D7.5 POSITION PAPER – NEW ROAD SAFETY CHALLENGES IN FUTURE MOBILITY

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Executive summary

The aim of SAFE-UP is to improve traffic safety by developing tools and innovative methods that proactively address the safety challenges of future mobility systems. This deliverable, which is the final report of the work performed in SAFE-UP T7.2 (Exploitation and roadmapping), aims to summarise the main research and development activities carried out during the project.

The main goal of the deliverable is to facilitate the awareness of our project outcomes to the general public, but specially to the different EU networks contributing and supporting the improvement of road safety (EUCAR, POLIS, CLEPA, EARPA, ECTRI, ERTICO, Euro NCAP), providing input to the EU on the vision of safety systems in future mobility.

This deliverable covers the different technologies developed in safety, namely:

- Advanced simulation models (WP2).
- Study and assessment of new seating positions in highly automated vehicles (Demo 1).
- Interaction between VRUs and vehicles under adverse weather conditions (Demo 2).
- Integrating advanced intervention functions to avoid critical events (Demo 3).
- V2X communications to enable timely warning provisions (Demo 4).

For each technology, a brief description of the developments as well as the boundary conditions is described. A summarised version of the tests and the impact assessment results carried out to assess the benefit of each technology is also included. For detailed information, check the deliverables of the respective developments on the SAFE-UP website.

Finally, a collection of lessons learned and future research directions are included for each technology, aiming at defining upcoming R&D collaborations to build upon the activities and outputs SAFE-UP has achieved.

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List of abbreviations

Abbreviation	Meaning
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AES	Autonomous Emergency Steering
ATD	Anthropometric Test Devices
AV	Autonomous Vehicles
C2B	Car-to-bicyclist
C2P	Car-to-pedestrian
CA	Consortium Agreement
CAV	Connected Automated Vehicles
D	Deliverable
EC	European Commission
FoV	Field of View
GA	Grant Agreement
KSI	Killed or Seriously Injured
OEM	Original Equipment Manufacturer
OMS	Occupant Monitoring System
PM	Person Month
PTW	Powered Two-Wheeler
R&D	Research and Development
RSU	Road Side Unit
SC	Steering Committee
SOTA	State-of-the-Art
T	Task
V2I	Vehicle-to-infrastructure
V2X	Vehicle-to-everything
VRU	Vulnerable road user
WP	Work Package

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1. Initial observed challenges

1.1 Road safety: our motivation upon kick-off (in 2020)

In 2020, the European Commission (European Commission, 2020) published a report announcing that the 50% reduction target in road fatalities for the 2010-2020 period was not going to be met with one year to go. Fatalities on the road have been decreasing during the past few years, but not fast enough to meet the initial expectation. The graph below shows the total fatalities in Europe over the period 2011-2021. The trend is clearly downwards, but apart for the first two years (2011, 2012) and the exception of 2020 – due to the pandemic, the decrease percentage averages around 1,5% a year which is clearly not enough given the ambitions.

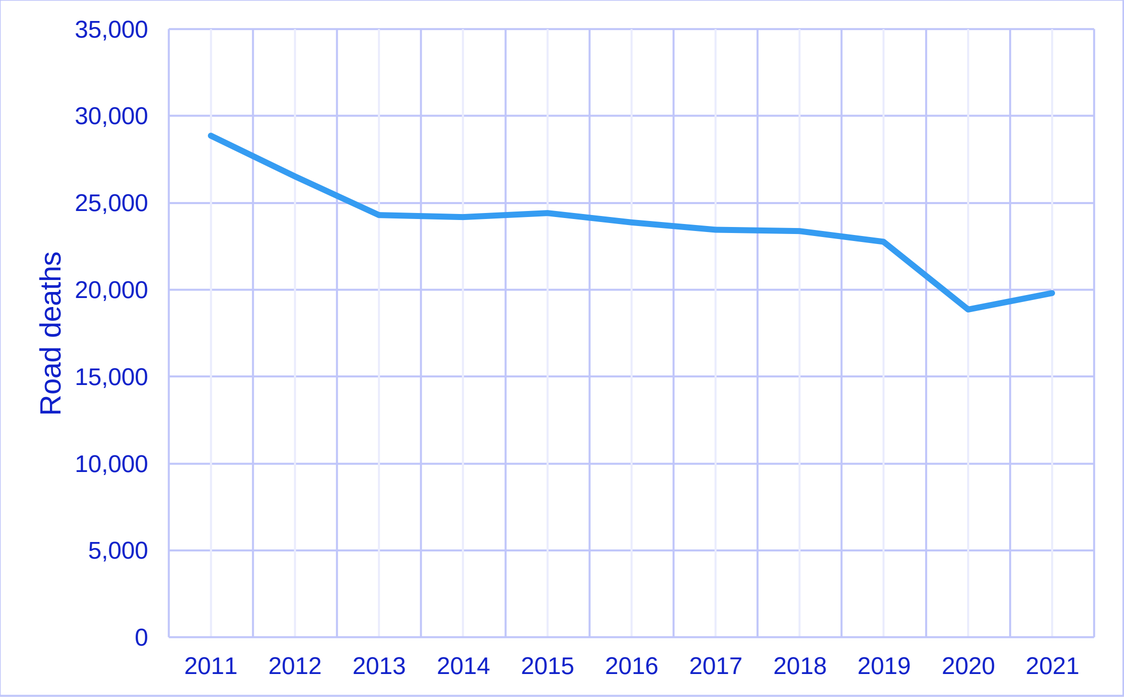

Figure 1: Road deaths between 2011 and 2021 in EU (Source: ETSC, 2021)

In addition to the slow decrease in road fatalities, a specific group of road users has seen even worse results for urban scenarios. Indeed, in SAFE-UP's deliverable 2.6, it was shown that VRU are especially at risks as more than half of the estimated urban fatalities in 2018 pertain to that group. For instance, the decrease in road deaths for cyclists (15%) represent only half the decrease in road fatalities overall (30%) (Eurostat, 2021).

The SAFE-UP project started in June 2020 with the main objective of developing and validating different groups of safety systems and technologies that would contribute to at least a 10% reduction in road traffic casualties.

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1.2 Road safety: Key priorities defined by EU networks

The main relevant networks working on road safety and CCAM in Europe have been publishing key roadmaps and papers aligned with the EU "Vision Zero" goal and how to achieve zero fatalities by 2050. For instance, EUCAR highlighted the importance for safe connected vehicles, defining safe vehicle as one that prioritize passenger safety, prevent accidents, and facilitate safe communication with drivers. For CLEPA, safety should be a top priority for automotive suppliers, endorsing the UN 2021-2030 decade of action for road safety - clearly stating that road death should be decreased by 50% by 2030. On the other hand, ERTRAC argues on the substantial differences on road fatalities between member states, which are hard to assess and understand, concluding that the progress on road death decrease is not fast enough.

A wide variety of safety systems and technologies aiming at assisting drivers are already available in the market, with many others being the focus of R&D, such as the V2I or V2X applications (CLEPA, 2021). ERTICO's roadmap for 2035 highlights the importance of assessing the impact of automated connected vehicle functions with dedicated demonstrations (ERTICO, 2022). For instance, the Intelligent Speed Assistance, which will become mandatory, should contribute to decrease fatalities by 30% and crash by 20% (POLIS, 2023). Euro NCAP is also going one step beyond, promoting to include rewards for those vehicles that will include such technologies (Euro NCAP, 2022).

Another dimension of safety efforts is to ensure that highly automated vehicles are being safely tested and evaluated: EUCAR, CLEPA, and Euro NCAP agree on the importance of developing virtual testing and tools to assess those driverless technologies. Euro NCAP identified four distinctive stages of a crash that need to be assessed: "safe driving, crash avoidance, crash protection and post-crash safety". ERTRAC and ECTRI voice their concerns about automated driving in mixed traffic for road safety as studies have revealed that drivers tend to excessively rely on automation systems to handle hazardous situations. They also have a tendency to engage in secondary tasks, even after being instructed to monitor the system. Furthermore, drivers exhibit a slow response to automation failures.

Finally, regarding VRUs (Vulnerable Road Users), it is important to improve the safety systems, accommodating them to increase their safety: while they represent 68% of fatalities in cities the decline in fatalities among VRUs has been considerably less (POLIS, 2020). Riders and pedestrians face a greater risk due to the limited safety solutions available to them compared to other road users (ERTRAC, 2019). The protection of VRUs has become a priority for most associations: the most effective safety measures should focus on improving infrastructure, modifying road user behaviour and preventing single-vehicle crashes of PTW-riders. Specifically, in terms of PTW (Powered Two-Wheelers), FEMA argues that current policies are not properly designed for motorcyclists, and should be updated as the majority of motorcycle accidents are not caused by the motorcyclists themselves (FEMA, 2020).

2. The SAFE-UP contributions

In this chapter, we delve into R&D performed in SAFE-UP, and the different focused topics within road safety. First and foremost, we explore the cutting-edge simulation models developed in WP2. Then we'll focus on the different demonstrators:

- Demo 1, where the assessment of passive safety systems in reclined positions has been conducted.
- Active safety systems developed in WP3, including Demo 2, which explores the interaction between vehicles and vulnerable road users (VRUs) under adverse weather conditions.
- Demo 3, focusing on advanced intervention functions aimed at averting critical events,
- and finally Demo 4, where the utilization of Vehicle-to-Everything (V2X) communication technology is harnessed to enhance safety.

Through detailed discussions on the work conducted, the tests performed, the primary findings, and the invaluable lessons learned, this chapter aims to provide a comprehensive understanding of the advancements achieved in advanced safety systems and simulation models, while paving the way for future research directions in this crucial domain.

2.1 Advanced simulation models

The advancements in autonomous vehicles (AVs) have raised numerous questions regarding their impact on road safety. In an attempt to understand this impact, SAFE-UP's WP2 was developed, utilizing newly developed behavioural simulation models of various road users (pedestrian, cyclist, PTW-rider, human-driven vehicle, automated vehicle) integrated in Aimsun Next. Throughout the project, several valuable lessons were learned, shedding light on the complexities and challenges associated with this field of research.

Firstly, it became evident that the state of the art in simulation models falls short when it comes to identifying "novel" critical situations. While existing models provide a good foundation, they often fail to capture unique scenarios that may arise in real-world conditions. This limitation underscores the need for further advancements and innovation in simulation modelling techniques.

A significant portion of the project was dedicated to modelling human driving, cyclist and PTW riding, and pedestrian behaviour. It became apparent that this aspect requires substantial investment in terms of research and resources. Developing accurate models that mimic human decision-making and response patterns is a highly intricate task, demanding continuous refinement and improvement.

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The project also highlighted the fact that simulation-based approaches form the basis for understanding the potential outcomes of AV deployment. By creating digital replicas of real-world environments, researchers can effectively simulate various scenarios and evaluate their implications. However, to achieve a digital "crystal ball" capable of predicting the future accurately, better data sources are imperative. This includes comprehensive information such as traffic-level data, trajectories, infrastructure maps, and accident data specific to the location under analysis.

Moreover, the project emphasized the need for computationally light-weight AV simulation models that can be easily scaled up. As the complexity of simulations increases, it becomes crucial to develop efficient models that allow for extensive analysis. This requirement ensures that the project's findings can be applied to a broader range of scenarios and locations, facilitating more comprehensive research.

A critical decision in the project was determining which type of AVs to use as the basis for analysis. Should the focus be on AVs experiencing growing pains or mature ones? This question underscores the importance of considering the various stages of AV development when conducting simulations. Understanding the challenges faced by AVs in their early stages versus their more mature counterparts can provide valuable insights into their impact on road safety.

Furthermore, it was observed that micro-simulators, which are agent-based simulators, are well-suited for simulating individual road users and their interactions. However, utilizing micro-simulators for causal inference and predicting the future necessitates the development of a more stringent methodology than what is currently available. Ensuring the reliability and accuracy of predictions requires careful consideration of experimental design, data collection, and analysis techniques.

In conclusion, WP2 yielded several valuable lessons. The limitations of existing simulation models, the complexity of modelling human behaviour, and the crucial role of simulation-based approaches were among the key takeaways. The need for better data sources, computationally light-weight AV simulation models, and a well-defined methodology for causal inference highlighted the challenges faced in this field. By acknowledging and addressing these lessons, researchers can continue to enhance our understanding of the impact of AVs on road safety, leading to safer and more efficient transportation systems in the future.

2.2 Demo 1 – New seating positions for highly automated vehicles

The initial challenge motivating Demo 1 lies in the fact that traditional restraint systems, such as seat belts and airbags, are designed to protect occupants in an upright seating position. The introduction of reclined seating positions thanks to higher automation levels poses a risk to occupant safety, as the occupants' bodies are positioned differently than in traditional seating positions. In addition, these new seating positions require a new approach to

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occupant protection, as the seat belt and airbag systems will need to be redesigned to adapt to these new seating positions.

To address these challenges, SAFE-UP developed a new occupant monitoring system (OMS) that can detect the position and posture of passengers in these new seating configurations. OMS can collect data on the occupant's body position, size, and weight, which will allow the restraint systems to adjust to the specific occupant's needs, ensuring maximum safety and comfort. This type of technology can improve the effectiveness of restraint systems and reduce the risk of injuries in the event of a crash.

Another challenge that needs to be considered is the development of new testing procedures to evaluate the safety of these new seating positions. Currently, most testing procedures are designed to evaluate vehicles with traditional seating configurations. New test procedures must be developed to evaluate the safety of vehicles with non-traditional seating positions.

Occupant Monitoring System (OMS)

The Occupant Monitoring System’s performance was evaluated with two metrics: the detection rate for head key points and for torso head points. The detection rate indicates the share of detected frames from all the frames collected. This was studied on a number of different anthropometries (including 10 female subjects and 6 male subjects), seat displacement and seat back rest angles, resulting in a combination of many test cases, covering the most common body movements inside the vehicle, including occlusion as well, caused by objects such as smartphones or newspaper (check D5.4 for more details). On average, the detection rate is 92,52% for head key points and 97,5% for torso key points.

For the Occupant Monitoring System, the data collection and results can guide future developments for better occupant detection models. The main limiting factor for the system is the body occlusions that can be caused by the occupant’s posture or by objects. Additionally, the methodology for collecting data with representative occupant anthropometries (weight, height, and gender) along with the test cases presented here can be used as a basis in future projects to help reduce the bias of the occupant detection function.

Occupant protection

On the other hand, novel seating positions, both for a female model and a male model, were studied. Passive safety was evaluated with a state-of-the-art (SOTA) restraint system and an improved one, adapting the seat belt, airbag and steering column with the aim of minimizing the risk for occupants in new positions (check D4.4 for more details).

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Figure 2: Studied positions for Demo 1

In order to know how many of the EU accidents would Demo 1 adapted restraint systems can be covering, it was assumed that simulations (with a male or female occupant) in upright seating position with the SOTA restraint system and without any deployment of any AEB system, represents the current crash environment, in terms of risk of KSI injuries in head-on crashes in EU. To scale to a representative number of head-on crashes with injuries on EU level, the CARE database was filtered for head-on crashes in year 2016 for EU-27 countries. The number of this type of crashes was 8655 crashes, of which 1106 were KSI. Conservatively, we assume that this is also the number of occupant killed or seriously injured.

For each one of the studied cases, the risk of death or severe injury was studied by means of virtual simulations.

When assessing the safety benefit of an AEB system, overall, 477 KSI will be reduced at the EU level if all vehicles have it (with SOTA occupant protection systems). This means a reduction of 43% in the number of killed or seriously injured (KSI) occupants.

As a continuation, the improved restraint system developed in SAFE-UP was studied. Compared to current SOTA occupant protection *with AEB*, the SAFE-UP improved restraint system will reduce an additional 190 occupants from being KSI i.e., a 30% improvement over current systems with AEB and a 60% improvement over current systems without AEB.

With the reclined positions, if occupants were traveling reclined and involved in a frontal crash and the restraint system used was the SOTA, even with AEB, they would have a higher KSI rate than when sitting upright. However, the SAFE-UP improved occupant protection system reduced number of KSI-occupants by 16%. If all vehicles were equipped with the improved SAEF-UP system and all occupants were reclined, the new system would save 208 KSI annually at the EU level. However, note that realistically, not all occupants will travel reclined. Interestingly, the increased risk due to reclining brings the injury rate up to near current levels without AEB. The SAFE-UP improved occupant protection produces better results than current without AEB, but worse than current systems with AEB and no recline.

All in all, it can be said that with optimized configuration of the restraint system, an improvement was observed by getting safer values in practically all body regions.

As for limitations, the main aspect is the pre-crash phase in the AEB braking cases. This is accounted for by selecting a static leaning forward position based on the volunteer study

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conducted by Virtual Vehicle. Consequently, predicted postures as a sum of head and torso angles were selected rather than dynamically simulating the pre-crash phase. However, it is currently not reasonable to run pre-crash simulations with the simulation model since it does not include neck muscle activation, which results in unrealistic head movement. This is an aspect that could be looked at in more detail in the future.

Considering that in the automotive market the presence of HAV, together with their new interior designs, is becoming more and more important, it is necessary to have improved Anthropometric Test Devices (ATDs) capable of being tested in reclined positions, without compromising its bio-fidelity. Further analysis with other adapted ATDs would serve to complement and compare results.

Finally, only one reclined seating position was studied (45º). The range should be widened and studied in future research projects.

2.3 Demo 2 – Interaction between vehicles and VRUs under adverse weather conditions

Advanced driver assistance systems including the perception systems are influenced by adverse weather conditions such as rain or fog. These challenges include:

- Reduced visibility: Fog and rain reduce visibility, which can make it difficult for sensors such as cameras, lidars, and radars to detect obstacles accurately. This can lead to false positives and false negatives, which can affect the vehicle's ability to make decisions and respond to changing road conditions.
- Sensor interference: Rain and fog can interfere with the functioning of sensors. Rain droplets can create noise in lidar and radar signals, which can make it challenging to distinguish between objects and their distances accurately. Similarly, fog can cause light scattering, which can affect the accuracy of cameras and lidars.
- Changing road conditions: Adverse weather conditions can cause changes in road conditions, such as wet and slippery roads. This can affect the vehicle's ability to maintain traction, which can impact the performance of the vehicle's control systems.

To overcome these challenges, SAFE-UP researchers have been working on quantifying the change in performance of detection systems under different adverse weather conditions with the main focus on different precipitation ranges.

To assess the detection performance of different sensor types under adverse weather conditions, two static measurement campaigns have been conducted with two different sensor sets. The experiments aim to analyse the performance of the system in detecting and avoiding collisions with vulnerable road users in real-world scenarios under varying weather conditions. The study results can provide insights into the current limitations of the

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detection system and help improve the safety performance of advanced driver assistance systems in adverse weather conditions.

The Demo 2 assessment simulations under adverse weather conditions investigate and compare in the defined car-to-pedestrian (C2P) and car-to-bicyclist (C2B) use cases for adverse weather conditions (Deliverable D2.6) the hypothetical safety performance of an generic automatic emergency braking (AEB) based on two different cameras. The conducted simulation focuses on the two different cameras with different field of views (FoVs) as the precipitation influence was found out to be higher for the investigated cameras than radars. Furthermore, the tests account for different precipitation rates, including light (1.7 mm/h), medium (3.6 mm/h), and strong (5.7 mm/h).

The evaluation of the AEB based on camera detection revealed promising results in avoiding collisions under adverse weather conditions. Depending on which camera was included in simulation with the respective field of view (FoV), between 71% and 93% of collisions could be avoided. However, there were four categories of collisions that could not be avoided. These included collisions at speeds higher than 60 km/h, obstructed views where the time to brake after object detection is insufficient, unobstructed views where the camera performance due to the FOV shape is crucial, and cases where there is an early detection of the object but a too late AEB triggering for the existing boundary conditions like friction coefficient.

To assess the safety benefits of the AEB based on camera detection, the probabilities of pedestrians and cyclists being killed or severely injured were analysed. The results showed that the probabilities of VRUs being killed or severely injured were mostly lower in the simulations with camera MC2 than with camera MC1 (see Figure 3). The performance of camera MC2, which has a wider and further view mode, was found to be higher, as more collisions could be avoided, and the probabilities of VRUs being killed or severely injured were partly lower.

Overall, the evaluation of the AEB based on camera detection suggest that ADAS functions can significantly improve the safety also under adverse weather conditions.. However, there are still limitations that need to be addressed, such as the need for AEB systems for higher speeds and the importance of camera performance in unobstructed views. Further research and development in these areas could help to further improve the safety of vehicles with ADAS under adverse weather conditions.

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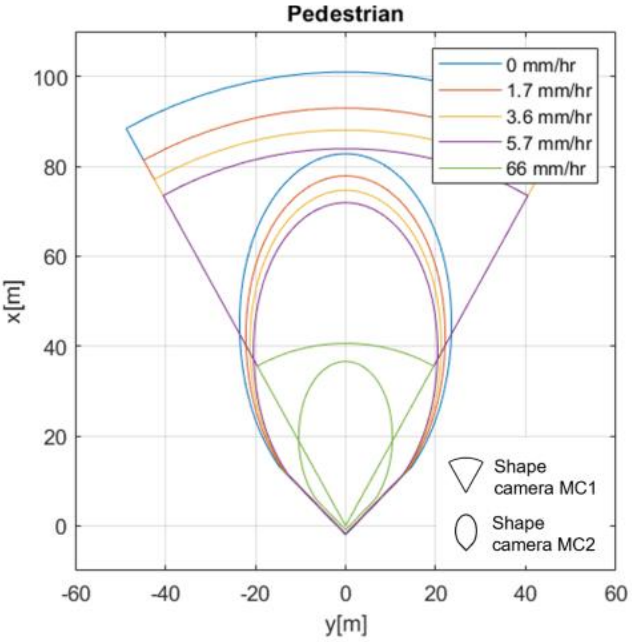

Figure 3: Variation of the FOV for each one of the two camera modules under different precipitation levels

The evaluation of the AEB based on camera detection has provided valuable insights into improving the safety of vehicles with ADAS under adverse weather conditions. However, there are still several aspects that need to be explored in future research directions.

First, the evaluation was mostly conducted in a static testing environment. Some dynamic cases were tested but not extensively, due to time and test hall constraints. Future research could validate the results in more dynamic testing conditions, where the vehicle is moving. This would provide a more realistic scenario for testing the performance of the AEB and camera detection systems under adverse weather conditions.

Second, the limitations of the test hall with the associated rain system should be further investigated by focusing on developing rain generation systems which cover minimum the area of the scenarios described in D5.7 for a time of at least 4s and which can produce homogeneous rain with lower intensities. Also, a comparison between in-hall and outside tests under rainy conditions would be beneficial to assess if the reflections inside the hall decrease the detection performance.

Finally, it has to be analysed how the friction coefficient can be reliably estimated by the vehicle, so it can adapt its AEB systems in order to improve emergency interventions.

Overall, these future research directions could help to further improve the safety of vehicles with ADAS under adverse weather conditions, and guide the development of more robust and reliable sensor technologies.

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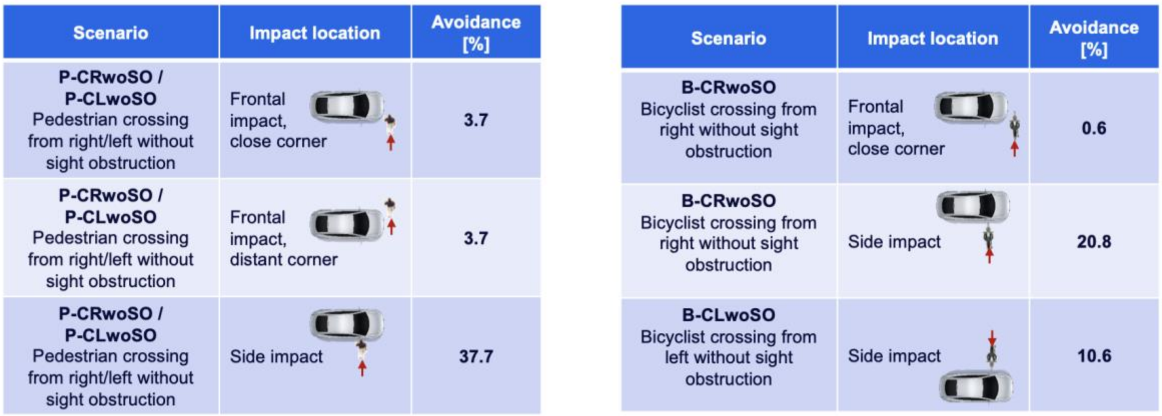
2.4 Demo 3 – Integrating advanced intervention functions to avoid critical events

Demo 3 tested the autonomous emergency steering (AES) as an active safety system to prevent collisions with vulnerable road users (VRUs). It has been tested both in real world settings at IDIADA's facilities in Spain and in a simulation platform. The main objective of the physical test campaign was to produce statistics on accident-avoidance rates in real-world conditions using a small number of test scenarios but with a high number of repetitions per scenario. This high number of repetitions was necessary because of the variability in the detection performance of VRUs, resulting in different timing triggers for the avoidance system and ultimately, different outcomes in accident avoidance.

To determine what scenarios are appropriate for field testing, a simulative analysis to quantify a theoretical field of effects was performed. The goal of the simulation was to identify what scenarios that can be addressed with the AES cannot be assessed by the AEB, so that those scenarios can be tested physically. Four scenarios were selected with frontal and side impact of pedestrian crossing right with or without sight obstruction and with different distance of the sight obstruction.

However, it needs to be said that, in the end, the results of the side collisions were not included because there were not enough runs to generate significant results. They were not analysed in simulation either, as it is expected that their occurrence probability in real world accidents is rather low.

The evaluation of the simulation test campaign showed that the avoidance share in impact cases for pedestrians could be high, reaching 37.7%. However, the avoidance share depends on the impact location, as it can be seen in the image below. The avoidance rate for cyclists varied between 10.6% to 20.8%, also depending on the side of impact.



Scenario	Impact location	Avoidance [%]
P-CRwoSO / P-CLwoSO Pedestrian crossing from right/left without sight obstruction	Frontal impact, close corner	3.7
P-CRwoSO / P-CLwoSO Pedestrian crossing from right/left without sight obstruction	Frontal impact, distant corner	3.7
P-CRwoSO / P-CLwoSO Pedestrian crossing from right/left without sight obstruction	Side impact	37.7

Scenario	Impact location	Avoidance [%]
B-CRwoSO Bicyclist crossing from right without sight obstruction	Frontal impact, close corner	0.6
B-CRwoSO Bicyclist crossing from right without sight obstruction	Side impact	20.8
B-CLwoSO Bicyclist crossing from left without sight obstruction	Side impact	10.6

Figure 4: Synthetic accident cases tested for Demo 3 with full-factorial parameter variation based on GIDAS vehicle and VRU speed data (Source: SAFE-UP D3.6)

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AES's impacts on reducing collision are higher, compared to AEB, for faster vehicles and slower crossing pedestrians. Indeed, the evasion manoeuvre required to avoid pedestrians does not have to be as consequent if the pedestrian walks slower.

A simulation has also been performed to assess the additional safety benefit provided by a combined VRU AEB+S at different market penetration rates of AES in the simulation. The base scenario considers that all vehicles use AEB. Eight scenarios were initially considered with pedestrians and cyclists crossing right and left, with and without sight obstruction, side or frontal collisions. In the end, only the frontal collisions were modelled since the side collision should be responsible for less collisions, and the results for the frontal collisions can be used to extrapolate the side collisions. The goal of the model is to identify the probability of crash avoidance, the distribution of initial conditions, the collision speed (in case of crash), and the injury risk.

The results from the simulation testing showed that AEB prevented most crashes, with a slight benefit when the idealised AEB+S was applied. The greatest reduction in KSI was observed in the pedestrian use cases, specifically P-CLwSO. The reduction in fatalities was greatest for P-CRwSO and least for B-CRwoSO.

The displayed figure below, containing results of the physical testing, indicates that cases without sight obstruction and with 2 m obstruction distance exhibit a higher AEB avoidance rate compared to the AES avoidance rate. However, as the obstruction distance is reduced to 1.5 m, the AES avoidance rate exceeds the AEB avoidance rate due to the later trigger time for the systems. In fact, for the closest obstruction distance of 1 m, only a single accident was prevented due to AES. Nevertheless, it is observed that the avoidance rates for both AEB and AES decrease as the obstruction distance is reduced. It is also noteworthy that the location of the collision is changed to the rear half of the vehicle, and the collision speed is reduced for non-avoided collisions.

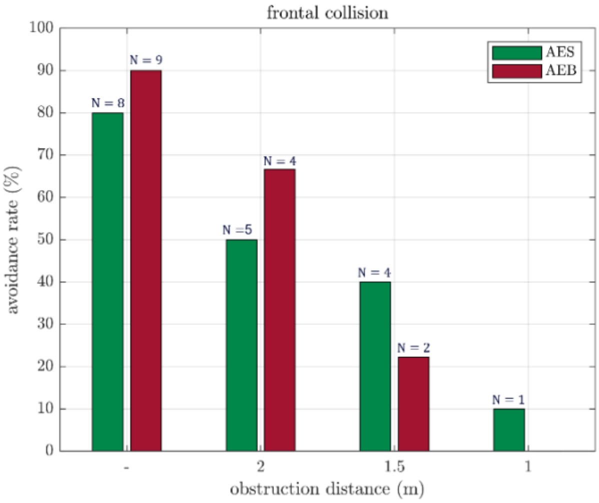

Figure 5: Avoidance rate in relation to obstruction distance as a result of the physical testing

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For the demo 3, not all scenarios could be tested. As mentioned, in cases where AES fails to avoid the accident, the collision impact location is changed to be on the side of the vehicle. As the current state of research lacks the knowledge of how this change in crash constellation effects the resulting accident severity, no final statement can be given in this regard. For a final assessment of the AES safety benefit, this effect would have to be compared to the AEB velocity reduction in cases where no full accident avoidance is possible.

Future research directions could involve testing and modelling the side collisions. Additionally, the testing considered AES and AEB separately, and both ADAS could be tested together to assess their effectiveness if used jointly.

2.5 Demo 4 – Safety solution based on V2X

V2X communication is a system that uses wireless technology to facilitate communication between vehicles, infrastructure, pedestrians, and the cloud. This technology, among others, has the potential to increase road safety and traffic efficiency, especially in urban areas where accidents involving vulnerable road users (VRUs) such as pedestrians and cyclists are common.

Demo 4 tests the application of V2X systems to avoid collisions between cars and VRUs by providing warnings to both the driver and the cyclist and/or by triggering automated functions in the vehicle such the Automatic Emergency Braking (AEB) system. To test the effectiveness of V2X communication in preventing accidents, experiments were conducted with real cyclists as well as pedestrians and cyclists' dummies in testing facilities. Each scenario had three testing modes: baseline (no V2X), Road Side Unit (RSU) V2X, and VRU V2X. The scenarios were focused on crashes with high Killed or Seriously Injured (KSI) relevance, especially those involving non-designated pedestrian and cyclist crossings, as well as scenarios where the VRU is obstructed.

The results of the experiments showed that the effectiveness of V2X as an extra perception system depends on the software and hardware capabilities and qualities. A high level of accuracy is necessary, and low latency with older technology or busy intersections can be a problem. Slow response times on slow movement, as well as the fact that human reaction time (for the pedestrian crossing the street as the tests did not involve a real person but a dummy) is not considered, can also be considered as limitations. However, turning scenarios that are hard to assess can benefit from early warnings in obstruction scenario, up to 16% of reduction in KSI cases in certain scenarios is reached by using V2X.

To address these limitations, experiments were also conducted to model the cyclist's reaction time and breaking time after hearing a signal. The VRU bicyclist warning times were set to 4 seconds as a light warning and 2 seconds as a strong warning. The simulation results showed a 94-99% estimated KSI reduction rate of the system for the specific use cases, depending on the case. These numbers are quite high, but since 2-4s warning time is quite early, almost all cyclists would be able to stop in time.

The coverage of the V2X communication system was estimated to address around 42% of all urban car-to-pedestrian (C2P) KSI cases and 73% of all urban car-to-bicyclist (C2B) KSI cases.

In conclusion, V2X communication has the potential to significantly increase road safety and traffic efficiency, especially in urban areas where VRUs presence is high. While there are limitations to the technology, simulations and experiments have shown promising results in reducing the number of crashes and KSI cases. Further development of V2X communication systems could have a significant impact on road safety in the future.

For future research, the V2X devices can be improved as they still are at the prototype stage. Future testing should consider the VRU reaction time, as well as the Human-Machine Interface (HMI) design and validation, which was not part of the scope in SAFE-UP. Also, future testing for the turning scenario should be considered, as it is the most difficult to assess.

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3. Vision and alignment

In D7.3 of SAFE-UP, a roadmap for a holistic pathway towards CAVs, several challenges that stand in the way of fully deployment of vehicle automation were delineated. In it, five pillars were defined, including: vehicle technology, infrastructure (physical and digital), regulations, user approach, and business models. To achieve a full and effective deployment of CAVs, none of these pillars can be omitted.

As it is obvious, there cannot be deployment until vehicle technology is not mature enough. Following this, infrastructure adaptations, both on a physical and specially digital layer are needed, to fully enable CAVs capabilities or compensate for some in-vehicle technology needs.

On the other hand, even if technology and infrastructure are ready, regulations need to be adapted in order to ensure safety and type approval of these novel vehicles. Additionally, with no regulation that allows driving on real-world environments, it will become very difficult to capitalise on all the benefits promised by CAVs. And finally, even if all the three pillars mentioned are ready, not much will happen if users don't accept these new solutions or if the business models behind are not profitable and sustainable over time.

Having said that, in D7.3 we also reflected on how SAFE-UP was contributing to overcome these challenges. In the end, **SAFE-UP mostly contributed to develop vehicle technology and the digital infrastructure pillars**, with the ultimate goal to prove that vehicle automation can help improving road safety by reducing the accidents involving Killed or Seriously Injured (KSI) road users, either vehicle drivers or VRUs.

After seeing the **impact assessment results** of the **four demonstrators** developed in **SAFE-UP**, we can **conclude** that **all of them**, to a higher or lesser degree, **contribute to reducing the KSI cases in the scenarios addressed and assessed**.

Demo 1 has contributed to improve passenger safety in new reclined seating positions thanks to an adapted restraint system. Additionally, part of the benefit assessment has been done via virtual simulation, which was also highlighted in the roadmap as a need for future type approvals, since testing many different positions and anthropometries with physical dummies would have required a lot of resources, of time and money. Future research should investigate more on the Human-Machine Interface of the Occupant Monitoring System and the comfort and ergonomics of the adapted restraint system.

Demo 2 has also proven to work and be effective with the boundary conditions considered. Advanced research in this field will surely contribute to achieve more robust and reliable perception systems, specially improving VRU detection under adverse weather conditions. This will enable vehicles expand to bigger Operational Design Domains (ODD), including more weather conditions, wider range of speeds, more types of roads, etc.

Demo 3 also shows promising results when it comes to collision avoidance. To continue, research in evaluating the HMI and the driver reaction to an AES system is needed, to ensure a seamless interaction between the driver and the vehicle.

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Demo 4 has proven that V2X technology can work, and it shows potential safety benefits when it comes to collision avoidance, especially in occluded view cases. It also helps research in validating a communication framework and inspiring the future work towards defining standardised interactions between infrastructure and CAVs. Research and industry should now work on the surrounding challenges: connectivity requirements, who is responsible if connection fails, human factors as a reaction to warning messages, accuracy and latency, V2X criticality (its role in ensuring road safety needs to be properly defined), cybersecurity (relying on external information might add some new challenges). And finally, once all these technical aspects are solved, equipping the roads, vehicles, and users, with the required digital infrastructure requires a significant amount of time, agreements, and economic resources.

SAFE-UP also provided input that can be relevant towards defining the future type approval based on CAV's needs, updating current procedures. It has also been noted that virtual testing can help in this direction (as mentioned in D7.3, future type approvals should consider virtual simulation as well), as it has been demonstrated in SAFE-UP. As a next step, an assessment that virtual testing positive results correspond to beneficial outputs in real-world conditions needs to be carried out. In SAFE-UP's D5.7, more information is provided towards the procedures of testing and validation of new technologies like the ones developed in SAFE-UP, providing input to Euro NCAP assessments.

Overall, in SAFE-UP it has become notorious that the introduction of CAV technology might be slower than the market initially expected. Testing procedures need to be meticulous and take a significant amount time and resources. But even with that, significant progress has been made in the project, and follow-up research initiatives should be encouraged from the administration bodies.

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4. Conclusions

This chapter summarises the information provided in this report related to the demonstrators developed in SAFE-UP. For additional details, the reader is invited to review D5.7 “Test procedure proposals for EuroNCAP”, containing more information regarding the limitations of each demo, the results, and guidelines and future research directions.

OMS developed in Demo 1 shows high accuracy when detecting passengers’ key points. Also, improved and adapted systems for reclined positions developed in Demo 1, proved that with optimized configuration of the restraint system, an improvement was observed by getting safer values in practically all body regions.

Demo 2 simulation testing confirmed high percentages of collision avoidance. However, the analyses showed that there were four categories of collisions that could not be avoided. These included collisions at speeds higher than 60 km/h, obstructed views where the time to brake after object detection is insufficient, unobstructed views where the camera performance due to the FOV shape is crucial, and cases where there is an early detection of the object but a too late AEB triggering for the existing boundary conditions like friction coefficient.

Regarding the evaluation of Demo 3, the physical testing campaign yields real-world evidence that in crossing pedestrian scenarios with close sight obstruction, AES can generate an additional accident-avoidance potential compared to state-of-the-art AEB systems. In cases where AES fails to avoid the accident, the collision impact location is changed to be on the side of the vehicle, with the majority of the cases showing impact locations at the rear half of the vehicle’s side. As the current state of research lacks the knowledge of how this change in crash constellation effects the resulting accident severity, no final statement can be given in this regard.

The test results from SAFE-Up Demo 4 confirm that communication technology has potential to improve road safety in obstruction-related scenarios where an increased distance at stop to the target could be seen. Nevertheless, the assessment could only focus on the activation of active safety systems and not on the provision of timely warnings since the human reaction to these warnings could not be evaluated and should be part of future work.

To conclude, full potential of developed technologies could not be demonstrated, because they were integrated in different vehicles separately, due to the need of working in parallel. The challenge and opportunity lie now in integrating all solutions into one demonstrator and increase the Operational Domain Design (ODD) potential by looking beyond actual limitations, such as traffic regulations and homologation requirements.

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