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SALIENT

Safer, Lighter, Circular, Smarter

» DELIVERABLE D1.1

Accidents and crash configurations of future vehicles in mixed traffic scenarios

Funded by the European Union

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DISSEMINATION LEVEL

Abbreviation	Meaning	
PU	Public, fully open (Deliverables flagged as public will be automatically published in CORDIS project’s page).	X
SEN	Sensitive, limited under the conditions of the Grant Agreement.	

LIST OF ABBREVIATIONS

Abbreviation	Meaning
PU	Public, fully open (Deliverables flagged as public will be automatically published in CORDIS project’s page).
AD	Automated Driving
ADAS	Advanced Driver Assistance System
AEBS	Automatic Emergency Braking System
AIS	Abbreviated Injury Scale
AdaptIVE	Automated Driving Applications and Technologies for Intelligent Vehicles

Abbreviation	Meaning
Aspeccs	Assessment methodologies for forward looking Integrated Pedestrian and further extension to Cyclists Safety Systems
AV	Autonomous Vehicle
DMV	Department of Motor Vehicles
EURONCAP	European New Car Assessment Programme
EU	European Union
FES	Front-End Structure
FPOC	First Point of Contact
GIDAS	German In-Depth Accident Study
HMI	Human-Machine Interface
iGLAD	Initiative for the Global Harmonization of Accident Data
interatIVE	Accident avoidance by active intervention for Intelligent Vehicles
IIHS	The Insurance Institute for Highway Safety
MPDB	Mobile Progressive Deformable Barrier
OSCCAR	Future Occupant Safety for Crashes in Cars
PEGASUS	Project for the establishment of generally accepted quality criteria, tools, and methods as well as scenarios and situations for the release of highly automated driving functions
PCM	Pre-Crash Matrix
RAIDS	Road Accident In-Depth Studies
SALIENT	Novel Concepts for Safer, Lighter, Circular and Smarter Vehicle Structure Design for Enhanced Crashworthiness and Higher Compatibility
SAV	Sport Activity Vehicle
SEN	Sensitive, limited under the conditions of the Grant Agreement.
STRADA	Swedish Traffic Accident Data Acquisition
STATS19	Road Safety Statistics
SUV	Sport Utility Vehicle
Safe-UP	Proactive Safety Systems and Tools for a Constantly Upgrading Road Environment
US	United States
UK	United Kingdom
VCTAD	Volvo Cars Traffic Accident Database
VRU	Vulnerable Road User

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1. EXECUTIVE SUMMARY

SALIENT WP1 aims to analyse the current context of collisions in mixed traffic, making use of collision database data, using previous projects in this area as a starting point such as OSSCAR project (1) in autonomous driving effects in traffic, to draw conclusions about the collision behaviour of traffic involving the front-end. With an understanding of the current context, the different collision scenarios where these types of accidents occur. The filtering of the data for the exploitation of the same in terms of safety for passengers in autonomous vehicles, is carried out in relation to the data that are available, giving a broader applicability to the solutions that are reached in this project. Also, relationships between different environmental variables are studied, such as the mass of vehicles involved in accidents for the correct adoption of design criteria for frontal safety systems in the current context of mixed traffic and the continued implementation of autonomous and electric vehicles in traffic, because these vehicles have a different dynamic behaviour in collisions, due to structural differences from other vehicles.

The working methodology applied in WP1 is based on the meta-analysis of projects related to the sector and the analysis of data from relevant databases in the field of mixed traffic collisions, to obtain variables that can be found and correlated in them. Some of the results consulted from other projects are based on data from databases such as GIDAS (2) and iGLAD (3) with German data and STRADA (4) for Swedish accidents. Data is also obtained from other databases such as the DMV (5) in California, focused on accidents with vehicles equipped with autonomous driving between others. The lack of homogeneity of the data from the different sources makes the estimation of relationships between relevant variables in accidents, common in the different scenarios, more complex to analyse. For this reason, basic criteria are established that simplify the collection of data and are analysed on the same basis, considering the difficulties in extrapolating the conclusions in different scenarios.

The main topics discussed in T1.1 Future Accident Scenarios and Crash Configurations in Mixed Traffic (M1-M4) are the following:

- Literature review and analysis of relevant datasets for understanding SAV and AV behaviour in mixed traffic;
- Predicting crash scenarios and crash configurations from data analysis;
- Conflicts analysis with resolutions and design considerations.

The limitations of WP1 are related to the different scenarios in terms of mixed traffic, their change and uneven evolution over time. The conclusions reached are limited by the different adoption of measures for the implementation of autonomous driving and electric vehicles, creating dynamic scenarios over time, different from what has been in the databases up to now.

2. OVERVIEW

2.1 MOTIVATION

Automotive safety is one of the most crucial factors in vehicle development, and the vehicles of the future need lightweight structures that are safer and more sustainable throughout their life cycle. Compatibility between vehicles on the roads is complicated when the increase of different vehicles, such as autonomous vehicles, electric vehicles, and SUVs on the roads, makes the context of mixed traffic variable in a short period of time. Therefore, it is necessary to analyse the current context based on the most recent data and the latest industry projects to find the most appropriate safety solution for the current and near future context.

In a global context, where the scope of safety solutions can be applied in different countries, under different laws and regulations, as well as in accident contexts that vary between communities, it is of fundamental interest to analyse the most relevant databases on the subject. The data collected on accidents are obtained under diverse criteria and different national legislation, adding complexity to the analysis of the accident data in general.

Therefore, finding a front-end structural solution for vehicles applicable to the current context and adaptable to the mixed traffic scenario in general, while complying with the principles of circular economy, eco-design, and environmental friendliness is a key challenge.

2.2 METHODOLOGY

Available accident data (load case, crash angles, collision points, overlapping with other vehicles) will be used to build a more sophisticated tool to predict traffic scenarios, with a special focus on light vehicles and mixed configurations between light vehicles and heavier vehicles. Key factors influencing SAV, and AV driving behaviour are mapped in a literature review as well as the impact on safety conditions.

The approach plan to analyse the current context of collisions in mixed traffic and identify the most appropriate safety solution for this context, consists of the following steps:

1. Review of projects related to the analysis of mixed traffic collisions;
2. Analysis of data from databases related to mixed traffic accidents;
3. Filtering of data for their exploitation in terms of safety for passengers in autonomous vehicles;
4. Study of relationships between different environmental variables, such as the mass of vehicles involved in accidents, for the correct adoption of design criteria for frontal safety systems.

3. STATE OF THE ART

There are many EU-funded projects that have addressed the evaluation of Advanced Driver Assistance System (ADAS) or Automated Driving (AD) functions as well as the definition of accident scenarios of future relevance. All these topics are relevant for SALIENT. Examples are PEGASUS (6), AdaptIVE (7), Aspeccs (8) or interactIVe (9). Of these projects, OSCCAR (1) and SAFE-UP are the two most recent ones that are relevant to the topic. Of these two, OSCCAR is the most relevant for SALIENT, as the objectives of its WP1 are very similar to those of SALIENT's WP1.

3.1 H2020'S EU PROJECT OSCCAR (2018-2021)

OSCCAR's work package 1 aimed to identify potential remaining non-identified accident scenarios, taking into consideration the gradual introduction of ADAS systems and autonomous vehicles into the vehicle fleet mix. The main results of this work package are reported in deliverable D1.1 (10), which is publicly available.

The starting point of the analysis was an estimation of the market penetration of autonomous vehicles, which suggests that by 2025 the EU fleet of passenger vehicles with partially autonomous functions will comprise 3% and that it would take 25 years to reach a penetration rate of 66%.

To reach these conclusions, a bottom-up approach was applied, which considered the effect of ADAS and active, passive, and tertiary safety systems, and simultaneously, a top-down approach was used to omit accidents caused by a violation of traffic laws, which autonomous vehicles would inherently avoid. The bottom-up approach used UK data from STATS19 (11) and RAIDS (12), while the top-down approach was conducted using German data from iGLAD (3) and GIDAS (2). The result of the combined procedures are the main crash scenarios listed in Table 1.

Table 1 - Main crash scenarios per road type (10)

Road Type	Selected crash scenario
Motorway	Collision against another vehicle moving ahead or waiting/stalled in front
Urban road	Collision while turning into or crossing the road at an intersection
Rural road	Vehicle leaving carriageway/collision against a fixed object

Once the bottom-up and top-down approaches were applied, and to answer the question of what will be the remaining crash configurations in the future in OSCCAR, a traffic simulation (13) was carried out using the simulation software openPASS (13) in which a model of an autonomous vehicle is equipped with an Automatic Emergency Braking System (AEBS). The authors restricted themselves to a case selection of motorway front-to-rear-end collisions and intersections situations from the German and Swedish PCM (Pre-Crash Matrix) (14) and VCTAD (Volvo Cars Traffic Accident Database) datasets respectively, on which a clustering procedure was applied to obtain the most representative clusters in the space of angles and velocities as the simulation baseline.

The vehicles involved in the accident were characterised by the angles between their centres of gravity and the first point of contact (FPOC), called CA AD for autonomous vehicles and CA opponent for opponent vehicles. Meanwhile, the yaw angle defines the relative direction of both vehicles which allows us to calculate the module of the relative velocity (ΔV).

The results for collision angles between -90° and 90° were selected, as they potentially involve the Front-End Structure (FES) of at least one vehicle. The size of the cluster is proportional to its cluster share within each case, from GIDAS and STRADA (4) databases and can be seen below in Figure 1 and Figure 2.

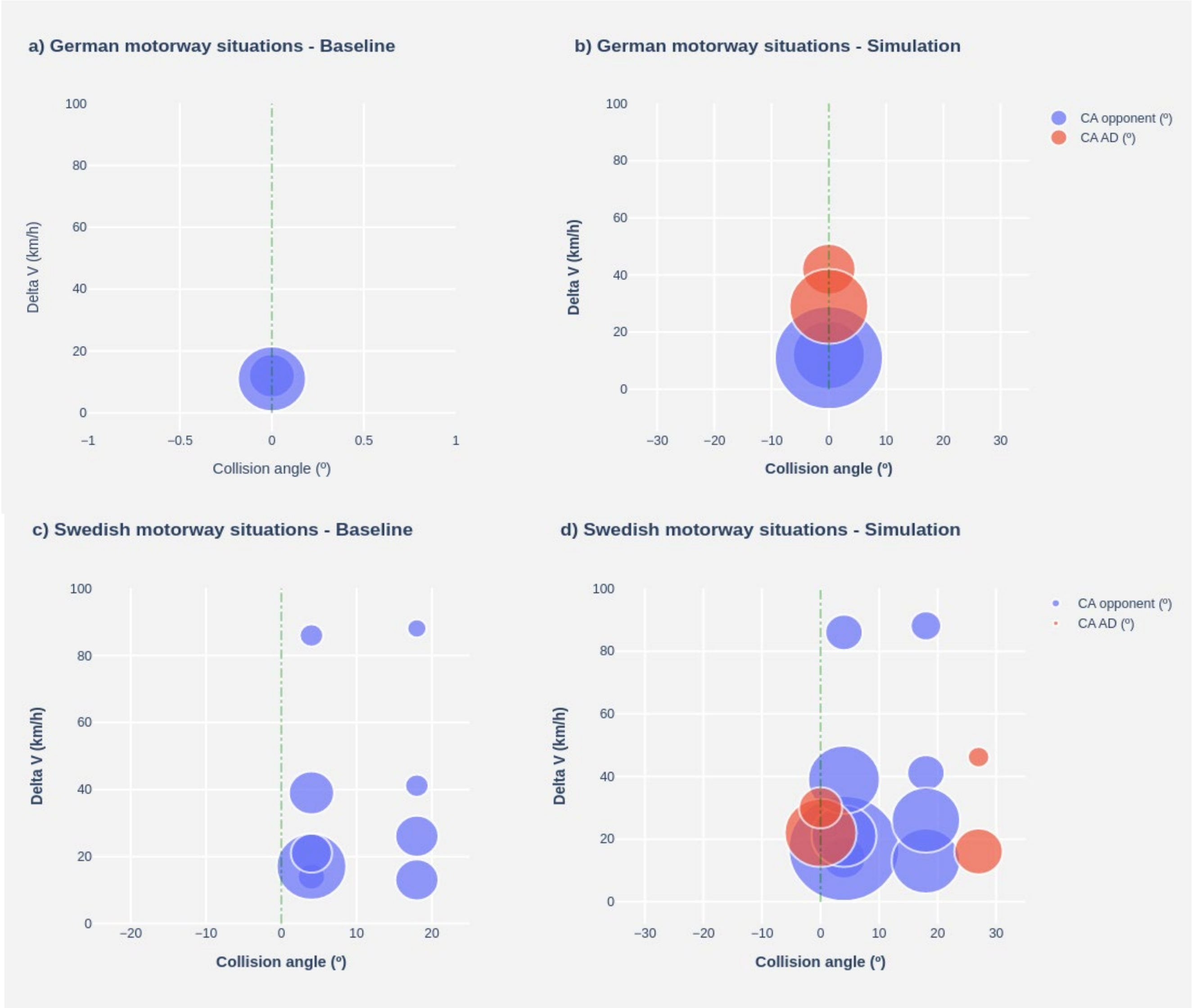

Figure 1 - Data visualisation of representative cases of motorway front-to-rear-end collisions: a) German motorway situations - Baseline and b) German motorway situations - Simulation, c) Swedish motorway situations - Baseline and d) Swedish motorway situations – Simulation (10)

Figure 2 - Data visualisation of representative cases of intersection situations: a) German intersection situations - Baseline, b) German intersection situations - Simulation, c) Swedish intersection situations - Baseline and d) Swedish intersection situations - Simulation (10)

The results of a data reduction and filtering are shown in Table 2 below.

Table 2 - Accident reduction, "Opponent" labels a regular car causing an accident, "Main" labels the AV causing an accident and "AVs" labels an accident between two AVs (10)

Country	Manoeuvres	Motorway scenarios			Intersection scenarios		
		Opponent	Main	AVs	Opponent	Main	AVs
Germany	No intervention	100%	0%	0%	15%	0%	0%
	Mitigated	0%	55%	55%	49%	10%	7%
	Avoided	0%	21%	21%	37%	19%	22%
	Inherently avoided	0%	24%	24%	0%	71%	71%
Sweden	No intervention	100%	0%	0%	0%	0%	0%
	Mitigated	0%	28%	28%	19%	23%	3%
	Avoided	0%	47%	47%	50%	55%	54%
	Inherently avoided	0%	25%	25%	31%	22%	43%

The comparison between pre-crash simulations in German and Swedish scenarios showed a difference of 26% in avoiding collisions, and of 27% in mitigating the crash. The German In-Depth Accident Study (GIDAS) provides information related to crash scenarios between 2000 and 2017, representing 70% of all cases. A research paper related to OSCCAR (15) demonstrated that by simulating ADAS logic rulesets under near-real conditions, the total number of crashes can be reduced, although the relative frequency of crashes on intersections in particular increased from 42% to 57%. This is of particular interest for the analysis of load cases for the development of future restraint systems. Table 3 contains the load cases involving injuries to the passengers to, at least, a moderate injury level (AIS2+).

Table 3 - Impact cases AIS2+, future driving (with ADAS logic ruleset applied) (15)

Load Case	Impact Angle (° degrees)	ΔV (Km/h)
Frontal Oblique Far-Side	60	26
	30 to 90	16 to 26
Frontal Oblique Near-Side	-30	44
	-30 to -60	29 to 44
Side Near-Side	90	22
	-90 to -120	8 to 22
Side Far-Side Forward Compartment	90	44
	-90 to -120	23 to 44
Side Near-Side Compartment	60	29
	60 to 90	12 to 37

The methodology applied above has come with limitations, which need to be taken into account when evaluating the results of this research. To validate the accuracy of these OSCCAR results, collision statistics are needed.:

- ADAS systems and AV software are highly heterogeneous and not open source. Test models of Avs could vary significantly from future realities;
- Accident data stems from subjective reconstructions by third parties, making it difficult to know precise details of each incident and verify data;
- Simulation of a highly complex system whose micro-physics are not well understood and which relies on human driver behaviour, experience and skillset;
- The amount of data clustering and filtering is limited, making it hard to know the statistical relative weight of each use case.

3.2 H2020'S EU PROJECT SAFE-UP (2019-2023)

SAFE-UP was a project that investigated case definitions and critical scenarios for driving safety, using real-world data of results for European Union traffic, from the perspective of passenger cars in situations ranging from car-to-car, car-to-heavy goods vehicle (HGV), and car-to-vulnerable road user (VRU) encounters. The goal of this project was to prevent injuries and fatalities of car occupants, evaluating restraint systems for in-crash protection and active safety systems for VRU avoidance. Several relevant deliverables are already publicly available, such as deliverable D2.6 (16).

The overall result for head-on situations shows that goods vehicles with total weight (HGV) ≥3.5t are disproportionally involved, which was used as distribution to generate input for further simulations.

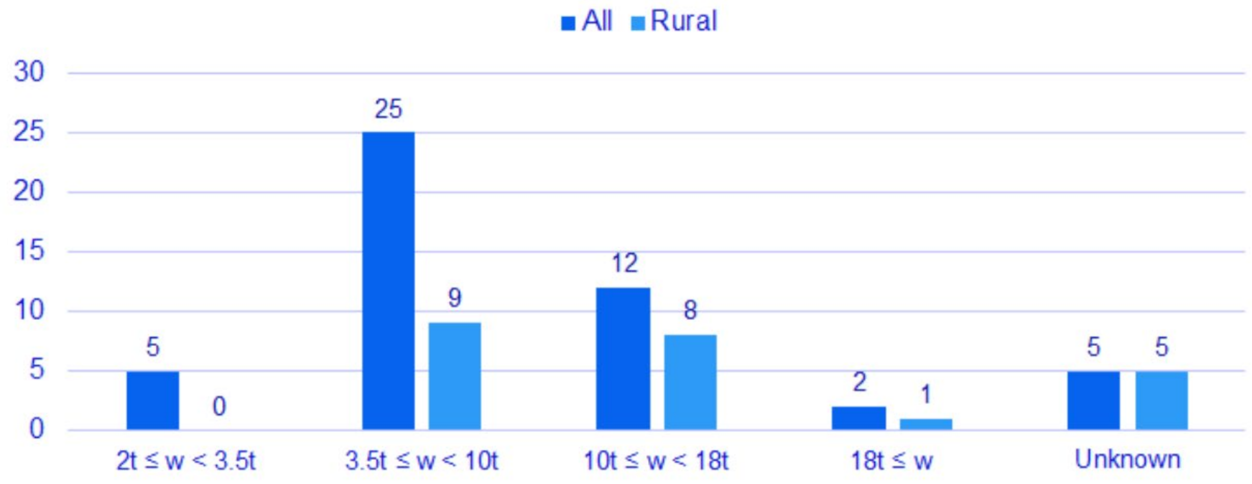

Figure 3 - Share of HGV >3.5t weight groups in head-on collisions by type of crash site (16)

The distribution of crash configurations for passenger cars against HGV ≥3.5t rear end collisions in GIDAS (2) shows that vehicles at the median (Q50: Weight PC up to 1.5t and Weight HGV 3.5 up to 10t) are relevant, because they involve light and heavy vehicle cases.

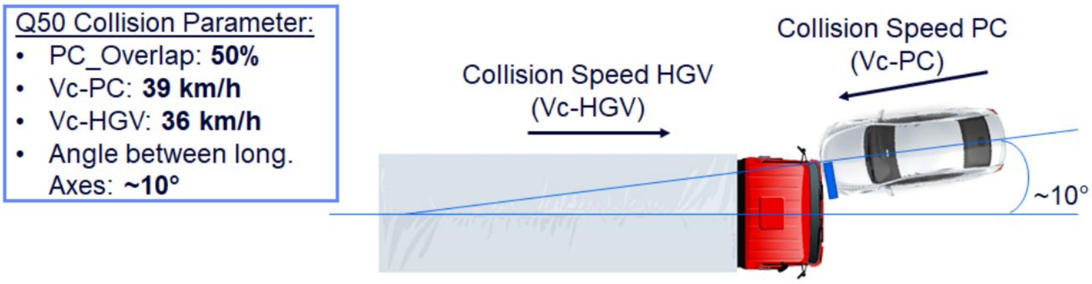

Figure 4 – Illustration of Q50 passenger car to HGV >3.5t head-on crash configuration (16)

As with OSCCAR, the SAFE-UP results and datasets have some limitations, which need to be kept in mind and considered moving forward:

- The data requirement imposed on the simulation approach which is necessary to accurately interpret the real-world results is extremely high, because the two stages to interpret real world results: measurements and the CAD approach require accurate crash angle data and overlapping;
- Data overlap between real-world measurements and simulations is often limited by the assumption of linear impact velocities;
- The data and assumptions used in simulations are complex and hard to interpret.

3.3 OTHER RESEARCH OF INTEREST IN MIXED TRAFFIC SCENARIOS

3.3.1 DMV AV collision reports

Based on the California Department of Motor Vehicles (DMV) AV collision reports from 2014-2018, 94% of all accidents involving AVs were passively initiated by other parties, while only 6% were directly related to AVs. Additionally, 63% of the collisions occurred while the AVs were in autonomous mode (17). More recent research has found that in 88% of the collisions, the AVs were not at fault, and 54% of the collisions happened while the AVs were in autonomous mode (18). In only 2 out of 30 collisions in which the AV was deemed to be at fault, was it in autonomous mode. In both cases, most of the collisions were rear-end collisions, as seen in Figure 5.

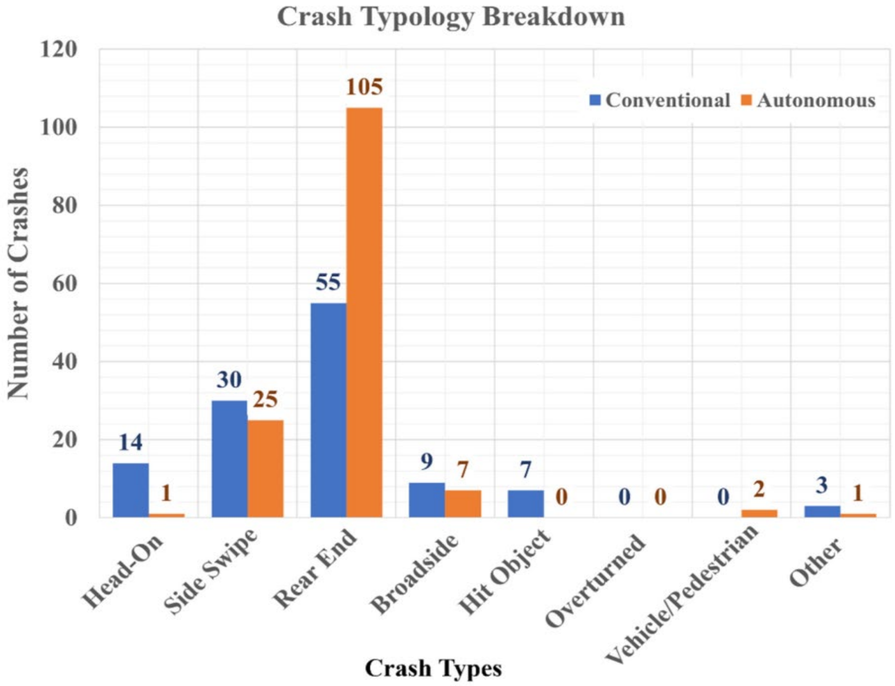

Figure 5 - Crash typology breakdown (19)

These results support previous hypotheses that AVs can prevent most crash scenarios in mixed traffic, except for rear-end collisions (20). Data also shows that out of all the collisions, 20.4% resulted in moderate damage and 1.0% resulted in major damage, as well as human injuries (21).

Additionally, 57% of the time the AVs were moving when the collisions occurred, while the other party was in motion 95% of the time. In terms of crash configuration (see Table 4), 62% of the collisions were rear-ended, 21% were sideswipe, 6% were heads-on, and 11% were other types of collisions. When the AVs were in autonomous mode, 65.2% of the collisions were rear-end crashes. Intersections are particularly dangerous for AVs, with 59% of the collisions taking place in cross intersections, 15% in T-intersections, 11% in Y-intersections, 9% in straight roads, and 5% in complex intersections (19). This is because non-AV drivers cannot react quickly enough to the leading AV movements. Furthermore, crashes tend to be less severe when the collision is a sideswipe, and more severe when the opponent vehicle is proceeding straight or making a right turn due to higher kinetic energy (21).

Overall, AVs have the potential to significantly reduce fatality rates, particularly in the case of head-on crashes, which account for 56% of US road fatalities. According to the Insurance Institute for Highway Safety (IIHS), head-on crashes are highly avoided by AVs in autonomous mode. Rear-end and side-impact crashes, on the other hand, make up 42% of deaths (19).

Table 4 - Distribution of crash typologies by driving mode and causing parties (19)

		Conventional Mode	Autonomous Mode	Total
Rear-End Crashes	**Absolute no of crashes**	47	103	150
	No of crashes with AV at fault	8	2	10
	Percentage of crashes with AV at fault	5.3%	1.3%	6.7%
Sideswipe Crashes	**Absolute no of crashes**	24	23	47
	No of crashes with AV at fault	6	2	8
	Percentage of crashes with AV at fault	12.8%	4.3%	17%

Rear-end collisions constitute around 32.3% of all crashes in the US, amounting to losses of around $3.9B in 2020. In the context of this publication and of our research, it is important to highlight that the AV is usually in front of the opposing vehicle (the other vehicle collides into the rear end of the AV). These crashes represent 73% of AVs crashes, although most of them happen at low speeds, with little damage to people. AVs SAE Levels 3–5 are found to be crashed from behind at a rate 4.8 times higher per unit distance travelled than cars driven by humans. AVs are more likely to be struck from behind when stopped than when moving compared to human-driven vehicles, suggesting that is the timing and locations of AV stops rather than the deceleration the main contributing factor behind AV rear-end collisions (22). Moreover, it has been found that in the time 2014-2019, there is a higher likelihood of collisions in adverse weather conditions when the AV is in autonomous mode and its prior condition was stopped (23).

Finally, it has been found that, in general cases, there is no significant change in crash proportions between more recent and older periods (24) and that the manufacturer of the AV plays a significant role in crash severity in the future (21). It is recommended that AV manufacturers consider fine-tuning several aspects such as external communication to other road users (e.g., via HMIs) as well as the smoothness of driving manoeuvres such as braking. For traditional automotive manufacturers, it is important to keep in mind that non-AVs will interact to an increasing extend with AVs on mixed traffic roads and it is advisable to not only improve ADAS systems in this regard, but also to upgrade FES to make smart decisions and feather off crashes in a more effective way.

3.3.2 Other considerations

According to recent research with data from the French database VOIESUR (25), a reduction of approximately 60% of injury crashes and fatal crashes could be expected by replacing light vehicles with autonomous vehicles in France (26), which encourages the introduction of autonomous vehicles into traffic, but even using Level-5 autonomous vehicles would not prevent all accidents.

It should be noted that, with the increasing number of cars using Advanced Driver Assistance Systems (ADAS) the future crash scenarios will be different from today’s collision scenarios. If all the vehicles on the road were AVs, then some constraints that ADAS and AD functions must meet to work in a mixed-traffic environment would disappear, allowing the new systems to be more efficient. The collision risk studies (27) show that AVs can be re-adapted to new scenarios to minimise the injury risk among all involved vehicles instead of ego vehicles only. Taking into account the differences between countries and datasets scenarios, the specific analysis of datasets by each country is useful to obtain details and useful information about future passenger car safety.

Currently, there are autonomous driver frameworks under development capable of avoiding or mitigating 100% of crashes aside from rear-end crashes during simulations, avoiding human errors as the most common factors in crashes (28). This could be significant for the type of collisions that would occur in the future.

3.3.3 Vehicle weight

Since 2004, the United States has seen a 1% annual increase in the weight of new vehicles. One of the factors behind this increase is the increase in average vehicle size (29). According to a recent review of new passenger cars by segment in the EU (30), SUVs (Sport Utility Vehicles) accounted for 46% of new sales in 2021, making them the most representative vehicle segment currently on the road (See Figure 6 - New passenger cars by segment in Europe).

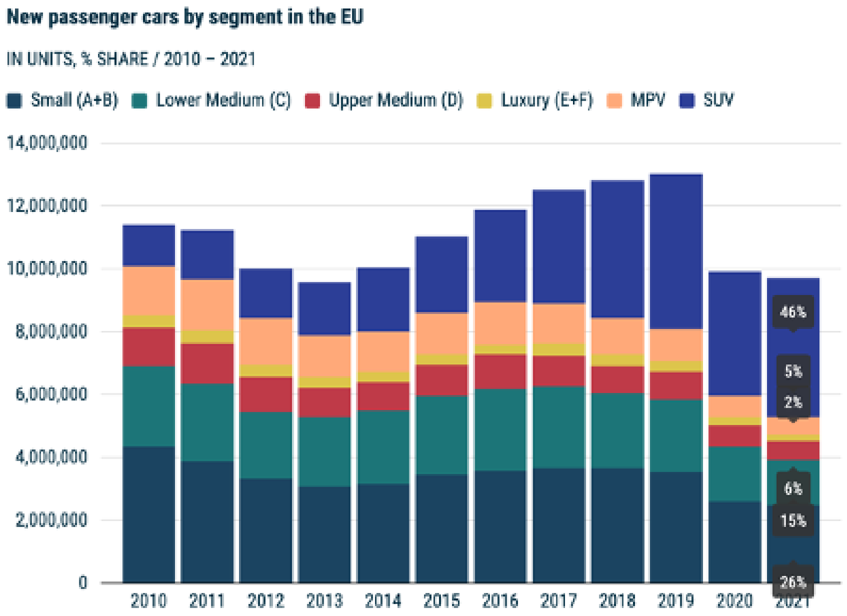

Figure 6 - New passenger cars by segment in Europe (30)

A more recent factor behind the increase in weight may be the increase in the number of electric vehicles (EVs) (31). On average, EVS are 10-25% heavier than non-EVs. Although most EVS are passenger cars in the smallest classes, the average weight of all registered electric cars in Norway in 2016 (1,488 kg) is somewhat higher than the average weight of all registered passenger cars with petrol or diesel engines (1,392 kg). Hybrid cars weigh an average of 1,499 kg. On the other hand, some initiatives propose a reduction in the weight of the vehicle fleet to accelerate the decarbonisation of the economy, such as the Horizon 2020-funded ALLIANCE project (32). These opposing trends could have an impact on traffic safety.

It is a well-established fact that (increased) vehicle weight has a positive impact on the overall safety (31) of passengers of the ego vehicle. For instance, there is a 7.5% reduction in the risk of being injured in a collision with a light vehicle for every 100 kg increase in the ego car, while the risk to the other party increases by 6.6% per 100 kg. In same-weight collisions, the probability of being injured as passengers decreases by 3.7% per 100 kg increase per vehicle. Nevertheless, the dependence on the weight of the total number of casualties has decreased over time (because the vehicles are safer).

However, there is no consensus regarding on whether a fleet with a lower average weight would result in fewer deaths and injuries (31). In this sense, and to circumvent the safety concerns that weight reduction might raise, some authors have proposed decreasing the weight of vehicle fleets (33). The weight of the overall vehicle, and in particular of the FES, is one of the main challenges of the SALIENT project, not only in terms of increased sustainability and circularity but also in terms of safety and crash compatibility. In order to advance knowledge further, it is recommended to complement the present literature review with the testing of different FES of various weights during the execution of the following technical WPs of the SALIENT project.

3.3.4 Fleet electrification

In recent years the number of new EVs, including hybrid electric, plug-in hybrid and battery electric vehicles, is rapidly rising. In the period from 2018 to 2021, the market share of this type of vehicle has increased from 5.9% to 37.6% (34). Moreover, as a part of the Fit for 55 packages (35), the EU is strengthening its decarbonisation agenda by targeting a -15%, -55% and -100% reduction in CO2 emissions for cars and vans for 2025, 2030 and 2035 respectively.

Therefore, EVs must be considered for any near-term future forecasts. And, as mentioned above, vehicle weight is a variable related to injuries in collisions. In EVs, the position and weight ratio of the battery with respect to the EV body mass affects the dynamic of the EVs (36), which directly affects the dynamic behaviour of a vehicle in a crash.

Automotive manufacturer Tesla has claimed that the lowering of the centre of gravity and the reduction of the polar moment of inertia due to the positioning of the battery pack in the floor of the car have positive impacts on vehicle safety, agility and manoeuvrability and enable safer structural designs for passengers (37).

On the other hand, a recent study based on data from Norway found that EVs are involved in 1.5 times more crashes with cyclists and pedestrians than internal combustion engine vehicles (ICEV). It has been hypothesized that the cause may be the lower noise level that EVs emit, making them more difficult for pedestrians and cyclists to notice. EVs are also found to be especially dangerous for motorcycles in terms of crash severity, although the reason is unknown. Therefore, special attention should be paid to motorcyclist protection in the future EV era. But there is still little data on EV accidents available today (38).

3.4 LIMITATIONS OF SIMULATIONS

Analysis of autonomous vehicle collision reports in California revealed that data are consistent with the ability of AVs to prevent most of the crash scenarios in mixed traffic, the major exception being rear-end collisions.

AVs are almost 5 times more likely to be crashed from behind than human-driven vehicles. This increase is not only due to the greater efficiency of AVs in emergency braking compared to non-autonomous vehicles but to the AVs' timing and choice of stopping locations. This problem is inherent to mixed traffic conditions and will tend to diminish as the level and share of automation of the total vehicle fleet increases. In the meantime, it will be a defining feature of mixed traffic if autonomous vehicle manufacturers do not implement behavioural corrections of autonomous functions or if drivers do not learn to predict and coexist with AVs.

The current state of research from the limited data available on real mixed traffic situations does not provide fine-grained information on the parameters characterising collisions, such as angles and speeds. OSCCAR's results reproduced the observed increase in rear-end collisions. They also predicted an overall reduction of ΔV in intersection situations, which could be compatible with the observed fact that crashes tend to be less severe for passengers when the collision is a sideswipe.

Studies that attempt to derive future crash scenarios from simulations suffer from some recognised limitations. In addition to the limitations listed by other authors, SALIENT will amend existing research by the following factors and analyses:

- **Lack of experimental validation and benchmarking**: No experimental validation of the simulation methodology used has been found in the literature. The scarcity of mixed traffic data makes this task difficult;
- **Reliance on simulations** of a highly complex system whose micro-physics is not well known: ADAS systems and AD functions are highly heterogeneous and not open source. The data from California shows that the manufacturer of the AV plays a significant role in crash severity. Abstracting this complexity into a toy model can produce results that diverge significantly from the simulated reality;
- **Non-linearities are not considered**: The behaviour of an AV in pre-crash scenario reconstructions derived from traffic with zero or negligible AVs is simulated. But it is reasonable to think that the introduction of a significant number of AVs will have an impact on these scenarios. For example, AVs might even generate new crash scenarios that human drivers would not repeatedly generate (39);
- **Lack of replication**: Difficulties are encountered in reproducing the results obtained due to the lack of definition in the workflow used in the simulations and data processing.

4. RELEVANT DATABASES

There are numerous agencies that are dedicated to obtaining accident data. In this project, some of the most relevant databases are considered, obtaining relevant samples to draw conclusions beyond what is strictly observable. In the case of the Databases from European Union countries, the focus is on DMV to obtain relevant case studies in mixed traffic.

When analysing data from the case studies, the information obtained from DMV is extrapolated from the rest of the available data, to create artificial samples applied in other countries. Most of the crashes with a risk of occupant injury are those involving the front of either vehicle. Data collection focuses on the study of frontal collisions in mixed traffic, obtaining collision information from autonomous vehicle data in this scenario.

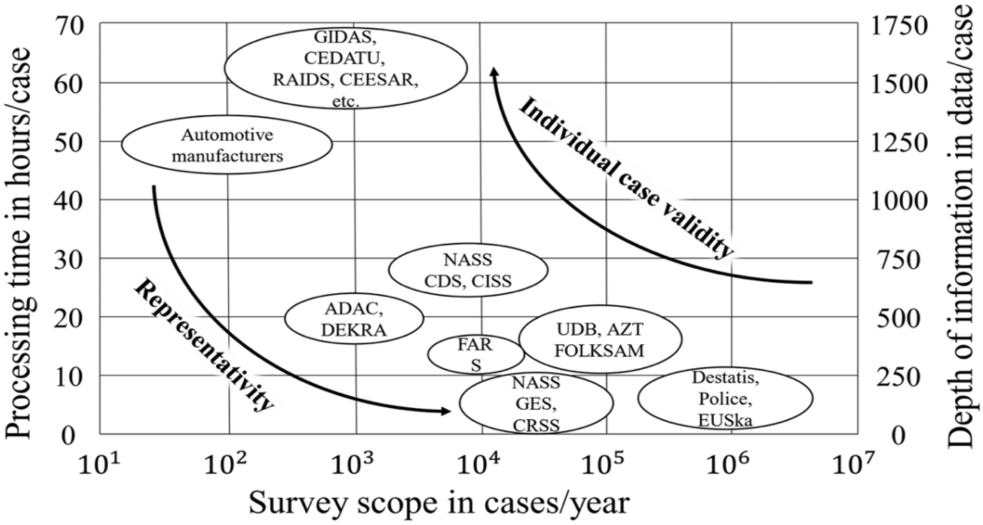

Figure 7 - Scope of data collection, processing effort & depth of information in accident surveys (40)

Other databases of interest are of the Spanish Government (City of Madrid (41)) and of the French Government and public organisations, provided by the French Road Safety Observatory (OINSR) and extracted from BAAC (French Government (42)). Both with a mixed traffic scenario datasets that allow to approximate the solutions to different crash cases. The data are grouped according to available information, Figure 8 below. In the case of available data, there are two geographical clusters. Comparison of the impact and importance of weights between datasets can be made with conservative assumptions, see Figure 9.

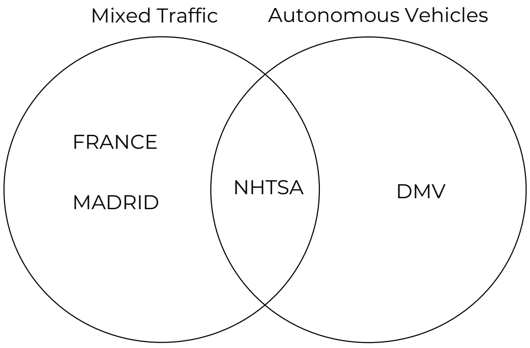

Figure 8 - Autonomous vehicles in mixed traffic conditions databases

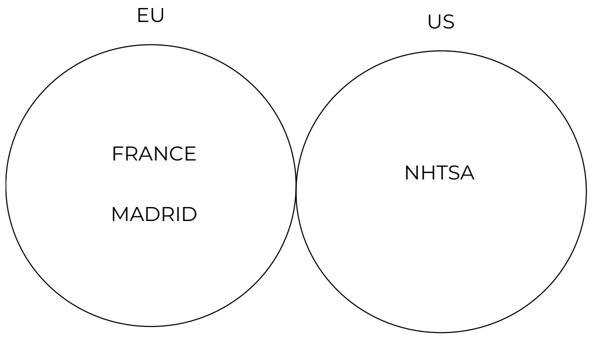

Figure 9 - European Union and United States geographical clusters

5. DATA ANALYSIS AND CRASH CONFIGURATIONS

5.1 EUROPEAN DATABASES

Data from different sources have unique particularities. US databases are generally more comprehensive than EU databases and often contain more detailed accident characteristics: climatic context, location, relative positioning of the vehicles and subjects involved in high detail. The different characteristics that can be extracted from sources such as NHTSA allow for detailed analysis of the collision between vehicles. In this way, a previous scenario could be generated, where the initial and boundary conditions are sufficient to generate collision simulations.

In the task of analysing data from different crash databases in mixed traffic, road users must be considered. In other words, the accidents that occur most frequently and cause the most severe injuries to those driving or using the road must be considered.

5.2 FRONT-END ANALYSIS

The selection of cases of interest for subsequent studies will help to reduce the severity of the most frequent accidents. For this reason, a common criterion is used, which is not very demanding based on the data available in the different databases. The low level of stringency in these selection criteria is due to the lack of uniformity in the different databases.

Accidents where two vehicles are involved and at least one of them has autonomous functionality shall be considered, whether its autonomous features are in operation when the accident occurs. In addition, if possible, a study of accidents that have data to help give context to the collision between the vehicles (e.g., that the vehicle causing the collision is known) will be taken.

In previous studies, the data considered was referenced to the relative velocity, which is related to the severity of the accident. This could be useful if relevant data, such as yaw angle, were available, but it must be analysed correctly since the collision point is not enough to obtain the necessary data for the correct simulation of the accidents. Collisions involving two moving vehicles require both angles from the different vehicles as different reference systems, which cannot be obtained in general cases and not in all the datasets.

5.2.1 Front-end AV collision

In the DMV database, the areas affected by collisions in different cases can be defined in depth. The cases are characterised by the situation of the vehicles before the impact. In frontal impacts, it is normal that if one vehicle is stationary and the other is moving, it is the moving vehicle that causes the impact, so the data is filtered in this way. Based on the vehicle's state of movement on the road and its immobile state, defined as "other situation", since it includes being immobile or in another situation not compatible with traffic mobility.

In the first analysis of the collisions, the heatmap shows the areas affected by impacts in relation to the frequency in the filtered DMV dataset, Figure 10. It can be seen from the data that autonomous vehicles have a higher impact rate on the right-hand side than other vehicles when in motion. However, when in other situations that does not involve movement, the front of the car shows a more even distribution of damage. This could be due to compatibility between the colliding vehicles and could be the source of human error during driving. Hence, they have a similar distribution.

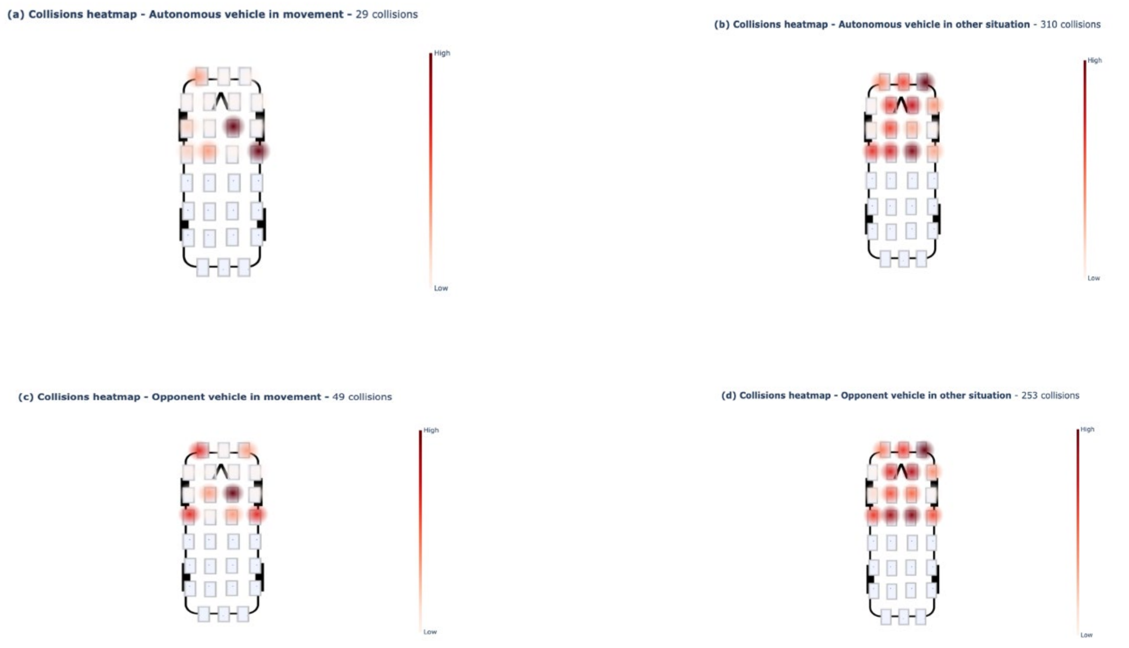

Figure 10 - Collision heatmaps in different scenarios in DMV database: a) autonomous vehicles in movement, b) autonomous vehicles stopped or in other situations, c) opponent vehicles in movement, d) opponent vehicles stopped in other situations

A more specific analysis allows to delve into the behaviour of front-end damage in specific cases where vehicles collide with other vehicles stopped on the road, as shown in Figure 11. It is remarkable that there is a difference in the damage to the front-end of the various vehicles, so that very different patterns are visible. According to these particular cases of collisions caused by autonomous vehicles in motion, most of the damage is concentrated around the front passenger and the right side of the car. While in the opposite case, the damage is distributed around the front bumper and the left side of the vehicle. This shows differences between the samples that are not trivial, as they may be caused by human driving habits and the poor adaptation of people to the driving dynamics of autonomous vehicles.

Figure 11 - Statistical weights for families of front-end involved impacts in autonomous vehicles in mixed traffic

Cases, where these areas are affected, are studied in the literature (15), being:

- Frontal oblique far-side;
- Frontal oblique near-side;
- Side near-side;
- Side far-side forward compartment;
- Side near-side compartment.

These types of collisions are sufficiently general and common to serve as a sample of the different databases.

The relative weights for frontal collisions in the DMV Database are shown in Table 5. The data shows a tendency for autonomous vehicles to receive more collisions while stationary in traffic (91.45%) than in the case of a non-autonomous vehicle (83.77%). On the other hand, autonomous vehicles in motion account for 5% of the collisions with stationary vehicles, with autonomous vehicles being hit by other moving vehicles 7.28% of the time when there are head-on collisions in this selection of cases.

Table 5 - Statistical weights for front-end involved impacts in autonomous vehicles in mixed traffic, DNV database

Crash with	**Autonomous in Movement (339 cases)**		**Opponent in Movement (302 cases)**		**General**	
	Percentage	**No.**	**Percentage**	**No.**	**Percentage**	**No.**
Autonomous stopped or in other situation			7.28%	22	91.45%	310
Opponent stopped or in other situation	5%	17			83.77%	253
General	8.55%	29	16.23%	49		

Different types of collisions are described in different databases, so the lack of uniformity of data means that the extrapolation of weights from one dataset to another is limited. The most common cases displayed in Table 5 and Table 6 will be considered as the main source of crashes in the databases studied, so accidents involving more than two vehicles, car rollover or pedestrian accidents have been excluded.

Accidents involving pedestrians, whether caused by being run over or otherwise, are not the subject of study in the SALIENT project. However, the most exposed and fragile road users are considered, as they are the ones who set the minimum safety requirements to be covered by the impact parts of the vehicles, in terms of safety.

In the case of the data held in the different databases, Table 6, special consideration shall be given to the cases of frontal impact, rear impact and side impact.

Table 6 - Extracting data for different collision cases in crash databases (2)

	DMV	GIDAS	Madrid	France
Heads on	5.79%	32.60%	2.71%	12.48%
Read end	61.78%	17.70%	26.03%	14.38%
Side	21.24%	23.30%	42.89%	28.69%
Chain	0%	0%	0%	8.86%
Multiple	0%	0%	8.55%	7.40%
Other	10.42%	0%	13.59%	24.34%
Without collision	0%	0%	0.37%	3.85%
Pedestrian	0.77%	0%	5.49%	0%
Overturned	0%	6.00%	0.37%	0%

The distribution of available data for each set, Figure 12, also shows the comparison between datasets. The data handled by the different databases are of mixed traffic, but not all of them contain information about the level of autonomy of the autonomous vehicles.

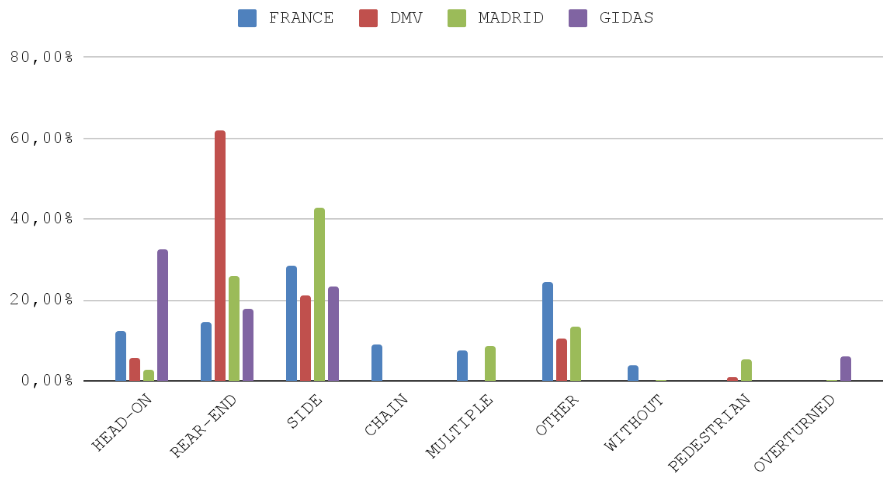

Figure 12 - Collisions distribution in databases, visual chart comparison with different accident cases

6. SAFETY CONDITIONS

Road safety is improved by two distinct bodies of standards: regulations and consumer tests. Regulations are set by governments and balance social and economic benefits with environmental and safety performance, while consumer tests express the market demand for better products. Regulations establish minimum safety requirements, while consumer tests provide impartial information to allow customers to make well-informed decisions when buying a car. The contribution of consumer tests on vehicle safety improvement has been dramatic, leading to higher energy absorption and intrusion containment, and very high strength steels being adopted in A and B pillar, floor, and roof, as shown in Figure 13.

SALIENT will focus on the FES, which connects directly to the A pillar of vehicles. While most previous improvements in terms of safety and sustainability have focused on the parts of the vehicles which lay between pillar A and C, there is still much room for improvements in terms of structure, composition, integrity and sensoring of the FES (green), and in addition the rear end structure (blue). The project aims at improving the FES section of the vehicle design to set a new expectation and standard also for the safety performance of FES on all types of vehicles, ranging from sedans and station wagons via SUVs to hatchbacks and a-segment cars.

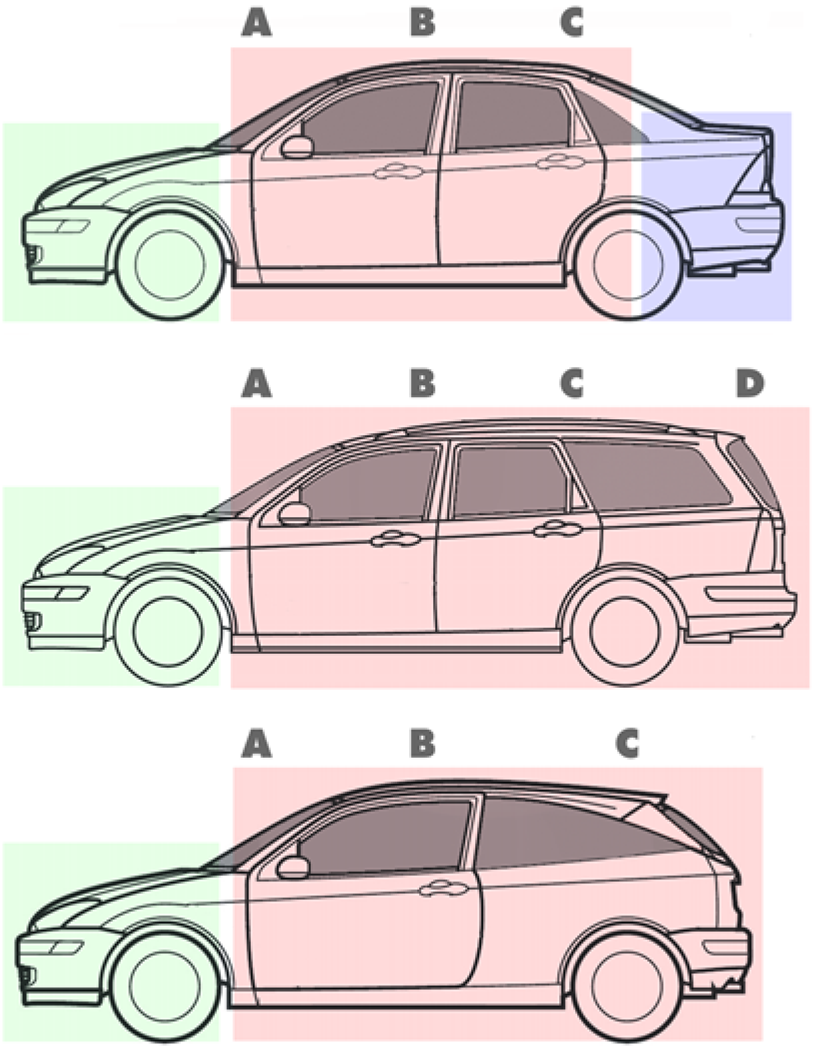

Figure 13 - Typical pillar configurations of a sedan (three box), station wagon (two box) and hatchback (two box) from the same model range

6.1 FRONT-END STRUCTURES

The Front-End Structure (FES) plays a significant role in protecting vehicle occupants during a crash. The FES absorbs some of the energy associated with a crash, dispersing it away from the occupants. This absorption of energy reduces the speed at which occupants move forward suddenly, lessening the effective force on the body. It is worth noting that the same mechanisms which absorb crash energy also reduce impact severity from the outside of the vehicle by slowing the car's deceleration rate. The FES also has an important impact on the crashworthiness of the vehicle in another way. By controlling the amount of vehicle deformation, the FES ensures that the space within the vehicle remains intact and does not collapse. This helps to protect the occupants from the risks of head, neck, and body injuries. Finally, the FES is also designed to limit the intrusion of the bonnet and bumper into the cabin space, lessening the risk of injuries to passengers in the cabin area.

The safety benefits associated with the FES are very clear; however, despite the availability of international standards and consumer tests, the current fleet of vehicles often fails to meet the design standards. This is where government regulations continue to play an important role, as they provide a baseline for vehicle safety performance. By establishing legal requirements, governments can ensure that no matter what the manufacturer’s design goals are, a minimum level of safety is always provided.

6.2 MIXED TRAFFIC CONDITIONS

Safety conditions considering a new and lighter FES with respect to existing production cars, involves the considerations of car manufacturers, current legislations, tested for existing FES, consumer testing and specific needs of current vehicles. Therefore, a coherent plan for the future of vehicle safety will be needed that combines consumer testing, appropriate regulation, and new technology developments.

Then, the risk of passengers in vehicles with the new FES in mixed traffic must be assessed considering the standardised internal limits for safety (namely homologation and qualification) and the current situation in the car fleets. The evolution of the car fleet in terms of size and weight will ensure the evolution of safety criteria to ensure occupant protection in case of collision with medium/large vehicles in the context of mixed traffic with AVs. The lightweight body structure in combination with ESC, airbag and FES is the basic key to a good compromise between design for passive safety in case of front/side/rear impacts and optimisation of the overall vehicle weight. In particular, the new FES will have to respect the requirements of type-approval and qualification standards and car manufacturers will have to consider their production fleet. Thus, to improve road safety, from the point of view of the new FES, car manufacturers must consider existing regulations and consumer evidence. They also need to be aware of how their car models fit in the context of mixed traffic with AVs and proportionate to the risk of their fleet (size and weight). In this way, they can act on advances in technologies to create lighter and safer structures according to established criteria and standards. In this way, car manufacturers can ensure that passengers in their vehicles benefit from increased safety conditions.

7. CONFLICT ANALYSIS & DESIGN CONSIDERATIONS

7.1 DESIGN CONSIDERATIONS

The cases presented in this deliverable will be studied in SALIENT's WP5 Collision Analysis and Virtual Testing during T5.5: Full Vehicle Simulation in Mixed Scenarios to gain insight into the conflicts between Front End Structures and safety performance requirements for different crash scenarios.

The crash scenarios considered in this deliverable are mainly rear impact, side impact, and frontal impact. Within the rear impact category, the motorway rear end and inner-city rear end will be studied. For frontal impact, the analysis will cover both frontal crashes and head-on collisions. The scenarios considered in the deliverable are the most relevant when it comes to assessing the performance of the new Front-End Structure (FES). These scenarios will be studied in detail and various simulations will be run to understand the conflicts between FES and safety performance requirements.

The simulations will also be used to assess the performance of the FES in terms of energy absorption, deformation control, and intrusion protection. The results of the simulations will be used to develop new FES designs that can meet the safety performance requirements for the different crash scenarios, identify potential areas of improvement, and develop new designs that can meet the safety performance requirements for the different crash scenarios. Finally, the results of the simulations will be used to develop a comprehensive safety assessment of the FES that can be used by manufacturers to ensure the safety of their vehicles.

The SALIENT FES requires focus on expected scenarios related to the frontal main structure of a vehicle:

- Legal ECE-R94 (43), R-100 (offset, 40% overlap deformable barrier at a speed of 56 km/h);
- Legal UN R137 (full frontal rigid barrier, 50 km/h);
- EuroNCAP (consumer testing scenarios);
- Additional scenarios that test improved compatibility (e.g., different weight, different height of bumper);
- MPDB with increased weight (IIHS side impact or equivalent) and height;
- Additional scenarios either using:
    - MPDP ant different angles (~ 0-30°, impact points 0-60% overlap);
    - Stationary barriers and adjusted speeds (reduced rel. velocities compared to ECE and current Euro NCAP test protocols);
    - Combination of compatibility testing and crash angle/velocity.

Scenarios that take SALIENT adaptive structures into account can be derived from all the above use cases. Special attention may be paid to the EuroNCAP frontal impact load cases as a test and validation example. The test vehicle is driven into a moving deformable barrier at a speed of 50 km/h mounted on an oncoming 1400 kg trolley (MPDB), also at 50 km/h, 50% overlap:

- Full-width rigid barrier (full overlap at a speed of 50 km/h);
- Offset, 40% overlap deformable barrier at a speed of 64 km/h;
- Mobile progressive deformable barrier.

7.2 RELEVANT CRASH SCENARIOS

According to literature, the prospective studies performed in - amongst others - OSCCAR and SAFE-up should be considered. According to the very limited set of Accident Data analysed (due to limited number of automated vehicles on roads worldwide), the following scenarios appear as relevant - all three of them should be explored during all of the following technical SALIENT WPs, from design conceptualisation, simulation design and crash test evaluation:

Table 7 - Selected crash scenarios in mixed traffic settings

Impact Area	**Impact Reason**	**Research Focus**
Rear	• Unexpected braking of AV, causing a rear collision into the AV on motorways, inner-city and intersection settings	• AIS1-2 injuries of AV occupants/passengers • Criticality for occupant/passengers of AV
Side	• Collision at turning point of intersection	• Criticality for occupant/passenger safety on-board of both vehicles
Front	• Failed detection object in front of AV • Human error of vehicle in on-coming traffic (e.g., wrong way drivers)	• Criticality for occupant/passenger safety on-board of AV

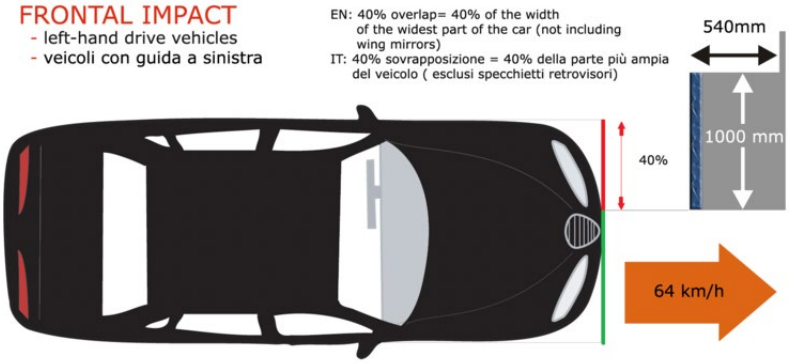

Figure 14 - Former Euro NCAP Frontal Impact Test replaced by the Mobile Progressive Deformable Barrier test in 2020 (44)

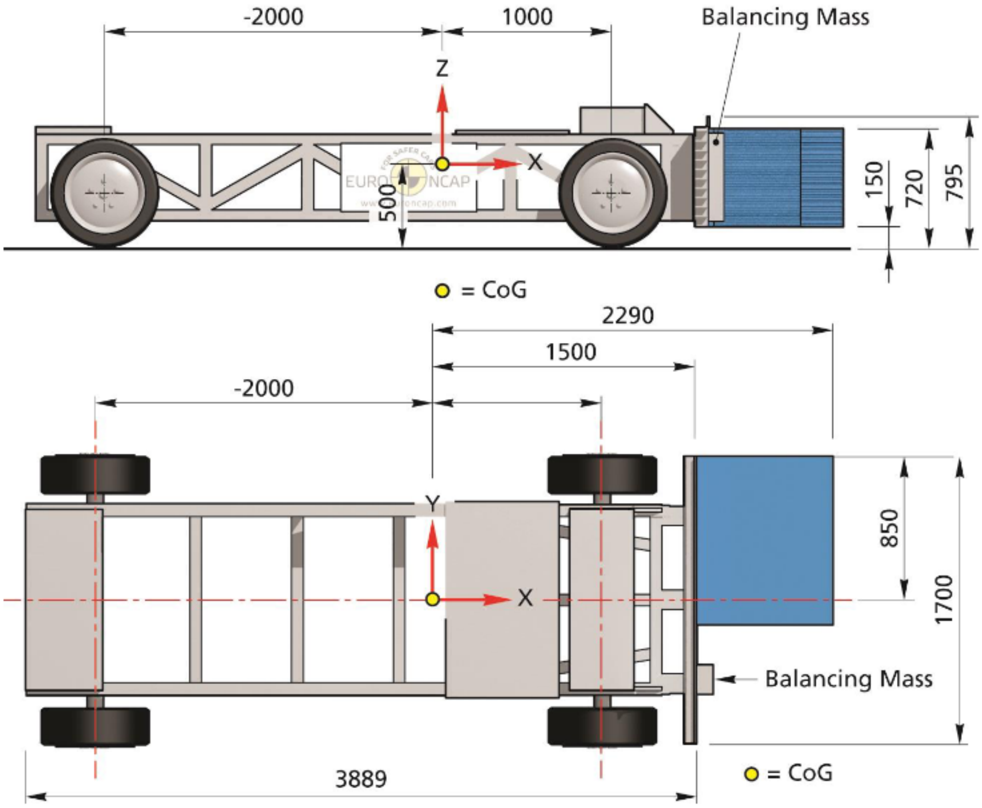

Figure 15 - MPDB trolley and barrier (45)

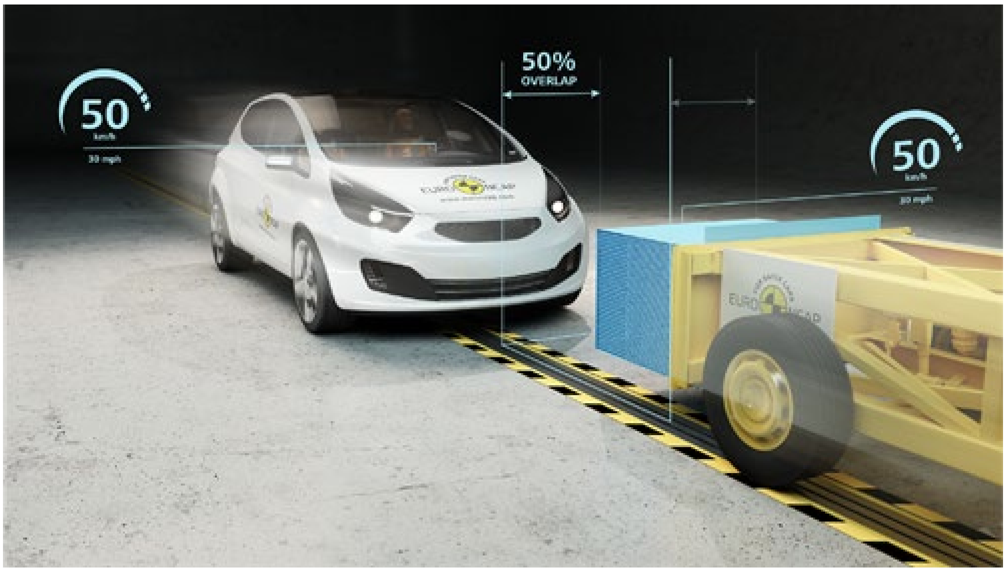

Figure 16 - Current EuroNCAP Fontal Test with MPDB (45)

Figure 17 - EuroNCAP Full Width Rigid Barrier

7.2.1 Additional SALIENT crash scenarios

In addition to the crash scenarios mentioned in the previous sections, SALIENT WP5 Collision Analysis and Virtual Testing during T5.5: Full Scale Structural Integrity and Safety Simulations including Future Mixed Traffic Scenarios will also consider the following crash scenarios:

- Rigid barrier with full overlap at a speed of 56 km/h;
- Offset, 40% overlap deformable barrier at a speed of 56 km/h;
- Mobile Progressive Deformable Barrier (MPDB) with increased weight (a la IIHS side impact or equivalent) and height;

- Mobile Progressive Deformable Barrier (MPDB) at different angles (~ 0-30°), impact points 0-60% overlap;
- Stationary barriers and adjusted speeds (reduced relative velocities compared to ECE and current Euro NCAP test protocols);
- Combination of compatibility testing and crash angle/ velocity;
- Crash avoidance scenarios (e.g., swerving to avoid a pedestrian, cyclist, vehicle.

The objective of the simulations is to assess the performance of the FES in these scenarios and evaluate the risk of injury to the occupants. The simulation results will provide insights into the design of the FES and will help to improve the safety performance of vehicles in mixed traffic scenarios.

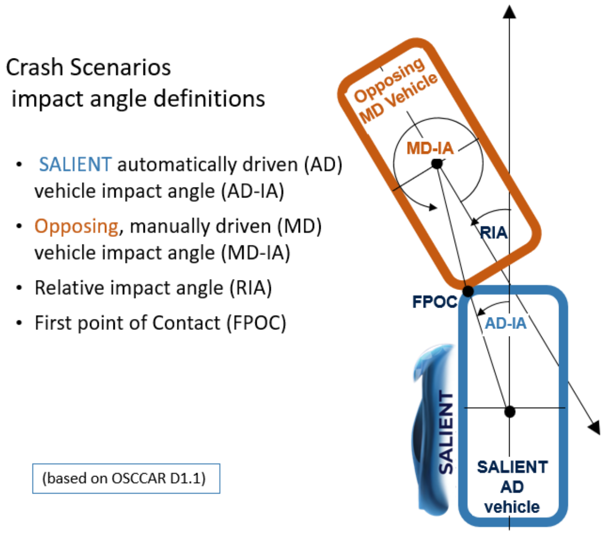

Figure 18 - Crash configuration impact angles

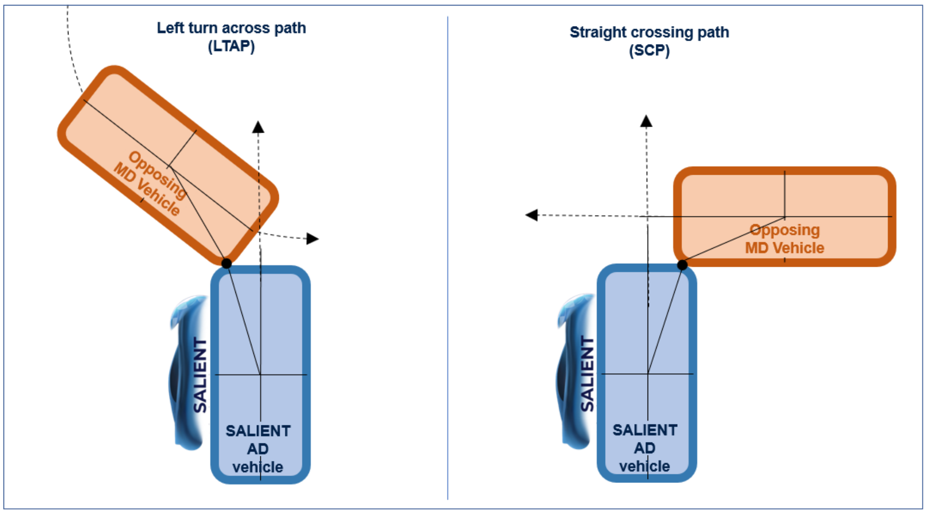

Figure 19 - Critical scenarios for AD vehicles

The following parameters are to be determined and documented in the following SALIENT specific crash tests:

- Frontal impact with different angles and speeds;
- Frontal impacts with vehicle-to-vehicle contact points;
- Side impact with different angles and speeds;
- Side impacts with vehicle-to-vehicle contact points;
- Rear impact with different angles and speeds;
- Rear impacts with vehicle-to-vehicle contact points.

To enable crash compatibility, between smaller and larger vehicles, SALIENT proposes to develop a suitable and potentially adaptive FES concept. Relevant scenarios in this respect are all current and future accident scenarios if mixed traffic is to be expected. That means the opposing vehicle of the SALIENT AV can be taken from the complete pool of vehicles in the field. Its size, weight and, especially relevant for SALIENT, its frontal crash structure, is statistically directly proportional to the respective vehicle fleet.

Statistically, vehicles got significantly heavier and bigger in the last ~30 years, providing hazards, especially for all smaller and lighter vehicles. SALIENT scenarios therefore will focus on a large variety of possible opponent vehicles, differing in size, height, and mass, and reflect the different internal load bearing, crash energy absorbing structures of such vehicles.

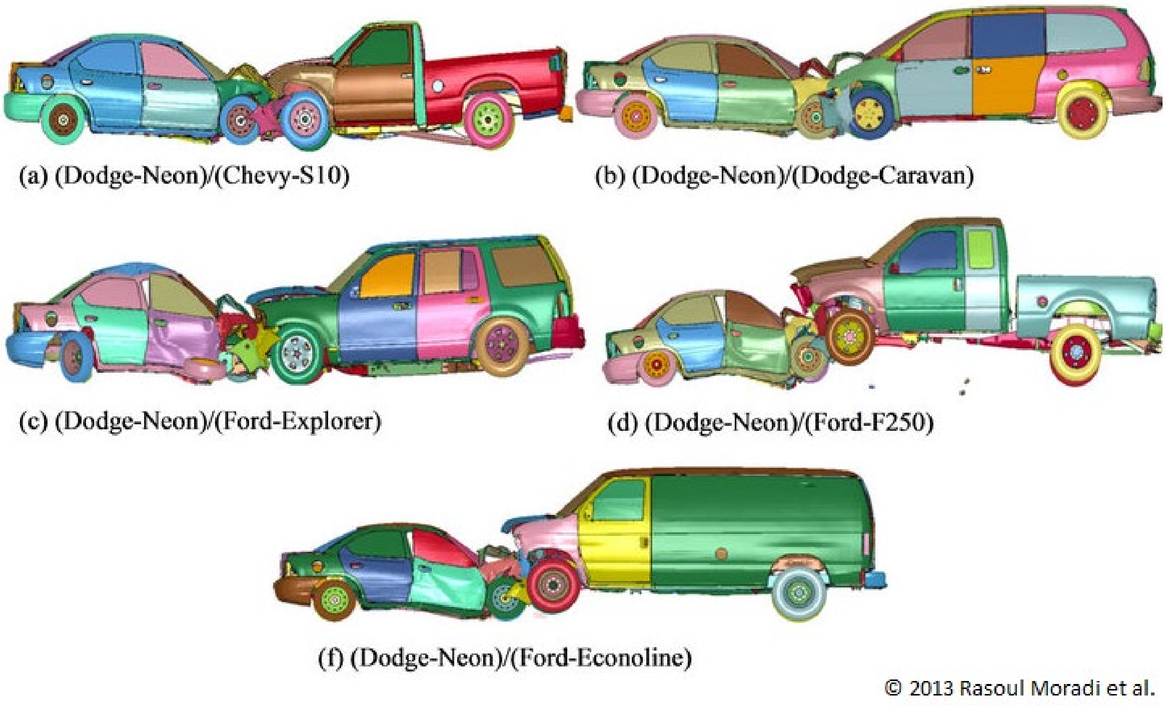

Figure 20 - Virtual crash simulations of passenger car against different LTV – an exemplary illustration of the crash compatibility (46)

Small vehicles may be considered any passenger car with a total mass of up to 1500 kg, a large vehicle is a SUV, MPV type of vehicle with a mass of up to 2000 kg and a very large vehicle is a heavy commercial vehicle with a mass of up to 4000 kg.

8. KPIS & MEASUREMENT OF SUCCESS

The SALIENT Grant Agreement calls for the achievement of Key Performance Indicators (KPIs). Objective 1 is to achieve the full understanding of technical requirements and future accident scenarios involving light vehicles. SALIENT will examine how the introduction of driving automation affects traffic safety in mixed traffic scenarios. It will consider the influence of automation on accident topology, such as new impact angles and speeds, crash configurations, and compatibility issues related to the mass and geometry of vehicles. Additionally, it will characterize mixed traffic flows between semi-automated and automated vehicles, as well as manually driven vehicles, to understand the relationship between driving strategies and traffic dynamics.

The Key Performance Indicator associated with this Objective is KPI1: A comprehensive set of new crash scenarios defining the impact parameters (e.g., speed, angle, energy, geometry); Identification of SAV and SAV traffic penetration rates (and accompanying roll-out strategies) with the potential to better predict future traffic accidents. The success of KPI1 can be measured by assessing how well SALIENT's proposed crash scenarios and roll-out strategies are able to predict future traffic accident, see Table 8.

Table 8 - Crash Scenarios relevant for SALIENT

Crash Scenario	Consideration
Rear impact	• Motorway rear end and inner-city rear and at crossings; • Due to unexpected braking.
Side impact at crossing	• Critical for occupant safety AV; • Not an AV specific issue.
Frontal impact	• Critical for occupant safety of AV.

This can be evaluated by comparing the results of simulations using SALIENT's proposed crash scenarios and roll-out strategies to real-world traffic accident data and observing how closely the two matches. If SALIENT's proposed crash scenarios and roll-out strategies can accurately predict future traffic accidents, then KPI1 can be considered as attained by the work conveyed in this report.

Other collision scenarios and vehicle compatibility are proposed in previous sections to test and simulate in SALIENT project and a data improvement is proposed for future accident studies, based on the limitations of the OSCCAR and Safe-UP projects, as shown in Table 9.

Table 9 - General limitations detected in previous projects

Limitation	Mitigation action proposed
The High Data Requirements for Simulations	• Cloud computing-based storage solutions to store the data required for the simulations; • Machine learning and AI algorithms to reduce the amount of data needed for the simulations.
Data Overlap between Real-World and simulations	• Establish clear guidelines for data collection; • Automating the data collection processes, while avoiding third parties.

9. CONCLUSIONS

The research presented in this document draws key conclusions from consulting available sources regarding collisions in mixed traffic from 2000-2017. This analysis provides a basis for the further development of a safety solution designed to be applicable to the current context and adapted to the mixed traffic scenario in general while meeting the requirements of circular economy, eco-design, and environmental friendliness.

The results obtained in D1.1 through the analysis of different database sources show that, in general, rear-end collisions are more frequent and differ according to weight and angle, which demonstrates the need to consider the different weights of light and heavy vehicles to increase crash compatibility.

From the literature review, it can be observed that the result of simulations presents the ability of active safety systems, standardised by European regulations, to mitigate or avoid some of the crashes in the GIDAS database by 26-27%. Nevertheless, the simulation approach used by the SAFE-UP project on the same database shows a different result, with a special emphasis on rear-end collisions between heavy goods vehicles and light passenger cars, which suggest that additional countermeasures for light-weight vehicles should be taken into consideration.

In general, the research presented allows the understanding of certain aspects of the context of mixed traffic which are relevant in the evaluation of safety solutions, in the design of restraint systems, in the study of the dynamic behaviour of autonomous and electric vehicles in collisions and as a basis for a better understanding of the effects of their implementation in the context of mixed traffic. Moreover, D1.1 lays the foundations for the project to design a safety solution that considers all the aspects discussed in the research and can work in different contexts and scenarios.

The results of this deliverable will serve as a basis for the transition of safety evolution from current user-driven vehicles to SAVs and AVs in mixed traffic, to maximise compatibility between vehicles to minimise human injuries in accidents. For this project a top-down and bottom-up approach has been applied, focusing mainly on German, Swedish and US data, due to their relevance and the variety of scenarios. Other EU projects, such as OSCCAR and SAFE-UP, have also been consulted, although their approach and data biases are different. Predictive traffic scenarios, SAV/AV mixes, and conditions, as well as conflicts and resolutions, were identified. An important aspect of the work presented in this D1.1 is the application of a common minimum criterion and the comparison of data from different databases, which, although not uniform, are sufficiently broad-based to be comparable and to extrapolate conclusions, as seen in the coordinates of the different relative speeds between vehicles in the case of yaw angle, which can only be obtained from one of the sources.

The limitations of the study stem from the lack of homogeneity of the data from the different sources and the different adoption of measures for the implementation of autonomous driving and electric vehicles, creating dynamic scenarios over time, different from what is contained in the databases so far.

Overall, the work presented in D1.1 helps to provide a better understanding of the current mixed traffic context, based on knowledge and data collected from a plethora of different sources. This will enable the development of safer vehicles in mixed traffic scenarios and the design of optimal front-end safety systems.

10. BIBLIOGRAPHY

1. Das Virtuelle Fahrzeug Forschungsgesellschaft. Future Occupant Safety for Crashes in Cars. *TRIMIS.* [Online] June 1, 2018. https://trimis.ec.europa.eu/project/future-occupant-safety-crashes-cars.

2. Verkehrsunfallforschung an der TU Dresden GmbH. German In-Depth Accident Study. *GIDAS.* [Online] October 6, 2022. https://www.gidas.org/start-en.html.

3. Chalmers University. Initiative For The Global Harmonisation Of Accident Data. *IGLAD.* [Online] October 6, 2022. http://www.iglad.net/.

4. Transport Styrelsen. Strada. *Transport Styrelsen.* [Online] October 6, 2022. https://www.transportstyrelsen.se/sv/vagtrafik/statistik/olycksstatistik/om-strada/.

5. DMV. Autonomous Vehicle Collision Reports. *DMV.* [Online] October 6, 2022. https://www.dmv.ca.gov/portal/es/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-collision-reports/.

6. Project for the establishment of generally accepted quality criteria, tools and methods as well as scenarios and situations for the realease of highly-automated driving functions. *TRIMIS.* [Online] January 1, 2016. https://trimis.ec.europa.eu/project/project-establishment-generally-accepted-quality-criteria-tools-and-methods-well-scenarios.

7. Volkswagen Group. AdaptIVe - Automated Driving Applications and Technologies for Intelligent Vehicles. *TRIMIS.* [Online] June 1, 2017. https://trimis.ec.europa.eu/project/adaptive-automated-driving-applications-and-technologies-intelligent-vehicles.

8. Idiada. Assessment methodologies for forward looking Integrated Pedestrian and further extension to Cyclists Safety Systems. *TRIMIS.* [Online] September 1, 2011. https://trimis.ec.europa.eu/project/assessment-methodologies-forward-looking-integrated-pedestrian-and-further-extension.

9. Ford Forschungszentrum Aachen. interactIVe. *TRIMIS.* [Online] January 1, 2010. https://trimis.ec.europa.eu/project/interactive.

10. Dobberstein, J, Lich, T and Schmidt, D. *D1.1 Accident data analysis - remaining accidents and crash configurations of automated vehicles in mixed traffic.* s.l. : OSCCAR - Future Occupant Safety for Crashes in Cars, 2018.

11. Department for Transport. Road Safety Data. *Data.Gov.Uk.* [Online] October 6, 2022. https://www.data.gov.uk/dataset/cb7ae6f0-4be6-4935-9277-47e5ce24a11f/road-safety-data.

12. Road Safety GB. The RAIDS database. *roadsafety.network.* [Online] October 6, 2022. https://roadsafety.network/kb/raids/.

13. Wössner, U. *openPASS framework for integrated.* USTUTT/HLRS. Stuttgart, Germany : OSCCAR Project, 2022.

14. Dobberstein, J, et al. *Future collision type matrix.* Several. s.l. : OSCCAR Project, 2021.

15. Östling, M, Jeppsson, H and Lubbe, N. *Predicting crash configurations in passenger car to passenger car crashes to guide the development of future passenger car safety.* Vårgårda : Autoliv, 2019. pp. 11-13.

16. Bálint, A, et al. *Use case definitions and inititial safety-critical scenarios.* s.l. : SAFE-UP Project, 2022.

17. *Safety of autonomous vehicles.* Wang, J, et al. s.l. : Journal of advanced transportation, 2020, Journal of advanced transportation.

18. Sinha, A, et al. Dataset. 1 *Crash and disengagement data of autonomous vehicles on public roads in California.* 2021. Vol. 8, pp. 1-10.

19. *A crash injury model involving autonomous vehicle: Investigating of crash and disengagement reports.* Sinha, A, et al. 14, 2021, Sustainability, Vol. 13, p. 7938.

20. *Examining accident reports involving autonomous vehicles in California.* Favarò, F M, et al. 9, 2017, PLoS one, Vol. 12. e0184952.

21. *What can we learn from autonomous vehicle collision data on crash severity? A cost-sensitive CART approach.* Siying, Z and Qiang, M. 174, 2022, Accident Analysis & Prevention, p. 106769.

22. *Comparison of automated vehicle struck-from-behind crash rates with national rates using naturalistic data.* Goodall, N J. 154, 2021, Accident Analysis & Prevention, p. 106056.

23. *Automated vehicle collisions in California: Applying Bayesian latent class model.* Das, S, Dutta, A and Tsapakis, I. 4, 2020, IATSS Research, Vol. 44, pp. 300-308.

24. *Exploratory investigation of disengagements and crashes in autonomous vehicles under mixed traffic: An endogenous switching regime framework.* Khattak, Z H, Fontaine, M D and Smith, B L. 12, 2020, IEEE Transactions on intelligent transport systems, Vol. 22, pp. 7485-7495.

25. Agence Nationale de la Research (ANR). *Vehicle Occupant Infrastructure Road User Safety Study.* s.l. : ANR, 2014.

26. *Estimated crash avoidance with the hypothetical introduction of automated vehicles: a simulation based on experts' assessment from French in-depth data.* Pilet, C, Vernet, C and Martin, J L. 1, 2021, European Transport Research Review, Vol. 13, pp. 1-8.

27. *Intelligent selection of two-vehicle collision conditions to minimize occupant injuries.* Yang, S, Wang, Q and Zhou, Q. 2022. IRCOBI Conference.

28. Scanlon, J M, et al. *Collision avoidance effectiveness of an automated driving system using a human driver behaviour reference model in reconstructed fata collisions.* s.l. : Waymo LLC, 2022.

29. United States Environmental Protection Agenca (EPA). *EPA Automotive Trends Report.* s.l. : EPA, 2021.

30. ACEA. New passenger cars by segment in the EU. May 18, 2023.

31. Høye, A. *Trafikksikkerhetseffekter av bilenes kollisjonssikkerhet, vekt og kompatibilitet.* s.l. : TØI Rapport, 2017. p. 1580.

32. Mercedes-Benz Group. AffordabLe LIghtweight Automobiles AlliaNCE. *CORDIS.* [Online] August 23, 2022. [Cited: October 6, 2022.] https://cordis.europa.eu/project/id/723893.

33. *The impact of reducing car weight on global emissions: the future fleet in Great Britain.* Serrenho, A C, Norman, J B and Allwood, J M. 2095, 2021, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, Vol. 375, p. 20160364.

34. ACEA. Fuel types of new passenger cars in the EU. May 18, 2023.

35. European Council. Fit for 55. *Consilium Europa.* [Online] [Cited: October 6, 2022.] https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/.

36. *Effect of electric battery mass distribution on electric vehicle movement safety.* Wang, P. 2020. Vibroengineering Procedia. Vol. 33, pp. 78-83.

37. Tesla. *Model 3 achieves the lowest probability of injury of any vehicle ever tested by NHTSA.* s.l. : Tesla, 2018.

38. *Exploration of the characteristics and trends of electric vehicle crashes: a case study in Norway.* Liu, C, Zhao, L and Lu, C. 1, 2022, European Transport Research Review, Vol. 14, pp. 1-11.

39. *The safety of autonomous vehicles: Lessons from philosophy of science.* Hicks, D J. 1, 2018, IEEE Technology and Society Magazine, Vol. 37, pp. 67-69.

40. *Determination of accident scenarios via freely avialable accident databases.* Bauder, M, et al. s.l. : De Gruyter, 2022, Open Engineering, Vol. 12, pp. 453-467.

41. Ayuntamiento de Madrid. Open data platform of vehicle collisions in Madrid.

42. Etalab (French Government). Open data platform of vehicle collisions in France.

43. European Union. L 254/77. *Regulation No. 94 - Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision.* s.l. : Offical Journal of the European Union, September 20, 2012.

44. EuroNCAP. MPDB frontal impact testing procotol. November 2021.

45. —. Mobile progressive deformable barrier. [Online] 2020. [Cited: December 13, 2022.] https://www.euroncap.com/en/vehicle-safety/the-ratings-explained/adult-occupant-protection/frontal-impact/mobile-progressive-deformable-barrier/.

46. *Use of finite element analysis for the prediction of driver fatality ratio based on vehicle intrusion ratio in head-on collisions.* Moradi, R, Setpally, R and Lankarani, H. 5A, 2013, Applied Mathematics, Vol. 4, pp. 56-63.

47. Idiada. proactive SAFEty systems and tools for a constantly UPgrading road environment. *TRIMIS.* [Online] June 1, 2020. https://trimis.ec.europa.eu/project/proactive-safety-systems-and-tools-constantly-upgrading-road-environment.

48. Pava. EuroNCAP frontal impact. April 12, 2012.