OSCCAR:
FUTURE OCCUPANT SAFETY FOR CRASHES IN CARS

Accident data analysis - remaining accidents and crash configurations of automated vehicles in mixed traffic

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1 EXECUTIVE SUMMARY

The idea of **WP1 within OSCCAR** is to use current accident data and predict traffic scenario as well as crash configurations which automated vehicles will be exposed to. Thereby, the influences of driver assistance and active safety technologies as well as automation are taken into account. Since human error is linked to more than 90% of all accidents, automated vehicles are expected to be involved in considerably fewer accidents and to improve road users' safety by eliminating accident causation factors related to human driver errors, e.g., speeding, right of way violations or inattentive driving. The greatest challenge is to predict which accident types will remain relevant. The accidents expected to remain are analysed and clustered in a further step to provide crash configurations. Depending on the vehicle characteristics, derived crash loads then provide the basis for deriving requirements for future restraint principles in OSCCAR WP2. Furthermore, the relevant future crash configurations and loads will be used as the starting point of the virtual occupant safety assessment toolchain and homologation scenario developed in OSCCAR WP4.

The **WP1 overall methodology** applied and described here in deliverable D1.1 is firstly estimating the remaining accident scenarios at the time of initial introduction of automated vehicles. In a second step analysing remaining accident scenarios in a simulation study to predict future collisions and corresponding crash configurations. For the initial step, we start by determining a possible, optimistic scenario for market introduction and market penetration of automated vehicles. Thereafter, we evolve from current European accident statistics by two different approaches, bottom-up and top-down, to predict remaining collisions. While the bottom-up approach addresses the impact of advanced driver assistance systems to estimate the future accident situation, the top-down approach is identifying causation factors related to human error, e.g., single accidents clearly linked to traffic rule violations. These accidents are assumed to be inherently avoided by automated vehicles. The remaining accidents lead to two specific accident scenarios which are analysed in great detail in a specifically designed simulation setup. The scenario simulation serves two purposes: firstly, it gives insight into remaining accidents within the accident scenario to further refine the prediction of future accident statistics and secondly, it provides crash configurations specific to the scenario by location (urban, motorway). The crash configurations will be clustered to identify a small number of representative configurations. The cluster representatives will be convoluted with future seating arrangements in the vehicle interior in WP2 to obtain a basis for the development of future occupant restraint principles.

The automated driving functions considered in OSCCAR WP1 are closely aligned with state-of-the-art **safety impact assessment** from previous EU and national projects (AdaptIVe, PROSPECT, PEGASUS) and relevant publicly available literature related to automated driving concepts. In particular, literature includes papers as "Voluntary Safety Self-Assessments" published by the NHTSA and the "Mobileye Model of Safe and Scalable Self-driving Cars" by Mobileye Technologies Limited. Based on these sources, we identify an "OSCCAR highway pilot" and an "OSCCAR urban self-driving car" as relevant functions and model the functionality to predict potential future collisions for both functions.

The **results** presented in OSCCAR WP1 deliverable D1.1 as follows

- The optimistic scenario of market penetration of automated cars predicts an equal distribution of automated and conventional passenger cars at the earliest in 2045 in roads within the European Union. Thus, automated cars for a long time will be faced with an accident situation comparable to the current accident situation. Nonetheless, crash configurations for the automated car may alter.

- The main remaining accident scenarios of automated vehicles, determined either by a bottom-up or a top-down approach, seem to show similar accident types for all analysed European countries (France, U.K., Germany). In urban areas the most prominent accident scenario is a collision while turning into another road or crossing. For motorways, the most prominent scenario is a front-to-rear-end collision.
- Based on the German accident situation, the top-down approach reveals that every fourth accident with casualties is caused by violation of the traffic rules. Those accidents are assumed to be inherently avoided by an automated car. Extrapolating to European countries and based on accident statistics of the year 2017, this could relate to a field of effect of about 290 000 fewer accidents with casualties annually if every vehicle would be automated.
- Re-simulation of reconstructed accidents imposing a simple virtual simulation model colliding with a human driven car, reveals large avoidance potential if the main causer of the original collision was replaced by the automated vehicle, ranging up to more than 90% at crossings. However, we expect that future automated cars will be involved in collisions, either caused by other traffic or by being faced with such an advert situation the automated car cannot avoid the collision. Thus, further improving protection principles for occupants in automated cars, especially in novel seating positions, is required.
- Clustering of remaining collisions of the simulations identified representative cases for each scenario. Example crash configurations for the WP2 demo test case of remaining intersection collisions are a frontal left oblique impact of a “left turn across path – opposite direction” scenario and a right side edge impact of a “straight crossing path” scenario.

Limitations within the WP1 approach and results include that the market penetration is estimated quite rough and is possibly associated with large uncertainties, an equal distribution between automated and conventional cars is assumed not before 2045 in spite of an optimistic nature of the estimations. Moreover, the identified scenarios, front-to-rear and side collisions, might lose in importance compared to other collisions. With regard to simulation results, the limitations become more prominent. The simulation results strongly depend on case selection (restricted to well reconstructed accidents in Germany and Sweden without extrapolation to national accident statistics), automated driving functionality (e.g. restricted to a TTC based automatic emergency braking system) and parametrization (e.g. fixed to an emergency braking threshold of 1.2 s). The clustering method just obtains one point for each cluster based on frequency; it is subject to the upcoming OSCCAR simulation studies and the iterative discussion of protection principles in WP2 to determine what will be most relevant.

The aim for the **D1.1 results** is to serve as an urgently needed starting point and guidance within OSCCAR in terms of insights on future crash configurations. Thereby, the other OSCCAR work packages know what the protection principles need to deal with and what the assessment tools (HBMs and crash test dummies) and procedures need to be capable of. These results were derived from current knowledge of automated functions potentially coming to the market and currently available accident data, but the flexible methodology developed in the process (including the grading scheme of test cases in WP2) is capable of incorporating future insights regarding accident predictions. Until the end of the project, WP1 will focus on addressing the limitations above and develop more advanced scenario models of the specific situations above, making use of the open source approach of the multi-agent simulation openPASS.

2 OVERVIEW ON WP1

2.1 Motivation

Since human error is involved in more than 90% of all traffic accidents on European roads (European Commission, 2016), the introduction of automated driving (AD) is expected to increase road transport safety by mitigating crash severity and decreasing the risk of accidents. At the same time, novel safety challenges need to be considered. These include changed accident scenarios for future mixed traffic where automated vehicles and conventional driven vehicles share the same infrastructure and roads. Uncertainty exists regarding the introduction phase leading invariably to mixed traffic scenarios, especially since many other underlying “mega trends” (connectivity, electrification, infrastructure) are influencing future mobility, too.

Accident data for automated vehicles to learn from is due to the comparably low mileage not available. The Department of Motor Vehicles in the State of California, where testing of automated vehicles on a larger scale is allowed, collects and publishes each “Traffic Collision involving an Autonomous Vehicle” (State of California, 2019). This “accident database contains n = 139 collisions so far, but the status mainly shows: relevant injury accidents in general are very rare events, so any data collection will never be able to measure or proof the safety impact or effectiveness of automated driving functions in sufficient time.

In its online publication “ Automated Driving 2.0 – A Vision for Safety”, the NHTSA provides voluntary guidance on the recommended crashworthiness of vehicles automated driving systems due to mixed traffic conditions: “Given that a mix of vehicles with ADSs and those without will be operating on public roadways for an extended period of time, entities still need to consider the possible scenario of another vehicle crashing into an ADS-equipped vehicle and how to best protect vehicle occupants in that situation.” (NHTSA, 2019)

At the same time, AD technology will allow the vehicle to become a platform for the occupants, especially the driver, to use their travel time for other activities. New interior concepts embrace these changes and aim for maximum relaxation or new communication opportunities. Automated driving might only gain full acceptance if these changes are allowed, so safeguarding the occupants in new seating and sitting positions and postures could be a crucial enabler for the overall safety benefit of an automated transport system.

The goal is to predict what accidents highly automated vehicles will be exposed to and how those crash configuration can be categorised. This is needed to guide the development of new protection principles for the occupant of such vehicles as well as the assessment tools, i.e., virtual human body models and well as traditional crash dummies.

2.2 State of the art: predicting remaining collisions

The approach in OSCCAR to determine future remaining accident scenarios is closely related to the prospective effectiveness assessment of ADAS or safety systems. Such simulation studies aiming to determine potential safety benefits have been conducted in multiple research projects such as Aspeccs, PROSPECT, AdaptIVe or interactIVe. Unlike these previous projects, OSCCAR does not focus on further analysing the avoidance potentials of safety technology compared with human error caused accidents but rather to investigate the remaining accidents and group them, in terms of crash configurations. The results (“future accidents”) are an assumption for remaining collisions in mixed traffic, where a model of an AD function would not virtually avoid the accident.

Recent research projects in this field use real world accident data to derive a limited set of test scenarios in order to reuse them in test setups (e. g-. PROSPECT) or for simulation studies and tool development (e.g. SENIORS, SafeEV, AdaptiVe, PEGASUS). Regarding simulation tools that allow prospective assessment of safety functions, state of the art are various tools that allow static scenario descriptions including environment models (TASS Prescan, VIRES, etc.) and various statistical models to carry out traffic simulation with a broad spectrum of vehicle positions and velocities, e.g. the open-source assessment framework openPASS or various in-house tools such as PREADICO. The “PEARS initiative” (https://pearsinitiative.com/) started as an open harmonization project in this field and provides technical input on that matter for an ISO subgroup. However across this field of research, there are no standardized and established procedures and interfaces for carrying out these pre-crash or traffic simulations.

The accident scenario definition in SafeEV (Task 1.1 in WP1, (SafeEV website, 2013)) was most similar to the role of WP1 in OSCCAR, since here, potential changes of the requirements due to new vehicle concepts were predicted, too. The approach based on accident statistics and conducted what-if studies to estimate pedestrian accident scenarios involving small electric vehicles based on the urban mobility use case of these vehicles. The EU FP7 project AdaptIVe (see section 3.1.1) focused on developing various automated driving functions for daily traffic by dynamically adapting the level of automation to situation and driver status. Further, the project addressed legal issues that might impact successful market introduction and assessed the impact of automated driving on European road transport (see website). The German PEGASUS project (see section 3.1.1.2) aims at the development of an assessment methodology and tool chain for virtual and physical testing and releasing automated drive (AD) functions. Similar to AdaptIVe, the scope of PEGASUS does not consider occupant injury risk as from the view of passive safety measures, but on avoidance or speed reductions metrics. However, the method systematically tests the system performance in traffic scenarios along the functional boundaries of the tested functions, which inevitably leads to unavoidable collisions. Hence, these situations, in which the vehicle with the tested function collides with a target, are the starting point for OSCCAR.

Details of these projects (AdaptIVE, PEGASUS, PROSPECT) and other literature is discussed regarding how it motivates the approach in WP1 / this deliverable D1.1 in section 3.1.3.

2.3 Approach and work plan

The idea of WP1 in OSCCAR is to make use of current accident data and predict how traffic scenario as well as the type of accidents AD vehicles are supposed to be exposed to, taking into account the influences of driver assistance and active safety technologies as well as automation. This leads to “future accident scenarios” (see Figure 1). The predicted collisions that are expected to remain are further interpreted to derive crash configurations (“load cases”), from which requirements for future collision principles can be derived. For example, a large share of front-to-rear collisions within the operational domain of an AD vehicle concept were expected to be avoided in a future traffic scenario, while side impacts are unavoidable in mixed traffic due to human opponents crashing into the vehicle’s side. Hence, the future crash configurations of AD vehicles should reflect this vehicle specific shift in accident frequency and accident severity and the protection principles could be adjusted to what remains relevant.

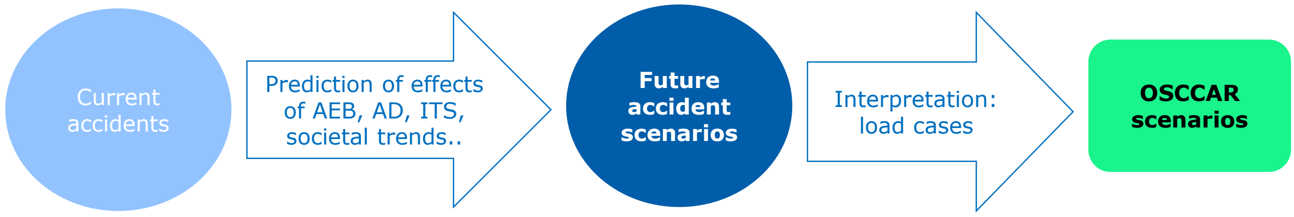


Figure 1: Overview OSCCAR WP1 workflow

The overall research question of WP1 is a two-fold question

- A) On a macroscopic level, we want to answer how the "general" accident situation will be when automated cars are introduced
- B) On a microscopic level, we assess in which accidents the automated vehicle will be involved into and how will the crash configurations look like

Even though answering A) goes beyond the scope of OSCCAR - without an answer to the first part – how many and which accidents will be avoided? - , it is hard to justify the selection of crash configurations for B). The method to answer the second – the "microscopic" – part of the question however can be implemented in terms of a selection method within remaining accidents – so if results from A) comply to the input interface of B), the overall toolchain can justify the specific selections of B).

During the project, there are two different methodologies applied, answering this question A) in two manners. First in D1.1 with preliminary crash configurations, later in D1.3 with a more sound prediction. In the beginning of the project, the WP 3 (focusing on tool development) and WP2 (focusing on occupant protection principles) need a sound and relevant starting point; resulting crash configurations in D1.1 must not be validated and exact, but a "good guess". This means the focus of this approach is on interpreting existing retrospective accident data – what will remain, what is potentially avoided by excluding human error or better reaction times. However, even though the pragmatic approach of re-simulating trajectories of real accidents has advantages (time, effort) and works for evaluating avoidance and mitigation potentials, it has limitations and is not applicable for understanding more complex impact mechanisms or continuous support. For instance, it only contains the behaviour of two participants and the reconstruction might not grasp the real character of the traffic situation. Hence, other options will be taken into account in a later stage in OSCCAR.

<u>Phase 1 => D1.1: Estimate remaining accidents</u>

- **Methodology**: the agreed approach to determine remaining accidents was to apply a "OSCCAR_AD_virtual_model" onto accident data by filtering accidents an AD would not cause (e.g. those related to violation of traffic rules) and run pre-crash simulation of the other cases to determine whether an emergency manoeuvre would have an effect.
- **Accident data analysis:** the starting point was a discussion on how to reflect safety minded driving and rule-compliant behaviour. Inherent avoidance is used as filter of accident causation for German, Swedish and European iGLAD data. In parallel, two studies on national French and UK accident data with slightly different approach are aiming to predict the accident situation in these markets with high ADAS market penetration and hence, large scale avoidance effects.
- **Pre-crash simulation of trajectories with AEB-like system model**: the simulation studies (highway scenarios and urban intersection for GER and SWE) amend the accident causation analysis in order to determine whether an emergency manoeuvre would have an effect.

- **Result of phase 1 in this D1.1** – from the "remaining PCM crashes", crash configurations were defined in a standardized collision data format & single data points extracted with a cluster analysis approach.
- These crash configurations are combined in the T2.1 Test Case Methodology with so called "Use Cases", hence all potential occupant and interior features that future vehicle concepts might bring forward. These test cases allow the other WPs to discuss protection principles and – once crash pulses are available - to run simulation studies, evaluating these new concepts with improved HBMs.

Furthermore, the "phase 1" covered the review of relevant research projects and publications with regard to safety of automated driving concepts and selected two exemplary functions (urban self-driving car and highway pilot).

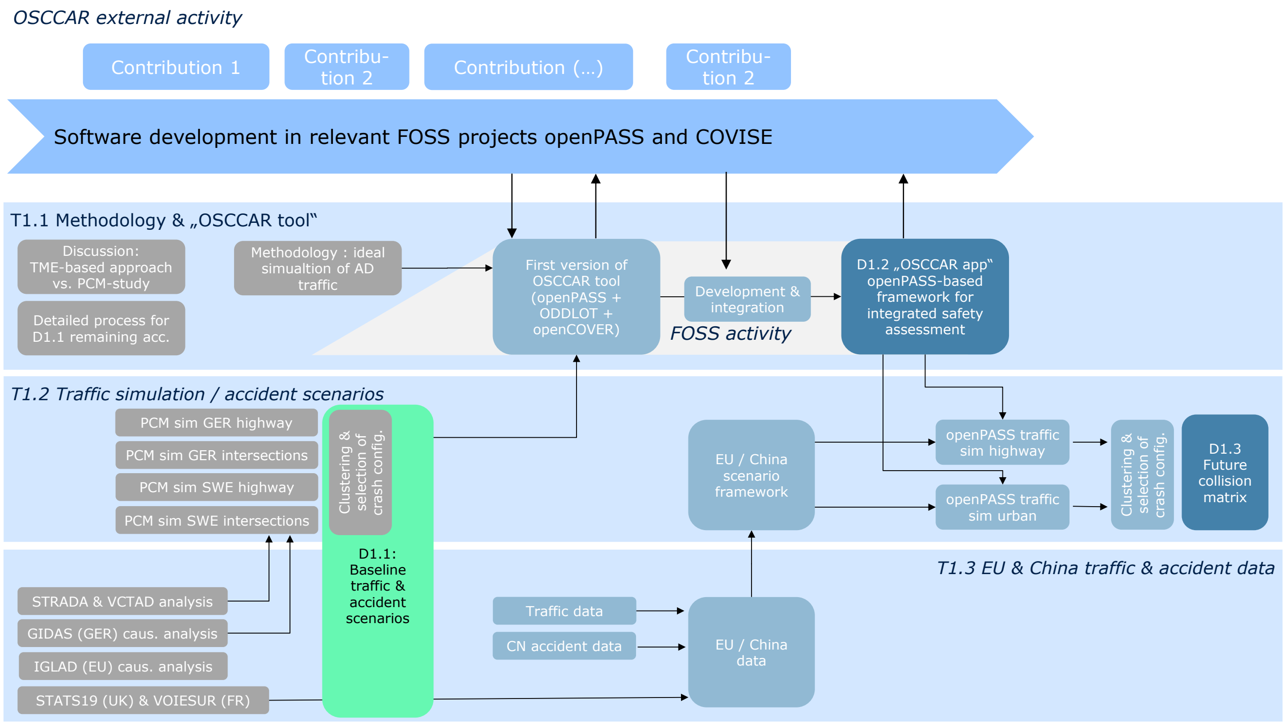


Figure 2: Detailed OSCCAR WP1 workflow

After the delivery of a first set of crash configurations in the D1.1, the WP1 work will continue and focus until the end of the project on the detailed answer to the question what is expected to remain (final WP1 results: D1.3). The WP1 partners will re-use parts of the work from the first phase (scope definition: highway and urban automated driving, pre-processed data, evaluation approach towards crash configurations), but use complex scenario components from openPASS to develop OSCCAR specific scenario / traffic models that provide more detailed aspects and variations of potential future mixed traffic with automated vehicles. However, the results – prediction of remaining crash configurations – are the same in terms of format and selection process, hence the Test Case Methodology will be applied again.

<u>Understanding future accident scenarios (Phase 2):</u>

- Same as phase 1: scope definition: highway and urban automated driving, pre-processed accident data as boundary conditions for scenario models

- New in phase after D1.1: experimental concept of multi-agent traffic scenarios according to traffic data, incorporating conflicts potentially leading to accidents
- New in phase after D1.1: experimental design – EU upscaling (integrating results, mix of “intelligent agents” and certain agents with deterministic behaviour of by means of pre-defined scenario definition (OpenScenario)
- New in phase after D1.1: incorporation of flexible scenario variations (different penetration rates, ADAS vs. AD, different vehicle types, ITS/connectivity options)
- New in phase after D1.1: full-scale AD model (open source implementation of Mobileye model?) for impact simulation of all driving phases; if needed, OEM internal co-simulation possible
- New in phase after D1.1: addressing possible variations of traffic situations with a stochastic approach
- Same as phase 1: standardized collision data format & cluster analysis approach
- Result of phase 2: “future accidents” of generic AD functions

By developing on top of the open-source scenario simulation platform openPASS, OSCCAR will create virtual scenario models based on relevant accident and traffic statistics in a pre-crash simulation environment available for all partners. OSCCAR scenarios will consider the whole scope of automation from free traffic flow to accidents instead of just parts of the reconstructed pre-crash phase by using the open format OpenSCENARIO which allows to separate between the “pre-crash phase logic” (described in generic XML templates) and the parameters coming from real world data (e.g. statistical distributions). While the current status of openPASS allows for traffic simulation of linear roads only (hence, mainly traffic scenarios relevant for an automated highway function), the OSCCAR WP1 may take up further improvements becoming available in the course of the project.

An added value of OSCCAR will be to deliver open-source “virtual accident scenario models” to the R&D community by improving and amending the assessment framework openPASS. So new components could be used beyond the scope of OSCCAR (e.g. projects focusing on VRU safety in mixed traffic) and improve the overall functionality of openPASS.

In the longer run of the project, the focus is further to contribute to the OSCCAR simulation tool chain for the integrated assessment of active and passive safety. State of the art is a separation between assessments of active and passive safety in accidents. Tools from different specific areas should be capable of being integrated or used alternatively: vehicle dynamics simulation (Siemens PLM), accident-based safety system assessment (in house tools), 3D visualization (COVISE) and assessment frameworks for traffic scenario simulation (openPASS).

For further details and how this approach is addressing the limitations of the D1.1 approach, see section 8.1.2

2.4 Contributions in OSCCAR WP1 deliverable D1.1

Mainly the partners BOSCH, Daimler, Autoliv, Volvo, TU Graz, Chalmers and Toyota Motors Europe were involved as contributors to this report. The methodology that was applied and documented in this deliverable was developed based on regular telephone conferences and two physical meetings with all partners. The section with the literature review in this report on related projects and further studies on automated driving functions was done by Daimler with input on the H2020 project PROSPECT from Chalmers. The work with accident data in sections 4 and 5 as well as the respective Annexes on the full technical details were contributed by the following partners: the iGLAD analysis and overview on databases by TU Graz, Stats19 and VOIESUR by Toyota Motors Europe, GIDAS analysis and discussion on accident causation by Bosch and Autoliv, the framework and summary on what is expected to remain was contributed by Bosch. The pre-crash simulation study and the generic automated driving function models were described by Bosch with input from Daimler, Autoliv and Volvo. This accounts for the results as well. The outlook summarizes feedback from the internal review and was provided by Bosch and Daimler.

3 LITERATURE

As described in the previous section, the approach in OSCCAR to determine future remaining accident scenarios is closely related to the prospective effectiveness assessment of ADAS or safety systems. Demonstrating this methodological link is the main purpose of this literature review.

However, the wider focus is on multiple points:

- What generic or publicly available descriptions of automated driving functions are there in terms of system logic, system parameters and system limitations?
- What considerations regarding their safety impact in terms of addressing which accidents were made in these sources?
- How do the respective assessment methods define their scope and steps, how do they link data, models and simulation tools?
- Are there any considerations regarding interpreting these finding in terms of crashworthiness of automated driving?

3.1 Related research projects

The projects we consider in this literature review are:

- AdaptIVe
- PEGASUS
- PROSPECT

3.1.1 AdaptIVe

The general objective of the FP7-EU project AdaptIVe was to develop and demonstrate new automated driving functions at different automation levels. These functions cover different driving scenarios and speed conditions aiming at improving safety, energy efficiency, dependability and user-acceptance of automated driving. The subproject "Evaluation" (SP7) was a horizontal activity within AdaptIVe supporting the vertical subprojects that focuses on the development of the automated driving functions. The part of the evaluation framework relevant to OSCCAR concentrates on the analysis of future benefits with respect to safety and environmental aspects (Fahrenkrog, Wang, Rösener, Sauerbier, & Breunig, 2017). The results of the safety impact assessment of the AdaptIVe highway pilot show a 43% reduction of accident risk for German highway accidents.

Results and insights of AdaptIVe relevant to OSCCAR are:

- The project described and evaluated relevant automated driving functions in terms of generic models (highway pilot, urban self-driving car) which can be referenced.
- In the work package SP7, results from accident data analysis in combination with further scenario analysis methods are used to determine the "top scenarios", i.e., the scenarios to be further investigated by traffic simulation.
- The impact assessment was conducted based on traffic simulation with openPASS traffic scenario and driver models that incorporated insights from real-world accident and traffic data.

3.1.1.1 Methodology

At the beginning of AdaptIVe in 2014, the review of assessment methods - as currently used - showed the need for new methodology besides hardware-in-the-loop procedures (e.g., for sensor / algorithm testing), testing of technical and human factors (e.g., driving simulator, test track, test rigs) and real-traffic testing (e.g., controlled studies, field operational tests, observational studies). Each of those test procedures solely assesses a function on a particular small subset of processes with singular factors influencing the traffic safety. Due to these limitations of conventional methods with respect to the above mentioned requirements, AdaptIVe identified the need for a new methodology.

Hence, in AdaptIVe, a virtual assessment method has been developed and was applied. It combines a scenario-based stochastic simulation with a continuous operation simulation that promises to meet all fundamental requirements adequately.

Figure 3 shows how this methodology was followed step-by-step: from literature review and accident data analysis, the driving scenario definition led to challenging scenarios for automated driving, the “Top scenarios”. For these identified “Top scenarios”, a stochastic traffic model including a human behaviour model (the “SCM” – stochastic cognitive model) was set up to compare the accidents in human traffic with traffic including the automated driving function. Different scenario variables (environment, road layout, traffic state) were varied stochastically.

The results were presented by means of the survivorship curve (Kaplan-Meier curves) comparing the human driver (vehicles driving by the SCM driver model) with the automated driving function. The Kaplan-Meier curves were determined by analysing for each simulation run, whether a collision of the relevant vehicles was detected and – in case of a collision – at which point of time the collision occurred. In the second step for each point it was calculated how many of the simulation runs remained collision free. By this approach, the overall benefit of a system was assessed.

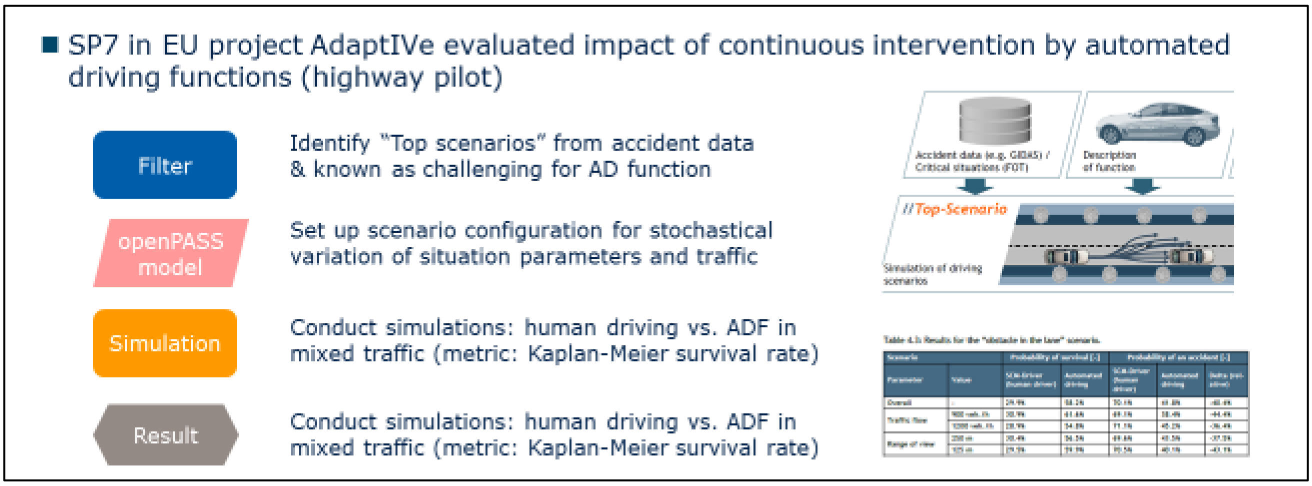


Figure 3: General methodology of AdaptIVe (own figure)

3.1.1.2 Accident data analysis

As stated above, the SP7 partners in AdaptIVe used both GIDAS and German national data to first determine challenging traffic situation for automated vehicles, and second, to determine the overall frequency of these “Top Scenarios” in order to integrate the results.

In the GIDAS database (Version January 2016), n = 1 080 cases in which a passenger car was involved in a motorway accident were analyzed. Based on the accident type, “Top 7 scenarios” were aggregated, of which “rear-end accidents” (17.7%), “cut-in” (16.1%) and “approaching traffic jam” (14.4%) were the most frequent accident situations in this data query (Figure 4).

Driving Scenario		Accident type according to GDV classification (GDV, 2016)	Proportion of accidents in GIDAS (N=1,080)
Top 1	Cut-In	631, 632, 635, 639, 641, 646, 649, 231, 232, 233	16.1%
Top 2	End in Lane	633, 643	1.1%
Top 3	Obstacle in the lane	731, 732, 741, 742, 751	3.3%
Top 4	Approaching Traffic jam	611, 612, 613, 614, 619, 642	14.4%
Top 5	Motorway entrance	305, 315	1.8%
Top 6	*Rear-end accident*	601, 602, 603, 604, 609, 621, 622, 623	*17.7%*
Top 7	Driving accident	101, 102, 109, 111, 121, 122, 123, 132, 139, 141, 151, 152, 153, 173	*28.0%*
Other	All other accidents	761, 771 651, 699, 762, 763 199, 304, 342, 401, 402, 422, 452, 501, 502, 571, 634, 645, 652, 661, 681, 682, 703, 711, 713, 774, 775, 799	17.6

Figure 4: GIDAS accident data analysis conducted in AdaptIVe (source: AdaptIVe D7.3)

GIDAS only represents accidents from the Dresden and Hanover regions, but the GIDAS data can be weighted according to the current official German accident statistics. Hence, post stratification was conducted using a common variable in both data sets, the accident character. The resulting data set covered by the “Top 7 scenarios” gained in terms of importance (post-stratified shares: 78.2%; GIDAS 72%) and the order within the “Top 7 scenarios” did not change (Figure 5).

Scenario	Proportion (National accident data)	Proportion (GIDAS)
No Scenario	15.2%	17.6%
Top 1: Cut-in	14.5%	16.1%
Top 2: End of lane	1.2%	1.1%
Top 3: Obstacle in lane	3.4%	3.3%
Top 4: Approaching traffic jam	19.7%	14.4%
Top 5: Motorway entrance	1.4%	1.8%
Top 6: Rear-end	22.7%	17.7%
Top 7: Single driving accident	21.8%	28.0%

Figure 5: Comparison of GIDAS and German national accident data (source: AdaptIVe D7.3)

3.1.1.3 Generic AD functions

The impact assessment was conducted for the functions developed in AdaptIVe. Independent of constraints and limitations with respect to the implementation of the functions, the behaviour in the simulation was approximated as far as possible to the real function behaviour. There was no clear SAE level defined for those functions, but the focus was on modelling the automated behaviour. However, with respect to the occupant use cases, full AD capabilities were assumed.

A generic setup was chosen for the analysis instead of considering a particular implementation of the “automated highway driving function”, due to the fact that implementation among the different vehicle manufactures involved in AdaptIVe differed. Figure 6 shows the available information regarding this function.

Category / Topic	Operation conditions
Road Type	Motorway
Limitations	No construction sites
Conditions, when function is deactivated	Invalid environment model, end of motorway, defect in vehicle, loss of sensor data, loss of software module(s)
Lighting conditions	Day and night
Weather conditions	Normal / light rain
Speed range	0-130 km/h
Sensor range (front / side left / side right / rear)	200 m / 40 m / 40 m / 200 m
Max. / Min. longitudinal acceleration (normal operations)	4,0 m/s² / -4,0 m/s²
Max. / Min. lateral acceleration (normal operations)	3,0 m/s² / -3,0 m/s²

Figure 6: AdaptIVe automated highway driving function (source: AdaptIVe D7.3)

For the “automated urban driving function”, no safety impact assessment was conducted. However, a speed range of 0-60 km/h, acceleration limits and sensor parameters were defined for this urban automated driving function (see Figure 7).

Category / Topic	Operations conditions
Road Type	Urban roads
Limitations	No construction sites
Conditions, when function is deactivated	Invalid environment model, defect in vehicle, loss of sensor data, loss of software module(s)
Lighting conditions	Day and night
Weather conditions	Normal / light rain
Speed range	0-60 km/h
Sensor range (front / side left / side right / rear)	100 m / 40 m / 40 m / 100 m
Max. / Min. longitudinal acceleration (normal operations)	3,0 m/s² / -3,0 m/s²
Max. / Min. lateral acceleration (normal operations)	3,0 m/s² / -3,0 m/s²

Figure 7: AdaptIVe automated urban driving function (source: AdaptIVe D7.3)

3.1.1.4 Results

Following the methodology as described above, multiple simulation runs for each of the Top Scenarios were conducted and aggregated (Figure 8).

- Per definition, single driving accidents that occurred within operation conditions of the system were assumed to be avoided, since "for a correct operating function a road departure can normally be eliminated due to the expected high safety standards of these functions" (see (Fahrenkrog, Wang, Rösener, Sauerbier, & Breunig, 2017).
- For the other six "Top 7" scenarios, it was calculated how many of the simulation runs remained collision free.
- The results of the safety impact assessment of the AdaptIVe highway pilot show a reduction of 43% change of accident frequency for German highway accidents.

- Results per top scenario of an exemplary automated driving function:

	// Top 1 Cut-In	// Top 2 End of Lane	// Top 3 Obstacle in the lane	// Top 4 Traffic jam	// Top 5 Highway entrance	// Top 6 Rear-end accident	// Top 7 Single driving accident[2]
Mean determined effect in the simulation	-83%	-14%	-40%	-40%	-49%	-73%	-100%
Accidents within the operation conditions[1]	72% (92%)	67% (83%)	78% (97%)	80% (89%)	95% (95%)	69% (96%)	67% (93%)
Expected change in the accident risk per scenario	-60% (-76%)	-9% (-12%)	-31% (-39%)	-32% (-36%)	-47% (-47%)	-51% (-70%)	-67% (-93%)

Figure 8: Results of the AdaptIVe impact assessment (source: AdaptIVe D7.3)

3.1.2 PEGASUS

In order to approve automated driving functions within the next years, new and harmonized quality standards and methods need to be developed –by close cooperation between research and industry. This is what the joint PEGASUS project, promoted by the German Federal Ministry for Economic Affairs and Energy (BMWi), is standing for: "**p**roject for the **e**stablishment of **g**enerally **a**ccepted quality criteria, tools and methods as well as **s**cenarios and **s**ituations for the release of highly-automated driving functions". The objective is to develop a procedure for testing of automated driving functions in order to facilitate the rapid implementation of automated driving into practice.

Results and insights of PEGASUS relevant to OSCCAR:

- The function chosen for the methodology development was a "Highway Chauffeur". It was described in much detail to allow for detailed requirements regarding the approval method. For a detailed overview, see Figure 9.
- Similar to AdaptIVe, accident data was analysed in order to learn from real-world data for the scenario catalogue.
- In principle, this approach would deliver the input data in terms of remaining accident needed for OSCCAR, hence the "active safety safeguarding" of automated driving in PEGASUS and the "passive safety safeguarding" envisioned in OSCCAR complement each other. All "PEGASUS test cases" not avoidable by the function under tests would be the "future AD vehicle accidents".

However, development processes in the automotive industry do not allow for sequential procedures, so simulations and other studies are required to predict and model potential collisions of future automated driving concepts.

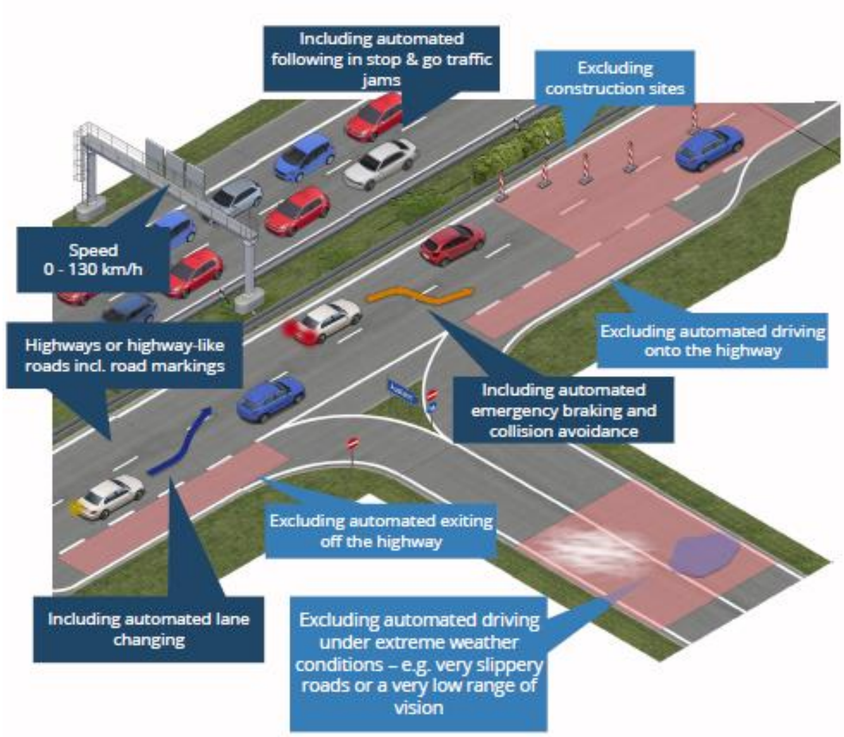


Figure 9 – PEGASUS function "Highway Chauffeur" (source: PEGASUS website)

3.1.2.1 Methodology

The procedure development is divided in four sub projects, which have dedicated roles: the SP1 and SP3 are delivering the content in terms of scenarios, criteria and tools, while SP2 and SP4 are evaluating the soundness of the approaches of SP1 and SP3, respectively.

Brief descriptions of the four SPs, shown in Figure 10, follow below. For full details, please see the website (PEGASUS, 2019)

- "The subproject 1 "Scenario analysis & quality measures", through the example application highway-chauffeur, defines methods for the derivation of relevant traffic scenarios based on generalized criticality, assesses the criteria and measures of the assessment of human and machine performance."
- "The subproject 2 "Implementation processes" analyses existent processes, which have already been established in the automotive industry, regarding the safeguarding theme and prepares the actual testing, in the form of modified development processes. This leads to a newly extended process methodology."
- "The subproject 3 "Testing" prepares methods and tools for carrying out tests in the laboratory, at the testing site as well as in real traffic situations and then demonstrates these in a practical manner. This incorporates setting up a test case database and implementing the evaluation chain based on the criteria as defined in SP1."
- "The subproject 4 "Result reflection & embedding" verifies that the results and procedures can also be transferred to further applications and higher automation levels, and that the tools and processes developed within PEGASUS can be integrated into the company."

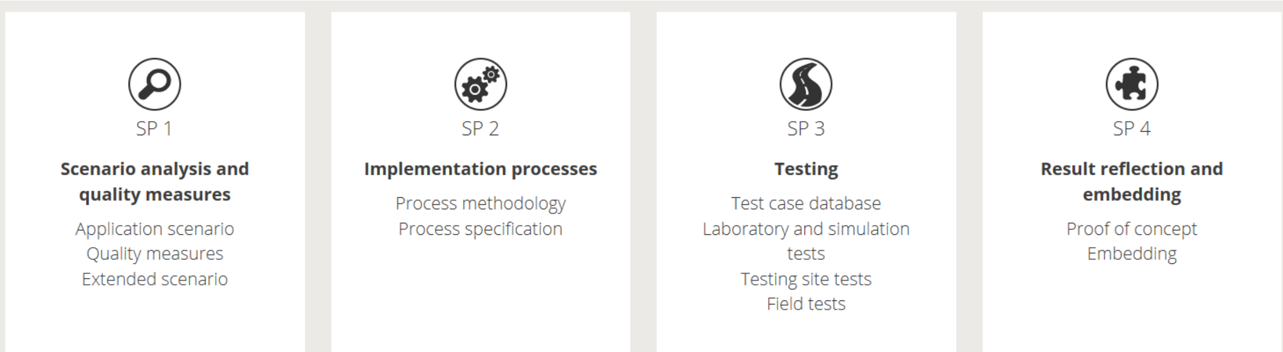


Figure 10: Work package structure of PEGASUS (source: PEGASUS website)

3.1.2.2 Accident data analysis

As part of SP1, GIDAS data (version: January 2017) was analysed to identify so-called additional "logical scenarios". The domain restrictions of the "PEGASUS Highway Chauffeur" and further system restrictions like the influence of weather were considered, such as cars without trailer on motorways and motorway-style roads. Five main filter were applied:

1. The velocity before reaction of the driver was less than or equal to 130 km/h,
2. The lane markings are existent and in good condition,
3. The road has no potholes (as cause of the accident),
4. The car is not driving on a ramp,
5. Further restrictions e.g. the influence of weather.

The remaining set of GIDAS cases (n = 918 cars) was considered for further analysis in the process of pre-filling the PEGASUS scenario database. Further studies focused on "human factors" in order to investigate the influence of human efficiency.

For more information, please see the respective symposium poster (PEGASUS, Accident data analysis, 2019).

3.1.2.3 Generic AD functions

The purpose of a common system definition (document similar to a requirement specification) in PEGASUS was to plan criteria and test procedures "around it" and to gather ideas what could potentially be relevant for the PEGASUS methodology.

The SAE level 3 function is described in terms of role definitions of human driver and automated driving function, basic functionality (keeping speed, following other traffic participants, changing lanes, etc.), exclusion of certain driving manoeuvres, requirements to activate the function and system boundaries (see Figure 9).

For full information, please see the respective symposium poster (PEGASUS, Generic AD functions, 2019).

3.1.3 PROSPECT

The aim of the H2020 project PROSPECT was to develop active safety systems for the protection of vulnerable road users (VRUs) with an improved effectiveness compared to those currently on the market (PROSPECT, 2019). Of primary interest was the protection of cyclists and pedestrians using autonomous emergency braking and/or steering functions in different scenarios, based on expanding the scope of scenarios addressed by the systems and advanced algorithms. The project was finished at the end of 2018 and at the time of writing this report, the final deliverable is not publicly available yet. Therefore, instead of a detailed description of results, what follows is a brief summary of the method for scenario definition and the application of simulation results for benefit assessment.

3.1.3.1 Methodology

The project started with the identification of the most relevant scenarios for VRUs, based on crash data and naturalistic observations. This task gave input to system specifications, which in turn was used to address sensor processing and control strategies to aid the development of the concepts of the systems for VRU protection. During the project, prototype systems were built and demonstrator vehicles equipped with the systems were tested on closed test tracks. Additionally, simulations with the rateEFFECT tool (and with openPASS for one scenario) were performed based on the system specifications, and an assessment method was developed for the estimation of the expected socio-economic benefit of the developed systems, based on a combination of simulation results and test results.

In Sections 3.1.3.2 and 3.1.3.3, the selection of relevant scenarios and the safety benefit assessment method are summarized briefly as these parts are considered most relevant for the purpose of OSCCAR in general and this deliverable in particular.

3.1.3.2 Accident data analysis

The analysis started with a general investigation of crashes with VRU involvement, based on high level results from CARE and more detailed national crash data from Sweden, Germany and Hungary. Most car-to-cyclist crashes occurred during daylight and in clear weather conditions. Substantial differences were found between the countries with respect to scenarios for slightly and seriously injured cyclists. For fatalities, the most relevant general scenario is that the car is traveling straight and the cyclist is moving in line with the traffic.

The level of detail for this general analysis was limited by the information available and comparability between different national databases. Therefore, the results were complemented with more detailed information from in-depth crash databases, including the German In-Depth Accident Study (GIDAS), in-depth data from Pest county (Hungary) and the Volvo Cars Cyclist Accident Database (V_CAD) (Sweden).

Additionally, analysing KSI crashes (“killed or seriously injured” crashes in which at least one person was seriously or fatally injured) and all injury crashes between cars and cyclists in GIDAS separately, 29 use cases were derived for KSI crashes and 35 use cases were derived for all injury crashes. The use cases were extrapolated towards the German national statistics based on accident type and injury severity and were ranked based on their projected relative frequency and the associated socio-economic costs. The results up to this point are described in detail in the project deliverables D2.1 and D3.1 (Wisch M. , et al., 2016; Stoll, Schneider, Wisch, Seiniger, & Schaller, 2016) and are summarized in a conference paper (Wisch M. , et al., 2017).

The most relevant use cases were then selected to be implemented in the vehicle demonstrators. This process is described in the project deliverable D3.2 (Kunert, et al., 2016). Specifically, 9 cyclist use cases and 3 pedestrian use cases were selected for consideration and were transformed and generalized in demonstrator-specific use cases with a special focus on perception. After the substantial reduction in the number of use cases, the reduced set of 12 use cases still represents 81% of all KSI cyclists and 36% of all KSI pedestrians (with KSI defined as police-reported injury level PVERL 4 or 5 in GIDAS), and 78% of all injured cyclists (including those with injury levels PVERL of 3, 4 or 5).

3.1.3.3 Safety benefit assessment

The GIDAS Pre-Crash Matrix (PCM) was analysed to identify crashes corresponding to the 12 demonstrator use cases (see Section 3.1.3.2) that contain sufficient information for simulation. Counterfactual simulations using relevant models for PROSPECT sensors and algorithms have been performed on car-to-cyclist and car-to-pedestrian crashes, in order to assess what the crash outcome would have been if the vehicle had been equipped with the investigated technology. Four algorithms of the PROSPECT systems have been modelled and implemented in the counterfactual simulation tool rateEFFECT.

The simulation results were updated with the results from vehicle-based testing on closed test tracks for each use case, based on a Bayesian statistical framework that was developed to combine results from the different sources. Injury risk functions for all cyclist use cases and for all pedestrian use cases were constructed based on GIDAS data, and a variant of the dose-response model, similar to its implementation in (Bálint, Fagerlind, & Kullgren, 2013), was used to compute the safety benefit of the systems, i.e., the reduction in the number of fatalities and injuries of different severity. This local benefit was extrapolated to EU-28 by using a decision tree method. Accounting for the assumed market penetration and user acceptance of the systems, the expected benefit for the period 2020-2030 was computed.

A detailed description of the method and results is given in (Kovaceva, et al., 2018), which is expected to be publicly available soon.

3.2 Further publications

3.2.1 Mobileye model of safe and scalable self-driving cars

The automotive supplier company Mobileye, subsidiary of the Intel Corporation, published in 2017 several documents regarding safety of self-driving cars: “A Plan to Develop Safe Autonomous Vehicles. And Prove It.” (Mobileye, 2017) and “On a Formal Model of Safe and Scalable Self-driving Cars” (Shai Shalev-Shwartz, 2017). The objective of these publications is to “establish a methodology and standard for safety validation in partnership with global standards–bodies and regulators.” It consists of the model of “Responsibility Sensitive Safety” (RSS) and a formal Semantic language for human and robotic driving policy.

Furthermore, Mobileye claims to “show how the resulting fusion methodology (based on the semantic language) guarantees the RSS model to the required 10^{-9} probability of fatality, per one hour of driving, while performing only offline validation over a dataset of the order of 10^{5} hours of driving data.”

Results and insights of the “Mobileye paper” relevant to OSCCAR are:

- The starting point of the paper is the key assumption of OSCCAR that even for a perfect function, in mixed traffic absolute safety is impossible. It further introduces among other definition the terms “Dangerous time” and “Blame time”, to formally define whether or not a vehicle can be responsible for an accident, depending on the behaviour of the vehicle at certain points in the course of events.

- The model of “Responsibility Sensitive Safety” formalizes common sense rules that can be seen as formal requirements towards an automated driving function when one implies that this function does not cause accidents or reduces potential risk and harm by cautious driving.
- These rules are: “1. Keep a safe distance from the car in front of you, so that if it will brake abruptly you will be able to stop in time; 2. Keep a safe distance from cars on your side, and when performing lateral manoeuvres and cutting-in to another car’s trajectory, you must leave the other car enough space to respond; 3. You should respect “right-of-way” rules, but “right-of-way” is given not taken.; 4. Be cautious of occluded areas, for example, a little kid might be occluded behind a parked car.”
- For future analysis (beyond this D1.1), the formalization of these rules in mathematical terms – what is a safe distance? What is safe in lateral manoeuvres? – could be implemented as openPASS open source algorithms for simulation of this behaviour in future traffic scenarios. This is to be discussed in the course of the project.

3.2.2 NHTSA voluntary guidance & voluntary self-safety assessments

With its voluntary guidance, NHTSA envisions that “Voluntary Safety Self-Assessments” (VSSA) contain concise information on how entities such as OEMs are utilizing the Voluntary Guidance and their own processes to address applicable safety elements identified in the Voluntary Guidance. The Voluntary Safety Self-Assessment covers “safety elements” such as Operational Design Domain (ODD), object and event detection and response, validation methods (testing simulations), but also crashworthiness and post-crash data recording.

Entities are not required to submit a Voluntary Safety Self-Assessment, nor is there any mechanism to compel entities to do so. Assessments are not subject to Federal approval. Still the NHSTA website links to n= 13 company website with VSSA disclosures, see (NHTSA, 2019).

- “highway function”: VSSA on “Mercedes-Benz L3 DRIVE PILOT”
- “urban function”: Apple, AutoX, Ford, GM, Mercedes-Benz/ Bosch L4-L5, Navya, Nuro, Nvidia, Starsky Robotics, Uber, Waymo, Zoox

The documents confirm the points taken away from the literature above, e.g., the approach how the automated functions are supposed to comply to traffic rules and take minimum risk strategies.

For example, the WAYMO document (WAYMO, 2019) lists in its “Appendix B. Avoidance or Mitigation of Common Crash Scenarios” types of crashes that account for a substantial percentage of all crashes, which the AD vehicle should be capable of avoiding or mitigating. The report references NHTSA reports and concludes that four scenarios accounted for the vast majority of crashes: 29 percent of the vehicles were involved in rear-end crashes, 24 percent of the vehicles were turning or crossing at intersections just prior to the crashes 19 percent of the vehicles ran off the edge of the road, 12 percent involved vehicles changing lanes. Based on these “Crash Avoidance Categories”, example test scenarios are derived.

3.3 Summary of literature findings

These are the key findings from literature review:

- All sources give a clear guidance related to the automated functions that should be considered for our further studies on crashworthiness and occupant protection of automated vehicles: highway pilot and urban self-driving car concepts.
- The research projects analysed GIDAS data to obtain scenarios and to further investigate the accident avoidance potential of automated driving functions.
- The Mobileye paper provided a sound concept how to formalize common sense rules for automated driving functions and hence, how to motivate that AD vehicles are supposed to drive “carefully” and to comply to traffic rules.

Table 1: Summary of literature review in D1.1

Project/reference	Methodology	AD functions	Accident data	Simulation
Adaptive	Goal: develop automated driving functions & conduct EU impact assessment	Motorway automated driving function; automated urban driving function	Top 7 scenarios from analysis of n°=°1,080 GIDAS cases on motorways	openPASS traffic simulation without (baseline) and with AD models in the loop
PEGASUS	Goal: Scenario database representing real-world conditions, integrated in virtual tool chain	Level 3 highway pilot	Selected (n = ~120) GIDAS-PCM scenarios contributed to scenario database	rateEFFECT PCM simulations in TP1, TP3 (“tools”): connect multiple tools linked to harmonized tool chain
PROSPECT	Goal: new VRU protection functions and impact assessment based on testing procedures and simulation	No AD functions, but methodology using e.g. rateEFFECT and openPASS is relevant	Analysis of EU-level and national data combined with pedestrian and cyclist cases in GIDAS-PCM for simulation	Counterfactual simulations using relevant models for PROSPECT sensors and algorithms with rateEFFECT and openPASS; Results are not yet publicly available

Project/reference	Methodology	AD functions	Accident data	Simulation
“Mobileye Paper”	Goal: model of “Responsibility Sensitive Safety” and a formal Semantic language for human and robotic driving policy	Generic automated driving function		Note: paper discusses an alternative approach to simulation
NHTSA guidelines / voluntary safety self-assessment	Goal: provide information, so NHTSA and the public may understand the safety principles based on standardized self-assessment	One highway function, n = 12 urban self-driving cars	in WAYMO VSSA: reference to NHTSA Pre-Crash Scenario classification	All VSSAs cover simulation approaches for validation of the presented ADS

4 EUROPEAN ACCIDENT DATABASES

Crash data on EU level are available in the community database CARE. This database contains police-reported crash data from all EU member states and Iceland, Liechtenstein, Norway and Switzerland, and has been used for general estimates (European Commission, 2018; European Commission, 2018). However, for the purposes of OSCCAR, more detailed data is needed than the general information in CARE, including detailed scenario definition, vehicle trajectories, pre-crash information for simulation, etc. Therefore, databases including national databases and in-depth crash databases containing very detailed crash information are reviewed, with detailed findings in the Appendix A. A summary of available databases is given in Table 2. The extrapolation of results from national and in-depth crash databases to a European level will be discussed in section 8.2.2.

#	Country	Source	Link	Period
1	Austria	CEDATU	www.tugraz.at	-
2	France	LAB VOIESUR	-	2011
3	Germany	DESTATIS (National statistics)	www.destatis.de	2017
4		GIDAS	www.gidas.org	1999-2018
5		PCM (Pre-Crash Matrix)	part of GIDAS	1999-2018
6	iGlad	11 countries	www.iglad.net	2007-2016
7	Sweden	STA/STRADA	www.trafikverket.se	since 1997
8	Sweden	VCC intern	-	since 1976
9	United Kingdom	STATS19, RAIDS, ODS	https://data.gov.uk	2016 (2003-2018)

Table 2 Overview of accident data sources

The following limitations should be noted:

- Some of the sources contain higher level data, whereas others contain evidence based on-spot investigated data. The latter can be used to distinguish the parameters for different scenarios in urban, rural or motorway areas. Consequently, the same level of detail is not available for all of the sources.
- The time periods for the selected data vary. Limitation of the data to a common timeframe would have reduced the data significantly and was therefore not applied. According to various studies performed over varying time frames it is assumed that there is no evolution on different scenarios.
- Some data is based on police reports only. As police officers are not necessarily experts in evidence based crash investigation, police reported data might contain more subjective information than in-depth accident databases.
- The definition of “fatally injured” and “seriously injured” is not harmonized within all databases. For instance, a casualty might be classified as “fatal” for one data source, if the

person died on the accident site while another database would list the casualty under "killed" if the person died within 30 days after the accident. The same holds for "seriously injured", although for most databases a severe injury could be defined as an injury with severity classified as MAIS 2+.

- For some sources, the number of samples might be low, especially if considering filter criteria as severity separated by location, and must be regarded with care when trying to draw statistically relevant conclusions. The same applies for predictions of future accident scenarios.

5 THE INFLUENCE OF AUTOMATED VEHICLES ON FUTURE ACCIDENT SCENARIOS

The overall research question of WP1 is a two-fold question

- On a macroscopic level, we want to answer how the general accident situation will look like in Europe at the time when automated cars are introduced
- On a microscopic level, we assess which accidents an automated car will be involved in and how the crash configurations will look like.

Here, the macroscopic level refers to a view of road traffic as a whole while the microscopic level addresses the view of the automated car by itself. In the sections 5.1 to 5.4, we impose an estimate of the future general accident situation to determine the most relevant accident situations a future automated car could be exposed to.

5.1 Accidents with casualties in the EU

As a first step, we evaluate the accident situation of crashes with casualties within the European Union in 2017. In total, national accident statistics of 12 large EU countries set a basis of this evaluation. All national accident statistics were of the year 2017 and covered a total of 848 466 accidents with casualties. This corresponds to 78% of all accidents with casualties within the European Union in which about 1.1 million accidents with casualties occurred (slight injuries to fatalities). Comparing different national accident statistics revealed a lack of common definitions for accident severity and accident kind. For instance, in Poland and France accidents with slight injured people are not fully reported. Thus, definitions similar to definitions of the German national accident statistic have been used. Thereby, annual national accident statistics were aggregated to give a comparative picture of the current accident situation within the European Union, see Figure 11. The national accident statistics included data from Austria, Belgium, Czech, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, Spain, and Sweden.

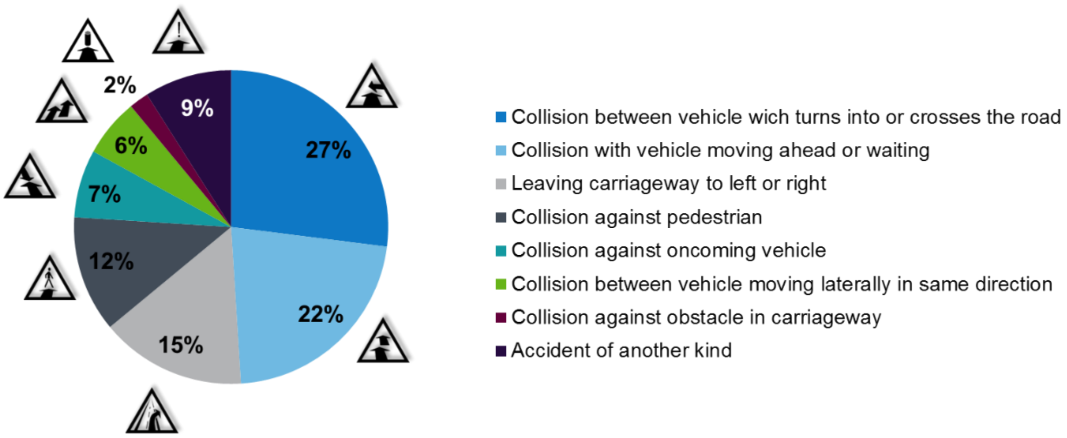


Figure 11: Accidents with casualties by accident kind weighted to EU (2017)
(n= ~1.1 mio. accidents)

According to Figure 11, almost every 3rd collision is an accident at intersections either while crossing the road or turning into a road followed by collisions against another vehicle moving ahead or waiting (22%). Thus, seeing the current accident situation as a first estimate for the future accident situation, automated cars will probably face the challenging task to avoid collisions while crossing or turning into road. In the following sections, we will refine this very rough estimate by predicting the future accident situation at the time of first introduction of automated vehicles.

5.2 Market penetration estimation of automated vehicles

Besides the functional behaviour of an automated vehicle impacting the accident scenarios in detail, it is seen that the overall penetration in the vehicle fleet within the EU will have a significant impact towards the overall accident situation. Knowing that around 253 million passenger cars (including cars, vans, taxis, hire cars, ambulances, motor-homes and micro-cars) were registered in 2016 within the EU, we estimate how long it will take to penetrate or fully replace the vehicle stock with automated vehicles. We adjusted a forecast model (Reiter, 2016) and applied it to a hypothetical scenario considering annually 16.5 million newly registered cars in the EU (Eurostat, 2019).

Passenger cars

(number)

	2012	2013	2014	2015	2016
Belgium	5 444 000	5 493 472	5 555 499	5 623 579	5 712 061
Bulgaria	2 807 000	2 910 235	3 013 863	3 162 037	3 143 568
Czech Republic	4 706 000	4 729 185	4 833 386	5 115 316	5 307 808
Denmark	:	:	:	:	2 465 538
Germany	43 431 000	43 851 000	44 403 000	45 071 000	45 803 560
Estonia	602 100	628 565	652 950	676 596	703 151
Ireland	1 951 130	1 984 550	2 018 310	2 060 170	2 102 720
Greece	5 167 557	5 124 208	5 110 873	5 107 620	5 160 056
Spain	22 248 000	22 025 000	22 029 512	22 355 549	22 876 830
France	32 132 000	32 858 000	32 531 000	32 326 000	32 076 000
Croatia	1 445 000	1 448 000	1 474 000	1 499 802	1 552 904
Italy	37 078 000	36 963 000	37 080 753	:	37 876 138
Cyprus	475 000	474 561	478 492	487 692	508 284
Latvia	618 270	634 600	657 799	679 048	664 177
Lithuania	1 753 407	1 808 982	1 205 668	1 244 063	1 298 737
Luxembourg	355 900	363 247	372 827	381 103	390 935
Hungary	2 986 030	3 040 732	3 107 695	3 196 856	3 313 206
Malta	249 612	256 096	265 950	275 380	282 921
Netherlands	7 916 000	7 932 290	7 979 083	8 100 864	8 222 974
Austria	4 584 000	4 641 308	4 694 921	4 748 048	4 821 557
Poland	18 744 000	19 389 446	20 003 863	20 723 423	21 675 388
Portugal	4 259 000	4 327 478	4 699 645	4 722 963	4 850 229
Romania	4 487 000	4 696 000	4 908 000	5 155 000	:
Slovenia	1 066 030	1 063 800	1 068 360	1 078 740	1 096 523
Slovakia	1 824 200	1 879 800	1 949 100	2 034 574	2 121 774
Finland	3 037 000	3 105 834	3 172 735	3 234 860	3 322 672
Sweden	4 446 349	4 494 661	4 584 711	4 668 262	4 767 262
United Kingdom (¹)	28 722 000	:	:	30 250 294	30 850 440
Iceland	:	:	:	:	:
Liechtenstein	28 000	28 100	28 470	28 802	29 241
Norway	2 443 000	2 500 000	2 555 000	2 610 000	2 662 910
Switzerland	4 255 000	4 321 000	4 384 000	4 458 000	4 524 000
Turkey	8 648 880	9 283 923	9 857 915	10 589 337	11 317 998
Former Yugoslav Republic of Macedonia	302 000	346 798	371 449	383 833	394 934

(:) not available.

(¹) Great Britain only.

Source: Eurostat (online data code: road_eqs_carmot)

Figure 12: Registered passenger cars in EU by country (Eurostat, 2019)

To determine the penetration of an automated vehicle (or system) the model considers the current and predicted overall vehicle fleet, the annual number of new registered vehicles in the EU, an optimistic hypothetical installation rate of automated vehicles in new registered vehicles, and a car-life-cycle function. While the annual growth rate of about 1.4% of new registered cars is easily obtained and was assumed to be a constant (average annual growth rate between 2000 (207.1 mio. registered cars) and 2016 (258.1 mio. registered cars) with 16.6 mio. new registered cars in 2016), the installation rate of automated cars is an optimistic assumption shown as red line in Figure 13. The car-life cycle function is a sigmoid-like function based on the probability to find a car of a certain age (Reiter, 2016). By applying the car life cycle function to the new registered vehicles, the overall market penetration of automated functions or -cars was determined, shown as the blue line in Figure 13.

In a hypothetically calculated scenario shown in Figure 13, it is assumed that by 2025 a **partial automated function** is going to have a share of 3% in new registered passenger cars (~500 000 vehicles) in the EU with increasing trend (and an increase of the installation rate by 5% p.a. by 2030). By that, it will take **25 years** to reach a penetration of 66% in the EU vehicle fleet **<u>with the same technology</u>**. Even if this scenario would not reflect a realistic introduction, it clearly shows the long lasting time frames for introduction of automated driving functions.

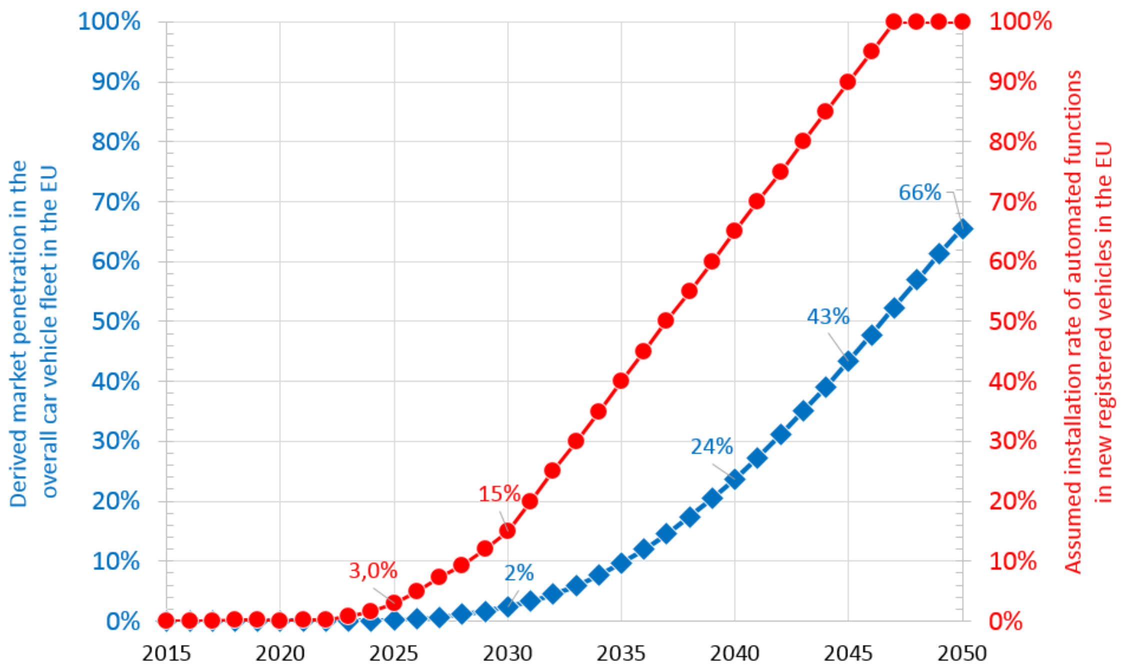


Figure 13: Estimation for a safety technology penetration in the overall vehicle fleet of the EU

Nevertheless, it was decided within this WP, that the baseline accident situation in 2025 needs to be assessed due to the fact that current state-of-the art car safety technologies will reach a certain market penetration and will continuously have an impact on the future accident situation.

In addition, following first important conclusions are determined:

- Automated functions or -cars will penetrate rather slowly in the overall vehicle fleet, therefore passive safety systems will still be required. This is valid both for occupants in self-driven car and for cars driven by humans, because an occupant in an automated vehicle could be involved in a crash caused by other road users (mixed traffic).
- Given the small market share of automated cars by 2025, an occupant in an automated car can be involved in collisions with other road users, most probably a conventional car.

- In the beginning, the introduction of more advanced automated driven cars (even partially automated cars) will not change the accident situation significantly on a global scale. A shift of single crash events (local scale) involving automated vehicles might occur. By reaching a substantial market penetration this may change.
- The behaviour of automated cars might provoke conventional car driver to erratic behaviour, which might lead to single crash events. It might also lead to additional crash events currently unknown or not classified.

5.3 Methods to determine future accident scenarios

To determine how the future accident situation will look like, a two-step approach as illustrated in Figure 14 was imposed. It comprises of a bottom-up approach and a top-down approach:

1. **Bottom-up approach:** This approach allows to set an evolutionary change estimation of the future accident numbers for, e.g., the year 2025. In this approach, next level car safety technologies, such as advanced driver assistance systems (ADAS), active-, passive- and tertiary safety, are considered. The benefit of each system is assessed and, in convolution with its prospective market penetration, its impact on the accident numbers is determined. Thereby, the baseline for the future accident situation changes and a prediction of the accident situation at the time when automated cars will reach an entry-level market penetration comes within reach.
2. **Top-down approach:** This approach estimates an additional AD effect of the future accident situation. Here, the minimal requirement that an automated car will not cause accidents which do not comply with traffic rules – so called "inherently" avoided crashes – eliminates all those inherently avoided crashes from the accidents statistics. Consequently, the remaining crashes within the accident statistics set an upper boundary for future accident numbers, which need a further assessment in a microscopic, accident-wise approach.

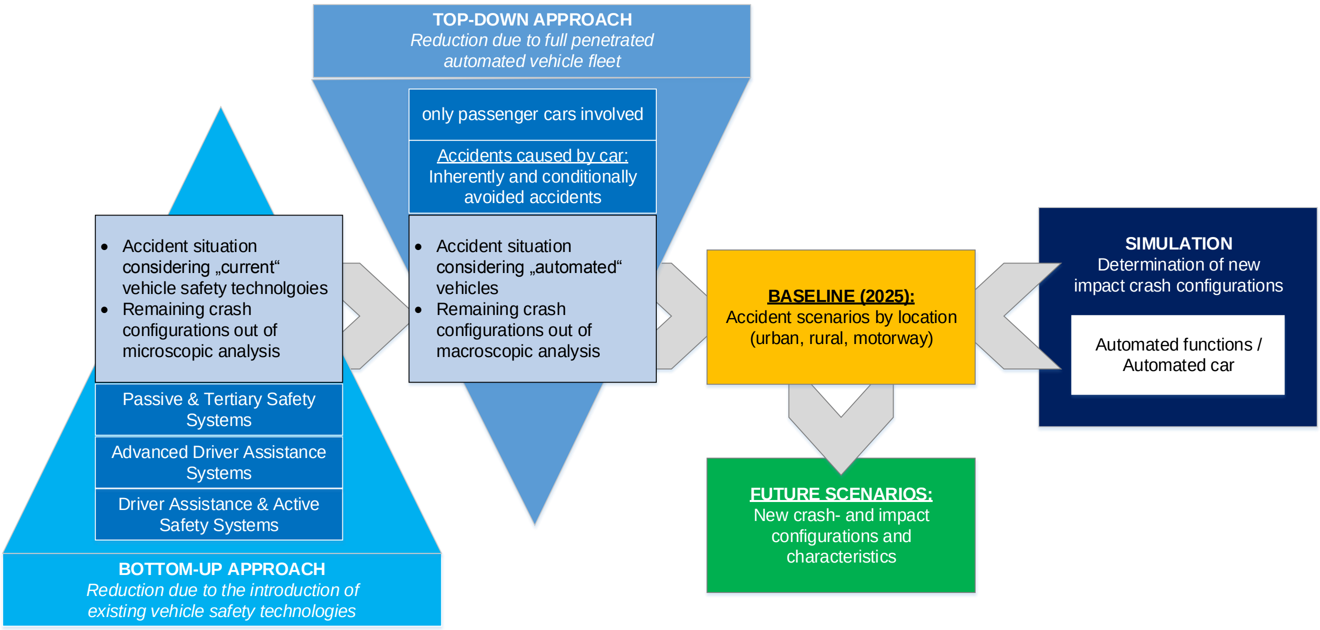


Figure 14: Baseline approach to determine the future accident scenarios and crash configurations

The overall methodology for assessing the future accident situations with involvement of automated cars, after applying the bottom-up and the top-down approach, is outlined in the following paragraph.

Both approaches compiled together can give an answer on the first OSCCAR WP1 research question: what will be the macroscopic accident situation the time of large-scale market introduction of automated vehicles. To account for different use cases of automated cars, such as, e.g., robotaxi and highway pilot, the remaining accident situations were separately analysed for different locations: urban, rural, and motorways. In a second step, these remaining scenarios were used in a pre-crash forward simulation to identify new impact configurations. The identified, possibly new crash configurations along with its characteristics will be used as input for WP2.

In the following sections 5.3.1 and 5.3.2, we describe the bottom-up as well as the top-down approach in detail. Thereafter, in section 5.4, the results of both approaches applied to accident databases of various European countries, introduced in the previous section, will be presented, identifying few main accident scenarios for further evaluation.

5.3.1 Bottom-up approach: Impact of existing vehicle safety functions

For the bottom-up approach of the future accident situation, existing vehicle safety functions are taken into account. The focus is identifying and analysing most common accident configurations by injury severity after the application of several safety systems, especially for the previously identified year 2025.

The baseline for each considered safety system was taking into account the safety measures proposed in the cost-effectiveness analysis conducted by the European Commission (Seidl, M., Khatry, R., Caroll, J., Hynd, D., Wallbank, C. and Kent, J., March 2018). In addition, well established safety measures available in the market as, e.g., electronic stability control, were taken into account, too. The effectiveness rates as well as the considered can be found in Appendix D. The approach is explained based on the example of the French VOIESUR database.

At first, the database was filtered to extract only car to car or single car accidents and considering both front and rear seat occupants who were older than ten years.

The accidents were then sorted out in four filter steps, as follows, illustrated in Figure 15:

- **Filter 1 – Driver assistance system:** Step 1 target population was filtered based on the type of driver assistance system that could be applicable to the involved casualties, considering accident causation. The remaining injuries after the application of driver assistance safety systems were calculated.
- **Filter 2 – Active safety system:** Several accident configurations were identified based on the collision configuration, e.g., rear-end or front-to-front, and grouped based on the type of accident, e.g., collision at junction or collision due to unintentional lane change. For each collision configuration, the remaining injuries after the application of active safety systems were calculated. The active safety systems that were applied for each collision configuration and its order of applicability was defined based on the decision tree shown in Figure 15.
- **Filter 3 – Passive safety system:** At this step, four main collision configurations were identified, based on the applicability of passive safety systems (rear-end, front-to-front, front-to-side, and rollover). For each of the configurations, the effect of different passive safety systems were applied and the remaining injuries after its application were calculated. The seat-belt retractor was applied before the breakdown of the four main collision configurations as it could apply to all of them.
- **Filter 4 – Tertiary safety system:** As the last step, the effect of a post-crash measures as, e.g., an automatic emergency call (E-call), was applied and the remaining injuries after its application were identified.

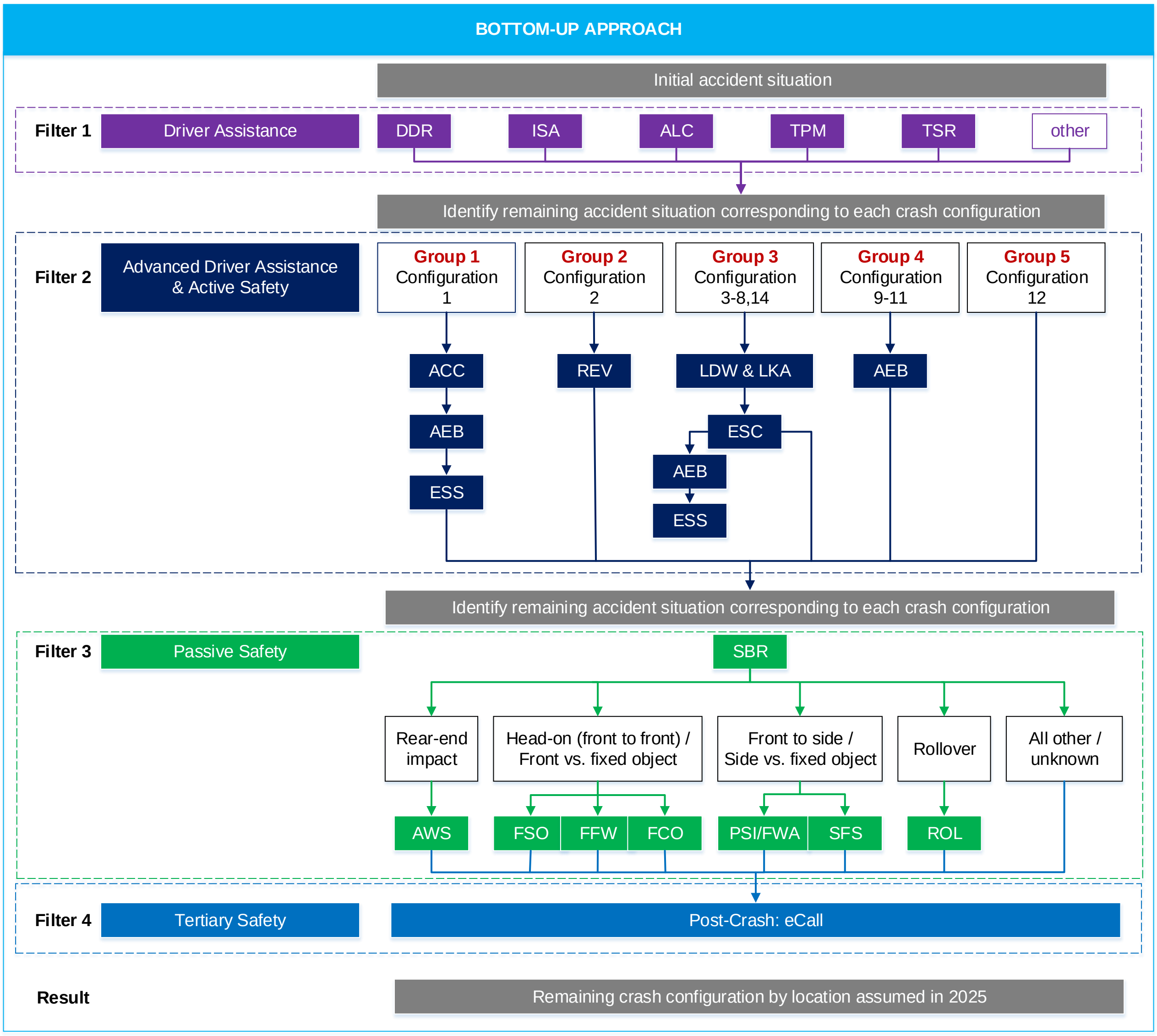


Figure 15: Safety technology application considering four layers in an accident event (Driver assistance, Active Safety & Advanced Driver Assistance, Passive- and Tertiary Safety)

Safety system effect: In order to apply the effect of safety systems, its target population was identified within the identified injuries. As the analysis wanted to identify remaining injuries by 2025, a certain penetration rate of the safety systems was also considered and applied to the calculation.

Calculation of remaining casualties: At each step, the remaining casualties were calculated. Here, the effectiveness rate *E* multiplied with the assumed market penetration rate *R* of the respective system defines the share of reduced casualties. Consequently, the number $N_{casualties}$ of remaining casualties becomes

$$N_{casualties} = N_{target}(1 - E \times R),$$

with the number N_{target} of the target population (in terms of casualties).

For further analysis, the obtained remaining casualties were divided according to collision configuration, but also the location (rural, urban, motorway), driving speed and manoeuver prior to accident.

For the U.K. database STATS19, given slightly different available information compared to the French VOIESUR database, a quite similar approach was used, see Appendix D.

5.3.2 Top-down approach: automated cars inherently avoid accidents

To identify future accident scenarios from the top-down approach, several filters will be applied consecutively to figure out which accidents are categorized as “inherently avoided by automated cars”, see Figure 16. The general idea is that an automated car would never violate traffic rules and, at the same time, adapt its driving to the actual road and traffic conditions. Consequently, replacing the accident causing car with an automated car, accidents with specific causation factors will be avoided. For instance, in an accident with a main causation factor “unadapted speed and exceeding the speed limit at the same time” will be avoided as the automated car will not exceed the given speed limit. For iGLAD database, the causation factor is denoted in the variable “contributing factor” whereas for GIDAS, the variable is called “HURSU”. A list of inherently avoided contributing factors, resp. HURSU variables, are displayed in Appendix A.

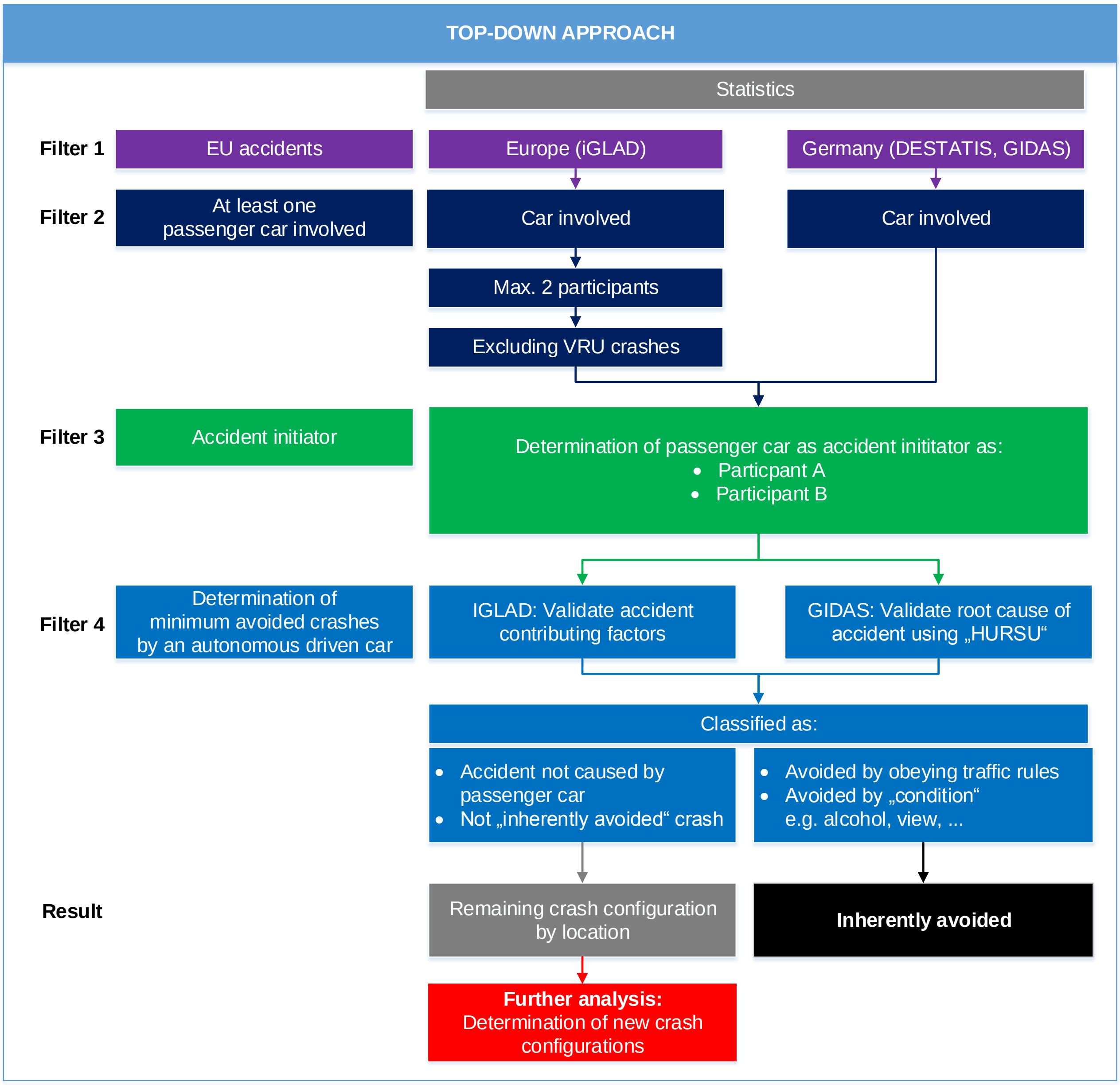
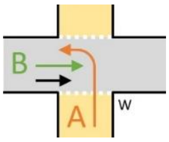
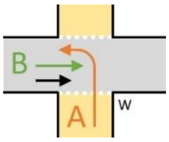
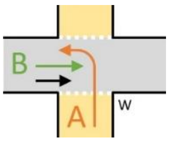
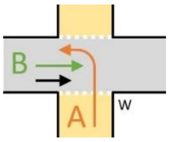


Figure 16: Two-step approach to identify future accident scenarios

The OSCCAR WP1 specific top-down approach starts with the all accidents of the respective accident database (iGLAD or GIDAS). By identifying all accidents that would be inherently avoided by an automated car, the minimal number of avoided accidents due to automated cars is obtained. Subtracting the minimal number of avoided accidents, the upper limit of accident numbers involving automated cars is determined. To do so, at first, from the full accident numbers of each accident database, the number of accidents caused by a car is calculated. Thereafter, all accidents with the causation factors given in Appendix A will be reduced from the dataset.

While the method of causation factors as described above applies especially for a full market penetration of automated cars, by specifying the combinations of automated cars involved in a car to car accident, a hinge on partial market penetration of automated driving functions is found. Assuming only two involved cars in an accident, each of the car could by assumed to be an automated car or a conventional car with a human driver. Therefore, four combinations of car to car accidents are possible: conventional vs conventional, conventional vs automated, automated vs conventional, and automated vs automated (see Table 3).

Table 3: Possible combinations associating an automated driven vehicle to participants in a specific way-of-right crossing accident scenario.

	Situation by initiator	Filter criteria
#1	Accident initiator („A“) 	**Human driver vs. human driver** • Participant „A“ is causing the accident and has a **human driver** • Participant „B“ has a **human driver**
#2	Non-Accident initiator („B“) 	**Human driver vs. automated car** • Participant „A“ is causing the accident and is **human driven** • Participant „B“ is referred to a passenger car and is **automated**
#3	Accident initiator („A“) 	**Automated car vs. human driver** • Participant „A“ is causing the accident and is **automated** • Participant „B“ is **human driven** ➔ <u>“*Inherently avoided*” because automated cars obey way of right</u>
#4	Accident initiator („A“) 	**Automated car vs. automated car** • Participant „A“ is causing the accident and is **automated** • Participant „B“ is **automated** ➔ <u>“*Inherently avoided*” because automated cars obey way of right</u>

As shown in the previous example for intersection, for all kind of accidents all the relevant combinations were identified within the different databases (IGLAD, GIDAS). For each accident initiator it was proven whether this accident causation will be "inherently" avoided or not. The relevant cases were pre-selected and filtered out.

Applying the top-down approach to a partial market penetration of automated cars becomes accessible by analysing the avoidance potential for each of the four combinations individually. Calculating the statistical probability to have one of the four combinations for a car to car collision, given by the product of market penetration of the automated car, the overall, macroscopic avoidance potential for a given market penetration becomes available.

Following filter criteria1 – 4 listed below are used to identify the baseline in detail. For iGLAD not all information is available thus slightly different filter criteria were selected:

- **Filter 1 – EU accidents only:** pre-selection of accidents in EU countries (iGLAD). For Germany also national data along with GIDAS data was selected.
- **Filter 2**: Selection of accidents with at least one passenger car involved and, for iGLAD, maximal two participants. Participation of vulnerable road users (VRUs) were also excluded.
- **Filter 3:** Selection of accidents for which the main causer of the accident is available
- **Filter 4:** Associate automated car to the accident (based on contributing factors) separated by
  - safe driving defined as not violate any traffic rules
  - cautionary driving, i.e., adapt appropriate driving conditions
  - otherwise categorize as "further analysis required"

The full list of accident causation factors along with the detailed results with respect to the major accident types is listed in Appendix A.

5.4 Future accident scenarios

To draw conclusions for the future accident situation among the European Union on a macroscopic level, data from France, Germany and the United Kingdom was applied as well as iGLAD data. Due to limitation on the accident information on EU level, the top-down approach was performed based on the example on the national accident situation of Germany (2016) and extrapolated to EU level.

The result of the top-down approach for German data by location is shown in Figure 17. Herein only accidents with casualties (including fatally injured) were considered. According to national statistics [DESTATIS (2017)], in total 308 145 accidents occurred in Germany in 2016. Thereof are 69% (211 686) in urban, 24% (75 266) in rural and 7% (21 193) on motorways.

As described, a pre-selection was made to eliminate accidents in which no car was involved, e.g., collisions between a truck and a motorcycle.

For the remaining car crashes (category A) which were initiated by the car, the inherently avoided collisions were identified (category B). Thereof, a distribution by location reveals the potential of inherently avoided collisions:

- 27% (57 155) of urban accidents w/ casualties,
- 32% (24 085) of rural accidents w/ casualties,
- 29% (6 145) of motorway accidents w/ casualties.

In total, about 87 000 crashes with casualties will be inherently avoided by an automated car which is a share of 28% of all accidents with casualties in Germany. In other words about every 4th accident with casualties could be inherently avoided by automated vehicles.

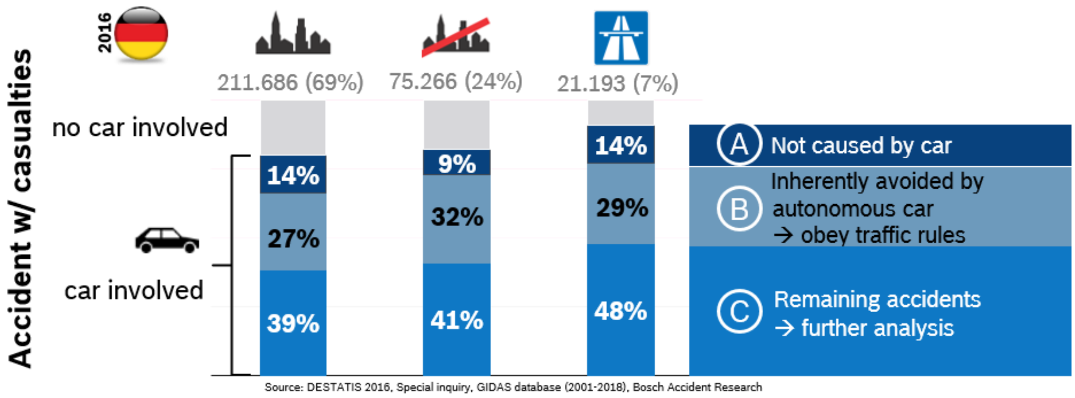


Figure 17: Future accident situation (macroscopic) including share of crashes inherently avoided by automated driven cars

Even if the German accident situation represents only 30% of the overall accident situation within the EU (Figure 12) it is expected that on a macroscopic level every 4th accident with injuries and/or fatalities could be inherently avoided by an automated car. With this assumption, after extrapolation to EU level, about 290 000 accidents with casualties could be inherently avoided by automated vehicles.

For the remaining crashes caused by car (category C of Figure 17), it is still required to determine which accident scenarios will occur and, thus, have to be investigated in more detail. As seen throughout the selection process and later in the simulation, an automated car will face all kind of collisions. A distribution of the remaining accidents by location and kind of accident is shown in Figure 18.

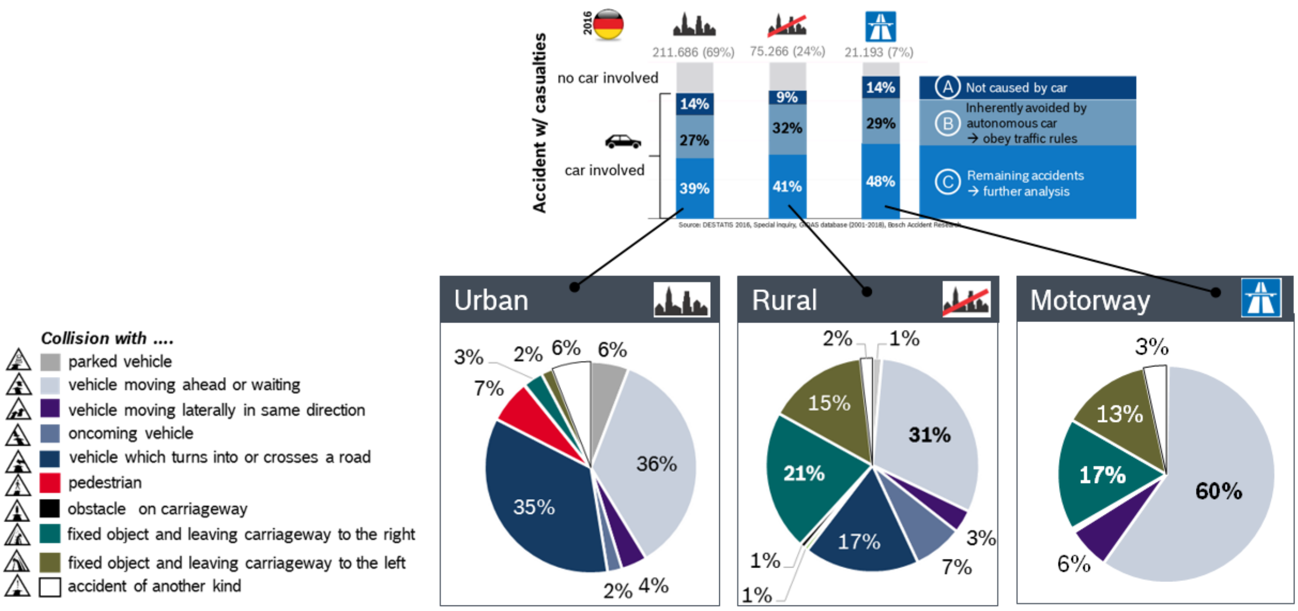


Figure 18: Remaining accident scenarios by kind of accident and location on macroscopic level

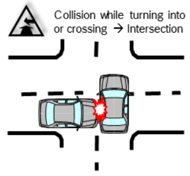
The following table summarizes the main crash scenarios obtained from the bottom-up approach (France, U.K.) and the top-down approach (iGLAD, Germany). Again, results from the bottom-up approach represents the national accident situation in 2025 assuming a certain impact of current safety technologies, whereas the results from iGLAD, Germany assumes inherently avoided collisions by an automated car.

Table 4: Main crash scenarios obtained from the bottom-up and top-down approach

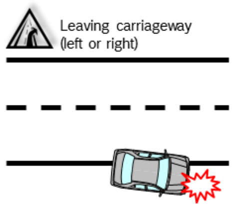
Country	Location	Accident scenarios
France	Urban	• Collision while turning into or crossing
	Rural	• Leaving carriageway/fixed object • Collision while turning into or crossing • Collision against oncoming vehicle
	Motorway	• Rear-end collision
Germany	Urban	• Collision while turning into or crossing • Rear-end collision
	Rural	• Leaving carriageway/fixed object • Rear-end collision • Collision while turning into or crossing
	Motorway	• Rear-end collision • Leaving carriageway/fixed object
U.K.	all locations	• Collision while turning into or crossing • Rear-end collision • Leaving carriageway/fixed object
EU (IGLAD)	Urban	• Collision while turning into or crossing
	Rural	• Collision while turning into or crossing • Rear-end collision • Leaving carriageway/fixed object
	Motorway	• Rear-end collision

To conclude and give a dedicated answer to the research question ("In which accidents will an automated car be involved into?") the following accident scenarios are most prominent and, to some extent, will be analysed in more detail in sections 6 and 7. However, even at this stage, it is expected that some accidents will be unavoidable due to physical limitations.

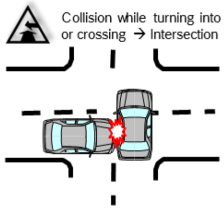
- **Urban area:**
  - Collisions while turning into or crossing the road at intersection



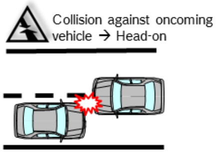
- **Rural area:**
  - Vehicle leaving carriageway / collision against fixed object



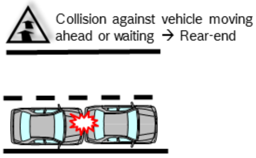
  - Collisions while turning into or crossing the road at intersection



  - Collision against oncoming vehicle



- **Motorways:**
  - Collision against vehicle moving ahead or waiting



In other words, it is expected that some accidents with involvement of automated vehicles will be unavoidable due to accident specific limitations, e.g., timewise. Thus, if an automated vehicle does not have full information of his entire surroundings there is always a chance that a collision occurs. An insightful examples are crossing pedestrians appearing suddenly from behind sight obstructions.

In the following section, we will discuss two of the identified main accident scenarios by means of a simulation study. Given the expected technological advances with respect to automated vehicles in form of a “highway pilot” and a “Robotaxi”, we will in this first step analyse motorway front-to-rear-end collisions (cf. sec. 6.3.2) and urban intersection collisions (cf. sec. 6.3.3). Other accident scenarios will be analysed at a later stage of the OSCCAR project (cf. discussion in sec. 8.2.1).

6 DETERMINATION OF FUTURE ACCIDENT SCENARIOS

6.1 The WP1 approach towards baseline accident scenarios

In this deliverable D1.1, the WP1 provides estimations on the accident scenarios that remain after future automated driving functions have been introduced. Here, future load cases will be given as a set of crash configurations derived from real world accident data. For D1.1, retrospectively collected accident data was used for a baseline and a simple automated driving functionality was suggested for treatment simulations. The outcome of this activity is a description of the remaining accidents that future automated vehicles will be exposed to. The key requirement towards this deliverable is to get adequate assumptions as early as possible in the project, to give mainly WP2 but also WP3 and WP4 a starting point regarding crash configurations to investigate when developing protection principles and tools.

In the second phase of the project (after Deliverable D1.1), the WP1 will focus on a more advanced method to answer the research question of “which remaining accidents a future automated vehicle will be exposed to”. The WP1 research question will be refined mainly by implementing more sophisticated methods. Those upcoming OSCCAR scenarios will consider the whole scope of automation from free traffic flow to accidents instead of just parts of the reconstructed pre-crash phase. It will use the open format OpenSCENARIO which allows to separate between the “pre-crash phase logic” (described in generic XML templates) and the parameters coming from real world data (e.g. statistical distributions), see 8 (Outlook).

The approach in OSCCAR to determine future remaining accident scenarios is closely related to the prospective effectiveness assessment of ADAS or safety systems. Such simulation studies aiming to determine potential safety benefits have been conducted in multiple research projects such as Aspeccs, PROSPECT, AdaptIVe or interactIVe (see section 3.1 with literature review). Unlike these previous projects, OSCCAR does not focus on further analysing the avoidance potentials of safety technology but rather to investigate the remaining accidents, in terms of crash configurations. The results (“future accidents”) are an assumption for remaining collisions in mixed traffic, where a model of an AD function would not avoid the accident in simulations.

The openPASS initiative addresses three in principle distinct methods of assessing the effectiveness of safety functions by means of pre-crash simulations like (Dobberstein, et al., 2017): accident simulations, driving scenario based simulation or traffic simulations. Many further combinations and subcategories are imaginable, e.g., incorporating a pre-defined critical manoeuvre or a reconstructed accident trajectory in a traffic simulation run or modifying “accident simulation” by pre-processing the scenarios or sampling from the original data. This complexity was the motivation for both the PEARS group (focus: methodology harmonization, see (Alvarez, Page, Sander, Fahrenkrog, & Helmer, 2017) (Page, 2015)) and the openPASS Eclipse Working group (focused on simulation framework harmonization).

Accident simulation

The current accident situation can be assessed by a set of real-world accident cases which were reconstructed and backwards calculated. These cases are provided in terms of trajectories (global positions, global yaw and velocity at each time step of each participants), such as the GIDAS-PCM (Schubert, Erbsmehl, & Hannawald, 2013).

<u>Advantages</u>: low modelling depth - no detailed knowledge of accident causation is needed, since it is implicitly comprised in the assumed course of events when taking accidents trajectories as they are as baseline.

Limitations: limited representation of real-world conditions of critical situations. The accident trajectories are not real time recordings of actual pre-crash sequences, but reconstructions with many assumptions. The GIDAS-PCM only models two participants and sparse information about surroundings defined in a non-standardized road description format.

Accident scenario-based assessment

Abstract and simplified scenarios are defined as generic baseline based on review and discussion of real-world data, e.g., the Euro NCAP active safety rating scenarios such as “Pedestrian crossing from far side”. A further example for the accident scenario-based assessment is the German R&D project PEGASUS that aims at providing a complete scenario database, incorporating all relevant traffic situations, conditions and scenario parameters as well as criteria for selecting test cases and evaluating the outcomes (see section 3.1.1.2 with summary of PEGASUS).

Advantages: once agreed, the conditions and parameters of these scenarios are controlled and repeatable. The scenarios are easy to understand and can be implemented both in physical and virtual assessment procedures.

Limitations: the simplification towards generic scenarios means summarizing a vast amount of very heterogeneous critical situations such as pedestrian accidents. Real-world differences are neglected and once implemented, large efforts are considered to re-design and maintain test catalogues – see PEGASUS.

Traffic simulation:

The baseline is fully generated as stochastic traffic, i.e., all manoeuvres are random effects and occur due to the stochastic, yet realistic behaviour of the agents. The input to such simulations are just a few pre-defined parameters regarding road design (number of lanes, geometry) and number and type of participants, and their behaviour leads to virtual accidents. In this baseline traffic (modelling human traffic including accidents due to human error), vehicles with assistance systems or automated vehicles can be injected.

Advantages: the two approaches above are event-based assessments, i.e., they take conflict situations as they currently evolve as given input and model these conflicts as accurately as possible to assess, e.g., AEB interventions. But adaptive cruise control (a predecessor of the upcoming automated driving functions) does not only influence the behaviour in a given (human) rear-end crash, but continuously enhances time-headway / distance keeping behaviour long before the situation gets critical. Hence, the traffic simulation assesses by design the effect of preventing the vehicle to enter critical traffic states. Considering a full-scale traffic model means that no multiple agent situations have to be pre-defined (e.g. cut-in from right lane due to slow vehicle into car follow situation), since they just happen during the runtime of the traffic simulation. Many additional aspects like effects of different traffic mixes or traffic flow changes (reduced traffic jams, improved travel time) can be simulated as well.

Limitations: large efforts are needed to model the baseline, to harmonize the assumptions and to validate it in order to create trust into these traffic models and the accidents they produce. Hence, it requires nothing less than an openly available and widely accepted human behaviour model for driving in normal traffic up until reacting on critical situations.

Up until now, there were only singular studies such as AdaptIVe conducted, documenting well the overall method and the results as well as the detailed steps how to work with such a model. But the driver model (in this case the “SCM” owned and developed by BMW) remain confidential, making it impossible to build up on or re-use these findings – in terms of analysing the “virtual AD accidents” that happened in the AdaptIVe simulation (see section 3.1.1 for full summary of AdaptIVe results).

OSCCAR work flow

In the starting phase of the OSCCAR project, other relevant EU projects (see section 3.1) as well as ongoing in-house studies of the WP1 partners were reviewed to account for recent developments on how to conduct effectiveness assessment of crash avoidance and derive remaining accidents. For instance, in openPASS, the current status of the software now allows for simulating PCMs with this harmonized open source framework – so it was discussed if some partners would commonly develop a PCM simulation approach with openPASS. But for the current openPASS use, it is still required to model additional components like sensors and algorithms, which lead to using existing and well-established in-house tools at this stage of the project (as it was defined in the Description of Work (DoW)/stage 2 proposal of OSCCAR).

As pre-selected in the OSCCAR DoW, the OSCCAR WP1 work flow towards this deliverable D1.1 focused on highway rear-end crashes and urban intersection crashes as most important remaining crash scenarios. First, potentially relevant AD functions for highway and urban areas were identified. Then, the WP1 partners filtered for relevant cases on accident data level, combined with simulation studies to account for further avoidance in mixed traffic. Finally, the WP1 work on accident data was linked to the set-up of the OSCCAR test case matrix. This interface means that the crash configuration derived from the WP1 analysis are taken up as one of three test case dimensions: crash configurations, interior/occupant use case and individual occupants characteristics.

6.2 The OSCCAR test case matrix

In parallel to D1.1, the WP2 fixed in D2.1 the structure of the OSCCAR test case to allow to handle the infinite number of potential relevant and/ or critical parameter variations arising from automated driving modes, future interior concepts and occupant behaviour. The overall objective with the Test Case Matrix is to provide a methodology for structuring the “Crash Configuration”, “Occupant Use Cases” and “Individual Human Variation”, for selection and motivation when used for studies on occupant protection principles in future car crashes.

Test Case = Crash Configuration + Occupant Use Case + Individual Variation

The Test Case Matrix should be as generic as possible, enabling several future Operational Design Domains (ODD) and flexible in terms of a universal method where parts can be refined based on, e.g., better accident predictions (e.g. from improved future scenario models) or further insights into how challenging new use cases are for state-of-the-art restraint systems.

The overall approach is to make the methodology applicable for a large scope, and thereby include all details that can be relevant for evaluation on occupant protection in future crashes. There are pre-processes with the purpose to filter out non-relevant combinations for the application chosen. The steps are called Pre-processes and Pre-pre-processes, see Figure 19.

The **Pre-pre-processes** provide input to more than one dimension of the Matrix, e.g.: year of target, SAE-level, Market, transport mode, vehicle use case, including user expectation. The objective of this activity is to derive overall boundary conditions and to help focusing on the characteristics of the automated driving function of interest. For example a SAE level 3 function for passenger car that drives automated on highways only limits the accident scenario that has to be considered for deriving crash configurations to highway accidents. It further will be designed similar to today’s conventional vehicles, so the degrees of freedom for the Occupant Use Cases are limited.

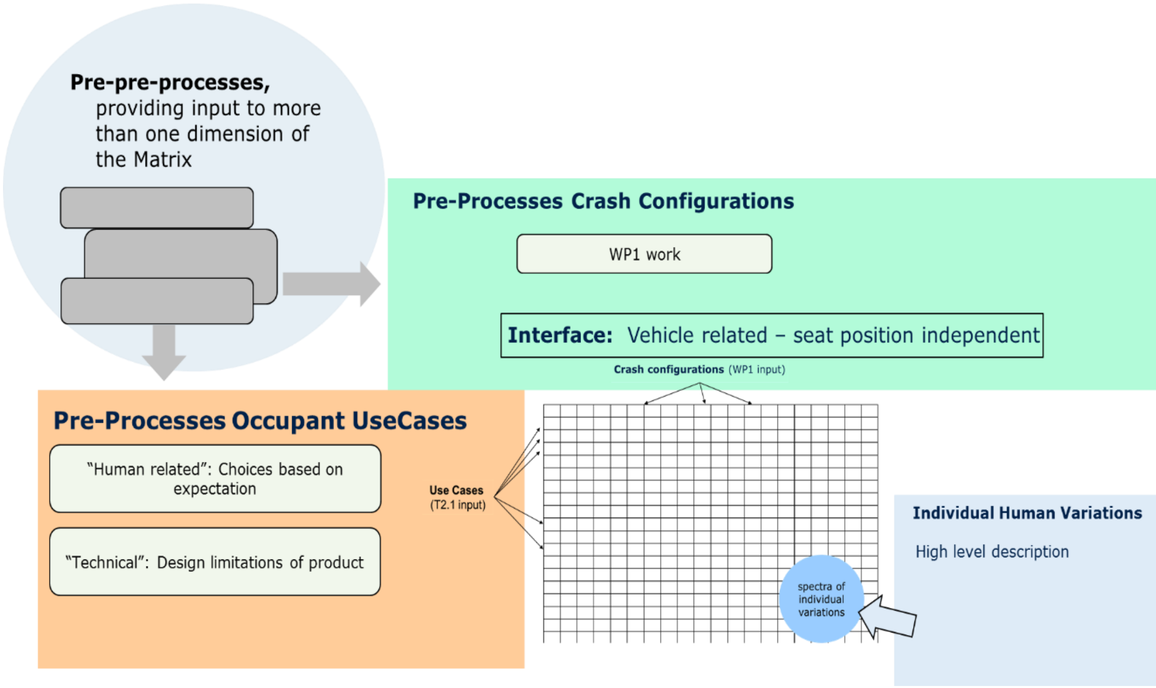


Figure 19: Test Case Matrix Process

Having the same overall purpose, the **Pre-Processes** relate to one dimension only. Examples of Pre-Processes related to the Use Case dimension could be the design of the vehicle allowing for some specific seat configurations only. For the full WP1 pre-process – as described throughout this Deliverable, see Figure 20: starting from real-world accidents, we obtain selected crash configurations – and additionally a relevance matrix based on the frequency (cluster share).

The following parameters describe the **Use Case dimension**, i.e., the situation inside the vehicle independent of the crash configuration: Seating configuration, seat position, sitting posture, Interior feature.

The following parameters describe the **selected Crash Configurations** in terms of vehicle based information, independent of the seat position (before transferred to a crash pulse): collision angels as well as host and opponent collision velocity.

Grading scheme: a process was developed that can be used for selecting and grading a Test Case by use of existing data or by use of engineering judgement when applicable. Grading criteria are related to frequency, severity and innovation level of a Test Case. Specifically, a methodology and specification of evaluation criteria were defined to help grade selected Test Cases potential candidates for Demonstrator Test Cases. The selected Use Cases and Crash Configurations are described at the top. An unlimited number of combinations can be included.

For the full definition of the Test Case Matrix and the Grading Scheme, see D2.1.

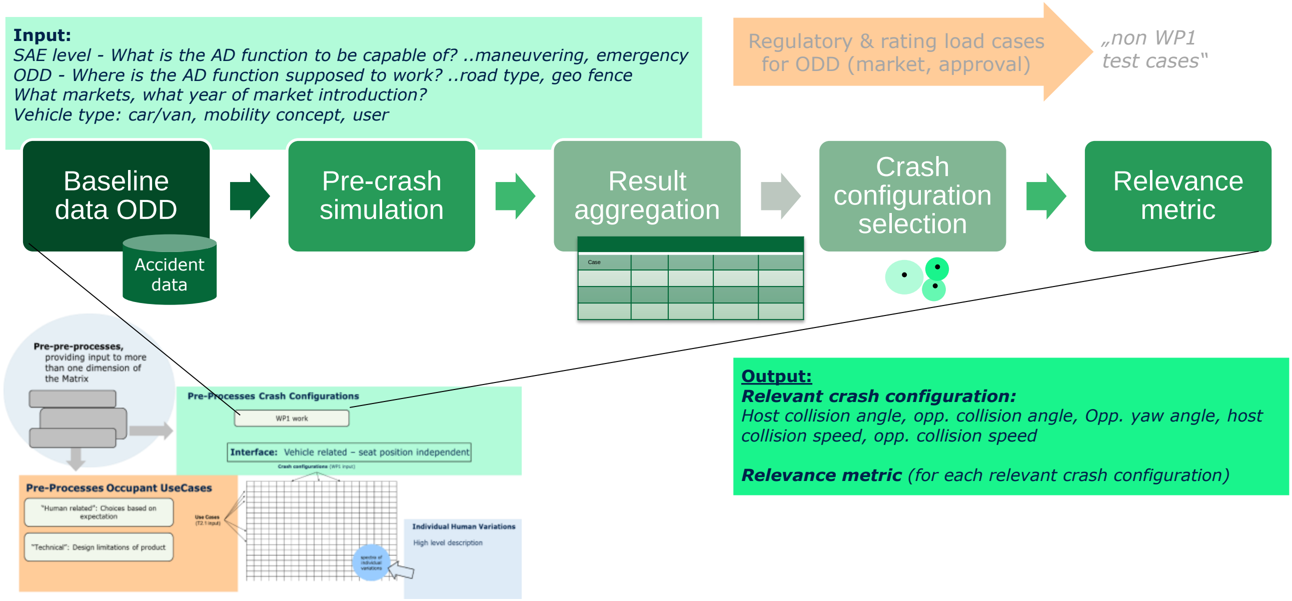


Figure 20: OSCCAR WP1 Pre-Process in T2.1

6.3 Automated driving function definition

In this section, we first will give an overview on the general system of the OSCCAR automated vehicle and thereafter describe the system definitions specific to the motorway and the urban crossing scenario, respectively.

6.3.1 Common OSCCAR system of automated driving functions

For OSCCAR WP1, we assume the automated vehicle will neither violate traffic rules nor suffer from lack of driving fitness. By full surround sensing it will be recognizing the traffic environment. Thereby, the automated vehicle will properly adjust its speed to given speed limits, account for right of way, traffic lights and other traffic rules. Furthermore, it will adjust its speed to current road weather conditions, e.g., if the road has a reduced coefficient of friction due to, e.g., icy conditions, it will keep longer distances to other vehicles or reduce its speed. Additional to accounting for traffic rules and conditions, the automated vehicle will not suffer from a lack of driving fitness as, e.g., alcohol, drowsiness or drugs. Consequently, such cases will be intrinsically avoided, i.e., by construction of the automated vehicle. In section 5.3, the corresponding top-down approach is described in detail.

At the OSCCAR project start a harmonized virtual model of an automated vehicle did not exist. Thus, the OSCCAR partners first defined a virtual automated model to mimic the basic functions of a future automated vehicle. While this model follows the general idea of an automated vehicle, it lacks the supposed ability to deal in various ways with challenging incidental situations. **The basic ability of an automated vehicle supposed by OSCCAR WP1 is an automatic emergency braking system.** The emergency braking system will overrule other automated driving functions if, e.g., a human driver in another vehicle disobeys traffic rules and is going to harm the automated vehicle.

In the D1.1 accident simulation, the automated vehicle will be equipped with an advanced automatic emergency braking system. Within the scope of D1.1, the automated vehicle will not perform evasive steering manoeuvres due to limited information of the traffic situation beside the collision partners in the datasets. Thus, minimal functional requirements of the AD system are given by all functions necessary to perceive and identify the other vehicle, predict its trajectory, as well as recognizing relevant environment characteristics, e.g., a speed limit or a wet road.

Each automated vehicle will be equipped with a set of sensors to perceive and identify its environment. For an automated vehicle released to operate on a street in an open context, we expect the set of sensors to fully cover all necessary ranges and angles. For the scenarios addressed in D1.1, a reduced sensor is set up. Concerning the technical specifications, the reduced sensor is providing a vision of a range up to 200m and a sensor angle of 180°, i.e., ±90° to the vehicle longitudinal axis (Figure 21). For purposes of the simulated scenarios, rear-end collisions on motorways and intersections in urban areas, these sensor ranges and angles are sufficient to mimic a set of sensor for full surround vision. As the datasets are limited to two vehicles involved in the original collision, the sensors in each of the vehicles are reduced to perceive and identify only one opponent. In the simulation, static sight obstructions might limit the sensor range and angle.

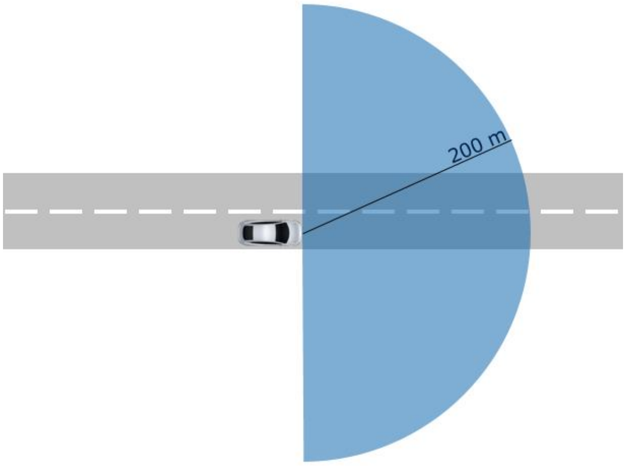


Figure 21: Illustration of the generic OSCCAR sensor field of view

If the opponent is for at least 150 ms within the defined sensors field of view, it is detected and classified as a vehicle. For a future automated vehicle, working on a combination of multiple sensors and even different types of sensors, the challenging time frame for perceiving and identifying the opponent within 150 ms could be overcome by sufficiently increasing the sensor range and/or additional vehicle-to-infrastructure communication.

While the automated vehicle is supposed to drive safely given the previously described requirements, an emergency situation may still occur. To handle such adverse situations, the automated vehicle has a generic automatic emergency braking system (AEBS) implemented. As an AEBS is already in the market, we consider the AEBS to be more advanced compared to current systems. Technically, starting from the time when the opponent is identified as an opposing vehicle, the AEBS initiates its safety algorithm. The AEBS predicts in each time step the points of collision based on a linear as well as on a decelerating prediction of the opponents trajectory. The time to the collision predicted to occur later is used for further calculations. Thereby, in the motorway scenario with both participants driving in the same direction, we assume the opponent not to brake.

For the urban intersection scenario, predicting the vehicles' future positions based on the assumption of constant acceleration and turn rate, a collision is anticipated if the predicted positions of two vehicles intersect in time and space. If, and only if, a collision is anticipated and the time to collision (TTC) is less than 1.2 s, AEBS is activated

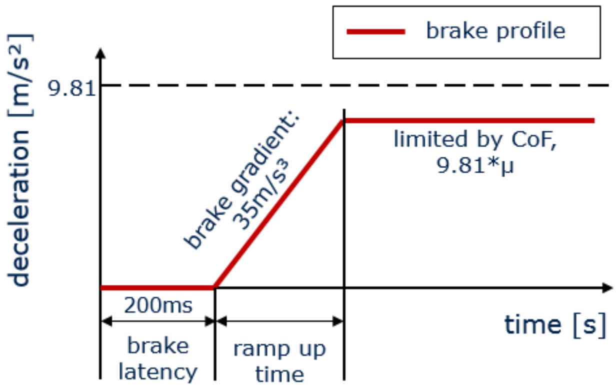


Figure 22: Functional scheme and parametrization for the automatic emergency braking system.

The brakes will start braking after a latency of 200 ms and ramp up the brake force with *35 m/s³* (Figure 22). The maximal deceleration is given by the coefficient of friction µ between tire and road. For a mostly dry road, we assume µ = 0.8 while for wet roads it is reduced to µ = 0.7. Therefore, the maximal brake deceleration is given by $7.8\,m/s^2$ and $6.9\,m/s^2$ for dry roads and for wet roads, respectively. Please note that in snowy and icy roads the automated vehicle will terminate automatic driving mode. Moreover, after once initiating the AEBS, a release of the brake force is not considered to maintain a fast simulation.

After defining the minimal requirements for a general automated vehicle implemented in the simulations in the following sections, we will further specify the systems for both scenarios.

6.3.2 OSCCAR highway pilot

The functional system of the automated vehicle applicable to the previously identified motorway scenario (section 5.4) is mimicking an automated vehicle SAE level 3 highway pilot. More precisely, the OSCCAR highway pilot performs longitudinal but also lateral driving tasks upon activation by the driver. If the system recognizes its limitations it requests the driver to take over the driving tasks with a sufficient time margin. However, if the time margin was not sufficient to hand over before a conflict situation arises, the system handles emergency situations itself.

The functional use case of the highway pilot will be elaborated in the following. First, it operates only on motorways or motorway-like roads. The vehicle identifies a motorway or motorway-like road either by its set of visual sensors or by geo-localisation on a map with a given satellite based positioning system. Second, the highway pilot will operate only within the speed range from 0 to 130 km/h including stop-and-go traffic. Further functional limitations are given by dense traffic, construction sites, exits of the motorway or extreme weather as, e.g., heavy rain, snow, fog or other vision limiting conditions, icy or otherwise slippery roads. For each of the given functional limitations, the system will hand over – within a sufficient time frame – the driving task to the vehicle driver.

The emergency procedure of the highway pilot is given by an abortion of a planned or initiated lane change or emergency braking. As discussed above, the automatic emergency braking system is considered in particular in D1.1.

All in all, the OSCCAR highway pilot as defined here, is closely aligned with other highway pilots, e.g., as defined in AdaptIVe or PEGASUS (see section 3.1).

6.3.3 OSCCAR urban self-driving car

The OSCCAR urban self-driving car is a functional system applicable to the urban crossing scenario identified in section 5.4. All of the following functional limitations are accounted for by filtering appropriate cases suited for the simulations.

The OSCCAR urban self-driving car is supposed to mimic a SAE level 4 driving function. In detail, the overall system concept covers, upon activation by the driver, all driving tasks within the urban environment. The vehicle will send a takeover request to the driver only in the case of reaching an anticipated system limitation, e.g., upon leaving the urban environment. Moreover, the notice to the driver has to be given at least one minute in advance. In other words, the system must be capable of handling all complex urban driving situations as well as emergency situations without asking the driver.

The functional use case is given mostly by its urban environment, i.e., a geo-fenced application area. Here, the localisation could be realised by a satellite based positioning system and a corresponding map. However, within the urban environment, the urban self-driving car performs all tasks from parking position to parking position up to a speed limit of 70 km/h. It is supposed to work in all kinds of typical weather, i.e., except extreme weather situations as, e.g., dense snow or heavy rain. Upon detection of an emergency situation for the urban self-driving car, it initiates and performs braking if applicable.

Although the urban self-driving car will be able to handle all typical situations within the urban environment, some situations could cause the car to reach its boundaries and ask the driver for support. In particular, if traffic is regulated by the police. Or if there is an accident in close proximity – without the automated vehicle being involved, but others might need help.

6.4 Pre-crash simulation

The path towards an OSCCAR test case matrix requires input from WP1 on crash configurations of remaining crashes after introduction of automated driving functions. As described in section 5, the crash configurations serve as a starting point to evaluate the impact of future crashes with novel seating positions on the severity of occupants and how to further increase occupant protection in those possibly different situations. In this section, we describe the general simulation approach, its simulation scheme and possible categories of simulation results.

6.4.1 General simulation approach

The method of choice to identify future crash configurations is by simulating the identified pre-crash situation of all relevant participants up to the first point of contact within the crash. The simulation starts five to 15 seconds earlier than the collision. By simulating typically two participants in their lateral and longitudinal dynamics, all information about decelerations and accelerations up to the collision are available. However a precise vehicle dynamic model is not considered yet.

The foundation of the pre-crash simulations are two independent sets of real-world accident data. The first one is the PCM as described in Appendix A. Cases of the PCM provide information about reconstructed pre-crash trajectories, as well as necessary physical parameters of the involved vehicles and further information on road conditions (e.g. coefficient of friction). The second set of data is the Time-History data (THd) from VCCs database VCTAD described in Appendix A. Here, detailed information of the involved parties is available as well as reconstructed pre-crash trajectories and general information of the road at the time of collision (e.g. dry or wet road).

The case selection for the pre-crash simulation is based on criteria developed and discussed in section 5. More specifically, two different situations are simulated. The first one is a front-to-rear end type of collision on the motorway, while the second one is a collision at an urban crossing. Consequently, the case selection within PCM and the VCTAD database follows either crash situation. Moreover, we account only for collisions between two cars. For PCM data, the main causer as well as the main reason of the accident was available based on information in GIDAS. Finally, each case was reviewed individually if it provides all required data for a successful simulation.

The simulation starts with the first step of the original reconstructed data. The following time steps within the simulation are determined by integrating longitudinal and lateral accelerations to velocities and subsequently to positions. The simulated trajectory follows exactly the original reconstructed trajectory unless there is an intervention by the additional crash avoiding driving function For the purpose of the simulations presented herein, the intervention to be performed is by a TTC based automatic emergency braking system (AEBS). In short, for each time frame, a sensor scans its surroundings and reports all identified vehicles. The AEBS takes the information of the traffic situation that is described in the PCM or THd case and determines whether a collision is predicted. If so, it automatically applies the brakes and decelerates the ego vehicle either to standing still or to the velocity for which a collision is no longer predicted. Independent of the collision prediction, the simulation framework checks for each time frame if there was a collision between the parties and stops thereafter.

6.4.2 Simulation scheme: from baseline to treatment simulations

After describing the individual simulation run in detail, the focus is set onto an overall simulation scheme. The respective pre-crash databases PCM and of VCTAD provide a set of cases applicable for simulation. The OSCCAR approach is to re-simulate those cases and evaluate the effect of automated driving (AD) functions in various ways. A simple re-simulation of the original cases is called baseline simulation while every alternation of the original cases by equipping cars with AD functions is called treatment or evaluationline simulation.

Each of the two cars in the original cases can be equipped with AD functions. Hence, there are four combinations of equipping cars with additional functionality. For further reference, the cars of the original PCM case are named “no 1” and “no 2”, while “no 1” is supposed to be assigned with the main causer of the accident

i. baseline: no car is equipped with AD functions,
ii. treatment 1: the NOT-main causer car (no 2) is equipped with AD functions,
iii. treatment 2: the main causer car (no 1) is equipped with AD functions,
iv. treatment 3: both cars (no 1 and no2) are equipped with AD functions.

The baseline simulation (i) is just a re-simulation of the original case and an additional test of the simulation framework. For treatment simulation 1 (ii), the automated vehicle is acting correctly, yet put into the critical situation by the other car and thus trying to avoid the original collision. A typical situation would be in the urban intersection setup a situation with right of way for the automated car and the other car is disobeying right of way. In treatment simulation 2 (iii), the car equipped with AD functions was originally causing the collision. For instance, at the exemplary urban intersection setup, the original case would be inherently avoided as the automated vehicle is obeying traffic rules and gives right of way at the particular intersection. However, other situations not inherently avoided by definition of the AD functionality, i.e., remaining cases, need detailed simulations to assess the impact of automation, exactly what is addressed by simulation (iii). Treatment simulation 3 (iv) is for the case of two cars with AD functions being involved in the conflict situation. Here, either of the cars might prevent the conflict situation and the most avoidance within the four simulations is expected.

For simulations based on the Swedish VCTAD the attribute “main causer” is not available. Here, the vehicles are distinguished as host vehicle and opponent, as described in detail in appendix A. The four combinations of simulations (i) – (iv) for PCM are adapted to VCTAD by

(1) baseline: no car equipped with AD functions,

(2) treatment 1: only host car equipped AD functions,

(3) treatment 2: only opponent car equipped with AD functions,

(4) treatment 3: both cars equipped with AD functions.

Here, the baseline simulation (1) is identical to the original case of VCTAD and treatment simulation 3 (4) is comparable to treatment simulation 3 (iv) of German data as both participants are equipped with the AD functions. A direct comparison of treatment simulations 1, i.e., (2) with (ii), and treatment simulations 2, i.e., (3) with (iii), is impossible as different cars are equipped with AD functions. However, for a post-simulation clustering process (see section 6.5), the simulation results of (ii) and (iii) are put into one combined dataset and the simulations (2) and (3) are put in one dataset, too. Thereby, we assure the crash configuration prediction results of German and Swedish data to be directly comparable in the sense that the dataset for clustering is in each case composed of a re-simulation of all applicable cases of the original accident databases GIDAS PCM and VCTAD, once with the first car equipped with the AD functions and in the second case it is the other / second car equipped with AD functions.

6.4.3 Available categories of simulation results

After simulating all cases, each case is categorized into one out of three possible categories: avoided, mitigated or no intervention. In the first category “avoided”, the vehicle equipped with the OSCCAR WP1 specific automated driving functions avoided the original collision. The second category accounts for all mitigated collisions for which the AEBS was active and initiated the emergency braking, however, a collision still occurred – typically with a reduced collision velocity. The third category resembles all cases for which the AEBS was not active and the collision parameters (collision velocity and impact) are identical to the original case.

For all remaining crashes, the simulation provides basic information on geometrical and dynamical crash configurations. The most prominent characteristics of crash configurations are the following:

- velocities of both participants at the time of collision,
- collision point in global coordinates,
- collision point in coordinates of each vehicle,
- impact angles, or
- overlap at each vehicle

As the simulation set up prohibits skidding, impact angles (i.e. difference between momentum vectors of both vehicles) and angles between vehicle axes are identical. Moreover, given the collision point, the overlap at each vehicle is easily deduced.

Definition of collision point angles

For any collision identified in the simulation collision point angles are calculated (Wågström L., 2019). The first point of contact (FPOC) between two colliding vehicles is understood as a birds-eye view of the physical appearance of the two objects when first contact occurs.

For the following description, the vehicles are called AD and opponent and the AD vehicle serves as a reference system. However, the general approach of collision point angles is independent of the particular choice of the reference system. The heading direction is defined to coincide with the longitudinal axis of each vehicle, even though for skidding conditions the velocity vector at the time of collision may differ from the heading direction. Imposing the geometrical centre point of the vehicles, the collision point angle of the automated vehicle (CA_AD) is defined as a counter-clockwise angle between the AD's longitudinal axis and the FPOC (see Figure 23).

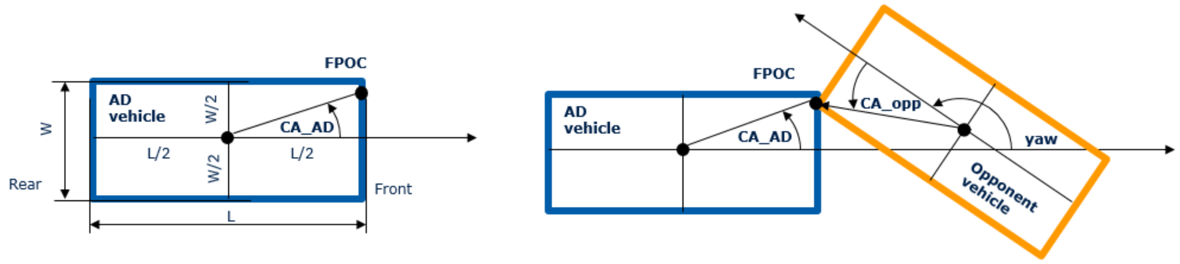


Figure 23: Definition of crash configuration angles.

Accordingly, the opponent collision point angle (CA_opp) is defined by the angle between the opponent's longitudinal axis and the FPOC in the opponent's coordinate system. A third angle describes the angle of the heading direction of the opponent vehicle relative to the heading direction of the host vehicle (yaw, see Figure 23). All angles will be measured in degrees.

By using the definitions described above, the description of the FPOC in terms of CA_AD and CA_opp will be dependent on the vehicle width-to-length ratio. A more universal way of describing the angles is provided when vehicle dimensions including the FPOC are scaled to a square unit car as described in Figure 24. In this way, transformed collision point angles and yaw angles are defined.

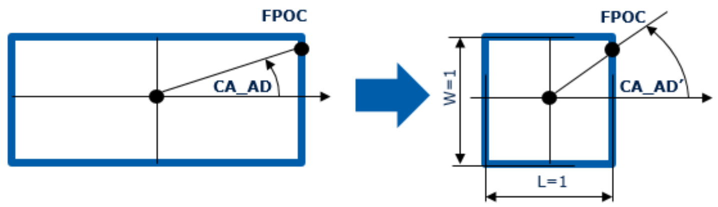


Figure 24: Description of transformation from actual appearance to square unit car system.

6.5 Selection of crash configurations: clustering method

To provide only few, representative crash configurations as an input for the OSCCAR test case matrix, a selection and clustering of remaining crash configurations is applied. The crash configurations identified in PCM and VCTAD simulations are clustered in a two-step process. First, a clustering by collision angles is applied and thereafter a clustering by collision velocities follows. This procedure applies for each situation – motorway front-to-rear-end and urban crossing situations – individually. The overall workflow is sketched in Figure 25.

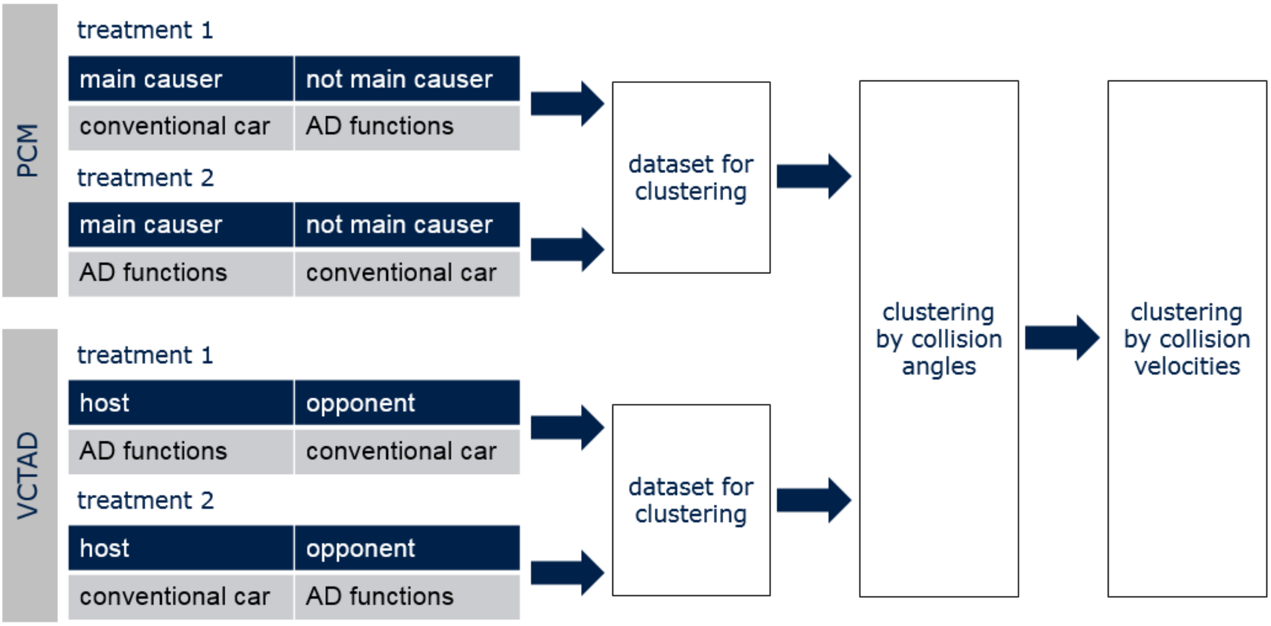


Figure 25: Overall workflow for the OSCCAR clustering process of simulation results

For clustering by collision angles, the datasets of treatment simulations 1 and 2 of PCM and of VCTAD simulations are combined. However, each accident situation is clustered individually. Here, the general idea follows an assumption of only few automated vehicles on the street and, thus, a collision between two automated vehicles becomes negligible. While combining all collisions of those two sets of simulations result in one dataset of size n, the overall input size of the specific collision angle dataset to be clustered is of size 3 x n, where the dimension “3” is spanned by both collision angles CA_AD and CA_opp as well as the yaw angle.

Afterwards a clustering of the collision angle dataset is performed. The clustering method selects one representative case out of the dataset that best match the cluster. Depending on the method used for selecting number of clusters, the number of clusters might vary for different datasets.

After clustering by collision angles, the clustering by collision velocity follows. For each collision angle cluster individually, all cases are aggregated in a dataset spanned by both collision velocities, of the automated vehicle and the other vehicle. Afterwards, another clustering is applied – the optimal number of clusters is again determined by, e.g., the silhouette coefficient (Rousseeuw, 1987).

An example of a clustering by collision velocities is shown in Figure 26, where the silhouette coefficient suggested a separation by two clusters. Each dot – blue circles and green triangles for each of the clusters, respectively – represents a single case. The representative case of each cluster is shown as a large circle/triangle.

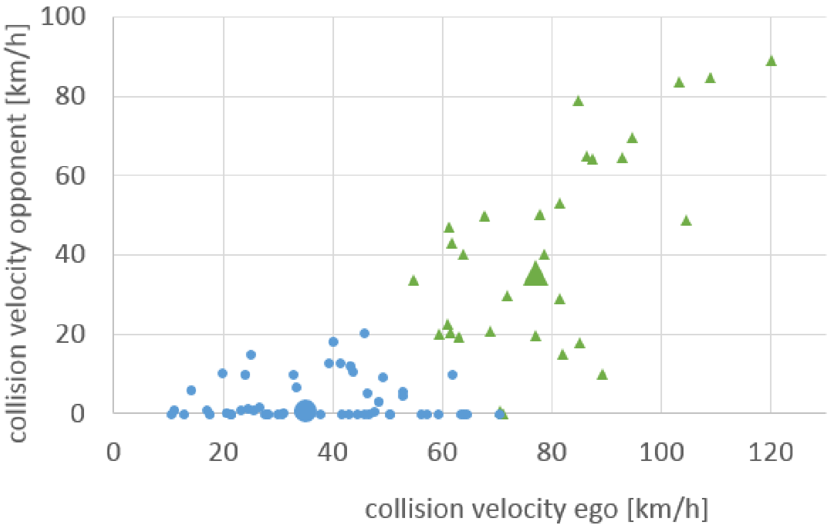


Figure 26: Exemplary clustering of a dataset for collision velocities of ego and opponent vehicles into two clusters.

7 RESULTS

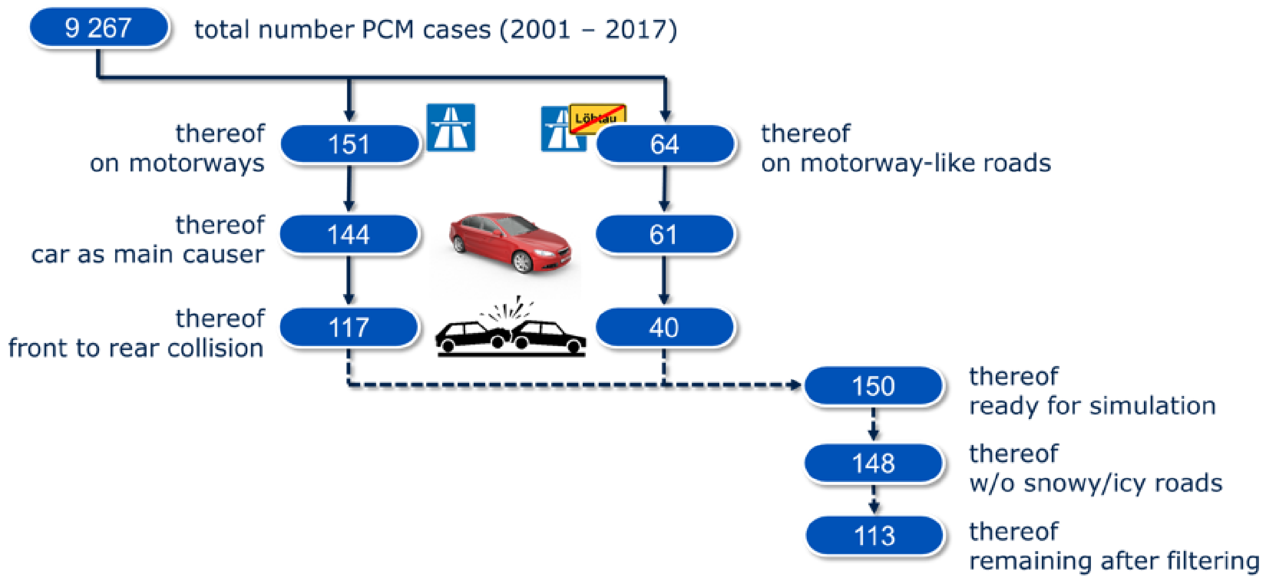
In this section, we present the results of the pre-crash simulations – compared to the original data, too – as well as the final clustering of the crash configurations. Finally, we discuss the results and the overall implications of the findings.

The case selection for the two situations is described in the first section 7.1. Thereafter, in sections 7.2 and 7.3, results of the pre-crash simulations including interventions by the AEBS are presented. The clustering of crash configurations according to section 6.5 is shown, too. In the final section 7.4, a summary of all simulation results is addressed.

7.1 Case selection for simulation

7.1.1 Case selection for German data – motorway situation

The PCM database consists of 9 267 cases for the years 2001-2017. Thereof, at least 205 cases occurred on motorways or motorway-like roads and involved a car as main causer. A motorway-like road is a road with at least two lanes per side and both sides are separated by a physical barrier. Out of 205 cases, in 157 cases, the collision was a front-to-rear end collision. Two of the cases were excluded according to the limitations described in section 6.3 as the road surface was described as icy or snowy. Finally, 148 cases were ready for simulations, i.e., providing all required information to successfully perform the simulations. Thereof, after applying the case filter to remove accidents inherently avoided by automated vehicles and specific to the highway pilot use case, a total of 113 cases needs further investigation by the detailed pre-crash simulations (see Figure 27). When applying clustering on the full dataset (148 cases) representative crash configurations are identified according to the table in Figure 27

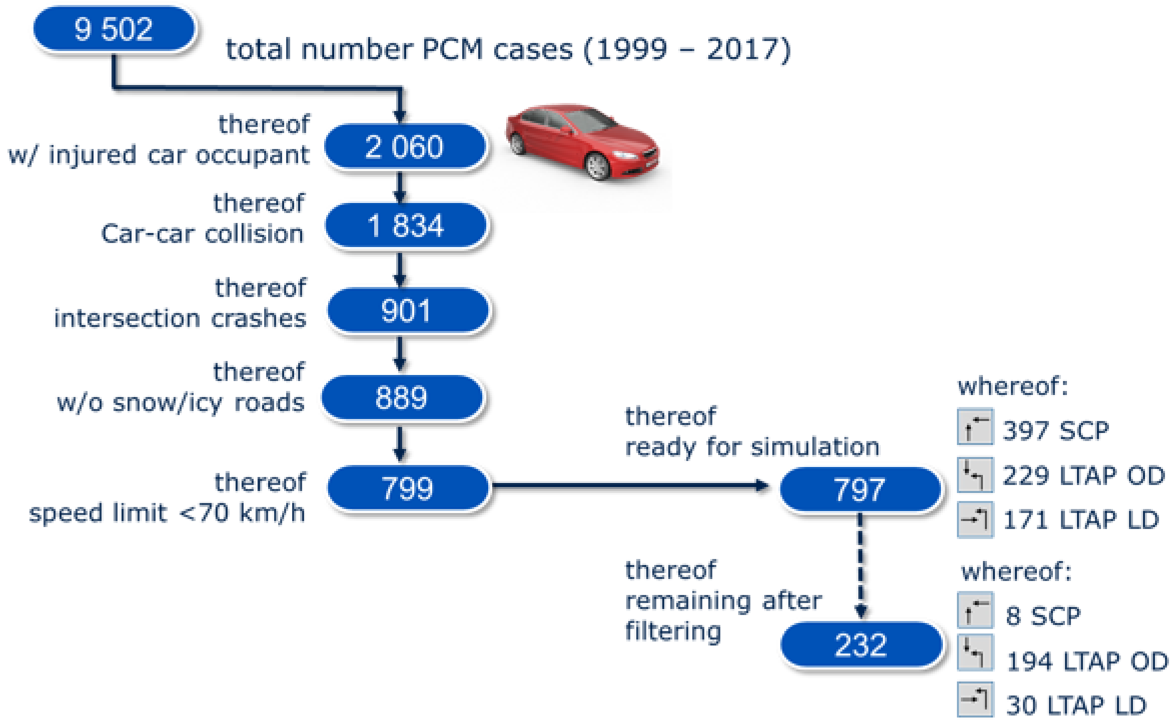


Visualization	CA main causer [°]	CA opponent [°]	yaw [°]	Cluster share	main causer V [km/h]	opponent V [km/h]
	180	0	0	31%	16	28
				69%	2	13

Figure 27: Case selection German motorway situations

7.1.2 Case selection for German data – intersection situation

The PCM database for the years 1999-2017 consists of 9 502 cases. Thereof, at least 2 060 cases include an injured occupant in the passenger car. Of those, 901 cases were collision between two cars at an intersection, identified as one of the three intersection scenarios, Straight Crossing Path (SCP), Left Turn Across Path – Lateral Direction (LTAP-LD) and Left Turn Across Path – Opposite Direction LTAP-OD), defined using the GIDAS variable UTYP (Lubbe, et al., 2018) A further restriction to only dry or wet roads and roads with a speed limit of maximum 70 km/h left 799 cases. Finally, 797 cases were ready for simulations, i.e., provide all required information to successfully perform the simulations. Of these, 397 were SCP cases, 229 were found LTAP-OD and 171 were of the LTAP-LD scenario. After applying the case filtering to remove accidents inherently avoided by automated vehicles and specific to the intersection situation, a total of 232 cases remained (see Figure 28). The 797 cases forming the baseline for further simulations were clustered, showing representative crash configurations in the table in Figure 28.



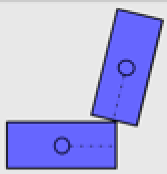
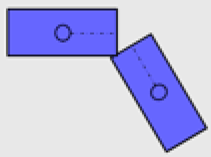
Visualization	CA main causer [°]	CA opponent [°]	yaw [°]	Cluster share	main causer V [km/h]	opponent V [km/h]
	24	-4	258	27%	15	28
				15%	42	13
	-24	15	121	12%	31	45
				8%	18	67
				16%	16	44
				12%	27	27
				6%	49	24
				4%	48	58

Figure 28: Case selection German intersection situations

7.1.3 Case selection for Swedish data

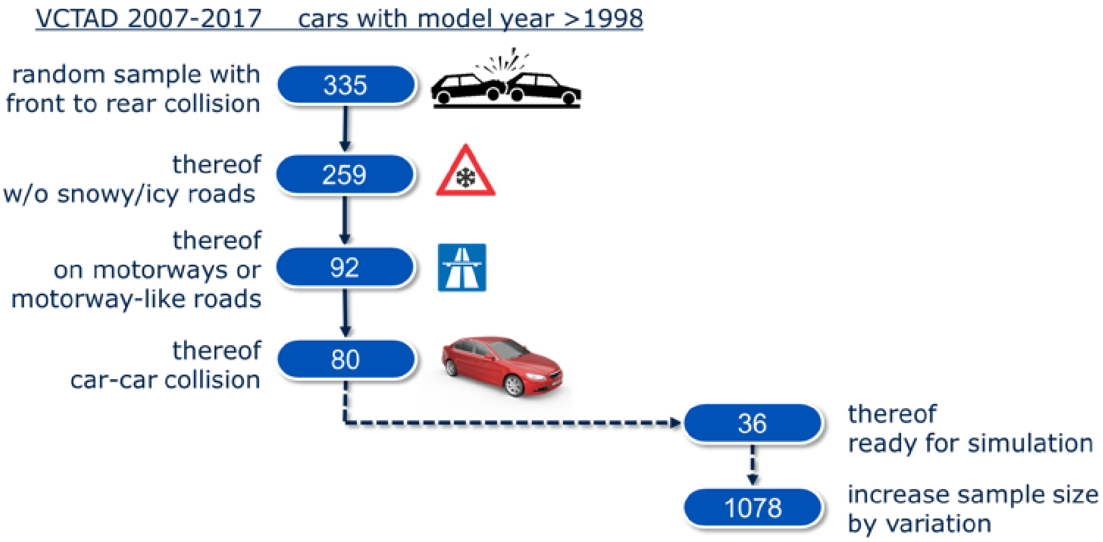
In order to identify relevant conflict situations for OSCCAR use cases, the Swedish Transport Accident Data Acquisition (STRADA) dataset was analysed for accident years 2010 and later. Filtering was applied for urban intersections and motorways – both for road surfaces noted as dry and wet (i.e. not icy or slippery). As it was not possible to classify all conflict situations automatically in the dataset, a review of the text description of parts of the dataset was performed. For further analysis, the most prominent conflict situations for urban intersections and motorways of “straight crossing path (SCP)” and “same direction rear-end frontal” collisions, respectively, were selected. Compared to the baseline crash data selection in German accident data, for the motorway situation the same conflict situation (front-to-rear-end) is studied, while for the urban intersection situation only one (SCP) out of three conflict situations is considered. For both identified conflict situations, cases of the Volvo Cars Traffic Accident Database (VCTAD) were selected and used for setting up a simulation baseline.

Since VCTAD cases are collected in the perspective of the Volvo car, the Volvo car was the host vehicle in the analysed cases. For the motorway front-to-rear-end situations, the host vehicle is always the car having a frontal impact.

Additional data was generated in form of synthetic cases based on distributions of selected parameters from relevant traffic safety data. In the OSCCAR study, variations in vehicle speeds (uniform variation in an interval with +/- range considering a percentage dependent of the estimated speed), initial lateral vehicle lane positions (+/- 0.3m) and start brake/stop times was applied. By this, the characteristics of the cases in the original baseline dataset were varied in a controlled way and a large sample of crashes was provided as a robust input to virtual pre-crash simulations. Brake profiles were modelled based on an event drive recorder (EDR) crash data sample (NHTSA, 2015) of the similar conflict situation, and matched to the baseline dataset using the variables host vehicle braking time, crash speed and lead vehicle behaviour.

In total, 1078 cases were provided as baseline simulation input for the analysis of motorway front-to-rear-end collision (see Figure 29) and 2 218 cases for urban SCP collisions (see Figure 30). The clustering of the full dataset into representative crash configurations is shown in the respective tables of Figure 29 and Figure 30.

Collisions which would be inherently avoided by the automated driving functions were filtered out and presented as inherently avoided in the simulation results. A case was assumed to be inherently avoided if the vehicle equipped with the OSCCAR WP1 model for automated driving functions was speeding (host vehicle initial speed > speed limit).



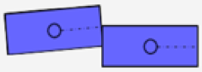
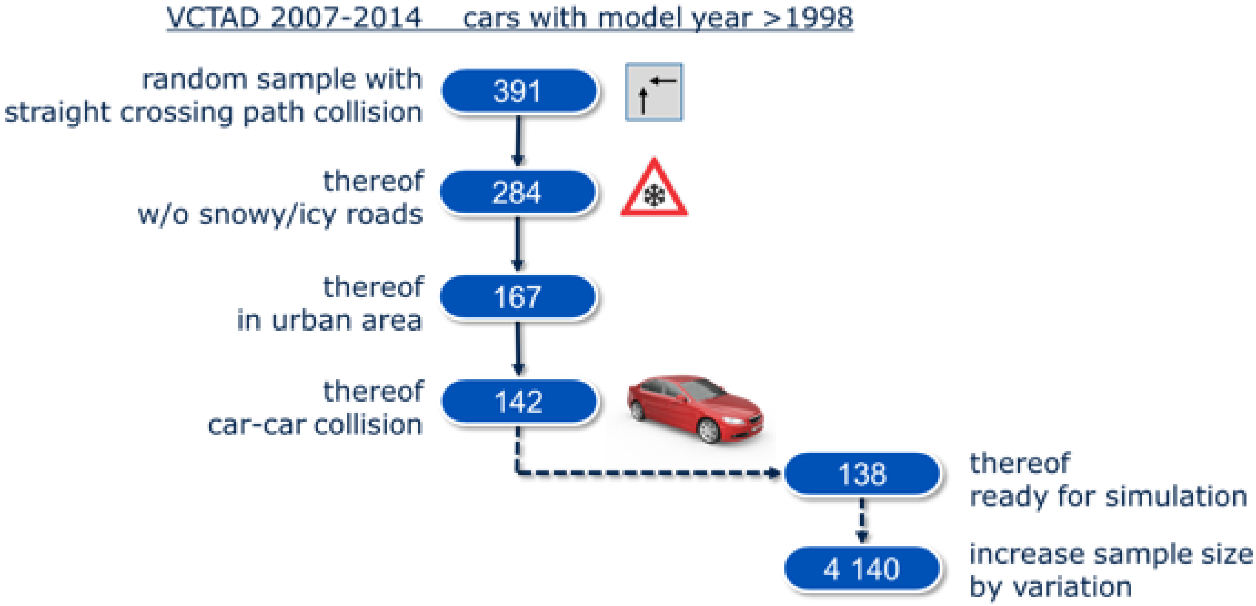
	Visualization	Cluster share	CA host [°]	CA opp [°]	yaw [°]	Share [%]	V host [km/h]	V opp [km/h]
#1		53%	4	-169	0	4%	93	79
						26%	23	6
						9%	55	34
						3%	86	0
						11%	48	9
#2		25%	18	145	-5	2%	109	21
						3%	64	23
						0%	85	77
						10%	18	5
						10%	37	11

Figure 29: Case selection Swedish motorway situations



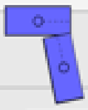
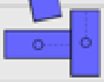
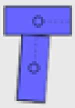
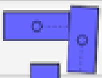
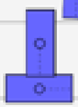
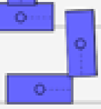
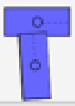
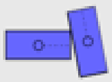
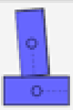
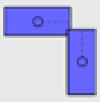
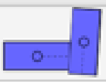
	Visualization	Cluster share	CA host [°]	CA opp [°]	yaw [°]	Share [%]	V host [km/h]	V opp [km/h]
#1		5%	-48	-27	101	3%	22	27
						2%	17	38
#2		11%	1	95	91	5%	17	48
						6%	27	29
#3		13%	-100	37	84	4%	36	28
						3%	22	57
						6%	14	33
#4		8%	-13	-102	-94	4%	34	44
						4%	31	23
#5		10%	74	28	-90	4%	20	38
						6%	42	28
#6		8%	48	-41	-88	4%	38	42
						4%	24	22
#7		12%	-82	-38	93	2%	42	45
						4%	18	40
						6%	27	22
#8		7%	19	-104	-79	4%	46	38
						2%	22	46
						1%	22	13
#9		9%	108	-39	-84	3%	27	17
						4%	36	45
						2%	51	16
#10		10%	-32	45	91	2%	45	38
						4%	18	27
						4%	22	51
#11		8%	-14	-64	-94	3%	23	28
						5%	39	41

Figure 30: Case selection Swedish intersection situations

7.2 Motorway situations

7.2.1 Pre-crash simulation results overview for German data

As described in section 6.4.2, there is a total of four simulations. In this paragraph an overview of each of the simulations results is provided. The simulation (i) (see section 6.4.2) is interpreted as two human drivers collide with each other and therefore, it is a re-simulation of the original PCM cases without any additional systems. Consequently, simulation (i) has only cases of category "no intervention". In simulation (ii), all 148 cases are simulated and the innocent party in the original accident is supposed to be automated. In the special case of the motorway front-to-rear-end collisions, the vehicle in front will be equipped with an AEBS. Being the vehicle in front of the other, an AEBS will never activate and avoid or mitigate a collision. Thus, the categorical simulation result is identical to simulation (i). However, for simulation (ii), re-simulation of the original PCM cases is evaluated from the automated vehicle in front, i.e., as a rear-end collision for the automated vehicle. In simulation (iii), the vehicle originally causing the collision is supposed to be the automated vehicle. Here, first the inherently avoided collisions are reduced from the case selection and a total of 113 cases are simulated. Out of 113 cases, 31 cases are completely avoided by the AEBS (for AEBS specifications, see section 6.3.1). In the remaining 82 cases, the collision was mitigated, where in 81 cases the collision velocity was reduced by more than 5m/s (18 km/h). Simulation (iv) is performed under the assumption of two automated vehicles being on collision paths. As the vehicle in front is not able to detect the other vehicle with its AEBS, there is no intervention by this vehicle and the simulation results are identical to the results of simulation (iii) (see Figure 31).

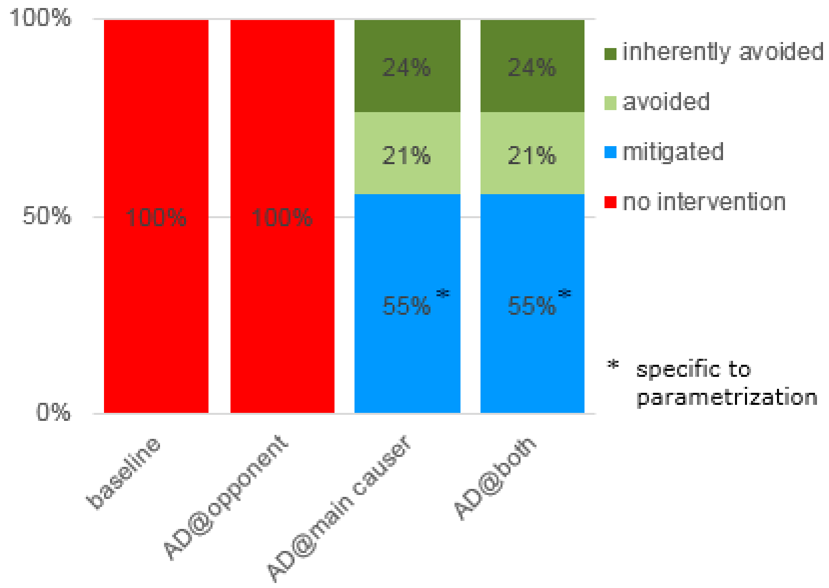


Figure 31: Result of PCM simulations (i) – (iv) of motorway situations

7.2.2 Clustering of crash configurations for German data

Assuming mixed traffic, the automated vehicle can either be hit by a human driver or faces a combination of adverse conditions provoking a collision the automated vehicle cannot avoid. For the motorway situation, we identified two types of collisions from the perspective of the automated vehicle: a front collision of which the automated vehicle cannot avoid impacting another vehicle in the rear and a rear collision if it gets hit by a human driver – simulations (ii) and (iii), respectively. For further analysis, we cluster each of the two collision types together by

- point of collision and angles between both vehicles,
- collision velocity of both participants,

as described in section 6.5.

For the motorway situation, the clustering by collision angles is straight-forward: all cases of simulation (ii) result in one cluster of rear-end collisions and all cases of simulation (iii) result in one cluster of front collisions. Consequently, a subsequent clustering of collision velocities for two individual clusters is performed. The silhouette method suggested for each angle cluster two clusters by collision velocity, resulting in a total of four clusters for the German motorway situation. The parameters of each representative case within the clusters including the cluster size is displayed in Figure 32. For visualisation of the collision, the automated vehicle is represented by a green box and the vehicle driven by a human driver is represented by a blue box. The dotted line is representing the vehicle moving direction.

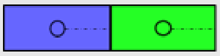
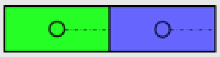
	Visualization	Cluster share	CA_AD [°]	CA_opp [°]	yaw [°]	Cluster share	V_AD [km/h]	V_opp [km/h]
#1		64%	180	0	0	20%	16	28
						45%	2	13
#2		36%	0	180	0	11%	72	30
						24%	30	1

Figure 32: Representative cases of German motorway front-to-rear-end collisions. Legend for visualisation: green car =ego automated car, blue car = opponent car

7.2.3 Results overview and accident reduction for Swedish data

For front-to-rear-end collisions on motorways only the vehicle in the rear is able to avoid or mitigate collisions with an AEBS. As all of Swedish motorway cases have a front collision of the host vehicle, the treatment simulation 2 (only opponent equipped with AD functions) is identical with the baseline simulation and treatment simulations 1 (only host equipped with AD functions) and 3 (both vehicles equipped with AD functions) are identical, too. In Figure 33, the results are shown for the set of original cases (left) and the simulations for which the host vehicle is equipped with the AEBS. For the simulation with an AEBS, 72% of all collisions were avoided and the remaining 28% of all collisions were mitigated (see Figure 33).

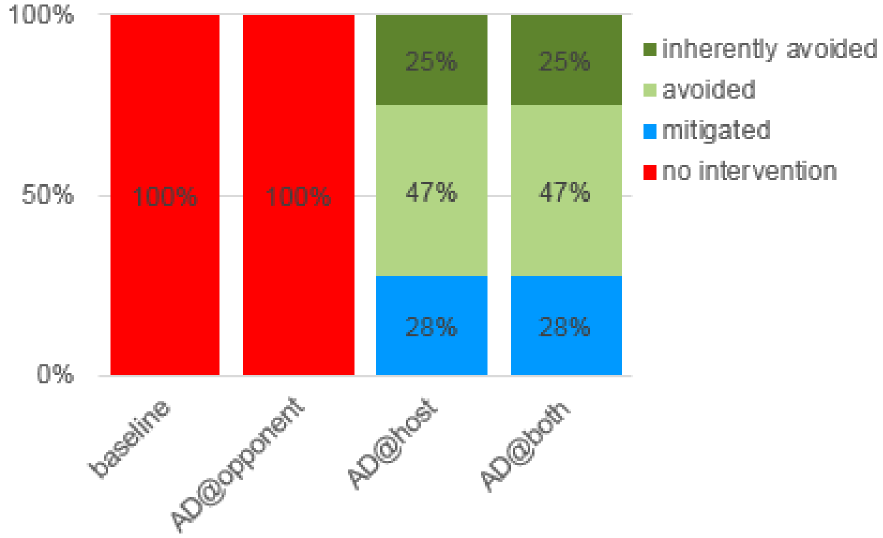


Figure 33: Simulation results for Swedish front-to-rear-end collisions on motorways

7.2.4 Clustering of crash configurations for Swedish data

For the motorway situation, clusters of crash configurations are shown for baseline and treatment 2 as well as treatments 1 and 3. The detailed characteristics of the representative cases of each cluster are depicted in Figure 34.

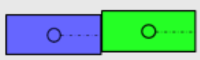
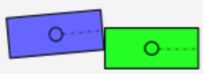
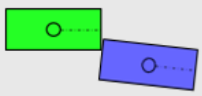
	Visualization	Cluster share	CA_AD [°]	CA_opp [°]	yaw [°]	Share [%]	V_AD [km/h]	V_opp [km/h]
#1		53%	-169	4	0	4%	79	93
						26%	6	23
						9%	34	55
						3%	0	86
						11%	9	48
#2		25%	145	18	5	2%	21	109
						3%	23	64
						0%	77	85
						10%	5	18
						10%	11	37
#3		7%	27	136	-6	5%	24	8
						1%	69	23
#4		15%	0	-174	0	11%	27	5
						4%	57	27

Figure 34: Representative cases of Swedish motorway front-to-rear-end collisions. Legend for visualisation: green car =ego automated car, blue car = opponent car

7.3 Intersection situations

7.3.1 Results overview and accident reduction for German data

As described previously, there is a total of four simulations. The simulation (i) is interpreted as two human drivers collide with each other and therefore, it is a re-simulation of the original PCM cases without any additional systems. Consequently, simulation (i) has only cases of category “no intervention”. In simulation (ii), all 797 cases are simulated and the innocent party in the original accident is supposed to be automated and equipped with an AEBS (see section 6.3.1). In contrast to the motorway situation, the automated car is able to avoid 292 out of 797 cases and mitigate 388 cases. In 117 remaining cases, no intervention is categorized due to obstruction of sight. In simulation (iii), the vehicle originally causing the collision is supposed to be the automated vehicle. Here, first the inherently avoided collisions are reduced from the case selection and a total of 232 cases are simulated. Out of 232 cases, 148 cases are completely avoided by the AEBS. In the remaining 84 cases, the collision was mitigated in 80 cases and in four cases no intervention was applicable. Simulation (iv) is performed under the assumption of two automated vehicles being on collision paths. Here, out of 232 cases, 178 cases are avoided by the AEBS and the remaining 54 cases were mitigated. In this simulation, no cases were classified as “no intervention” (see Figure 35).

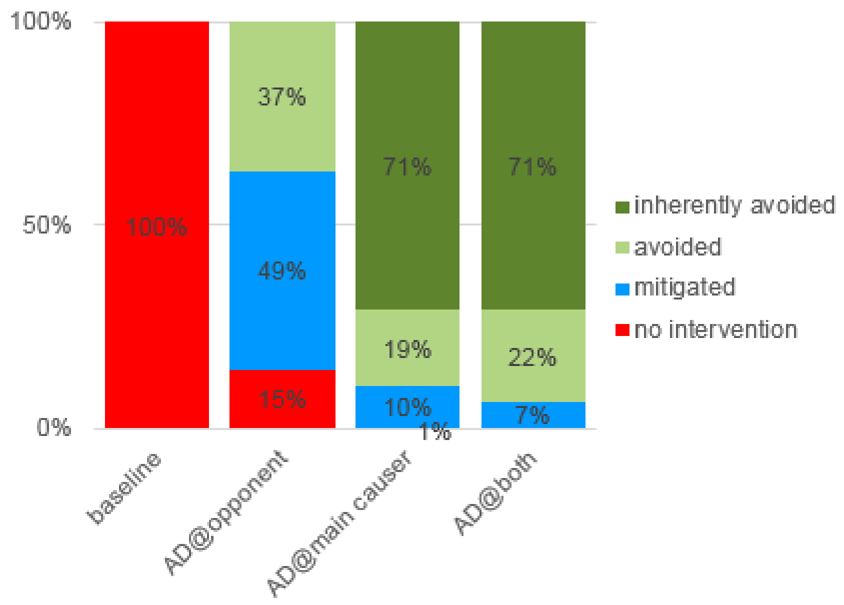


Figure 35: Result of PCM simulations (i) – (iv) of intersection cases

7.3.2 Clustering of crash configurations for German data

7.3.2.1 Clustering of crash configurations: all intersection cases

For the clustering of crash configurations, all remaining collisions of simulations (ii) and (iii) (involving two cars with one driven by a human driver and one car being automated) are combined together in one dataset with 589 cases. Clustering by collision angles results in two clusters, both frontal impacts where the opponent strikes from left or right. A further clustering by collision velocities results in two clusters for each angle cluster. In total, four clusters are identified (see Figure 36). In the visualisation, the position of the green box is always set to the left in a horizontal position – even if the automated vehicle not turning.

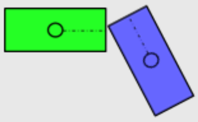
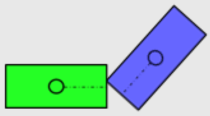
	Visualization	Cluster share	CA_AD [°]	CA_opp [°]	yaw [°]	Cluster share	V_AD [km/h]	V_opp [km/h]
#1		50%	4	23	118	37%	34	20
						13%	5	47
#2		50%	9	-23	228	23%	42	25
						27%	15	22

Figure 36: Representative cases of German intersection collisions. Legend for visualisation: green car =ego automated car, blue car = opponent car

7.3.2.2 Clustering of crash configurations: straight crossing path (SCP)

For the clustering of crash configurations of accidents with an original straight crossing path situation, simulations (ii) and (iii) are out together with a total of 207 cases. Clustering by collision angles results in two clusters, both frontal impacts where the opponent strikes from left or right. A further clustering by collision velocities results in three clusters for both the opponent striking from the right side and for the opponent striking from the left side. All six clusters are further specified in Figure 37.

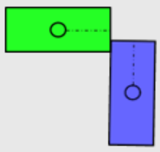
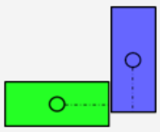
	Visualization	Cluster share	CA_AD [°]	CA_opp [°]	yaw [°]	Cluster share	V_AD [km/h]	V_opp [km/h]
#1		51%	-20	28	89	13%	55	29
						23%	30	21
						15%	37	49
#2		49%	19	-34	271	23%	43	31
						8%	23	53
						13%	18	25

Figure 37: Representative cases of German collisions in a straight crossing path situation. Legend for visualisation: green car =ego automated car, blue car = opponent car

7.3.2.3 Clustering of crash configurations: left turn across path – opposite direction (LTAP – OD)

For original situations being characterised as left turn across path – opposite direction collisions, simulations (ii) and (iii) have a total of 233 cases. Clustering by collision angles results in three clusters – for all clusters the automated vehicle is hit at the front. A visualisation of the cluster representatives is depicted in Figure 38. While clustering by collision velocity results in five clusters for the first angle cluster, it results in two and three clusters for the second and third angle cluster, respectively. Again, the optimal number of clusters is found by the silhouette method, i.e., the number of clusters with the largest silhouette coefficient is chosen.

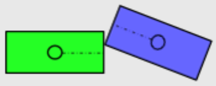
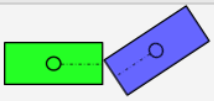
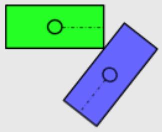
	Visualization	Cluster share	CA_AD [°]	CA_opp [°]	yaw [°]	Cluster share	V_AD [km/h]	V_opp [km/h]
#1		29%	10	20	160	3%	21	57
						6%	0	79
						8%	0	50
						9%	0	30
						3%	40	22
#2		62%	4	21	214	24%	45	19
						38%	18	17
#3		9%	-20	-129	231	5%	31	26
						3%	5	17
						1%	86	30

Figure 38: Representative cases of collisions in left turn across path – opposite direction situations. Legend for visualisation: green car =ego automated car, blue car = opponent car

7.3.2.4 Clustering of crash configurations: left turn across path – lateral direction (LTAP – LD)

For original situations being characterised as left turn across path – lateral direction collisions, simulations (ii) and (iii) have a total of 149 cases. Clustering by collision angles results in three clusters – for all clusters the automated vehicle is hit at the front or close to the front. A visualisation of the cluster representatives is depicted in Figure 39. While clustering by collision velocity results in two clusters for the first angle cluster, ten clusters are found for the second and three clusters for the third cluster.

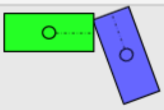
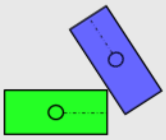
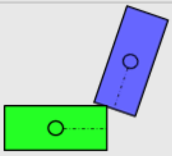
	Visualization	Cluster share	CA_AD [°]	CA_opp [°]	yaw [°]	Cluster share	V_AD [km/h]	V_opp [km/h]
#1		59%	10	23	110	29%	47	15
						30%	24	13
#2		26%	24	127	123	5%	12	15
						2%	53	28
						3%	32	26
						2%	50	8
						2%	20	30
						3%	35	10
						3%	42	16
						1%	67	14
						1%	23	20
						3%	11	5
#3		15%	22	-7	252	6%	1	31
						7%	0	47
						2%	0	72

Figure 39: Representative cases of collisions in left turn across path – lateral direction situations. Legend for visualisation: green car =ego automated car, blue car = opponent car

7.3.3 Results overview and accident reduction for Swedish data

Given the different nature of the THd of VCTAD compared to the German PCM data, the simulation approach was different as described in 6.4.2.

The overall performance of the automated driving functions in urban SCP accidents is shown in Figure 40. For simulation (2), 77% of the urban SCP crashes were avoided and in 23% the speed was reduced, i.e., the crash was mitigated. With the automated driving functions in the opponent car (simulation 3), 82% of the original SCP accidents were avoided and in 18% the crash was mitigated. For treatment simulation 3, i.e., both cars equipped with AD functions, 98% of all crashes were avoided and the remaining 2% of crashes were mitigated.

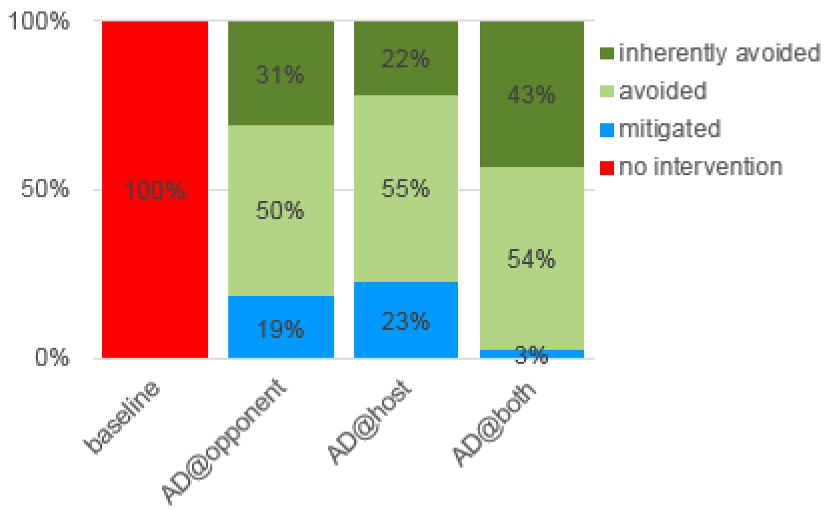


Figure 40: Simulation results for Swedish urban intersection SCP collisions

7.3.4 Clustering of crash configurations for Swedish data

The most representative crash configurations of all remaining SCP crashes were defined with a clustering method. The representative crash configurations including the AEBS for either the host or opponent vehicle are presented in Figure 41.

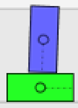
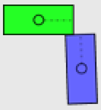
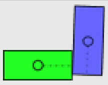
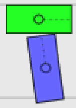
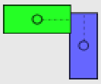
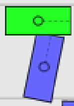
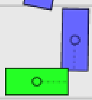
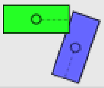
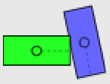
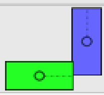
	Visualization	Cluster share	CA host [°]	CA opp [°]	yaw [°]	Cluster share	V host [km/h]	V opp [km/h]
#1		7%	65	37	-92	2%	0	31
						5%	31	9
#2		24%	-48	41	92	14%	3	32
						4%	4	57
						6%	21	14
#3		16%	-3	-51	-92	4%	14	30
						12%	34	12
#4		7%	-61	-43	98	4%	14	13
						3%	15	30
#5		14%	-6	54	90	7%	36	17
						7%	9	24
#6		6%	-90	42	79	3%	11	56
						3%	17	19
#7		19%	48	-42	-92	10%	14	33
						9%	30	13
#8		2%	-34	-116	-108	1%	18	50
						1%	21	27
#9		4%	21	-95	-78	1%	50	18
						2%	19	51
						1%	17	14
#10		1%	6	132	90	1%	23	34

Figure 41: Representative cases of Swedish intersection collisions. Legend for visualisation: green car =ego automated car, blue car = opponent car

7.4 Results overview

In the following section, we want to highlight the most relevant simulation results and compare simulation results of German with Swedish origins.

For the motorway situations with the automated vehicle colliding onto the opponent's rear-end, we identified for both, German and Swedish data, cluster representatives with either standing still (or almost standing) opponents or driving opponents. If the opponent was driving, the velocity of the opponent at the time of collision was 30-40 km/h. The collision velocity of the automated vehicle having the front collision is again clustered into velocities "slow" (around 30 km/h) and "fast" (around 70 km/h). For all cases, the collision angles are perfectly in-line (German data) or almost in-line (Swedish data).

For the intersection cases, the simulation results are more heterogeneous. For the LTAP-OD and LTAP-LD situations, results are only available from simulations of German PCM accidents. For both LTAP situations, there is a most relevant cluster identified: for LTAP-OD, the largest cluster has a share of 64% and is a typical frontal oblique case (see also selection for Test Case Matrix in section 8.1.1). For the LTAP-LD situations, the most relevant cluster has a share of 86% and the automated vehicle is hitting with its front the opponent's left side. In the relevant clusters of both LTAP situations, the opponent's collision velocity is in the range of 15-20 km/h, while the collision velocity of the automated vehicle is either at about 25 km/h or 45 km/h.

Comparing straight crossing path (SCP) accidents of German and Swedish origin, the vehicle orientations to each other at the time of collision are typically close to orthogonal – given the nature of the accident situation. However, other crash parameters are more diverse: for German and for Swedish data, in some clusters it is the automated vehicle that hits the opponent and in others it is vice versa. Consequently, all combinations of front to side or edge collisions appear in the simulation results. The diversity holds for the collision velocity, too, with some clusters having a faster automated car and in others it is the opponent with faster collision velocity. Yet, the collision velocity of the automated vehicle is typically below 50 km/h (with one cluster at 53 km/h) as well as the collision velocity of the opponent.

A further result – strictly coinciding within all simulations – are the form of pre-crash accelerations. Longitudinal and lateral pre-crash accelerations are of particular interest for determining a pre-conditioning of occupants as a starting point for the evaluation of occupant restraint systems. So far, the simulation results presented in this report have displayed only direct collision parameters. In Figure 42, a typical pre-crash acceleration profile of a representative motorway case from the German data is displayed (in section 7.2.2, case #2 with share 24%). The emergency situation is identified at time step 1.0s before the original collision, due to a strongly decelerating opponent in front of the automated vehicle. After 0.15s, the ramp up of brake force until 80% of the gravity is applied. The deceleration is kept constant until the collision. After the collision, the vehicles are decelerated with the same brake force until standstill. The specific form of the pre-crash deceleration is determined by the simulation setup of an advanced emergency braking system for mimicking an automated system.

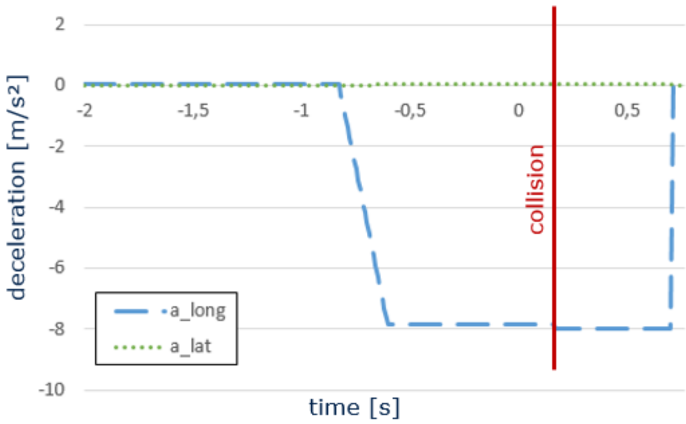


Figure 42: Typical pre-crash emergency braking profile for a motorway situation with a decelerating opponent in front.

8 OUTLOOK

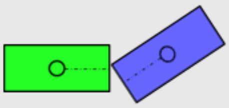
In the section, we review how the goals related to the state-of-the art (section 2 and 3) were handled in sections 5 to 7, and evaluate the results. Furthermore, we discuss what actions were derived in the process of working on this OSCCAR WP1 deliverable D1.1 and provide an outlook of the phase of WP1 after D1.1.

8.1 Discussion of results

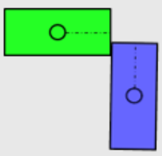
8.1.1 Selection of crash configurations for Test Case Matrix

As described in detail in deliverable D2.1, the vehicle with the automated urban function used for the OSCCAR demonstrator will operate mainly in mixed traffic in urban areas. The applicable crash configuration is incorporated in a Demo Test Case as described in section 6.1. The crash configuration for the Demo Test Case, is supposed to be derived from the WP1 crash simulations as presented in this deliverable D1.1. Consequently, data is taken from the remaining intersection crash scenarios (see section 7.3).

- **Example Case 1 – frontal oblique impact.** The intersection simulation study for GIDAS cases included a high number of left-turn across path opposite direction (LTAP–OD) accidents, with the opponent vehicle turning into the vehicle path. With the automated vehicle decelerating prior to the collision, the collision has an about 35° oblique impact condition. The collision velocities for the automated vehicle and the opponent are 45 km/h and 19 km/h, respectively. The overall cluster size is rather large with a cluster share of 25% within all LTAP–OD cases.

	Visualization	Cluster share	CA_AD [°]	CA_opp [°]	yaw [°]	V_AD [km/h]	V_opp [km/h]
#1		24%	4	21	214	45	19

- **Example Case 2 – “edge impact”.** The goal for selecting a second example was a configuration that appears with a large cluster share in both, the German and the Swedish intersection data. The result was the depicted edge collision (from the right / far side) very close to the vehicle front / front edge of the host vehicle. Large collision speeds (automated vehicles: 55 km/h; opponent: 29 km/h) were chosen as deliverable to WP2 in order to present a safety relevant example for the grading.

	Visualization	Cluster share	CA_AD [°]	CA_opp [°]	yaw [°]	V_AD [km/h]	V_opp [km/h]
#2		13%	-20	28	89	55	29

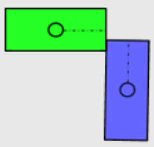
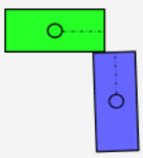
Especially the second example (#2) is a challenging one in terms of how to proceed in the OSCCAR tool chain. It shows the complexity of the Test Case selection process, when looking at the clusters from which it was chosen (see Table 5). Due to differences in German and Swedish data as well as method of simulation and clustering (see section 8.1.2), the clusters in Table 5, representing almost the same impact geometry, differ largely in collision velocity and cluster share. Moreover, the cluster samples are neither weighted for German or Swedish national accident data, nor weighted to European accident statistics.

Even though the geometric configuration in terms of angles looks similar and the values do not differ at a larger scale, these “edge impacts” differ in terms of “which vehicle hits which vehicle?”. The speed of the opponent vehicle hitting from the side has an additional large influence on the development of the collision: how do the vehicles interact, what structures are supposed to be involved, what about wheel influences? Hence, these six entries could lead to all different crash pulses – it is hard to judge up front without running a detailed finite-element simulation with the considered vehicle structure.

Furthermore, the speeds between the Swedish and the German data set are different, so even if the differences are not further investigated, the criteria for selecting one case is unclear. If the focus is on the most “relevant, because challenging” crash, this answer might strongly depend on the interior use case or the shape and deployment sensoring of the restraint system. If the occupant is in a forward facing but reclined position, the higher host collision speed would cause more of a longitudinal principle direction of force – hence, the first speed cluster from #2 GER is “the most relevant”. Alternatively, the Use Case could include a slightly sidewise turned seat or a seating configuration with two occupants facing each other, the speed clusters with higher opponent speeds (#2 GER, 37 km/h vs. 49 km/h; #2 SWE, 4 km/h vs. 57 km/h) could cause a relevant side impact and hence, more challenging conditions to protect the occupant. At first glance, the configurations looked the same, but cannot be reduced to one configuration.

This leads to the advice for future Test Case discussions having a careful consideration of the crash configurations. A single “typical load case” cannot be expected. The method needs to be capable of dealing with large variations and cases like this “edge impact” needs to be approached iteratively by designing relevant studies. This exemplary crash configuration should rather be covered by a parameter study and further refined into further parameter discretions.

Table 5: selection of “edge impact” crash configurations from GER and SWE

	Visualization	Cluster share	CA_AD [°]	CA_opp [°]	yaw [°]	Cluster share	V_AD [km/h]	V_opp [km/h]
#1 (GER)		51%	-20	28	89	13%	55	29
						23%	30	21
						15%	37	49
#2 (SWE)		24%	-48	41	92	14%	3	32
						4%	4	57
						6%	21	14

8.1.2 Limitations

The methodology presented within this OSCCAR deliverable is a compromise between various demands and serves as a method imposing different approaches for prospective determination future accident situations in a short time frame. It applies only a vague description of automated driving functionality. Thus, the overall methodology of OSCCAR WP1 D1.1 faces some limitations with immediate implications on the results. In this section, a few limitations will be addressed in more detail to give an idea on the different levels of limitations – not providing a full list of all limitations.

Method: baseline vs simulation of automated driving functions

The complexity of understanding real traffic and how to model it to provide trustworthy simulation tools for safeguarding automated vehicles remains a huge challenge for the automotive industry, way beyond the scope of OSCCAR WP1. In that respect, the domain of accident research "takes a shortcut" by predictions based on current accident data. Accident data comes from reconstruction, and reconstruction means modelling complex situations based on high level assumptions (reaction time, speeds, and trajectories) – mainly in order to understand the collision mechanism and the crash severity. Thus, simulations of complex traffic mechanisms with or even based on accident data must be taken with caution. However, other approaches (see section 6.1), e.g., incorporating measurements from real-world traffic, have to prove yet the supposed higher accuracy.

One limitation is that current accident data as the German GIDAS-PCM may only cover the pre-crash behaviour of two participants. There is no information available on other participants. Consequently, avoiding in the simulation the original collision of the GIDAS case, another collision between the evasive vehicle and another participant is excluded. Thus, "new accidents", i.e., collisions that could be provoked by an automated car reaction will never appear. For instance, to avoid a side collision in the urban intersection situation, the automated car brakes strongly and, thereby, could provoke a front-to-rear-collision of the following car. A function reacting in critical events avoiding accidents (similar situation as above, but original situation would be a "near miss" of its opponent), could lead to "additional accidents", if the following vehicle does not react properly.

As discussed in AdaptIVe, continuous support functions must take into account traffic behaviour effects. Hence, a function keeping adjusted speeds, large time-headways and adapting immediately to any change in the environment will face less critical situations. This cannot be covered by only re-running accident trajectories, originating from critical events. On the other hand, it might occur that larger time gaps on motorways provoke more cut-ins compared to car following situations, which could lead to different kinds of rear-end accidents. So the simulation of pre-crash situations derived from "human reconstructions of human accidents" may not cover changes in exposure to critical situations of an AD function compared to human drivers.

A further argument for a higher modelling depth of the traffic situations (the pre-crash phase) are underlying worst case assumptions, e.g., regarding the reaction of the PCM opponent: if the AD vehicle breaks to avoid the collision in SCP scenarios, the opponent would get more time to react or would get more evasion space, so the opponent could react by steering, more easily avoiding cases like the side impact to the front edge. Furthermore in the simulation leading to the results in section 7, the opponent is not equipped with ADAS or AEB (compare with market scenario in section 5.3).

Accident data selection

The data selection in section 5 sets priorities on a quite high level and determines the largest populations expected to remain, but the picture of predicted collisions is not complete. Real-world accidents are quite heterogeneous and many small samples as well as other than car to car collisions might remain unanalysed (accidents leading to head-on collisions in urban areas, accidents leading to side swipe collisions). The argument in WP1 is based on large experience and in-depth knowledge of the current data – but given the expected large shifts due to automated driving ("90% accidents linked to human error") smaller populations may gain importance. Additionally, since the conventional seating position or the vehicle interior concepts are about to change, accident data (up to now covering conventional cars only) does not provide any information about occupant injury severity in new configurations. This is already addressed by WP2 by the methodology around the Test Case Matrix, but any "expert judgement" related to current vehicle safety requirements has to be taken with care.

Moreover, after specifying the most important accident situations in section 5, the simulations performed in section 6 and the results presented in section 7, rely strongly on the baseline input dataset. Yet, the datasets vary by how an accident is chosen to become part of an accident database in different countries, by the available data, i.e., variables and their interpretation, as well as size of the accident database. A detailed description of the accident databases available in different European countries can be found in Appendix A. Additionally, the accident databases as well as the simulation results, are not yet weighted to European accident situations and statistics.

Technology under test model

A limitation with straightforward implications on the outcome of simulation results is the model of the technology under test itself. The model presented in section 6.3 is supposed to mimic a future automated driving function on a high-level description. While the individual OSCCAR partners might develop automated driving functions, for the automated driving functions of OSCCAR WP1 conceptual functions were applied. The harmonization process not only adjusted the model to a virtual AD model in terms of providing a partner-independent functionality, but also limits itself to an emergency braking system and only one model function for both simulated situations, the motorway front-to-rear-situation and the urban crossing situation. Both, the functional design as an emergency braking system as well as the parametrization of the system for both situations at once, are neither applied to the specific use cases nor to anticipated future accident situations.

For instance, for an automated vehicle approved for real world traffic, we do not expect a large share of accidents for the motorway situation as indicated in section 7.2.1. While the rear-end collisions are not avoidable by the automated vehicle due to physical reasons, the simulated front collisions are ought to be avoided. The functional domain of a future system application "highway pilot" will be required to avoid this kind of standard situations of the simulated PCM cases. According to the reconstructed data in the PCM database, there are no sight obstructions. The large number of 81 cases with mitigated collisions is understood as a result of the emergency braking function being identical for both, urban intersections and motorways. However, initiation of the automated emergency braking for an anticipated time to collision of 1.2s is unsuitable for a motorway situation. Given large sensor ranges, no recorded sight obstructions and a target braking algorithm, an emergency braking system that is appropriately designed should avoid all front collisions. Including an even more realistic comfort braking before emergency braking in the automated vehicle, the criticality of each case can be reduced even further.

Clustering

A further limitation concerns the clustering method of the simulation results. The clustering is an extremely helpful tool to look for single points in the n-dimensional space. A space which is difficult to be judged by engineering expertise (which point to select?) and even harder to discuss in an integrated project. It should be noted, that this method provides the most frequent points (i.e. cluster representatives). By applying the clustering, we now provide median collision velocities, but 75% or 90% percentiles from the collision speed distributions could be reasonable, too. Moreover, the clustering method relies strongly on the number of clusters. Although the harmonisation approach for the OSCCAR WP1 simulation results specified the clustering method and how to determine the optimal number of clusters, the final cluster representatives may differ from the presented results if the clustering methodology would be slightly adjusted: clustering in four dimensions (collision angles and collision velocities of both collision participants) instead of clustering first by collision angles (two dimensions) and afterwards clustering by collision velocities (additional two dimensions) could identify different cluster representatives and thereby alter the demo test cases presented in section 8.1.1.

8.2 Outlook on future WP1

8.2.1 Actions from current approach

When taking into account the limitations above, there are various actions that could address the limitations / questions raised by refining the current approach.

- **Additional accident and pre-crash data**: The data queries for determining relevant cases (from which remaining collisions are obtained) could the widened, so all accidents potentially within the ODD are included in both the analysis of causation factors ("HURSU discussion") and the simulation studies.
- **Analysis of further accident situations**: The results of section 5 obtained from the top-down approach as well as from the bottom-up approach revealed the most prominent remaining crash scenarios. In a next step, other remaining crash scenarios could be included into the simulation studies. Except from car to car accidents, a focus could be set on vulnerable road users, too.
- **Additional simulation studies**: Additional studies, e.g., with different parameters or with the combination "AD vs. ADAS" could improve the way the "AD market scenario" is approached.
- **Weighting**: Based on the approaches of previous projects, the data sets from German and Sweden used for simulations could be merged and specifically weighted to be representative for EU accident data. Especially taking into account accident data of France and the UK, the WP1 results could be improved and made representative for Europe (cf section 8.2.2).
- **Further ADAS/AD functionality**: By now, the vehicles only consider braking as collision avoidance mechanism. Especially the AEBS models used to address intersection cases could be amended and take into account steering intervention.
- **Negative effects of AD**: Automated driving functions may cause additional accidents, especially while avoiding another collision a previously unaffected participant could be involved. A famous example is illustrated by an AEBS braking stronger and faster than a human driver in behind. Such negative effects of automated vehicles could be analysed.
- **Provide further statistics on remaining crashes**: In the discussion with WP2, it became obvious that it is interesting for the protection principle experts in WP2 (but not only to them) to understand the "overall collision statistics" from which the crash configuration are selected. This could be histograms or charts such as "how many front/side … oblique/straight ... moderate/high speed collisions occur?" The approach how to use this information has to be amended in the methodology around the Test Case Matrix by WP2, too.
- **Common simulation environment openPASS**: For the D1.1 simulations results, there was no common simulation environment for the pre-crash simulations. A suitable simulation environment could be based on the open-source framework openPASS.

However, the OSCCAR WP1 needs to carefully consider how much resources are spent for “finetuning” the current D1.1 results. These are resources that would not be available for the widened scope (“phase 2”) as described in section 2.3. Some activities could run in parallel and shared across partners, of course, but the aim for D1.3 should include just small updates on the D1.1 results. The “full picture” should be obtained from using the yet to be developed “OSCCAR app”.

8.2.2 Extrapolation of results to EU level

The crash scenarios described in this report were derived from in-depth crash databases (see section 4 and appendix A). The accident data for those databases were either collected within specific regions or are the combinations of such databases like iGLAD. However, for the benefit assessment of potential systems on a European level, it is important to investigate how well these data represent the general crash population in the EU and how information from different databases can be combined to improve representativeness. This section contains a brief review of the possible methods for this purpose.

Generally, analysis of representativeness and methods for extrapolation are related to the comparison of the joint distribution of a set of parameters in a smaller region, where detailed data are collected, and a larger region that the results should be extrapolated to. The larger region in this case is the EU with accident data available in CARE for the EU level. CARE contains general variables about the accident, road, traffic units and people involved in the accidents. For the full list of variables and additional information on CARE, see the Common Accident Data Set glossary (European Commission, 2018).

A challenging aspect of extrapolation is the selection of appropriate variables whose distributions can be compared between CARE and the in-depth databases. General requirements on these variables include the following points:

1) definitions are compatible in the in-depth databases and CARE;
2) quality and frequency of the variables are sufficient in all databases;
3) joint distributions can be computed or approximated to a sufficient precision.

The limiting factor points is typically the CARE database as it contains data from all EU countries having historically different data collection methods whose harmonization is a major challenge. In particular, the variable selection should be limited to variables marked by (H) in (European Commission, 2018), indicating high reliability and importance for the analysis, and have a sufficiently low relative frequency of unknown values (e.g. <20%).

A good summary of different extrapolation methods in the context of traffic safety is given in (Niebuhr, Kreiss, & Achmus, 2013), (Kreiss, et al., 2015) and (Kreiss, Feng, Krampe, Meyer, & Niebuhr, 2015) which all address the extrapolation of GIDAS to Europe. The method applied for such data extrapolation varies from project to project, ranging from simple hypercube weighting (i.e. cell-by-cell projection using, e.g. cross-tabulations of injury severity, accident location classified as urban/rural/motorway) to the usage of recursive decision trees, with the potential application of iterative proportional fitting to approximate the joint distribution from marginals. Implementations of state-of-the-art extrapolation methods for data weighting to EU level in recent projects include (Flannagan, et al., 2018; Kovaceva, et al., 2018). However, there is no single “correct“ method to be used and the advantages and disadvantages of different methods require a careful assessment.

An “OSCCAR innovation” in this field of extrapolation is the idea to not extrapolate from one retrospective data set to another existing data set, but to give generic scenario models an “European shape”. How this is possible requires additional literature review, too. Most traffic simulation models only account for the scenario from which the validation data originated, e.g., car/truck traffic on

German motorways. So the modelling challenges for "European scenario models" could mean dealing with regional differences not only, e.g., regarding casualty distribution over mode of transport, but also related to infrastructure, obeying to traffic rule or speeds. This depends on the complexity of the model. On the other hand, the approach could be rather simple and similar to the weighting from GIDAS to German national data in AdaptIVe, the "OSCCAR weighting" just calculates "EU weights" for the final step how to add up the results from different submodels. Another open point is how to include the insights from the French and UK studies, hence how to model regional characteristics incorporated in the accident data analysis results when defining the parameter for the scenario models.

The most appropriate method will be selected and implemented during the next phase of the project and will be described in D1.3.

8.2.3 OSCCAR scenario models & "OSCCAR" App

As described in section 2, the further work of OSCCAR WP1 aims at using complex scenario components from openPASS to develop OSCCAR specific scenario / traffic models that provide more detailed aspects and variations of potential future mixed traffic with automated vehicles. However, the results – prediction of remaining crash configurations – are the same in terms of format and selection process, hence the Test Case Methodology will be applied again.

The Eclipse Working Group openPASS was founded in August 2016 by BMW, VW GoA, Daimler and ITK to jointly develop a harmonized tool for effectiveness evaluation within the scope of the Eclipse Foundation. In 2018, TÜV Süd, Bosch and Toyota Motors Europe joined. The openPASS Working Group aims at fostering open source solutions for simulation tools in the field of active and passive vehicle safety. The open source approach makes use of infrastructure and the vivid ecosystem of the Eclipse foundation that provides synergies of both professional software development and open source spirit. Currently, in the openPASS project and its simulation framework within the governance of the openPASS Working Group, two exemplary "use cases" are available – a PCM app and a traffic simulation experiment based on a virtual OpenDRIVE road network, see (openPASS Working Group wiki, 2019).

Example: "scenario-based assessment" The next minor release of openPASS is expected to be available in Q2/2019 and will cover an update of the traffic simulation use case, hence certain vehicles ("Scenario Cars", marked in blue in Figure 43) can be manipulated by trigger events defined in the XML format OpenSCENARIO (see the concept presented in the openPASS Architecture Committee (Findling, Das, & Platzer, 2018). For instance, at a certain simulation time or if certain traffic conditions have been reached, a single or several scenario cars follow a pre-defined trajectory and generate critical events in the traffic that may lead to accidents. Especially for intersection scenarios, using trajectory following with different initial conditions could be a good approach to model the behaviour of the relevant conflict parties, without having to deal with modelling the complex driving task of navigating through different urban crossings. Applied to the OSCCAR context, the input parameters for the generic OSCCAR intersection scenario model simulated in openPASS would come from accident statistics.

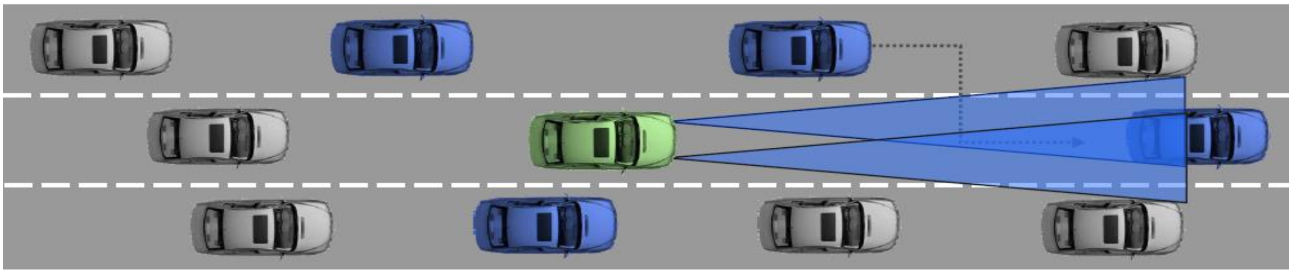


Figure 43: Example cut-in scenario for scenario-based assessment (source: BMW presentation available on openPASS wiki)

OpenSCENARIO is an open file format for the description of dynamic contents in driving simulation applications, mainly as addition to the de-facto standard OpenDRIVE which is covering the static content of driving simulation environments, e.g., by covering the different events of a scenario in a storyboard, see (OpenSCENARIO Project, 2018). This project has been transferred to ASAM e.V. in November 2018 where many additional features are under discussion, e.g., traffic and stochastics – see (ASAM e. V., 2019). Figure 44 shows how a storyboard including a cut-in is described with this format.

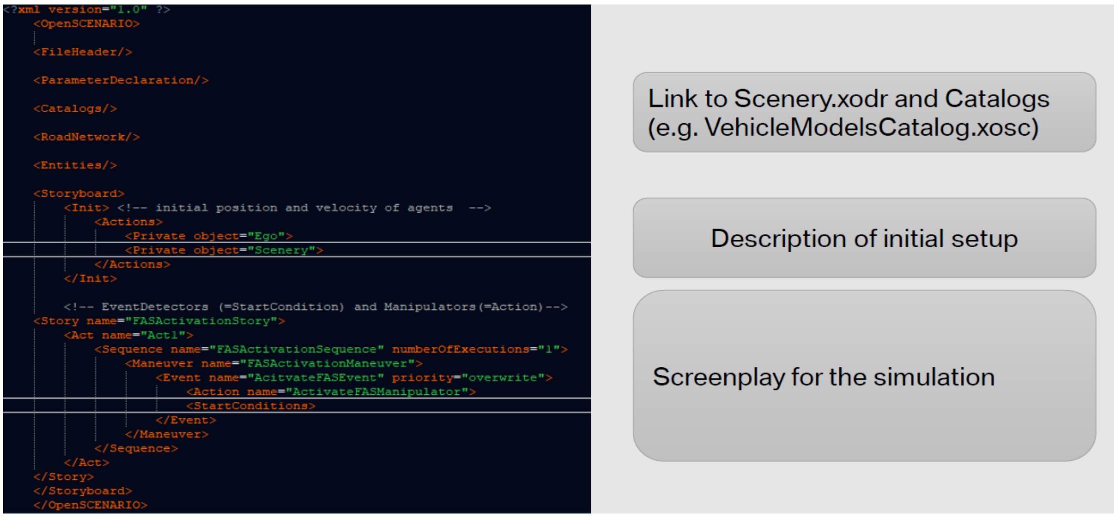


Figure 44: OpenSCENARIO code (XML) for cut-in scenario for scenario-based assessment (source: BMW presentation available on openPASS wiki)

Example "traffic simulation": Additionally, there is the opportunity to refactor the AdaptIVe approach to a certain extent based on open source components and provide a traffic simulation based assessment (see Figure 45 for an openPASS example for the end of a traffic jam on a motorway). The challenge is to further develop the existing components of this openPASS "use case" (driver model for car following and lane changing, configurations, and road layouts), integrate further improvements and to use them with proper parametrization. Finally, collisions occurring in this traffic model need to represent real-world accident frequency and characteristics. This was not addressed by the assessment approach in AdaptIVe, since AdaptIVe just accounted for a relative safety assessment in terms of changes in risk "human vs. AD function" (see section 3.1.1.4). This activity is currently pushed forward in the project "KAUSAL" of the Tech Center i-protect by Daimler and Bosch, see (Schmidt, et al., 2018).

Figure 45: Visualization of openPASS traffic simulation of the scenario “end of traffic jam” on a motorway (three lanes, traffic flow from left to right)

Furthermore, links to other software components were discussed since the start of OSCCAR, mainly to link the openPASS simulation core and its components with the COVISE framework which allows editing and visualizing traffic scenarios, see (COVISE at HRLS University of Stuttgart, 2019). Hence, the graphical user interface of the so-called “OSCCAR app” would be an integrated and tested selection of various existing tools (ODDLOT, openPASS, and openCOVER). At the end of OSCCAR (mid 2021), the user should be able to configure the simulation experiment based on “scenario models” from ODDLOT (road design) and openPASS (traffic parameters), get the results displayed in terms of relevant simulation parameters and watch a visualisation of the generated scenarios and traffic situations.

9 DISSEMINATION

The results of WP1 reported in this deliverable are supposed to be the basis for further work within OSCCAR, especially by identifying relevant crash configuration for the OSCCAR Test Case Matrix. The results from the analysis of different accident databases as well as the methodology how to select single configurations will be subject of conference presentations. The identified configurations and their characteristics will be further investigated in order to support the work on protection principles in T2.3. Furthermore, the work within WP1 on generic scenario models that allow a more detailed prediction of the AD effects on future accidents (D1.2, D1.3) will be based on the finding with regards to highway and intersection accidents. It will also take into account the interfaces to WP2 as defined in D1.1 and D2.1."

Beyond OSCCAR, this approach will be spread in the accident research community as an example how to combine accident data analysis, pre-crash simulation and statistical evaluation in order to derive potentially relevant test cases.

A. DETAILED DESCRIPTION OF ACCIDENT DATABASES

AUSTRIA: CEDATU

CEDATU (Central Database for In-Depth Accident Study) was initiated and developed as an in-depth accident database at the Graz University of Technology, Vehicle Safety Institute (Tomasch & Steffan, 2006) (Tomasch, Steffan, & Darok, 2008). The data collection is based on court cases including police reports, medical reports, technical reports, witness reports, pictures from the vehicles and accident site. Currently approximately 3 300 cases are collected. The dataset contains of accidents with fatal, serious and slight injuries.

CHINA: CIDAS

From July 2011, an in-depth traffic accident investigation project named as China In-depth Accident Study (CIDAS) was set up by the China Automotive Traffic and Research Center (CATARC). CIDAS is aimed at providing the basic data for China's automotive safety standards and regulations, C-NCAP, vehicle identification, and vehicle safety technology research and development by investigating road traffic accidents in China, collecting in-depth accident data and analysing such data. The CIDAS project, is a cooperation between the CATARC and the automotive industry. For the time being there are five investigation areas (Changchun, Ningbo, Foshan, Weihai and Qianxi'nan) including urban, countryside and expressways (Figure 46). Annually approximately 700 accidents involving at least one motorized 4+ wheeled vehicle and personal injury collected. By the pre-selection, single vehicle crashes under-represented along with accidents in which a powered two wheeler is involved. However, the investigation methodology was setup according to other international investigation methodologies and currently holds 3 081 cases (Status 1/2019) in a new database format and approximately another 2 000 cases in an old database structure.

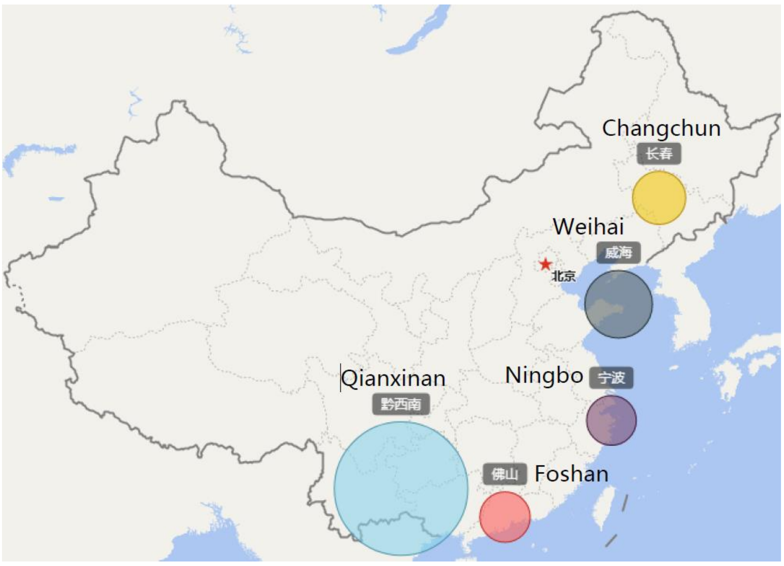


Figure 46: CIDAS investigation areas in China

FRANCE: VOIESUR

VOIESUR (Vehicle Occupant Infrastructure and Road Users Safety Studies) database is the result of a French research project run by the French research organisations CEESAR, CEREMA, IFSTTAR and LAB and funded by the ANR (French National Research Agency) and Foundation MAIF. Based on the direction set by the European Commission on halving road fatalities between

2010 and 2020, this project aim was "To reduce road accidents and injuries by identifying road safety issues or giving stakeholders knowledge to make decisions" (https://www.fondation-maif.fr/pageArticle.php?rub=1&id=295).

To do so, the project analysed almost 9.000 traffic accidents which had been coded by the police during 2011 in all France. The database covers all fatal accidents which happened in 2011 (around 3500 accidents), all the accidents which happened at French Rhone department (around 2500) and overall a ratio of 1/20 of injury accidents in France (around 3000).

The specialists, based on the police reports, analysed each case providing up to 350 different variables per accident, which is a lower figure when compared to in-depth accident databases but it is certainly higher than national statistics (ONISR, May 2014). Some of the information coded is as follows (CEESAR, 2015):

- Information before the accident: User ID (age, driving experience…), vehicle ID, infrastructure ID
- Information about the Pre-collision: Driving speed, manoeuvre prior to collision, conflict type, responsibility…
- Information after the collision: Collision deformation classification, collision chronology, injury mechanisms, EES, passive safety systems for vehicles and users, Injuries (AIS), Emergency call.

The injuries are coded as fatal (death within 30 days after the crash), severe (injuries which require hospitalization for more than 24 hours), slight (injuries which require medical attention with no hospitalization or hospitalization less than 24 hours) or not injured.

The database by applying a weight on injurious cases is representative of the police reports at national level. Additional correction factors can be added to cover under-reporting by the police, a known common practice for slight injuries accidents in France, however these factors were not used for this study.

GERMANY: DESTATIS, GIDAS AND PCM

For Germany three data sources are used. First, DESTATIS, data provided by the Federal Statistical Office in annual reports covering the national accident situation based on police reported crashes including severe property damage crashes only. The report is available on an annually base. Furthermore the GIDAS project, the German In-Depth Accident Study, is a cooperation between Federal Highway Safety Research Institute (BASt) and the Automotive Research Association (FAT) since 1999. Approximately 2 000 crashes involving personal injury are recorded in the area of Hanover and Dresden annually. Each case in GIDAS is also reported by the police, therefore GIDAS is a real subsample of the national accident data. With appropriate weighting factors, GIDAS can be extrapolated towards Germany. However, more information prior to the collision is covered by the GIDAS-based Pre-Crash-Matrix (PCM): by simulating the pre-crash scenario, additional and standardized data to describe the pre-crash sequence of an accident in a very high detail is generated and documented in the GIDAS-based PCM database. The PCM contains relevant data to reproduce the pre-crash-sequence of traffic accidents from the GIDAS database until 5 seconds before the first collision.

SWEDEN: STRADA, VCC

Data are used from the Swedish Transport Administration fatal database (STA) and the Swedish Traffic Accident Data Acquisition (STRADA). STRADA is a national information system collecting data of injuries and accidents in the entire road transport system. STRADA is based on information from the police as well as the hospitals. The hospital records consist of ICD diagnoses and AIS coded injuries.

Furthermore, Volvo Car company has its own internal database, Volvo Cars Traffic Accident Database (VCTAD) that cover crashes in Sweden where Volvo cars were involved and the car damage exceeded a certain repair cost. Data from VCTAD is used to establish virtual test-scenarios, i.e.,Time-History data (THd) batches for, e.g., CAE simulations in traffic safety effectiveness prediction studies targeting a specific conflict situation. (In VCTAD, the crashes are classified according to the Conflict Situation classification scheme[1]). An analysis is performed of the pre-crash phase of each traffic situation (case) in detail. Each critical traffic situation is digitized and described numerically in a THd format where each time step, in 15s before the crash, depicts the vehicle trajectories, the road environment, the participants and their characteristics. Digitized cases of a certain conflict situation, forms a THd-batch. In order to compensate for uncertainties in the data (case data quality- and contingency of distributions' doubts) variations of parameters are implemented as synthetic cases in the THd-batch (e.g. vehicle speed and traffic flow). For example, car speed is investigated in other crash datasets, driving data, or observational data for the conflict situation at hand, and is then matched to the cases in the original dataset. Finally, A *quality rating scheme* describes the THd-batch representativeness and the content quality.

WORLD: IGLAD

Although many countries worldwide provide national statistical accident data on road fatalities and injuries on a aggregated level, in-depth accident data on single cases, environment, collisions, safety systems, etc. are not everywhere available. Thus, one of the main difficulties in analysing global non-aggregated accident data is the lack of a common dataset. The IGLAD project (Initiative for the Global Harmonization of Accident Data) was initiated by Daimler AG, ACEA and different research organisations as a working group at the FIA Mobility Group 2010 (Bakker, 2015) (Bakker, et al., 2017) (Bakker, Ockel, & Schöneburg, 2014) (Ockel, Bakker, & Schöneburg, 2012) (Ockel, Bakker, & Schöneburg, 2012) to close the gap of a worldwide accident dataset with an agreed data scheme.

The objectives of IGLAD can be summarized as:

- build up a common in-depth accident database on the same format on an international level
- not to build a new database, but use available sources of different organisations
- have detailed data of single accident cases with appropriate variables in an in-depth level rather than on macroscopic (national) level.
  (Approximately 100 variables are associated to each single case).
- harmonised data scheme to allow comparable analysis of different countries

As there is no umbrella organization for IGLAD, an administrator was established who cares for the correct flow of data and financial resources (Figure 47) (Bakker, et al., 2017). Strategic decisions are taken by a steering group supported by a technical working group regarding the maintenance of the database, scheme, codebook and related questions.

[1] The conflict situation classification aims to describe (only) the movement of the involved road users in relation to each other before the crash or near-crash. A conflict situation does not include any information about why the crash occurred or the crash circumstances (e.g. traction lost, driver's distraction, light conditions, etc).

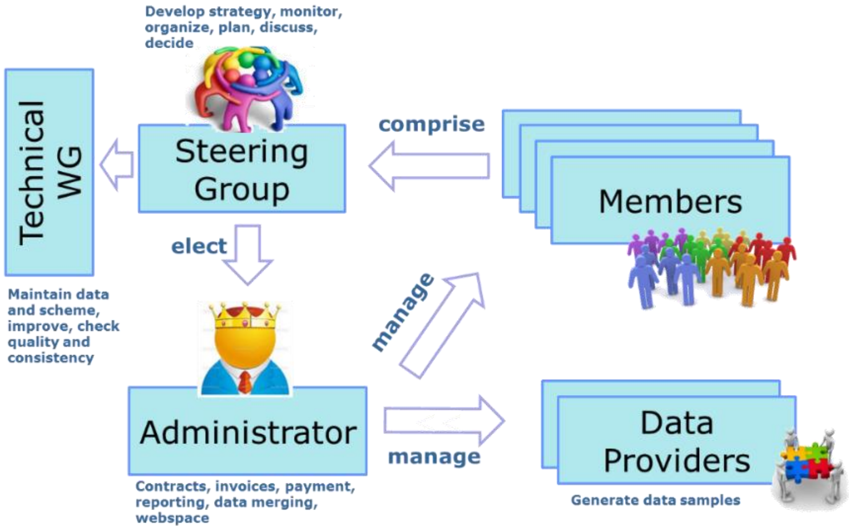


Figure 47: Organizational structure of the project for phase 2014+ (Bakker et al., 2017)

The dataset is organised in four tables: accident, participant, occupant, and safety system. Each single case comprises information of the accident (accident/collision type, accident site, road type, time, etc.), involved traffic participants (body style, driving speed, collision speed, delta-v, CDC (Collision Deformation Classification), etc.), occupants (age, gender, injury severity, MAIS, etc.) and safety systems (type, use, etc.). For each participant of an accident contributing factors e.g. lack of safety distance, excessive speed for conditions, etc. are selected. At maximum three "Contributing factors" are associated to each participant. At the moment the total database contains 4 950 cases from 11 different countries (Figure 48). Two third of the cases are reported from Europe, approximately 20% are from Asia.

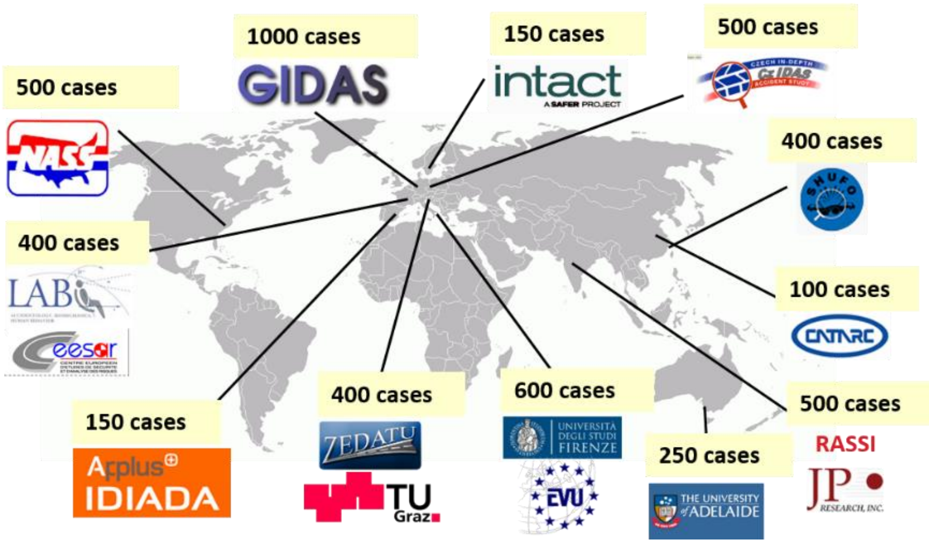


Figure 48: IGLAD accident case distribution by country

UK: STATS19, RAIDS AND OTS

The STATS19 Road Accident dataset is used for the UK. The police definition of serious injury covers casualties admitted to hospital, as well as those with specific types of injury (for example fractures or severe cuts). Severity of injury is known to be prone to misclassification in STATS19 due to the difficulties of such assessment by non-experts at the scene of the accident. Comparisons with death registration statistics show that very few, if any road accident fatalities are not reported to the police. However, the database includes accidents with personal injury reported by the police and not occurring on private roads or car parks. The severity of the casualties is coded as being either slight, serious or fatal:

- Slight: includes Whiplash, shallow cuts, lacerations, abrasions, sprains and strains not necessarily requiring medical treatment, bruising, slight shock requiring roadside attention,
- Serious: includes casualties who were admitted to hospital as an inpatient.
- Fatal: includes cases where death occurs in less than 30 days. Fatal does not include death from natural causes or suicide.

Casualty numbers were taken from STATS19 database for the years 2011-2015. 2016 casualties were calculated from the 2016 total casualty number and considering the average proportion of casualties per collision configuration (e.g. car-to-car front-to-front configuration) during 2011-2015.

The Road Accident In-depth Study (RAIDS) database collects high quality information on all aspects of road traffic collisions. It further considers information dating back to 1998. The data investigation is funded by the Department for Transport and covers mainly two types of investigations:

- Crash scene investigation on the spot with focus on vehicles, road users and motorway **issues** which could include non-injury crashes and those with relatively minor vehicle damage
- Backward looking investigation which examines vehicles that have had to be recovered from the crash site having suffered more serious damage and where the occupants have attended hospital due to their injuries

The investigation is done on a contract base by the Transport Research Laboratory (TRL) along with Transport Safety Research Centre at Loughborough University (TSRC). Investigations mainly covered in the Thames Valley and Hampshire region along with Nottinghamshire and other closely surrounding urban and rural areas of Nottinghamshire. Thus a valuable mix between rural and urban roads along with motorway environments are covered.

In order to identify collision scenarios (e.g. overtaking and changing lane), the Road Accident In-depth Studies (RAIDS) was used. RAIDS is funded by the UK Department for Transport (DfT) and pulls together four separate historical studies:

- The Co-operative Crash Injury Study (CCIS) run between 1983 and 2010. The study investigated car collisions in a retrospective way,
- The On The Spot (OTS) which collected crash data at the scene for all vehicle types and accident severities between 2000 and 2010,
- The Heavy Vehicle Crash Injury Study (HVCIS) which collected detailed information on collisions involving heavy goods vehicles, light commercial vehicles, large passenger vehicles, minibuses, agricultural vehicles,
- The RAIDS on scene (all injury severities including non-injury crashes) and RAIDS retrospective (cases with at least one occupant admitted to the hospital, Phase 1: 2012-2015, Phase 2: 2015-2018).

Current study only used accident data from RAIDS on scene and OTS from the year 2003 onward. Accidents with at least one casualty and involving passenger cars were considered.

B. APPROACH USING IGLAD AND GIDAS DATA

To identify “inherently” avoided accidents, accident causation parameters available in IGLAD and GIDAS was used. For each criteria listed, a valued was assigned if this crash causation is going to be avoided by an automated vehicle or not. The following Table 6 shows the assigned values as example.

Table 6: Extracts of accidental contributing factors and assigned automated function

Definition	Assigned value
Safe drive defined as **not violate any traffic rules**, e.g. “police will stop you”	1
Cautionary boundaries adapt driving after driving condition, e.g. visibility, weather	2
Further analysis required e.g. simulation of crash scenario	3

#	Accidental cause	Filter value
CATEGORY: FITNESS TO DRIVE		
1	Alcohol	1
2	Other stimulation substances, eg.g. drugs, medication	1
3	Drowsiness	2
4	Other physical or psychical deficiencies	2
CATEGORY: WRONG BEHAVIOR OF DRIVER, ROAD USAGE		
10	Use of wrong lane or illegal road usage	1
11	Violation against lane discipline, e.g. driving on outside lane	1
CATEGORY: SPEED		
12	Speeding (exceeding speed limit)	1
13	Excessive speed for conditions (not exceeding speed limit)	3
CATEGORY: DISTANCE		
14	Lack of safety distance / safety distance	3
15	Heavy braking without obvious reasons	3

The methodology to identify remaining accidents if more contributing factors needs to be combined is shown in Table 7. If two factors would indicate a "*safe drive*" and the third indicates "*further analysis required*" the factor "*further analysis required*" will be valid.

If one of the factors was coded as "*unknown*" the factor "*further analysis required*" will be valid. Value "0" indicates that there was no contributing factor associated to the participant and for automated vehicles "*safe drive*" would apply.

Table 7: Combination of contributing factors to identify remaining accidents for further analysis

Factor 1	Factor 2	Factor 3	Remaining accident
1	1	2	2
1	0	0	1
1	0	0	1
3	3	0	3
3	2	0	3
1	1	3	3
1	3	2	3
1	2	0	2
99	0	0	3

DEFINITION OF THE BASELINE - REMAINING ACCIDENT SCENARIOS USING IGLAD

After applying the filter criterions 544 accidents with passenger cars as main causer (participant "A") and 36 accidents with passenger cars as non-main causer (participant "B") remain. At average approximately 24% of the accidents in IGLAD could be identified as "safe drive" and "cautionary boundaries" with differences at the accident sites motorway, rural and urban. It looks that the most promising effects on inherently avoided (safe drive) accidents by automated vehicle counts for rural sites (32%). 27% of "safe drive" and "cautionary boundaries" can be found on motorways and about 20% at urban sites (Table 8).

Table 8: Remaining accidents separated into road type and accident participant “A” or “B”

		motorway	rural	urban	total
	IGLAD total	1 030	1 596	2 326	4 955
Filter 1	all accidents (EU)	541	926	1 737	3 205
Filter 2	at least one passenger, max. two participants	319	523	1204	2046
Filter 3	no vulnerable road user	278	468	643	1389
Filter 4	unknown whether passenger car is participant “A” or “B”	274	450	637	1361
Filter 5					
	Main causer (participant “A”)				
	Safe drive	85	215	234	534
	Cautionary boundaries	28	35	25	88
	Remaining accidents	119	144	281	544
	Non-Main causer (participant “B”)				
	Safe drive	31	42	82	155
	Cautionary boundaries	3	0	1	4
	Remaining accidents	8	14	14	36

The most frequent remaining accident type on motorways is identified as rear-end collision (Figure 49). Further head-on collisions would remain after applying the filter criterions. This is a kind of surprising accident type but can be explained by the definition of motorways in IGLAD. To have a common dataset motorways are described as “arterial roads”. This can be either an arterial road with and without physical lane separation of the carriageway. Some accident types are indicating accidents at junctions (Type 20, 30, 32 and 21). This might be at the end of the motorway exit but needs more details.

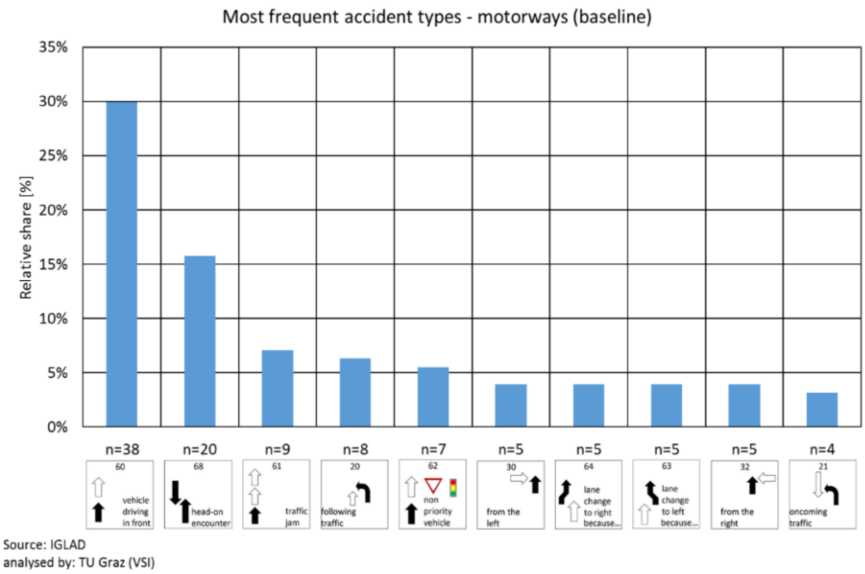


Figure 49: motorway: Most frequent remaining accident type

After applying the filter criterions crossing accidents at rural sites remain as most frequent in the dataset (Figure 50). Rear end collisions at junctions becomes second most frequent.

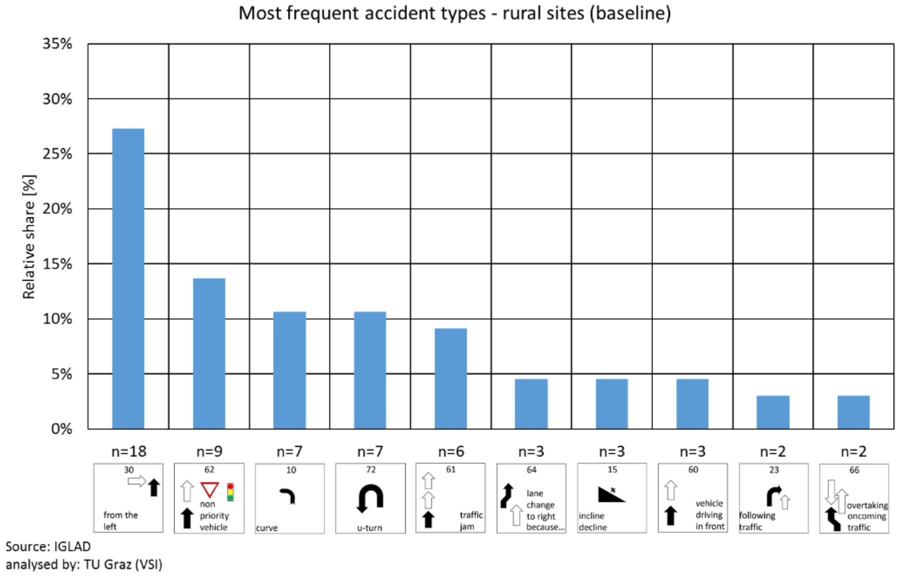


Figure 50: Rural sites: Most frequent remaining accident type

At urban sites the most frequent accident type was identified as turning to left and collision with oncoming traffic (Figure 51). Another quite high share of collisions were found for crossing accidents. Collisions with overtaking vehicles would remain as the third most accident type in the dataset.

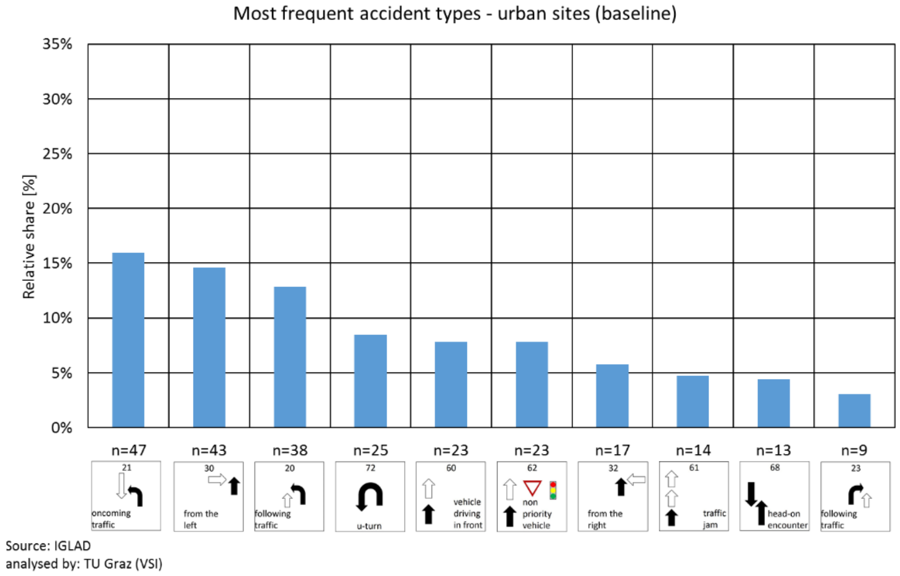


Figure 51: Urban sites: Most frequent remaining accident type

The following Table 9 shows the full list of accident contributing factors in detail and their description which were assessed to determine whether an automated vehicle can inherently or conditionally avoid an accident.

Table 9: Full list of accident contributing factors

Contributing Factor ID	Contributing Factor Description
1	none
2	alcohol
3	other stimulation substances, e.g. drugs, medication
4	drowsiness
5	other physical or psychical deficiencies
6	use of wrong lane (also wrong direction) or wrong parts of the road (e.g. shoulder)
7	violation against the rule of the road e.g. obligation to keep to right/left side)
8	speeding (exceeding speed limit)
9	excessive speed for conditions (no exceeding of speed limit)
10	lack of safety distance
11	heavy braking without obvious reason
12	overtaking on the wrong side (undertaking)
13	overtaking into oncoming traffic
14	overtaking though traffic situation is not clear
15	overtaking without adequate visibility
16	overtaking without consideration and adequate warning to following traffic
17	mistake in returning to initial lane
18	other overtaking mistakes
19	mistake when being overtaken, e.g. swerving, acceleratin
20	disregarding the oncoming traffic's right of way when passing stationary vehicle or obstacle
21	disregarding the following traffic's right of way when passing stationary vehicle or obstacle
22	failure during driving in congested traffic or lane merging
23	disregarding the traffic regulation "priority to the right"
24	disregarding the traffic regulation signs (give way)
25	disregarding the priority traffic when joining a motorway or dual carriageway
26	disregarding the right of way by vehicles joining from a track way
27	disregarding the direction of traffic regulation by traffic lights or police officers
28	disregarding the priority of oncoming traffic when shown by sign 208
29	disregarding the priority of railway traffic
30	mistake during turning
31	mistake during u-turn or reversing
32	failure during joining the flowing traffic
33	wrong behavior towards pedestrians at pedestrian crossings
34	wrong behavior towards pedestrians at traffic calmings for pedestrians
35	wrong behavior towards pedestrians when turning
36	wrong behavior towards pedestrians at public transport stops
37	wrong behavior towards pedestrians at other places
38	forbidden stopping or parking

Contributing Factor ID	Contributing Factor Description
39	failure of adequate warning for stopped/broken down vehicles, accident scenes, or stopped school busses
40	traffic rule violation during vehicle loading or unloading
41	disregarding the lighting regulations
42	overloading
43	not adequately secured cargo
44	other mistakes of the driver
45	defective lighting
46	defective tires
47	defective brakes
48	defective steering
49	defective towing device
50	other technical deficiencies
51	wrong behavior of the pedestrian in traffic situations regulated by traffic lights or police officers
52	wrong behavior of the pedestrian at crossings without regulation by traffic lights or police officers
53	wrong behavior of the pedestrian near crossings or junctions, traffic lights or pedestrian crossings during dense traffic in other places
54	wrong behavior of the pedestrian due to sudden emergence from view restricted areas
55	wrong behavior of the pedestrian (ignoring the road traffic)
56	other wrong behavior of the pedestrian
57	wrong behavior of the pedestrian due to nonusage of pedestrian path
58	wrong behavior of the pedestrian due to usage of wrong road side
59	wrong behavior of the pedestrian due to playing on or besides the road
60	wrong behavior of the pedestrian due to other mistakes
61	road soiling due to oil leakage
62	other road soiling by road users
63	snow, ice
64	rain
65	other influences (leaves, clay etc.)
66	lane grooves in combination with rain, snow, ice
67	other state of the road
68	inappropriate road sign condition
69	inadequate street lighting
70	inadequate securing of railway crossings
71	influence of weather / view obstruction due to fog
72	influence of weather / view obstruction due to rain, hail, snow
73	influence of weather / view obstruction due to sun glare
74	influence of weather / view obstruction due to cross wind
75	influence of weather / view obstruction due to storm
76	inappropriate or not secured construction site on the road
77	game animals on road
78	other animal on road
79	other obstacles on the road
80	darkness
81	another vehicle which is gone

Contributing Factor ID	Contributing Factor Description
77777	not applicable
88888	other causes
99999	unknown

C. APPROACH USING FRANCE DATA – VOIESUR

DETERMINATION OF REMAINING ACCIDENTS IN VOIESUR

TME has analysed VOIESUR database together with CEESAR in France with the focus of identifying and analysing most common accident configurations by injury severity after the application of several safety systems by a certain timeframe, which in this case was 2025.

The basis for the safety systems considered was taking into account the measures proposed in the Cost-effectiveness analysis conducted by the European Commission (Seidl, M., Khatry, R., Caroll, J., Hynd, D., Wallbank, C. and Kent, J., March 2018) and some additional measures available in the market already either as existing measure (e.g. ESC, SBR, AWS…). The effectiveness rates considered can be found in Table 10.

At first, VOIESUR database was filtered to extract only car to car (M1-M1) or single car (M1) accidents and considering both front and rear seat occupants who are aged more than ten years old.

The accidents were then sorted out in 4 steps, as follows (Figure 52):

- Step 1- Driver assistance system: Step 1 target population was filtered based on the type of driver assistance system that could be applicable for the involved casualties, considering accident causation. The remaining injuries after the application of driver assistance safety systems were calculated.
- Step 2- Active safety system: Several accident configurations were identified based on the collision configuration (e.g. Rear end, Front to Front…) and grouped based on the type of accident (eg. Collision at junction, Collision due to unintentional lane change…). For each collision configuration, the remaining injuries after the application of active safety systems were calculated. The active safety systems that applied for each collision configuration and its order of applicability was defined based on the decision tree shown in Figure 52.
- Step 3- Passive safety system: At this step, four main collision configurations were identified, based on the applicability of passive safety systems (Rear-end, Front-to-front, Front-to-side and Rollover). For each of the configurations, the effect of different passive safety systems were applied and the remaining injuries after its application were calculated. The seat-belt retractor was applied before the breakdown of the four main collision configurations as it could apply to all of them.
- Step 4-Tertiary safety system: As last step, the effect of post-crash measure (E-call) was applied and the remaining injuries after its application were identified.

Safety system effect: In order to apply the effect of safety systems, its target population was identified within the identified injuries. As the study wanted to identify remaining injuries by 2025, a certain penetration rate of the safety systems was also considered and applied to the calculation.

Calculation of remaining casualties: At each step, the remaining casualties were calculated based on the formula below:

$$\text{Remaining casualties} = \text{Target population} \times (1\text{- Effectiveness \%} * \text{Penetration \%})$$

To analyse further the remaining casualties, the information obtained after the filtering provided not only the collision configuration, but also the driving speed, location of accident and manoeuver prior to accident.

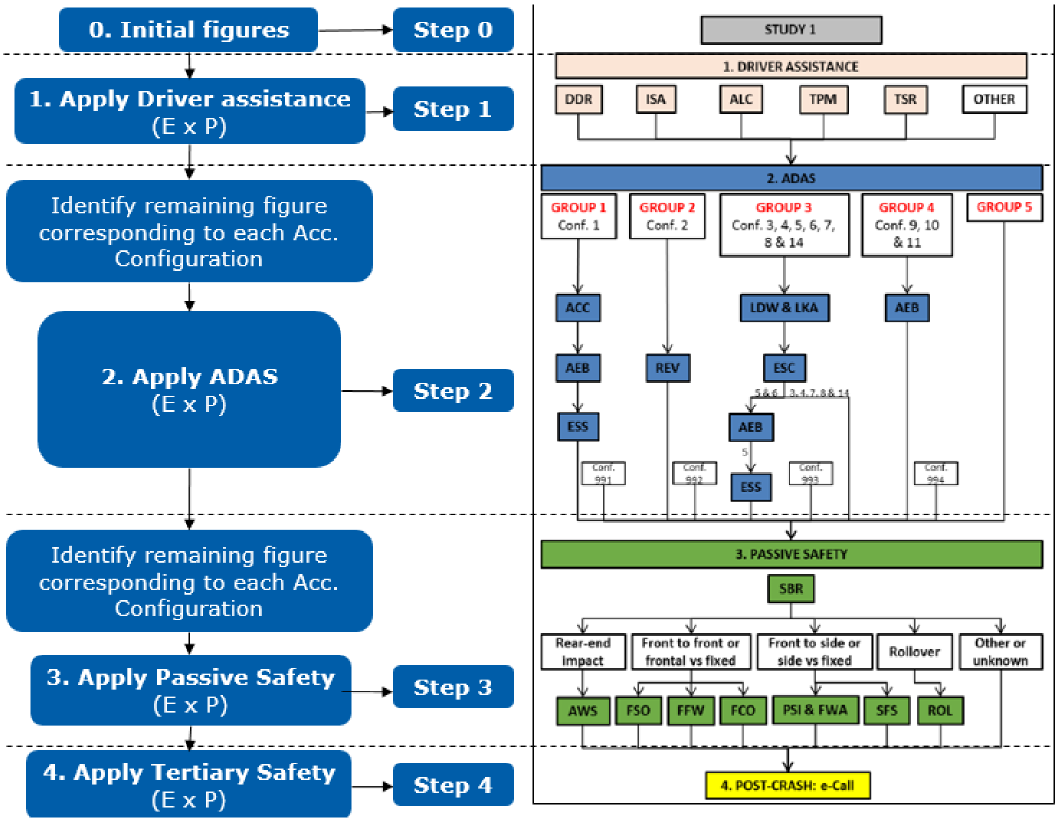


Figure 52: Safety technology application considering four layers in accident event (Driver assistance, ADAS, Passive safety, Post-crash)

DESCRIPTION OF NOWADAYS MAIN ACCIDENT CONFIGURATIONS BY SEVERITY

Looking at VOIESUR database, the most common accident types differ depending on the injury severity. The main reason is the amount of accidents for each of the injury severities, being this number much greater for slight injuries than for severe and fatally injuries.

As example, when considering all injury severities and slight injuries, accidents at junction are most common. However, when looking at fatality rates and severity injuries, the single vehicle accidents appear at the top.

A brief analysis comparing all type of injuries and fatal injuries most common accidents is shown below:

When considering all type of injuries, the most common accident type was related to collisions at junctions, particularly front to side accidents (19%). The second most common type was single vehicle accident leaving the road and impacting against an obstacle (10%), and third most common was related to junctions with impact configuration front to front, side to side or unknown impact configuration (9%).

When looking at fatal injuries, the most common accident type was single vehicle accident leaving the road and impacting against an obstacle (27%). The second most common type was head-on (10%) and the third most common was single vehicle accident leaving the road impacting ground or ditch (9%).

As it is the scope to identify remaining accidents, the study focused on all injuries.

Figure 53 shows the overall distribution of the accident configuration of VOIESUR database.

Group and configuration	Opponents	Location	Infrastructure	Collision configuration	Initial figures			
					Fatal injuries	Serious injuries	Slight injuries	All injuries
Groupe 1 conf 1:	M1 vs M1		Out of intersection	Rear end collision	1%	1%	7%	5%
groupe 3 conf 14:	M1 vs M1		Out of intersection	Side to front	6%	3%	1%	2%
groupe 3 conf 3:				Head-on	10%	6%	2%	4%
groupe 3 conf 4:				Side to side	0%	0%	1%	1%
groupe 3 conf 5:				Rear to front	0%	0%	0%	0%
groupe 3 conf 6: 2	M1 alone			Frontal, Side or Rear impact against obstacles	27%	15%	7%	10%
groupe 3 conf 7:				Frontal, Side or Rear impact against ground-ditch	9%	6%	2%	4%
groupe 3 conf 8:				Rollover	7%	4%	3%	3%
groupe 3 conf 99	M1 vs M1			Front to rear or Front to side	1%	4%	3%	3%
groupe 4 conf 10:	M1 vs M1		At Intersection	Front to rear	0%	2%	7%	5%
groupe 4 conf 11: 1				Front to side	6%	13%	22%	19%
groupe 4 conf 9:				Frontal vs stationary	0%	0%	3%	2%
groupe 4 conf 99: 3				Front to front, Side to side, unknown	3%	6%	10%	9%
groupe 5	M1 vs M1 M1 alone		Going straight on road or at Intersection	Frontal mainly and Side	29%	40%	32%	34%
Total					100%	100%	100%	100%

Figure 53: Accident configuration distribution in VOIESUR (Initial figures, 2011)

FURTHER DETAILS ON TOP 3 ACCIDENT CONFIGURATIONS

Based on the method described in section 0, the most common accident types after every step can be identified. The results shown in this section are the ones corresponding to Step 2 (Active Safety systems) as those systems are the ones having a greater contribution (15%) compared to the other ones (Figure 54).

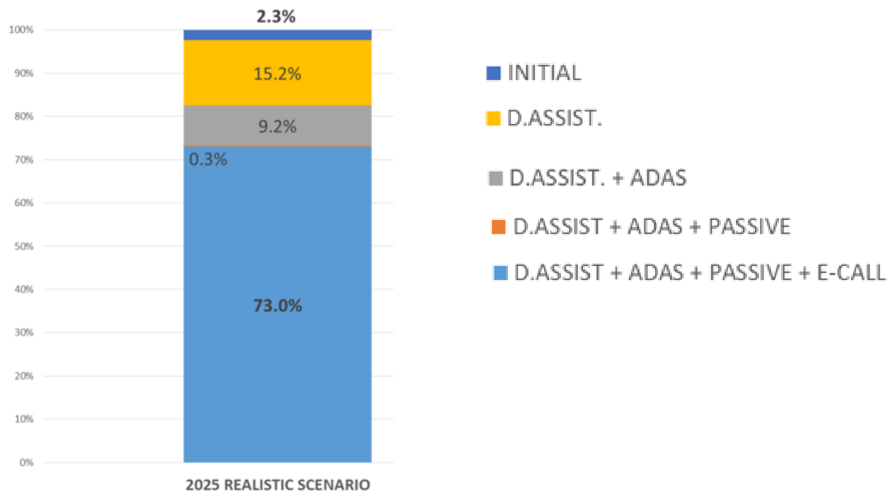


Figure 54: 2025 casualty reduction due to the introduction of driver assistance, ADAS, passive safety and E-call technologies

Same as it for the initial figures, the results differ depending on the injury severity. As it is the scope to identify remaining accidents, the study focused on all injuries.

The most common remaining accidents at 2025, after the application of both Driver assistance and Active Safety systems for all injuries are related to intersection, being Front to Side collision the most common configuration (20%). The second most common remaining accident is relating to two possible accident types, one is at intersection with Front to Front or Side to side collision configuration, and the other one is related to single vehicle accident with impact to an obstacle. Both types have 9% of the remaining accidents. The third most common configuration is relating again to intersection with Front to Rear collision configuration (5%) (see Figure 55). The main reason for this can be related to two main factors:

- Based on the sample data, collisions at intersection represent the most common accident type of VOIESUR database
- There is no safety system specific for Intersection accidents.

Within the scope of OSCCAR and automated cars, it might be assumed that single car collisions (Group 3) will be avoided as automated vehicles will drive cautiously. From 2025 remaining casualties in VOIESUR, Rear-end collisions (Group 1/config. 1) will then belong to the top 3 accident configurations.

Note: Group 5 gathered accidents not belonging to any other groups. This represents a large part of the sample. This group is in approximately 60% of the cases related to single car accidents.

Group and configuration	Opponents	Location	Infrastructure	Collision configuration	Remaining injuries afetr ADAS (Study 1 - realist 2025)			
					Fatal injuries	Serious injuries	Slight injuries	All injuries
Groupe 1 conf 1:	M1 vs M1		Out of intersection	Rear end collision	1%	1%	6%	4%
groupe 3 conf 14:	M1 vs M1		Out of intersection	Side to front	5%	2%	1%	1%
groupe 3 conf 3:				Head-on	10%	6%	2%	3%
groupe 3 conf 4:				Side to side	0%	0%	1%	0%
groupe 3 conf 5:				Rear to front	0%	0%	0%	0%
groupe 3 conf 6:	M1 alone			Frontal, Side or Rear impact against obstacles	23%	14%	6%	9%
groupe 3 conf 7:				Frontal, Side or Rear impact against ground-ditch	8%	5%	2%	3%
groupe 3 conf 8:				Rollover	6%	4%	2%	3%
groupe 3 conf 99	M1 vs M1			Front to rear or Front to side	1%	4%	3%	3%
groupe 4 conf 10:	M1 vs M1		At Intersection	Front to rear	1%	2%	7%	5%
groupe 4 conf 11:				Front to side	8%	14%	23%	20%
groupe 4 conf 9:				Frontal vs stationary	0%	0%	3%	2%
groupe 4 conf 99:				Front to front, Side to side, unknown	4%	6%	11%	9%
groupe 5	M1 vs M1 M1 alone		Going straight on road or at Intersection	Frontal mainly and Side	34%	42%	33%	36%
Total					100%	100%	100%	100%

Figure 55: Accident configuration distribution in VOIESUR (Remaining casualties, 2025)

Location

For the three most common remaining accidents, the location of the accident, based on injury severity is shown in Figure 56 to Figure 58 respectively.

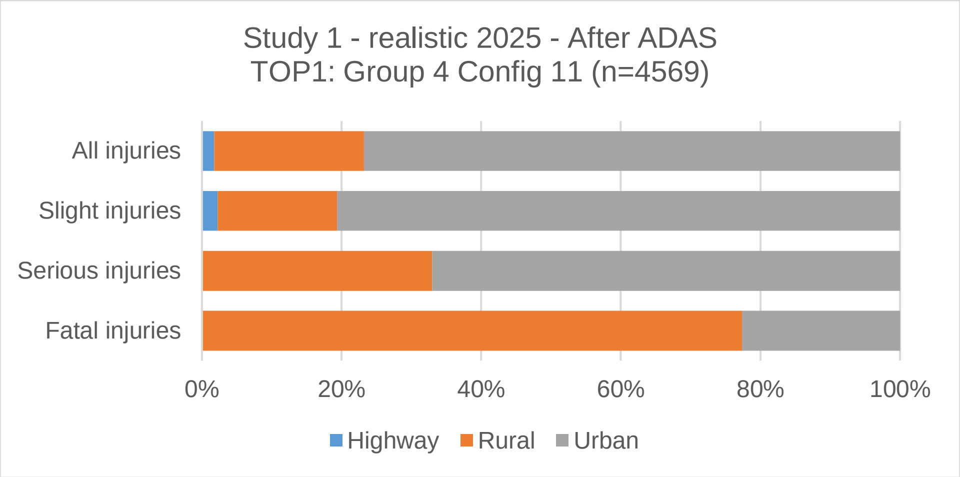


Figure 56: Remaining 2025 Intersection/Front-to-Side accidents location

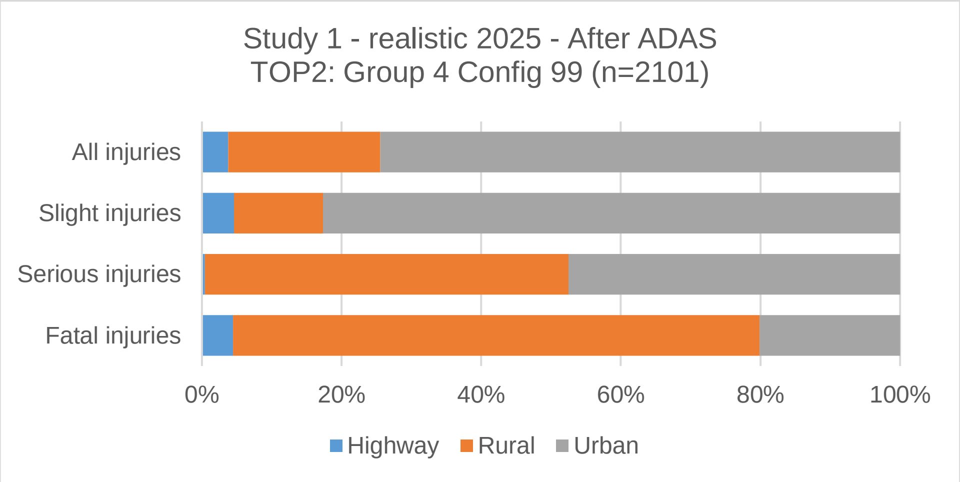


Figure 57: Remaining 2025 Intersection/Front-to-Front, Side-to-Side accidents location

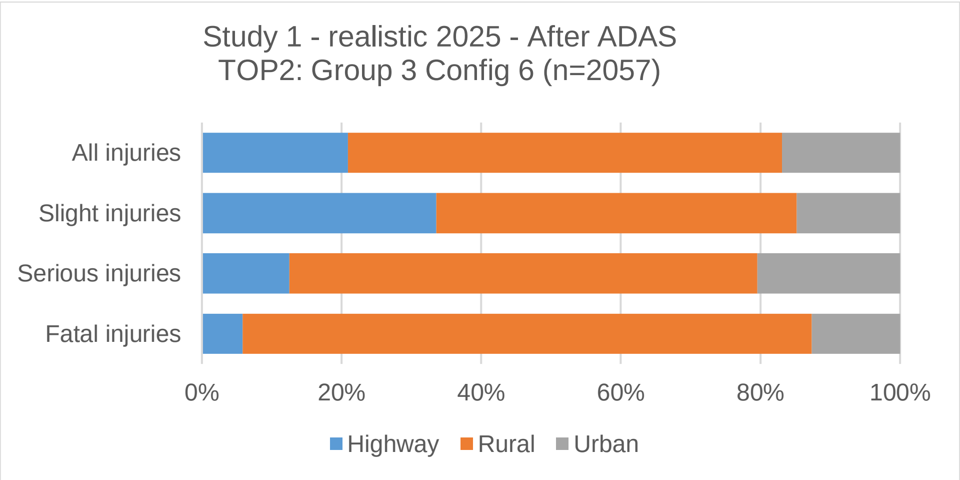


Figure 58: Remaining 2025 M1 alone against obstacle accidents location

The results show a main difference between the first two most common remaining accident configurations (Group 4 Config 11 and Config 99) and the third one (Group 3 Config 6), as the first two configurations are related to intersection cases, which are more common of urban and rural environment and the latter one is related to single vehicle accident where rural is most common location.

The first two groups show a difference in location depending on the injury severity, being fatal and severity injuries related to rural environment and slight injuries, which is the biggest contributor in terms of absolute numbers (n=3508, 77%), to urban environment. In these groups, the cases related to motorway are referring to exit/entrance, as they are coded as intersection within VOIESUR database.

For the third group, the injury severity does not have such a big impact on the results, although motorway cases seem more relevant to slight injuries.

Driving speed distribution

For the three most common remaining accidents, the driving speed of the accident, based on injury severity is shown in Figure 59 to Figure 61 respectively

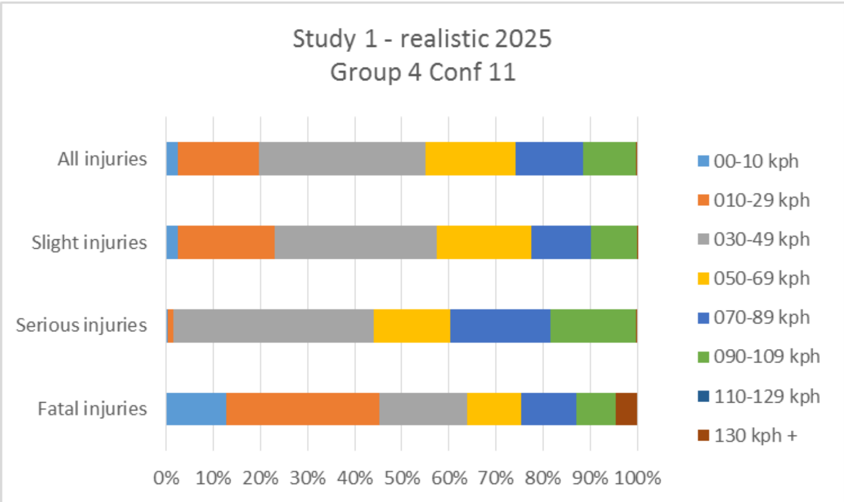


Figure 59: Remaining 2025 Intersection/Front-to-Side accidents driving speed

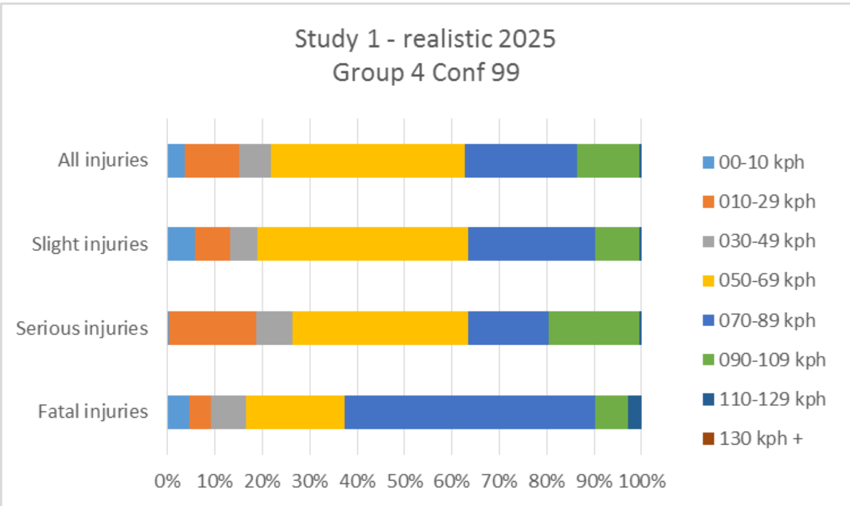


Figure 60: Remaining 2025 Intersection/Front-to-Front, Side-to-Side accidents driving speed

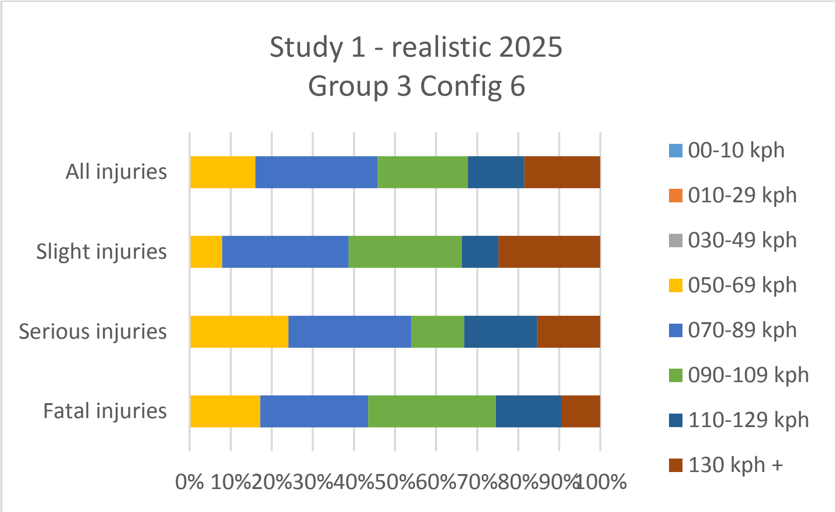


Figure 61: Remaining 2025 M1 alone against obstacle accidents driving speed

The results show a main difference between the first two most common remaining accident configurations (Group 4 Config 11 and Config 99) and the third one (Group 3 Config 6), as the first two configurations are related to intersection cases, which are more common of urban and rural environment and the latter one is related to single vehicle accident where rural is most common location.

For the first group, considering all injuries, the driving speed is lower than 50Kph for more than 50% of the cases. This frequency varies depending on the injury severity from 43% (lowest rate, corresponding to severities) to 63% (highest rate, corresponding to fatalities). Looking in details the fatalities, a speed value lower than 30Kph is common for more than 40% of the cases which it is assumed to be due to the low speed of the vehicle impacted on the side.

The second group shows a higher speed tendency, where a speed between 50Kph and 90Kph accounts for more than 50% of the cases regardless of the injury severity

For the third group, the most common speed is higher than in the two other configurations, being over the speed limit for at least 10% of the cases independently of the injury severity.

Infrastructure and manoeuvre

For the three most common remaining accidents, the manoeuver prior to the accident, based on injury severity is shown in Figure 62 to Figure 64 respectively.

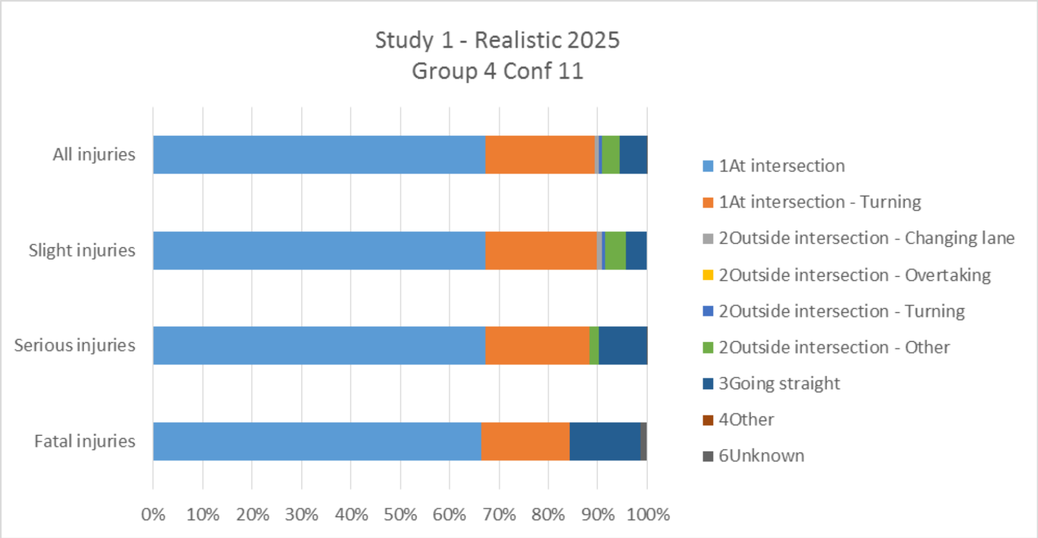


Figure 62: Remaining 2025 Intersection/Front-to-Side accidents manoeuvres

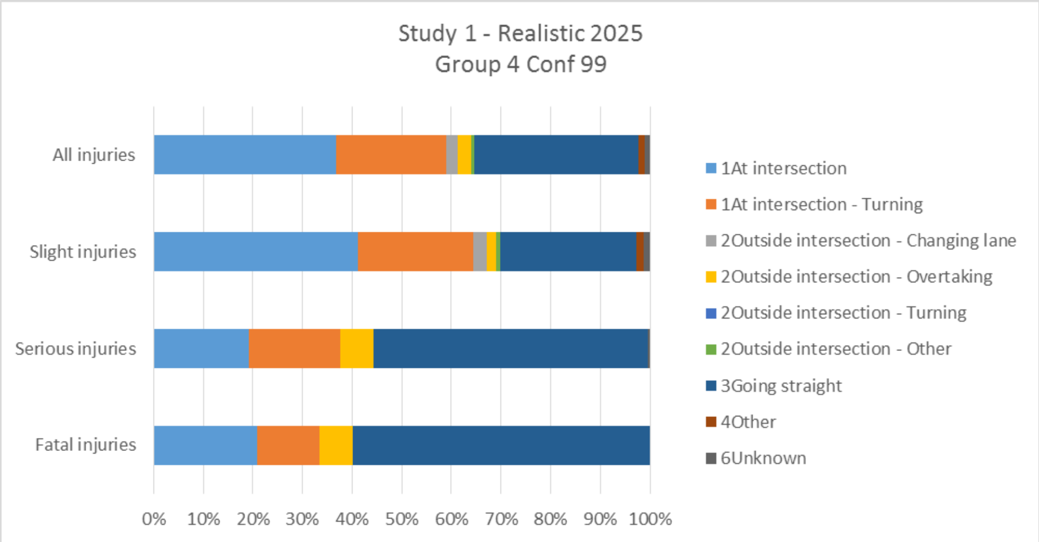


Figure 63: Remaining 2025 Intersection/Front-to-Front, Side-to-Side accidents manoeuvres

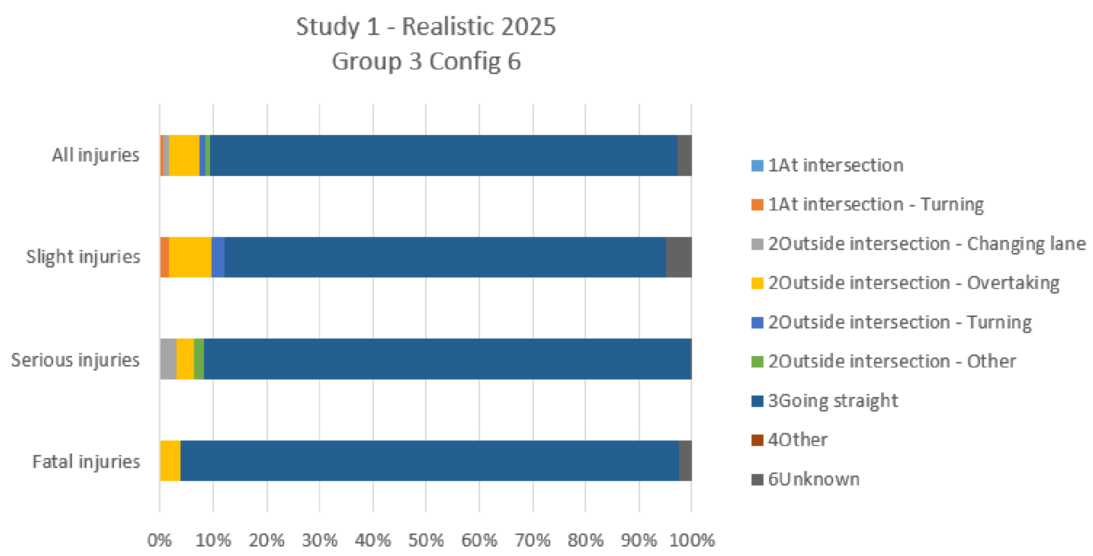


Figure 64: Remaining 2025 M1 alone against obstacle accidents manoeuvre

One of the main difference of this analysis compared to the two other parameters analysed (location and driving speed) is that the results are similar for different injury severities within each accident configuration.

The most common manoeuver prior to the accident differs between the three most common accident configurations. While the most common configuration has a direct link with 1At intersection (vehicle at intersection), the second most common configuration does not have a single main manoeuver type, being both 1At intersection (vehicle at intersection) and 3Going straight the most common cases, reaching over 70% of the cases . Finally, the third most common accident configuration (Group 3 Config 6) is directly linked to a vehicle going straight, which could be either on straight road or in a curve according to the coding in VOIESUR database.

D. APPROACH USING UK DATA - STATS19 & RAIDS

DETERMINATION OF REMAINING ACCIDENTS IN STAT19/RAIDS

The objective was to quantify the remaining passenger car casualties after considering the penetration of different safety technologies (driver assistance, ADAS, passive safety) into the Great Britain (GB) passenger car fleet by the year 2025. The remaining collision configurations and collision scenarios were identified using STATS19 and RAIDS respectively. Only passenger car-to-passenger car (M1-to-M1) accidents and single passenger car accidents (single M1) were included in the analysis.

The safety technologies considered as well as their effectiveness values are indicated in Table 10. These values were in line with the study performed by TRL for the European Commission on General Safety Cost-Effectiveness (Seidl, M., Khatry, R., Caroll, J., Hynd, D., Wallbank, C. and Kent, J., March 2018). Same goes for the target population definitions and the safety measure penetration in the fleet.

Table 10: Safety measures with their effectiveness

Safety measure	Description	Avoidance Effectiveness [%]			Mitigation Effectiveness [%]		
		Fatal	Serious	Slight	Fatal	Serious	Slight
ALC	Alcohol interlock	100	100	100	NA	NA	NA
DDR-ADR	Advanced distraction recognition	16.7	16.7	16.7	NA	NA	NA
DDR-DAD	Drowsiness and attention detection	16.7	16.7	16.7	NA	NA	NA
ISA	Intelligent speed assistance	19	19	19	6.7	8.4	NA
ESC	Electronic stability control	38	21	21	NA	NA	NA
ESS	Emergency stop signal	5	10	20	20	20	NA
AEB	Autonomous emergency braking for vehicles	19	19	42	19	19	NA
LKA-ELK	Emergency lane keeping assistance	53	38.5	38.5	NA	NA	NA
FFW-137	Full-width frontal occupant protection based on UN R137	NA	NA	NA	5	5	NA
FFW-THOR	Full-width frontal occupant protection using THOR-M ATDs	NA	NA	NA	6	6	NA
PSI	Pole side impact occupant protection	NA	NA	NA	54	54	NA

Figure 65 describes the method used to calculate the remaining casualties in Great Britain by 2025. From STATS19, target populations for the safety measures were identified from collision configurations and contributory factors.

The remaining casualties were calculated by

$$\textit{Remaining casualties} = TP \times (1 - E\% * P\%) \quad (1)$$

where

TP is the target population

E% is the safety measure effectiveness rate

P% is the safety measure penetration rate

For mitigation, the rules was to change fatal casualties into serious casualties and serious casualties into slight casualties. Slight casualties were not mitigated. When a casualty could be avoided by a series of safety measures (e.g. driver assistance, ADAS and passive safety), it was removed from the target population of the first safety measure and from all subsequent target populations of other safety measures as shown in Figure 66.

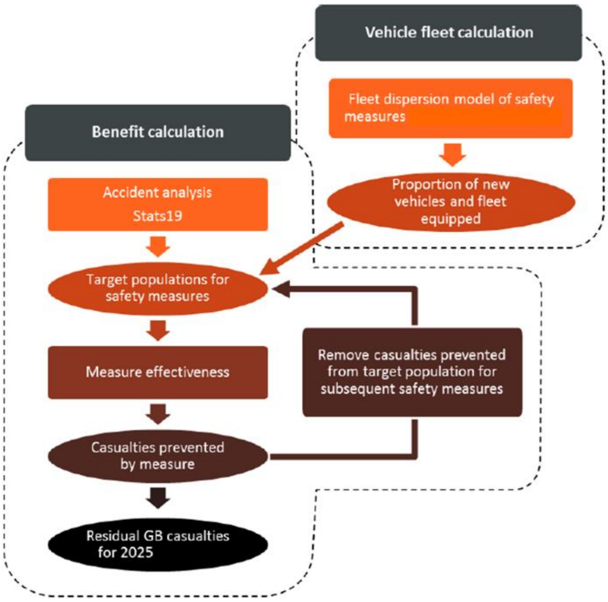


Figure 65: Calculation model applied by TRL

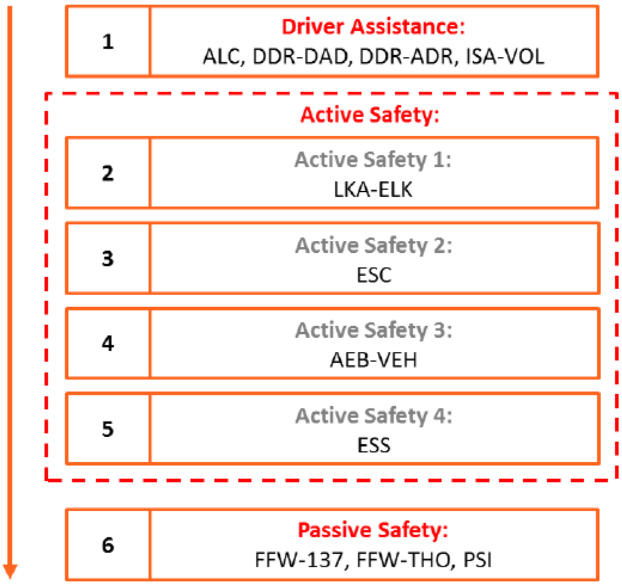


Figure 66: Vehicle safety measures order of application in the model

Initial (2016) and residual (2025) GB casualties per collision configuration for fatal, serious and slight were provided by the model. Collision configurations were coded according to first point of impact on the car (Front, Back, Left, Right) or no impact (with an opposing car or object).

The collision configurations defined by STATS19 analysis were further broken down by collision scenarios of RAIDS as shown in Figure 67. The matrix defines the manoeuvre prior to the collision.

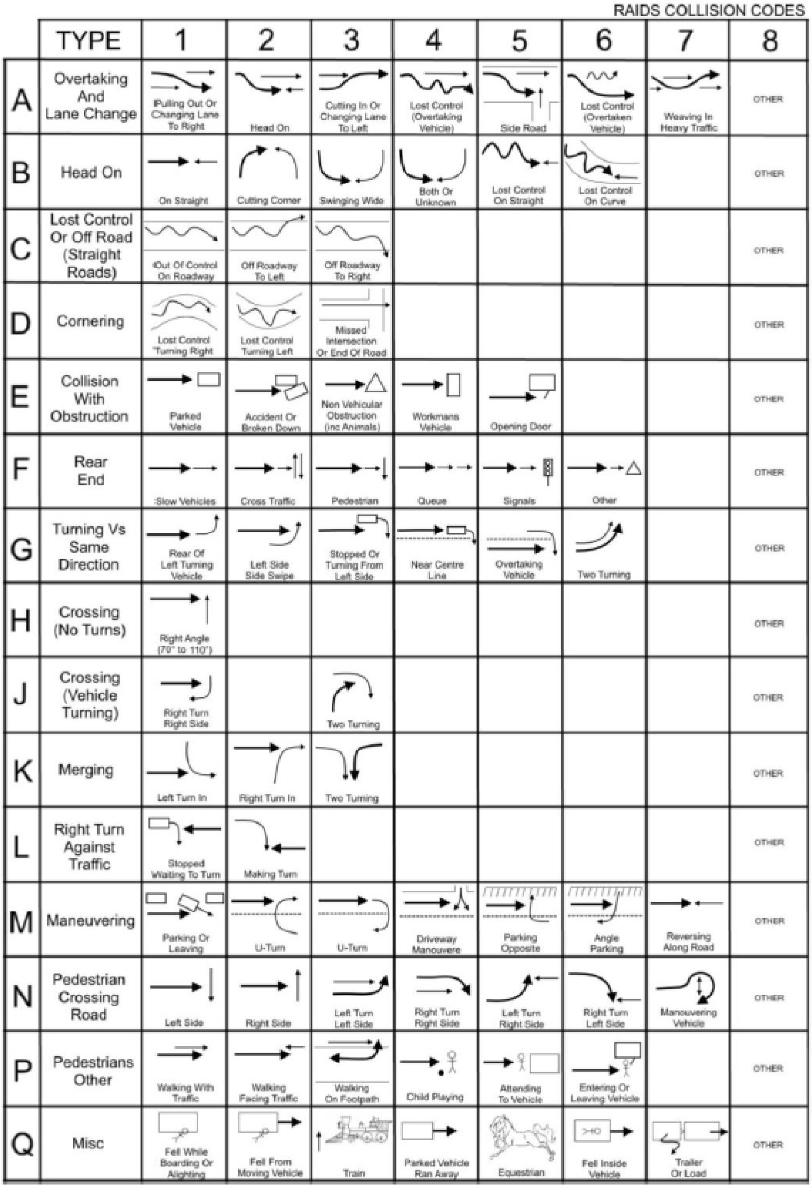


Figure 67: Collision scenario matrix used in RAIDS database

DESCRIPTION OF CURRENT AND 2025 MAIN ACCIDENT CONFIGURATIONS BY SEVERITY

The residual passenger car occupant (M1) casualty changes in total number and by collision configurations and collision scenarios distribution in Great Britain was quantified between the year 2016 and the year 2025.

The study focuses on M1-to-M1 and single M1 collisions. Other collision types were not included in the analysis. Figure 68 shows the reduction of casualties after considering the implementation of safety technologies in vehicle fleet. The overall casualties are expected to significantly reduce between 2016 and 2025: 30% reduction for fatalities, 21% reduction for serious injuries and 14% reduction for slight injuries.

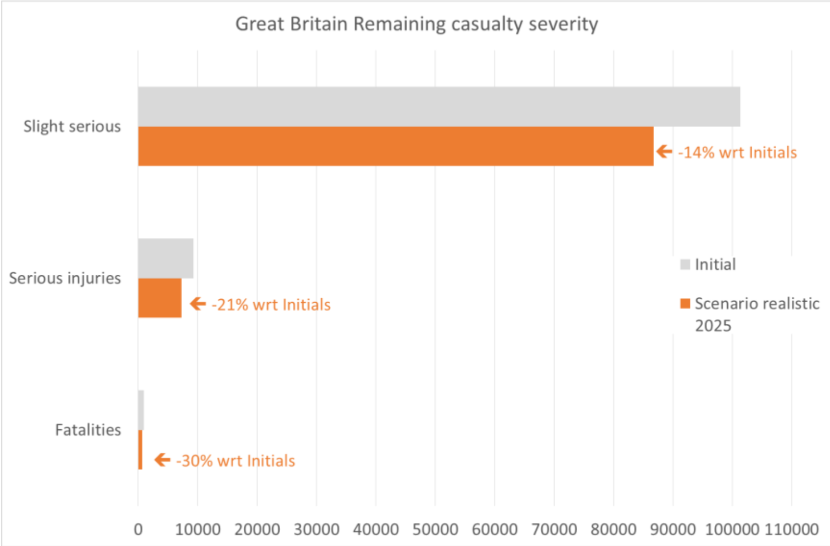


Figure 68: Great Britain casualty reduction and severity distribution in 2016 and 2025

Figure 69 and Figure 70 describe the casualty distribution by severity and collision configuration nowadays (year 2016) and by 2025 respectively.

In 2016, fatalities and serious casualties occur primarily in:

- Single car collision configuration,
- Front-to-front collisions and
- Front-to-side collisions.

This situation is expected to remain similar by 2025.

The slight casualties rank the collision configurations differently with the top 3 configurations being:

- Rear-end collisions,
- Side-to-front collisions and
- Single car collisions.

In 2025, the front-to-side collisions are expected to become the first collision configurations for slight casualties representing 26% of all M1-to-M1 and single M1 casualties.

Making the reasonable assumption that single car accidents may be inherently avoided by automated driving (no speeding, loss of control), then main collision configurations in 2025 will be: for fatalities:

- Front-to-front collisions,
- Front-to-side collisions,
- Side-to-side collisions

For serious casualties:

- Front-to-front collisions,
- Front-to-side collisions,
- Rear-end collisions

And for slight casualties:

- Front-to-side collisions,
- Rear-end collisions,
- Rear-end collisions.

Opponent	Collision configuration	Initial figures: Fatal injuries	Initial figures: Serious injuries	Initial figures: Slight injuries	Initial figures: All injuries	Initial figures (%): Fatal injuries	Initial figures (%): Serious injuries	Initial figures (%): Slight injuries	Initial figures (%): All injuries
M1 alone	M1 Front, Rear, Left, Right	529	3796	19771	24096	55.0%	41.1%	19.5%	21.6%
M1 vs M1	Front-to-Front	207	2322	15965	18494	21.5%	25.1%	15.8%	16.6%
M1 vs M1	Front-to-Side	130	1553	23402	25085	13.5%	16.8%	23.1%	22.5%
M1 vs M1	Rear-end	27	770	30774	31571	2.8%	8.3%	30.4%	28.3%
M1 vs M1	Side-to-Side	24	351	6989	7364	2.5%	3.8%	6.9%	6.6%
M1 vs M1	Side-to-Back	2	30	626	658	0.2%	0.3%	0.6%	0.6%
M1 vs M1	Reversing	0	6	364	370	0.0%	0.1%	0.4%	0.3%
M1 alone or M1 vs M1	No impact	15	190	1519	1724	1.6%	2.1%	1.5%	1.5%
M1 vs M1	Others	28	224	1931	2183	2.9%	2.4%	1.9%	2.0%
	Total	962	9242	101341	111545	100%	100%	100%	100%

Figure 69: Great Britain casualty severities by collision configurations in 2016

Opponent	Collision configuration	2025 figures: Fatal injuries	2025 figures: Serious injuries	2025 figures: Slight injuries	2025 figures: All injuries	2025 figures (%): Fatal injuries	2025 figures (%): Serious injuries	2025 figures (%): Slight injuries	2025 figures (%): All injuries
M1 alone	M1 Front, Rear, Left, Right	341	2660	16214	19215	50.5%	36.6%	18.7%	20.3%
M1 vs M1	Front-to-Front	153	1962	14764	16879	22.7%	27.0%	17.0%	17.8%
M1 vs M1	Front-to-Side	113	1443	22620	24176	16.7%	19.8%	26.1%	25.5%
M1 vs M1	Rear-end	16	514	22361	22891	2.4%	7.1%	25.8%	24.2%
M1 vs M1	Side-to-Side	18	316	6683	7017	2.7%	4.3%	7.7%	7.4%
M1 vs M1	Side-to-Back	2	25	593	620	0.3%	0.3%	0.7%	0.7%
M1 vs M1	Reversing	0	5	349	354	0.0%	0.1%	0.4%	0.4%
M1 alone or M1 vs M1	No impact	10	162	1398	1570	1.5%	2.2%	1.6%	1.7%
M1 vs M1	Others	22	187	1796	2005	3.3%	2.6%	2.1%	2.1%
	Total	675	7274	86778	94727	100%	100%	100%	100%

Figure 70: Great Britain casualty severities by collision configurations in 2025

Further details on Top 3 accident configurations

In 2025, front-to-front collisions, front-to-side collisions and rear-end collisions were identified as the three main collisions configurations. RAIDS collision scenarios matrix provides further information on the manoeuvres (or collision scenarios) that mainly lead to these collision configurations.

Main manoeuvres for the top 3 collision configurations were quantified considering all casualty severities.

Front-to-front collision configurations (Figure 71) mainly happen between two cars driving on a straight (B1), colliding in turning scenarios (L2 and J1) and in the case of one of the car losing control in a curved road (B6).

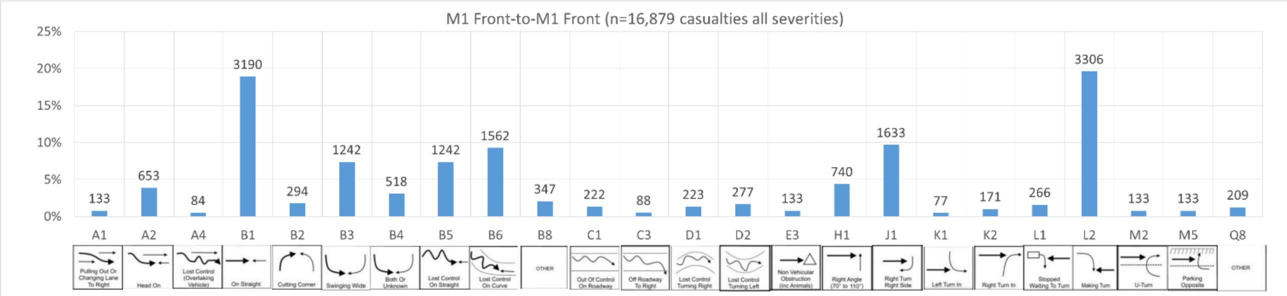


Figure 71: All severity casualty distribution by manoeuvre for M1 front-to- M1 front collision configuration (remaining casualties in 2025)

Rear-end configurations (Figure 72) are mainly due to a car striking the back of a preceding car queueing (F4) or being slow (F1).

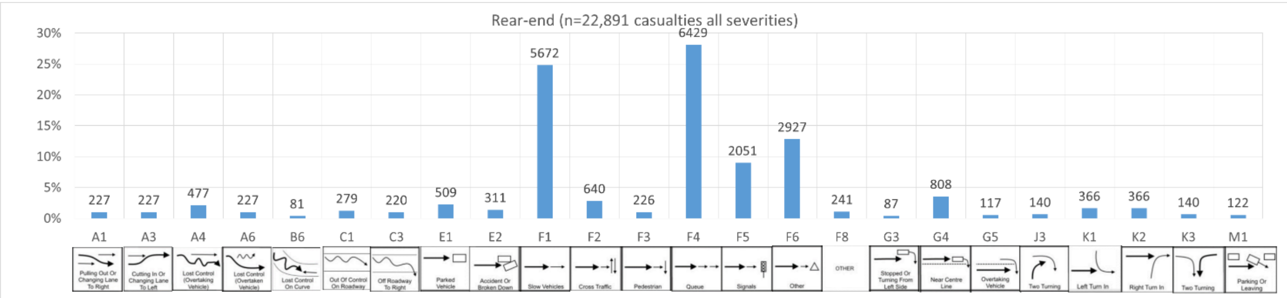


Figure 72: All severity casualty distribution by manoeuvre for M1 rear-end collision configuration (remaining casualties in 2025)

Front-to-side configuration (Figure 73) happen for a large part between two cars with perpendicular driving direction (H1) or when one car intends to turn right and the other one goes straight (H1).

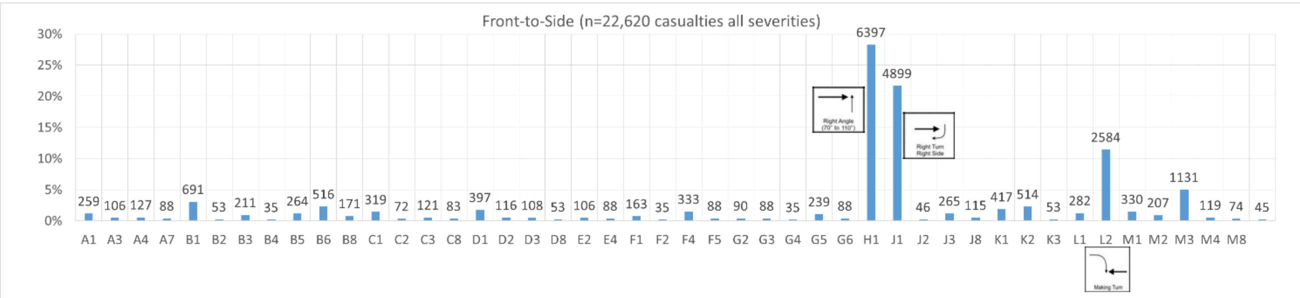


Figure 73: All severity casualty distribution by manoeuvre for M1 front-to- side collision configuration (remaining casualties in 2025. For all collision scenario description, see Figure 67)

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