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Executive summary

The world is in a process of transformation: global warming, resource scarcity, demographic changes, and urbanisation provide the backdrop for uncertainties that also influence the automotive industry. Automation technologies are being challenged to respond to these uncertainties in transportation and beyond. These efforts go much further than safe and sustainable travel – they have the potential to enable innovations in mobility, logistics, and new services to widely benefit society.

To better understand the current and potential future requirements for enhancing driving automation, large-scale piloting in real road traffic conditions is a necessity. The data gathered from road tests can help to pinpoint the areas that still require further development before automated vehicles (AVs) enter the stage of product refinement and deployment. Above all, we need to have further knowledge of user experiences and demands for marketable products.

The objective of the L3Pilot project was to test and study the viability of automated driving as a safe and efficient means of transportation, to explore and promote new service concepts to provide inclusive mobility. To achieve this overall goal, several technical objectives had to be defined and met before we could present the first empirical data-led assessment of the potential for automated driving to change transportation. The key in piloting was to ensure that the systems were exposed to variable conditions, and that the test vehicles' performance could be compared between automated and non-automated modes across the test sites. The large scale Piloting meant the inclusion of numerous European OEM and research prototypes to gain a full range of automated vehicles.

L3Pilot testing and evaluation was based on the FESTA methodology. This methodology, however, was originally designed for field-operational tests (FOTs) with market-ready products, including advanced driver assistance functions, and it did not fully apply to studies of prototype automated driving functions (ADFs). Thus, adjustments to the original methodology were needed to accommodate the testing of prototype automated vehicles in real traffic.

L3Pilot's experimental procedure was developed to provide a solid base for the evaluation methodology and to ensure that the results from the tests across the pilot sites could lead to a comprehensive evaluation, also taking into account possible implementation constraints. Furthermore, the aim was to harmonise the evaluation criteria by providing detailed recommendations to the various pilot sites. It was important to carry out both baseline measurements (automation mode switched off) and so-called treatment measurements (automation mode switched on) to be able to compare the performance of automation systems with non-automated driving. Single or multiple video streams and around 415 signals from vehicle sensors were recorded in the test vehicles with a frequency of up to 10 Hz.

The evaluation work focused on four primary areas of analysis:

1. *Technical and traffic evaluation* assessed the effect of the ADF on vehicle behaviour and the surrounding traffic based on data logged directly in the on-road tests and simulations that, for the first time, could derive parameters from real road data collected in a similar time span by partners across Europe.
2. *User and acceptance evaluation* assessed users' evaluation and acceptance of automated driving functions and behaviour with the functions.
3. *Impact assessment* extrapolated these results and the potential impacts of so-called mature ADFs on traffic safety, personal mobility, traffic efficiency, and the environment.
4. *Socio-economic impact assessment* utilised the above analyses to determine monetary values for the estimated effects, weighing expected costs and benefits of the ADFs.

Fourteen partners in total, among them car manufacturers, automotive suppliers, and research institutes conducted the pilots on motorways, urban roads, and in parking scenarios. The pilots began in spring 2019 and included seven countries: Belgium, Germany, France, Italy, Luxembourg, Sweden, and the United Kingdom, also with some cross-border activities. The different pilot sites were led by Volkswagen, Aptive, Audi, BMW, CRF, FEV, Ford, Honda, ika/fka, JaguarLandRover, Group PSA, Renault, Toyota Motor Europe, and Volvo Cars. The project equipped a total of 70 vehicles. The fleet comprised 13 different vehicle types, from a compact passenger car to a Sport Utility Vehicle (SUV).

The project's experimental part was split into two different paths: (i) large-scale piloting across Europe on the public road network and so-called (ii) supplementary studies focusing on specific user-related research questions that were difficult or even impossible to address in large-scale piloting on public roads for safety and practical reasons.

The large-scale piloting part consisted of some 750 test persons driving more than 400,000 kilometres on motorways and more than 24,000 km in automated mode in urban areas. The test participants experienced automated driving at SAE level 3 (L3) either as a regular driver or as a passenger. In addition, SAE L4 functions were tested in parking applications.

Although vehicle communication standards such as CAN and Ethernet are prevalent, the collected raw data is interpreted differently for each OEM, sometimes even between platforms of one brand. A novel common data format (CDF) was derived to transform the widely varying data already at the vehicle level into a compact data stream that could be processed by all analysis partners. The CDF is available to the public.

The consolidated database (CDB) was built for data analysis to enable the sharing of data from all the pilot sites to answer the project's research questions concerning the expected impacts of the SAE L3-L4 ADFs. The research questions aimed to analyse the vehicle/driver performance in different experimental conditions (ADF vs. baseline), road types (e.g., motorway, urban), and specific driving scenarios, such as cut-in, approaching a lead vehicle, following a lead vehicle, driving in a traffic jam, etc. While the idea was simple, the actual sharing of automotive data from advanced automated driving functions turned out to be a complex task given the heterogeneity of the proprietary vehicular environments and obvious confidentiality-related issues. Thus, collaboration between academia, research institutes, and industry was needed right from the beginning to safeguard the confidentiality of the industrial partners, on the one hand, and to ensure answers to the research questions, on the other hand.

The supplementary studies complemented the large-scale piloting by providing the possibility to more deeply explore the behaviour and experiences of subjects either in a simulator environment, with a Wizard-of-Oz vehicle, or on a closed test track without jeopardising the safety of the test persons. Consequently, eight supplementary studies were carried out, focused primarily on specific research questions delving deeper into the behavioural dynamics of the test drivers. These studies were also extensive, comprising a total of some 600 test persons.

In responding to the need to address global users' differences in attitudes and opinions towards automated driving, the L3Pilot *Global User Acceptance Survey* was conducted to analyse user acceptance, attitudes, and expectations towards AD with a particular focus on SAE L3 technology. The aim of the survey was to answer the central research question: What are the attitudes towards and acceptance of SAE L3 automated cars, and what are the factors influencing attitudes and acceptance? The survey was extensive and covered some 36,000 respondents globally.

The survey results indicated that overall, the respondents were very satisfied with the SAE L3 ADFs, providing high ratings of (expected) comfort and safety, usefulness, ease of use, and perceived enjoyment. They indicated a high intention to use conditionally automated cars, which is a common proxy to measure acceptance, given that conditionally automated cars have not yet been commercialised. Across all of the data, 42% of the respondents expressed an intention to use an SAE L3 automated car. Respondents from European countries were less enthusiastic about using conditionally automated SAE L3 cars than respondents from non-European countries.

The results from the pilots indicated benefits for society deriving from the introduction of SAE L3 ADF on motorways, in urban environments, and for parking. Results of the impact assessment on safety showed potential reductions in injury and fatal accidents within the operational design domains (ODDs) both in motorway and urban traffic. As for efficiency and the environment, the results indicate a slight decrease in fuel consumption and CO_2 emissions, and a slight increase in travel times compared to the baseline. Driving with automation led to a reduction in lane changes and approaching scenarios. More driving time was spent in stable scenarios such as car-following. Furthermore, the following observations were made from the analysed driving scenarios: while driving with the ADF, speed was significantly lower across scenarios, the distance to the lead vehicle was greater, and lane keeping was more stable. The overall conclusion is that automated vehicle behaviour is similar to that of human driving in urban environments.

Furthermore, the participants in the pilots and supplementary experiments were interviewed, as well. The majority of drivers did not experience driving with the system as stressful, difficult, or demanding. In summary, it seems that the evaluation of ADFs becomes more positive with growing experience or remains at the same, mostly high, level. Professional safety drivers, however, were less positive than ordinary drivers when evaluating the system, potentially due to system familiarity. If given the opportunity, most of the ordinary drivers would engage in a secondary task while the system is active. The majority of participants agreed that their experience of driving with the system was comfortable, with no reports of motion sickness during the drive.

The economic environment of the automotive industry continues to focus on innovations, owing to intensified market introduction of electric vehicles and new players entering the business. For these reasons, it was imperative for the L3Pilot project also to explore possible service concepts providing new mobility solutions and to chart the deployment potential of automated vehicles. Four business model archetypes were developed and analysed. These were service-based and relate to (i) In-Car Services, a time-value-dominant offering, (ii) Data+ Platform, a data-dominant offering, (iii) MaaS (Mobility as a Service), a mobility service-dominant offering, and (iv) RoboTaxi, a vehicle-dominant offering. The latter is a relatively clear example of how a highly automated vehicle can be exploited as a service – but it remains a project for the future, due to the need for access to SAE L4 automated technology.

The project also continued the tradition of providing guidelines for the development of Advanced Driver Assistance Systems (ADAS) by creating the Code of Practice (CoP) for ADFs. The *CoP-ADF* provides a comprehensive guideline for supporting the automotive industry and relevant stakeholders in the development of automated driving technology. The CoP-ADF is derived from knowledge accumulated by the industry as well as the collected best practices from different topics. Thus, the CoP-ADF includes the following: (i) collection of best practices on the topics that have been identified in L3Pilot as relevant; (ii) a typical process for the development and release of ADF; (iii) safety aspects and methods to ensure the safe operation of ADF; and (iv) a checklist to support the path towards automated driving considering insurance, regulation, and homologation.

The project employed strong promotional actions to make the activities and results known in the automotive world and beyond. Given the extent of the undertaking to execute a Europe-wide pilot of SAE L3 automated driving and its key role for the automotive industry, the goal was to establish L3Pilot as the European reference project for AD. The dissemination measures were built on four pillars: (i) the automated driving campaign, comprising four driving demonstrations, workshops, press and social media dialogue, and respective dissemination material such as posters and videos; (ii) liaison and knowledge exchange; (iii) the participation and active contribution of L3Pilot to industry events; and (iv) publication of technical papers. The project provided a frequently visited website and online channels to communicate dissemination activities. A number of communications means and basic elements were available and used throughout the project.

The project reviewed its own work and collected both the main positive and negative experiences into *lessons learned* with a view to recommending good practices for future work. Priority was given to topics relevant for automated driving, since addressing this rather young technology required novel methods and innovative tools throughout the project.

Future development needs were discussed and analysed. These relate to vehicle performance in challenging conditions and complex city scenarios as well as better understanding driver performance in the cockpit.

In total 22 public deliverables were written to collect the findings, most of which are for a wider public.

The L3Pilot project organised its Final Event and Showcase at the ITS Word Congress in Hamburg in October 2021. The piloting outcomes were presented at this event, and the congress attendees had the opportunity to experience the L3Pilot automated vehicles in city traffic and in a motorway environment: 3 cars were brought for urban driving demonstrations, 6 cars for motorway demonstrations, and 13 cars for static demonstrations. With over 400 square metres of exhibition space, the project was among the most spectacular presenters at the ITS World Congress.

1 Introduction

1.1 100 years of evolution, from driver support to automated driving

Driver support dates back further in time than we might at first think. Even back in the 1920s the first thoughts of automated driving were presented. That decade saw the development of synchronous transmission, soon followed by automatic transmission in passenger cars, with the aim of simply providing the driver with more time to focus on the road. After 100 years of driver support systems a new chapter in vehicle operation has now arrived: to ensure accident-free and comfortable travel through the step-by-step replacement of the driver at the wheel completely.

The L3Pilot project is now highlighting that the acceleration of that development over the past decades. From 1986 to 1994 the *EUREKA* Prometheus Project carried out extensive investigation on enabling technologies for automated driving, but technology at that time was far from ready for automated applications. Major European activities in the past 20 years – such as *PReVENT*, with an electronic safety zone around the car; *DRIVE C2X*, with cooperative driving; *InteractIVe*, anticipating automated driving by applying active steering and braking power in critical situations; *euroFOT*, taking these technologies to large-scale road tests comprising more than 1000 vehicles; and *AdapatIVe*, developing automated driving functions for daily traffic by adapting automation to situation and driver status – prepared the ground for more mature road tests. Recently, there has been a lot of hype surrounding automation fuelled by overseas activities involving automated cars initiated by *US DARPA Grand Challenge* competitions, *Google-Waymo* driverless cars, and *TESLA*. Similar developments have been seen in China, Korea, and Japan.

Today, the automotive sector is undergoing a disruptive change initiated both within the sector itself and by external mega-trends penetrating most vertical sectors in society. Changing forces are transforming the world: global warming, resource scarcity, demographic changes, and urbanisation provide the backdrop for uncertainties that also confront the automotive industry. Automated driving is being challenged to respond to these uncertainties in transportation and beyond. The transformation would go much further than sustainable travel. It would enable innovations in mobility, logistics, and new services to widely benefit society.

Even before their development, the idea of automated cars evoked mixed feelings among users, ranging from enthusiasm to sheer terror. Surveys suggest high levels of concern about riding in automated vehicles, issues related to system failure, and the inability of automated vehicles to perform as well as human drivers. Consequently, we are facing three parallel areas where work is needed to bring automated vehicles to market: (i) ensuring the technology is mature for safe operation, (ii) enabling infrastructure developers and regulators to adapt to the change, and (iii) encouraging users to reassess how automated driving technology may serve their daily mobility needs.

Major technological developments, building on user acceptance, legislation, and infrastructure adaptations, are still needed to enable automated driving. Great advances toward automation are being seen today in new vehicles equipped increasingly with first levels of automated systems. As the L3Pilot project has now provided a huge amount of data, it has also boosted extensive SAE L4 testing in Europe. SAE L4 tests under strictly defined ODD are already ongoing in the USA as well. The biggest remaining barrier standing in the way of high-automation vehicles is the ability to drive under any visibility conditions and to handle complex city scenarios to ensure safe travel.

Consequently, L3Pilot is also paving way for high-level automation (SAE L4-L5) through the recently launched Hi-Drive project. Hi-Drive will build on the results of L3Pilot and will be testing the feasibility of high-level automated driving in variable harsh conditions and driving cultures across Europe, beyond the earlier very narrow ODD characterising SAE L2-L3 automation.

1.2 Deliverable structure and how to read the report

This deliverable presents the L3Pilot piloting process, including the methodology developed, main results, lessons learned, and outlook to the future. For a reader to be able to assess the work done and results obtained, it is important to understand the procedure and logic of how the project concept was transformed into a holistic methodology and research questions that led to road tests across Europe in a harmonised piloting environment. Furthermore, support activities, project promotion, and their results are also reported since mere piloting is of little use if the results are not harnessed to promote and pave the way for the deployment of automated vehicles.

The work described is split into ten main chapters, of which the first, Chapter 1 *Introduction*, explains the project structure, automated driving landscape, and forces pushing transport and societies to digitisation, followed by the project concept, which stresses user aspects and objectives.

Chapter 2 *Methodological framework for European piloting* is divided into three main parts: (i) overall methodology, (ii) experimental procedure, and (iii) evaluation methods. Chapter 2.1 *Overall methodology* explains the main features of the project's methodology, making use of previous field tests and the FESTA V-shaped methodology originally developed for ADAS testing. Consequently, the methodological framework created the rules for piloting and data analysis, thus binding the project's work areas together. Chapter 2.2 *Experimental procedure* explains experimental procedures carried out at the pilot sites and introduces the methods used to organise data collection in such a way that an L3Pilot-level evaluation could be conducted across the pilot sites. Chapter 2.3 *Evaluation methods* introduces the methods used for evaluating the ADFs and answering the research questions in four primary areas of analysis: (i) technical and traffic evaluation, (ii) user and acceptance evaluation, (iii) impact assessment on the potential impacts of so-called mature ADFs, and (iv) socio-economic impact assessment to determine monetary values for the estimated effects.

Chapter 3 *Pilots* describes the large-scale piloting of ADFs, primarily SAE automation Level 3 functions, with additional assessment of some L4 functions tested in seven European countries. This chapter explains the logic of road tests; a pre-test phase with the main goal of validating the system under evaluation, as well as the complete toolchain, before the full-scale experiment; and lastly, the pilot execution phase, for collecting large sets of vehicle and user data for the analysis and assessment activities to be carried out in the subsequent evaluation phase. Piloting made up the core of the project efforts in a challenging pandemic situation, which posed additional safety issues for the work. The tests aimed to answer more than 100 research questions defined to examine the impacts of automated driving all the way from user behaviour to the societal level. In addition to the actual piloting activities, data management itself played a role, as the collected data were used to form a consolidated database, and to support high-level impact assessment and traffic and technical assessment within the L3Pilot consortium.

Chapter 4 *Key results of piloting* is split into four main areas: (i) technical and traffic evaluation, (ii) user and acceptance evaluation, (iii) impact evaluation, and (iv) conclusions based on the results of these areas. The evaluation plan was essential, explaining how the research questions led through several phases to the evaluation and what needed to be considered in the data analysis to answer the research questions defined. Ultimately, the key results feature the project phase, highlighting the work done by providing the results of this large project. The results are projected on a European level to provide an overall view of the possible impacts of SAE L3 automated driving. Impact evaluation explains the results on the four impact areas listed in Chapter 2.3 as a target for evaluation methods.

Chapter 5 *Supplementary experiments – detailed studies on user experience* explains and reports the results of the studies that were planned in addition to the on-road piloting, with the aim of studying system usage and other relevant user topics with ordinary, non-professional drivers in a safe environment either on a test track, normal road, or in a simulator. These extensive studies with over 600 subjects focused on short- and long-terms impacts of automated driving as well as stress, fatigue, workload, alcohol, and impacts of side-tasks while driving an automated vehicle.

Chapter 6 *Support activities* describes work that is not directly associated with piloting on roads but rather supports the overall project aim of a later deployment of SAE L3 automated vehicles. Here, ethical, legal, and cyber-security questions associated with piloting are discussed and solutions proposed. A lot of effort was also taken to prepare the Code of Practice, outlining the principles and issues in developing and building automated vehicles. This work is geared toward the global community involved in developing AVs. Furthermore, exploitation and innovation activities were also included in project activities to create a broad and open model that deals with a range of different business environment scenarios, novel business models for new mobility solutions, and possible deployment perspectives. Finally, a large and global quantitative user acceptance survey on SAE L3 automation was planned and executed in three phases in 2019–2021 to examine general attitudes towards L3 systems and the factors predicting the acceptance of automation.

In the same way, also Chapter 7 *Project promotion* brought the project results to stakeholders outside the project community and to the general public, thereby supporting the adoption of automated technologies among the users – also globally. Here dissemination and communication featured as the guiding activities in promotion. The work done in all supporting activities is geared toward making the project results known through dissemination and communication, public showcases, and liaison activities. Furthermore, this chapter also describes how the project enabled access to two different open data repositories.

Chapter 8 *Impact* contemplates the achievements of L3Pilot in the three major impact areas identified for L3Pilot: (i) knowledge impact, (ii) societal impact, and (iii) business impact. All these impact areas are closely related to the transformation of society into a digital world where we will all be connected, and this has deep-going consequences for our daily lives – already now and in the upcoming future. Also featured are the impacts listed and expected in the EU work programme.

Chapter 9 *Conclusions* completes the L3Pilot project activities by assessing the significance of the work done, obstacles on the way to the goal, and what has been learned from this large project. This chapter covers the main activities of the project work from the methodology to data management, evaluation, and Code of Practice, to an analysis of the lessons learned from the project.

Finally, Chapter 10 *Upcoming and future research* covers the remaining challenges in automated driving. These relate to winning over users' interest in AD, adapting the new technology, and taking the role of passenger rather than driver. A key aspect here is the functionality and reliability of automated functions that still face challenges in complex and low visibility environments. Furthermore, to be able to meet the usability and technology goals, extensive testing programmes are still needed, and responsibility needs to be shared among road operators, industry, legislators, and service providers in order to boost automated travel.

This L3Pilot Deliverable D1.7 *Final Project Results* – especially Chapters 2 to 7 – builds on the deliverables that describe the entire L3Pilot project. The project deliverables are listed together with other references in *References*. ANNEX 1 gives an idea of the extent of the dissemination and communication work engaged in by the partners during L3Pilot.

Technically, the work objectives consist of answering the defined 116 research questions. All research questions and hypotheses are not listed in this deliverable, to save space and to avoid excessive technical language. Instead, there are numerous references to the deliverables and their chapters for further detail, also including the formulated research questions. For the reader interested in precise measurement methods, defined indicators, statistical testing, and the reasoning behind the choices made, as well as the constraints of the studies, it is highly recommended to turn to the deliverables referred to in the text.

In this publication, we generally briefly explain the objective(s) of the work area in question, how the data has been collected, the results, and the conclusions that can be drawn. Also, the main lessons learned from the whole project – selected from the various work areas – are described.

To understand the nature of testing here, it is still to be reminded that SAE L3 automation does not require the driver to supervise the driving task, but the driver needs to be available as a fall-back for the system within a limited time span when the system issues a take-over request (TOR). If the driver does not respond properly to the TOR, the vehicle will perform a minimal risk manoeuvre. To be able to assess the functionality of the automated system against manual driving, in the work we speak about *baseline driving* conditions, which means manual driving, and then *treatment conditions*, which means driving with automated mode activated. By comparing these two conditions we can judge the effects and functionality of automated driving (please see Chapter 2.3 of this deliverable).

1.3 Piloting landscape

It is necessary to pilot automated vehicles in normal traffic in order to understand the potential and further enhancement needs of current SAE L2 to L4 automation in functioning applications. The data gathered from road tests will pinpoint the areas that still require refinement of automated systems before beginning actual product development and entering the final phases of deployment. Above all, we need to have more knowledge of user experience from road trials and user requirements for marketable automated driving products.

Pilot projects typically involve moderate to extensive road trials under different conditions, often with professional safety drivers i.e., drivers with the qualification to drive test vehicles. Piloting also includes so-called naïve subjects, i.e., those without previous experience of driving vehicles equipped with automated functions. Further on in the text, these non-experienced drivers are referred to as *ordinary drivers* or *test drivers.*

Road tests of vehicle automation require careful preparation to meet the goals defined for the activity. In L3Pilot, a methodology was created to cover all steps needed to draw valid conclusions from the data obtained. See L3Pilot, the Deliverable D3.2 *Experimental Procedure* (Penttinen et al., 2019) and the Deliverable 3.4 *Evaluation plan* (Innamaa et al., 2020). This phase included the preparation of pilots on public roads and parking areas, data management, and the analysis of the collected data.

The big picture for automated vehicle piloting and an enabling methodology is characterised by an interplay between multiple overlapping factors (Figure 1.1). These are:

- Status quo of current automated driving and resulting availability and maturity of the testable automated driving functions (ADFs).
- Legal and ethical framework on what is allowed to be tested on European roads, and observation of the General Data Protection Regulation (GDPR) when setting up the legal framework for piloting during the tests and beyond in the analysis phase.
- Knowledge needs for automated driving impacts (safety, technical, user acceptance, environment, traffic efficiency, social, economic, security).
- Acquisition of data and information in the key areas of automation technology development under various constraints, whether associated with measurement techniques, ethical issues, confidentiality, or proprietary rights.

When considering automated vehicle tests on public road networks, several agreements specify the legal framework for national road traffic legislation. One of the most important is the 1968 Vienna Convention on Road Traffic. In 1968, automated systems had not yet been developed and consequently, no framework was defined. Automated systems have been permitted since the last change of the Vienna Convention in March 2016.

The work on legal aspects focused on the needs of each pilot site to consider the specific national regulations where the respective tests were carried out. This also included cross-border operations.

A detailed survey was conducted on the legislation to be applied; see the L3Pilot Deliverable *D4.2 Legal Requirements for AD Piloting and Cyber Security Analysis* (Vignard et al., 2019). All pilot site leaders followed a set of defined guidelines and ensured that they had permission for experimenting with cars equipped with AD functions. Furthermore, a common approach was taken to ensure compliance with data privacy requirements at the European and national level.

At the same time, the reliability of the piloted functions, safety, and ethical aspects were taken as a basis for each pilot site together with the detailed definition of what should be measured from the technical and users' point of view. Finally, the L3Pilot methodology represented the common thread guaranteeing the homogeneity of data acquired in all the test sites.

In the background, influencing all of these factors, there are several global megatrends that are currently changing our lives at a constantly increasing pace. The automotive world is no exception. Global warming is shaping the way vehicles will be used and built; in the same way, digitalisation is affecting but also boosting industries and businesses. Artificial intelligence (AI) has a similar role, and its influence in the development of automated technologies is of paramount importance in enabling automated vehicles to behave in a manner that replicates the best features of human driving behaviour.

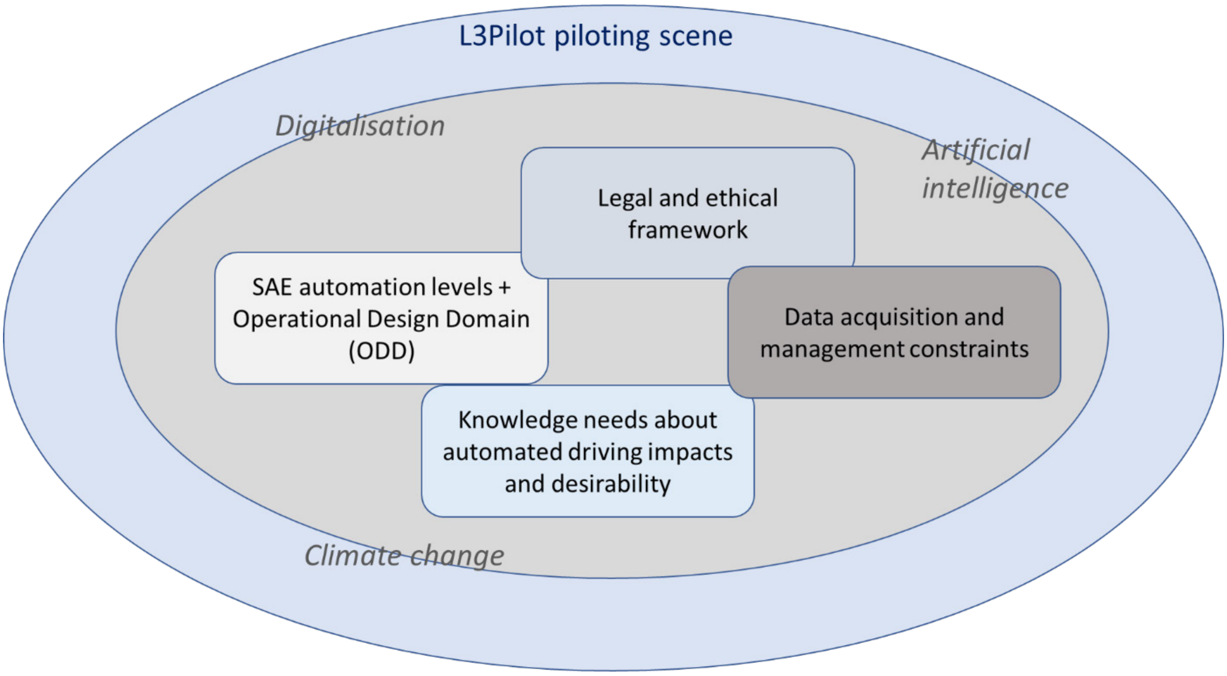


Figure 1.1: L3Pilot piloting scene under global mega trends and work constraints.

1.4 L3Pilot goals

The objective of the project was to test and study the viability of automated driving as a safe and efficient means of transportation and to explore new service concepts to provide inclusive mobility.

To achieve this overall goal, several technical objectives had to be defined and met before we could present first empirical, data-led guesses of the potential of automated driving in changing transportation and mobility.

The now completed work did not focus on road tests alone for collecting vehicle data and users' impressions, analysing, and reporting the results. Large-scale piloting could not address all open questions on possible impacts and driver-vehicle interaction due to safety issues. To partly overcome these issues, extensive and more detailed supplementary experiments needed to be executed to cover these matters. Overall, the project work handled over 100 research questions on possible impacts of ADF.

The piloting activity on public roads presupposed first creating a harmonised Europe-wide piloting environment for automated driving together with coordinating activities across the piloting community to acquire the required data. Furthermore, to make this happen, an 'operating system' for piloting was needed, and this meant tailoring a methodology to encompass all the requirements needed for automated driving tests in real traffic. Finally, piloting and the obtained data had to be managed and transferred to the analysis centres to study different phenomena, ranging from driver reactions to anticipated societal-level impacts.

Consequently, the first major activity area for the project was *to create a European-wide testing environment*, unify it by means of a comprehensive methodology, carry out the needed testing, and manage the data all the way to the analysis and concluding results.

The second activity area, *promotion*, consisted of the use and spread of newly acquired knowledge through dissemination and communication as well as liaison activities towards the public and private stakeholders that maintain and develop road infrastructure, regulations, and commercial solutions.

Equally important was to make use of the experience gained from the project work and build guidelines on how to further develop automated technologies in the form of a *Code of Practice* as well as to promote the project findings and ensure that the results obtained would also be available to stakeholders outside the consortium. These two activity areas characterise the goals set for L3Pilot, and they were built into the work structure.

The deployment of automated vehicles is a long process. Many of the promotion activities dealt with non-technical deployment challenges, such as user expectations and acceptance, a lack of investment in infrastructure, unintended negative effects of AD, and fragmented legislation across Europe. The project also built upon the business environment scenarios and business models for automated driving by 2030. Surveys of ADAS suggest that while consumers are willing to use intelligent vehicle safety systems, they are reluctant to invest in them. This willingness to use and pay for automated driving applications is not clear-cut and furthermore, allowing machines to take decisions may present an acceptance problem. It is not yet known how quickly the driving public will embrace this new concept. These questions still needed an answer.

Eventually, legislation and regulations need to adapt to the new definitions and categories of road users, the role of operators/drivers, and the decline in vehicle ownership. These challenges are not insurmountable, but they may be meaningful deterrents in the process of promoting AD systems. The fundamental requirement for accelerating the market introduction of automated vehicles is that their use on public roads be permitted by law. To push development and maintain competitiveness, the European automotive industry needs a secure legal framework – both at a national level and globally. For these reasons, the status quo of legislation needed to be investigated as well.

1.5 User-centric approach

The L3Pilot project carried out large-scale piloting of automated driving functions, primarily SAE L3 functions, including some L4 functions related to parking. The key in testing was to ensure that the functionality of the systems was exposed to variable conditions and that the automated vehicle performance would be measurable and comparable between automated and non-automated modes across the test sites. Furthermore, the vehicle performance in the automated mode should be shown to be consistent, safe, and secure. This would bring a successful experience to the users. A good experience of using automated driving systems will accelerate acceptance and adoption of the technology and improve the business case to deploy AD.

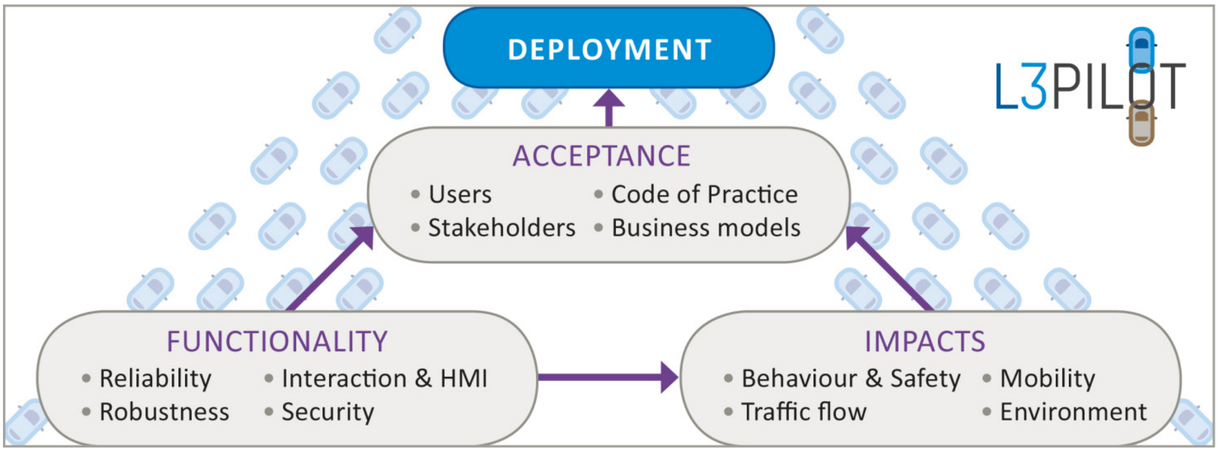


Figure 1.2: L3Pilot approach and the mechanism for deployment.

The aim of the project was not only to pilot automated driving, but also to study user reactions, preferences, and willingness to use the vehicles equipped with AD functions. This information led the consortium to create plans for business scenarios and the deployment of AD. The piloting and supplementary studies carried out paved the way for this target.

User acceptance and attitudes towards AD form a complex and confusing issue. In fact, all separate activities in the project are aimed at user acceptance. Technically functioning automated cars are a prerequisite for acceptance. This is not sufficient, however; we need to know how users interact with automated vehicles. This is especially important in SAE L3 automation, which still requires the driver to take over control when requested to do so by the vehicle, and it occurs not infrequently under a relatively restricted ODD. Dissemination and communication in the project were essential to be able to provide adequate information of the status quo. This information in turn was obtained by piloting in real road conditions as well as from supplementary studies that examined specific questions concerning the driver-vehicle relationship.

Furthermore, a great number of studies and literature provide valuable insights into factors behind user acceptance, revealing scepticism and concerns about AD among potential users. What is missing is a long-term perspective and analysis of the development of acceptance and attitudes towards AD and SAE L3 cars and influencing factors over time. Moreover, a global perspective analysing acceptance is necessary, as future mobility is a worldwide matter, and the mobility market is global but with regional and country-specific differences. Finally, to draw valid conclusions about user acceptance, a differentiated analysis of knowledge, understanding, and expectations towards AD in general and L3 as the next level of vehicle automation was required. The project focused also on these matters to support the deployment of SAE L3 automation (see L3Pilot Deliverable D7.1; Nordhoff et al., 2021).

As a base for deployment, alternative business models for automated driving were elaborated following a service-dominant logic. This required intense collaboration among different stakeholders from various sectors. Accordingly, an appropriate methodology for the design of collaborative and service-dominant business models needed to be applied to describe and analyse future business models to fulfil the L3Pilot concept contents.

2 Methodological framework for European piloting

2.1 Overall methodology

L3Pilot evaluation was built on FESTA methodology (see FOT-Net and CARTRE 2018). However, as this methodology was designed to be applied to field-operational tests (FOTs) with market-ready products, it was not fully suitable for studies with current prototypal ADFs in its original format. Thus, some adjustments to the original ‘V’ structure were needed to enable the testing of prototype automated driving functions in real traffic. The piloting nature of the tests raised some practical and ethical issues and constraints to conclusions drawn from their implementation and expected impacts. To draw valid conclusions from the impacts of the ADFs, the principles for collecting the evaluation data needed to be considered carefully. Consequently, the project adapted the original FESTA V to better describe the needed steps in the work (Figure 2.1). The details of changes made and reasons behind these changes as well as a description of each step can be found in the Deliverable D3.4 *Evaluation plan* (Innamaa et al., 2020).

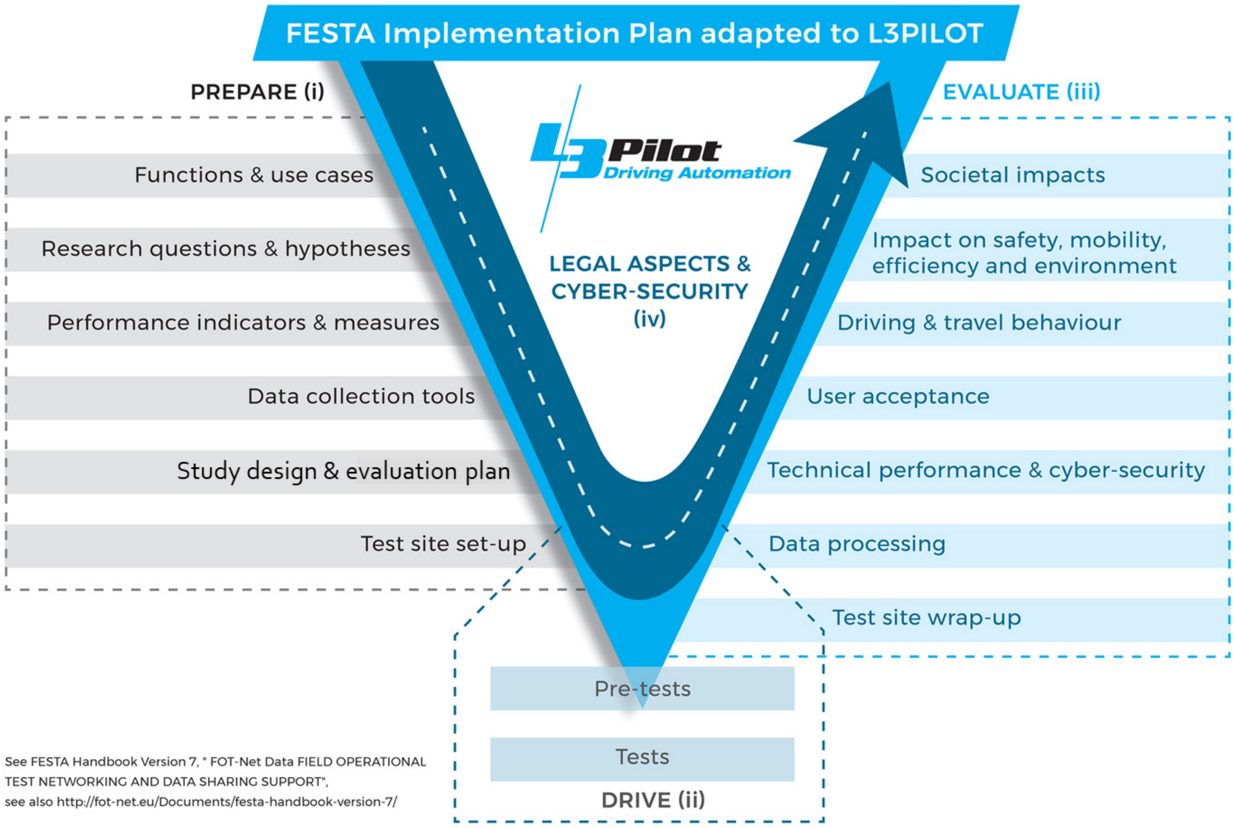


Figure 2.1: FESTA V adapted for the L3Pilot project (Innamaa et al. 2020).

In the PREPARE phase (Figure 2.1), the description of the automated driving functions and use cases of the test vehicles were drawn from the user’s viewpoint of what the vehicle is capable of performing, which operational design domains offer the automated driving functions, and how the test vehicle communicates the availability of ADFs and requests the user to resume control (HMI).

This description was made for the piloted functions as well as for how the vehicle manufacturers assume the mature function will be.

The description of the piloted automated driving functions provides an accurate image of the functions as discussed in the concepts of the taxonomy – see L3Pilot Deliverable D4.1 *Description and taxonomy of AD functions* (Griffon et al., 2019). The report gives a visual presentation of each function by means of icons and graphics. Starting from the consideration that partners will test a number of different functions, the deliverable allows a quick comparison among several kinds of automated functions tested by the different partners. The work on taxonomy supported the grouping of AD functions into consistent classes. Two kinds of taxonomies were proposed: the first provides a general understanding while the second is more detailed and directed at the technical applications. In line with the main driving scenarios, functions were grouped into *Motorway functions*, *Traffic Jam functions*, *Parking functions*, and *Urban functions*.

The evaluation methods for the developed functions were proposed and discussed thoroughly in the Deliverable D3.3 *Evaluation methods* by Metz et al. (2019). That work defined the methods that can be used for datasets collected at different pilot sites with the aim of combining the results across the pilot sites. The methods ensured that the research questions are addressed in the data analysis. Furthermore, the methods had to ensure that the parts of the analysis dealing directly with the data from the on-road tests (technical and traffic evaluation, user and acceptance evaluation) provide the necessary information needed for estimating the impact of ADF on road traffic in Europe (impact assessment) and, in a next step, on society (socio-economic impact assessment). The decision on final details of the methodology was the task of SP7 Evaluation, when the quality of the data could be assessed (see L3Pilot Deliverable D7.1 by Nordhoff et al., 2021; D7.2 by Metz et al., 2021; D7.3 by Weber et al., 2021, and D7.4 by Bjorvatn et al., 2021).

The second step of the preparation phase defined research questions and hypotheses. These began with the theories behind the evaluation areas and with an early description of the functions and use cases. The feasibility of the research questions was verified for the data availability, test design, and availability of research tools and methods, as well as time and human resources. Prioritisation was needed to select the final list of research questions. The research questions defined for L3Pilot totalled 11 main questions (Level-1) in four evaluation areas: technical and traffic evaluation, user and acceptance evaluation, impact assessment, and socio-economic impact assessment. More detailed questions were developed where appropriate. In all, there were 37 Level-2 and 68 detailed Level-3 research questions. The process of defining the research questions is described in the Deliverable D3.1 *From research questions to logging requirements* (Hibberd et al., 2018) and the final list of research questions is found in D3.4 *Evaluation plan*.

The third step was to define (i) the performance indicators needed to enable the research questions to be answered, (ii) the derived measures that were needed to calculate these indicators, and (iii) the signals that were needed to calculate these measures. The performance indicators and derived measures for the research questions are explained in the Deliverable D3.1 *From research questions to logging requirements*. That activity led to the common data format (CDF) for the signal level data (Hiller et al., 2019). This format followed a dialogue between the evaluation team, the vehicle owners, and the team developing pilot tools and data processing. The common data format that was developed enabled the use of common data processing tools in the evaluations.

The fourth step, defining the data collection tools, was a task for all the pilot sites in the preparation phase, and it involved locating and developing data collection tools capable of logging the data agreed in the previous step – the common data format, in the case of L3Pilot (Hiller et al., 2019). This step also included the definition and development of databases to store the data for the different phases of processing and analysis, and the planning of additional supplementary data collection methods to facilitate answering the research questions.

The fifth step consisted of defining the study design and the evaluation plan. An important step in the preparation of the pilots was to agree on the study design to be implemented across the pilot sites. This included selecting the test routes and test persons, executing the user tests, collecting the baseline and treatment data, etc. Here, the evaluation team needed to anticipate and plan for how to utilise the controlled tests on open roads and supplementary studies to collect the data needed for the evaluation. See the Deliverable D3.2 *Experimental procedure* for the definition of experimental procedures and D3.4 *Evaluation plan* for an update of recommendations for the AD pilots. In this step, the evaluation plan was defined for all the research questions concerning evaluation methods (tools, data needs) to plan how the collected data would be used and what additional data or information was needed.

As the last step of the PREPARE phase, the test site setup, an active dialogue between the evaluation/methodology team and the pilot site, was required to ensure that the agreed experimental procedures were correctly understood and implemented across all the test sites. In the L3Pilot project, an evaluation partner was assigned to each pilot site to plan the practical tests together. Each evaluation partner was also responsible for the analysis and processing of the field data from the respective pilot site. Therefore, the details of the field experiments needed to be fully understood.

The DRIVE phase included the pre-tests and the actual tests. The pre-tests included running all the phases of the project on a small scale to ensure that all the processes and tool chains functioned as intended. This included setting up the hardware and software for data acquisition, implementing all the safety and quality assurance procedures, dealing with legal issues, selecting and instructing the driver, and finally managing the actual experiments on the road. The test phase also included limited data collection of both objective and subjective data and a preliminary analysis of the data.

The first step of the EVALUATE phase was the test site wrap-up, which delivered the collected data and metadata for evaluation. Before delivering the data, the pilot sites handled the data processing and converted their raw data into the common data format. The evaluation partners processed this data according to the commonly agreed principles and tools. They also uploaded the data to a consolidated database for later use by the other evaluation partners in different evaluation areas.

The evaluation of technical performance and cybersecurity was aimed at understanding the system that the users experienced in the field tests. The results related to the technical performance are presented in the Deliverable D7.3 *Pilot evaluation results* by Weber et al. (2021). Due to the prototype nature of these products, cybersecurity was not evaluated. However, advanced techniques for ensuring secure data management were investigated.

The evaluation of user acceptance focused on users' experiences and their acceptance of the tested automated driving functions. The results are presented in the Deliverables D7.1 *Annual quantitative survey about user acceptance towards ADAS and Vehicle Automation* by Nordhoff et al. (2021), D7.2 L3/L4 *Long-term study about user experiences* by Metz et al. (2021) and D7.3 *Pilot evaluation results* by Weber et al. (2021).

Driving and travel behaviour evaluation focused on understanding the changes that the introduction and use of ADFs would bring about. These changes were reflected in the subsequent phases of the evaluation. Driving behaviour was addressed in the Deliverable D7.3 *Pilot evaluation results* (Weber et al., 2021). Travel behaviour evaluation was included in the Deliverable D7.4 *Impact evaluation results* by Bjorvatn et al. (2021) under mobility impact assessment.

The next phase of the evaluation assessed automated driving impacts on safety, mobility, efficiency, and the environment. These results were then scaled up to the EU level utilising the data and results from the driving and travel behaviour evaluation and the user acceptance evaluation. Finally, societal impacts were assessed using the results of the previous step in the cost-benefit analysis. The Deliverable D7.4 *Impact evaluation results* (Bjorvatn et al., 2021) reports these findings.

2.2 Experimental procedure

When designing experimental procedures for a pilot study, the differences between Field Operational Tests (FOTs) of close-to-market products and pilots of prototype systems was acknowledged. These differences were addressed in the Deliverable D3.4 *Evaluation plan* (Innamaa et al., 2020).

The experimental procedure that was presented in the Deliverable D3.2 *Experimental procedure* (Penttinen et al., 2019) was developed to provide a solid basis for the evaluation methodology. It also helped to ensure that the results from the tests across all pilot sites made a L3Pilot-wide evaluation possible, also considering the practical limitations of the tests' implementation. Furthermore, the aim was to harmonise the evaluation criteria by providing detailed recommendations for the pilots for a comprehensive evaluation of the data collected.

Experimental procedures began with a review of available information related to various approaches for data collection, the selection of the test persons, and an experimental design. The experimental design covered some aspects of the FESTA-V 'Prepare' phase (Figure 2.1). It was first determined which approaches would be applied to the data collection in the pilots (i.e., whether the approach would be subjective, such as surveys, or objective, such as an experimental study or simulations). The definition of participant types was closely related to the approaches – the selection of test participants, the generalisation of the findings to the larger population, and the optimal sample size required to ensure sufficient statistical significance. The experimental design encompassed several topics (within- versus between-participants design, pre- and post-measurements, definition of baselines, variable types). This made it possible to determine the framework for both the data collection and analysis. The pros and cons of each of these approaches, participant types, and experimental designs were analysed, also taking into consideration the goals and constraints of the project. Finally, at the end of the theoretical analysis, recommendations for the research questions were listed.

To provide the needed practical support for piloting, on-site support visits were made to every pilot site and to the partners responsible for the experimental procedure. The visits also included the partners responsible for the evaluation and the persons in charge of the pilot sites. The visits were planned for discussing and reviewing the pilot test plans. Feedback was received and fed into the preliminary plans, and several points critical to the success of piloting and evaluation were checked during the visits.

Finally, a list of practical recommendations was drawn up to help the pilot sites finalise their preparations for the piloting. The results are reported in the Deliverable D3.2, and an update to the recommendations based on the feedback and remarks by the pilot sites when the tests were already ongoing is found in Deliverable D3.4.

2.3 Evaluation methods

2.3.1 Overview of the evaluation areas

The evaluation procedures focused on four primary areas of analysis:

1. *Technical and traffic evaluation* assessed the effect of the ADF on vehicle behaviour and the surrounding traffic based on data logged directly in the on-road tests.
2. *User and acceptance evaluation* assessed users' evaluation and acceptance of automated driving functions and behaviour when using the functions.
3. *Impact assessment* extrapolated these results and assessed the potential impacts of so-called mature ADFs on personal mobility, traffic safety, traffic efficiency, and the environment.
4. *Socio-economic impact assessment* utilised the above analyses to determine monetary values for the estimated effects, as well as weighing expected costs and benefits of the ADFs.

Traffic simulation was the primary method for assessing the impacts of ADF on traffic safety, traffic efficiency, and the environment, while personal mobility assessment mainly utilised results from the user evaluation. Based on these estimated impacts, the socio-economic impact was assessed in area 4 (above) of the analysis.

The evaluation areas not only addressed different aspects of the evaluation but also worked with different datasets. In Figure 2.2, the blue area indicates the datasets that were used for the different analysis areas and their topics, e.g., the socio-economic impact evaluation made use of a cost-benefit analysis featuring aggregated data, whereas acceptance was investigated by using the data from single vehicles and the data combined at a fleet level. The research questions were defined for all the different areas, and they are listed in the Deliverable 3.1 (Hibberd et al., 2018).

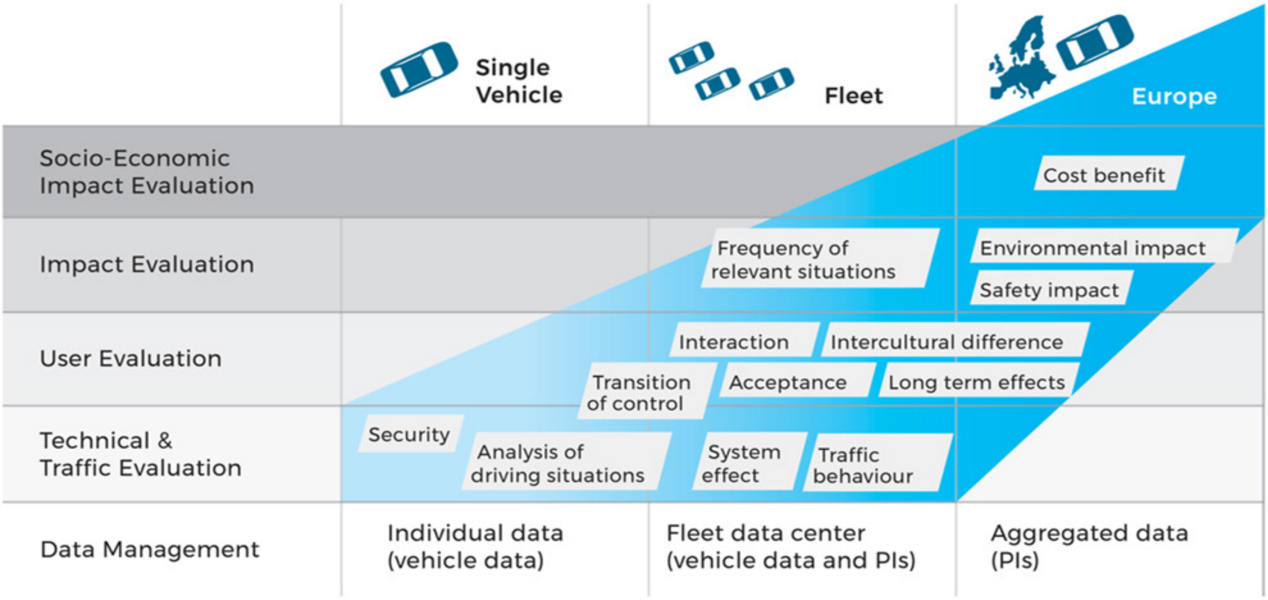


Figure 2.2: Evaluation areas and the scope of assessment.

2.3.2 Technical and traffic evaluation

The objective of the technical and traffic evaluation was to answer the research questions related to technical performance and the effects resulting from an automated system's behaviour in traffic. Different effects were evaluated by comparing the defined performance indicators. These indicators were numerical values that could be compared between the baseline and treatment conditions. Performance indicators were scalar values that could be evaluated and compared between the two conditions. Values considered statistical parameters such as minimum, maximum, mean, and standard deviation. Furthermore, the frequencies of certain events per time or distance were compared. See the Deliverable D3.4 *Evaluation plan* (Innamaa et al., 2020) for the full methodology.

A distinction was made between the performance indicators that were evaluated per trip, such as the frequency of given events or scenarios, and others that were evaluated per driving situation. In this case, a trip generated multiple values per performance indicator to be considered for evaluation due to instances of the driving scenario appearing multiple times during a trip. A driving scenario is a short period of driving defined by its main driving task (e.g., car following, lane change) or triggered by an event (e.g., an obstacle in the lane). For all performance indicators, a mapping between the indicators and driving scenarios was generated. This was to show which performance indicators delivered meaningful values in different scenarios. More information on this is given in the Deliverable D3.3 *Evaluation methods* (Metz et al., 2019).

2.3.3 User and acceptance evaluation

A multifaceted user & acceptance evaluation approach was used to form a comprehensive view of user behaviour with automated driving functions and their acceptance. The design of this approach was underpinned by the research questions. The project employed several quantitative and qualitative data collection methods to provide data to answer the research questions. These methods focused primarily on piloting, including pilot site questionnaires, videos of the driving scene, recordings of the driver's head, hands, and posture during the pilot, and vehicle-based data. Data were also collected from supplementary studies (see Chapter 5), including driving simulator and Wizard-of-Oz studies, and a large-scale global survey (Chapter 6.6). See also the Deliverable D3.4 *Evaluation plan* by Innamaa et al. (2020) for the full methodology.

2.3.4 Impact assessment

The impact assessment did not focus on the prototype implementations that were addressed in the technical & traffic and user & acceptance evaluations. This is because the aim of impact assessment was to study the potential impacts of *mature* ADFs from the perspective of their use on a large scale. It is expected that the ADFs will be further developed than those tested in L3Pilot. Therefore, so-called mature functions were defined to represent future ADFs. In the mature function descriptions, the ODD under which the functions are assumed to work was specified. The mature function descriptions were developed in cooperation with the evaluation/methodology team and ADF developers. Thus, they took into account the knowledge from the project work and used it to represent our current knowledge of ADFs that are considered mature enough to be used by consumers*. It is important to note that the defined mature ADFs do not represent any given L3Pilot ADF tested at any of the pilot sites. Rather, they provide a generic description of how these ADFs could look once having penetrated the market on a large scale*. See the description of the mature ADFs in the Deliverable D3.3 *Evaluation methods* (Metz et al., 2019).

<u>Mobility impact assessment</u>

The mobility impact assessment used a multidisciplinary approach to define the potential mobility impacts of ADF, and to further answer questions about potential impacts on actual travel exposure. The focus was on the three points of view described in the FESTA Handbook: amount of travel, travel patterns, and journey quality. The overall approach had four major steps: (i) description of the currently realised mobility behaviour, (ii) identification of the scope of the impacts by analysing the proportion of current trips on which ADFs would be available and who would be the first to start using them, (iii) assessment of the potential impacts for all the research questions, and (iv) scaling-up of some of the potential impacts into quantitative estimates relative to the current travel behaviour (actual trips made), which we call realised mobility. Scaled-up impacts were important considering the implications of the mobility impacts for efficiency, the environment, and safety, as changes in mobility also affect travel exposure.

<u>Safety impact assessment</u>

For the safety impact assessment, the scenarios were divided into those in which technology reduces risks (typically the scenarios in which something goes wrong, and hence an accident happens), those that are not directly affected by the technology (for instance scenarios outside the ODD of the mature L3Pilot ADFs), and those in which potentially new risks occur (e.g., due to a minimum risk manoeuvre). For a comprehensive assessment, it was necessary to analyse all potential scenarios – positive as well as negative. The basic principle was to investigate the effects of ADF in dedicated scenarios – which consisted of driving scenarios and more detailed traffic scenarios. The evaluation of the effects was based on sophisticated stochastic computer simulations and injury risk functions, complemented by other methods where simulations were not feasible. The results were then scaled up at a later stage to EU27+3 (all EU member states + UK, Norway, and Switzerland) based on statistics from the European-wide CARE accident database, national, and in-depth accident databases.

Efficiency and environmental impact assessment

The efficiency and environmental impact assessment focused on the impacts of ADF on traffic efficiency and the environment in terms of changes in macroscopic traffic flow such as travel times, throughput, and greenhouse gas emissions. Both direct and indirect impacts were considered. Direct impacts are those resulting from changes in individual vehicle operation, such as differences in speed or in time headway. Indirect impacts derive from changes in other impact areas: changes in the number of accidents and incident-induced congestion, or changes in mobility behaviour and consequently in vehicle kilometres travelled (VKT). The direct effect was investigated by means of a traffic microsimulation software of numerous different road sections with respect to road layout (number of lanes, with and without ramps), speed limits, and different traffic scenarios (volume, fleet composition). Impacts on the environment were studied with an emissions modelling software calculating the emissions for the traffic simulations. The outcome of the simulations was assessed across the simulation runs of baseline and treatment conditions for each scenario as well as by comparing the two conditions by means of standard statistical approaches. The scale-up was based on simulated effects and estimated VKT driven inside ODD with the ADF in use.

Socio-economic impact assessment

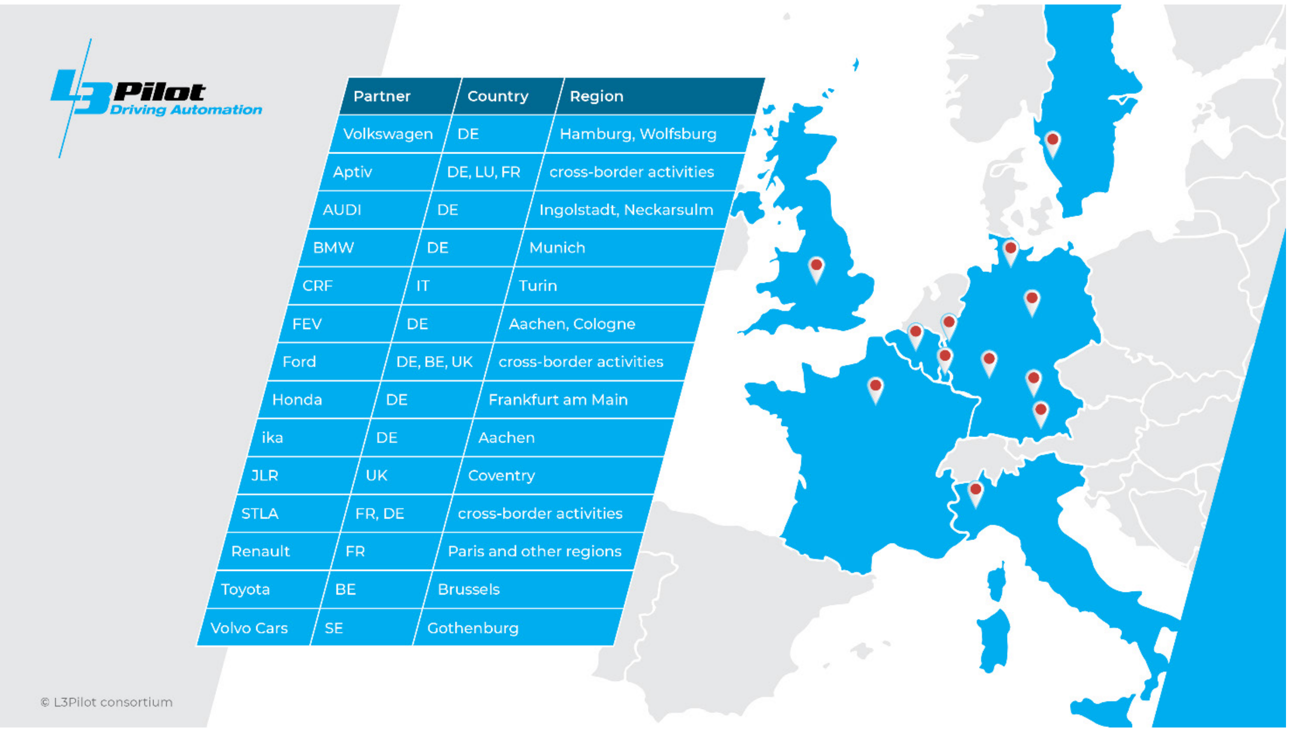
The socio-economic impact assessment considered the net welfare effect for society with regard to L3 automated driving functions. The net welfare effect or gain for a society is the difference between benefits and costs to the society and its stakeholders. The purpose of the assessment was to clarify whether the benefits of equipping vehicles with ADFs outweigh their costs. If this is the case, the implementation of the technology is considered beneficial to society and/or its stakeholders. Given that the traditional and widely used cost-benefit analysis approach was not applicable in L3Pilot, a snapshot approach was chosen for quantifying the socio-economic impacts. The socio-economic impact assessment further included qualitative considerations of unquantifiable impacts, also when interpreting the empirical findings in the snapshot approach.

See the Deliverable D3.4 *Evaluation plan* for the evaluation methods (Innamaa et al., 2020) and the Deliverable 7.4 (Bjorvatn et al., 2021) for the results.

3 Pilots

3.1 Test areas and functions

A total of fourteen partners – including car manufacturers, automotive suppliers, and research institutes – executed the pilots on motorways, urban networks, and in parking scenarios. The pilots, which began in spring 2019, involved seven countries: Belgium, Germany, France, Italy, Luxembourg, Sweden, and the United Kingdom, and included two cross-border activities (Germany – Luxembourg and Germany – Belgium – United Kingdom). The pilot sites were led by Volkswagen, Aptive, Audi, BMW, CRF, FEV, Ford, Honda, ika/fka, JaguarLandRover, Toyota Motor Europe, Group PSA, Renault, and Volvo Cars (Figure 3.1 below).



Partner	Country	Region
Volkswagen	DE	Hamburg, Wolfsburg
Aptiv	DE, LU, FR	cross-border activities
AUDI	DE	Ingolstadt, Neckarsulm
BMW	DE	Munich
CRF	IT	Turin
FEV	DE	Aachen, Cologne
Ford	DE, BE, UK	cross-border activities
Honda	DE	Frankfurt am Main
ika	DE	Aachen
JLR	UK	Coventry
STLA	FR, DE	cross-border activities
Renault	FR	Paris and other regions
Toyota	BE	Brussels
Volvo Cars	SE	Gothenburg

Figure 3.1: L3Pilot test areas.

All vehicles were specifically built and had a tailored sensing, decision, and actuation system for the tests. In particular, they were equipped with sensors to detect the road environment (including cameras, radar, LiDAR, ultrasonic sensors) and control systems to enable the lateral and longitudinal control of the vehicle in all different scenarios under the given operational design domain. During the driving sessions, data on the system performance and driving experience were collected: single or multiple video streams and around 415 signals from vehicle sensors were recorded in the test vehicles with a frequency of up to 10 Hz.

The data were processed to enable the evaluation of the technical performance of the automated vehicles as well as the impacts of automated driving from users' and societal viewpoints. For example, a video camera recorded the subject's facial expressions and gestures. This specific information was used to evaluate the interaction between the driver and the vehicle. Data were also collected to evaluate vehicles' functioning in traffic, e.g., interaction with other vehicles, bicycles, and pedestrians; approaching traffic lights or a motorway junction; and the use of vehicle-to-x communication.

In addition to the data recorded before and after the test drives, the subjects' opinions, attitudes, and experiences were collected using questionnaires. This information provided insights into user experiences in driving SAE L3 automated vehicles.

The project focused on SAE L3 automated driving functions on motorways and in urban traffic, with SAE L4 functions targeted exclusively to parking and close-distance scenarios. The SAE L3 features conditional automation, which requires that the driver respond appropriately to a request to take over vehicle control for a fall-back manoeuvre (Figure 3.2). In the event that the driver does not respond properly to a take-over request, the vehicle eventually performs an automatic minimum risk manoeuvre to safely stop the vehicle.

Figure 3.2: Graphical representation of the SAE L3 automation level.

The ADFs piloted in the project are still in a prototype phase. However, they reflect the state of the art from the industrial partners, and they have been designed to consider the characteristics of the different vehicles specifically upgraded for the project. The L3Pilot functions tested in the different pilot sites were the following:

Traffic Jam Chauffeur at SAE L3 relieves the human driver from exhausting manual driving during traffic jams. On motorways and similar roads, the car takes over the driving in the traffic jam sections up to 60 km/h. When the detection of slow-driving vehicles in front indicates a traffic jam, the function can be activated. In some instances, the car changes lanes to react to a slower vehicle ahead or to the road infrastructure, as in the case of exit lanes.

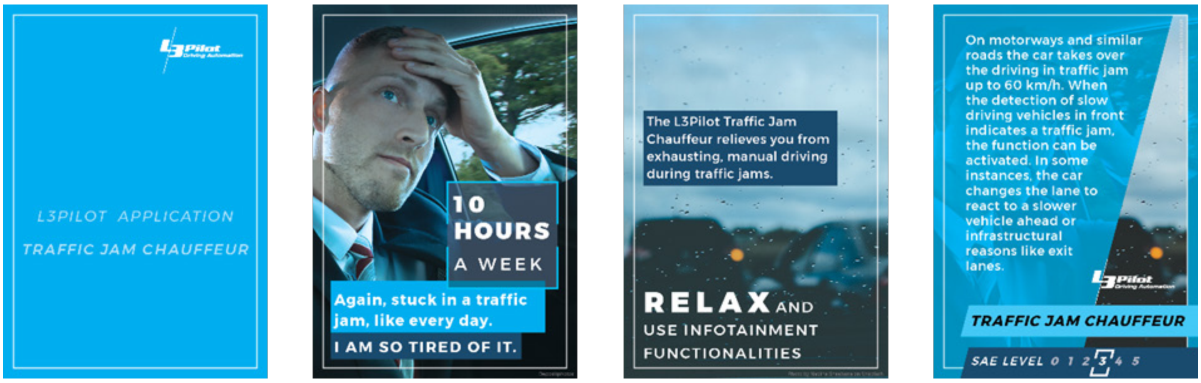


Figure 3.3: SAE L3 Traffic Jam Chauffeur.

Motorway Chauffeur at SAE L3 enables the car to adapt to various traffic conditions up to 130 km/h. The car follows the lane and adjusts speed according to various factors such as keeping a safe distance to the vehicle in front or maintaining the speed limit. If a preceding slower vehicle is detected, the car overtakes automatically as soon as it is safely possible.

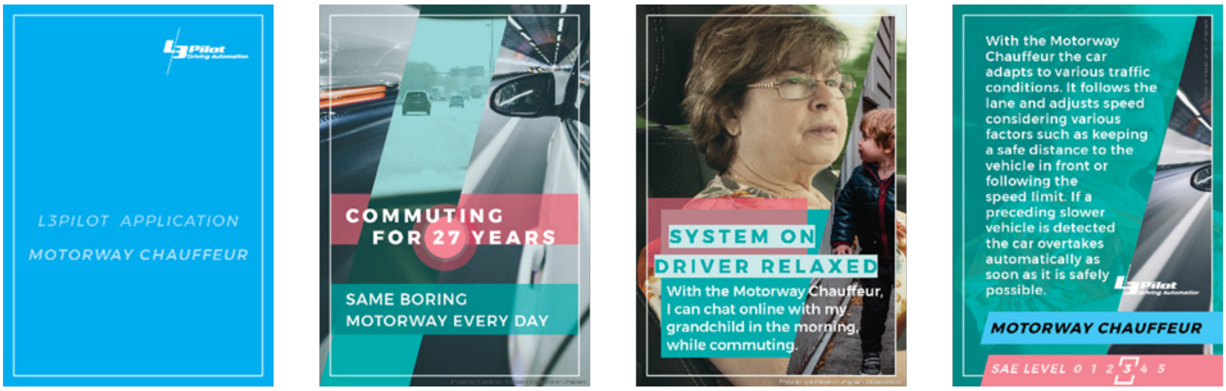


Figure 3.4: SAE L3 Motorway Chauffeur.

Parking Chauffeur is a vehicle function that allows the user to request their vehicle to complete manoeuvring into and out of garages and driveways. The car either learns a fixed trajectory from the entrance of the house to the home garage and vice versa or determines a suitable manoeuvre to enter or pull out of a nearby parking position. This automated driving feature relieves the driver from repeating parking manoeuvres. Depending on the ODD, the Parking Chauffeur has also been tested at SAE L3 or L4, namely without the need to hand over vehicle control to the human driver in the event that a fall-back manoeuvre is required.

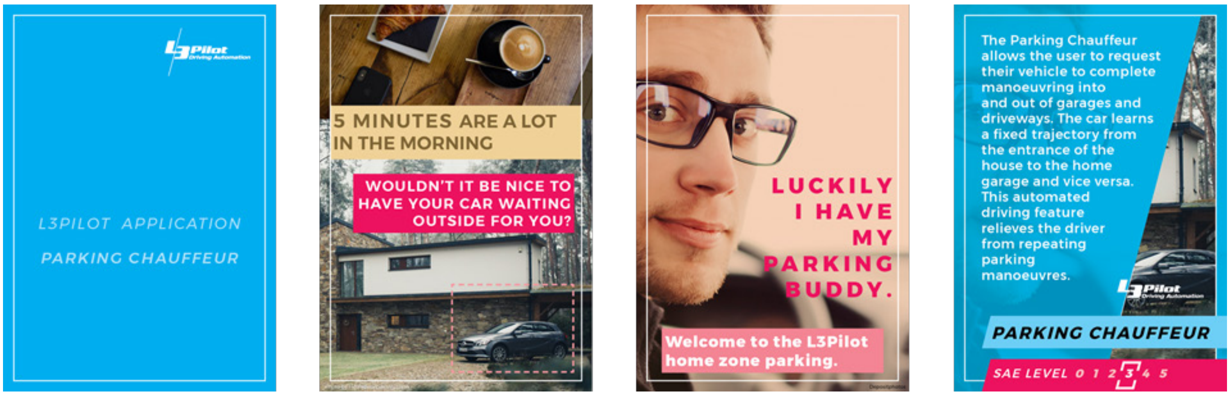


Figure 3.5: SAE L3-4 Parking Chauffeur.

Urban Chauffeur at SAE L3 targets stress-free driving in urban areas. With the Urban Chauffeur activated, the vehicle automatically follows the lane, starts and stops, and handles overtaking in cities. When arriving at a crossing the car handles right and left turns, recognises on-coming traffic and vulnerable road users such as pedestrians, and selects the correct crossing path, even if no lane markings are present.

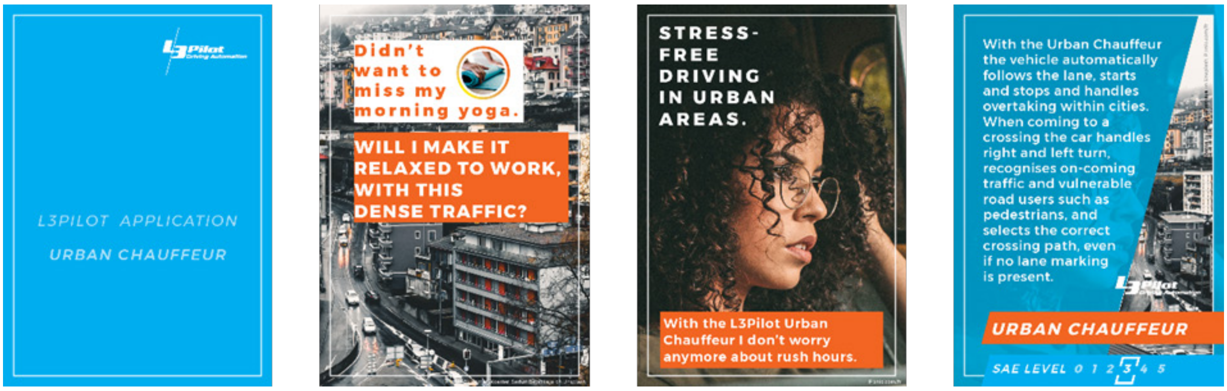


Figure 3.6: SAE L3 Urban Chauffeur.

3.2 Fleet

The project equipped a total of 70 vehicles for large-scale piloting: 70 for the motorway environment, 8 for parking, and 6 for urban situations. The fleet comprised 13 different vehicle types, from a compact passenger car to an SUV. In addition to these vehicles, further test vehicles were equipped for use in the supplementary experiments.

Figure 3.7 below shows an example of the pilot vehicle by ika/fka with its sensor system. The vehicle also provides a general description of the sensor systems used in the pilot vehicles. There are naturally brand-specific features in the pilot vehicles, but in practice all vehicles cover their surrounding area with a sensor suite consisting of near-field and long-range sensors. The data from various sensors are fused to provide status information of the vehicle's surroundings for the decision-making involving HMI and/or possible actuation.

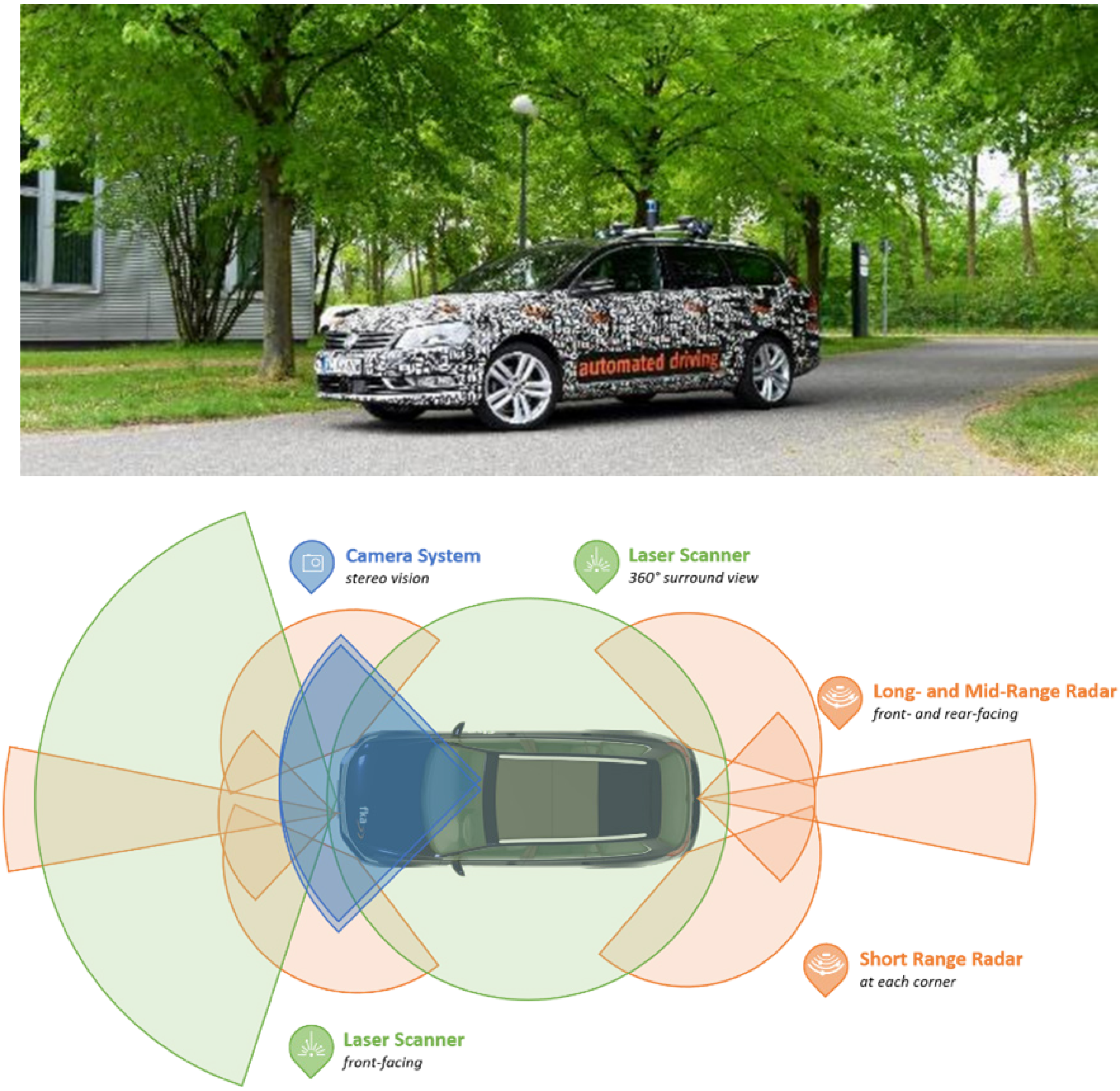


Figure 3.7: Ika/fka pilot vehicle.

Below is shown a group figure of different vehicle brands participating in the pilots (Figure 3.8). The piloting fleet consisted of different vehicle types, from normal family cars and SUVs to high-end sedans.

Figure 3.8: A collection of piloting vehicles.

3.3 Subjects

For the large-scale piloting over 750 persons were recruited for the road tests. The subjects tested automated driving of SAE L3 either as regular test drivers or as passengers.

The test persons participating in the pilots were selected on the basis of the specifications provided by the methodology team. The team established a comprehensive piloting methodology based on all the research questions to be answered by the project. The specific instructions for the selection of participants are found in the Deliverable 3.2 (Penttinen et al., 2019) which also includes further details of the methodological aspects of the piloting phase.

The requirements for recruiting test persons concerned mainly two aspects: user selection criteria and sample size. At the same time, the recruitment process had to cope with the fact that in several cases vehicles were subject to vehicle owners' rules that limited test drivers to company employees or even professional drivers. The recruitment considered the representativeness of the test drivers to the driving population as a whole and to potential users of the system. The more test users with different backgrounds, age, and preferences, the more representative the results would be. This also included the gender balance.

Furthermore, the recruited drivers had to undergo what is known as an *informed consent procedure*. The purpose of the informed consent procedure is to explain the tests in detail to the subjects and to ensure that they understand the different aspects of participation. The information includes details about the test, data handling, potential risks, and the responsibilities of the participant and the organisation performing the test. Informed consent was mandatory in the L3Pilot project.

The legal settings differ throughout Europe, with national regulations affecting the performance of the tests. Still, the topics to be addressed in an informed consent form were the same, as was part of the content. In order to ensure that vital elements would be included in all consent forms across

L3Pilot, an informed consent checklist was developed. See the Deliverables 8.1–8.3 by Gellerman et al., 2019.

Ethical Requirements No.1 – No.3, Annex 2 (Gellerman et al., 2019) were also considered. Each test site followed the checklist and prepared a consent form in compliance with Art. 7 of the GDPR [Regulation (EU) 2016/679].

Due to safety regulations, the vehicle owners had specific requirements for who was allowed to drive the prototype vehicles used in pilots. Two aspects were taken into account when working with the company drivers. First, they have a different relationship towards the product due to their employment. This was assumed to have an influence on the attitude and perception of the systems and could bias the evaluations of the automated systems. Second, the developer bias could influence the behaviour of the drivers due to their expectations and knowledge about the system. This applied to baseline driving and interaction with the automated system. For this reason, when company employees and professional drivers were the only ones allowed to drive the piloting vehicles, *the selection needed to exclude those who had been involved in the design and development of the vehicle AD systems*.

During the road tests a professional driver served the same function as a driving instructor, with double vehicle controls available on the passenger side to provide the possibility to intervene in driving if necessary. This driver was usually called *a safety driver* and served as a supervisor and backup in the event of an emergency. Such a procedure was mandatory when testing prototype systems in normal traffic.

3.4 Tests – Preparing for pilots and the procedures

First, pre-tests were needed to ensure that the methodology developed could be executed as planned. Since the piloting process was complex and included a number of situations that could go wrong, advance testing was necessary to uncover all possible sources that could jeopardise successful piloting. Previous road tests have taught how important it is to reserve enough time for this phase. It ensures that possible pitfalls and bottlenecks can be solved before entering the actual road tests. Correcting errors during the subsequent road test phase throughout the European test community would have been time-consuming and would have affected the project's timetable.

All pilot site leaders carried out their own pre-tests on their own pilot site for the defined main scenarios (urban, motorway, traffic jam, and parking). The core activities of the pre-test phase consisted of a set of tasks that can be summarised as follows:

- All pilot test vehicles went through a final check to ensure that each installed automated driving function was working technically as planned, including the specific installations for data recording.
- The preparation and administration of specific training courses for safety drivers was required by each pilot site.

- The recruitment of test persons had to include ordinary drivers (without prior experience on intelligent vehicle safety systems) as well as professional drivers, to ensure the safe operation of vehicles.
- Documentation had to be prepared and issued in order to obtain the permissions necessary to execute the pilots in the different countries, including specific technical tests when requested.
- The data toolchain needed to be tested and fine-tuned to ensure that the data could be managed as planned from in-vehicle recording all the way to the statistical treatment of the data.

Special emphasis was placed on the L3Pilot data toolchain functionality during the pre-test phase to: (i) assess the maturity of the tools used for the data analysis and (ii) verify the quality of the data recorded and converted to the common data format (CDF). Therefore, all tools were adjusted to the data available from the pre-test phase. The test results from each processing step were assessed regarding their suitability for the data analysis.

As has been explained, the L3Pilot project focused on the first European large-scale piloting of automated driving functions, primarily SAE L3 functions, including additional assessment of some L4 functions for parking and close-distance scenarios.

A more detailed description of the tested functions and their grouping (Figure 3.9) in feasible ODD including infrastructure requirements, road and traffic environment, weather, etc. is given in the Deliverable D4.1 (Griffon et al., 2019). Since L3Pilot is a pre-competitive collaboration project, the anonymisation of the automated driving functions was a pre-requisite to protect the individual business interests of the vehicle owners. At the same time, in light of the global advent of the first marketable AD applications, the entire consortium strongly benefits from the L3Pilot pre-competitive collaboration. The data sets recorded and pre-processed from the different pilot sites were analysed, fused, and reported as mean figures for each automated driving function across the test sites. No brands could be identified from the data. Consequently, a comparison and benchmarking of the different systems during the pilot tests was avoided, which was an important factor for the successful future deployment of the systems.

Figure 3.9: Grouping of L3Pilot Automated Driving Functions.

The test persons drove more than 400,000 kilometres on motorways, including 200,000 km in an automated mode and 200,000 km manually as a baseline to compare user experiences and the evaluation of impacts. More than 24,000 km were travelled in the automated mode in urban traffic.

Most of the studies that involved ordinary drivers on the driver seat included a driving time of 1 to 1.5 hours per drive (ranging from 60 km to 133 km). However, some drives were as short as 30 minutes, and others took as long as 6 hours. All studies were conducted in daylight with clear, cloudy, or light rain weather conditions – there was no testing in extreme weather like in heavy rain or snow conditions, and only limited trials were conducted at night-time.

In some studies, the participants were allowed to take their eyes, hands and mind off the driving during the automated drive and to engage in a non-driving related activity (NDRA), but in other studies, this was not possible. Drivers were required to take over control when prompted, when they reached the end of the ODD of the piloted system. To request drivers to take over, the vehicle provided both auditory and visual HMIs in all cases, although the design of HMI varied across systems, and the time when the drivers were informed of an upcoming take-over request also varied. Moreover, the drivers were also informed when AD was available by means of both visual and auditory cues.

Pre-experimental briefings were conducted in all studies, where drivers were informed about the organisation of the experiment, system functions and limitations, how to activate and deactivate the ADF, and the route. They were instructed to respect the rules of the motorway code during manual driving, and to keep safe and regulatory distances from the surrounding traffic. Where applicable, the drivers were informed about the cameras installed in the vehicles. They were also informed about the role of safety drivers, and whether they were allowed to engage in non-driving-related activities. In most studies, practice drives were conducted before the test drives. The objectives of the practice drives were to familiarise drivers with the dynamics of the vehicle, the activation and deactivation of the system, manual drive and automated drive, and to understand the capabilities and limitations of the vehicle. Practice drives lasted from 15 to 30 minutes either on a motorway or on a test track.

The number of test drives per participant varied from one to three depending on the study. The time between studies ranged from days to months. Drivers were told that they had full responsibility for the vehicle during manual driving. When the ADF was available, they should activate the system. In some studies, drivers were allowed to engage in a non-driving-related activity (NDRA) but they were asked to take over control when prompted. However, in some other studies, local regulations did not allow the test drivers to engage in NDRAs since the piloting vehicles were still in the prototype phase. All drivers were compensated for taking part in the study, with the exception of company test drivers.

Safety drivers were present in the vehicle unless it was a Wizard-of-Oz study. When safety drivers were present, they usually sat on the front passenger seat, and in some cases a technician sat on the back seat monitoring the system with screens. The role of the safety drivers included hazard monitoring, prompting the driver to take over during critical situations, in some cases taking over control themselves (i.e., when the technician informed the safety driver that the system was no longer working), monitoring the system, and supervising the safety and appropriate conduct of the study. Otherwise, the safety drivers were asked not to interact with the drivers and to minimise interruptions and distractions. Safety drivers only intervened in the event of dangerous situations or technical failures, at which time participants were instructed not to touch the controls and to let the safety driver drive.

In *motorway automated driving studies* where it was not possible for ordinary drivers to operate the vehicle, the vehicle was driven and supervised by a professional driver. When the automated mode of the vehicle was activated, the safety driver continued to supervise the vehicle in order to override the system in the event of critical situations. For some systems, it was necessary for the safety driver to confirm the lane change decision of the vehicle before a lane change was executed. The safety drivers were not allowed to engage in NDRAs during the automated operation.

For the majority of pilot sites, it was also necessary to collect the baseline data with professional safety drivers. In such cases safety drivers were not instructed to follow any particular driving style.

Urban automated driving studies were conducted on busy and non-busy multiple-lane urban roads including signalised and non-signalised intersections, pedestrian crossings, traffic lights, and the presence of bicycle lanes. The speed limit of urban roads was 50 km/h. The urban ADF was able to detect VRUs such as pedestrians and cyclists. Studies were also conducted in daylight, cloudy, sunny, and light rain conditions, but not in adverse weather.

The testing locations were in Brussels, Aachen, and Hamburg. The length of the test routes varied from 2.4 km to 2.8 km, and the duration of the drives was 10–40 minutes. As most of the participants were passengers, visual and auditory signals and messages were presented to the safety drivers for taking over the controls and also to inform the safety drivers when the AD system was available.

The test persons sat either on the front passenger seat or on one of the rear seats, and were asked to focus, observe, and experience the urban ADF, but in some studies, participants were allowed to engage in a secondary task because they were the passengers and not the driver. A pre-experimental briefing was conducted, whereby participants were informed about their roles, test routes, and the duration of the study. They received a brief description of the urban ADF, which included capabilities (i.e., to detect VRUs), limitations (i.e., still a prototype and not at the production level; not suitable for adverse weather). In some studies, participants were not allowed to ask questions during the experiment but were allowed to do so at the end. Some participants were also asked to imagine that they were sitting on the driver's seat and would need to be aware of take-over requests from the vehicles.

Safety drivers in these studies were seated on the driver's seat, and their role was similar to the role of safety drivers while testing the Motorway ADF. However, as the participants were the passengers, the safety drivers did not have to warn the participant or take over control from the participant. The driver simply took over control when requested by the system or when the driver felt that it was necessary.

3.5 Data management and consolidated database for the evaluation

A consolidated database (CDB) was designed and built for data management and analysis to enable the sharing and fusing of the data from all the pilot sites (Figure 3.10). The CDB made it possible to analyse all the data and answer the defined research questions. The research questions aimed at an analysis of vehicle/driver performance in different driving scenarios and experimental conditions (automated driving function off vs. automated driving function on), road types (e.g., motorway, urban), and specific driving scenarios, such as cut-in, approaching a lead vehicle, following a lead vehicle, driving in a traffic jam, etc.

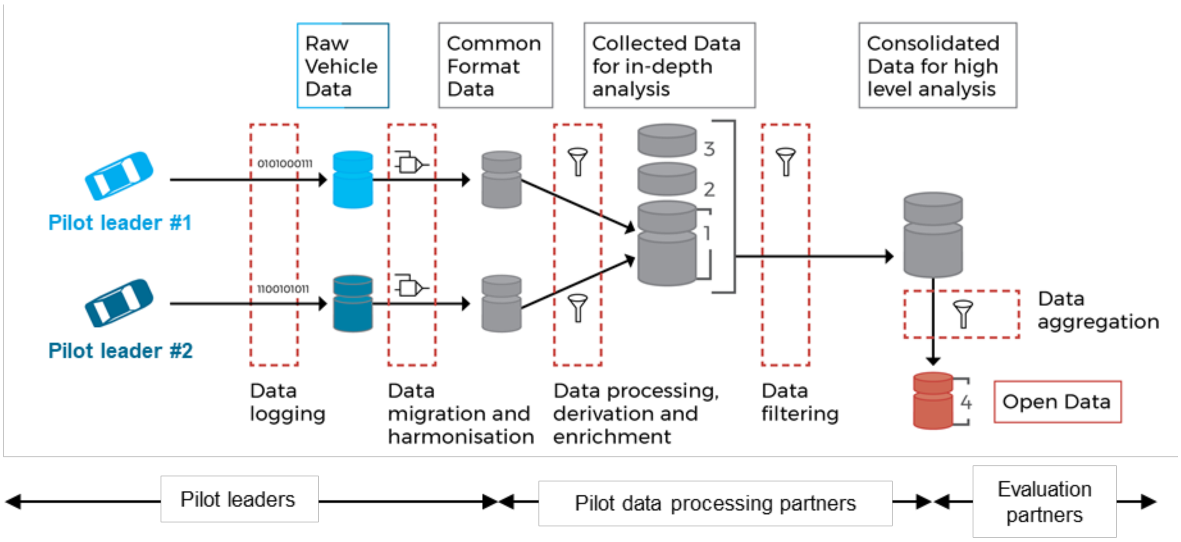


Figure 3.10: L3Pilot data management process.

While the idea was simple, the actual sharing of the data from advanced automated driving functions turned out to be a complex task, given the heterogeneity of the proprietary vehicular environments and the obvious confidentiality-related matters. Thus, a collaboration between academia, research institutes, and industry was necessary right from the beginning to safeguard the confidentiality of the industrial partners on the one hand and to ensure answers to the research questions on the other hand.

Consequently, *the project investigated the overall impact of new AD systems on the road, not the impact of a single manufacturer's vehicle.* It was therefore important to extract the relevant general information while preserving the confidentiality of the vehicular raw data. The manufacturers and their systems could not to be identified, ranked, or compared through any information shared in the project.

Three main constraints applied to the data uploaded to the CDB:

- Within each scenario there was no possibility to identify which pilot site was the source of any uploaded data. For example, attention was paid to avoid the inclusion of any metadata, such as temperature or date, that might hint at the location of the pilot site.
- No personal data about the driver, passengers, or other test participants were uploaded.
- There was no possibility to characterise in detail the behaviour of a specific vehicle function. This was because vehicular sensor data were not uploaded to the CDB as time series but as summarised performance indicators.

4 Key results of piloting and impact evaluation

4.1 Technical and traffic evaluation

4.1.1 Driving scenarios and the evaluation procedure

This chapter continues the preceding descriptions of methodology, piloting procedures, data management, and interviews of the test persons by focusing on the data analysis and the results obtained from the pilots.

The objective of technical and traffic evaluation was to assess the effect of the automated driving functions on the vehicle behaviour and the surrounding traffic to ensure that the vehicle was behaving in automation mode as designed. Consequently, the evaluation focused on answering the research questions concerned with technical aspects and the vehicle behaviour in traffic. There were 23 research questions in total on motorway driving, urban driving, and parking (see Chapter 4 of the Deliverable D7.3 by Weber et al., 2021).

To carry out the technical and traffic evaluation, numerous steps were needed, which are described in several different deliverables (see D7.3, Chapter 2.3). The data evaluation determined the impact of SAE Level 3 ADFs based on numerous parameters in the vehicle behaviour in traffic as well as aspects related to the user's attitudes towards automated driving when experiencing these systems (see Chapter 4.3 on user and acceptance evaluation). The data were not evaluated from individual systems but based on a merged dataset comprising all pilot sites.

For the technical and traffic analysis, *driving scenarios* constitute the basic unit of analysis concerning driving behaviour. A driving scenario is a short period of driving defined by its main driving task (e.g., car following, lane change) or triggered by an event (e.g., an obstacle in the lane). A *driving situation* represents a single segment in time that is assigned to a certain driving scenario (see Innamaa et al. 2020). A driving situation can be considered an instance of a driving scenario. Driving situations within different driving scenarios differ fundamentally, whereas situations of the same driving scenarios are similar. The hierarchy of driving trip analysis is given below (Figure 4.1).

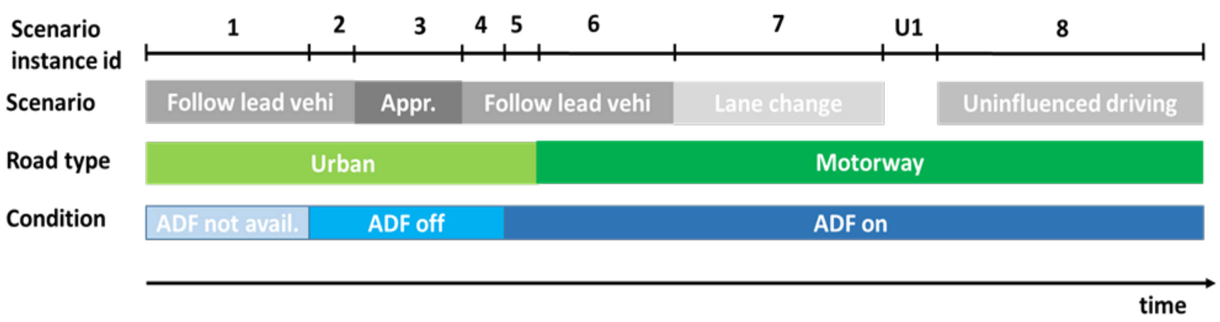


Figure 4.1: Example of a scenario segmentation during a trip.

A total of 17 driving scenarios were covered in the technical and traffic evaluation. These were related to typical manoeuvres that describe driving on motorways and in urban areas (Table 4.1).

Table 4.1: Driving scenarios to analyse driving on motorways and in urban areas.

Scenario	Definition	Motorway	Urban
Uninfluenced driving	The ego vehicle follows its path without being influenced by objects located in or moving into its path. Uninfluenced driving is classified when no lead object is detected, or if the time headway (THW) between the ego vehicle and lead object is more than 3.5 s. Also, uninfluenced driving is classified if the THW between the two vehicles is between 2 and 3.5 s and the lead object is driving faster than the ego vehicle. The ego vehicle's speed must be higher than 5.56 m/s and all of these conditions must be met for more than 2 consecutive seconds. Uninfluenced driving scenarios are divided into sections of 10 s duration and performance indicators are calculated per section.	X	X
Approaching a lead object	The ego vehicle is approaching an object located in its path and travelling at a lower speed. Approaching a lead object is classified when the THW between ego vehicle and a lead object is less than 3.5 s and the ego vehicle is travelling at a higher speed (>1.4 m/s) than the lead object. If a lead object is moving very slowly or standing still (less than 1 m/s) then the scenario is classified as approaching a static object. The THW must then be less than 2 s to ensure that the quality of the lead object measurement is valid.	X	X
Following a lead object	The ego vehicle is following a lead object. Following a lead object is classified when THW between the two vehicles is less than 2 s. Additionally, following a lead object is classified if the THW between the two vehicles is between 2 and 3.5 s and the speed difference between the two vehicles is within ±1.4 m/s. The ego vehicle speed must be higher than 5.56 m/s and all of these conditions must be met for more than 2 consecutive seconds. Following scenarios are divided into sections of 10 s duration and performance indicators are calculated per section.	X	X
Approaching a traffic jam in a motorway	The ego vehicle is approaching a queue of vehicles in its lane travelling at a low speed. The 20 s before a traffic jam are used to classify this scenario.	X	
Driving in a traffic jam	The ego vehicle is following a queue of vehicles in a motorway travelling at a low speed (<60 km/h) for at least 180 s.	X	
Lane change	The ego vehicle changes lane to the left or right. Lane changes of the ego vehicle are derived from the lateral position of the ego vehicle with respect to the position of the lane markings. When the left or right marking is crossed, a lane change is detected and its start and endpoint are determined. The starting point of the lane change is the point where the car starts moving in the direction of the lane marking before crossing the marking. The end point of the lane change is the point where the car stops moving away from the lane marking after crossing the marking. A maximum window size of 10 s before and after crossing the marking is set to limit start and endpoint respectively. Left and right lane changes are coded separately.	X	X

Scenario	Definition	Motorway	Urban
Cut-in	An object changes lane (or initiates a lane change) to the lane of the ego vehicle such that the resulting scenario is following or approaching a lead object (cut-ins from the left and the right lane are considered).	X	X
Crossing (without conflict)	The ego vehicle is travelling across an intersection without being influenced by another object.		X
Crossing with static object	The ego vehicle is travelling across an intersection with a static object located in its desired path.		X
Crossing with lead object	The ego vehicle is travelling across an intersection while being influenced by a lead object.		X
Crossing with laterally moving object	The ego vehicle is travelling across an intersection approaching a conflict zone, which it has in common with another object travelling laterally towards the path of the ego vehicle.		X
Turning (without conflict)	The ego vehicle is turning at an intersection without being influenced by another object.		X
Turning with static object	The ego vehicle is turning at an intersection with a static object located in its desired path.		X
Turning with lead object	The ego vehicle is turning at an intersection while being influenced by a lead object.		X
Turning with laterally moving object	The ego vehicle is turning at an intersection approaching a conflict zone, which it has in common with another object travelling laterally towards the path of the ego vehicle.		X
Overtaking of oncoming traffic (passive)	The ego vehicle is following its lane while a vehicle from the oncoming lane changes into the lane of the ego vehicle with the intention to change back to its initial lane.		X
Overtaking on oncoming lane (active)	The ego vehicle changes into the lane of the oncoming traffic, overtakes some obstacle and changes back to its own lane.		X

A detailed description of the scenarios is available in Annex 2 of the Deliverable D7.3. The driving scenarios are mutually exclusive.

Several research questions addressed the impact of ADF use on the frequency of critical driving situations (see the Deliverable D3.1, Chapter 6.1 *Technical and traffic evaluation* by Hibberd et al., 2018). These types of events can be also called incidents or near crashes. The frequency of such situations was analysed for selected driving scenarios. The situations identified based on objective driving data were not verified via video. The situations detected according to the threshold for lateral dynamic incidents were not included in the analysis, because there were too many detected events in the database in order to make a realistic estimate of critical situations.

For the technical and traffic evaluation, vehicle data were collected at the different pilot sites and then provided to research partners for analysis to answer the defined research questions. The data were segmented into instances of driving scenarios such as *free driving*, *following*, *lane change*, or *cut-in*. For each instance of a driving scenario detected in the data, specific performance indicators were derived by an automated toolchain.

The code of this toolchain was created collaboratively and used by all involved partners so that a harmonised evaluation could be ensured. For each individual pilot site, the derived performance indicators were uploaded to the consolidated database to create the data basis for answering the research questions. In order to avoid any benchmarking between the systems by the different manufacturers, the database was set up in such a way that it could not be determined which pilot site contributed to which entries in the database, while the partners providing the data could identify and if necessary remove or update only the data they supplied. The parking data were evaluated individually per study and combined anonymously.

4.1.2 Evaluated automated driving functions

In the following, the different automated driving functions evaluated in L3Pilot are given a high-level description. While all systems follow the description, the individual layout implementation and the resulting behaviour of the system may differ slightly. The detailed functionalities of the systems are not disclosed.

Motorway Chauffeur and Traffic Jam Chauffeur

L3Pilot considers two different ADFs for operation on motorways (both referred as *Motorway ADF* below). One of them is an SAE Level 3 *traffic jam chauffeur*, which allows the driver to hand over the driving task to the ADF without a need to supervise the process. The Traffic Jam Chauffeur operates on motorways (controlled-access) and similar roads up to a speed of 60 km/h. The operation of the traffic jam ADF requires a lead vehicle to be present. In the event that a slow vehicle is in front of the ego vehicle, the ADF can execute a lane change to a lane with faster flowing traffic. In contrast, the SAE Level 3 *motorway chauffeur* covers a speed range of up to 130 km/h on motorways and similar roads. The motorway chauffeur may either follow a lead vehicle or maintain a speed below the speed limit. Depending on the system design, the motorway ADF may execute lane changes in order to maintain its desired speed.

The evaluation in L3Pilot did not make a distinction between the traffic jam and motorway ADF on a system level. Instead, if an evaluated system was in a driving situation that could be considered a traffic jam suitable for a traffic jam chauffeur, the situation would be considered relevant for a traffic jam chauffeur even if the system would also allow a full speed range operation on motorways. Hence, in that case no distinction would be made between the two systems. Both are considered to be motorway ADFs, while a distinction between traffic jam situations and normal motorway driving is made on the level of the driving scenario (see the deliverable D7.3, Section 3.5.1).

Urban Chauffeur

Urban chauffeur aims to provide stress-free driving in urban areas. In the urban chauffeur mode the vehicle automatically follows the lane, starts and stops, and handles lane changes – either to overtake or to fulfil the navigation task within a city. When approaching an intersection, the car handles right and left turns, recognises on-coming traffic and vulnerable road users, and selects the correct crossing path even if no lane marking is present.

Parking Chauffeur

Parking chauffeur is a vehicle function that allows the user to request their vehicle to complete manoeuvring into and out of garages and driveways. The car either learns a fixed trajectory from the entrance of the house to the home garage and vice versa or determines a suitable manoeuvre to enter or pull out of a nearby parking position. This automated driving feature relieves the driver from repeating parking manoeuvres. Depending on the ODD, the parking chauffeur has also been tested at SAE L3 or L4, i.e., without the need to hand vehicle control over to a human driver in the event a fall-back manoeuvre is required.

4.1.3 Summary of the technical and traffic evaluation results

Motorway ADF

The interpretation of the results on system availability and stability needs to be made carefully, since the tested ADFs were still on a prototype level. Furthermore, it is likely that the circumstances of data collection (e.g., prototype ADFs, interventions of safety drivers) affected the results as well. For these reasons, a direct conclusion on driving with an imagined, future market-ready mature ADF is challenging based on pilot results. For instance, the frequency of take-over requests might be underestimated from trips where safety drivers prevented unusual situations by taking back control before the end of ODD actually resulted in a take-over request. In other trips that were part of experimental test drives to introduce non-professional drivers to the ADF, the number of take-over requests might have been overestimated, because those trips were designed in such a way that take-over requests took place frequently during every drive.

Regarding the measured effect of ADF on driving behaviour, some stable effects were observed. Overall, the following observations were made from the analysed driving scenarios:

- Automated vehicles drove at slower speeds compared to the baseline situations without automation over all evaluated scenarios.
- While in the automated mode, the vehicle maintained significantly greater headways compared to the baseline.
- The lane-keeping behaviour of the automated vehicles was found to be more stable than in baseline driving.
- Automated vehicles spend more time in stable driving scenarios such as free driving or following. However, for several considered systems, lane changes had to be signed off by the safety driver, potentially reducing their frequency.

At the same time, the results on vehicle dynamics and longitudinal regulation differed across scenarios. During approaching, cut-ins, and lane changes, the ADF decelerates more strongly than a manual driver does, while in car following it decelerates and accelerates more strongly. If we look at the variation of speed and acceleration, the longitudinal regulation is more stable with the ADF during uninfluenced driving and low-speed scenarios, while in more dynamic scenarios, such as approaching and cut-ins, it is more abrupt. In summary, it seems that in scenarios that require continuous reaction to other vehicles and that might also benefit from the anticipation of situational development, driving with an ADF is related to more pronounced longitudinal regulation than would be the case in manual driving.

Lateral vehicle dynamics decrease with the ADF for all scenarios except lane changes. Overall, driving with the ADF becomes more stable and more lane-bound due to a reduction in the number of lane changes and approaching situations. This results in a higher proportion of driving time spent in the vehicle-following scenario, in particular.

The interpretation of results on the frequency of potentially critical driving situations again needs to be treated cautiously. Overall, results indicate that especially the frequency of close distances to the lead vehicle is reduced. One explanation is that the ADF on average maintains a greater distance to the vehicle and follows less closely. In addition, these results might be directly influenced by the nature of testing prototype functions: safety drivers were present during all drives, and it was their task to intervene before critical situations occurred. This might directly reduce the frequency of critical situations. Furthermore, the overall analysis is based entirely on objective thresholds applied to vehicle data with no verification based on video recording. In particular, the indicators assessing rare events such as critical situations tend to be influenced by unusual events: outliers as well as sensor errors, such as ghost objects. For instance, the in-depth analysis done for a subset of data on critical situations with relation to surrounding traffic revealed that most of the objectively detected events were false positive events. In the end, for that subset of data the absolute number of verified critical situations was too small to draw any conclusions on the effect of ADF on event frequency.

The analysis of calculated energy demand reveals a surprisingly high reduction in energy requirements with the ADF. The reported effect is based on changes in driving behaviour (lower speed, more stable driving scenarios, etc.). Effects of other influencing factors such as vehicle type and the energy demand of additional equipment were not considered. The overall reduction is probably partly influenced by the lower speed range of the trips that took place on the urban motorway. It should be noted here that some drives repeatedly took place on urban motorways with a speed limit of 70km/h. An incompletely balanced proportion of trips taking place in baseline and ADF conditions might have impacted the overall results of energy demand. Nevertheless, also for trips that mainly consisted of driving in traffic jams a reduction in energy demand of 12% on average was found.

Urban Automated Driving Function

As with the motorway ADF, the interpretation of results on system availability and stability needs to be done carefully for the urban ADF as well. It is important to keep in mind that the tested ADFs are still on a prototype level. Furthermore, it is likely that the circumstances of data collection (e.g., prototype ADFs, safety drivers who might prevent sudden take-over requests (TORs) through early intervention) impact the results as well, so that a direct conclusion on driving with a market-ready mature ADF is challenging. As an additional factor for the urban analysis, it should be considered that the urban pilot sites of this project cover only a small portion of the variety of urban settings and traffic. As in the case of the motorway, certain scenarios will probably also not be recordable during the pilots, as safety drivers are always present to intervene. Moreover, these safety drivers always occupy the driver's seat at the urban pilot sites, so that driver reactions to unexpected behaviour of automated driving cannot be thoroughly investigated. Additionally, this also holds true for TORs, which cannot be analysed in the urban setting as most pilots cover the complete pilot route within the ODD of the ADF, i.e., from starting on the parking lot to ending on the parking lot so that there are no planned TORs in traffic. Furthermore, no TORs occurred during the piloting or were caught by the safety driver quite early.

An overall conclusion is that ADF behaviour is similar to that of human driving within the urban environment. Considering the overall reduced speed of the ADF, an increase in safety can be asserted. Of course, this also leads to slightly longer travel times, but the differences here are marginal, so that the overall effect should be minimal. Furthermore, another advantage of the ADF is increased attentiveness and the fact that the ADF is always alert and has rapid reaction times. This can lead to an overall increase in safety with the introduction of ADFs in the urban environment. Since incidents were not in the scope of the pilot analysis within L3Pilot, only assumptions can be made on this topic.

For lane-bound scenarios, a difference between influenced and uninfluenced driving (free from other vehicles) can be observed. In influenced scenarios, the effects are rather small, which can be explained by the ADF having a better ability to sense subtle changes in the dynamics of other vehicles and, therefore, an advantage when reacting to other vehicles. For uninfluenced driving, larger effects were observed. This holds true especially for vehicles dynamics and driven speeds.

For intersections, however, for most research questions no overall effect can be determined. What can be said is that intersections and the handling of those scenarios are mainly influenced by the infrastructure and the other traffic participants. As a consequence, effects are often mixed depending on the performance indicator and the scenario. For most intersection scenarios it can be stated that travelling through intersections takes longer when using the ADF.

An additional point which influences the results for the urban ADF is that the data were bootstrapped. The bootstrapping method also added some noise to the data (to prevent identification). In principle, this makes it more challenging to find significant effects. This may also exaggerate the extreme values (minimum or maximum) visible in the histograms. However, the amount of noise added was so small that these potential drawbacks cannot have influenced our conclusions. (A detailed discussion of the bootstrapping process can be found in Annex 4 of the Deliverable D7.3 by Weber et al., 2021.)

For urban ADF the quantity of piloting data made it difficult to evaluate the impact of automated driving on a large scale because a great variability of interactions at intersections could not be covered in the pilots. Main findings for urban ADF include:

- Urban AVs spend more time in the intersection, suggesting more careful behaviour while passing through or turning at an intersection.
- Urban AVs did not drive above the speed limit, whereas drivers in baseline conditions without automation did so slightly.

- The behaviour while following a lead vehicle did not differ significantly from the behaviour of human drivers in the baseline situation, suggesting that AVs would not interfere in the traffic flow in urban areas.
- In general, driving dynamics – both longitudinal and lateral accelerations – may be reduced while driving with ADF activated.

Parking Automated Driving Function

Over all studies, parking with a parking chauffeur takes significantly longer than manual parking. This is due to lower speed and more stopping in the course of a parking manoeuvre. Furthermore, lateral dynamics are reduced while parking with the ADF. It seems that this is also a direct consequence of the reduced speed while parking with the ADF.

For the parking ADF, the following points are noteworthy:

- Parking with an ADF takes longer and involves more stops.
- In parking with an ADF, speed is lower than during manual driving.

4.2 User and acceptance evaluation

4.2.1 Questionnaire method

The aim of the user and acceptance evaluation was to map users' experiences before, during, and after the piloting trials and to see how hands-on or nearly hands-on experiences affected the test persons.

This chapter presents the results of the user and acceptance evaluations from the pilot studies and supplementary studies. The results for the motorway, urban, and parking ADF are presented.

In order to carry out the user and acceptance evaluation for the three different ADFs considered for the evaluation in L3Pilot, three different pilot site questionnaires were designed, one for each environment, with function-specific questions for ADFs operating in each environment. This method allowed to collect responses that were context- and ADF-specific (see Chapter 2.4 of the Deliverable D7.3 by Weber et al., 2021).

The questionnaire was split into two parts (the questionnaire is included as the Annex in D3.3 by Metz et al. (2019) and the guidelines for information and instructions for participants are included as the Annex in D3.4 by Innamaa et al., 2020). The first part of the questionnaire was administered before the pilot drives commenced and included questions related to socio-demographic factors (age, gender, country of residence, education level, employment status, income, and family size), vehicle use and purchasing decisions, driving history, in-vehicle system usage, activities while driving, trip choices, and mobility patterns. The data collected in the first part was used to create different user groups for the evaluation and to understand the impact of various socio-demographic factors on participants' acceptance and perception of the ADFs.

The second part of the questionnaire was administered immediately after the pilot drive or after the final pilot drive if a test driver participated in more than one drive. It examined participants' initial reactions regarding their experience while using the particular ADF, including acceptance, safety, and comfort, among others. To examine whether participants felt that they would change any of their behaviours should they have access to that particular ADF in their daily lives, they were again asked questions about vehicle use and purchasing decisions, driving history, in-vehicle system usage, engagement with non-driving tasks, trip choices, and mobility patterns. The questions in this section were phrased to address the specific ADF under investigation, with the only exception being motorway and traffic jam ADFs, which utilised the same questions, because they have similar ODDs.

As an optional additional section, where feasible, users' performance and perception of the situation during and after a take-over was evaluated mid-drive, following any need to resume manual control from the ADF. For this analysis, drivers were asked immediately after a take-over scenario to rate the criticality of the preceding situation as a whole, using a ten-point scale to judge the criticality of the situation, ranging from harmless (1) to uncontrollable (10). The scale is based on Neukum et al. (2008), and it allows a direct comparison of drivers' own evaluation of the take-over with the post-drive evaluation by an expert. These data were collected for ordinary drivers, and at pilot sites where the safety protocol permitted mid-drive evaluations.

In total, data from 354 unique drivers were collected for the motorway pilot site questionnaire from the CDB. The data were further tabulated into three groups: professional safety drivers from the pilot sites, ordinary drivers from the pilot sites (some of which included Wizard-of-Oz studies conducted on test tracks), and ordinary drivers from the simulator studies.

In total, data from 175 participants were collected for the urban pilot site questionnaire from the CDB. The data consisted of 15 professional safety drivers and 160 passengers and were analysed without being separated into different groups.

For parking, the questionnaire data were collected in three studies conducted at three different test sites. Since the studies on parking ADFs differed substantially between the test sites e.g., with regard to tested manoeuvres, test environment, and experimental approach, the subjective data for the evaluation of parking ADFs were not merged on the level of single questionnaires but on the level of studies. All studies were analysed separately and then the results from the different studies were merged in such a way that each study contributed to the overall results with one data point.

As shown in the previous section, there were five research questions that were related to users' acceptance and awareness. To answer each of these, different questions were administered using a six-point scale, unless otherwise stated, whereby 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree, and 6 = don't know.

To answer the L3Pilot user and acceptance research questions, each relevant questionnaire item was explored according to the driver/test type. To provide an overview of the spread of participants' responses, the percentages of each response were presented in figures. In addition, the findings were described to answer each research question under each figure. Finally, hierarchical regression was conducted to investigate how user experience, driver type, and system familiarity affected willingness to use the respective systems. All results are included in Chapter 5.3 of the Deliverable D7.3 (by Weber et al., 2021).

4.2.2 Video analysis method

While the main methodology for the user and acceptance research area was the developed questionnaire, some behaviour-related aspects could be studied in depth by analysing the videos of the drivers during the exposure. For this purpose, several cameras were installed in the cabin to observe driver interaction with an automated driving function. Especially, the transition phases were of particular interest as the behavioural processes of handing over control to the vehicle as well as taking back control have implications in terms of safety and the HMI design. For several research questions, such as '*How do drivers respond when they are required to retake control?*', video data can provide an insight into the actual response process. For this purpose, observable measures that were objectively identifiable needed to be determined and collected in a code book that was used for annotations. The behavioural features were then labelled frame by frame by annotators.

4.2.3 Summary of the user and acceptance evaluation results

Motorway Automated Driving Functions

To evaluate the L3Pilot motorway ADF, professional safety drivers and ordinary drivers were tested at different pilot sites and in a driving simulator. Generally, drivers were positive about the system, giving high ratings of willingness to use, perceived trust, perceived safety, and system usefulness. Overall, professional safety drivers were less positive in their ratings (i.e., willingness to use, perceived safety, take-over perceived safety, perceived usefulness, trust, fun) than ordinary drivers. Although all drivers believed that system performance and the expected behaviour of the system could be further improved, the margin for improvement was considered higher by professional safety drivers.

The majority of drivers did not believe that driving with the system was stressful, difficult, or demanding. However, some drivers thought that using the systems on a long journey would make them tired. This finding seemed to be higher for drivers who took part in the simulator study with repetitive testing, which could potentially be due to simulator fatigue. If given the opportunity, most of the ordinary drivers would engage in a secondary task while the system is active, but professional safety drivers were less inclined to do so. Most drivers were also in favour of engaging in the secondary tasks that were allowed such as music, audio books and talking to passengers.

The majority of participants agreed that their experience of driving with the system was comfortable, with no reports of motion sickness during the drive. However, future studies should focus on longer engagement in secondary tasks and driving that is more demanding, with more lateral and longitudinal movements with environmental changes. Vehicle behaviours such as distance maintained from other vehicles, negotiating curves, braking, acceleration, and smoothness were all rated as comfortable. However, vehicle behaviours at motorway junction areas and during lane changes were deemed to be less comfortable. It is possible that more interactions were required in these situations, which may have led to the reduced comfort ratings. Future studies should focus on how the system should perform to meet drivers' expectations and increase the understanding of the system's intentions to improve comfort and acceptance. The majority of drivers felt safe when taking over control from the system, although once again, ordinary drivers provided higher ratings than professional safety drivers.

Overall, professional safety drivers were less positive than ordinary drivers while evaluating the system, potentially due to system familiarity. However, a regression analysis shows that driver type and system familiarity did not predict willingness to use, suggesting that this difference does not have a significant impact. Willingness to use was predicted by drivers' workload/emotions, system expectations, system information, system monitoring, and Van der Laan's usefulness scale. Findings revealed that the more positive that drivers were in terms of workload/emotions, system expectations, and usefulness, the higher their willingness to use. Similarly, the more they wanted system information and the more willing they were to engage in a secondary task, the higher their willingness to use the motorway ADF.

To sum up the results:

- The drivers who experienced motorway ADF were generally positive about the piloted system, including the take-over experience, but there remained room for improvement in the system performance to match users' expectations of vehicle behaviour, as this would increase willingness to use the system.
- No motion sickness was reported by the studies' participants, and drivers agreed that the system was comfortable, especially behaviours in situations where the vehicle was less interactive with other traffic participants.
- The opportunity to engage in secondary tasks and the usefulness of the system increase the willingness to use.
- Professional safety drivers were revealed to be less positive with the motorway ADF than ordinary drivers. However, system familiarity and driver type did not affect willingness to use the system.
- In more than 60% of take-over situations it took less than 4 seconds until the drivers reacted to the take-over requests and deactivated the function. The reaction time in 99% of situations was below 10 seconds. All of the take-over requests took place during the daily driving situations.

<u>Urban Automated Driving Functions</u>

To evaluate our L3Pilot urban ADF, participants (mainly passengers) were tested at different pilot sites. As in the findings for the motorway ADF, participants were generally positive in their ratings of the system (i.e., willingness to use, perceived safety, usefulness, and trust), but with some margin for improvement for system performance and system expectations. Although the participants seemed to be quite positive in general, the ratings were not as high as the evaluation of the motorway system. The majority of the participants did not find the system demanding, difficult, or stressful to use, but there seemed to be individual variance on how tiring the participants found the system.

The majority of the urban participants claimed that they monitored the urban automated system and surrounding environment more than in manual driving. However, this could potentially be due to the participants' instructions, whereby they were asked to monitor their surroundings like they would if they were driving themselves. Slightly more than half of the participants would engage in a secondary task, which was less than the ordinary drivers on the motorway but more than professional safety drivers on the motorway.

Most of the participants also felt comfortable with the system. However, there were a few behaviours that the system could improve on to maximise comfort, for example the distance maintained from pedestrians and cyclists when overtaking and turning behaviour at intersections and curves. Finally, results show that unlike in the motorway evaluation, system familiarity predicted participants' willingness to use the urban system. The more familiar they were with the system, the higher their willingness to use it. The other factors predicting willingness to use the urban system include system monitoring and Van der Laan's usefulness scale, with higher ratings of system usefulness, and increased willingness to engage in secondary tasks, leading to increased willingness to use the urban system.

To sum up, the following were the most consistent observations on user acceptance in urban automated driving:

- Users were generally positive about the urban system, although slightly less so than the users of the motorway systems.
- No motion sickness was reported by the users who experienced the system.
- The more familiar the users were with the urban ADF, the more willing they were to use the system.

Parking Automated Driving Functions

For parking, it was not possible to merge the questionnaire data at the level of single responses. Therefore, merging was done at the level of studies on parking ADF. For each study and each analysed questionnaire item, information on the proportion of drivers agreeing or disagreeing with the statement were merged. The combined results are based on answers collected from three different studies on parking. The following results are from the user interviews:

- Across all studies, the majority of drivers agreed or strongly agreed with the statement that they would be willing to use the parking ADF.
- Across studies, the majority of drivers stated that they felt safe parking with the parking ADF, trusted the ADF to park, and believed the system to be useful. A large proportion of the drivers agreed with the three statements and only a small proportion disagreed.
- In all studies, drivers reported that parking with the ADF was not demanding. In two studies drivers stated that parking with the ADF was not stressful, while in the third study, use of the ADF was perceived by the majority of drivers as stressful. Therefore, perceptions of stressfulness results varied across studies and functions.
- There were differences among the studies in terms of the perception of how parking with the ADF influenced drivers' awareness of the environment. In one study, the majority of drivers stated that they were more aware of their environment when parking with the ADF. However, in the other

studies, the drivers tended to disagree with that statement. It should be considered that the different studies might have used completely different ADFs.

4.3 Impact evaluation

4.3.1 Mature functions as a basis of evaluation

Impact assessment and the later introduced socio-economic assessment did not address the prototype implementations that were tested in the pilots and analysed in the technical & traffic and user & acceptance evaluations above. The reason is that the impact assessment analyses the potential impacts of ADFs from a *future perspective*, when they are to be used on a large scale. It is expected that such ADFs will be further developed than those tested in L3Pilot. Therefore, so-called *mature functions* and their ODDs were defined to represent such future ADFs (see the Deliverable D3.4, Chapter 5.1 by Innamaa et al., 2020).

The mature function descriptions were developed in cooperation with ADF developers and were cross-checked with the data from the pilot experiments. Thus, they consider L3Pilot knowledge and represent ADFs that are mature enough for usage on public roads by ordinary drivers. *The defined mature ADFs do not represent any particular L3Pilot automated driving function tested at any of the pilot sites*. Rather, they provide a generic description of what these ADFs may look like when they have acquired a high penetration rate.

All mature functions keep the vehicle in lane and a safe distance to the vehicles in front. Lane changes are performed automatically. All mature ADFs operate both in daylight and at night, and in good weather conditions or in light or normal rain. However, heavy rain, snow, fog, and extreme weather conditions, as well as icy or snowy road surfaces, are outside their ODD. The ADFs can handle small gaps in lane markings. At the end of the ODD, a take-over request is sent to the drivers, and they are required to take control of the vehicle. In addition to these characteristics common to all ADFs, additional ones are listed below per ADF.

This deliverable can only give a very general description of the extremely thorough work done for the impact assessment. This includes for example, the key concept definitions; the four mature ADFs for motorway, traffic jam, urban driving, and parking; an overview of mature L3Pilot ADFs sensors and their parameters; an overview of actuation criteria such as lane changes; the analysed scenarios; and the used baseline and treatment conditions, as explained in the Deliverable 7.4 by Bjorvatn et al., 2021. These are only some key matters to be followed. An extensive literature review in this area can be found in the deliverable as well.

4.3.2 Mobility impact

Personal mobility behaviour is determined by individual travellers' choices, which are constrained by their available time budget and means of travel and influenced by personal and cultural features. Therefore, the assessment of mobility impacts of conditionally automated cars at SAE L3, which are not yet in use, is about understanding people's attitudes and beliefs, and how they can turn into future behaviour. Because of this complexity, the impacts cannot easily be separated for each ADF as with the other impact assessment areas. Hence, the assessment was primarily performed for more general mature conditionally automated car functions instead of motorway, urban, and parking functions separately.

The mobility impact assessment approach included the impact on travel quality, travel patterns, and amount of travel. These three points also feature in the research questions to be answered. For the mobility impact assessment, data were gathered through pilot site questionnaires, focus group discussions, and an impact assessment survey.

It was expected that ADFs would increase the quality of travel by enabling non-driving-related activities and increasing travel comfort (Singleton, 2019). The results from both the pilot sites and impact assessment survey suggest that travel quality was indeed good with the ADFs.

The pilot site participants experienced the piloted ADFs mainly positively. This suggests that mature ADFs are likely to be well received once they are on the market. The impact assessment survey investigated how ADFs were expected to change travel quality compared to manually driven cars. About half of the respondents did not expect changes, but among the rest, a majority expected a positive impact on travel comfort and stress, a feeling of safety, the certainty of reaching destinations as planned, and the productive use of travel time.

Respondents were looking forward to engaging in non-driving-related activities during the automated mode. The pilot site test persons were keener on engaging in NDRAs than the impact assessment survey respondents. At the pilot sites, the median responses were ‘frequently’ to ‘every now and then’. In the impact assessment survey, the median responses were ‘rarely’ to ‘sometimes’. Willingness to engage in leisure activities appears to be higher than willingness to work. Activities particularly mentioned were interacting with passengers and digital devices.

Focus group discussions suggested that ADFs can make travelling more comfortable, especially in situations where the driving task is either too boring or monotonous (e.g., long trips on motorways) or too demanding (e.g., traffic jams or when fatigued).

Over 90% of the respondents in both the pilot site questionnaire and impact assessment survey were willing to accept some additional travel time if they would not need to drive themselves. On average, participants were willing to accept an additional 4–15 minutes for 30-minute trips, which translated into a value of travel time savings from 12% to 25%. This suggests that drivers might be willing to consider choosing routes within the ODD over non-ODD routes even if it would take a slightly longer time. Travelling by car during rush hour despite longer travel times may also become more attractive because of increased comfort and use of travel time for tasks other than driving. With the assumption that the additional travel time accepted reflects increased travel quality, this gives a clear indicator that ADFs are likely to increase travel quality in comparison to manually driven cars.

Survey-based results indicate that a higher willingness to use conditionally automated (L3) cars predicted higher expectations for a decreased use of public transport and active travel (Lehtonen et al., 2021). The intention to use conditionally automated cars was also stronger among multimodal travellers who currently actively use public transport and active travel modes. Overall, these results suggest that ADFs can make it more attractive to take longer trips by car or to replace existing public transport or active travel trips by conditionally automated car trips.

Results suggest that ADFs would increase the amount of car travel: of the pilot site respondents, 23–45% agreed that they would either start making more trips (either new trips or switch from some other modes) or select destinations further away. Of the impact assessment survey respondents, 24–27% expect an increase in the number, distance, or travel time of trips. The results suggest that improved travel quality due to automated driving is the driving force in motivating more travel by car. Nine out of ten were willing to accept longer travel time in automated driving. In line with that, many participants were positive towards the idea of making longer trips by car. In practice, this could mean expanded choices of locations for living, working, and free-time activities. In particular, many focus group participants mentioned that making long-distance trips by car would become more attractive with conditional automated driving, as travelling would be more relaxing.

Conditionally automated cars may also address some of the currently unmet travel needs. The opportunity to multitask may render additional trips possible if the limiting factor was previously a lack of time. Some travellers expressed the desire that conditionally automated cars could help them to cope with fatigue and driving in darkness so that they would be able to travel more by car. This is not without risks, as driving when fatigued increases the chance of falling asleep, which would not be allowed in conditionally automated cars.

Further information concerning the actual impact evaluation; the precise methods used; impacts in detail on travel quality, travel patterns, amount of travel; scaling up; limitations of the methods and data; and lessons learned can be found in the Deliverable 7.4 (by Bjorvatn et al., 2021).

The main outcomes of the mobility impact analysis are the following:

- ADFs are likely to increase the quality of travel by enabling non-driving-related activities and increasing travel comfort. Especially leisure activities and interacting with passengers were often mentioned as activities to be enjoyed during automated driving.
- The experience of travel quality depends on the individual traveller, and some travellers may also experience decreased travel quality with ADF.
- On average, increased travel quality may decrease the perceived costs of travelling by car. Value of travel time savings estimates vary between 12% and 25%.
- Drivers may switch to routes within the ODD. Nine out of ten participants would accept additional travel time on a route within ODD if they would not need to drive themselves.
- Vehicles with ADFs may make driving under demanding or stressful conditions feel easier, for example during the rush hour or when fatigued. Consequently, drivers may be willing to drive more under these conditions. Nine out of ten participants would accept additional travel time during rush hour if they would not need to drive themselves. Drivers for whom fatigue or darkness currently restrict driving expect to travel more frequently with ADF-equipped cars.
- Travellers may partially switch from using public transport or active travel modes to driving a car even though most travellers do not expect to change their use of public transport or active travel modes due to the introduction/availability of ADF. Surveys show twice as many respondents

expecting to decrease the use of public transport (26–29%) than those expecting to increase its use (12–15%).

- Taking longer trips by car may become more attractive. Some travellers may also start making completely new trips. However, the majority of participants do not expect to increase their amount of travel.

4.3.3 Safety impact

Safety is the primary motivator for developing automated driving systems. Human error has been shown innumerable times as the main cause of traffic accidents. By giving vehicle control to a machine, human errors can be eliminated from the vehicle control loop. A lot of support has already been given to this argument by the ability of highly developed ADAS to enhance the safety of driving (see e.g., ERSO, 2018). A logical assumption is that automated driving systems can further increase safety, since vehicle control is fully given to a system that would not have concerns other than driving or suffer from fatigue or intoxication.

The main objective of the safety impact assessment was to assess the effect of ADFs on traffic safety. The research questions on the safety impact assessment concerned the likelihood of accidents and accident severity:

- What is the impact of ADF on the number of accidents in a certain driving scenario / for specific road users?
- What is the impact of ADF on accidents with a certain level of injuries / damage in a specific driving scenario?

These research questions were further detailed and are presented in the L3Pilot deliverable D3.3 (Metz et al., 2019). The details of the applied methods are presented in the Deliverable D3.4 (Innamaa et al., 2020) and the Deliverable 7.4 (Bjorvatn et al., 2021). The assessment of the research questions required a quantification of possible effects of ADFs on traffic safety. The effects can be either positive (i.e., technology reduces accidents) or negative (i.e., potentially new safety risks occur e.g., due to a minimal risk manoeuvre). Both types of effects were comprehensively assessed in the Deliverable D7.4.

The methodology defined for the L3Pilot safety impact assessment is presented in Figure 4.2 below, and it is described in more detail in L3Pilot Deliverable D3.4 (Innamaa et al., 2020). The aim was to investigate the effects of ADF within *driving and traffic scenarios*. The results that were obtained from these scenarios were also scaled up to the EU27+3 (UK, Norway, and Switzerland) level.

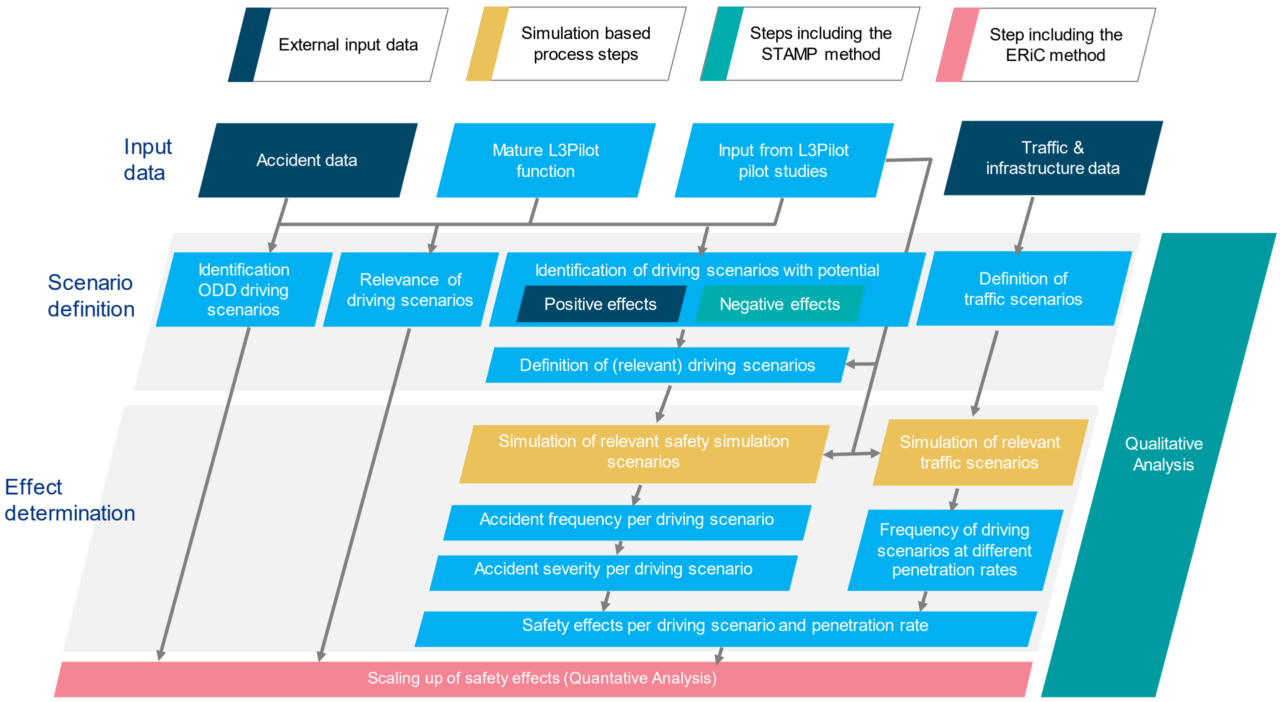


Figure 4.2: L3Pilot approach to safety impact assessment.

As can be seen from Figure 4.2 above, the L3Pilot safety impact assessment combines different methods to achieve the required comprehensiveness. Due to the lack of data from real accidents, the methods used are based on simulations and existing literature, as well as accident statistics that include the estimates of injury risk functions (IRF) and insurance claims. The collection of methods and their logic is presented in detail in the Deliverable 7.4, Chapter 4.2 *Method and input data of safety impacts assessment* by Bjorvatn et al. (2021). As a last step in the safety impact assessment, the simulation results, which represent specific conflicts or traffic conditions, were scaled up to the EU27+3 level. This process, including several steps, is explained in detail in the above-mentioned chapter.

Computer simulations of traffic and driving scenarios played an important role in determining the change in the accident risk and severity and the frequency of scenarios. Furthermore, the injury risk function approach was used to estimate the probability of a specific level of injury associated with a specific crash parameter, for a specific population, when a road crash occurs. The estimation of the ADF effectiveness is based on a prospective analysis by means of computer simulations.

As a last step in the safety impact assessment, the simulation results, which represent specific conflicts or traffic conditions but not any country or region, needed to be scaled up to the EU27+3 level. This step was done by means of the ERiC method (see Rämä and Innamaa, 2021).

A more comprehensive understanding of the methods, data used, and possible limitations can be obtained from Chapter 3 *Results* of the Deliverable 7.4. Especially useful are the conclusions drawn from the work done.

As for motorways and urban areas, after having defined the mature ADFs, the evaluation approach was the following: first, cluster driving situations into typical driving scenarios; second, simulate automated and baseline driving for each of these scenarios; third, compare accident outcomes with manual driving; lastly, scale up results to the EU27+3 level.

Driving situations were categorised into driving scenarios and traffic scenarios. A driving scenario is a short period of driving defined by its main driving task (e.g., car following, lane change) or triggered by an event (e.g., an obstacle in the lane or a cut-in situation). A traffic scenario has a broader horizon and covers a specific road section with certain traffic characteristics. Driving scenarios and traffic scenarios were simulated with different simulation techniques and tools and different input data, including in-depth accident data, naturalistic driving studies data, and of course L3Pilot data collected in piloting.

Thousands of simulations were conducted for each scenario. The general principle was to compare the injury accident outcome in the computer simulations when manual driving, on the one hand, and automated driving, on the other hand, were considered separately. Differences in injury accident outcomes per scenario in the simulations led to the estimations of effectiveness (reduction or increase in injury accident risk) per scenario. The results of simulations were then scaled up to the EU27+3 level by using matching simulated driving scenarios with the accident types of the EU CARE accident database, changes in overall injury accident risk, accident severities, and changes in frequency of these driving scenarios due to the introduction of ADFs. For the scenarios that could not be simulated, such as loss-of-control injury accidents or rare injury accidents on motorways, experts' estimates complemented simulations. A European-wide accident analysis was supported by national in-depth accident databases. Analysis was conducted on injury accidents per level of severity (slight, severe, fatal) for ADF penetration rates of 5%, 10%, and 30%. It was not possible to investigate a penetration rate of 100% due to simulation restrictions.

As for parking ADFs, relevant cases were identified in insurance claims in one European country and combined with relevance to ODD and a priori estimates of effectiveness (reduction of relevant cases by 75% or 100%). Then estimates of actual usage led to overall estimations of the percentage of avoidable accidents. The results were not scaled up to the EU level.

Both motorway and urban ADF had positive safety effects on road accidents with all severities at all penetration rates. Both ADFs are estimated to be effective in reducing injury accidents within ODD and within motorway/urban accidents. However, since motorways are relatively safe, especially in good weather conditions, the estimate of the share of all prevented injury accidents within motorway accidents is relatively small, even at the highest simulated penetration rate.

The two clearly most common accident types on motorways were rear-end collisions and single vehicle accidents with run-off the road. The simulated scenarios linked to the first accident type therefore dominated in the effect estimation. The effect on the latter type was based on the expert assumption that ADFs have no run-off-road accidents (within ODD of good weather conditions). It remains to be seen how well these results and assumptions will reflect the reality. The most common accident types in the urban environment were rear-end collisions and accidents in crossing or turning. Several scenarios were simulated to these accident types.

The number of target accidents was significantly higher for the urban ODD than for the motorway ODD. The proportion of prevented accidents was also larger in urban environments than on motorways. Hence, the number of prevented accidents was large in urban environment. Additionally, the determination of accidents taking place within ODD was more reliable on motorways than for urban accidents. Also, the missing pieces of information in motorway accident records were easier to complement for motorway accidents with more reliable sources than for urban accidents.

The traffic scenarios in which most vehicle kilometres are driven include the lowest traffic volumes on two-lane motorways with 130 and 120 km/h speed limits. As the traffic scenario simulations for safety did not include the highest traffic volumes, it is possible that some of the phenomena taking place in congested conditions are not reflected in the driving scenario frequency results. In addition, the simulation results on the frequency of driving scenarios on motorways were not considered fully reliable, since not all results were in line with pilot results reported in the L3Pilot Deliverable D7.3 (see Annex 1.3.2.3). It is not clear what caused the differences. Therefore, future research is recommended on this topic. The frequency changes could not be assessed for urban environments.

The assessment based on already existing accident types on motorways is likely more reliable than the assessment of new accidents without corresponding accident causation mechanisms today (Minimum Risk Manoeuvre (MRM) and wrong activation), as the frequency of such events is hard to estimate. In addition to MRM and wrong activation, there may also be other new factors leading to additional accidents (such as sudden errors of localisation or sensor failures), or the carry-over of trust from ADF to ADAS functions resulting in crashes. For now the ADF was assumed to work without failures, and no changes in driver behaviour in other driving scenarios (e.g., with ADAS) were considered (which might not be fully realistic).

It must be noted that some additional indirect safety effects (not covered in the above calculations) can also be obtained. First, indirect impacts of additional benefits of the sensors during assisted manual drive may be significant when compared to the direct impact during the automated drive. In addition to the automated emergency braking (AEB), the ADF sensor setup potentially enables the use of some additional key active safety systems. Furthermore, automated driving is likely to increase vehicle km travelled by car, and travellers are also more likely to use cars rather than other modes (public transport and active travel). Even though these changes may be rather small, the effect on the number of road accidents could be fairly substantial, since these changes affect all accident types and not only those targeted by ADFs.

The current work on safety impact analysis had its limitations due to very obvious facts. First, COVID-19 placed a huge time pressure on the final phase of the L3Pilot project due to the late start of the analysis. This meant limited possibilities to react to issues in simulations and less time to use the pilot data for parameterisation of the simulation and scenarios than planned.

Furthermore, the results obtained are only valid for the simulated mature L3Pilot ADF, which is only an approximation of a real ADF and does not represent any particular implementation in L3Pilot. A reduction in the number of simulations would have reduced the meaningfulness of the results. Therefore, the simulation of a 100% penetration rate of ADF had to be skipped.

The L3Pilot pilot database included pre-defined indicators from recorded driving situations. Thus, there was no time series data available for the safety impact assessment. This limited the possibility to parameterise and validate the simulations in the safety impact assessment. Instead, for the simulations, other data sources outside L3Pilot had to be utilised.

Since the behaviour of human drivers is complex and variable, it is still not fully understood. Driver models can only approximate this behaviour. This means that the behaviour of the models will only represent the behaviour of real drivers to a certain extent. Also, the development and any validation of driver models used data sources other than L3Pilot.

Finally, the data used for simulations and analysis comes from multiple sources and this sets limitations to the use of models and the results obtained. The qualities of e.g., upcoming vehicle characteristics could not have been considered in the injury risk functions used in the study, and they are consequently rather generic.

To sum up, the main results of the safety impact assessment are the following:

- Overall, automated driving is capable of reducing the number of injury accidents. For the motorway ADF, the reduction of all road accidents might not appear to be large (0.1–1.2%, depending on the penetration rate (5%, 10%, 30%) and the accident severity). However, considering the already high safety status of motorways, the reduction potential is large both on motorways in general (2.0–19.0%) and within the ODD (3.8–27.6%). For the urban ADF, the reduction of all road accidents is between 0.8–10.2%, depending on penetration rate and accident severity.
- A positive effect in accident reduction is expected for most of the analysed scenarios. For the motorway ADF, an increase in the number of accidents was assessed for the Minimum Risk Manoeuvre scenario and a minor one for the wrong activation scenario. For the urban environment, a reduction in the number of accidents is expected for all simulated driving scenarios. However, it must be noted that MRMs or wrong activations were not simulated there.
- Overall, the number of fatal accidents on motorways is estimated to be reduced by 2.0% (5% penetration rate), 4.2% (10% penetration rate), and 13.1% (30% penetration rate). Within the ODD, these figures are 3.8%, 8.0%, and 25.1%, respectively. In the urban environment, the corresponding estimates were 2.0%, 4.1%, and 12.2%, and in the second case 4.3%, 8.6%, and 25.9%, respectively.
- Overall, on the motorways, the number of accidents with serious injuries is reduced by 2.3% (5% penetration rate), 5.1% (10% penetration rate), and 15.2% (30% penetration rate). Within the ODD these figures are 4.0%, 8.8%, and 26.3%, respectively. In the urban environment, the corresponding estimates were 2.3%, 4.5%, and 13.5%, and in the second case 4.2%, 8.3%, and 24.9%, respectively.

- Overall, on the motorways, the number of accidents with slight injuries is reduced by 2.9% (5% penetration rate), 6.3% (10% penetration rate), and 19.0% (30% penetration rate). Within the ODD the figures are 4.2%, 9.2%, and 27.6%, respectively. In the urban environment, the corresponding estimates were 2.4%, 4.8%, and 14.5%, and 4.0%, 8.0%, and 23.9%, respectively.
- As for the parking ADF, the avoidable share of all insurance claims could reach 7% for a penetration rate of 30%, and probably more than 20% for a penetration rate of 100%, depending on usage rates.
- The qualitative safety impact assessment made implicit 63 macro safety requirements that need to be fulfilled to completely achieve these safety benefits, whereas the simulations often assume that the functions work perfectly in all ODD conditions. The safety requirements are technology-related (sensors, actuators, algorithms), HMI-related, or driver-related (mental model, perception of automation, procedures, etc.). Moreover, assuming that compliance with speed limits, lower speeds, smaller speed variances, and longer time headways compared to manual driving are more likely to be associated with automated driving and with a lower accident risk, the positive safety benefits are in line with expectations. Behind lower speeds and longer time headways is the technology design with highly developed perception and decision algorithms.

4.3.4 Efficiency and environmental impact

The objective of the efficiency and environmental impact assessment was to assess the potential impacts of mature Level 3 ADFs on travel times, delay, throughput, CO_2, and energy demand. In addition to investigating the effects of motorway and urban ADFs in the simulated traffic scenarios, the scaled-up impacts of motorway ADFs on EU27+3 countries were estimated. This was achieved by the use of representative traffic scenarios in terms of motorway layout, speed limits, and traffic volumes, as well as considering the weather conditions under which the ADF is able to operate.

The efficiency and environmental impact assessment concerned the mature motorway and urban ADFs. The traffic jam ADF was assessed together with the motorway ADF, as separate scaling up was not possible due to lack of available EU-wide data on traffic jams. The parking ADF was excluded from the assessment due to the small influence of parking manoeuvres on overall travel time and emissions. The method for efficiency and environmental impact assessment is presented in the Deliverable D3.4 *Evaluation plan* by Innamaa et al. (2020), and on the implementation of methods in D7.4 by Bjorvatn et al. (2021).

The impacts of the motorway ADF were studied in more detail than impacts of the urban ADF. The same approach as for motorways could not be applied to the latter due to the complexity of the urban networks and a lack of sufficient data available from the different road layouts – which vary significantly more than motorways – and traffic volumes. The impacts in both environments were assessed based on traffic simulations. Motorway simulations covered a large proportion of different motorway layouts in Europe at several traffic volumes. The urban ADF was studied on a more general level using two examples of urban road networks.

A snapshot approach was selected for scaling up the motorway results, meaning that the situation in 2018 was used as a baseline with only the addition of a motorway ADF for the treatment conditions with penetration rates of 5%, 10%, 30%, and 100% among passenger cars. Accordingly, the vehicle fleet considered in scaling up was otherwise the same as at present. It was assumed that the applied statistics were valid over the area of interest for scaling up, including EU27+3. Results for urban areas were not scaled up to the European level due to the lack of data allowing scaling up.

Impacts on traffic flow efficiency were studied with traffic simulations using PTV VISSIM, a microscopic traffic simulation tool for modelling multimodal traffic. The environmental and energy impact assessment used the outputs from traffic efficiency simulations. CO_2 emissions were calculated with EnViVer, which is an emissions modelling software that takes its input from the vehicle speed profiles produced by VISSIM. It enables the estimation of emissions from multiple traffic scenarios and the comparison of the total exhaust emissions as a result of changing traffic situations.

Sources for the input data included OpenStreetMap, European-wide traffic volume, vehicle fleet and weather data from various national or European sources, as well as the L3Pilot technical and traffic evaluation output.

The results of simulations and scaling up show that benefits are possible in situations with high traffic volumes, where ADFs have the potential to improve efficiency and reduce emissions especially on motorways. Scaled up to the EU27+3 level, the expected impacts are overall positive but small (less than 1% decrease in CO_2 emissions and less than 3% decrease in energy demand, for all penetration rates) due to most vehicle kilometres being travelled in low traffic volumes, where no large impacts were detected. The scaled-up impact on travel time and delay at the European level is estimated to be small, a less than 2% increase. On a local level, larger impacts may be observed, for example on regularly congested urban motorways. However, the focus of the assessment was on achieving an overview of the situation in Europe as a whole.

4.3.5 Socio-economic impact

The aim of the socio-economic impact assessment was to analyse the social value of SAE L3 automated driving technology. As far as possible, the social values were expressed in monetary terms. Those impacts that could not be quantified were qualitatively evaluated. The purpose of the work was to undertake a comprehensive socio-economic investigation of each of the L3 ADFs in question. This is in line with the overriding research question presented in L3Pilot Deliverable D3.3 *Evaluation Methods* (Metz et al. 2019): *What is the overall socio-economic impact of L3 ADF technology designed for different specific environments?*

The focus is on the net welfare effects for society of L3 ADFs, i.e., benefits gained from implementing L3 ADF equipment held up against the costs of *not* implemented them.

Impacts were expected to be estimated for each of the four different L3 ADF systems: Motorway ADF, Traffic Jam ADF, Urban ADF, and Parking ADF. In practice, however, the upscaling of impacts from Traffic Jam ADF has not been studied separately, but as an integrated part of Motorway ADF. The impacts of Urban ADF were studied separately, while it was not possible to detect and upscale the impacts of Parking ADF.

The socio-economic impact assessment was structured so that it first briefly recaptured the basic components of the analytical approach chosen to investigate the welfare effects of L3 ADF. Then, it presented expected impacts as they are estimated regarding safety, mobility, efficiency, and environment, and possible impacts that may be derived from these findings. This allowed a fairly comprehensive perspective on impacts of L3 ADF from a societal point of view. The approach and its theoretical and empirical basis are presented in Deliverables D3.3: *Evaluation Methods* (Metz et al., 2019) and D3.4: *Evaluation Plan* (Innamaa et al., 2020), as well as in Deliverable 7.4 (Bjorvatn et al., 2021).

It was, however, impossible to calculate realistic future scenarios with and without the relevant L3 ADF for the next 10–20 years. A baseline scenario over this time period without L3 ADF is not feasible because the relevant technology is already in a prototype phase and presumably soon ready for market introduction. Furthermore, future scenarios limited to the use of only L3 ADF technology would also be very unrealistic, because L3 ADF technology is regarded as a stepping-stone for higher levels of automated driving within the same time perspective. Thus, a simplification was chosen, in which the time perspective was narrowed down to one year. This is what we call the 'snapshot approach'.

At the time when the impact assessments were carried out, the most recent statistics on the traffic and accident situation available were for the year 2018. Therefore, we used 2018 as the baseline scenario, which means that official public statistics for that year would form the basis for describing what the world would look like without L3 ADF technology.

The question then posed for the evaluation was the following: *How much higher (or lower) would the welfare have been if the relevant L3 ADF systems had been installed in a share of the passenger cars on the roads that year?*

The advantage of this approach is that the baseline scenario cannot really be questioned, as it is built on established statistics regarding accident rates, accident severity, traffic flow, and so on. The treatment scenarios then focus on what would have happened if a certain percentage of the passenger cars in that year had been replaced by cars with L3 ADFs in use.

The input data for the socio-economic impact assessment were provided by the impact assessments on safety, efficiency, and the environment, as well as on mobility. These are partly quantified measures of potential impacts of ADF technology. From the evaluation of safety impacts, information on the extent to which ADFs influence the number of accidents and their severity was obtained. The evaluation of efficiency impacts provided information on the impact of ADFs on different aspects of travel time and delay. The evaluation of environmental impacts provided information on how ADFs affect fuel consumption and CO_2 emissions. The evaluation of mobility impacts shed light on behavioural impacts as well as on aspects regarding the comfort and quality of travelling.

Impacts were detected for different treatment scenarios reflecting different shares of passenger cars that actually use ADF technology. For the analyses, the focus was on the scenarios with 5%, 10%, and 30% penetration rates.

For the results of the socio-economic impact, the following can be stated:

- For the motorway ADF, the benefit–cost ratio for the quantified impacts is less than 1 for all penetration rates (5%, 10%, and 30%). On the other hand, the non-quantitative impacts are evaluated as beneficial for society, except for the amount of travel and changes in travel mode. Therefore, even though the quantified estimates are not sufficient to generate net benefits that exceed the cost of motorway ADF, this ADF may be expected to be beneficial from a societal point of view.
- For the urban ADF, the expected net social benefits from accident prevention clearly exceed the social costs of this ADF for all penetration rates. Moreover, the safety impacts of the ADAS equipment included in urban ADF on accidents occurring outside the ODD, and the impacts on the cost of travel time, indicate monetary benefits on a level that may cause the benefit–cost ratio to be above 2.5.
- Differences in the socio-economic impact assessment results for the motorway and urban ADFs are primarily related to traffic accidents. While approximately two thirds of all injury accidents occur in urban areas, less than 15% of these accidents happen on motorways. Therefore, the number of preventable or mitigatable accidents is higher in urban areas than on motorways, leading to higher monetarised safety benefits for urban ADF.

4.3.6 Summary of the impact evaluation results

The impact evaluation covered the four impact areas of the project: mobility, safety, efficiency, and environmental impact, as well as socio-economic impact. Impact assessment did not address the prototypes that were tested in the pilots and analysed in the technical & traffic and user & acceptance evaluations above. The reason is that the impact assessment analysed the potential impacts of ADFs in a future perspective, when they are in use on a large scale. The current prototype functions do not represent a future ADF technology.

The most interesting impact area is safety, which is often given as the main argument for the introduction of automated technologies. A positive effect in the reduction of accidents is expected for most of the analysed scenarios. The estimated safety impact is also reflected in the socio-economic impact assessment results, less for motorway driving – due to its already good safety records – but above all in urban traffic and outside the defined ODD of SAE L3 functions.

Apart from their impacts on mobility, efficiency, and the environment, ADFs are likely to increase the quality of travel and decrease the use of public transport. Furthermore, benefits are possible in situations with high traffic volumes, where ADFs have the potential to improve efficiency and reduce emissions, especially on motorways.

It should be noted that the results are based largely on survey and simulation results, and they contain several constraints that were not possible to control in the studies. A very thorough impact assessment is given in the Deliverable D7.4, Chapters 3 to 6 (Bjorvatn et al., 2021).

4.4 Conclusions, discussion and recommendations

4.4.1 Technical, traffic, user, and acceptance evaluation

When comparing the different systems (motorway, urban, parking), only a few overall conclusions can be drawn. One point that is common for all is the lower speed driven when ADFs are activated in comparison with baseline driving. Additionally, for urban and motorway cases, driving is more stable, i.e., scenarios such as following a lead vehicle continue longer and lane-keeping performance increases.

Overall, participants were positive towards the functions, with some variations among the functions. In general, the participants felt comfortable while experiencing automated driving. However, for all systems, drivers were also aware of or noticed shortcomings of the tested prototype functions or expected different behaviour of the functions in some cases. But it can be noted that even with the shortcomings of the prototype functions, no motion sickness was encountered by the participants.

Going further into detail, the conclusions for the functions differ, as do the use-cases. Therefore, no further overall conclusions can be drawn.

The vehicles used in the pilots were equipped with prototype human-machine interfaces and control systems enabling automated driving. These systems are still under development, and their maturity inevitably varied between and within the pilot sites, should any updates have been required during the prolonged testing schedule at some pilot sites. The use of 'imperfect' prototypes and any unexpected behaviour of the systems may have resulted in unpleasant driving or interaction experiences for users, which may have influenced users' experiences and thus acceptance of the system, since a development system that is prone to errors is likely to elicit different acceptance ratings compared to a market-ready system. Therefore, these factors should be borne in mind when assessing the results.

The following statements and recommendations can be drawn from the piloting data:

- The potential for urban ADF has been shown. However, it would benefit from more and diverse data to be able to show results.
- The pilots were completed either with the presence of safety drivers monitoring the participants' performance or with the vehicles completely piloted by safety drivers. In either case the role of the safety driver was to deal with any unusual situation. Therefore, participants could potentially feel a higher sense of safety as well as a sense of 'ease', leading to over-trust in the system. Furthermore, the systems would always be overridden if faced with critical situations, which made the evaluation of ADF in these situations impossible.
- We need to be cautious when comparing systems, driver types, and test and study types. This was mainly due to the nature of the different systems and data being collected via different pilots that consisted of different study designs.

- Findings reported are designed to be used as a guide and to provide overall impressions. More research is needed to understand the implications of these findings for driver interaction with mature systems.
- Users' subjective experiences and their evaluation of the system predict willingness to use, and it is therefore important to ensure the acceptance of those systems and to ensure that users have positive experiences in future evaluations.
- Users' ability to engage in secondary tasks was a significant predictor of willingness to use. The most widely reported secondary tasks that users were likely to engage in while the system was active included listening to music, radio, and audiobook, navigation, interacting with a passenger, using smartphone apps, and texting. Therefore, it is important that manufacturers consider these preferences when designing their user interfaces, to make it as easy and comfortable as possible to engage in these tasks.
- User evaluations suggest that there are some system performance elements that could be further improved. These include behaviour at motorway junction areas and lane-changing behaviour, the distance maintained from obstacles and road markings, the smoothness of driving in the city, turning behaviour at intersections and curves, behaviour when approaching pedestrians at intersections, and the distance maintained from pedestrians and cyclists when overtaking in urban environments. The majority of these are situations where interaction with other road users is more likely to occur, and therefore, the safety implications may be considered higher.
- In the future, more testing should be conducted, especially to extend the system's capabilities *between* ODDs, as well as to investigate users' ability to take over control in critical situations when the system becomes more mature.
- Studies should be conducted considering long-term exposure to automated driving once the maturity and legal framework for piloting the systems allows such studies. Until then, simulation-based studies should be used complementarily.
- It should also be considered that the SAE L3 ADFs are leading to vehicles with much better environment perception (sensors), which can be used also for the improvement of active safety systems, and which also extend the use of those active safety features beyond the ODD of the L3 ADF. Therefore, the safety benefit of L3 ADF can be improved significantly with very low additional cost.

4.4.2 Impact evaluation

L3Pilot assessed the impacts of passenger car ADFs for motorways, urban areas, and parking on mobility, traffic safety, traffic efficiency, and CO_2 emissions and estimated the overall welfare for society based on the monetarisation of the impacts and the estimation of production costs of ADFs. Various types of collected data were constructed to feed the impact assessment as well as the user acceptance and technical and traffic assessments (Deliverables D7.1, D7.2 and D7.3). In addition to the pilots, the data from *supplementary* and *support* activities completed the picture as a whole and made the assessments successful.

Mobility impact assessment

The mobility impact assessment of AVs must understand who the potential users of AVs are, how they would use AVs in their daily life, and how AVs could transform their daily life and the society surrounding them. This requires interdisciplinary understanding of the psychological, sociological, and technological factors and of their interactions.

The main results indicated that ADFs are likely to increase travel quality by enabling non-driving related activities and increasing travel comfort. Leisure activities and interaction with passengers were often mentioned as preferred activities during automated driving. On average, increased travel quality may decrease the perceived costs of travelling by car. Values of travel time savings estimates vary between 12% and 25%. Some drivers expect to switch to routes within the ODD. 90% of participants would accept additional travel time on a route within ODD if they would not need to drive themselves. Drivers may be willing to drive more under demanding or stressful conditions if driving with ADF feels easier than manual driving. Some travellers expect to partially switch from using public transport or active travel modes to car driving even though most travellers do not expect to change their use of public transport or active travel modes due to the introduction/availability of ADFs. Also, taking longer trips by car is expected to become more attractive and some travellers may also start making completely new trips. However, the majority of participants do not expect to increase the amount of travel.

The current investigation was focused on how the user experience influences travel quality and may induce changes in travel behaviour. This analysis could be complemented by focusing more on the context where automated driving would be performed, e.g., by analysing individual trips based on travel diaries and considering the effects of automation on those.

Even though L3Pilot focused exclusively on passenger car automation, automated public transport, shuttles, and robot taxis will certainly also have a large impact on passenger mobility and modal share. It is likely that mobility research will look more deeply into mobility impact in an increasingly holistic approach from now on.

The impacts of mobility may be determined by a multitude of factors we cannot yet foresee. While technological advances promise gains in productivity and reductions in human error, they also run the risk of leaving lower-skilled workers behind. A few years ago, McKinsey (2017) estimated between 400 million and 800 million workers worldwide could be displaced by automation. Some 75 million to 375 million may need to switch occupational categories and learn new skills. A larger challenge will be to ensure that workers have the skills and support needed to transition to new jobs. Countries that fail to manage this transition could see rising unemployment and depressed wages. This above is just an example we may encounter in the impacts of AD on our lives and mobility, and in the estimation of possible changes in society that may have far-reaching effects, from mobility to the quality of life more widely.

Safety impact assessment

The main results of the safety impact assessment indicated that overall, automated driving is capable of reducing injury accidents. The reduction potential is large both on motorways in general (2.0%–

19.0% with penetration rates of 5%–30%) and within the ODD (3.8%–27.6% respectively). For the urban ADF, the reduction of all road accidents is 0.8%–10.2%, depending on penetration rate and accident severity. A positive effect in terms of reduction of accidents is expected for most of the analysed scenarios. For the motorway ADF, an increase in the number of accidents was assessed for the 'Minimal risk manoeuvre' scenario and a minor increase for the 'Wrong activation' scenario. These scenarios were not addressed for the urban ADF, and a reduction in the number of accidents is expected for all simulated driving scenarios there. For the parking ADF, the avoidable share of all insurance collision claims can reach 7% for a penetration rate of 30%, and probably more than 20% for a penetration rate of 100%, depending on usage rates.

From a methodological viewpoint, assessing the safety benefits of automated driving is a complex and demanding topic, with regard to the quantity of driving scenarios considered as well as for the simulations. During the simulations the tools reached their limits, which led to the fact that not all planned scenarios could be investigated and the 100% penetration rate option could not be reached. Of course, implementation can be improved, and more computation power will be available in the future, but the efforts and time required for computation should not be underestimated for future studies.

The format of input data needs to be considered. In L3Pilot, a database was set up to provide the data from the pilot experiments for the different assessments. Limitations to the safety impact assessment resulted from the format of the database. Due to the need for confidentiality and the avoidance of benchmarking between different ADFs in the pilot, it was not possible to share time series data. This limited the utilisation of the data for certain approaches in the safety impact assessment. Therefore, in the future further options for providing data should be evaluated that allow for sharing time series data while keeping the anonymisation level intact.

Efficiency and environment assessment

The main results of the efficiency and environmental impact assessment indicated positive effects for efficiency in terms of potential decreases in travel time (up to 8%–14% on motorways), as well as fewer delays (up to 17%–36% on motorways) in situations with high traffic volumes and with 100% penetration rate among passenger cars. Regarding the environment, positive effects in terms of decreases in CO_2 emissions (up to 20% on motorways) are possible in high traffic volumes and with 100% penetration rate. In low traffic volumes, the effects are small and can be positive or negative, depending on the changes to average speeds. Scaled up to the EU27+3 level, the expected impacts are overall positive but small – a less than 1% decrease in CO_2 emissions and less than 3% decrease in energy demand, and a less than 2% increase in travel time and delays for all penetration rates between 5% and 100% – as most vehicle kilometres are travelled in low traffic volumes, where no large impacts were detected.

A flexible methodology was developed for the simulation and scaling up of ADF impacts for motorways, taking into consideration the variations in motorway layouts, traffic volumes, and speed limits across the EU27+3 countries. This method can be further improved by adding more data from traffic volume measurements and improving the driver models of the simulations. More accurate traffic models together with a more detailed analysis of the local impacts, such as on urban motorways, would provide insights on how to make best use of ADFs. In future work, it would be worthwhile to apply a similar methodology also to other environments, when more data, for example on urban road networks and traffic volumes, are available.

Socio-economic impact assessment

The main results of the socio-economic impact assessment indicated for motorway ADF found a benefit–cost ratio for quantified impacts substantially lower than 1 for all penetration rates, implying that the benefits of motorway ADF do not outweigh its costs. However, this ADF system may be beneficial from a societal point of view if all relevant impacts are addressed, adding the benefits not quantified in the L3Pilot evaluation. For urban ADF, the expected net social benefits from accident prevention clearly exceed the social costs of implementing the ADF for all penetration rates. Likewise, the additional impacts considered regarding the safety impacts of inbuilt sensors in urban ADF on accidents occurring outside the ODD, and the impacts on travel time costs when driving with the ADF on urban roads, indicate monetary benefits on a level that exhibit a benefit–cost ratio of more than 2.5. Finally, it is likely the case that a package consisting of all ADFs – motorway, urban, and parking – would generate social benefits that exceed the social costs of installing such a package.

It is worthwhile applying a snapshot approach to create a basis for the estimation of the economic impacts of ADFs. A major focus in L3Pilot was knowledge development with regard to the direct impacts of ADFs inside their ODD. Future research ought to consider their potential impacts more broadly. From the socio-economic impact assessment's point of view, it is reasonable to suggest that more attention be paid to the safety impacts of utilising components in the ADF systems outside their ODD. In addition, future research is needed for a better understanding of how the cost of spending time on travel is affected when driving with ADF-equipped vehicles, as well as for a closer elaboration of potential negative environmental impacts as a result of increased travel and the change from other travel modes to ADF-equipped vehicles.

Constraints

The impact evaluation results are conditioned to the availability and reliability of the data, assumptions, methods, and techniques, which all have their own limitations and restrictions. These are reported in detail for each assessment area in Chapters 3 to 6 of the Deliverable 7.4 (Bjorvatn et al., 2021).

The limitations relate to matters such as:

- The necessity for approximation. The results provided are valid for the so-called *mature* ADFs, which are today's approximations of real ADFs.
- Reduction of complexity in driving and traffic scenarios. To cope with the large variety of driving and traffic scenarios, especially in urban areas, the simulations needed to reduce the number of real-life scenarios and simplify the possible parameters considered in each scenario.
- Projection in an abstractive future world and subjectivity. Mobility impact assessment was a future-oriented activity. Because there were not yet data on the realised changes in personal

mobility due to automated driving, it was necessary to conduct the assessment based on people's attitudes and expectations, thus subject to individuals' perception and subjectivity.

- As for safety impacts, the L3Pilot pilot database included pre-defined indicators for the recorded driving situation. Thus, no time series data were available from the L3Pilot data collection.
- As for computer simulations, these required driver models to define vehicle behaviour in the baseline simulations and in some ADF situations. Since the behaviour of human drivers is complex, the models can only approximate this behaviour. In addition, the behaviour of ADFs in lane-change situations and the interactions with manually driven vehicles are not known and thus may be simulated inaccurately.
- Injury risk functions used for the severity outcome of accidents are those extracted and adapted from the literature. Other risk functions would probably have produced slightly different results. As for accidents involving only property damage, these are not recorded in the EU CARE accident database. Therefore, only the impacts from injury accidents were scaled up within the safety impact assessment.
- Estimates of parking ADF effectiveness were conducted by analysing insurance collision claims in one country. No scaling-up could be done for parking ADF, as parking accidents seldom lead to injury accidents.
- As for the efficiency impact assessment, the amount and level of detail of the traffic data on motorways differed greatly among the EU27+3 countries. Despite significant effort put into data collection, data were not found for all countries and only some countries provided the hourly traffic data that was needed for the assessment.
- As for socio-economic assessment, some effects were not quantifiable (e.g., safety impacts outside the ODD, travel time reliability, perceived risk of accidents) or were at best estimated by independent experts (cost of producing and maintaining ADFs).
- Scope of impact: for example, the socio-economic impact assessment would have benefited from a more thorough investigation of impacts outside the ODDs, because ADF's built-in sensors can improve the performance of ADAS on other roads, as well as from an investigation of impacts of ADFs on the cost of travel time.

5 Supplementary experiments – detailed studies on user experience

5.1 Scope and aim of the studies

The L3Pilot experimental part was split into two different paths: (i) *large-scale piloting* across Europe on a public road network involving approximately 750 participants, as described in Chapters 2 to 4, and so-called (ii) *supplementary experiments* focusing on specific user-related research questions difficult or even impossible to address in large-scale piloting due to safety and practical considerations. The supplementary studies were planned in addition to the on-road piloting in order to investigate automated system usage and other relevant user topics with ordinary, non-professional drivers in a safe environment. These studies were also extensive, consisting of over 600 subjects in total.

One major topic of the supplementary studies was behavioural and attitudinal changes that are expected to occur with the usage of ADF. This type of research provides insight into how the usage of ADFs and users' experiences of the system change over time. The drivers using an ADF for the first time – as in most on-road studies in L3Pilot – can be assumed to focus their attention on the system and concentrate on system behaviour. With growing experience, drivers will become accustomed to the system and their usage and the experiences of the system might change. This change over time is especially important when future ADF use is being estimated. Furthermore, it was assessed how ADF use affects manual driving behaviour immediately after a transition of control.

Below and in Table 5.1 an overview is given of the supplementary studies reported in this chapter.

- Three supplementary studies investigated – amongst other concepts – the changes in ADF usage and acceptance with repeated experience of the system. This change is also referred to as *behavioural adaptation* (BA) with a more long-term perspective.
- Two studies in the driving simulator and several on-road studies with a Wizard-of-Oz vehicle investigated short-term changes in manual driving behaviour after driving with an ADF and the impact of ADF design. These are also referred to as short-term BA.
- The impact of ADF use on drivers' fatigue was assessed in a Wizard-of-Oz study taking place on a test track.
- In an online survey, the drivers' expectations regarding secondary task interaction while using an ADF were investigated.

Around twenty research questions with related hypotheses were defined to study the long-term effects of automated driving and others were addressed to behavioural adaptation also outside the long-term perspective. The research questions are those defined and listed originally in the Deliverable D3.1 (Hibberd et al., 2018).

Table 5.1: Overview of the supplementary studies.

Study Nr	Study title	Main Topic	Addressed SAE level	Approach	Additional description
1	Wizard-of-Oz study on long-term behavioural adaption	Behavioural adaptation – long-term	L3	Wizard-of-Oz	Case study, repeated usage (3 times)
2	Driving simulator study on long-term behavioural adaption	Behavioural adaptation – long-term	L3 and L4	Simulator	Repeated usage (6 times)
3	On-road study on long-term behavioural adaption	Behavioural adaptation – long-term	L4	On-road study	Repeated usage (3 times)
4	Driving simulator study on short-term behavioural adaption	Behavioural adaptation – short-term	L3	Simulator	Impact of ADF on manual driving
5	Driving simulator study on ambient peripheral light display	Behavioural adaptation – short-term	L3	Simulator	Impact of HMI on take-over response and acceptance
6	Wizard-of-Oz studies on take-over performance	Behavioural adaptation – short-term	L2 and L3	Wizard-of-Oz, test track and Wizard-of-Oz, public road	Variation of take-over situation Take-over response process N=4 studies
7	Driver impairment study	Fatigue and alcohol (BAC ≈ 0.1%)	L0, L2, and L3.	Wizard-of-Oz, test track	Sleepiness and visual attention
8	Online study on user acceptance	NDRA engagement		Survey	Secondary task interruption by TOR

5.2 Commonly used methods

Although the presented studies addressed a variety of user-related topics in different experimental settings, some methods to assess the user-related concepts were used across the studies (Table 5.2). These methods are: the L3Pilot questionnaire developed in the project (see Metz et al., 2020) to investigate relevant driver-related concepts, the Van der Laan scale (Van der Laan et al.,1997) to assess the usefulness and satisfaction of the ADFs and the Karolinska Sleepiness Scale (Åkerstedt and Gillberg, 1990) to assess driver fatigue.

Table 5.2: Methods used in different supplementary studies. WoZ = Wizard-of-Oz study, DS = driving simulator study.

Method	Study Nr. and short title							
	1	2	3	4	5	6	7	8
	WoZ long-term	DS long-term	On-road long-term	DS short-term	DS ambient light	WoZ take-over	Impairments	Survey
L3Pilot questionnaire	X	X	X					
Van der Laan Scale	X	X			X			X
Karolinska Sleepiness Scale		X				X	X	

A questionnaire was developed to cover the common research questions (RQs), which was suitable for addressing all common RQs in one study. In one part of the questionnaire, there is a list of statements with which drivers can agree or disagree on a 5-point Likert scale. These items link directly to the RQs (see Metz et al., 2020).

The methods dedicated to each study are described in the Deliverable 7.2, Chapters 4 to 11.

5.3 Summary of the studies

5.3.1 Long-term behavioural adaptation

Three studies were carried out to study long-term behavioural adaptation (as shown in Table 5.1):

1. The objective of a *Wizard-of-Oz on-road study* on long-term behavioural adaptation was to explore the change of acceptance and usage of an L3-ADF with growing experience by using a Wizard-of-Oz vehicle. The work was conducted by the Federal Highway Research Institute

(BASt) in Germany. A detailed description of the research questions, study method, and procedure are given in Chapter 4 of the Deliverable D7.2.

The so-called 'Wizard-of-Oz' principle can be used to simulate an automated driving function in a research vehicle. There are two drivers on board the vehicle: a test person who controls the vehicle during periods of manual driving, and a second driver who controls the vehicle during all periods of *allegedly* activated ADF. As the second driver is hidden, the test participant believes that an automated driving system is activated during the periods of automated driving. This technique is useful for studies on human machine interaction and psychological issues such as trust or acceptance.

2. A *driving simulator study* on long-term behavioural adaptation explored the change of acceptance and usage of an L3/L4-ADF with growing experience. The work was conducted by WIVW. The main focus of this simulator study was the investigation of behavioural adaptation (BA) with repeated usage of a motorway ADF. To study this, the test drivers experienced an L3/L4-ADF for a total of six times in a driving simulator. Driver-related concepts such as system usage, acceptance, and trust were assessed and their change over time was analysed. With this approach, a number of research questions from the list of L3Pilot research questions was addressed with a focus on changes over time. A detailed description of the research questions, study method, and procedure are given in Chapter 5 of the Deliverable D7.2.

3. An *on-road study* on long-term behavioural adaptation aimed to explore the change in acceptance and usage of a SAE L4-ADF with growing experience. The study was conducted by Renault, and the analysis was done by WIVW and Leeds University. This study consisted of three automated drives on a motorway, each lasting approximately 1 to 1.5 hours – depending on the traffic flow. The second drive was conducted two to three weeks after the first one, and the third drive two to three months after the first one. The vehicle's Automated Driving Function (ADF) became available on the motorway and performed overtaking manoeuvres and lane changes. For safety reasons, the AV's system did not perform the lane changes automatically and these were initiated by the safety driver but executed by the vehicle. Another manually driven vehicle followed the AV on the motorway to ensure safe lane changes for the AV. A detailed description of the research questions, study method, and procedure are given in Chapter 6 of the Deliverable D7.2.

Table 5.3 below provides a summary of the results on long-term behavioural adaptation. As can be seen, the results on behavioural adaption are mixed across studies. In particular, the on-road study (see Chapter 6 of the Deliverable D7.2) on public roads with a prototype ADF found no changes in driver behaviour and acceptance with repeated usage. In this case, as with some measures used in the simulator study (see Chapter 5), the main reason for this is presumably a ceiling effect, stemming from the already very positive evaluations during the first contact with the ADF. Results from the simulator study and case study (see Chapter 4) indicate that with growing experience the evaluation of the ADF becomes more positive as a consequence of more trust. There is little room for measurable changes in indicators that are already at the positive end of the scale after first contact.

In none of the studies and for none of the investigated indicators there was a decrease of acceptance with repeated usage.

In summary, it seems that the evaluation of the ADF becomes more positive with growing experience or remains on the same, mostly high level. This is reflected in the objective parameters of the handling of the system in an increase in the time spent on NDRAs and in a decrease in time spent on supervising the ADF and the surrounding traffic environment.

Table 5.3: Summary of results on long-term behavioural adaptation. Green indicates that the hypothesis is clearly supported by results, grey that there are no significant results, and yellow that results are mixed. Non-significant results are counted as not supporting the hypothesis. There were no results that explicitly contradicted the hypotheses, which would be marked in red. The number of the RQ refers to the original list from the Deliverable D3.1 (Hibberd et al., 2018).

ID	Specific hypotheses	Case study BA	Simulator BA	Pilot study BA
RQ-U1	Willingness to use increases with increasing experience of function.			
RQ-U3	Perceived safety increases with increasing experience of function.			
	Perceived comfort increases with increasing experience of function.			
	Perceived reliability increases with increasing experience of function.			
	Trust increases with increasing experience of function.			
RQ-U4	With increasing experience, understanding of the system increases.			
RQ-U5	Over AD usage time, drivers experience less stress.			
	After a familiarisation period, drivers will become drowsy more rapidly.			
	Over AD usage time, drivers experience less workload.			
RQ-U6	With increasing experience, attention to other road users decreases.			
RQ-U9	Secondary task interaction increases with increasing experience with function.			
RQ-U10	Take-over performance increases with increasing experience of function.			

ID	Specific hypotheses	Case study BA	Simulator BA	Pilot study BA
RQ-U11	Pattern of system activation will become more dependent on driving scenario with increasing experience of function.			

Regardless of the methodological approach used (simulator, Wizard-of-Oz, on-road study), the results indicate that drivers are either highly positive about the tested ADF from the beginning or become more confident with it with repeated usage. However, this is not reflected in increased knowledge of the ADF or in drivers' becoming more adapted to the situation.

The main effect of behavioural changes over time is visible after the first usage of the ADF. Trust, acceptance, and the willingness to use the ADF increased after the first drive and then remained stable on a high level.

5.3.2 Short-term behavioural adaptation

Studies

The potential impact of ADF use on immediate driving behaviour was studied in two ways: (i) the impact of ADF implementation on driving behaviour either during the transition to manual driving or after the transition to manual driving, and (ii) the impact of the duration of active automated driving on the transition to manual driving.

Three studies were carried out to study short-term behavioural adaptation as shown in Table 5.1 and below:

1. *Driving Simulator Study* on short-term behavioural adaptation. This study explored the change in manual driving behaviour directly after driving with an SAE L3-ADF. The study was conducted by Leeds University. The main aim of this driving simulator study was to understand whether the experience of automated car-following influences drivers' subsequent manual car-following behaviour. The second aim of the study was to understand how engagement with the driving task during automated car-following influenced whether drivers changed their THW in subsequent manual car-following. The experiment was conducted in the full motion-based University of Leeds Driving Simulator (Figure 5.1). When active, the simulator-ADF assumed lateral and longitudinal vehicle control and maintained a maximum velocity of 40 mph. However, in the presence of a slower lead vehicle, the system would reduce its speed, to maintain the time headway of the respective condition. A detailed description of the research questions, study method, and procedure are given in Chapter 9 of the Deliverable D7.2.

Figure 5.1: An example of the in-vehicle HMI with the automation status symbol (Left: automation not engaged, Right: automation engaged) and the vehicle speed (mph).

2. *Driving Simulator Study* to evaluate an ambient peripheral light display in automated driving. Ambient LED displays provide peripheral light-based cues to drivers about a vehicle's current state, along with requests for a driver's attention or action. The study explored the impact of HMI design, in this case of an ambient display on trust and system usage (Figure 5.2). The study was conducted by the University of Leeds. In general, drivers are sensitive to peripheral cues. However, only a few studies have investigated the use of these displays to improve drivers' perceptions of trust and safety during automated driving, and to facilitate transitions between L3 automated driving and manual driving. The study evaluated the effectiveness of an ambient peripheral light display in terms of its potential to improve drivers' trust in L3 automation, first as measured by a questionnaire and, second, through their level of engagement in a non-driving task during L3 automated driving (RQ-U9). Third, it was assessed whether HMI could be used to facilitate effective transitions of control between L3 automated driving and manual driving, compared to an auditory alert. A detailed description of the research questions, study method, and procedure are given in Chapter 10 of the Deliverable D7.2.

Figure 5.2: Example of the Lightband HMI during automated driving (left), and the placement of the automation status symbol and vehicle speed in the dashboard display (right). In both figures, the Driver Monitoring System is located on the dashboard above the steering wheel.

3. *Wizard-of-Oz studies* on take-over performance and conflict response. The aim of the studies was to investigate drivers' response process when they were required to resume manual control from L3 automation. The test-track studies investigated take-over performance in conflict situations in a controlled environment. Moreover, take-over performance was investigated in normal (non-conflict) traffic scenarios in a public road study. Also, the influence of trust on the conflict response was investigated in the ADEST study. The studies were planned by Chalmers and VCC, and the data were collected by VCC staff. Investigating take-over responses in conflict scenarios required a controlled setup both for precise situation replication and to ensure the safety of the test participants. A test track was used for this purpose. Take-overs under non-eventful driving can, however, be studied in real traffic. In this case, during the WoZ study, the pilot was conducted on public roads. A detailed description of the research questions, study method, and procedure are given in Chapter 7 of the Deliverable D7.2.

Main results

Results show that the use of ADFs has an immediate effect on different driver behaviours and acceptance. This was especially evident in, but not limited to, take-over situations.

In Wizard-of-Oz studies (Chapter 7, D7.2), the immediate take-over performance and reaction times were independent of the duration of driving with the ADF active directly before the take-over request and the timing of the take-over requests. It was found that drivers adapted their reaction times to a take-over request with growing experience of an ADF over several drives and multiple experienced take-over situations (Chapter 5, D7.2). Overall, it can be concluded that drivers tend to react quickly to a take-over request during a first contact. It requires repeated experiences of take-over situations to learn to use the time budget provided by the ADF. In the simulator study, however, reaction times increased significantly with growing experience when the ADF allowed drivers to take their time.

In the ADEST study (see Chapter 7, D7.2) about one third of drivers reacted too late and therefore crashed into a stationary on-road object not sensed by automation while supervising a near-perfect SAE L2 automation system. A hands-on-wheel requirement had no effect on whether the drivers crashed or not when attempting to steer past the object. High trust in automation was associated with a delayed response and crashing.

In the study of drivers' take-over performance (take-over times and driving performance in a road-work zone) was found not to be considerably influenced by automation duration (4.5 minutes vs. 14 minutes). In fact, the effect of automation (L3 vs. manual) was greater than the effect of automation duration. Drivers started to steer away earlier (farther away) from a road-work zone after L3 automation (both durations) compared to the manual driving baseline.

In the L3Pilot test track study, drivers' take-over performance was not influenced by the timing of the take-over request in response to the conflict object (i.e., take-over time budget). That is, drivers used a similar amount of time for their first glance at the instrument cluster, placing hands on the steering wheel, glancing at the road ahead, and deactivating automation. However, issuing the take-over request early may result in drivers slowing down before a conflict object becomes visible (precautionary braking) and thereby, having more time to assess the status of the automated system and the surrounding environment before stabilising the gaze to the road ahead.

In the WoZ pilot all drivers managed to resume manual driving from automation in response to the take-over request. The longest observed take-over time took about 9 s. All drivers eventually placed their feet on the accelerator pedal, whereas a few drivers touched the brake pedal.

Besides the impact on behaviour during the transition of control, the effects of driving with an ADF on continuous manual driving afterwards was of interest. Manual driving behaviour was affected by the experience of automated driving (Chapter 9). When drivers were exposed to a short time distance to the lead vehicle, measured as Time Headway (THW) during automated driving, they also chose short THWs during manual driving. This simulator study was conducted to initiate a scientific discussion and the short THW setting was chosen to investigate an extreme automated driving configuration. It is not likely that such a setting will be implemented in the near future. This study was limited to the investigation of short-term effects. Hence, it only allows limited conclusions on the effect of automated driving on general car-following behaviour.

5.3.3 Impact of ADF level on driver behaviour and system evaluation

Drivers rated the SAE L4 motorway chauffeur more positively than the L3 motorway chauffeur, although the two implementations were tested in a between-group design (see Chapter 5, D7.2). Furthermore, there was no impact of ADF level on the development of fatigue, neither in the comparison L3 vs. L4 (Chapter 5) nor in the comparison L2 vs. L3 (see Chapter 8). Across the studies, there was a slight increase in reported fatigue on the Karolinska Sleepiness Scale (KSS) during a 30-minute drive.

The average change of KSS as a function of drive time was remarkably similar at different levels of automation (L0–L3) and alcohol (BAC = 0.0 or 0.1%, see Chapter 8, D7.2). A general trend indicated a larger standard deviation of KSS change during the drive in L3 compared to L1 (L3Pilot ASTA study), and under intoxication in L3 compared to the L3 baseline and lower levels of automation. Drivers directed considerably less attention to the road in L3 automation compared to manual driving (SAE L0) and L2 automation in the sober baseline drive of the impairment study. The effect of alcohol (BAC 0.1%) increased the PRC (The percentage of time that glances fell on-path) during non-task segments, while decreased PRC during secondary tasks was seen in all levels of automation compared to baseline.

During secondary tasks, the off-path glance durations were considerably longer in L3, compared to L0–L2. The effect of alcohol further amplified the effect of automation on the long off-path glances during the secondary tasks.

5.3.4 Non-driving-related activities while driving with ADF active

In the Wizard-of-Oz case study participants mainly used their smartphone or read a magazine when engaging in non-driving related activities during automated driving (see Chapter 4). Other activities such as the use of a tablet PC or office work were observed less frequently. The time spent on *non-driving related activities* (NDRAs) varied widely: for three of six participants, an increase in NDRA engagement over time could be seen. Two participants spent the vast majority of automated driving time on all three drives with NDRAs, so that there was barely room for a further increase. One participant spent only a little time with NDRAs during his first and third drive, but more than half of the time in the second drive.

With increasing experience with an ADF, drivers spent more time during drives with the ADF on non-driving related activities (see Chapter 5). Also in the simulator study, drivers mainly engaged with their smartphone. However, engagement in other activities, such as reading, eating or drinking, or doing paperwork, could be observed. This preference is supported by questionnaire data collected from the participants at the end of the experimental sessions. The drivers who had experienced an L4-ADF stated that they would watch movies and sleep more frequently than drivers who had used an L3-ADF.

The online study on user acceptance and NDRA engagement (see Chapter 11, D7.2) supports these findings and shows that the most popular NDRAs were ‘watching the environment’, as well as many smartphone-related NDRAs and food consumption. Office work, watching a movie, and gaming on a smartphone/tablet were less popular.

5.3.5 Take-over situations

Transitions of control (take-over situations) were one of the main focuses of the supplementary studies. Wizard-of-Oz and driving simulator studies as well as online surveys focused on driver acceptance and behaviour during take-over situations.

The criticality of a take-over situation generally depends on a variety of factors, such as the traffic situation, e.g., the presence of other vehicles or conflict objects, the driver’s state, and the take-over modality. The frequency of crashes was not affected by the requirement to place the hands on the wheel during AD (Deliverable 7.2., Chapter 7.3). However, the drivers’ trust level affected the crash rate: high-trust drivers crashed more frequently than low-trust drivers.

The results on the effects of the take-over time budget on the drivers’ take-over response were mixed. Drivers provided with a large time budget of 45 s showed later responses to a TOR than drivers provided with a take-over time budget of 15 s in a driving simulator study (Chapter 5). In a Wizard-of-Oz test track study, there was no effect of time budget (9 s vs. 18 s) on the take-over response time (Chapter 7.3). It should be considered that after increasing experience with the ADF and take-over situations, drivers’ take-over responses were prolonged in the 45 s condition in the simulator study (Chapter 5). In the Wizard-of-Oz study, the take-over situation was only presented once and therefore, no changes in take-over response were captured.

When a short take-over time was provided, there was no change in take-over response with repeated experience of TORs (Chapters 5 and 10, D7.2). However, with a longer take-over time, drivers’ take-over responses became delayed after repeated experience of TORs (Chapter 5). This delayed reaction was not associated with a decreased take-over performance.

The take-over modality had no effect on the take-over response or on trust and perceived safety. However, drivers preferred an auditory warning over a peripheral light (Chapter 10).

5.3.6 The impact of driver state on the acceptance and usage of ADFs

The acceptance and usage of ADF was affected not only by the system condition but also by the driver's condition. Drivers reported less stress and lower workload with repeated usage. They also directed less visual attention to the road with increasing trust levels. Despite some empirical evidence from other research (as discussed in the Deliverable D7.2, Section 3.3), drivers did not agree with the statement that automated driving would make them tired. The drivers' sleepiness did not increase during automated driving (Chapter 5), not even when drivers had a BAC level of 0.1% (Chapter 8). However, drivers' visual attention was affected by alcohol intoxication: when intoxicated, drivers directed more attention to the road when they were not engaged in a secondary task and less attention when they were engaged in a secondary task.

Even though automated driving did not increase driver sleepiness, the drivers' behaviour changed significantly when they were sleepy. Unsurprisingly, the drivers closed their eyes for longer periods of time and a significant number of drivers fell asleep. However, the drivers' evaluation of the ADFs was not affected by sleepiness.

5.4 Conclusions and recommendations

5.4.1 Behavioural changes and safety

A wide range of user-related topics was addressed in the supplementary studies. For this purpose, different methods were used. The findings of the supplementary studies helped to create the 'bigger picture' of user behaviour and acceptance of AD and changes over time.

Behavioural adaptation to ADFs can potentially have consequences for overall safety. Increasing trust with increasing usage can generally be seen as a positive development. However, increasing trust is accompanied by an increasing engagement in tasks that involve both hands, and thus might compromise take-over performance, lead to longer take-over times, and even lead to a misuse of the system by sleeping (Chapter 5). Driver monitoring systems should be able to detect any adverse behaviour and the ADF needs to take actions to stop or prevent such behaviour.

The design of the system or HMI has also proven to affect drivers' behaviour and should be designed to account for behavioural adaptations. Drivers reduced their headway to the lead vehicle during manual driving when they had experienced shorter distances during automated driving. This finding emphasises that behavioural adaptations go beyond driver behaviour during ADF usage and shape driver behaviour during manual driving, as well. Designers of ADFs should take into account that the drivers' behaviour can be affected on many levels by the ADF use and even during manual driving.

With higher levels of automation, drivers spend less attention to the road and monitor the driving environment less. As a consequence, drivers might fall 'out of the loop'.

5.4.2 Recommendations

<u>For future research</u>

With regard to the fundamental changes that the introduction of SAE L3 automated driving functions would bring to the tasks and responsibilities of drivers, the topic of behavioural adaption will remain a relevant one. Based on the supplementary studies, some methodological conclusions for future research can be drawn:

- Relevant behavioural changes can be observed already after two or three times of system usage. Therefore, for many study purposes medium-term setups with a few measurement points rather than usage over weeks might be a good starting point.
- Some behavioural adaptions to specific decisions in system / HMI-design (e.g., transition times) become more pronounced with repeated usage of a system. To study those, experimental setups focusing on a first contact with an ADF might not be the best approach.
- The ceiling effect, especially in the on-road study on long-term behavioural adaption, highlights that the indicators for measuring behavioural changes should be chosen carefully. They need to allow room for changes. Indicators such as questionnaire items that tend to bring highly positive ratings already after first contact with an ADF are not the best choice, because any behavioural changes in these indicators might not be measurable.

<u>For practice</u>

The highest behavioural adaptation was evident between the first and second drive. For future studies on driver behaviour in AD, this could mean that in order to make predictions about the users' actual behaviour, at least two test sessions should take place. However, further relevant changes in behaviour might be observable in a longer-term perspective. It should be considered that all presented studies had a more or less standardised protocol and drivers did not show 'naturalistic' behaviour. For instance, they were not free to use an ADF at any time or on any road. More naturalistic testing approaches could give a deeper insight into driver behaviour and changes in driver behaviour.

The studies suggest that L3-ADFs might be prone to misuse by the drivers. In the simulator study but also in a pilot study on public roads the drivers indicated that they would use such a system at least now and then to sleep while driving. In the simulator study it became clear that drivers knew that they were not allowed to sleep but should remain attentive at all times. Still, they felt it was safe to sleep because they were still able to handle the take-over situations. This is in line with results reported for the pilots (see Weber et al., 2021). This indicates that driver monitoring systems might be necessary in order to prevent misuse.

Hand in hand with the issue of potential misuse goes the problem of over-trust in an ADF. In a test track study, it was shown that drivers who reported higher trust in the system were more frequently unable to handle a take-over situation safely. For the introduction of L3 ADFs it might be helpful to develop strategies that support drivers to develop a realistic picture of the capabilities of ADFs over time. This could be a way to prevent over-trust and maybe also misuse of an ADF.

In several studies the drivers used the time while driving with an active ADF for other non-driving-related activities. Interaction with a smartphone was one of the most popular activities. Regarding safety, this is first of all good news, because smartphones are rather small devices that allow the driver to still look on the road if necessary and to have at least one hand free for reactions required for driving. However, it might further enhance safety if smartphones and their applications could be designed in such a way that tasks could be interrupted more easily if necessary. Here, new solutions are required that help to integrate (popular) side tasks and the HMI of the ADF to keep the driver in the loop and to support a safe transition of control.

6 Support activities

6.1 Ethical requirements

Ethics is an integral part of all research activities involving human behaviour, and ethical compliance is pivotal for research excellence. Ethical research conduct implies the application of fundamental ethical principles, including the principle of proportionality, the right to privacy, the right to the protection of personal data, and the protection of human health.

When automated vehicles are increasingly tested in normal road traffic, several principles of good testing conduct need to be observed. Testing in public environments with ethically acceptable behaviour includes both handling the data collected in a discreet manner as well as ensuring safety and security to those inside and outside the test vehicles. The L3Pilot project piloted, tested, and evaluated AD functions while engaging users of diverse socio-demographic backgrounds in the evaluation of AD systems.

To meet this goal, personal data protection and several other ethical and legal issues were analysed and identified at the beginning of the project. Under European Union (EU) law, personal data is defined as ‘any information relating to an identified or identifiable natural person’. The collection, use, and disclosure of personal data at a European level are currently regulated in the General Data Protection Regulation (GDPR) [Regulation (EU) 2016/679]. The GDPR establishes the legal framework for L3Pilot during the tests and beyond.

The data management regulations put in place by the GDPR were reflected in L3Pilot to ensure that the outcome of the project was compliant. The enhanced right to be forgotten and the need for a related data control and deletion process, 72-hour incident reporting, and data portability were all requirements that called for further development of current procedures.

Furthermore, national data protection legislation is complemented or overlapped by sector-specific legislation that also needed to be considered. Therefore, it was highly recommended to consult a lawyer to get a clear and comprehensive picture of the data protection requirements for any given country.

Compliance with ethical requirements involved the general procedures for recruitment and the provision of checklists for instructing test drivers before the tests as well as draft legal consent forms for test sites to adjust to their specific test design. The draft consent form checklist described the main details for handling subjects and their data and set the minimum requirements for informed consent throughout L3Pilot. It was highly recommended to involve national legal counselling when developing the final consent form for each test site. A process was set up to ensure that the consent forms at the different test sites included the required content.

Personal data were only to be collected, handled, and analysed by organisations specifically approved in the consent forms and in accordance with the GDPR and the respective national legislation.

L3Pilot focused on safety and its experimental setups were designed by considering appropriate safety procedures based on the partners' experience, which was consolidated over several years of research and development. Of the potential ethical issues, safety was found to be the most relevant, as test users were trying out prototype vehicles. The use of trained professional drivers, safety instructions, and supervised driving (an additional driver or a remote operator), along with consideration of the test site infrastructure, were the main risk mitigation methods.

In L3Pilot, personal data were collected during the recruitment phase (name, age, contact information, etc.) and during the piloting phase (video, GPS, questionnaires). Anonymous indicators were derived from the collected log data for statistical work and assessment of societal and other impacts. The impact assessment was done using scientific methodology and principles, ensuring that the focus was on the behaviour of large user groups instead of on individuals and their data. All evaluation reports as well as any other public deliverables were peer reviewed. If data of an individual was reported, it was checked that the participant had given informed consent for the publication of the data.

The personal data collected in L3Pilot were not sensitive according to the legal definition. In the event that health data, e.g., related to motion sickness, might be collected and processed, informed consent was obtained from all participants according to the EU legislation.

Still, the personal data were rigorously protected and all personal data that were not needed for scientific work were collected and deleted as soon as the tests ended. Test sites were required to comply with the GDPR [Regulation (EU) 2016/679] on data protection practices.

The handling of personal data is common to all user tests in vehicle development and most involved organisations have existing company practices and facilities available. The main difference to past testing was that in automated driving tests the vehicle drives itself much of the time where in the past tests, only the drivers did. The logged data may reveal details of technical implementation of the vehicle algorithms. Therefore, parts of the datasets are also company confidential information in addition to containing personal data.

Where data were shared between organisations (e.g., between the test organiser and a selected analysis partner), related provisions in Art. 24ff. GDPR were observed. These arrangements were based on project agreements and consent forms and, if necessary, additional bilateral agreements, defining appropriate processes and liabilities (special attention in this context was paid towards Art. 28 GDPR and the contractual legal requirements stated therein). The anonymous indicator data were shared without bilateral agreements as far as the risk of re-identification of the individual was excluded.

A list of measures to minimise the risks to research participants and staff was developed and was implemented throughout the project.

A detailed discussion on the ethical principles of road tests for the L3Pilot project is described in Deliverable (8.1–8.3) *Ethical Requirements No.1–No.3* (Gellerman et al., 2019). The discussion and guidelines include topics such as identification and recruitment of research participants, informed consent procedures, ethical approval, data handling and management, Horizon 2020 ethical standards, and measures to minimise risks for research participants and staff. Related checklists are also included in the deliverable.

6.2 Legal aspects

L3Pilot focused on safety, and its experimental orientation was designed to take into account appropriate safety procedures based on the partners' experience consolidated in experimentation on public roads. Of the potential ethical issues, safety is still the most relevant one, as test users are trying out prototype vehicles that are not market-ready.

An integral part of the L3Pilot was that relevant ethical, safety, and privacy issues were identified from the very beginning and related risk mitigation plans integrated into the test plans. The work on safety and ethics benefitted from numerous large-scale user trials of vehicle ICT in the last ten years, as well as from existing guidelines from the field operational test community.

The work on legal aspects focused on the needs of each pilot centre, taking into consideration the specific regulations of the participating country where the respective tests were planned to be carried out and also possible cross-border operations. A detailed survey was conducted on the legislation to be applied. All vehicle owners, following a set of defined guidelines, ensured that they held suitable permission for experimenting with cars equipped with AD functions. Furthermore, a common approach was taken to ensure that data privacy requirements at the European and national level were completely fulfilled (see the L3Pilot Deliverable 8.1–8.3).

In most countries, legislation or regulation requires specific authorisation for experimenting with automated cars on public roads. A review of these requirements was conducted for each country where experiments would take place in the course of the project (2018–2021).

The review on legal aspects focused mainly on the countries where experiments were planned: Belgium, France, Germany, Italy, Sweden, the Netherlands, and the United Kingdom. The review consisted of a presentation of requirements in each country, using a standard template to allow comparisons between countries. It is worth highlighting that the requirements are set by the rule of law in all countries except for the UK, where only recommendations are given.

All car owners in the L3Pilot project complied with the regulations in the countries where they carried out experiments, including cross-border experiments. The procedures reported in the Deliverable D8.1 can also be used by any car owner who would like to apply for permission in any of the countries, thereby facilitating access to national procedures.

The collection of regulations was intended to provide a comparative overview of a variety of European countries. Some regulations are more detailed and spell out, for example, the mileage demanded in simulations or test track driving, or they require the names of the streets where the experiment takes place. Other codes are less specific and recommend safe practices in more general terms.

The information provided on legal aspects in experiments on public roads was given on an as-is basis and was designed solely to provide guidance to vehicle owners. Furthermore, the information was not intended to be a substitute for vehicle owners seeking personalised professional advice. The working group made no claims as to accuracy, completeness, suitability, or validity of any information and would not be liable for any errors, omissions, or delays. As such, the information given did not constitute legal advice and was not to be interpreted as such. Vehicle owners accepted the information ‘as is’ and assumed all responsibility for the use of such information.

Due to the limited available experience regarding AD in mixed traffic, we should expect constant updates of the regulatory scheme. The many safeguards now in place reflect the unknown realm of this technology as used in variable situations encountered in ordinary traffic. In particular, they remind us of the concerns regarding full automation, under which the vehicle may suddenly perform completely unexpected manoeuvres.

Nevertheless, L3Pilot partners consider these initiatives to be a key milestone for the deployment of the technology. The framework created the prerequisites for highly and fully automated systems and also showed the interest of many stakeholders in the potential benefits of AD. At the same time, the different national regulations represent an additional challenge. For this reason, *the project partners suggest further work towards an internationally harmonised legal framework for automated driving*.

In this context, all vehicle manufacturers in L3Pilot have implemented internal processes regarding the conducting of experiments on public roads. These processes are based on their consolidated experience with prototypes and on the knowledge collected during the development of similar products (e.g., ADAS functionalities), with the objective of increasing safety for all road users, not forgetting the driver/passengers of the test vehicle. Such processes include driving permits for prototype vehicles, medical tests, and specific training for unexpected behaviour of the vehicle or the environment. In addition, a detailed examination of functional safety has an integral role in the process, and in this respect the system developers have strived to include a large range of use cases that may at first seem quite remote from everyday operation.

The L3Pilot work highlighted the legal, ethical, and privacy principles that need to be taken into account throughout the project work. It discussed general procedures for recruitment and provided checklists for instructing the test drivers before the tests and draft legal consent forms for test sites to adjust to their specific test design. The draft consent form checklist describes the main details on handling participants and their data and sets the minimum requirements for informed consent throughout L3Pilot. It was highly recommended to involve national legal counselling when developing the final consent form for each test site. A process was set up to ensure that the consent forms at the different test sites include the required content. Personal data were only collected, handled, and analysed by organisations specifically approved in the consent forms and in accordance with the GDPR and the respective national legislation.

6.3 Cyber-security

Modern vehicles contain a large volume of electronics to meet the highly diversified requirements of drivers, passengers, safety, security, and regulations. Today’s vehicles provide safety systems, dynamic control systems, engine controls, and wireless connectivity, to name just a few (Figure 6.1).

In fact, electronics systems powered by semiconductor-based integrated circuits comprise 40% of the cost of a new car. That is up from 18% in 2000 and 20% in 2007 and is projected to reach 45% by 2030 (Ramsey, 2020).

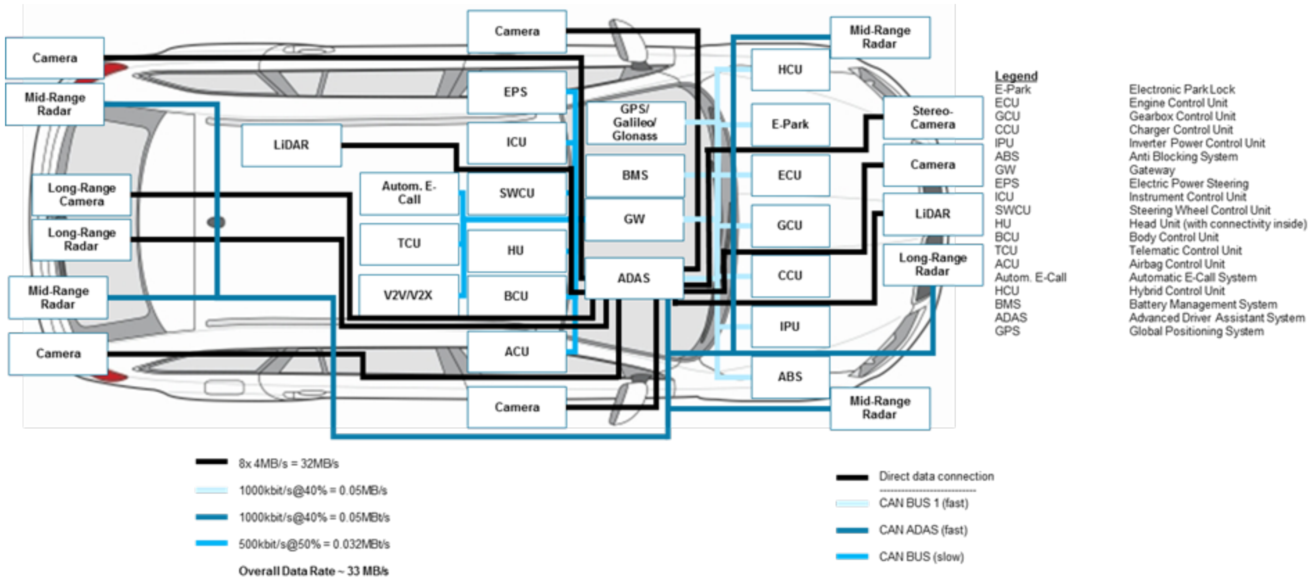


Figure 6.1: Generic system architecture of typical vehicle-based sensor inputs and processing. Derived by L3Pilot vehicle owners.

Such functions are normally activated using an electronic control unit (ECU) for each major task. The ECUs are connected to each other over different underlying networks such as CAN bus, FlexRay, or Ethernet. The ECU networks are segregated according to the desired functionalities, such as safety-critical and non-safety-critical networks or high-speed and low-speed networks. As an example, a high-speed bus may be used to interconnect powertrain components that generate real-time telemetry, whereas a separate low-speed bus might be used to control binary actuators such as those for lights and doors. In the case of multiple networks, there might still be a need for interaction between the individual networks. These (sub-) networks are then interconnected through a gateway.

The work on cyber security in L3Pilot focused on three generic functions under development – Urban Chauffeur, Motorway Chauffeur, and Parking Chauffeur – which served as important representative use cases. The study produced an analysis of the current state of the art and a methodology for identifying relevant cyber-attacks while assessing their criticality. This, in turn, allowed the development of strategic and technical recommendations for the vehicle owners.

The employed methodology was a Threat Analysis and Risk Assessment (TARA), tailored to the objectives of level L3 functions with respect to cyber-attacks. As part of this method, the probable points of intrusion were identified for each use case and a risk assessment was computed, considering the probability and the impact of each attack. The AD functions implemented in the project fleets were verified to be cyber secure before the pilot phase. The analysis took a generic perspective with regard to vehicles featuring L3 automation. This included the vehicle system architecture, an overview of the possible intra-system communication interfaces, as well as communication with external digital infrastructure privately owned by the OEM and remotely located on the cloud (e.g., in use for secure over-the-air software updates).

In addition to TARA, a well-established state-of-the-art framework recommended in SAE J3061, a novel model for the cyber-security analysis of L3 Automated Driving (AD) systems was proposed by integrating aspects of functional safety. The proposed TARA+ model quantifies the likelihood and the impact of an attack and combines them to derive an attack risk value as in the traditional model. The novelty lies in the bespoke integration of the impact calculation, which incorporates the notion of controllability of an attack by the AD system and/or by the driver (ISO 26262 controllability definitions were extended to fit the proposed analysis). As part of this method, the probable points of intrusion were identified, both external (e.g., road infrastructure manipulation) or internal to the system (e.g., AV connectivity with the cloud), and for each use case a risk assessment was performed considering the probability and the impact of each attack. Finally, based on the above analysis and the SoA (Service-oriented Architecture), general cyber security guidelines were recommended to every pilot leader.

After a general description of some relevant technologies, the adopted methodology was described, work was done on the assessments, and the practical recommendations for cyber security were produced.

The conclusions of the TARA+ analysis, together with a literature survey and interviews with the automotive partners, allowed a list of high-level cyber security recommendations to be compiled. These recommendations were intended for further use by the L3Pilot vehicle owners during the design and execution of the pilot studies.

The recommendations are summarised below (for a complete list, see D4.2 *Legal Requirements for AD Piloting and Cyber Security Analysis*):

- *Establish and use a sound secure engineering process:* Perform threat analysis of the vehicular environment using standard threat analysis methods such as TARA and others.
- *Internal and external connectivity/communications:* Close the debugging access to the electronic devices in the production vehicles. This includes several measures, such as: closing the debug access to ECUs; permanently shutting down flashing interfaces such as JTAG after the initial flash; segregating the safety-critical infrastructure from the non-safety-critical infrastructure.
- *Self-Auditing:* Gather information about the policies and procedures currently in place; gather information on vulnerabilities; test the system – particularly the safety-critical systems or sub-systems.
- *Vulnerability or incident detection and response:* Establish an information sharing and analysis centre (ISAC); establish a vulnerability disclosure and reporting procedure; develop and have in place a standard operating procedure to address the identified or reported vulnerabilities; if a protocol is found to be using cryptographic algorithms or mechanisms that are found to be broken,

the updated and/or patched version of those protocols should be used as soon as available; log the incidents, especially those that might have an impact on security (as distinct from safety).

6.4 Code of Practice

6.4.1 Code of Practice – a brief history

Code of Practice (CoP) activities started with the rise of Advanced Driver Assistance Systems (ADAS) at the end of last century. Back then, it became clear that ADAS have a high potential to improve traffic safety. However, technical limits as well as liability issues delayed their market introduction. A proposal to establish a Code of Practice was confirmed by the Commissions Communication COM (2003) 542 of 15 September 2003. These circumstances gave birth to the RESPONSE project (1998–2001). That activity proposed the creation of a Code of Practice for the development and validation of ADAS. These principles were established on a voluntary basis following a common agreement between all involved stakeholders. The requirements for such an ADAS Code of Practice were further elaborated within the RESPONSE 2 project (2002–2004). The RESPONSE 3 project (2004–2008) continued this path in the PReVENT project. The outcome was the final 'Code of Practice for the Design and Evaluation of ADAS' (CoP-ADAS; see Knapp et al. 2009), which provided the vehicle industry with tools and a common understanding to manage the issues regarding safety and liability for ADAS.

Since PReVENT, research and development have led to technologies that support the driver or even take over the driving task in a wide range of situations. Like ADAS, automated driving technologies face challenges that need to be addressed to avoid delays in their market introduction. Therefore, the CoP activities were continued in the European research project AdaptIVe (2014–2017), which dealt with the development of automated driving functions (ADF). RESPONSE 4 – a sub-project of AdaptIVe – focused on the classification and legal aspects of AD. Furthermore, by identifying the crucial challenges within the development of ADF, it provided the basis for the development of the CoP-ADF in L3Pilot (see Deliverable D2.3 *Code of Practice for the development of ADFs*).

The *Code of Practice for the development of Automated Driving Functions* provides a comprehensive guideline to support the automotive industry and relevant stakeholders in the development of automated driving technology. The CoP-ADF is derived from knowledge accumulated by the industry as well as collected best practices from different topics. Thus, the CoP-ADF includes the following aspects:

- Collection of best practices on the topics that have been identified in L3Pilot as relevant.
- A typical process for the development and release of ADF.
- Safety aspects and methods to ensure the safe operation of ADF.
- A checklist for engineers and to provide support to the AD development community.

A detailed description of the CoP is provided in Deliverable 2.1 *Framework of CoP* (Wolter et al., 2018), Deliverable 2.2 *Draft and results from pilot application of draft CoP* (Fahrenkrog et al., 2020), and Deliverable 2.3 *Code of Practice for the development of ADFs* (Cao et al., 2021). The following condenses some of the key aspects of the Code of Practice for automated driving functions developed by L3Pilot.

6.4.2 L3Pilot Code of Practice

Scope

The CoP-ADF focuses on SAE L3 and L4 functions in passenger cars for which steering wheels and pedals are available in the vehicle all the time. In addition, the driver is available:

- To take over the driving task upon request by the function (user ready to take over): at any time, given a sufficient lead time, for L3 functions; at the end of the Operational Design Domain (ODD) for L3 and L4 functions.
- To cover driving scenarios outside the scope of the function (e.g., function limits, outside of the ODD, ADF switched off); and
- To retake control from the automated driving function at any time.

Regarding the covered regions and ODD, the CoP-ADF is written from a European standpoint and focuses mainly on motorway and parking ADFs. However, these aspects will apply to a large extent as well for ADF beyond this scope, namely:

- ADF operating in other regions outside the EU market, such as China, Japan, or the USA.
- ADF with higher levels of automation or driverless operation (e.g., robot taxis operating in a geo-fenced ODD).
- ADF with other ODD, such as on urban or rural roads.

Moreover, the CoP-ADF provides relevant references to specification documents, legal guidelines, and literature.

Development process

The development of CoP-ADF was started by defining the CoP-ADF framework (D2.1. *Code of Practice Framework*, Wolter et al. 2018). The criteria were defined in order to evaluate whether a certain topic was relevant for the CoP-ADF. These criteria are as follows:

- The topic / process poses a common challenge in the development process that requires cooperation.
- A wrongly applied approach to the topic / process would lead to serious consequences (e.g., malfunctions in certain traffic situations leading to non-release of the function).
- A frequent misapplication of an approach to a topic / process is highly likely.
- The topic and process can be described in a general way that does not lead to unreasonable limitations in the development process (company independent).
- For optional criteria: the topic and process are of relevance for L3Pilot prototype vehicles and can be evaluated in this project.

Once the framework was defined, the actual work on the CoP-ADF began. The first step was to collect relevant literature based on the status at the end of 2020, which included project reports, industry documents, scientific publications, standards, and regulations, and to analyse them. Based on the literature research, a set of relevant questions for the draft of CoP-ADF was defined and then improved and consolidated using an iterative update process (D2.2. *Draft and results from pilot application of draft CoP*, Fahrenkrog et al., 2020).

Stakeholder feedback was then required to ensure broad acceptance of the final CoP-ADF. The draft of CoP-ADF was presented to L3Pilot partners in a dedicated workshop in the General Assembly of L3Pilot project in November 2019. The collected feedback was used to prepare an updated version of the CoP-ADF, which was afterwards presented to external stakeholders not involved in L3Pilot, namely 12 experts from different disciplines, including Functional Safety (FuSa), Cybersecurity, Human-Machine Interface (HMI), Vehicle-to-Everything (V2X), Regulation, and Verification and Validation (V&V). A dedicated workshop took place in October 2020 and was arranged as a virtual event to collect the external experts' feedback and to discuss their applicability to a new version of CoP-ADF. The validation process ended with the final review of 4 experts in the L3Pilot project, and the collected feedback was used to derive the final CoP-ADF (D2.3 Cao et al., 2021).

Application of the CoP-ADF

The CoP-ADF is intended to support developers of ADF by providing a series of so-called 'questions' that have been defined based on experience gained in the development process. These questions guide the user through different topics that are relevant for the development of an ADF. It is important to note that it is not necessarily required to answer all CoP-ADF questions with 'Yes' to develop an ADF. Depending on the question, a 'No' might also be an appropriate answer. Some questions might also not be relevant for certain ADFs. Thus, the purpose of the question is not necessarily to lead to a specific answer, but to initiate the developers' reflection about a question and to encourage them to report whether and how a certain topic has been addressed in the development.

L3Pilot does not prescribe how the CoP-ADF should later be used within companies that develop ADF. One option would be to address the questions directly in a dedicated process, the other option is to include the questions in already existing development processes. Thus, the approach taken needs to be decided by each company individually.

Timeline, categories, and topics of the CoP-ADF

In the development and start of production of a technology, different aspects become relevant at different stages. In order to consider this aspect, the CoP-ADF is split along the development process into different phases (Figure 6.2).

Figure 6.2: Development phases applied in the CoP-ADF.

After defining the development phases, the categories and related topics of the CoP-ADF were established. Each question is assigned to a certain topic and development phase. One CoP-ADF question can be assigned to several development phases.

The structure of the categories is provided in Figure 6.3 and the structure of the topics in Table 6.1.

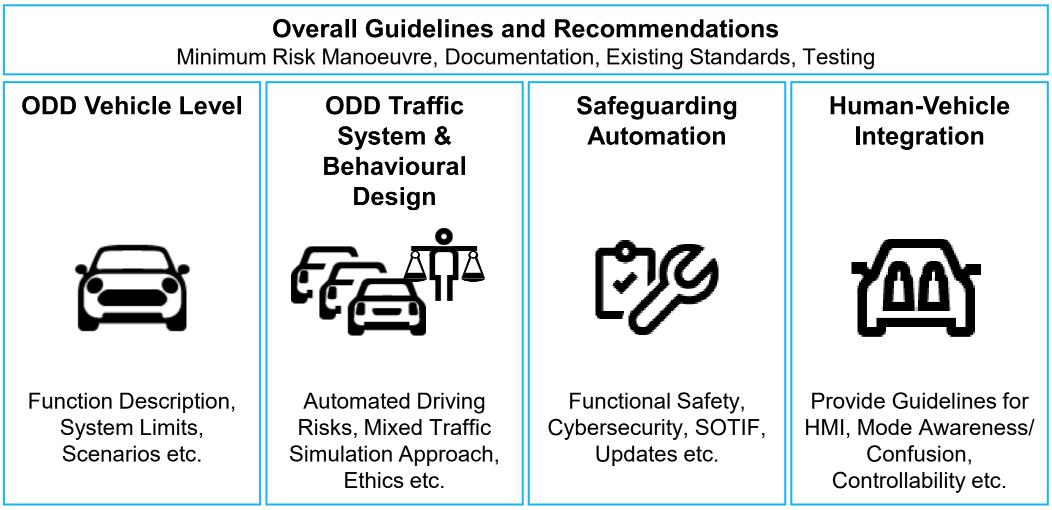


Figure 6.3: Categories used for CoP-ADF.

Therefore, the CoP-ADF covers 22 different topics in one of five categories. The 22 topics were identified by L3Pilot partners as common challenges or as issues that could lead to a frequent misapplication during the ADF development process.

Table 6.1: Overview of the CoP-ADF categories and the corresponding topics

Category	Topics
Overall Guidelines and Recommendations	• Minimal Risk Manoeuvre • Documentation • Existing Standards • Testing (incl. Simulation)
ODD Vehicle Level	• Requirements • Scenarios and Limitations • Performance Criteria and Customer Expectations • Architecture
ODD Traffic System & Behavioural Design	• Automated Driving Risks and Coverage of Interaction with Mixed Traffic • V2X Interaction • Traffic Simulation • Ethics and Other Traffic-related Aspects
Safeguarding Automation	• Functional Safety • Cybersecurity • Implementation of Updates

Category	Topics
	• Safety of the Intended Functionality • Data Recording, Privacy, and Protection
Human-Vehicle Integration	• Guidelines for HVI • Mode Awareness, Trust, and Misuse • Driver Monitoring • Controllability and Customer Clinics • Driver Training and Variability of Users

The CoP-ADF consists of 155 main questions (plus sub-questions) assigned to one of 5 categories and one of the 22 topics. The questions should be checked and evaluated by the user during the development process of ADF.

Table 6.2 below shows an example of a question for the category ‘Human Vehicle Interaction’ and topic ‘Guidelines’, the question being relevant for the concept selection phase.

Table 6.2: Example of question and sub-questions.

<table>
<tr><th>Question 4-1-2</th><th>Relevant Phase(s)</th><th>DF</th><th>CO</th><th>DS</th><th>VV</th><th>PS</th></tr>
<tr><td colspan="2">Are unintentional activations and deactivations of the ADF prevented?

☐ Yes / ☐ No</td><td colspan="5">• Are the ADF controls designed in such a manner as to reduce accidental activation / deactivation?
• Is the ADF able to determine accidental activations / deactivations vs. intentional ones?
• Is a fall-back considered in the event that an accidental deactivation occurs and the driver is not in the loop?</td></tr>
</table>

It must be noted that the scope of the CoP-ADF is not to provide technical solutions, but to support the development of ADF by ensuring that relevant aspects have been considered. Therefore, there is not necessarily a right answer to all CoP-ADF questions.

The Deliverable D2.3 (Cao et al., 2021) presents the final version of the Code of Practice for the development of Automated Driving Functions of the L3Pilot project.

6.5 Exploitation and innovation

6.5.1 Role of exploitation and innovation activities in the project

An overview of future deployments in the domain of AD expected by L3Pilot partners is described in Chapter 8.1 – Impacts expected by the project.

However, a broader perspective is needed when considering the role of exploitation and innovation activities in the project. The economic environment of the automotive industry continues to focus on innovation owing to customers’ desires for increased efficiency, safety, and comfort, with new concepts of sustainable mobility being explored. The landscape is also characterised by intensified market introduction of electric vehicles and new players entering the business. Also, the mega-trend of digitisation is shaping industries world-wide – not only the automotive sector. Software expertise is taking an ever-increasing role in ‘everything’, including intelligent vehicle development. How the automotive market will make its way through this tumult is much more difficult to predict than was the case in the previous decades.

For these reasons, it was imperative for the L3Pilot project also to explore possible service concepts providing new mobility solutions and to chart the deployment potential for the market introduction of automated vehicles. The large European consortium of key players along the automotive value chain has great potential to accelerate the progress of automated driving functions. Since AD technology beyond SAE L2 is not yet on the market, a large majority of users have not yet experienced vehicle automation. Therefore, the future of AD market introduction and user acceptance remains uncertain.

Concrete objectives were to:

- Understand the viability of AD-related business models that drive the demand for new service- and data-driven mobility solutions.
- Understand the collaboration required from the different actors across the AD ecosystem.
- Identify key challenges for OEMs and other stakeholders.
- Create potential business models and analyse them.

The exploitation and innovation approach applied in L3Pilot had to deal with an uncertain future for the deployment of automated driving technology. Even among experts, expectations and trend analyses diverge when it comes to anticipating the speed and intensity of major future developments and trends, such as the application of artificial intelligence, connected mobility, vehicle electrification, sharing models, etc. These will deeply influence the future automotive business.

Nonetheless, the automotive industry, as well as public authorities and decision-makers, is keen on shaping its desired future by making automated driving a success and promoting its interests in the transformation of mobility. Given the uncertainty of long-term future developments – 10 or more years ahead – the L3Pilot exploitation approach is based on a broad and open model that deals with a range of different business environment scenarios, novel business models for new mobility solutions, and possible deployment perspectives.

The following trends were described and discussed in relation to their impact on the automotive business:

- *Artificial Intelligence and Big Data*: Companies in the automotive sector increasingly view data as a competitive asset. This includes both the data directly obtained from the vehicles as well as data gathered via partners in the data ecosystem.
- *Automated Driving:* Automated Driving most strongly affects automotive business models as it allows new ways of using vehicles and of using driving time for other activities. Furthermore, it

introduces new players, includes many different subsystems and services, and might have desirable – or undesirable – effects on urban transport systems.

- *Connected Mobility:* Connected Mobility introduces new players and includes new vehicle- and infrastructure-related subsystems when vehicles can be connected to practically 'anything'. The value of connected mobility lies in improved travel experiences for users, such as greater comfort, improved safety, more reliable travel times, etc.
- *Shared Mobility and Electrification:* Both shared mobility and electrification are pushed by sustainability goals. This trend does not change the function of a car as a transportation means; yet it does make a large impact on the how the service is perceived in terms of sustainability, comfort, driving experience, privacy, costs, etc.

To deal with these long-term uncertainties, *a scenario approach* method was used in the project. This approach offered the opportunity to work with variable future developments instead of only one trend-based development (for a detailed description of the activity, see Deliverable D1.5 *Trends and business scenarios*; Beuster et al., 2020).

Furthermore, for the evaluation of the business models, a multi-step procedure was developed with the help of project-internal and external experts. The results were used iteratively to refine the business models and understand key stakeholder requirements and major challenges concerning desirability (customer acceptance), technological feasibility, and viability. This procedure is explained in detail in the deliverable D1.6 *Deployment strategies and business models for ADFs* (Beuster et al., 2021)

6.5.2 Scenario development

Scenario development allowed recommendations to be defined on how to prepare for possible futures. Moreover, the scenario development was carried out as a collaborative process that elaborated scenarios in a participatory way involving different stakeholders with their interests, perspectives, and expertise. This was also regarded as one of the method's major assets.

To carry out a scenario process, a research question was first defined. The research question had to contain regional, time, and subject scopes. For the scenario development in L3Pilot, the following research question was defined:

'What will the European business environment for automated driving-related business models look like in 2030?'

This question provided the basis for identifying the driving forces in the turn to automated driving with the possibility to affect mobility and have even further impacts.

Driving forces are factors that have a strong impact on business models. Driving forces originate from different areas such as society, technology, economy, ecology, politics, and legislation. A total of 18 driving forces were identified using different sources such as the trend developers' own knowledge and experience, previous national and international research projects, and third-party trend reports. The description of the driving forces was discussed and adjusted with the participants of the L3Pilot General Assembly 2018 in Athens and was revised based on a follow-up discussion.

In order to identify critical driving forces serving as a starting point for the scenario-building, all driving forces had to be evaluated with respect to their impact on the key question of *the European business environment in 2030 for AD-related business models* and the uncertainty of their potential occurrence. The participants in the L3Pilot General Assembly 2018 in Athens also took part in this evaluation step. For the evaluation of impact, they rated the Top 5 impact factors from their point of view. For the evaluation of uncertainty, they had to state whether they believed in option A or option B, or if they were uncertain about it. On this basis, the Uncertainty/Impact Matrix in Figure 6.4 below was developed.

The left part of the matrix contains the driving forces with relatively low uncertainty. The superscript letter expresses the mainstream expectation of the participants, e.g., $T2^B$ means that most of the participants expected an 'evolutionarily increased automated driving technology' (driving force T2: automated drive technology; option B: evolutionarily increased). Only a minority expects a revolutionarily increased technology (Option A) or is explicitly uncertain about it. The right upper corner of the matrix contains the so-called critical driving forces with high impact and high uncertainty.

Three critical driving forces from three different environmental areas were identified: L1: Legislation for AD, S1: Societal acceptance of AD, and T3: Application of artificial intelligence.

This allowed three different combinations of two driving forces for the scenario cross. In this case, it was the responsibility of the core team to select two of the three critical driving forces. After an intensive discussion, the stress field between the technological capabilities for AD and related business models, on the one hand, and societal acceptance, on the other hand, was selected as the scenario basis and was used for the scenario cross.

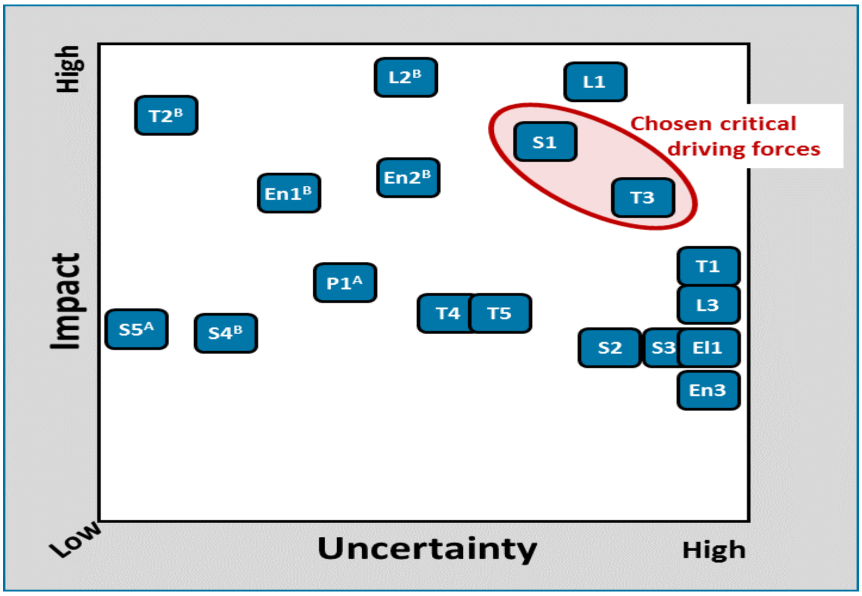


Figure 6.4: Uncertainty/Impact Matrix and the chosen critical driving forces.

6.5.3 Scenario cross

The resulting scenario cross is shown in Figure 6.5. With two different options for each of the two critical driving forces, four different scenarios (I to IV) were created and named:

- Scenario I is seen as 'AD-Paradise', because the developed technological capabilities are accompanied by a significant increase in societal acceptance. This is an ideal environment for AD-related business models.
- Scenario II is characterised by significantly increased societal acceptance, but the technological capabilities are only evolutionarily increased. The situation is that of the Greek mythological character 'Tantalus', whose desires are not fulfilled.
- Scenario III shows a rather slow development of the AD business environment. Technological capabilities develop only evolutionarily, and societal acceptance is stagnating. There is development, but only 'Slowly but Surely'.
- In Scenario IV, a 'Tech Push' is in place but is hampered by a lack of societal acceptance, since most potential customers are rather reluctant.

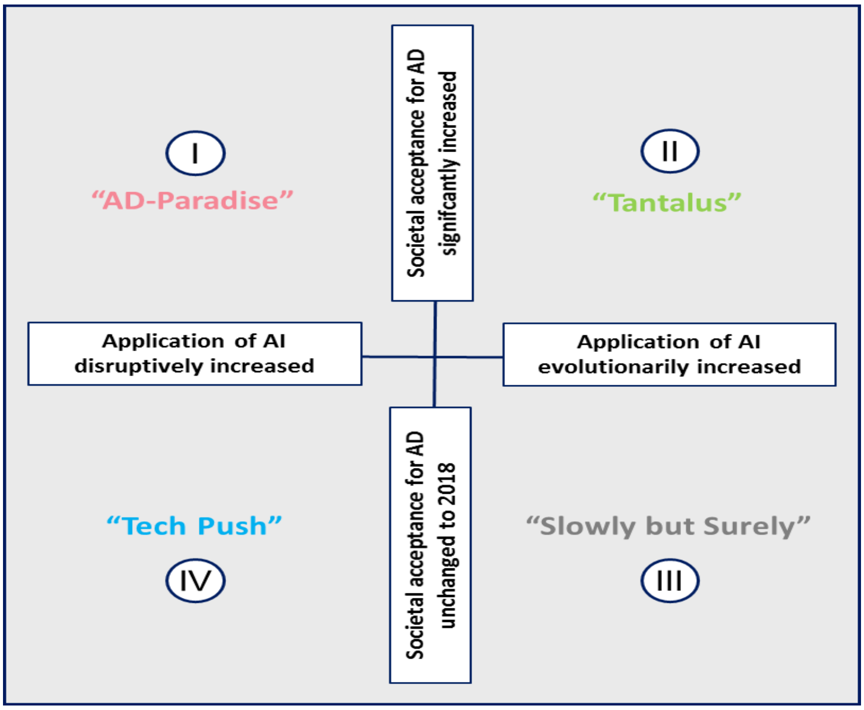


Figure 6.5: Scenario cross with four different scenarios (I to IV).

6.5.4 Collaborative business models for automated driving

Globally, organisations are preparing business models to create value for the use of automated driving technologies. New ways of providing mobility services have shown lacunae in the traditional business models of car manufacturers: selling hardware (cars) for mobility. Not all current mobility services, however, will be viable for many.

Currently, hardware and software for AD are mainly sold as a product. A trend toward increased partnerships between major car manufacturers and software start-ups with the latest AD technology can be observed (Ford, VW, and Argo AI; Toyota and Pony.AI). Some exceptions to this trend are the IT technology giants that are attempting to create their own AD-based mobility services. In this case, the car manufacturers provide the hardware (also semi-automated), and the complete software package comprising complex technologies is provided and integrated by the IT tech companies into a fully autonomous product (Waymo, Amazon). As the software can be integrated into any hardware, this type of business model gives a competitive advantage to the IT tech companies through economies of scale, thus leading to fleets of automated vehicles (AVs) providing mobility services. The software package requires and implies continuous management and updates.

This includes new functionalities, better software performance, and updated security of the software package, for example, with a logical step-up to subscription rather than transaction sales.

Another trend observed is the shift towards the sharing economy and shared taxi services (Uber, Lyft). With high automation technology, the increased associated costs are no longer a concern for the driver in a pay-as-you-go model, thereby providing a case for this business model. In combination with ‘platformisation’, with applications and rides being sold as a service to the customers, on-demand and door-to-door mobility services are scaled up quickly with minimum effort. A variant of this business model is crowd-sourced car fleet sharing services (peer-to-peer), where it will be possible for any individual (or group) with a highly automated vehicle to participate by renting out their vehicles to provide temporary access to a car.

Consequently, the four different AD- and future-related business models that were selected to drive the demand for AD span a broad solution space for AD-related business. Furthermore, they are generic and configurable to many settings. A detailed description of the business models and their service-dominant logic as well as the collaboration of different stakeholders from various sectors is explained in detail in Deliverable 1.6 (Beuster et al., 2021).

The emphasis on customer demands for integrated, value-oriented solutions driven by digitisation is highly applicable to the future of automated driving. These elements coincide with so-called service-dominant logic: customers are increasingly focused on the value they derive from the actual use of a product, rather than the product itself. The business models are closely linked to major automotive and mobility trends and refer to broadly considered business opportunities for the automotive industry players. The four business models focused on in this work are listed below:

- *In-Car Services*, a time-value-dominant offering. When travelling in an automated vehicle, the driver’s time spent on work or leisure activities would then be enhanced by several In-Car Services.
- *Data^{+} Platform*, a data-dominant offering. As data sharing and enriching is crucial in AD, this business model organises data as a service for the ecosystem.
- *MaaS (Mobility as a Service)*, a mobility service-dominant offering. AVs could provide another crucial modality in the modality mix that jointly fulfils travellers’ needs. The share of AV-based transportation can gradually increase where and whenever available.

- *RoboTaxi*, a vehicle-dominant offering. This is a relatively clear example of how a highly automated vehicle can be exploited as a service.

The In-Car Services represent a time-value-dominant offering to the driver and passengers of an AV. The Data+ Platform is a digitisation-driven and data-dominant offering, as is the Mobility as a Service business model, which exemplifies a mobility service-dominant offering. Finally, the RoboTaxi business model presents a vehicle-dominant offering to the customers. The four different but related business models were described and analysed based on the Service-Dominant Business Model Radar (SDBM/R) approach. Furthermore, the business models were evaluated regarding (i) their fit to the business environment scenarios, (ii) the evaluation criteria desirability, feasibility, and viability, and (iii) the stakeholder requirements. A fourth step analysed the extent to which key stakeholder requirements are addressed by existing roadmaps for automated driving. Finally, major challenges for OEMs were discussed and business model-specific recommendations for OEMs and other stakeholders were derived.

6.5.5 Results and conclusions

In order to shape the future of automated driving and render its market implementation a success, the results of the business scenario development indicate that a collaborative approach incorporating stakeholders from different industries as well as from the public sector seems to be most promising. For example, AD-related mobility solutions for urban areas (e.g., RoboTaxis) might lead to an increase in road traffic, cannibalising public transport means. At the same time, current urban initiatives from citizens and municipalities are aimed at reducing the traffic in cities and developing concepts for an alternative use of urban space. Hence, new business models for AD need to take into account these interests and possible restrictions by public authorities in order to be successful.

Following a collaborative approach could also be an option for the automotive industry with regard to its relations with the IT players, since these represent the biggest challengers to the automotive sector in the field of automated driving, with their huge competitive advantage in data-driven business. The question is whether the OEMs are able to catch up and become serious competitors or if strategic cooperation with the tech companies is the only way to keep up with data-driven and AD-related business.

The second phase of the work described in the Deliverable D1.6 *Deployment strategies and business models for ADFs* (Beuster et al., 2021) provides viable business models for automated driving and discusses the challenges for but also competitive advantages of the automotive industry with regard to new competitors from the IT sector and the speed they bring services to the competition. Moreover, in D1.6 the business models’ fit for possible future business scenarios was elaborated and strategies were derived for how to prepare AD-related business. The different business models were qualitatively analysed, comprehensively and in detail, in the reported work. The Hi-Drive project, which builds upon the work and findings of L3Pilot, plans to further detail the analyses of business models that promote the market dissemination of AD technologies and vehicles.

What does this mean in detail? In the *In-Car Services business model*, OEMs will hardly be able to compete with the big tech companies and their already existing comprehensive ecosystems for the focal role, that of service platform provider. Two newly suggested roadmap milestones for this business model have been identified: (i) develop concepts and classifications to ensure personal confidentiality in the verbal communication with the driver as opposed to the other passengers, and (ii) create concepts and devices for attractive presentations of available service offerings for the driver. Based on the methodology presented in the deliverable, OEMs are advised to focus their deployment strategy on two specific topics:

- The development of attractive vehicle interior concepts and devices that provide an outstanding environment for an inspiring in-car service experience by using their key competencies in vehicle design.
- The development of own data-based services to be offered to the drivers as in-car services.

The *Data⁺ Platform business model* as a B2B model includes the acquisition, analysis, and processing of a vast amount of data (Big Data) related to vehicles, drivers, and the environment. OEMs and suppliers need to find their role in this business, as big tech players are strongly ahead. Three suggested roadmap milestones for this business model were identified: (i) the access to and usage of enriched data need to become easier and more convenient, (ii) reliable data-based services need to be developed, and (iii) maps need to be enriched with contextual information data. The most important recommendations following from the analysis for a promising deployment strategy focus on the following:

- There needs to be concerted action among all relevant stakeholders to define rules and regulations for data access and usage that consider the needs and requirements for data privacy and data protection as well as the conditions for viable business models to create value for the different stakeholders.
- The OEMs need to create their own data-based viable services not only for vehicle users but also for third parties (public authorities, private companies).

In the *MaaS business model*, the AV complements or competes with other modalities. The MaaS provider, if not the OEM, controls the customer's interface and thus the customer relationship, potentially diminishing the visibility of the OEM. Moreover, the MaaS business model requires intensive local configurations, dealing with city-specific conditions. This potentially hampers the scaling up of this business model. Newly suggested roadmap milestones for this business model have been identified: the MaaS business model must be able to realise emissions reductions, provide reachability, and establish seamlessness, flexibility, and reliability for multi-modal journeys through real-time asset control. The most important recommendations following from this analysis for deployment include the following:

- Unite the interests of cities and OEMs, focusing on societal value creation, and establish collaboration to create the organisational leverage necessary to provide scale and societal value, with a more prominent role for OEMs.

- Ensure the interoperability of AD vehicles in the context of the MaaS business model. This includes establishing proper data interoperability and sharing.

In the *RoboTaxi business model* OEMs might compete with big tech players for the role of the RoboTaxi service provider that controls the customer interface and thus the customer relationship. RoboTaxi, as the most ambitious business model (requiring AD on SAE level 4), is being intensively discussed inside and outside the automotive industry. Unsurprisingly, current roadmaps cover the requirements of RoboTaxis very well. Nevertheless, the most important recommendations from the analysis of OEMs' deployment strategies are to:

- Create a viable concept for the integration of RoboTaxis into an effective urban transportation system, taking into account the needs of all participating stakeholder groups.
- Develop, as a RoboTaxi service provider, the capability to scale up this business model under strongly varying local conditions and regulations.

6.6 Global User Acceptance Survey

6.6.1 Aim and approach

To make data-guided deployment plans for the market introduction of SAE L3 automated vehicles, we must learn more about users, how they would like to use a given application, and what they think about it. Information about knowledge, attitudes toward ADF, preferable features, differences between markets, and willingness to purchase will be carefully considered when planning the market introduction and its timing. This information, together with the actual behaviour obtained from the large-scale piloting and from more detailed supplementary road tests, supplies the knowledge base on which the exploitation plans of the project will be founded.

On-road studies naturally do not address global differences in attitudes and opinions about automated driving. It is, however, vital for the industry to know their different markets as well as to understand differences in users' opinions and willingness to purchase AD applications. Furthermore, it is important to educate the public about the capabilities and limitations of ADFs in order to reduce misunderstandings and create a realistic image of the potential of automated driving. All this knowledge lays the foundation for the precise tailoring of products the way users want them. The survey methods, background material, results, and conclusions are detailed in the Deliverable 7.1 (Nordhoff et al., 2021).

To respond to these needs, the *L3Pilot Global User Acceptance Survey* represents a global study to analyse user acceptance, attitudes, and expectations towards AD with a particular focus on SAE L3 technology. The aim of the survey was to answer the central research question: *What are the attitudes towards and acceptance of L3 cars, and what are the factors influencing attitudes and acceptance?* This main objective was divided into the following technical objectives to:

- Explore user needs and preferences in order to design L3 technologies that promote acceptance and successful market implementations.
- Identify cross-national differences in attitudes and expectations towards SAE Level 3 automation.

- Predict user uptake by identifying key factors of user acceptance and expectations about L3 automation.
- Provide the necessary input for the impact assessment study to complement the data obtained from the pilots.
- Contribute to societal discourse about automated driving through the development of strategic recommendations for public and private decision-makers.
- Lay the foundation for a long-term study on the acceptance of L3 and higher levels of vehicle automation, which will be continued and advanced in the Hi-Drive project.

The process entering the survey phase started with a review of the literature to identify the state of the art and research gaps. The results were then discussed and aligned through workshops and expert discussions. Through this process, specific research questions were defined to contribute to the objectives of the project and the scientific discourse on the acceptance of automated vehicles. Furthermore, the exploration phase led to the use of the Unified Theory of Acceptance and Use of Technology (UTAUT2) as a theoretical framework and baseline model for the design of the Global User Acceptance Survey. The survey process is shown in Figure 6.6 below.

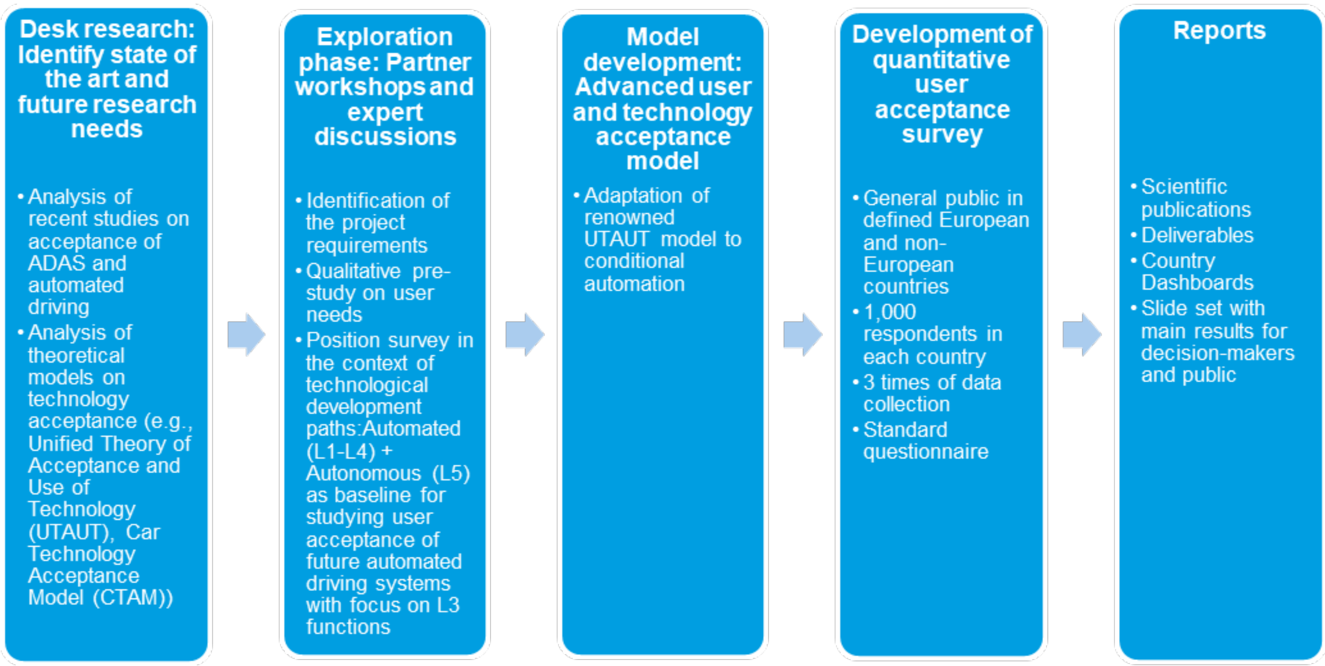


Figure 6.6: Overview of the survey process.

The survey also supported the project's impact assessment, the results of which are reported in L3Pilot Deliverable D7.4 (Bjorvatn et al., 2021). Data representing the views of the general public were necessary to conduct the socio-economic and mobility impact assessment. Information on the general public's willingness to pay for SAE L3 cars was required for *the socio-economic assessment*. The information in turn on potential changes in travel behaviour once L3 ADFs are available was important for *the mobility impact assessment*. Willingness to pay for ADFs and expected changes in personal mobility are both naturally related to respondents' acceptance and willingness to use automated driving technology and were therefore included in the User Acceptance Survey.

This user survey aimed also at shedding more light on those user questions and delved deeper into the factors determining the acceptance. The specific approach of the quantitative user acceptance survey of SAE L3 systems targeting the research needs was to:

- Represent both the European countries and have a global scope.
- Be iterative, with several phases to give an indication regarding the robustness of attitudes.
- Obtain both quantitative and qualitative data, interlinked and supporting the research process of L3Pilot technology goals and vice versa, including relevant new questions and findings in the quantitative questionnaire.

The questionnaire data were collected in three phases. The first phase was conducted between April and June 2019 among a representative sample of car-drivers in seven European countries and the United States and China. The European countries included Germany, France, Finland, Sweden, Hungary, Italy, and the UK. The second and third phase were executed in February and September 2020, respectively. In the second phase, data were collected between March and April 2020 among a representative sample (in terms of age, gender, and income) from Spain, Brazil, Russia, India, Indonesia, Japan, Russia, South Africa, and Turkey. In the third phase, data were collected among a strong set of representative countries from the phases 1 and 2, including Brazil, China, Germany, France, Hungary, Japan, Russia, the UK, and the US. The countries were selected on the basis of their car market size and geographical representation. The survey coverage is presented in Figure 6.7.

In the second phase, the attitudes of respondents from eight additional countries not surveyed in the first phase were examined to complement the global view. These countries included Indonesia, India, South Africa, Turkey, Russia, Spain, Brazil, and Japan. Data from China and the US collected in the first phase were merged with the data collected from non-EU countries in the second phase. The data from Spain were merged with data from other European countries.

For the third phase, the survey was adapted to incorporate lessons learned from the first two phases and was administered to the most relevant and globally representative set of countries.

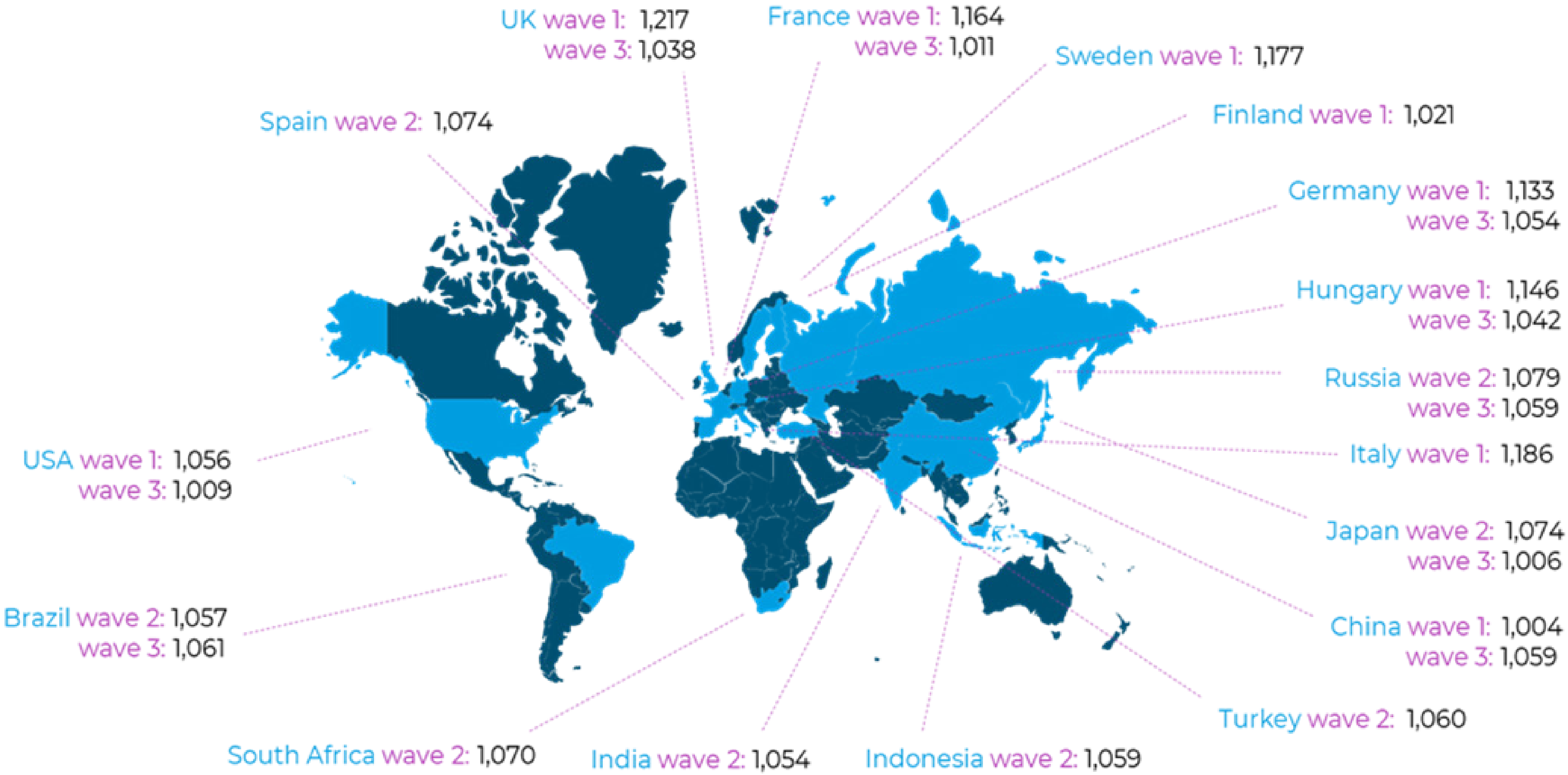


Figure 6.7: Global user survey coverage. The countries coloured in light blue represent the countries surveyed by the L3Pilot User Acceptance Study and the areas coloured in dark blue represent the countries not addressed by the survey.

6.6.2 Executing the survey and the data analysis

The invitation to participate in the survey study was sent via email by online panels that had access to a large number of respondents. Once a representative sample per country was obtained, the questionnaire was closed, and participation was no longer possible.

Due to the reliance on online panels for the recruitment of respondents, the profiles of respondents varied across the three data collection points / waves. Furthermore, several technologies were used to enhance the data quality to ensure that the respondents were real (i.e., not bots), without suspect proxies or email addresses, and that participants did not take the same survey more than once – e.g., via multiple email or panel accounts from the same computer.

Before the questionnaire was programmed and launched, it was pre-tested in several iteration rounds, to ensure clarity in terms of a common understanding of the flow of the questionnaire (e.g., order of items) and the content of the questionnaire (i.e., meaning of items). This also encompassed ensuring that the questionnaire was correctly translated into the different languages. In addition, a soft launch of the questionnaire was done with approximately thirty respondents, to resolve any implementation or wording errors. To ensure that responses were not influenced by the order in which questionnaire items were presented, those that did not follow a specific logic were presented in a random order across respondents.

Several types of analyses were carried out. First, for each questionnaire item descriptive statistics (i.e., frequencies, mean, standard deviation) were calculated as a summary for each questionnaire item (see in detail the Deliverable 7.1, Chapter 3.4 *Data evaluation and analysis*).

More refined analysis methods were then used to explore the sources of variation in the dataset. These included, among other things, methods to form homogenous, mutually exclusive groups, to assess the similarity between the groups, to characterise the clusters and detect significant differences between the groups, to study the relationships between the factors influencing L3, to assess the reliability and validity of the measurement instrument, and to examine respondents' willingness to pay for each of the four L3 automated driving functions – to name some of the most essential targets for the analysis methods.

6.6.3 Main results

Intention to use was one of the main interesting areas of the survey to reveal differences between countries (Figure 6.8).

Across the data as a whole, 42% of the respondents expressed an intention to use an SAE L3 automated vehicle. Respondents from European countries were less enthusiastic about using conditionally automated cars than respondents from non-European countries. India, Indonesia, and Turkey had the highest proportion of Enthusiasts (individuals who expressed agreement with the questions measuring intention to use). The European nations Sweden, Germany, and Finland had the lowest proportion of people who were enthusiastic towards using conditionally automated cars. Russia, Japan, Hungary, and Spain had the highest proportion of Neutrals (people who were neutral towards using conditionally automated cars), while Brazil, Indonesia, and India had the lowest.

Consequently, Finland, Germany, and Sweden had the highest proportion of Sceptics (people who were sceptical towards the use of conditionally automated cars), while China and Indonesia had the lowest.

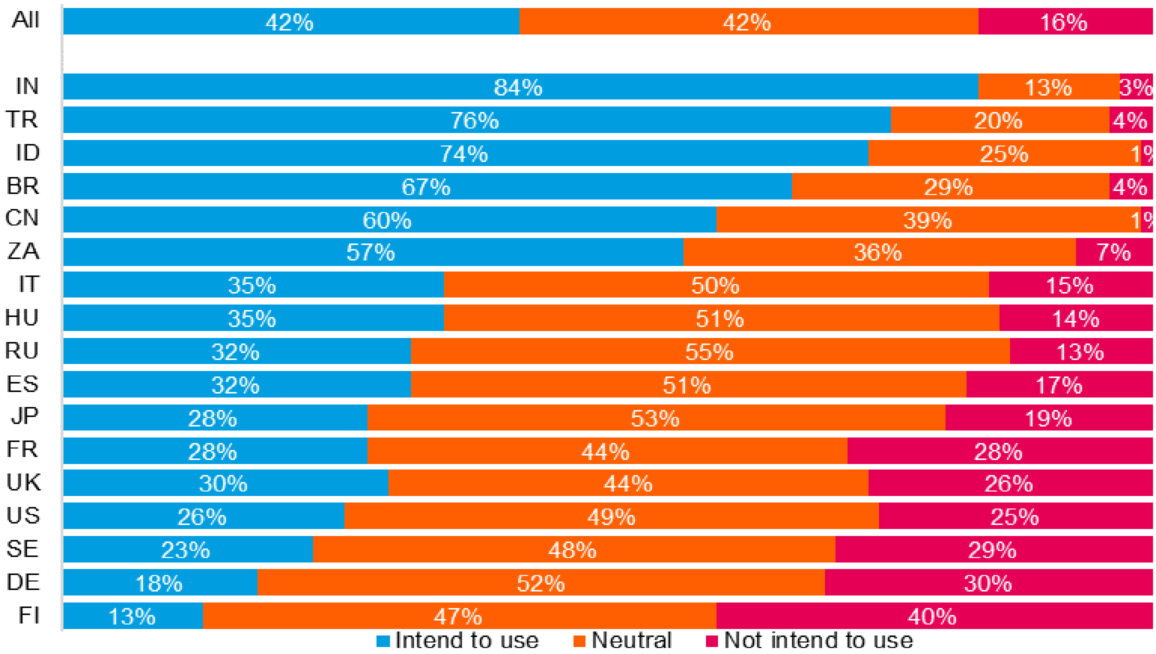


Figure 6.8: Proportions of Enthusiasts, Neutrals, and Sceptics towards conditionally automated cars.

The results were also presented in the form of a 'dashboard' by country for the interested reader to gain more information about the survey countries (see an example below). The results of dashboards by country can be found as a part of the annual survey data under:

https://l3pilot.eu/data

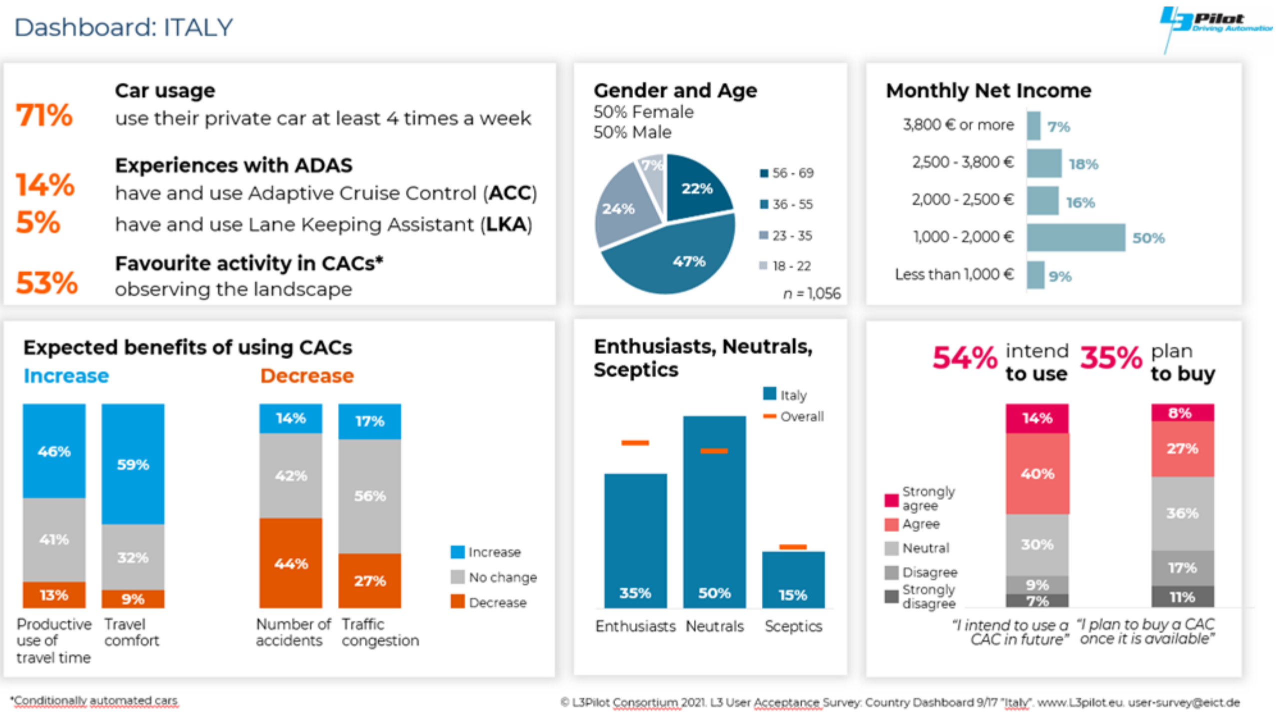


Figure 6.9: An example of a dashboard style of presenting intention to use and buy an SAE L3 car.

To measure the willingness to pay for L3 ADFs, respondents were asked to indicate how much extra they would be willing to pay in addition to the price of a car to equip their car with an ADF. For each ADF, respondents were given several price options to choose from, including 0 if they were unwilling to pay any extra amount.

The results in this section are reported for phase one of the survey. The analysis was performed among respondents from eight European countries. The analysis included respondents who indicated that they were willing to use a conditionally automated car once it would become available in the market. Figure 6.10 illustrates willingness to pay in each country and across all countries.

As shown by Figure 6.10 there are differences in the willingness to pay for ADFs in each country and also across all countries. The share of respondents who were not willing to pay any extra amount for automated driving systems on urban roads, motorways, traffic jam, and parking was 28%, 29%, 32%, and 26%, respectively. This implied that the willingness to pay for parking, urban, and motorway was slightly higher than the willingness to pay for traffic jam ADF. The results suggest that the majority of respondents were willing to pay for ADFs. In all countries, willingness to pay for ADFs decreased with an increase in prices.

The survey respondents were representative of age, gender, and income of their respective country populations. In order to recruit a representative sample of a country population, specific criteria were used to select respondents for the national samples.

Figure 6.10: Willingness to pay per ADF, by country and across all countries.

To sum up, the present L3Pilot Global User Acceptance Survey investigated the acceptance of and attitudes towards conditionally automated cars among a large sample of car drivers from various European and non-European countries. It revealed which acceptance factors were most influential in predicting the acceptance of conditional automation, thus providing important implications for the key decision-makers.

Furthermore, the following major findings can be summarised from the survey:

- People reported receiving most information about automated cars from online communities; websites about IT, cars or motoring; and social media – followed by radio; TV; newspapers and magazines; and friends, family, and colleagues. People received the least information from car dealers, manufacturers, and suppliers.
- A negative correlation was found between a country's developmental status and the overall intention to use conditionally automated driving functions, with respondents from higher-GDP countries being more neutral towards conditionally automated cars than respondents from lower-GDP countries.

- There was a positive correlation between a country's estimated number of road deaths per 100,000 inhabitants and the intention to use conditionally automated driving functions. The countries with a higher number of death rates expressed higher overall intentions to use conditionally automated driving functions.
- The intention to use conditionally automated cars was higher than the purchase intention. Only 28% plan to buy a conditionally automated car, while around 60% intend to use conditionally automated cars once they are on the market. This apparent contradiction can possibly be explained by respondents' lack of physical exposure to L3 cars. Furthermore, respondents may not be able to afford an L3 car or a new car in general.
- The average unwillingness to pay extra for conditionally automated cars on urban roads, motorways, traffic jams, and for parking was 28%, 29%, 32%, and 26%, respectively. The willingness to pay for parking, urban, and motorway ADFs was slightly higher than for a traffic jam ADF. In general, the majority of respondents were willing to pay extra in order to equip their cars with ADFs for driving on urban roads, motorways, in traffic jam situations, and for parking.
- The intention to use conditionally automated cars across different environments (motorway, traffic jam, urban, and parking) was high; the highest intention to use was found for using conditionally automated cars in parking.
- The strongest effect on the acceptance and use of conditionally automated cars was perceived enjoyment, i.e., the extent to which conditionally automated cars would be considered enjoyable.
- The effect of age and gender on the acceptance and use of conditionally automated cars was generally small. Males had higher intentions to use conditionally automated cars in all four environments (i.e., for urban roads, motorways, parking, and traffic jams). People aged 30–39 had the highest intention to use, followed by people aged between 18 and 29. People over the age of 60 had the lowest intention-to-use scores across all four environments.
- People who currently use Adaptive Cruise Control in their cars were more likely to have a higher intention to use conditionally automated cars. People currently using self-parking assist systems were more likely to intend to use conditionally automated cars.
- The intention to use conditionally automated cars was associated with a decreased intention to use public transport, active travel modes, and multimodality.
- People who received only positive information about conditionally automated cars (i.e., information about capabilities) were slightly more likely to intend to use conditionally automated cars in parking and less likely to use conditionally automated cars on motorways than people who also received information about the limitations of conditionally automated cars.
- The willingness to engage in secondary eyes-off-road activities was moderate, with people reporting a willingness to engage in less resource-intensive and more familiar activities (e.g., talking to fellow travellers, surfing the internet, watching videos or TV shows, observing the landscape, monitoring how the car is functioning).

6.6.4 Conclusions

The User Acceptance survey investigated *the acceptance of and attitudes towards* SAE L3 conditionally automated cars among a large sample of car drivers from various European and non-European countries. The survey has advanced our understanding of the attitudes towards and acceptance of conditional automation. It has shown which acceptance factors were most influential in predicting the acceptance of conditional automation, thereby revealing important implications for key decision-makers.

Overall respondents were very satisfied with the conditionally automated system, providing high ratings of expected comfort and safety, usefulness, ease of use, and perceived enjoyment. They reported a high intention to use conditionally automated cars, which is a common proxy to measure acceptance, given that conditionally automated cars have not yet been commercialised.

It was discovered that the respondents were generally knowledgeable about the capability of conditionally automated cars to stay in the lane and to allow them to engage in secondary activities other than sleeping, and about the possibility that such cars could ask them to take over control at any time. However, they were less knowledgeable about the capability of conditionally automated cars to initiate automatic lane change manoeuvres, and the fact that their operation is limited to certain conditions. It is noteworthy that the responses were relatively homogenous when it came to knowledge of the lane-keeping behaviour of L3 cars, while their knowledge about the operation of L3 cars in operational design domains seemed to be more limited.

To be commercialised, conditionally automated cars will have to enable a safe, comfortable, and efficient take-over situation, without jeopardising the added benefits that this level of automation entails. If this is achieved, human drivers will not have to divide their attentional resources between the driving environment, including supervision of the performance of the automated system, and engaging in their own activities at the same time. To be safe, useable, and acceptable, the systems that enter the market will have to allow the driver to comfortably engage in non-driving related activities and provide sufficient time for a request to intervene and take over control of the automated system.

It was found that hedonic, pleasure-seeking motivation was the strongest predictor of individuals' behavioural intention, implying that individuals who consider conditionally automated cars enjoyable are more likely to intend to use them. The second-strongest predictor of behavioural intention was social influence, implying that individuals who believe that people important to them in their social network appreciate their use of conditionally automated cars are more likely to intend to use them.

The correlation between age and behavioural intention was negative, implying that elderly people were less likely to use conditionally automated cars. Males were more likely than females to intend to use conditionally automated cars.

Respondents' limited knowledge about conditionally automated cars may reflect the global confusion and incorrect expectations about automated cars. The media and representatives of the car industry have oversold the capabilities and expected market release of automated cars. Conditionally automated cars have received less media coverage than partly- and fully-automated cars (e.g., Tesla's AutoPilot system and Waymo's self-driving car project).

Harmonised user education and training campaigns worldwide, including detailed and differentiated objective and factual knowledge, should be developed in order to educate the public and align the public's expectations about automated cars to the actual technical capabilities and limitations of automated cars. Furthermore, the SAEJ3016 taxonomy, which is the leading definition of automation among scientists and practitioners to date, could be translated into a simpler version for the public in order to better explain the differences between the automation levels in terms of the functionality of the car and the role of the driver, and to overcome the barrier of the technical language of communication.

Finally, it must be noted that the respondents were not physically exposed to L3 conditionally automated cars, but were asked to imagine the use of such vehicles. Therefore, we recommend that future research should survey users with real-world experience of SAE L3 cars and investigate their attitudes towards and acceptance before and after having tried out SAE L3 cars.

7 Project promotion

7.1 Dissemination and communication

7.1.1 Goals

Given the extent and the uniqueness of the Europe-wide pilot of SAE L3 automated driving and the key role of AD for the automotive industry, the dissemination objective was to *establish L3Pilot as the European reference project for automated driving*.

Trust is the key emotional state concerning automated driving. Ultimately, drivers decide whether they will trust and use AD systems. How to make people trust automated vehicles is a big question that confounds industry and related players across the globe. Consequently, L3Pilot communication was aimed at supporting the enhancement of trust in ADFs. Communicating the functionality and benefits of automated driving was a key topic in the project. In addition, L3Pilot focused on the individual trust of stakeholders in the technology: the more that individuals are convinced by the technology, the stronger their commitment to purchase an automated car is expected to be.

Visually, L3Pilot represented different types of users with common concerns and needs to demonstrate the benefits of AD (see Figure 7.1).

Figure 7.1: Different types of users represented in the L3Pilot project.

The users and their driving experience while making use of AD technologies were the core concerns of L3Pilot project communication. Therefore, the user in interaction with the systems was the target of the communication means, channels, and events in the project.

Focusing on the driving experience also meant that we needed to provide the platform to create this experience. The task was to involve all relevant stakeholder groups right from the beginning to realise a series of showcases throughout the project's lifetime. This was achieved – with some hurdles caused by Covid-19 on the way. These showcases were also open to specific user groups and were linked to dedicated topics in the project, such as the Code of Practice. Users' opinions also provided feedback to the project. The immediate driving experience was intended to enhance the individual commitment of the stakeholders to AD.

7.1.2 Key messages and target groups

To ensure appropriate communication and dissemination of the project, these key messages were drawn up:

- L3Pilot joins the forces of 13 European car manufacturers to boost the deployment of automated driving in-vehicle functions on European roads.
- L3Pilot is the first comprehensive test of ADFs with hands off the wheel on public roads across Europe. The tests comprise all relevant traffic scenarios in three test areas: North, South-West, and South, including cross-border testing.
- L3Pilot will test ADFs in 100 cars with 1,000 drivers across 10 different countries in Europe. The tested functions will be mainly of SAE automation level 3, some of them of SAE L4.
- Together, the European automotive industry, suppliers, and researchers will pave the way for large-scale piloting on public roads, creating a harmonised Europe-wide testing environment.
- Any driving systems being introduced to the market require a set of rules for system engineering and safety validation. L3Pilot will define these requirements for automated driving systems, captured in a Code of Practice for ADFs.
- L3Pilot will develop a comprehensive methodology on how to execute a pan-European pilot on automated driving. L3Pilot is committed to providing open data on AD in Europe.
- L3Pilot will provide valid data on driving safety and on the impact of AD on traffic efficiency, safety, and fuel efficiency.
- L3Pilot puts the acceptance of the technology and the user experience in the focus of its research.
- L3Pilot shows new service potentials emerging with disruptive technology.

7.1.3 Activities

The dissemination measures of L3Pilot were built on four pillars:

- The Automated Driving Campaign comprising four driving demonstrations, workshops, press, and social media dialogue and respective dissemination materials such as posters and videos.

- Liaison and knowledge exchange.
- The participation and active contribution of L3Pilot to automotive industry events.
- Publication of technical papers.

The project provided online channels to communicate the dissemination activities. A number of communications means and basic elements were available and used throughout the project.

Figure 7.2 below shows the basic structure of the implementation of the communication and dissemination means, measures, and channels.

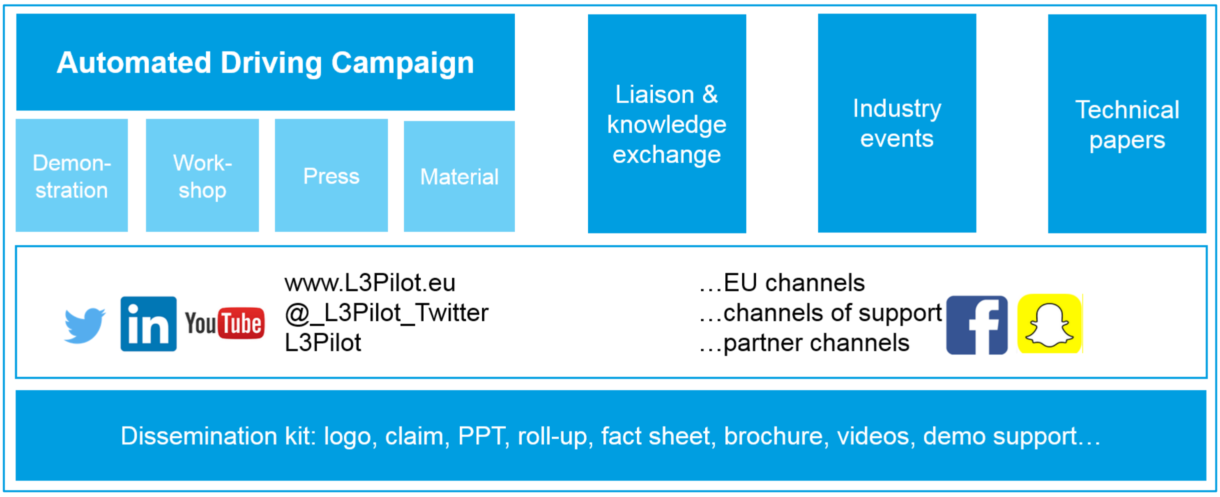


Figure 7.2: Implementation structure for communication and dissemination.

The showcases and their contents are presented in Table 7.1. Figures 7.3 to 7.8 below illustrate the showcases and dissemination events.

Table 7.1: Showcases and detailed information of their purpose and contents.

	Showcase 1: Preparing the Fleet for the Road **6–7 November 2018** **Autoworld Brussels, Belgium** **In conjunction with EUCAR Annual Reception & Conference**	**Showcase 2:** **EUCAD 2020 EUROPE TAKES THE LEAD** **2–3 April 2019**	**Showcase 3: Piloting Automated Driving** **6–7 November 2019** **In conjunction with EUCAR Annual Reception and Conference**	**Virtual EUCAD 2021 YES, WE CCAM** **20–22 April 2021**	**Showcase 4: Final Event in Conjunction with ITS World Congress 2021 in Hamburg** **11–15 October 2021**
Demon-strations	Dynamic and static demonstrations of seven prototype cars	Static demonstrations of five prototype cars Model car Sedric of Volkswagen	Static demonstrations of eleven prototype cars Model car Sedric of Volkswagen	Driving scenes from the test sites included in the video	3 cars in urban driving demonstrations 6 cars on motorway demonstrations 13 cars in static demonstrations
Exhibition and material	Posters and videos with each vehicle General overview posters Give-aways	Posters and videos with each vehicle General overview posters Give-aways	Posters and videos with each vehicle General overview posters Video on business scenarios Give-aways	Virtual booth: https://eucad2021-conference.eu/page-4011 New video created on pilot trials across Europe	13 prototype cars with posters and videos 14 posters on overall project results General posters Printed Code of Practice Event brochure Updated video Give-aways
VIP tours	Yes	Yes	Yes	Guests online VIP driving demonstration through Brussels with Mariya Gabriel, European Commissioner for	Yes: High-level national and international representatives from politics and industry

	Showcase 1: Preparing the Fleet for the Road **6–7 November 2018** **Autoworld Brussels, Belgium** **In conjunction with EUCAR Annual Reception & Conference**	**Showcase 2:** **EUCAD 2020 EUROPE TAKES THE LEAD** **2–3 April 2019**	**Showcase 3: Piloting Automated Driving** **6–7 November 2019** **In conjunction with EUCAR Annual Reception and Conference**	**Virtual EUCAD 2021 YES, WE CCAM** **20–22 April 2021**	**Showcase 4: Final Event in Conjunction with ITS World Congress 2021 in Hamburg** **11–15 October 2021**
				Innovation, Research, Culture, Education, and Youth	
Presen-tations	Lightning round	Panel discussions Evening reception	'Towards an integrated approach to testing automated driving on public roads' by Aria Etemad Lightning round	Presentations from L3Pilot during Plenary Sessions and Breakout sessions 1:1 talks online during the exhibition hours	Conference on 13 and 14 September 2021 from 9:00 to 18:30 each day
Research topic in the focus	User experience assessment on-site	Focus on Piloting	Workshop on future scenarios and business perspectives User study	Focus on end of piloting	All major L3Pilot results
Media	Press release, website, news, newsletter, social media	News, newsletter, social media	Press release, website, news, newsletter, social media	News, newsletter, social media campaign promoting individual session contributions	Press release Individual press relations by partners Video production planned
Outreach	EUCAR R&C high-level guests from industry and politics as multipliers Self-driving cars promoted	EUCAD audience and VIPs during evening reception High visibility on panel and mention in opening speech of EUCAD conference	EUCAR R&C high-level guests from industry and politics as multipliers Progress of project promoted	EUCAD audience with live streaming Twitter outreach via Commissioner Gabriel	

Figure 7.3: Impressions from Showcase 1: Driving demonstration of BMW and user experience assessment on site.

Figure 7.4: Impressions from Showcase 2: EUCAD 2019.

Figure 7.5: EUCAD @ Brussels Teaser 2019.

Figure 7.6: Impressions from Showcase 3: EUCAR Reception & Conference 2019.

During the pandemic, events were arranged virtually. Another example besides the EUCAD 2020 is the sponsoring of AutoUI 2021, where L3Pilot, with the user focus of its project, became a main sponsoring partner.

Figure 7.7: L3Pilot virtual booth at AutoUI 2021.

Figure 7.8: AutoUI virtual conference with identification of L3Pilot as sponsor.

Technical dissemination was an important pillar of the L3Pilot project. This is also reflected in the number of publications, congress presentations, and other papers of the project (see ANNEX 1).

L3Pilot paved the way for a comprehensive testing of ADFs in series production cars in a harmonised testing environment. To achieve this harmonisation, exchange and collaboration were needed not only among different automotive manufacturers, but also among the industry players as a whole and even between the diverse departments within the individual partners. Dialogue between policy, industry, and science was triggered by L3Pilot dissemination and liaison work. Therefore, as a third task L3Pilot communication supported the creation of links and shared knowledge among various stakeholder groups. Major liaison partners include EUCAR, CCAM Working Group, and the ARCADE initiative, as well as C-ROADS, Headstart, and FESTA.

Table 7.2 below gives an overview of the events, communication channels, and the dissemination kit provided.

Table 7.2: Overview of communication elements, means, and channels.

L3Pilot events	Online communication channels	Offline communication channels and means of communication	Basic communication elements
Showcases	Website with download option, news and newsletters	Journal publications and conference papers	Logo, corporate design with icons, use cases images, pictures
Workshop on Code of Practice	Social media: Twitter, LinkedIn, YouTube	Presentations and technical posters	Illustrations
Workshop on Technical Aspects	Wikipedia	Public deliverables and abstracts	Boiler plate
General Assemblies	Conferences and congresses	Brochure, fact sheets, posters	Project presentation
Summit on AD	Webinars	Videos	PPT and MS Word templates
	Press and social media; also channels of EU, supporters, and partners	Press releases	Boiler plate
		Giveaways	Demo support: stickers, magnets

7.2 Open data

7.2.1 Several datasets

As has been explained, the L3Pilot vehicle owners collected data during piloting on public roads to evaluate ADF. The anonymised and aggregated data collected in the pilot trials was shared among partners for the evaluation process in a common data format (CDF).

Drone datasets and other data, e.g., from simulator tests, provided additional information; large-scale international surveys with 36,000 respondents assessed attitudes towards L3 technologies and their effects on mobility.

In line with the EU requirement for access to open data for parties outside the consortium, the project created open data repositories as described below.

7.2.2 Data from the Global User Acceptance Survey

The data collected from the *Global User Acceptance Survey* have been rendered open access. The data from waves one and two were published before the end of the project, except for the willingness-to-pay questions, which will be embargoed until November 2022. The data from the third wave will likewise be embargoed until November 2022. During the embargo period, the research team will have time to review and publish the main results and their interpretations and possible limitations. This will ensure that the users of the open access data will know how to utilise and interpret the data correctly.

The data are stored at the Zenodo repository. Zenodo was created in 2013 by the EU-funded OpenAIRE project and CERN to be an all-purpose open research repository. The dataset has a digital object identifier (DOI), which provides a way to refer to the data. The data are also presented and links are provided at the L3Pilot Open Data Hub, which provides an overview of the open data produced by L3Pilot project. Together with the data, detailed instructions are provided for external users in the form of a README file to ensure that the data can be correctly used and interpreted by those sharing or publishing the data.

As shown earlier, the dashboards can be found later on as part of the annual survey data under https://l3pilot.eu/data website. The direct Link to the repository, where all the 1st phase annual survey data is stored, is an external one:

https://zenodo.org/record/5255950#.YYjybLoxlhE

The README file contains the following information: title of the dataset (L3Pilot Global User Acceptance Survey), first phase data, short description of what the dataset contains, contact information in case users have questions about the data, methodological description for analysing the data with links to the current deliverable, data-specific information including full names and definitions of the headings of the columns (i.e., variable names), measurement units, definitions for codes to represent missing data, sharing and access information, and licences / restrictions placed on the data to regulate the use of the data.

7.2.3 Data from the pilots

The second type of open data concerns the data obtained from large-scale piloting. The data were extracted from the consolidated database and aggregated from the high-level analysis of the pilots (See Figure 3.10). In this context, the project developed a common data format (CDF) for both data collection and processing and implemented a consolidated database for the processed data collection. The proposed CDF enables the sharing of driving data and user questionnaire data and promotes the development of tools for the testing, verification, and validation of AD functions. The comparison of performance indicators across pilot sites per driving scenario is enabled. The format is considered a useful specification item for follow-up projects in the field, and it is expected to contribute in the future to the harmonisation of AD testing in Europe.

The data derive from the following driving scenarios: Free Driving, Following, Driving in Traffic Jam, and Lane Changes. The number of variables available vary from 4 (e.g., lane change) to 17 (e.g., car following / driving in traffic jam).

Data analysts interested in using the L3Pilot-CDF may visit the published code at:

github.com/l3pilot/l3pilot-cdf

The following disclaimers should be considered with regard to the data: data come from pre-series vehicles; data from manual driving were mostly collected by professional drivers and may not reflect driving styles of ordinary drivers; behaviour of ADF in data may not reflect behaviour of a market-ready system; regulations may change; testing permits may be extremely restricted; systems may improve; behaviour of others towards ADF may change; data quality is not perfect; data have been acquired in studies with different designs and ODDs.

7.2.4 Drone datasets

The L3Pilot partners Volkswagen AG and fka GmbH (Linked 3rd Party) provide open drone datasets that were created in the course of the L3Pilot project. Drone datasets add valuable information to the data recorded during the pilot trials in the test vehicle and from user questionnaires.

In conjunction with the in-vehicle data and the answers received from questionnaires, these support the evaluation of the data received.

The *OpenDD dataset* published by Volkswagen Group Innovation is an extensive anonymised trajectory dataset, covering seven roundabouts in Wolfsburg and Ingolstadt, Germany (Figure 7.9).

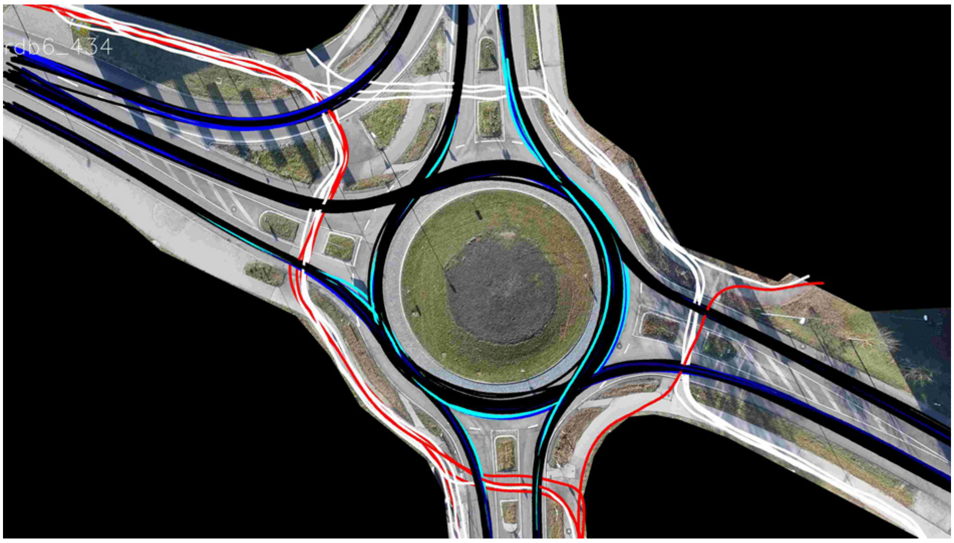


Figure 7.9. Drone dataset illustration on test vehicles driving through a roundabout.

The dataset offered by fka provides non-static reference measurements for the vehicle under test in public traffic in Aachen, Germany. The novel approach of flying along with the test vehicle allows valuable data to be recorded, supporting the technical evaluation. The drone data serves as a reference for the in-vehicle perception data and enhances the validity and reliability of data analysis.

The dataset can be downloaded here:

https://l3pilot.eu/data.

All the other datasets are linked here as well. In some cases, links to other pages, such as the fka drone dataset, require that a form be filled in, which is why they are not hosted on the L3Pilot page directly.

8 Impact

8.1 Impacts expected by the project

Despite unforeseen circumstances caused by the global pandemic, L3Pilot tested, demonstrated, and evaluated the impacts of SAE L3-L4 automation to an unprecedented extent in Europe and beyond. Furthermore, the project generated data and knowledge not provided by previous ADAS-projects. Large quantities of new information and exploitable results are now presented in the extensive list of the project deliverables, many of which are public. These relate to the scientific part of the work, business development, and the impacts of automated driving functions.

The project's pilots and supplementary studies provided valuable data for the OEMs that could not be taken for further analysis from the raw signal recordings of each vehicle owner, for proprietary reasons. However, a great deal could still be shared with the scientific community and those applying and developing automotive systems in Europe and beyond. Perhaps one of the most important impacts of the project was to strengthen trust and European cooperation in the area of intelligent vehicle development. This applies to the industry as well as to the research sector and authorities.

It is essential to consider three main impact areas to prepare society and industry for the introduction of automated driving in the latter half of the 2020s:

- *Knowledge impact.* This impact area is the most obvious one, based on the enhanced methodological and technical knowledge generated by the project, and as soon as the evaluation data are available for the industrial partners, it will be possible to start planning for further elaboration of AD systems. This concerns both technical performance as well as optimal user and vehicle interaction so that users are able to understand the AD functionalities, their limits, and correct use of the system. Knowledge of user behaviour and, to the same extent, user attitudes will also help to create realistic deployment plans and offer AD applications that users are willing to purchase – even globally. This was the motivation for including a large number of users in the tests. Only by deploying a large user representation can we create an image of the final development needs before market introduction.
- *Societal impact.* Over 90% of traffic accidents are attributed to human error. The impact of AD is expected to be greatest in reducing accident rates. It is predicted that automated motor-vehicle fatality rates could eventually approach those seen in aviation and rail, about two percent of current rates. There will be great challenges in realising the full safety benefits in the long transition period to automation. In the long run, however, this is possible. AD has the potential to reduce emissions and improve efficiency – a fact that was indicated in the studies. Even though it is impossible to give precise estimations of future developments, a positive effect in terms of a reduction in accidents is expected for most of the analysed scenarios. A cost benefit is also reflected in the socio-economic impact analysis results, less for motorway driving due to its already good safety records, but above all in urban traffic.
- *Business impact.* User acceptance is the key to the success of AD systems on the market. The business models are closely linked to major automotive and mobility trends and refer to broadly

considered business opportunities for automotive industry players. The project developed four business models archetypes that focused on service-oriented business scenarios: (i) In-Car Services, a time-value-dominant offering. When travelling in an automated vehicle, the driver's time spent on work or leisure activities would then be enhanced by several In-Car Services. (ii) Data+ Platform, a data-dominant offering. As data sharing and enriching is crucial in AD, this business model organises data as a service for the ecosystem. (iii) MaaS (Mobility as a Service), a mobility service-dominant offering. AVs could provide another crucial modality in the modality mix that jointly fulfils travellers' needs. The share of AV-based transportation can gradually increase where and whenever available. (iv) RoboTaxi, a vehicle-dominant offering. This serves as a relatively clear example of how a highly automated vehicle can be exploited as a service.

The significant interest in automated driving means that the knowledge impact will be exploited immediately after the project's termination. Societal and business impacts are expected to be fully realised in the longer term, with AD systems expected to reduce accidents as soon as their penetration rates increase. Even though the impacts cannot yet be directly seen in society and on the road, the results corroborate the assumptions made in the project planning phase.

The following table condenses and summarises the results that enable various activities, some already in the course of the project work (e.g., CoP, pre-deployment activities) and some immediately after the project cessation.

Table 8.1: Main impacts created by the L3Pilot project.

Impact area	Impact shown
Knowledge impact	• Methodology tailored to the needs of SAE L3 automated systems and with some adaptations with the potential to carry out also higher levels of automation road tests. • Test data management system with the Consolidated Database (CDB) built for data analysis, making it possible to analyse data from different test sites and vehicle owners without jeopardising the confidentiality and right of vehicle owners to their own data. • The CDB also enables precisely defined open data to be extracted by parties outside the consortium for their own research work. The open data are suitable e.g., for the validation of simulations. • Another open data release from the L3Pilot User Acceptance Survey made available via the L3Pilot Open Data Hub. Anyone interested in the data behind attitudes towards and acceptance of L3 automation can access these data for further research questions or as a basis for decisions to lay the foundation for a large-scale implementation of L3 cars on public roads. • Four areas covering the potential impacts of L3 automation: (i) Technical and traffic evaluation assessed the effect of the ADF on vehicle behaviour and the surrounding traffic based on data logged directly in the on-road tests; (ii) User and acceptance evaluation assessed users' evaluation and acceptance of automated driving functions and behaviour with the functions; (iii) Impacts on personal mobility, traffic safety, traffic efficiency, and the environment were shown; and (iv) Socio-economic impact assessment utilised the above analyses to determine monetary values for the estimated effects, weighing expected costs and benefits of the ADFs.

Impact area	Impact shown
	• Supplementary studies raised important issues on user behaviour when travelling in an automated mode, especially those related to so-called established behaviour when getting used to the systems. Even though not all results were conclusive, they helped to narrow down the focus area for the follow-up project Hi-Drive. • A Code of Practice was created for immediate use in the development of automated systems. • Lessons learned were collected and analysed from the main activity areas to be used in subsequent automated driving projects including road tests. These are reported in Chapter 9.2 of this deliverable and in given project deliverables.
Societal impact	• Potential for automated driving functions to reduce accidents was shown. This has been the main motivator for introducing automation in vehicles. • Quantitative potential impacts on personal mobility, traffic safety, traffic efficiency, and the environment were determined. • Global survey data on attitudes, knowledge, and opinions towards automated driving. Recommendations and dialogue with decision-makers: the findings of the L3Pilot User Acceptance Survey and derived recommendations will be discussed with key stakeholders to establish a long-term dialogue platform. The main purpose is to collect feedback from stakeholders enabling and enacting this technology on our roads, e.g., by making the necessary laws or initiating pilots to enable this technology. • The role of Artificial Intelligence in the development of automated technologies will certainly accelerate and will create thousands of new jobs in Europe. Overall, there are variable societal impacts caused by automation technologies, the impacts of which will be both negative and positive but are at this point impossible to evaluate in a reliable way.
Business impact	• User preferences, reactions, and willingness to use vehicles equipped with SAE L3 AD applications were studied globally in 17 countries. This information provided valuable input for different markets in the world, especially concerning the prediction of user uptake by identifying key factors of user acceptance and expectations about L3 automation. • User reactions and attitudes towards SAE L3 were also studied after piloting experiments, including detailed information on developing ADF to better respond to user needs and capabilities, including HMI. • Four business model archetypes for automated driving were elaborated, analysed, and evaluated. These serve as a basis for business plans including deployment activities. • Recommendations as a basis for the competitive development of business models that foster the market dissemination of AV. • The Code of Practice created a comprehensive set of guidelines compiled from a large base of engineering knowledge. This will speed up the necessary stakeholder process toward deployment of automated driving technologies.

8.2 Contribution to the impacts expected in the EU work programme

The following table summarises the project's responses to the requirements of the EU work programme. The project responded to the call "ART-02-2016 - Automation pilots for passenger cars".

Table 8.2: L3Pilot response to the impacts expected by the European Commission work programme.

Impact expected by the EU work programme	Impact shown
'Demonstrate the technological readiness, reliability and safety of the AD functions in a large scale Pilot at European scale.'	• Piloting and supplementary tests carried out showed that the vehicles functioned properly in variable traffic conditions under the defined ODD. This was indicated in the vehicle lateral and longitudinal control and speed behaviour. Safety benefits estimated show promising results in conditions where safety impacts were expected, and a positive effect on the reduction of accidents was found for most of the analysed scenarios – and in motorway and urban scenarios for all addressed penetration rates. The results are in line with the assumptions made prior to the tests and are now underpinned by analysis using real data. Please see Deliverables D7.3 and D7.4.
'Test automated vehicles at automation level 3 (and possible additional functions towards level 4) in mixed traffic situations.'	• L3 and some L4 functions focused on detailed large-scale testing in seven European countries on 14 test sites with cross-border tests included. Three different traffic scenarios (parking, urban, motorway) in mixed traffic were tested. Parking scenarios included SAE L4 tests. Please see Deliverable D6.5.
'Demonstrate that AD systems for passenger vehicles can contribute to increase road safety and transport efficiency, reduce energy use, pollutant emissions and traffic congestions.'	• Safety effects were shown possible in most tested scenarios. Both motorway and urban ADFs were found to have positive safety effects on road accidents with all severities at all penetration rates. Although the assessment is based on data not yet representing future automated systems and using simulations, the results are in line with earlier estimates on the considerable safety potential of driving automation. Please see Deliverables D7.3 and D7.4. • Fuel consumption decreases at a high penetration rate on motorways, especially in high traffic volumes. • CO_2 emissions decrease slightly with increasing penetration rates. • Please see Chapters 4.3.3–4.3.4 and Tables 4.2–4.3 of D7.4.
- User acceptance and the interaction between the driver, the vehicles and the traffic environment	• The pilot site participants experienced the piloted ADFs mainly positively. Intention to use SAE L3 automation systems varied considerably by country; non-European countries expressed the greatest intention to use automated systems. • No motion sickness was reported by the studies' participants. • Drivers agreed that the system was comfortable, especially for driving behaviour in situations where the vehicle was less interactive with other traffic participants. • In more than 60% of take-over situations it took less than 4 seconds until drivers reacted to the take-over requests and deactivated the function. The reaction time in 99% of situations was below 10 seconds. • User evaluations suggest that there are some system performance elements that could be further improved (see Chapter 5 of D7.2).

Impact expected by the EU work programme	Impact shown
- Wider socio-economic impacts of AD	• It is likely the case that a package of all ADFs, i.e., with motorway, urban, and parking, would bring social benefits that exceed the social costs of installing such a package. Please see Chapter 6, D7.4
- Uptake of new business models	• The project developed four potential business models based on extensive analysis of market needs and using expert workshops. Please see D1.6.
- Benefits from the interaction between AD and V2X communication.'	• Some of the functions used V2X communication to gain the needed situational awareness, such as VW did with traffic lights. Localisation and digital maps were shown in city traffic by VW test vehicles. Fka's test vehicle used the V2X traffic light information during the final event demonstration at the ITS World Congress, 2021 in Hamburg.

9 Conclusions and lessons learned

9.1 Conclusions

9.1.1 Challenges in procedures

L3Pilot set ambitious goals for large-scale piloting: 1000 test drivers and 100 automated vehicles in 10 European countries from north to south. Unexpectedly, the project had to face an unanticipated challenge: the Covid-19 pandemic forced the consortium to re-schedule piloting and support activities. Considerable efforts were taken to respect the project's idea of comprehensive and large-scale testing. In the end, piloting was able to proceed with 750 test persons and 70 automated vehicles in 7 European countries. In addition to this, over 600 persons participated in detailed tests investigating driver reactions to automated driving systems, including repeated trials. The global surveys on user acceptance and other attitude-related factors covered 36,000 respondents.

In this light, the outcome of the project can be regarded as a success, despite the unforeseen conditions that severely restricted face-to-face communication and challenged the close cooperation and interaction needed in road tests. Also here, digitisation boosted ways to cooperate when issues common to the piloting community had to be solved remotely with partners who were scattered all over Europe.

The main practical challenges of the work were executing the pilots with their related data collection, creating a digital environment for the management of the vast quantity of collected data, transforming the raw data into a common data format, and finally uploading all the data into the consolidated database for evaluation. Not only that, but this also had to be done in such a way that the rights of the industrial players to their own data could be secured while simultaneously ensuring confidentiality. Covid-19 disrupted the execution of the project in a number of ways, especially by causing delays in piloting. This in turn influenced the data management, and eventually the delay ramped up the pressure for the data analysis and reporting.

Designing, planning, organising, and executing pilots took a huge effort. Even before the actual piloting could begin, several preparatory activities were needed to enable piloting and data collection on public road networks. A key aspect was that relevant ethical, safety, legal, and privacy issues were identified from the very beginning and related risk mitigation plans were integrated into the tests. The work on safety and ethics benefitted from large-scale user trials of intelligent vehicle tests over the past two decades, as well as from the established guidelines created by the field operational test community in Europe. A solid methodology tailored to automated driving functions testing was designed early in the project. The methodology served as a guidance for the activities and ensured that the work could be carried out in a consistent manner across the test sites. All ethical, legal, and experimental procedures were executed in the same way.

Together with creating the methodology for piloting, equally important was the gathering of information on national legislation addressing AD testing, so that the project teams involved in the pilots could operate safely, following the necessary procedures and obtaining the necessary permissions required by the authorities to address completely new questions. The negotiations with national and local authorities were time-consuming, and for future testing activities these negotiations must be initiated early enough, also taking into consideration cross-border activities, to ensure that road tests can be launched as planned.

Ethical and privacy principles were considered throughout the project. Another issue to be faced concerned the general procedures for recruiting test drivers: these included checklists for instructing the subjects before the tests and a legal consent form, which had to be adjusted to the specific needs of each pilot site. The consent form described the main details of treating data and handling participants and, in particular, their informed consent. In future tests, it is highly recommended to involve national legal counselling when developing the final consent form for each pilot site.

Since the tests also recorded personal data, these were collected and analysed only by organisations specifically approved in the consent forms and in accordance with the General Data Protection Regulation (GDPR) and the respective national legislations.

L3Pilot experimental procedures were also designed to follow appropriate safety procedures, based on the partners' experience, consolidated over several decades of research and testing. The use of trained professional safety drivers, safety instructions, and supervised driving, along with consideration of the pilot site infrastructure, ensured effective risk mitigation methods for the trials.

The personal data of test drivers were anonymised, with specific indicators being derived from collected data for statistical work and assessment of societal impacts. The impact assessment was carried out using scientific methodology and principles, ensuring that the focus was on the behaviour of large user groups instead of focusing on individuals and their data. Without agreeing to these principles, it would not have been possible to protect the rights of the participating companies in the data analysis.

The challenge in the data management was to handle the huge amounts of data generated from the pilots while preventing any comparison among automated vehicle functions developed by the partners. This required special techniques and a solution to make it possible. At the same time, the data analysts had to provide answers to more than 100 research questions defined by the methodology development team. The consolidated database provided an innovative way to treat the dataflow from the raw signals of single vehicles, each one in a proprietary format. This database brought the data all the way to the impact analysis – and even further, as a portion of the data was made available as *open data* after the end of the project. The created consolidated database method will save a great deal of time in future large-scale road tests and serves as a model on how to manage large amounts of data without jeopardising the rights of participating companies.

The piloting data collected made it possible to exploit advanced evaluation methods and answer the research questions ranging from user behaviour to societal level impacts, as well as to provide data-led results on the impacts of automated driving. With an eye to the future, these activities were analysed and reported also as *lessons learned*, which were recorded by each sub-project to enable the partners to learn from the project work and improve practices that needed improvement. The main features of the lessons learned from various L3Pilot activities are summarised in Chapter 9.2 of this deliverable.

As noted above, European-wide piloting needed precise rules and procedures on how to execute the tests to ensure that the data could be collected to assess different level impacts of automated driving. This would not have been possible without a methodology tailored to the needs of automated driving pilots. One of the first tasks was to get behavioural scientists, research engineers, and other professionals to speak the same language, use the same concepts, and agree on the principles of experimental testing in addition to focusing on the technical functionality of the test vehicles. Here, it was essential to observe the principle of collecting extensive baseline measurements to obtain data and knowledge on how users and vehicles behave without automation. Once this knowledge was acquired, it was possible to compare automation with non-automated driving and draw conclusions about the impacts of automated driving. The consortium followed this basic principle of methodology to enable meaningful analysis of the data. Another important point in the execution of the methodology was the close cooperation of the methodology team with the pilot sites, including visits to each pilot site and face-to-face discussions on the steps needed to carry out the tests.

The applied methodology made it possible to analyse how automated vehicles behave in traffic – already at a stage before their market introduction – and how users accept the systems and interact with them, while also avoiding benchmarking between the individual piloted systems. The anonymised merging and evaluation of data required substantial efforts to ensure data quality already at the beginning of the data evaluation toolchain. Future work involving on-road tests with automated vehicles is recommended to focus more on long-term effects related to users of SAE L3 ADF by executing multiple drives per test subject over a longer time span. Furthermore, a more in-depth analysis should be carried out for situations at the edge of the operational design domain of such systems or in unexpected situations during their operation. For this, processes need to be established that allow the sharing of disaggregated and more in-depth data. However, at the same time, the processes need to be established in such a way that they still prevent re-engineering of the systems or benchmarking between them.

9.1.2 Results and their promotion

Concerning the impacts of the project work, safety has been by far the greatest motivator for developing automated driving technology. The current rate of over 1 million annual fatalities in road traffic is simply unacceptable. Fortunately, the results indicate clear improvement ahead, and the reduction potential is large, especially in urban areas. This naturally presupposes a mature automated vehicle market with sufficiently high penetration rates that cannot be achieved in the short term.

For urban automated driving, the expected net social benefits from accident prevention clearly exceed the social costs of implementing ADF at all penetration rates. Likewise, the additional impacts considered – such as the safety impact of inbuilt sensors in urban ADF on accidents occurring outside the ODD, as well as the impact on travel time costs when driving with ADF on urban roads – indicate monetary benefits on a level that approaches a benefit–cost ratio greater than 2.5. Finally, it is likely that a package consisting of all ADFs, i.e., with motorway, urban, and parking, would generate social benefits that exceed the social costs of installing such a package.

A great deal of effort in the project was put into user experiences and expectations concerning the automated vehicles. These questions were the focus in the actual pilots, in detailed on-road-tests, in a simulator, and as a global survey mapping users' knowledge and feelings about upcoming SAE L3 automation systems. Overall, it can be said that both the expectations and the experiences were clearly positive. The assumed usefulness of L3 cars was associated with their perceived comfort and safety. The next task in attitude studies is to delve deeper in the minds of those who have been using prototype automated vehicles – both those doing it for work and those participating in road tests.

The results are still somewhat inconclusive, as when professional safety drivers experienced SAE L3 systems less positively than test persons with only a brief experience of the vehicles. This implies that the systems are not yet mature enough, especially concerning the limited operational design domain of these vehicles.

Furthermore, the results also suggest that a great deal of work is still needed inside the cabin to understand both short- and long-term impacts of driver-vehicle interaction. It is essential that users understand and get along with the system, especially with regard to the SAE L3 system in situations where the driver's intervention is necessary. The period before full automation systems are achieved may still last some time.

The project also identified and examined four potential business models as potential futures for automated travel. However, the numerous uncertainties in the global economic, social, environmental, and business landscape make it difficult to predict the role of automated travel in society. At the moment, it looks likely that highly automated mobility in future will be based more on service than vehicle ownership by users.

The work also continued an almost traditional activity of creating a Code of Practice for the development of automated systems. The aim of the activity was to create a kind of de-facto standard and guidelines, in the form of questions to be considered, to facilitate the development of automated driving functions. The guidelines were made public for all interested parties in order to promote automated driving in Europe and overseas. An interest in the promotion of vehicle automation is common to all industries and stakeholders alike. Promotion work is needed to make all possible users aware of the possibilities of the Code of Practise. Based on experiences from previous CoPs, those using it have been satisfied with the possibilities it provides to the development work of intelligent vehicles.

The L3Pilot project organised its Final Event and Showcase at the ITS Word Congress 2021 in Hamburg in October 2021. The piloting outcomes were presented at this event, and the Congress attendees had the opportunity to experience the L3Pilot automated vehicle functions in city traffic and in motorway scenarios: 3 cars were brought to urban driving demonstrations, 6 cars to motorway demonstrations, and 13 cars to static demonstrations. The project, with over 400 square metres exhibition space, was among the most spectacular presenters at the congress.

9.2 Lessons learned

9.2.1 Designing the experiments

This section elaborates on the main positive and negative experiences of L3Pilot with a view to recommending good practices for future developments. Priority is given to topics that are relevant for automated driving, since addressing this rather young technology required novel methods and innovative tools throughout the project.

A multidisciplinary methodology tailored to testing and assessing ADFs was a key factor in ensuring the success of the experiments in the project. Considering the variety of tests planned by L3Pilot across Europe, it was essential to implement standard methods for all the partners, with the same tools and protocols. The common data format allowed the OEMs to deliver vehicle data that all analysis partners could understand regardless of the various in-house encodings. In particular, the project developed a code depository for the definition of experiments, including driving scenarios, a signal-list, common indicators, and measuring techniques. Similarly, online tools were used for the administration of questionnaires in order to obtain harmonised subjective data.

A basic requirement for piloting in traffic was to increase safety according to company rules and the legislation in different countries. A careful analysis of the application domain was therefore conducted when designing the experiments to define safety protocols. The use of prototype systems of a far-from-market-ready product was also a concern. In particular, it was not possible to include a study of how ordinary drivers behave during their daily routines. Nevertheless, the methodology included the analysis of various ad-hoc safety concepts, such as the role of safety drivers, subjects placed as observers in the passenger seat, and particular Wizard-of-Oz techniques.

A relevant issue faced by L3Pilot was how to maintain the confidentiality of vehicle data and avoid benchmarking while at the same time safeguarding a comprehensive evaluation. Detailed data from each pilot site was only handled by one or two research partners. A sophisticated data-sharing process designed to anonymise the data was used at a level of aggregation suitable for analysis. Moreover, results from several pilot sites were merged in such a way that sensitive information was protected, still allowing the averaged impact of a function to be investigated for a particular technical solution without revealing data.

With an eye to future developments in the area of methodologies, some points that were derived from the experience in L3Pilot are the following:

- Compared to experiments on ADAS, testing of ADFs requires more flexibility and iteration between the different phases to deal with the ongoing development of the functions, as well as legal and other restrictions.
- It can be expected that tests with ordinary drivers in their normal travels will be progressively implemented relying on the improved maturity of AD functions. Important outcomes of this approach will be to investigate user acceptance more reliably and to avoid some of the bias related to trained safety drivers.

- An important asset will be the definition of a protocol for safety procedures in AD experiments, based on a codified analysis of the test conditions. Industries and stakeholders in general will benefit from this evolution.
- Efforts will be directed to improving the ability to include all aspects of the experimental environment (road type, traffic, weather conditions, geographical location, etc.). This is especially important as environmental conditions can vary significantly, and invalid conclusions may be drawn if these are not taken into account. These things can be partly addressed by carefully keeping the baseline and treatment conditions a similar as possible – but all variable conditions can't be managed this way either.

9.2.2 Preparing the pilots

When preparing the pilots, the project team was particularly involved in providing optimum technical solutions while preserving the distinguishing features of each experiment.

The set-up of sensors and equipment in the vehicles benefitted from the partners' experience consolidated over several years of research and development. A key aspect was the selection of a uniform approach for data-logging tools and for data formats (see section 9.2.3 below), assuring an easy integration into the general data chain.

Obtaining the authorisations for testing AVs in public was very time-consuming. While significant work was done by public authorities to issue the first regulations in this area, a huge difference in procedures still exists among the different countries. This led to a mismatch in the timing to obtain permissions for different partners and generated difficulties, especially for cross-border experiments.

The importance of the pre-testing phase was confirmed by all partners. This task was delayed in some cases due to adaptations of the functions in the cars. Experience has shown that pre-testing should begin when the functions are well developed. Moreover, it was fundamental to validate the complete experimental process with the data chain on a sample case before starting the full pilots.

Dealing with cybersecurity for new functionalities posed considerable challenges. A useful approach was the extension of Threat Analysis and Risk Assessment tools, with a focus on handling the shared control between system and driver.

Several aspects requiring further research were identified and the following areas can be highlighted:

- It will be important to harmonise the regulations regarding permission to execute AD tests at the European level or even beyond. L3Pilot has shown the need to test vehicle automation across borders, as a key element for future market deployment.
- The adoption of a common terminology remains an area of interest, especially with respect to elements of the ODD, system-driver control, and hand-over and fall-back mechanisms. A set of well-established concepts and terms is currently missing, although efforts to fill this gap are ongoing, for example in ISO working groups.

- The huge volume of video data and their integration with other CAN data brings requirements for smart synchronisation and compression to minimise local storage needs. In several cases video recording was required by the public authorities that gave permission for pilots.
- More research in the direction of safety and cybersecurity is needed to enhance system controllability, possibly in relation with the TARA concept for system design. In this context, relationships with the infrastructure and related threats should also be considered, in view of a progressive penetration of connected vehicles.

9.2.3 Executing the pilots and handling the data

The primary objective of the piloting phase was to acquire a large set of data of high quality in order to provide input for the comprehensive evaluation.

Driver recruitment was not a simple process. In several cases, legislation or company rules required the selection of company or professional drivers. However, the aim was to recruit drivers that were newcomers to AD.

Another aspect requiring attention was the domain of ethics and privacy. As with any experiment with subjects, the pilots had to respect the GDPR rules. Data delivery to a third party involved additional efforts for the preparation and signing of bilateral agreements.

AD testing called for extensive video recording for technical reasons and often to fulfil the regulations established by the authorities. However, the legal situation regarding the sharing of videos, even within a consortium, is not sufficiently clear. Thus, there is a clear need for EU-level practices regulating the sharing of videos to avoid lengthy legal preparations and different interpretations. At the moment, the best practice might be to add clauses to the consortium agreement.

Translating the raw data into the common data format demanded a significant effort, coping with different characteristics at each test site. This work was especially onerous in the set-up phase but was rewarded with enormous advantages afterwards, when evaluating the data. For example, it was useful to exploit common algorithms for the detection of driving scenarios, harmonising derived measures, video annotation, data distribution analyses, and several other scripts.

Data quality was another key issue to be considered from the beginning of the pilots. In this regard, an effective concept for both experimenters and analysts was the use of a data-quality checklist.

Another good practice deployed in the piloting phase was the consolidated database, to which the test results were uploaded. A convenient feature was the web-based graphical user interface, which supported a good user experience when querying the database. The partners appreciated the efficient storage, data sharing, easy configurability, and portability.

The way forward will see larger and more diversified experiments that can rely on the existing experience and tools, such as those developed in L3Pilot. Enhanced maturity of AD functions will allow an extension of the ODD and a move towards systematic field operational tests.

The following guidelines can be derived from the work done in this project:

- A good operation of pilots originates from a well-defined methodology, a comprehensive digital environment with a data-chain exploited by all the participants, preparation of the vehicles, and attention to safety. Significant time and resources should be devoted to these tasks before starting the tests. A structured and complete pre-test phase is considered a must to ensure a smooth overall process.
- The effort of dealing with the legal framework, hopefully harmonised in the different countries, should be taken into account.
- When testing AD functions, data for baseline conditions should be collected in order to gain knowledge on how users and vehicles behave without automation. Since debates on this topic still exist within the research community, it will be important to clarify the baseline conditions before performing a series of experiments. Furthermore, the baseline and treatment data should be collected in comparable conditions to enable to determine the effect of automation compared with driving without automation.
- The baseline data recorded in earlier projects are useful for basic measures (speed, acceleration, etc.) but the need to have measurements done by the same sensor suite and environmental perception algorithms as the automated systems restricts the use of earlier data collections.
- Special attention should be dedicated to AD in urban traffic, where the variety of situations and the highly dynamic conditions still pose serious challenges.
- For extensive field trials it is recommended to leverage the availability of a common data format from the very early stage of the project. A starting point is the format defined by L3Pilot, which is publicly available.
- Shared tools are a powerful instrument for facilitating coordinated work. It is likely that several advanced data and simulation tools will become available in the next 3–5 years.
- The partners recognise the importance of driver training. It will be beneficial to implement commonly agreed safety courses regarding AD testing even for professional drivers.

9.2.4 Analysing the results

The analysis of results was greatly facilitated by the techniques and tools described in the previous subchapters. The experience in L3Pilot has shown the importance of the following main points.

- The adapted FESTA methodology provided guidelines that can be applied to piloting studies that address automated driving. It was important to reach an early and consistent agreement for all partners concerning the evaluation objectives and the data to be shared.
- Assessing the benefits of automated driving was demanding. This concerned difficulties in covering a variety of scenarios, as well as the constraints of simulation tools, which reached their limits in a number of cases. In general, having a broader catalogue of scenarios for evaluation would make it possible to go into further detail and remove some confounding factors. Nevertheless, the resources required for such an assessment should be kept in mind, with regards to both time and the necessary computation.

- Obtaining a subset of pilot data as early as possible, even in a preliminary form, was a winning factor. This allowed effective coordination between the experimenters and the evaluation team for all the different steps of the assessment (e.g., indicators, formats, scripts, error tracing, etc.).
- Due to the nature of prototype functions, the analysis of stable driving behaviour was in general fairly straightforward. The evaluation of rare or critical events was more challenging, especially for urban traffic. In the future, efforts will be needed to address the variety of uncommon events that may occur during driving.
- Although the anonymisation of the data was a useful method to maintain confidentiality, it also made error-tracing a time-consuming task, as it was hard to investigate whether all pilot sites were affected or just a single one. In some cases, this required reprocessing and a new data upload. In this respect, it was valuable to set up a systematic approach for versioning the toolchain and the uploaded data.
- A concern for the impact evaluation was related to the format of the database. The requirement to store aggregated information did not allow time series data to be shared, affecting some of the initial ambitions for the assessment. In future experiments, further options might be investigated to enable the sharing of time series data while maintaining the level of anonymisation.
- With the progress of technology, it is expected that higher automation levels will be investigated and societal impacts will be studied with a broader viewpoint. In this context, it will be important to consider traffic with a mix of automation levels, and to analyse the influence of new trends in mobility and transport, such as urbanisation, electrification, communication, sharing, new services, etc.

10 Upcoming and future research

Despite the progress made in automated technologies over the past years, even today the remaining complexity stays high. The goal is still the same: to create automated vehicles that operate in a reliable manner in all conditions and in unforeseen events and that perform even better in traffic than vigilant drivers everywhere. If the operational design domain sets the limits to the operation of expensive vehicles in good weather conditions outside complex traffic scenarios, it means that the benefits of automated driving (AD) will be small. A less optimistic outlook might be that after some years, full automation will share the fate of nuclear fusion: seemingly possible, but not yet. Unlike nuclear fusion, however, partial automation has been achieved and works comfortably – and relatively inexpensively at that.

Concerning enabling technologies, current sensors across almost all sensor types need considerable performance enhancement. For example, today an SAE L3 test vehicle may contain up to 20–30 sensors, including LiDAR, radar, cameras, and ultrasonic sensors. It goes without saying that the number, size and price of sensors, as well as their footprint, needs to be considerably smaller in production vehicles.

It is obvious that higher levels of automation need a fool-proof environment perception system in all conditions. Equally important is the need to speed up deployment of the lower level of automation, L3, to enter the market in the coming years. The conclusion is that current sensing technology, with the system performance and reliability of today's in-vehicle safety applications, significantly declines or even fails under bad environmental conditions. This prevents automated driving technology from proceeding further to higher levels of automation and more extended ODDs than is the case today.

The current ODD of self-driving vehicles has several restrictions, such as the difficulty in making decisions in complex traffic situations and transforming them into smooth action, and environment perception in inclement weather such as fog, rain, and snow. Consequently, L3Pilot limited its ODD in road tests to mainly temperate weather conditions during daylight hours.

Nevertheless, advancements have been made in sensor development for adverse driving conditions, as demonstrated in the projects RobustSENSE and DENSE. However, more comprehensive development is needed to enhance individual sensor performance, sensor data fusion, and better inclusion of artificial intelligence (AI) to bring the technology closer to higher levels automated driving. Previous work in this demanding field of machine vision in bad visibility conditions has been rather scant and has not yet led to a breakthrough. Consequently, more work is still needed in basic enabling technologies to allow vehicles to operate in unrestricted operational design domains.

Recent R&D, however, has shown the way to proceed to solve these issues, and the results thus far in sensor development for variable travel conditions are very promising, as described below:

- The performance of short-wave infrared (SWIR) LiDAR is potentially significantly better than that of the conventional near-infrared (NIR) LiDAR under good weather conditions and especially in bad weather conditions.

- The gated camera clearly outperforms a standard camera in inclement weather and in night-time sensing. It penetrates bad weather clutter also significantly better than LiDAR. Furthermore, it offers a depth estimation for each pixel.
- High resolution MIMO Radar (Multi-Input-Multi-Output) offers new quality of a radar image with substantially more capabilities than standard radar, allowing for a classification of objects (e.g., pedestrian) and stationary objects (parking car vs. hydrant) and allowing a meaningful fusion with camera and LiDAR images. However, MIMO Radar is currently computationally far too expensive, and it needs transformation on a field-programmable gate array (FPGA) in such a way that the information can also be used for the fusion approach.
- A new AI-based approach for signal enhancement needs to be created by focusing on a new intelligent processing unit for signal amplification and fusion based on convolutional neural networks. The gains reached since the last wave of AI in the 1990s are impressive and hopes for a breakthrough (as well as fears) are mounting.
- The task of integrating the solutions mentioned into a proof of safe performance is daunting and requires transparent models for re-simulation, especially with the increasing amount of AI decisions that are not comparable in repeatability to predictable algorithms that do not change during their lifetime.

These results point out the direction along which we need to proceed in creating a perception system that enables higher levels of automated driving.

However, it is not only technical challenges that need to be addressed. Equally important is to understand the minds of users, as well as the minds of those who are responsible for transport governance, who build and operate infrastructures and cities. Public awareness and acceptance may take far longer than the remaining technical challenges. This will depend on the prototype vehicles' performance and the time it takes to implement legal and political changes, such as enacting national laws governing the use of automated cars and solving the liability issues of automation.

Furthermore, concerning SAE L2 - L3 driving, it has been suggested that human drivers over-trust automated technology and do not monitor the roadway carefully enough to be able to safely take control when needed (Waymo, 2018). For this reason, Waymo took a decision to start experimenting solely on SAE L4 systems – although in very a limited ODD, but still pointing out the need for higher automation levels in vehicle control. It will be essential in up-coming R&D to focus on what is happening inside the vehicle to understand how users become accustomed to automated systems and to learn whether they exploit the full potential benefits of conditional automation. In addition to enhancing the environment perception systems of future automated vehicles, we need to investigate and ensure that the HMI in upcoming vehicles is able to keep the driver in the loop even though automation releases the driver from the continuous monitoring of the travel environment. Nonetheless, there are still a number of years ahead with SAE L2 - L3 systems. We need not forget that highly automated systems may be socially and ethically mandated if they have the potential for damage limitation (Di Fabio, 2017).

The recently launched Hi-Drive project will in part answer these requirements. The project will push concepts of automated driving further towards high automation. Robust automation functions and interaction with other traffic participants will be demonstrated, enabling the industry to proceed towards market deployment of these systems by 2030. The aim is to advance the state of the art and (i) to demonstrate complex interaction with other road users in normal traffic, (ii) to implement connected and secure automation providing vehicles/their operators with information beyond the line of sight and on-board sensor capabilities, (iii) to enable AVs to travel in challenging conditions covering variable weather and traffic scenarios, and (iv) to acquire new information about user preferences and reactions including comfort and trust – and eventually, to enable viable business models for automated driving.

High-level AD will be tested in very different conditions and driving cultures across Europe from north to south, liberated from the earlier very narrow ODD that characterised SAE L2 - L3 automation. High automation enables considerable safety benefits compared to manual driving when taking AVs into demanding, error-prone conditions – particularly those not yet seen or recorded. Tests and data collected in these conditions are expected to reveal essential enhancement needs for AD systems and standards before the release of marketable products.

Automated driving systems must be made interoperable between brands and across borders. Otherwise, the systems remain at the demonstration level only, while the passion is to create evolution in the transport system and respond to peoples' mobility needs. Hi-Drive has, for the first time, a chance to collect data across EU borders in variable traffic, weather, and visibility conditions – a prerequisite for an extended ODD characterising high-automation driving. Furthermore, this project's extensive geographical coverage enables the results to be scaled up to an EU level more realistically than before.

In contrast with pilot site testing, large-scale public roads testing and demonstrations like Hi-Drive are the only way to assess high automation, its robustness, and its impacts on user behaviour, traffic, and the transport system as a whole.

The shift to automation requires everyone from automakers to consumers, insurers, planners, and officials at all levels of government to work together. Being proactive about guiding this technological change is essential. Rather than waiting until it happens or leaving it to the last minute, now is the time for providing education, improving standardisation, enhancing public awareness, and planning viable business cases for upcoming AD.

The Hi-Drive project will respond to the above-described R&D needs through these features:

- Complexity: High-level mode driving in variable conditions and weather in 12 areas – from southern Europe to the arctic.
- Connectivity: Hybrid V2X (comprising ITSG5 and 5G), V2P/VRU, in motorways, urban, and across borders while always remaining connected, also between brands.
- Testing: First-time comprehensive and large data set acquired from high-automated driving in representative conditions.

- Standards: The standardisation and regulatory framework will be focused on, since it needs more of a push than has hitherto been the case.
- Safety assurance: Determine the level of scenario-based testing and safety evidence needed e.g., for edge cases.
- Security: Develop a holistic cyber-security model.
- Infrastructure support: ISAD system will be used in classifying infrastructure support; harnessing IRF for this.
- Cutting-edge technology scenarios: Restricted visibility; no road markings present but instead powder and drifting snow; interaction with other traffic participants including vulnerable road users and lorries.
- Furthermore, the state of the art will be advanced in business scenario development, general public involvement in testing AVs, high-automation testing and evaluation methodology development, and user-vehicle interaction.

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ANNEX 1: L3Pilot publications, congress presentations, and other papers

Year	Journal/ Event	Title	Responsible author	Co-authors
2021	ITS World Congress 2021	Analysis of Safety Framework for Piloting Automated Driving Systems on Public Roads	Benjamin Altpeter	Sebastian Klaudt Felix Reimer Adrian Zlocki Lutz Eckstein
2021	ICTCT 2021	Safety critical event detection – Applying and evaluating different Surrogate Safety Measures in a roundabout traffic scenario	Juan Trullos	Marek Junghans Mandy Dotzauer
2021	Human Factors	Driver glance behaviour before and after take-over requests in conditional automation on public roads	Linda Pipkorn	Marco Dozza Emma Tivesten
2021	Driving 2021 Assessment Conference	Driver glance behaviour before and after take-over requests in conditional automation on public roads	Linda Pipkorn	Marco Dozza Emma Tivesten
2021	To be decided (TBD)	How does interaction with cut-in and rear-vehicles change in automated driving?	Thomas Streubel	Jordanka Kovaceva
2021	Transportation Research Part F: Traffic Psychology and Behaviour	Investigating trust in automation and implications on driver behaviour in a Wizard-of-Oz study on public roads	Thomas Streubel	Fredrick Ekman, Mikael Johansson (both Chalmers)
2021	Human Factors	Misuse of automation – what are the factors putting drivers to sleep during conditionally automated driving?	Johanna Wörle	Barbara Metz
2021	TBD	Expected mobility impacts of L3 AVs: Analysis of the impact assessment survey data	Fanny Malin	Esko Lehtonen, ... (TBD)
2021	TBD	Why travel more with L3 AVs? Insights from a real-world study	Esko Lehtonen	Fanny Malin, ... (TBD)

Year	Journal/ Event	Title	Responsible author	Co-authors
2021	TBD	The impact of drivers' experiences with an L3 automated vehicle on their willingness to use motorway and urban control systems: A real-world study	Yee Mun Lee	Ruth Madigan, Tyron Louw, Natasha Merat, and many others (TBD)
2021	International Journal of Environmental Research and Public Health	Drivers' Intentions to Use Different Functionalities of Conditionally Automated Cars: A Survey Study of 18,631 Drivers from 17 Countries	Tyron Louw	Ruth Madigan, Yee Mun Lee, Sina Nordhoff, Satu Innamaa, Esko Lehtonen, Fanny Malin, Afsane Bjorvatn, Natasha Merat
2021	TBD	Physiological Indicators of Driver Workload During Car-Following Scenarios and Take-overs in Highly Automated Driving	Vishnu Radhakrishnan	Natasha Merat, Tyron Louw, Rafael Cirino Gonçalves, Guilhermina Torrao, Wei Lyu, Pablo Puente Guillen, Michael G. Lenné
2021	Journal of Advanced Transportation	Profiling the Sceptical, Neutral, and Enthusiastic Users of Conditionally Automated Cars in 17 Countries: A Questionnaire Study	Sina Nordhoff	
2021	PhD thesis	Big Data Management for Impact Assessment Study: Validation of Level 3 Automated Driving Functions	Nisrine Osman	
2021	AutomotiveUI 2021	The effect of driver engagement and presence of obstacles on drivers' gaze behaviour patterns during non-safety-critical transitions of control from vehicle automation	Rafael Cirino Gonçalves	Natasha Merat, Tyron Louw, Vishnu Radhakrishnan Guilhermina Torrao, Pablo Puente Guillen
2021	AutomotiveUI 2021	Evaluation of a motorway ADF: Impact of technology readiness, system experience, and system level	Barbara Metz	Johanna Wörle

Year	Journal/ Event	Title	Responsible author	Co-authors
2021	Transportation Research Part F: Traffic Psychology and Behaviour	It's about time! Early take-over request in conditional automation enables safe response to a lead-vehicle cut-out scenario	Linda Pipkorn	Marco Dozza Emma Tivesten
2021	EUCAD2021	The L3Pilot Approach From vehicle data collection to a common data base	Barbara Metz WIVW	Johannes Hiller
2021	EUCAD2021	Vehicle Automated Functions Challenges	Luisa Andreone	
2021	TBD	Integrity monitoring of positioning and navigation systems for autonomous vehicles: State-of-the-art and open challenges	Hao Jing, Univ. Warwick	Yang Gao, Sepeedeh Shahbeigi, Mehrdad Dianati
2021	ITS World Congress 2021	An original approach for SAE L3 Automated Driving System, experimentally tested on Public Highways	Pandeli Borodani	Michele Basso, Pallaro Nereo
2021	Intelligent Vehicles (IV) Symposium	Aggregation of Road Characteristics from Online Maps and Evaluation of Datasets	Johannes Hiller	Johannes Hiller, Fabian Müller, Lutz Eckstein
2021	ITS World Congress 2021	Evaluation of Collaborative Business Models for Automated Driving	Frank Berkers	Anja Beuster Eckhard Schueler-Hainsch David Ertl Sri Ramakrishnan Ganesa Isabel Wilmink
2021	ITS World Congress 2021	Automated Evaluation of Automated Driving within Urban Environments across Multiple Test Sites – Practical Challenges and Solutions	Hendrik Weber	Johannes Hiller Henri Sintonen Esko Lehtonen
2021	TBD	Evidence on impacts of automated vehicles on traffic flow efficiency: systematic review	Elina Aittoniemi	

Year	Journal/ Event	Title	Responsible author	Co-authors
2021	TBD	Scaling up method for E&E impacts	Satu Innamaa	Elina Aittoniemi, Teemu Itkonen
2021	TBD	Emission and energy impacts	Elina Aittoniemi	Satu Innamaa Teemu Itkonen
2020	Seminario AEIT Sulle Frontiere Della E-Mobility: Guida Autonoma, Sistemi Manned-Unmanned	Exploring the challenges for vehicle automation, the L3Pilot European project	Luisa Andreone	
2020	ARCADE Stakeholder workshop on Common Evaluation Methodology	No title, (Content: Brief introduction of L3Pilot and how it can contribute to CEM)	Satu Innamaa, VTT	
2020	Sensors	Managing Big Data for Addressing Research Questions in a Collaborative Project on Automated Driving Impact Assessment	Francesco Bellotti	Osman, N.; Arnold, E.H.; Mozaffari, S.; Innamaa, S.; Louw, T.; Torrao, G.; Weber, H.; Hiller, J.; De Gloria, A.; Dianati, M.; Berta, R
2020	Transportation Research Part F: Traffic Psychology and Behaviour	Repeated usage of a motorway automated driving function: Automation level and behavioural adaption	Barbara Metz, WIVW	Johanna Wörle, Michael Hanig, Marcus Schmitt Aaron Lutz
2020	Scientific journal	Identifying the safety potential of conditionally automated vehicles (SAE3) in Finland	Fanny Malin, VTT	Anne Silla, VTT, Johannes Mesimäki, VTT Satu Innamaa, VTT Harri Peltola, VTT

Year	Journal/ Event	Title	Responsible author	Co-authors
2020	Transportation Research Part F: Traffic Psychology and Behaviour	Using the UTAUT2 model to explain public acceptance of conditionally automated (L3) cars: A questionnaire study among 9,118 car drivers from eight European countries	Sina Nordhoff, EICT	Tyron Louw, Leeds Satu Innamaa, VTT Esko Lehtonen, VTT Anja Beuster, EICT Guilhermina Torrao, VTT Afsaneh Bjorvatn, SNF Tanja Kessel, EICT Fanny Malin, VTT Riender Happee, TU Delft Natasha Merat, Leeds
2020	Cognition, Technology, and Work	Do drivers change their manual car-following behaviour after automated car-following?	Tyron Louw, Leeds	Rafael Goncalves, Leeds Guilhermina Torrao, Leeds/VTT Vishnu Radhakrishnan, Leeds Wei Lyu, Leeds Pablo Puente Guillen, TME Natasha Merat, Leeds
2020	29th Aachen Colloquium Sustainable Mobility	Evaluation in L3Pilot: Toolchain and First Results	Johannes Hiller, ika	Hendrik Weber, ika Lutz Eckstein, ika Adrian Zlocki, fka

Year	Journal/ Event	Title	Responsible author	Co-authors
2020	Transportation Research Interdisciplinary Perspectives	Are multimodal travellers going to abandon sustainable travel for L3 automated vehicles? (previously: Intention to use L3-automated cars and sustainable travel-mode use: Is there a link?)	Esko Lehtonen, VTT	Fanny Malin, Satu Innamaa, VTT Tyron Louw, Natasha Merat, Leeds Sina Nordhoff, EICT Afsaneh Bjorvatn, SNF
2020	Automated Vehicles Symposium	Evaluation plan for the real-world pilots in L3Pilot	Satu Innamaa, VTT	
2020	Automated Vehicles Symposium	Methodological challenges related to real-world automated driving pilots and solutions in L3Pilot	Satu Innamaa, VTT	
2020	Automated Vehicles Symposium	How to do evaluation in an open road automated driving study?	Satu Innamaa, VTT	Tyron Louw and Natasha Merat, Univ. of Leeds Guilhermina Torrao and Elina Aittoniemi, VTT
2020	Scientific Journal	Driving behaviour before and after sleep: Comparing the driver states of sleepiness and sleep inertia in automated driving	Johanna Wörle, WIVW	Barbara Metz, WIVW Martin Baumann, University of Ulm
2020	Transportation	Travel experience matters: Expected personal mobility impacts after simulated L3/L4 automated driving	Esko Lehtonen, VTT	Fanny Malin, VTT Johanna Wörle, WIVW Barbara Metz, WIVW Satu Innamaa, VTT

Year	Journal/ Event	Title	Responsible author	Co-authors
2020	Measuring Behavior	Development of an algorithm to identify stabilisation time for car-following after transitions of control from vehicle automation	Rafael Goncalves, Leeds	Wei Lyu, Leeds Vishnu Radhakrishnan, Leeds Guilhermina Torrao, Leeds Pablo Puente Guillen, TME Tyron Louw, Leeds Natasha Merat, Leeds
2020	Measuring Behavior	Applying Entropy to Understand Drivers' Uncertainty during Car-following	Wei Lyu, Leeds	Rafael Goncalves, Leeds Fu Guo, Northeastern University Guilhermina Torrao, Leeds Vishnu Radhakrishnan, Leeds Pablo Puente Guillen, TME Tyron Louw, Leeds Natasha Merat, Leeds
2020	Licentiate Thesis	The automation effect: Investigating factors that influence the driver response process to a safety-relevant event during assisted driving and after unsupervised automation	Linda Pipkorn	
2020	IEEE Transactions on Intelligent Transportation Systems	Automation aftereffects: The influence of automation duration, test track, and timings	Linda Pipkorn	Marco Dozza, Chalmers Trent Victor, VCC Emma Tivesten, VCC
2020	Accident Analysis and Prevention	Investigating Sleep Inertia in Automated Driving: Methodological considerations and results from a driving-simulator study	Johanna Wörle, WIVW	Barbara Metz, WIVW Martin Baumann, University of Ulm

Year	Journal/ Event	Title	Responsible author	Co-authors
2020	Electronics Journal	The L3Pilot Data Management Toolchain for a Level 3 Vehicle Automation Pilot	Johannes Hiller, RWTH Francesco Bellotti, DITEN	Sami Koskinen, VTT Riccardo Berta, DITEN Ben Nagy, JLR Nisrine Osman, DITEN Ashfaqur Rahman, JLR Erik Svanberg, SAFER Hendrik Weber, RWTH Eduardo H. Arnold, WMG Mehrdad Dianati, WMG Alessandro De Gloria, DITEN
2020	To be decided (TBD)	Analysing Cyber Attacks and Risks in V2X-Assisted Autonomous Highway Merging	Chao Chen, University of Warwick	Ugur Ilker Atmaca, University of Warwick Konstantinos Koufos, University of Warwick Mehrdad Dianati, University of Warwick Carsten Maple, University of Warwick
2020	'Information' journal	Human-Vehicle Integration in the Code of Practice for Automated Driving	Stefan Wolter, Ford	Giancarlo Caccia Dominioni, TME Sebastian Hergeth, BMW Fabio Tango, CRF Stuart Whitehouse, JLR Frederik Naujoks, BMW

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2020	IEEE Transactions on Industrial Informatics	Atmosphere, an Open Source Measurement-Oriented Data Framework for IoT	Francesco Bellotti	Riccardo Berta, Member, IEEE Ahmad Kobeissi Francesco Bellotti Alessandro De Gloria
2020	Transportation Research Part F: Traffic Psychology and Behaviour	Driver conflict response during supervised automation: Do hands on wheel matter?	Linda Pipkorn, Chalmers	Marco Dozza, Chalmers Trent Victor, VCC Emma Tivesten, VCC
2020	7th International Conference on Driver Distraction and Inattention (DDI2020)	Understanding the effect of automation and its duration on driver behaviour in conflicts: A Wizard-of-Oz test-track study	Linda Pipkorn, Chalmers	Marco Dozza, Chalmers Trent Victor, VCC Emma Tivesten, VCC Pär Gustavsson, VCC
2020	Applied Human Factors and Ergonomics Conference (AHFE), San Diego, USA, 16-20 July 2020	Automated driving on the motorway: A user's perspective on conditional versus high automation	Johanna Wörle, WIVW	Barbara Metz, WIVW Aaron Lutz, WIVW Marcus Schmitt, WIVW
2020	7th International Conference of Traffic and Transportation Psychology (ICTTP) 2020	Mobility profiles and intention to use L3 automated cars	Esko Lehtonen, VTT	Fanny Malin, VTT Sina Nordhoff, EICT Anja Beuster, EICT Afsaneh Bjorvatn, SNF Tyron Louw, Leeds Guilhermina Torrao, Leeds Satu Innamaa, VTT Tanja Kessel, EICT Natasha Merat, Leeds

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2020	Information	Repeated usage of an L3 motorway chauffeur: Change of evaluation and usage	Barbara Metz, WIVW	Johanna Wörle, Michael Hanig, Marcus Schmitt, Aaron Lutz
2020	Bachelor Thesis	TITLE?	Aaron Lutz, WIVW	
2020	TRA2020, Helsinki	Change of acceptance with repeated usage of an L3-motorway chauffeur	Barbara Metz , WIVW	Johanna Wörle, WIVW
2020	TRA2020, Helsinki	Applying the FESTA methodology to automated driving pilots	Satu Innamaa, VTT	Natasha Merat, Tyron Louw, Guilhermina Torrao, LEEDS Elina Aittoniemi, VTT
2020	TRA2020, Helsinki	Assessing user behaviour and acceptance in real-world automated driving: The L3Pilot project approach	Tyron Louw, LEEDS	Natasha Merat, Guillermina Torrao, LEEDS Barbara Metz, Johanna Wörle, WIVW Satu Innamaa, VTT
2019	HFES Europe	Driving with a L3 – motorway chauffeur: How do drivers use their driving time?	Johanna Wörle, WIVW	Barbara Metz, WIVW
2019	Master’s thesis	Impacts of Automated Driving on Health and Quality of Life	Reetta Mäkinen, VTT	
2019	Bachelor's thesis	Entwicklung der Akzeptanz beim hochautomatisierten Fahren im Simulator	Marcus Schmitt, WIVW	
2019	20191027-30_ITSC 2019	Recognition and Pseudonymization of Data Privacy Relevant Areas in Videos for Compliance with GDPR	Johannes Hiller, IKA	Michael Schuldes, RWTH Lutz Eckstein, IKA

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2019	20191021-25_ ITS World Congress, Singapore	Methodological challenges related to real-world automated driving pilots	Satu Innamaa, VTT	Tyron Louw, Natasha Merat, LEEDS Barbara Metz, WIVW Thomas Streubel, CHAL Christian Rösener, IKA
2019	20191021-25_ ITS World Congress, Singapore	Assessing mobility impacts of automated driving in L3Pilot	Salla Kuisma, VTT	Tyron Louw, Guilhermina Torrao, LEEDS Satu Innamaa, VTT
2019	20191021-25_ ITS World Congress, Singapore	Setting up Experimental Procedure for Level 3 Automated Driving Pilots	Merja Penttinen, VTT	Barbara Metz, WIVW Satu Innama, VTT Pirkko Rämä, VTT Rino Brouwer, TNO
2019	20191021-25_ ITS World Congress, Singapore	Methodology for evaluating automated driving in Europe	Satu Innamaa, VTT	
2019	20191021-25_ ITS World Congress, Singapore	Building a Data Management Toolchain for a Level 3 Vehicle Automation Pilot	Erik Svanberg,CHAL Announced by Ben Nagy, JLR	
2019	IET Intelligent Transport Systems Journal	Building a Data Management Toolchain for a Level 3 Vehicle Automation Pilot	Erik Svanberg,CHAL Announced by Ben Nagy, JLR	

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2019	2019105-7_AachenerKolloquium	Pilot Study for Level 3 Vehicle Automation	Benjamin Altpeter, FKA	Sebastian Klaudt, FKA Adrian Zlocki, FKA Johanna Josten, IKA, RWTH Christian Rösener, IKA, RWTH Lutz Eckstein, IKA, RWTH
2019	2019069-12_Intelligent Vehicle Symposium, Paris	Designing an IoT Framework for Automated Driving Impact Analysis	Francesco Bellotti, University of Genoa	
2019	2019069-12_Intelligent Vehicle Symposium, Paris	Controllability-aware Threat Analysis and Risk Assessment for L3 Automated Driving Systems	Anastasia Bolovinou, ICCS	Ugur-Ilker Atmaca, WMG Al Tariq Sheik, WMG Obaid Ur-Rehman, FEV Gerhard Wallraf, FEV Angelos Amditis, ICCS
2019	20190610-13_ESV19, Eindhoven	The L3Pilot common data format – Enabling efficient automated driving data analysis	Johannes Hiller, IKA	Erik Svanberg, CHAL Sami Koskinen, VTT Francesco Bellotti, Nisrine Osman, DITEN – University of Genoa
2019	Book 'Road Vehicle Automation 6'	Evaluation of Automated Driving by Large Scale Piloting on European Roads – the L3Pilot Project	Christian Roesener, IKA	Adrian Zlocki, FKA Hendrik Weber, IKA Johannes Hiller, IKA
2018	PhD Thesis	Sleep in automated driving (working title)	Johanna Wörle	

Year	Journal/ Event	Title	Responsible author	Co-authors
2018	20181104-07_ITSC_Hawaii	Modelling Human Driver Performance for Safety Assessment of Road Vehicle Automation	Christian Roesener, IKA	Michael Harth, RWTH Aachen University Hendrik Weber, IKA Johanna Josten, IKA Lutz Eckstein, IKA
2018	20180917-21_ITS World Congress, Copenhagen	Methodology for evaluation in L3Pilot	Satu Innamaa, VTT	Daryl Hibberd, LEEDS Christian Rösener, IKA Merja Penttinen, Pirkko Rämä, VTT Barbara Metz, WIVW

List of abbreviations and acronyms

Abbreviation	Meaning
AD	Automated driving
AdapatIVe	Automated Driving Applications and Technologies for Intelligent Vehicles (EU project)
ADAS	Advanced Driver Assistance System
ADF	Automated Driving Function
API	Application Programme Interface
AV	Automated vehicle
BASt	Bundesanstalt für Straßenwesen
CARE	European Union's Road Accidents Database
CARTRE	Coordination of Automated Road Transport Deployment for Europe
CDB	Consolidated Database: a data repository for controlled merging of data while at the same time hiding the identity of the individual pilot sites from the evaluation partners
CDF	Consolidated data format
CLI	Command Line Interface
COM	Commissions Communication
CoP	Code of Practice
CoP-AD	Code of Practice for Automated Driving
CO_2	Carbon dioxide
CPU	Central processing unit
DM	Derived measure
DRIVE C2X	DRIVing implementation and Evaluation of C2X communication technology in Europe (EU project)
Driving scenario	A short period of driving defined by its main driving task (e.g., car-following, lane change) or triggered by an event (e.g., an obstacle in the lane)
ECU	Electronic control unit
EuroNCAP	The European New Car Assessment Programme
FESTA	Field Operational Test Support Action; a handbook on FOT (Field operational tests) methodology
FIA	Fédération Internationale de l'Automobile (International Automobile Federation)
FPGA	Field-programmable gate array
FOT-Net	Field Operational Test Networking and Data Sharing Support
FuSa	Functional Safety
GDPR	General Data Protection Regulation
Gitlab	Web-based DevOps lifecycle tool
HMI	Human Machine Interaction, Human Machine Interface

Abbreviation	Meaning
ID	Identification (e.g., of a trip in the data)
InteractIVe	Accident avoidance by active intervention for Intelligent Vehicles (EU project)
IRF	Injury risk function
ISO	International Standardisation Organisation
KSS	Karolinska Sleepiness Scale
LiDAR	A sensor determining ranges (variable distance) by targeting an object with a laser and measuring the time for the reflected light to return to the receiver
LimeSurvey	Online questionnaire tool
L3Pilot	Piloting Automated Driving on European Roads (given SAE L3 and L4 functions)
Measurify	An IoT Framework to build powerful edge-cloud applications
MIMO Radar	Multiple-input multiple-output radar
MongoDB	A non-relational database
MRM	Minimum Risk Manoeuvre
Naïve subject	A person participating in a test and having no prior experience on the testable matter (here automated driving and functions). Also used as a synonym for the term 'ordinary driver'.
NIR	Near-infrared
NodeJS	JavaScript runtime built on Chrome's V8 JavaScript engine
ODD	Operational design domain
OEM	Original Equipment Manufacturer (here auto manufacturer)
PI	Performance indicator (e.g., speed, deceleration)
PRC	The percentage of time that glances fell on-path
PReVENT	Preventive and active safety applications contribute to the road safety goals on European roads (EU project)
RESTful	An open-source Representational state transfer
R&I	Research and innovation
RQ	Research question
SAE	Society of Automotive Engineers
SAEJ3016	SAE taxonomy for the classification of automated driving
SDBM/R	Service-Dominant Business Model Radar
SDV	Software Defined Vehicle
SLAM	Simultaneous localisation and mapping
SoA	Service-oriented Architecture
SP	Sub-project
SPSS	Statistical package for social sciences
Subject	A person participating in a test (here in a pilot)

Abbreviation	Meaning
SUV	Sport Utility Vehicle
SWIR	Short-wave infrared
TARA	Threat Analysis and Risk Assessment
THW	Time headway
TOR	Take-over request
Traffic scenario	A specific road section with certain traffic characteristics describing a larger traffic context, which includes different (not pre-defined) driving scenarios
Uninfluenced driving	Driving free from other vehicles. Usually, not driving in a queu.
VCC	Volvo Car Corporation
VKT	Vehicle kilometres travelled
VRU	Vulnerable road user
VTTS	The value of travel time
V2X	Vehicle-to-Everything communication
WIVW	The Würzburg Institute for Traffic Sciences
Wizard-of-Oz	An experimenter (the ‘wizard’) not present to the subject
zip.file	File compression, encryption concept