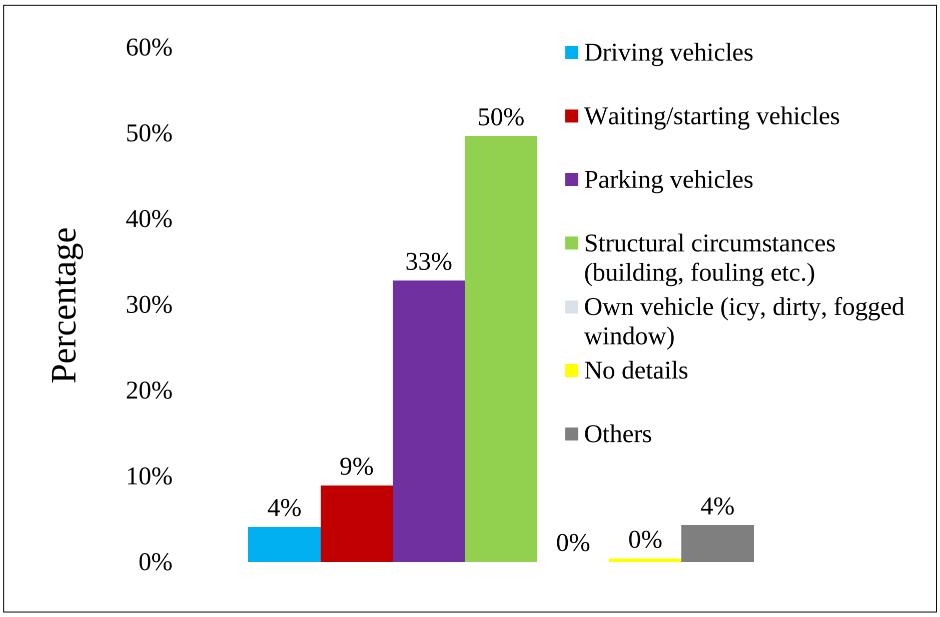
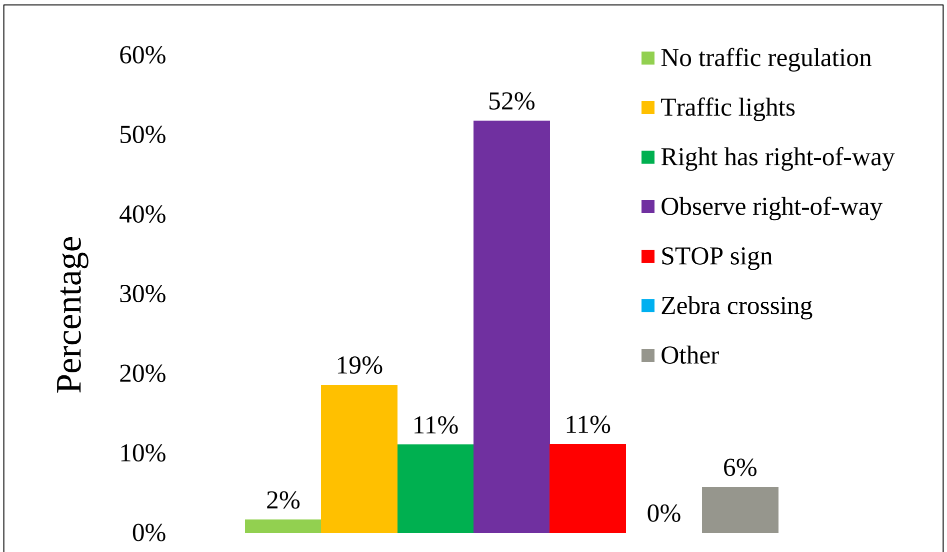


Figure 3. Kind of view obstruction – Ego.

Figure 4 shows that in 52% the traffic regulation is "observe right-of-way" and in 26% of these cases the ego vehicle is the main causer of the crash. The ego vehicle is mostly responsible in intersection regulated by traffic light and "right has right-of-way".



Ego is main causer	14%	61%	95%	26%	36%		30%

Figure 4. Kind of traffic regulation – Ego.

Table 7 shows the speeds distribution, the ego vehicle initial speed is rather concentrated while for the opponent it is more spread on an important range.

Table 7.
Initial speed - Ego vs. Opponent

Initial speed Ego [kph]		Initial speed Opponent [kph]																
		0	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76	From
From	To	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	…	To
0	5	16	1	1	3	2	2	6	11	11	26	13	8	5	3	2	3	5,0%
6	10	3			2	1	3	1	3	6	3	4	2	1	1			1,3%
11	15	1	2	1	3	2	1	3	7	4	9	5	2	2	1	2	3	2,1%
16	20	2	2	4	3	2	8	6	9	7	15	9	5	1	2	1	9	3,7%
21	25	4	1	4	5	9	11	14	5	11	15	4	8	3	3		4	4,4%
26	30	19	9	12	10	9	19	16	22	11	20	12	9	5	5	1	9	8,2%
31	35	11	16	11	8	11	20	16	15	18	22	10	6	3	3		2	7,5%
36	40	28	18	10	14	19	24	22	25	16	17	12	11	1	5	2	4	10,0%
41	45	50	24	28	22	12	32	21	10	24	27	13	2	2	4	4	1	12,1%
46	50	86	51	42	32	26	32	33	23	18	47	13	6	3	4	2	2	18,4%
51	55	39	14	26	8	16	15	6	12	5	9	7	6	5	2	1	1	7,5%
56	60	33	11	17	8	8	8	10	2	6	7	5	2		4	1	2	5,4%
61	65	23	12	6	10	8	8	5	7	5	7	2	3	1	1		1	4,3%
66	70	14	6	10	8	9	7	5	4	1	3		2	1		1		3,1%
71	75	16	6	5	6	1	2	3		1	1	2			1		1	2,0%
76	80	5	8	4	4	2	2	2	4		4	1	1	1	1			1,7%
81	85	2	2	5	1	3	2	1	1		2	1	1					0,9%
86	90	3	4	4	2		3	2										0,8%
91	95	2	1	2	1		1			1				1				0,4%
96	100	3		1	1	2			1		3							0,5%
101	…	2	1		1	1	3									1		0,4%
		15,9%	8,3%	8,5%	6,7%	6,3%	8,9%	7,5%	7,1%	6,4%	10,4%	5,0%	3,2%	1,5%	1,8%	0,8%	1,8%	**Total**

Less than 10 cases
10…20 cases
More than 20 cases

Straight Crossing Path – Right Direction (SCP-RD) Bicyclist

The SCP-RD BC is a collision in which a vehicle travels forwards along a straight path across a junction, towards a bicyclist crossing the junction on a perpendicular path, from the right direction.

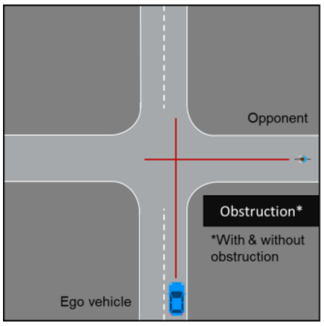


Figure 5. SCP-RD BC pictogram.

Table 8.
Detail analysis results for SCP-RD BC

Parameter	**Description**
Weather condition	In the majority of the cases (92%) there was no precipitation.
Light condition	With a share of 87%, the majority of crashes happened during daylight conditions.
Illumination of the road	In 71% of the named group of cases, the road was illuminated with street lighting.
Percentage of view obstruction	In 35% of the crashes with cyclists there was a view obstruction for the ego participant.
Kind of view obstruction	The view obstruction was due to structural circumstances in 69% of the obstructed cases. In 20% the view obstruction was due to parking vehicles.
Topology of road / intersection	In most of the cases, the ego participant was driving towards an intersection on a single lane for either left or right direction only (24%), all directions (23%), right direction only (22%) or right or straight only (5%).
Kind of traffic regulation	In 55% of the crashes one of the participants had to observe the right-of-way. In 81% of these cases, the crash was mainly caused by the ego.
Traffic density	During four out of five crashes the traffic density was either light, or only sporadic vehicles. Around every fifth ego had a crash during dense traffic.

Crash cause	Nearly 60% of the crashes happened mainly, because one participant made a failure at observing the traffic signs regulating the priority. The second big type of main crash causation were mistakes at entering the flow of traffic (16%).
Initial speed ego	In the majority of the cases (63%), the initial speed of the ego vehicle was less than 21 kph and 0 kph to 35 kph represent 80%. The initial speed of the opponent was most frequently (82%) between 6 kph and 20 kph, which are typical speeds for cyclists.
Initial speed opponent	

Figure 6 shows the distribution between the different types of obstruction. Structural circumstances the main type of obstruction with 69%. Complementary, vehicle obstruction is also a notable type of obstruction.

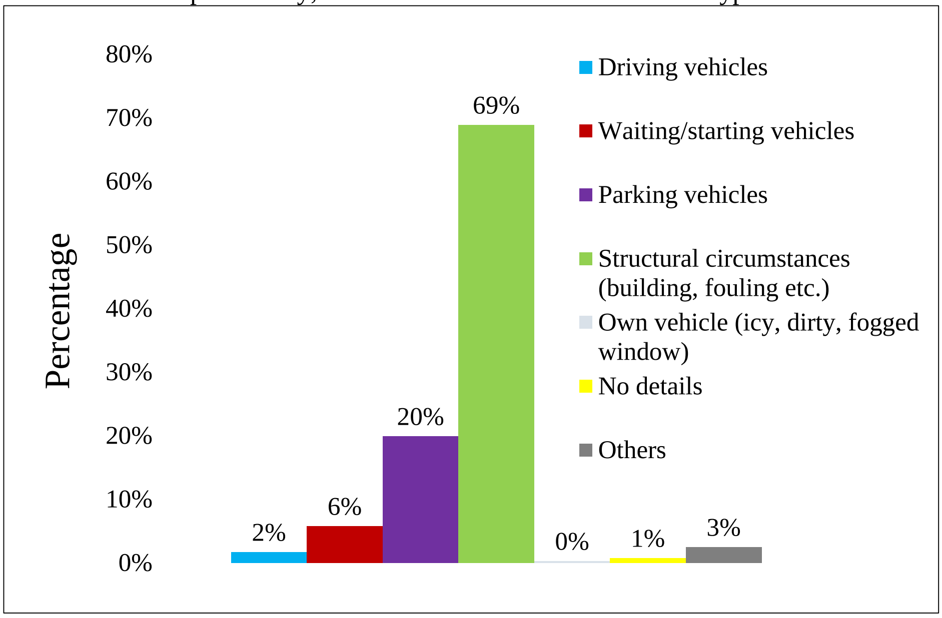


Figure 6. Kind of view obstruction – Ego.

Figure 7 shows the kind of traffic regulation. In 56% the kind of traffic regulation is “observe right-of-way” and in 81% of these cases the ego vehicle is the main causer of the crash. The ego vehicle is also mostly responsible in “stop sign” and “right has right-of-way” regulation.

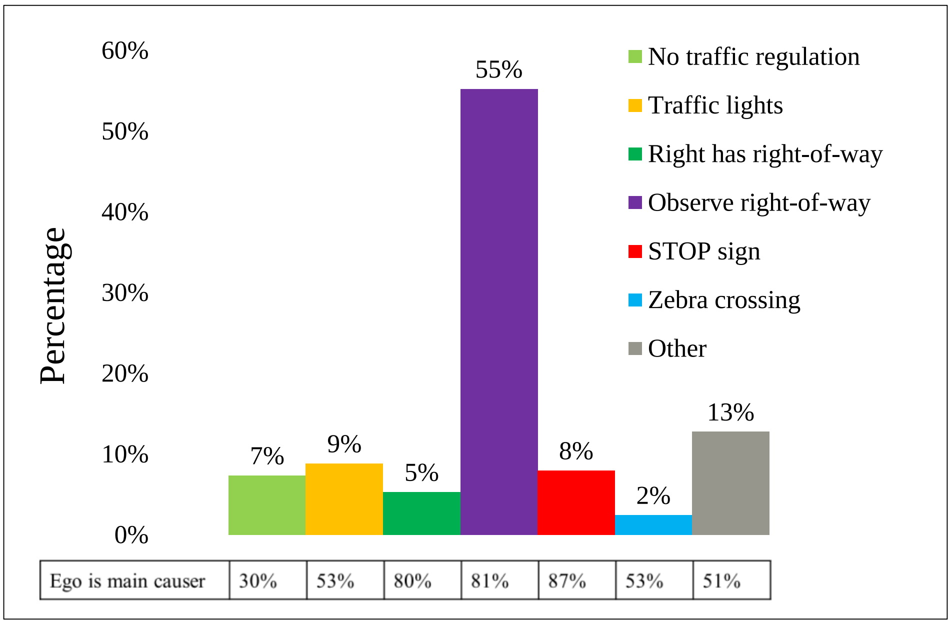


Figure 7. Kind of traffic regulation – Ego.

Table 9 shows the speed distribution. The ego vehicle initial speed is concentrated between 0 kph and 35 kph while for the opponent it is between 6 kph and 20 kph.

Table 9.
Initial speed - Ego vs. Opponent

Initial speed Ego [kph]		Initial speed Opponent [kph]											
		0	6	11	16	21	26	31	36	41	46	51	From
From	To	5	10	15	20	25	30	35	40	45	50	…	To
0	5	37	143	223	178	71	22	4	1	3			29,3%
6	10	7	96	119	55	16	5	3	1				13,0%
11	15	5	59	99	53	31	11	1	1				11,2%
16	20	3	54	74	58	17	5	1	1				9,1%
21	25	5	37	48	43	17	3	2	1				6,7%
26	30	6	35	66	45	14	1						7,2%
31	35	7	12	28	26	8	2			1			3,6%
36	40	7	31	43	28	11	1						5,2%
41	45	14	19	23	22	6	2						3,7%
46	50	19	37	51	23	11	5						6,3%
51	55	7	13	10	7	5							1,8%
56	60	6	14	5	3	1							1,2%
61	65	2	7	2									0,5%
66	70		7	7	2	1							0,7%
71	75	2	2										0,2%
76	80		3										0,1%
81	85	1	1	1									0,1%
86	90												0,0%
91	95												0,0%
96	100	1											0,0%
101	…				1								0,0%
		5,5%	24,5%	34,3%	23,4%	9,0%	2,4%	0,5%	0,2%	0,2%	0,0%	0,0%	**Total**

Less than 10 cases
10…20 cases
More than 20 cases

Complementary, [13] provide additional data on the SCP-RD BC and SCP-LD BC crash scenarios, with a focus on UTYP 341 and 342.

DISCUSSIONS & LIMITATIONS

Discussions

Research question n°1 objective was to identify the main crash scenarios leading to severely injured or killed persons described by road configuration, types of opponents, pre-crash manoeuvres and their relative frequencies. The answer is provided in the Table 5 and [1].

Research question n°2 objective was to identify the main other criteria linked to V2X that characterise each of these injury crash scenarios. Complementary the following discussions focus on the important characteristics of these injury crashes that could be addressable by V2X technology solutions in addition to conventional ADAS sensors.

Besides the positive impact, ADAS systems based on on-board sensors have on injury mitigation and accident avoidance, they are now facing their technological and physical limits. Most of all with sight obstructions and in poor environment conditions. V2X is an answer to improvements of ADAS. The referred paper [14] analyses how V2X can provide additional benefit to the road fatalities reduction with V2X-enhance-ADAS.

The scenario "*Straight Crossing Path – Right Direction (SCP-RD) Passenger Car"* is a good illustration of obstructions, as the main area identified where V2X could bring potential benefits. As described in the results, these obstructions often are structural circumstances (building) or vehicles (driving /waiting /starting /parked). In most cases, one participant fails to observe the right-of-way. V2X could reduce the danger by providing information about the opponent’s presence and, therefore, improve the driver anticipation. Here, the countermeasures driver “Awareness” and “Warning” as introduced in the subsection V2X-related crash countermeasures are particularly relevant to help the driver to anticipate the hazardous situations. Conventional systems cannot provide these due to their physical limits, sensor range and line-of-sight. Furthermore, a significant number of the crashes occur in poor light conditions such as are “darkness” or “dawn/twilight”. Precipitation and dense traffic are also relevant. These three last elements impact the driver’s visibility, the road comprehensibility and the conventional sensors' capabilities, robustness and efficiency. As camera-based systems have limitations in difficult lighting conditions such as night and precipitation, V2X can support by confirming object detection, classification and positioning in uncertainties. Note that V2X Awareness should be taken with caution since the driver will be potentially aware of many potential hazards at the same time, and they will have to be prioritized by the system to avoid too many inputs in addition to the inputs the driver takes directly on the scene. Information from the system should not be competing but complementary and consistent.

Likewise, the "*Straight Crossing Path – Right Direction (SCP-RD) Bicyclist"* scenario, obstruction is an important field where V2X could bring potential benefits [3], [4]. The obstruction is mostly due to structural circumstances, i.e., buildings. In most of the cases, the ego vehicle caused the crash after failing to observe the right-of-way of the bicyclist. V2X could reduce the danger by providing information about the opponent's presence and, therefore, improve the driver's anticipation. Here the countermeasures driver "Awareness" and "Warning" are particularly relevant to avoid the dangerous situation. Dense traffic remains also in this scenario with the same impact on the driver and classical sensors than in SCP-RD PC. A significant part of the crashes occurs when the speed of the ego vehicle is very low (0-10 kph). In this case, the bicyclist is out of the range of conventional sensors due to the speed differential. V2X could bring potential benefits here to improve conventional sensors' detection capabilities and efficiencies to classify and detect the bicyclist. It should also be noted that bicycles cannot easily participate in V2X communication themselves, however third-party vehicles can increase the visibility of bicycles using Collective Perception V2X [14].

As for vehicle action, the characteristics of crashes relevant to V2X communication are still to be identified as a complement or substitute to traditional sensors. Particularly these actions require high performance of V2X solutions based on accurate relative positioning of participants.

From a general perspective, V2X allows safety systems to detect an object before onboard sensors themselves see it, by providing additional information such as the road user type and its dynamic parameters (speed, positioning, driving lane, heading, acceleration/braking, turning indication, airbag status, etc). These data could be used to do path prediction and to anticipate critical situation earlier. As mentioned above, V2X is almost not impacted by weaknesses of ADAS. V2X allows new services to the user through the share of specific situation information with a wide range (crash risk, danger ahead, local hazards, VRU awareness, etc.).

Limitations

This study is based on the German crash data obtained from GIDAS and DESTATIS and, therefore, does not provide a picture on crashes across the EU. To cope with this, the target population study based on CARE estimated the EU representativity. In addition to this, a study on IGLAD was conducted. The aim was to compare the main crash selection of both databases considering for IGLAD only EU cases. In contrast to the GIDAS database, the data in IGLAD are not representative for the occurrence of crashes in the countries where the data originates from. That is caused by some data providers who only record and provide fatal crashes. Therefore, the results of the analysis are only given as an additional information. While comparing the data of GIDAS and IGLAD [1], it sticks out that the results are very similar. However, in the IGLAD database, the frequency of KSI occupants in category 9 and category 21 is much higher than in GIDAS. The reason for that could be, that in IGLAD the condition that the ego vehicle must be equipped with ESC, was not used due to quality issues of this criterium in IGLAD. In category 1, category 13 and category 14, KSI occupants appear more frequently in GIDAS than in IGLAD.

This study is a target population study, crash scenarios have been identified and some characteristics of the crashes have been highlighted. However, the potential V2X safety benefits are not estimated in this paper. Target population is the first step to identifying the potential effectiveness of a countermeasure. However, previous studies highlighted the limits of conventional sensors (even ideal) and the benefits of V2X as an additional sensor to support them [3], [15], [4]. Crash parameters of these studies are not necessarily identical to those in SECUR.

To strengthen the analysis and give more insights into capabilities or limitations of V2X, a complementary study about production of failures would be interesting, to identify drivers needs and potential vehicle actions. This could provide other analysis angles to understand the needs for driver alerts, or cooperative driving, or effectiveness of warning for example.

CONCLUSION

An analysis of the main traffic crashes based on GIDAS was performed. We selected crashes for which the ego vehicle is a passenger car while the other participant could be a passenger car, a PTW, a bicyclist or a pedestrian. First, a catalog of crash "categories" has been created to cluster the different conflict situations of the crashes available in GIDAS. The aim of this categories catalog was to select the main crash situations to address with V2X. To cover all crash cases included in the GDV classification, the perspectives of both participants in the conflict situation (participant A and participant B) were considered in each case. Therefore, a safety measure will not only assist one participant but both and the crash could also potentially be addressed from both sides. Second, 15 "crash scenarios" were defined to describe the possible relevant combinations of the categories and the road user types. The crash scenarios were selected based on KSI frequencies. Third, these crash scenarios as shown in Table 5 were studied in detail. Fourthly, complementary studies based on CARE and IGLAD were done to estimate the EU target population of the selected crash scenarios.

Over the 15 crash scenarios studied deeply with GIDAS, 2 were used as illustrations in this paper: "*Straight Crossing Path – Right Direction (SCP-RD) Passenger Car*" and "Straight Crossing Path – Right Direction (SCP-RD) Bicyclist". 11 over the 16 parameters selected for the in-depth study were analysed for those two scenarios.

Important characteristics of these injury crashes that could be addressable by V2X technology solutions in addition to conventional ADAS sensors were identified based on the performed in-depth analysis.

The scenario "*Straight Crossing Path – Right Direction (SCP-RD) Passenger Car"*, is a good illustration of obstructions as the main area identified where V2X could bring potential benefits. Then, in most cases, one participant fails to observe the right-of-way. Furthermore, a significant number of the crashes occur in darkness. Precipitation and dense traffic are also present. These three elements impact the driver visibility, the road comprehensibility and the conventional sensors' capabilities, robustness and efficiency.

Likewise, in the "*Straight Crossing Path – Right Direction (SCP-RD) Bicyclist"* scenario, obstructions due to structural circumstances are also very relevant in this scenario. In most cases, the ego vehicle caused the crash after failing to observe the right-of-way of the bicyclist. Dense traffic is also relevant in this scenario with the same impact on the driver and classical onboard sensors than in SCP-RD PC. A significant part of the crashes occurs when the speed of the ego vehicle is low.

Besides the positive impact of ADAS systems based on on-board sensors on injury mitigation and accident avoidance, they are facing technological performance limitations in situations with sight obstructions and in poor environment conditions. V2X can help to improve the ADAS performance.

From a general perspective, V2X can provide additional information to safety systems such as the knowledge of the road user type and its dynamic parameters (speed, positioning, driving lane, heading, acceleration/braking, turning indication, airbag status, etc). These data could be used, under certain conditions, to do path prediction and to anticipate critical situations earlier. Additionally, it will allow new services to the user through the sharing of a wide range of specific situation information (crash risk, danger ahead, local hazards, VRU awareness, etc.).

SECUR is the first Euro NCAP-oriented project focused on V2X with the objective to outline a consistent proposal for V2X testing and assessment.

Beyond that, additional work would be required to complete and move forward on the identification, standardisation, and definition of safety V2X applications.

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APPENDIX

Table 10.
List and description of crash databases used

Database	Country Covered	Database type	Description
CARE	**Europe**	High level	Community database on road crashes resulting in death or injury (no statistics on damage-only crashes).
IGLAD	**Europe**	In-depth	Community database on EU road crashes. It was developed containing crash data according to a standardised data scheme that enables comparison between datasets from different countries.
DESTATIS	**Germany**	High level	National data on road traffic crashes recorded by the police. The DESTATIS data are easily used to weight the GIDAS data.
GIDAS	**Germany**	In-depth	GIDAS is the German study for in-depth traffic crash data collection and stands for German in-depth Crash Study. This database reaches up to 3,000 encoded parameters per crash.
BAAC	**France**	High level	National Road injury traffic crashes database based on police reports file (Bulletin d'Analyse des Accidents Corporels).

Table 11. Overview of the main crash scenarios selected and studied (GIDAS)

This table is only an overview of the detailed analysis conducted in SECUR WP1. Please refer to deliverable D1.2 for the full results.

OVERVIEW OF MAIN CRASH SCENARIOS STUDIED (GIDAS 2020)

			Weather condition	Light condition	Road surface	Obstruction	Topology	Traffic regulation	Traffic density	Accident cause	Initial Speed	Deceleration	Radius of curve	Human failure
	Crash Scenario **(For**	**OPPONENT**	NP : No Precipitation R : Rain S : Snow	DL: Daylight DN: Darkness/ Dawn	DR: Dry W: Wet D: Damp S: Snow I: Ice	N: No Y: Yes SC: Structural Circumstances VH: Vehicle (Driving/ Starting/ Waiting/ Parking)	Main topology I: Intersection SL: Straight Line	NR: No Regulation ORW: Observe right of way TL: Traffic Light ST: Stop sign RRW: Right as right of way	LS: Light/Sporadic D: Dense TJ: Traffic Jam/stop and go	FP : Failure to observe the traffic signs regulating the priority FPL: Failure to observe the traffic lights/policemen regulating the priority MEF: Mistake Entering the flow of traffic IB: Improper behavior of the pedestrian S: Speed MD: Mistake made by the driver (e.g. distraction) ID: Insufficient Safety Distance TL: Turning Left Mistake WW: Wrong Way Driving AD: Ability to drive (alcohol, overfatigue)		BP: Breaking Percentage MV: Median value of breaking NA: No Action LD: Low Deceleration	MR: Main Radius	Y: Yes N: No
1	**Oncoming**	**PC**	NP: 85% R: 13% S: 2%	DL: 71% DN: 29%	-	N: 91% Y: 9% (SC: 53%; VH: 37%)	I SL	-	LS: 75% D: 23%	TL: 46% WW: 11%	Ego: 26-75kph (81%) Opp: 0-56kph (81%)	-	-	Y: 75% N: 25%
2	**Straight Crossing Path – Right Direction SCP-RD**	**BC**	NP: 92% R: 7%	DL: 87% DN: 13%	-	N: 65% Y: 35% (SC: 69%; VH: 27%)	I	ORW: 55% TL: 9% ST: 8% NR: 7% RRW: 5%	LS: 80% D: 17%	FP: 58% MEF: 16%	Ego: 0-35kph (80%) Opp: 6-20kph (82%)	-	-	-
3	**Straight Crossing Path – Right Direction SCP-RD**	**PC**	NP: 86% R: 13%	DL: 74% DN: 26%	-	N: 70% Y: 30% (SC: 50% and VH: 46%)	I	ORW: 52% TL: 19% ST: 11% RRW: 11%	LS: 79% D: 18%	FP: 86% MEF: 6%	Ego: 21-70kph (81%) Opp: 0-50kph (86%)	-	-	-
4	**Straight Crossing Path – Right Direction SCP-RD**	**PD**	NP: 87% R: 11%	DL: 74% DN: 26%	-	N: 61% Y: 39% (VH: 76%; SC: 18%)	SL I	NR: 54% TL: 20% ORW: 14%	LS: 73% D: 21%	IB: 56%	Ego: 16-55kph (80%) Opp: unknown (pedestrian)	-	-	-
5	**Straight Crossing Path – Left Direction SCP-LD**	**PD**	NP: 83% R: 16%	DL: 60% DN: 40%	-	N: 60% Y: 40% (VH: 77%; SC: 9%)	SL I	NR: 51% TL: 22% ORW: 16%	LS: 75% D: 21%	IB: 54%	Ego: 16-55kph (80%) Opp: unknown (pedestrian)	-	-	-
6	**Loss of Control in Curve**	**NONE**	NP: 73% R: 21% S: 5%	-	DR: 45% W: 22% D:20% S: 7% I: 6%	-	-	-	LS: 90% D: 9%	S: 77% MD: 12%	Ego: 46 - 100kph (80%) >100kph: 10%	-	MR: 101-200m (33% of LOC-CU)	No: 85% Yes: 15%
7	**Straight Crossing Path – Left Direction SCP-LD**	**PC**	NP: 86% R: 13%	DL: 73% DN: 27%	-	N: 73% Y: 27% (SC: 60% and VH: 40%)	I	ORW: 44% TL: 25% ST: 12% RRW: 17%	LS: 80% D: 17%	FP: 91%	Ego: 11 - 60kph (80%) Opp: 16 - 60kph (78%)	-	-	-
8	**Loss Of Control in Straight Line**	**NONE**	NP: 73% R: 21% S: 5%	-	DR: 45% W: 22% D:20% S: 7% I: 6%	-	-	-	LS: 90% D: 9%	S: 45% MD: 36% AD: 8%	Ego: 46 - 100kph (64%) >100kph: 26%	-	-	No: 81% Yes: 19%
9	**Straight Crossing Path – Left Direction SCP-LD**	**BC**	NP: 88% R: 11%	DL: 80% DN: 20%	-	N: 70% Y: 30% (SC: 57% and VH: 36%)	I	ORW: 50% RRW: 15% TL: 12%	LS: 80% D: 17%	FP: 75% MEF: 11%	Ego: 0-40kph (84%) Opp: 6-25kph (92%)	-	-	-
10	**Rear End - Following vehicle RE-FV**	**PC**	NP: 87% R: 12%	DL: 78% DN: 22%	-	N: 97%	SL	-	LS: 42% D: 37% TJ: 22%	MD: 45% ID: 35% S: 14%	Ego: 26-60kph (64%) >100kph (8%) Opp: 0-50kph (87%)	Ego: BP 77%; NA 18%; MV 5,2m/s² Opp: BP 44%; LD; NA 53%; MV: 0m/s²	-	-
11	**Rear End - Previous vehicle RE-PV**	**PC**	NP: 87% R: 12%	DL: 78% DN: 22%	-	N: 100%	SL	-	LS: 42% D: 37% TJ: 22%	MD: 45% ID: 35% S: 14%	Ego: 0-50kph (87%) Opp: 26-60kph (64%) >100kph (8%)	Opp: BP 77%;NA 18%; MV 5,2m/s² Ego: BP 44%; LD; NA 53%; MV: 0m/s²	-	-
12	**Left Turn Across Path – Opposite Direction LTAP/OD**	**PC**	NP: 86% R: 13%	DL: 68% DN: 32%	-	N: 90% Y: 10% (VH: 66%; SC: 14%)	I	TL: 52% ORW: 38%	LS: 66% D: 31%	TL: 80% FPL: 11%	Ego: 0-40kph (87%) Opp: 36-75kph (80%)	-	-	-
13	**Left Turn Across Path – Opposite Direction LTAP/OD**	**PTW**	NP: 91% R: 8%	DL: 71% DN: 29%	-	N: 86% Y: 14% (VH: 65%; SC: 15%)	I	ORW: 46% TL: 29% NR: 8%	LS:73% D: 24%	TL: 88%	Ego: 0-30kph (81%) Opp: 26-60kph (78%)	-	-	-
14	**Left Turn Across Path – Left Direction LTAP/LD**	**PC**	NP: 84% R: 14%	DL: 76% DN: 24%	-	N: 67% Y: 33% (SC: 43% and VH: 54%)	I	ORW: 69% ST: 10% TL: 6%	LS: 77% D: 20%	FP: 75% MEF: 13%	Ego: 0-25kph (82%) Opp: 26-70kph (83%)	-	-	-
15	**Left Turn Across Path – Left Direction LTAP/LD**	**PTW**	NP: 93% R: 7%	DL: 79% DN: 21%	-	N: 57% Y: 43% (SC: 37% and VH: 60%)	I	ORW: 74%	LS: 71% D: 22% TJ: 6%	FP: 77% MEF: 16%	Ego: 0-20kph (87%) Opp: 26-60kph (79%)	-	-	-