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Summary

The L3Pilot project carried out large-scale Piloting of automated driving with the developed SAE Level 3 and Level 4 functions in passenger cars. A comprehensive series of trials exposed the test vehicles to different users and mixed traffic environments, namely motorway, traffic jam, urban traffic and parking. Four Automated Driving Functions (ADF's) were selected and specified: Traffic Jam Chauffeur, Motorway Chauffeur, Parking Chauffeur and Urban Chauffeur.

This document reports the outcome of the Pilots and shows how a complete data chain has been managed all the way from the acquisition of objective and subjective data during road tests to data management by using specified procedures and common formats. The outcome of the Piloting phase can be summarised as follows: eleven series of tests with different cars have been done on motorways, and three on urban scenarios, with more than 220.000 km driven in a vehicle automation mode. Moreover, three Pilot Sites addressed automated parking and low speed manoeuvres. Totally, over 750 users participated in the Pilots.

This document also deals with the outcome of the L3Pilot Piloting activities in the different Pilot Sites and scenarios. The goals of the Pilots were data collection, the creation of the digital environment for the management of the huge data set, transformation of the Piloting raw data into a common data format designed by L3Pilot, and the data upload on the Consolidated Database (CDB) for the data delivery to the L3Pilot evaluation experts. At the same time, the ultimate goal of the Pilots is answering more than 100 research questions by the data analysis to be reported in the related L3Pilot deliverables in the fall 2021. However, already from the Piloting execution several considerations could be derived, especially those related to vehicles' automated functions operational design domains (ODD's) as reported in this document.

Finally, the document explains a good number of lessons learnt in the Piloting phase. These are related to the following aspects: Pilots' scheduling within the pandemic situation, technical challenges when recording data and/or uploading the data to the consolidated database, legal constraints for a permission to drive a vehicle in an automation mode, to deliver the data to other parties and challenges in recruiting subjects for Piloting.

1 1 Introduction

1.1 Motivation for the L3Pilot project

Over the years, numerous projects have paved the way for Automated Driving (AD). Significant progress has been made. However, the technology is rapidly advancing and today in a stage that justifies automated driving tests in large-scale Pilots.

L3Pilot is taking one of the latest steps before the introduction of automated vehicle functions in daily traffic. Drivers are used to Advanced Driver Assistance Systems (ADAS), and numerous vehicles are equipped with ADAS. However, automation is not solved simply by integrating more and better technology. This topic needs a focus on user behaviour with automated driving functions. User acceptance is a key to the success of AD on the market as well as the legal and technical challenges on shared operational responsibility that firstly need to be discussed and solved on a broad level. The legislative processes need to be put in place and assist with policies, regulations and practices which means understanding the technology, how it operates, and what that means for the users involved. In parallel with Piloting, the project also addresses legal and ethical issues related to the operation of automated vehicles.

The idea of the vehicle controlling itself by a computer can create uneasiness among the global populous akin to the first impression in the 1800s when a motor vehicle was firstly introduced. The lack of acceptance may hinder the introduction even of the lower levels of automation, like for driver assistance systems, despite their obvious benefits for safety and efficiency. In order to overcome public concerns, automated vehicle functions need to be designed according to user needs; otherwise, they will not be accepted.

1.2 Objectives

The overall objective of the L3Pilot project is 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.

AD technology has matured to a level motivating a final phase of road tests which can answer the key questions before market introduction. These newly attained levels of maturity will ensure an appropriate assessment of the impact of AD, what is happening both inside and outside the vehicles, how vehicle security can be ensured, while evaluating societal impacts and emerging business models.

Recent work indicates how driver assistance systems and AD functions can be validated by means of extensive road tests with a long operational time, to allow extensive interaction with the driver and the functions. The project uses large-scale testing and Piloting of AD with developed SAE Level 3 (L3) functions (Figure 1.1) exposed to different users, mixed traffic environments, including conventional vehicles and vulnerable road users (VRUs), along different road networks. Level 4 (L4) functions have also been assessed in close distance / parking scenarios.

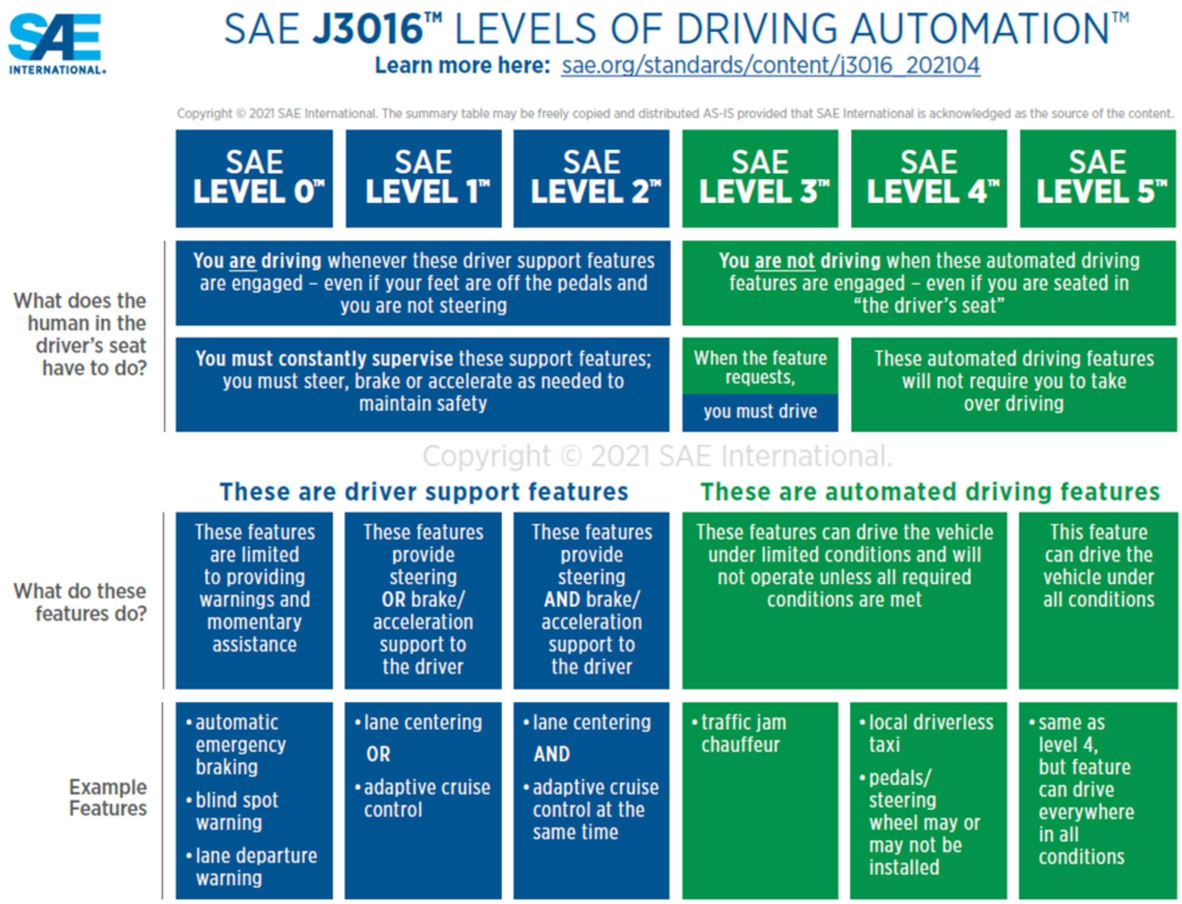

Figure 1.1: SAE Levels of Driving Automation J3016_202104(Copyright 2021 SAE International).

The data collected in the Piloting sessions supports the following L3Pilot goals:

- Lay foundation for the design of future, user-accepted L3 and L4 functions to ensure their commercial deployment. This will be achieved by assessing user reactions, experience and preferences of the AD functionalities.
- Enable non-automotive stakeholders, such as authorities and certification bodies, to prepare measures that will support the uptake of AD, including updated regulations for the certification of vehicle functions with a higher degree of automation as well as incentives for the user.
- Create unified de-facto standardised methods to ensure further development of AD applications by creating of a Code of Practice (CoP) for designing and developing automated vehicles.

- Acquire a large dataset to enable simulation studies of the performance of AD over time which are not possible to investigate in road tests due to the time and effort needed.

The consortium addresses four major technical and scientific objectives, listed hereafter:

1. Create a standardised Europe-wide Piloting environment for automated driving.
2. Coordinate activities across the Piloting community to acquire the required data.
3. Pilot, test and evaluate automated driving functions and connected automation.
4. Innovate and promote automated driving for wider awareness and market introduction.

1.3 Approach and scope

L3Pilot focused on large-scale Piloting of ADFs (Automated Driving Functions), primarily L3 functions, with additional assessment of some L4 functions. The idea in Piloting was to ensure that the functionality of the systems is exposed to variable conditions. Furthermore, the aim was to show that the automated system performance is consistent, reliable and predictable. This would allow a successful driving experience for the users. A good experience of using AD will accelerate acceptance and adoption of the technology and improve the business case to deploy automated vehicles.

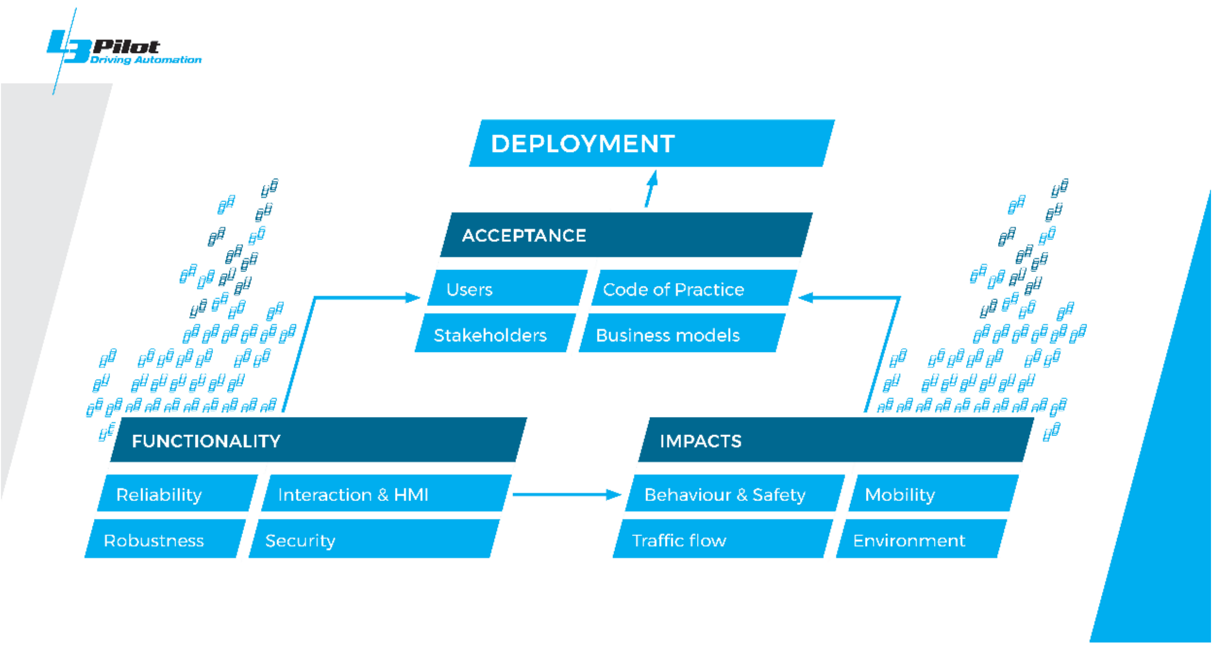

Figure 1.2: L3Pilot approach and mechanism towards deployment.

The L3Pilot consortium brought together stakeholders from the whole value chain, including OEMs, suppliers, academic institutes, research institutes, infrastructure operators, governmental agencies, the insurance industry and user groups. More than 750 users tested 70 vehicles across Europe in 7 Countries, including: Belgium, France, Germany, Italy, Luxembourg, Sweden, and the United Kingdom, as shown in Figure 1.3. The project lasted for 50 months, road tests started in April 2019 and Piloting on variable road conditions took two years.

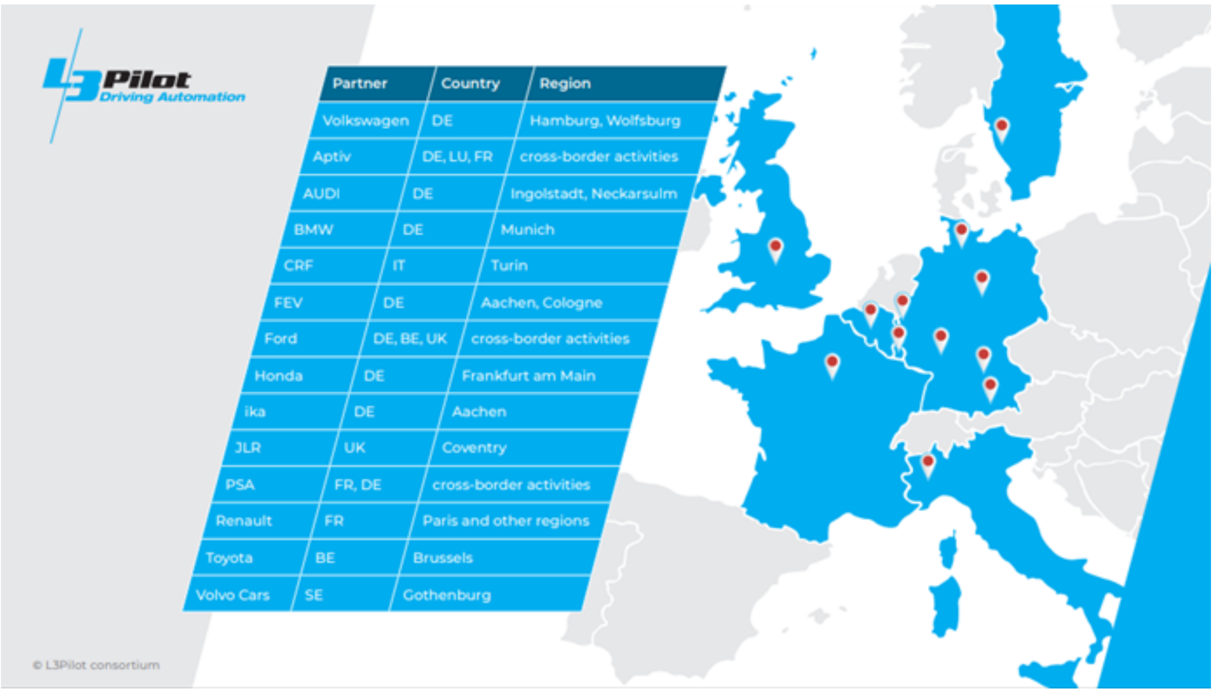

Figure 1.3: L3Pilot Piloting Maps.

1.4 Structure of the document

This deliverable presents L3Pilot Piloting procedures with associated background, enabling factors and challenges faced along the Piloting way. For a reader to be able to assess the work done and the way the data were obtained and managed, it is important to know how the project concept has been transformed into a holistic methodology and research questions that led to road tests across Europe in a harmonised Piloting environment. Also, constraints to Piloting are discussed and solutions described. The work presented is divided into six main chapters.

Chapter 1 *"Introduction"* presents the L3Pilot project concept and scope.

Chapter 2 *"L3Pilot methodology principles"* explains the project's methodology main features making use of previous field tests and the FESTA V-shaped methodology, originally developed for Advanced Driver Assistance Systems (ADAS) testing. Consequently, the methodological framework created the rules for Piloting and data analysis.

Chapter 3 *"Pilots execution"* gives an overall view on the vehicle fleet used for Piloting in the test Sites across Europe, the number and types of subjects that participated in Piloting and the extent of Pilots in numerical figures. Finally, supporting activities to the actual Pilots are also described.

Chapter 4 *"Data management and Consolidated Database"* informs about the subjective data from interviews and objective data from Pilots obtained and distributed by test scenario and describes the creation of the Consolidated Database used for the data analysis. This chapter also deals with the confidentiality requirements of the data from subjects' point of view and from car makers' point of view.

Chapter 5 *"Lessons Learnt"* describes issues and procedures that challenged the project and could not have been anticipated in the planning phase. This chapter paves the way to following field operational and road tests.

Chapter 6 *"Highlights and Conclusions"* pulls together the whole Piloting activities, with its challenges and major achievements.

2 L3Pilot methodology principles

2.1 Piloting landscape

Pilot road tests are needed to understand effects of vehicle automation in real application. Their outcome can have a strong impact on the deployment of vehicle automated functions.

Pilot projects typically involve from moderate to extensive road trials under different conditions, often with professional drivers i.e., drivers with the qualification to drive testing vehicles. Piloting also includes so called naïve subjects, i.e., those not having previous experience of driving vehicles equipped with automated functions.

Road tests of vehicle automation require a careful preparation to meet the goals defined for the activity. In L3Pilot, a methodology has been created to cover all steps needed to draw valid conclusions from the data obtained (see L3Pilot, Deliverable D3.2 “Experimental Procedure”). This included the preparation of Pilots on public roads, streets and parking areas, data management and the analysis of the collected data.

The big picture for automated vehicles Piloting and an enabling methodology is characterised by an interplay between multiple overlapping aspects (Figure 2.1):

- Status quo of current automated driving and resulting availability of testable automated driving functions (ADFs).
- Legal and ethical framework on what is allowed to be tested on European roads, and to observe The General Data Protection Regulation (GDPR) making the legal setting for L3Pilot during the tests and beyond.
- Knowledge needs on the automated driving impacts (safety, technical, user acceptance, environment, traffic efficiency, social, economic, security).
- What data & information can be obtained in the key areas of automation technology development under various constraints, whether they are associated with measurement techniques, ethical issues and confidentiality.

When considering automated vehicle tests on public road networks, there are several agreements that 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 were not developed yet and consequently, no framework has been defined yet. Automated systems have been permitted since the last change of the Vienna Convention in March 2016.

The work on legal aspects is focused on the needs of each Pilot Site to consider the specific national regulations, where the respective tests shall be carried out. This included also cross-border operations. A detailed survey has been conducted on the legislation to be applied (L3Pilot, Deliverable D4.2 “Legal requirements to AD Piloting and cyber security analysis”). All Pilot Site Leaders, following a set of defined guidelines, ensured that they held a permission for experimenting with cars equipped with AD functions. Furthermore, a common approach has been 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 have been taken as ground base 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 Piloting methodology represented the “fil rouge” to guarantee the homogeneity of data acquired in all Piloting test sessions.

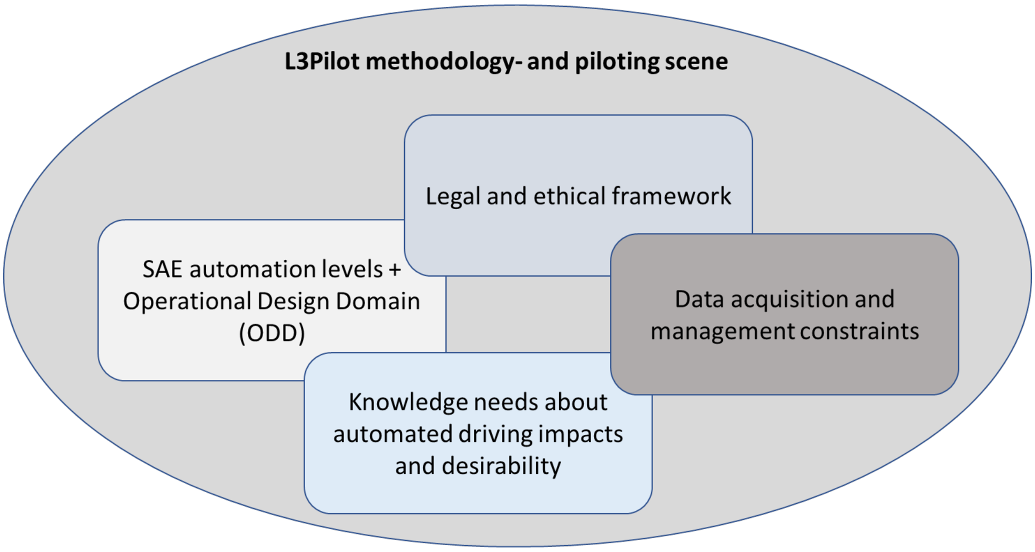

Figure 2.1: Aspects of L3Pilot methodology and Piloting.

2.2 Building on FESTA methodology

The L3Pilot project is specifically dedicated to managing Piloting activities across the European Pilot Sites. The project needs to ensure that the developed methodology and the defined time-plan are adhered to while guaranteeing consistency of data to be analysed. The whole Piloting activity is based on a methodology providing the guidelines to the Pilots. The aims of the Piloting activity include:

- Planning and managing pre-tests all the way up to the Pilot Site ramp-up, providing feedback to improve/tune Piloting procedures if needed, and provide the data samples for the analysis.
- Ensuring that the procedures and tools are properly set up at each Pilot Site.
- Ensuring that data collection is performed at each Pilot Site according to the agreed procedures.
- Monitoring that data delivery is properly handled by data owners and by the project, with regards to agreed data verification rules.

- Coordinating the Pilot preparation activities in terms of users involved and data management.

L3Pilot followed and enhanced the FESTA methodology for setting up, implementing, and conducting road tests, within the four main pillars: (i) Prepare, (ii) Drive, (iii) Evaluate and (iv) Address legal and cyber security aspects.

The goal was to demonstrate and assess the Level 3 and 4 ADFs in real contexts and environments. However, the Pilot nature of the field tests brought practical challenges to conduct road tests. To receive meaningful and valid results on impacts of the ADFs, it was important to carefully consider the principles underlying the approach of collecting the essential data for the evaluation process.

To meet the L3Pilot goals, the project's methodology had to be nimble and capable of providing answers to the essential questions of AD, so involving the following elements:

- Develop a methodology for the Piloting, testing and evaluation of AD systems for achieving reliable results.
- Reconsider the theoretical background and impact mechanisms required for building a multidisciplinary evaluation methodology.
- Consider not only the expected positive impacts on road and user safety and traffic flow, but also the unintended and possibly negative impacts of AD.
- Facilitate a good understanding of all possible effects of AD on the transport system, including the effects on equity of mobility and well-being of people, behavioural adaptation, safety, fuel consumption and emissions.
- Provide input to the L3Pilot Code of Practice for AD testing, and to the Human Machine Interaction (HMI) aspects of vehicle automated functions.

Based on the developed methodology, L3Pilot defined a list of Research Questions (RQs) to be answered to meet the objectives. This is ensured by the development of an appropriate experimental procedure to collect the data required to answer the RQs and the development of a structured and robust evaluation plan to ensure reliable and valid results are achieved from the Pilots. The methodology features a stepwise process observing and modifying the FESTA methodology for L3Pilot needs to produce comprehensive guidance on the evaluation. Consequently, L3Pilot provided a methodology that would ensure that the systems deliver real-world benefits. This matches a key objective of L3Pilot, hence the selection of this approach. The FESTA methodology updates have also been documented as recommendations for the L3Pilot Code of Practice for the evaluation of AD functions.

2.3 From L3Pilot research questions to Piloting data requirements

One of the methodological main goals is to operationalise knowledge needs into precisely defined Research Questions and Hypotheses. Here the focus is on:

- Technical and traffic evaluation.
- User and acceptance evaluation.
- Impact evaluation (safety, mobility, efficiency and environment).
- Socio-Economic evaluation.

RQs have been generated hierarchically, first as high-level RQs, to provide a set of sub-categories for the development of more detailed and specific questions. Hypotheses are then defined for the more detailed RQs to support an extensive investigation of the impact of AD systems. RQs for technical evaluation include aspects such as performance, reliability and readiness of ADFs, and security-related topics. RQs related to traffic and driving behaviour include topics such as car following, speed patterns, in lane positioning, and interactions with the infrastructure and other vehicles, e.g., vehicle behaviour at intersections.

RQs related to user acceptance evaluation include aspects such as trust, interaction with other vehicles and VRUs, switch between the AV and the driver, human behaviour during AD, automation awareness, user acceptance, comfort and convenience.

The process of setting the RQs for impact assessment considered background literature and theory regarding the specific impacts that an ADF may have. Detailed function descriptions and the role of the users were also essential ingredients. RQs for safety impacts cover direct and indirect impacts on road safety. For mobility impacts, the choice of driving mode is included, for efficiency impacts, RQs cover road capacity and traffic flow, and for environmental impacts, RQs cover emissions and energy use.

RQs related to socio-economic evaluation include different aspects of the economic and welfare effects of ADF use in Europe. Fewer car accidents, fewer causalities and health injuries are examples of socio-economic gains that mean saved lives, reduced hospital- and rehabilitation time, and less traffic disruption.

The RQs were specified for different driving contexts (motorway, traffic jam, urban and parking) and experimental conditions (ADF on, off and not available). Baseline drives have been also mandatory to allow a scientifically valid comparison.

More information on the L3Pilot RQs can be found in (L3Pilot, Deliverable D3.1 “From Research Questions to Logging Requirements”).

2.4 Piloting experimental design

The main purpose for selecting the approaches to the study was to adapt the common research methodology to practical requirements and boundary conditions at the different Pilot Sites. It has been important not only to list the approaches and fit them into each Pilot Site, but also to ensure that the overall combination of various approaches in different Pilot Sites could provide the L3Pilot evaluation with a representative example of impacts of various automated driving functions of passenger cars. In order to evaluate comprehensively the impacts, methods for objective and subjective data collection are needed. As the external validity (i.e., transfer of results to the real world) of the results increases, the controllability of the conditions/experiment decreases. Among other factors, this interdependence needs to be considered when designing the procedure of an experiment.

The goal of the experimental design has been to enable verification of the research hypotheses regarding the impacts of AD. Furthermore, the experimental design needs to enable organising the tests and data collection in such a way that all variables are identified and controlled as well as possible. The experimental design also determines the integration of data and results across the Pilots.

The project's experimental procedure was developed to lay basis for a solid evaluation and ensure that the results from tests across all Pilot Sites can lead to an L3Pilot-wide evaluation, also considering the practical limitations related to road tests. Furthermore, evaluation criteria have been harmonized through the provision of detailed requirements for the Pilots in order to achieve a complete evaluation of results for the whole project. More information can be found in (L3Pilot, Deliverable D3.2 "Experimental Procedure").

The Piloting sessions observed the experimental design, namely the behaviour of test drivers/vehicles have been compared in approximately similar conditions with the AD function switched off (baseline) to the situation where the AD function is switched on (treatment).

Four types of variables were needed in Pilots:

- Dependent variables: operationalised as performance indicators (PI) such as distribution of speed, frequency of harsh braking, lateral position, perceived comfort or usefulness. They are calculated with vehicles' direct measures or with subjective users' questionnaires. Vehicle sensors are set up to acquire data related to dependent variables.
- Independent variables: variables that can be varied systematically, and are related to the AD function, e.g., driving with an automated driving function on or off.
- Control variables: variables related to the driving situation e.g., road environment and test-participants' type and age. These variables are varied to some degree or kept constant, depending on the experimental design.
- Confounding variables: variables relevant to describing the circumstances, which cannot be varied systematically but are part of the data for explanatory purposes, e.g. weather, specific traffic situations, etc. The identification of the presence of confounding variables may also be used to judge the quality of the data.

The framework for L3Pilot considers all the different variants of the ADFs tested on all the Pilot Sites. Furthermore, some of the Pilot Sites split their tests into several phases of data collection which differed for instance with respect to:

- Participant type.
- Driving environment.
- Test condition-specific instructions.
- Presence of a safety driver in the vehicle.

The L3Pilot methodology recommended that the presentation order of the different conditions (baseline and treatment) is varied systematically (e.g., half of the test participants starting with the baseline-treatment, the other half with the treatment-baseline). This is the so-called ABBA-design, used to control the order of presentation of ADF to prevent systematic bias to the results. Furthermore, a careful plan the timing and order of different test conditions has also been recommended.

Based on the RQs and of the Pilot Site constraints, the following experimental designs were recommended:

- Parking Chauffeur Pilot: Controlled study in a closed environment, such as a private parking lot. Within-participants design with two conditions: manual parking vs. usage of ADF.
- Urban Chauffeur Pilot: Controlled drives on public roads. Within-participants design, or between-participants design with two conditions: manual driving vs. use of ADF.
- Motorway / Traffic Jam Chauffeur Pilot – Design 1: naturalistic driving / field operational tests approach. Within-participants design, or between-participants design with two conditions: ADF available vs. ADF not available.
- Motorway / Traffic Jam Chauffeur Pilot – Design 2: Controlled drives on public roads. Within-participants design with three conditions: 1) manual driving, 2) ADF driving, 3) driving where the test participant can decide whether to use ADF or not.

The research questions related to the impact on safety, efficiency, environment, mobility and socioeconomic aspects will not be answered directly from the data collected in the Pilots but are based on data processing. Overall, test track studies have been preferred for parking functions, while motorway, traffic jam and urban Pilots have always been conducted in real traffic scenarios.

2.5 Pilot Pre-tests

When preparing extensive road tests, the whole procedure should be checked, including instructions to test drivers, verification of vehicle functionality, data management and analysis of the test data sets. This proved to be a useful method to ensure that the whole Piloting process would work as planned.

Previous road tests have taught how important it is to reserve enough time for this phase. It ensures that possible and likely pitfalls and bottlenecks can be solved before entering actual and extensive road tests. Correcting errors at the subsequent road tests phase throughout the European test community is time-consuming and may affect the project's timetable.

All Pilot Site Leaders carried out their own pre-tests on their own Pilot Sites for the defined scenarios (urban, motorway, traffic jam and parking). The core activities of the pre-test phase comprised a set of tasks that can be summarised as follows:

- A Pilot test vehicles final check that each installed function is technically properly working including the AD functions and the specific installations for data acquisitions.
- The preparation and administration of new and specific training courses for safety drivers, where needed by the Piloting design and required by each Pilot Site procedures.
- The recruitment of driving subjects, including naïve subjects and professional drivers.
- The preparation and issuing of the documentations needed to obtain the permissions to perform the Pilots in the different countries, including specific technical tests, when requested.
- Testing and fine-tuning of the data toolchain to achieve a "go to be ready for launching the mission of Piloting".

A special effort has been put on the L3Pilot data toolchain functionality during the pre-test phase with two main objectives: assess the current maturity of the tools used for the data analysis and verify the data quality level recorded and converted to the Common data Format (CDF). Therefore, all tools have been applied to the data available from the pre-test phase. Intermediate results from each processing step have been analysed regarding their suitability to process the required results. In the following, examples are given showing which areas of improvement could be identified.

A first improvement implemented in the toolchain is the consideration of chunking the scenarios. This approach allows generating more statistically stable results for the Performance Indicators (PI) such as the mean position in lane or the standard deviation of position in lane. For instance, if a car-following situation is ongoing for a long time, the deviation from the mean may be biased since the speed of the ego vehicle may gradually increase. To compensate this difficulty, long situations are split into chunks of e.g., 20 seconds, and, for each chunk, the Performance Indicators are calculated. This procedure is comparable to a low pass filter.

A further necessary improvement, that could not be anticipated, was the fact that a change in the system state may divide a recorded situation into multiple instances. This may be the case, if the driver initiates a lane change, which may result in a very brief switch from the system state "ADF active" to "ADF available". This has been corrected by introducing a new category of scenarios, for which a short transition between system states is allowed.

Overall, working with the data revealed minor issues in the toolchain which have been discussed among all partners involved with Pilot activities. This allowed fixing the bugs in the code computing the derived measures and performance indicators. Changes to the toolchain could be easily validated and adopted by all Pilots.

A central aspect of the toolchain for processing the Piloting data is the detection of driving scenarios. The list of scenarios to be detected includes "Free Driving", "Following a lead vehicle" and "Approaching a static object".

In general, the scenarios to be detected for motorway functions have been successfully parameterized, with expert analysis, only rare scenarios needed further investigation. The detection for scenarios in urban areas started with motorway thresholds, upgrading the thresholds when data from all Pilot Sites have been made available.

All in all, the major challenges encountered during the L3Pilot pre-test phase are:

- Technical bottlenecks in recording data and/or in uploading data to the consolidated database (the cloud system where data from all the Pilot Sites are stored for the evaluation phase).
- Legal constraints to get permissions and to deliver data to Pilot data processing partners.
- Constraints in recruiting Piloting drivers/users.

About technical bottlenecks in recording and/or uploading data

The deployment and usage of the Consolidated Database in the pre-Pilots has been useful and allowed the consortium to learn important lessons for current and future activities. It has been essential to get acquainted with the overall data management process which is complex, involves different actors, and needs verification and tuning.

About Legal Constraints to get permissions and to deliver data to Pilot data processing partners

Bilateral Non-Disclosure-Agreements had to be prepared and signed to enable Pilot Site Leaders to deliver data to Pilot data processing partners.

This activity revealed to be time consuming, consequently a good practice is to start this activity at the earliest stage when planning the Pilots. This applies also to the request of permissions to conduct Pilots in the different countries.

About constraints in recruiting Piloting drivers/users

Constraints in recruiting Piloting drivers/users were connected to company policies of Pilot Site Leader's and rules for driving a prototype vehicle. In addition, the specific country rules for permission to conduct Pilots on public roads should be taken into account. Up to a certain extent, these rules allowed recruiting professional drivers only, in total 164 professional drivers had to be involved, out of a total of 750 users.

3 Pilots Execution

3.1 L3Pilot Piloting storyboard in a nutshell

This section provides an overall description of the execution of the Pilots in terms of three main factors: number of vehicles, number of subjects and number of driven kilometres.

Moreover, the information provided in this section summarizes the collaboration of all the Pilot Sites. Collaboration through periodical meetings and other collaboration/communication tools has been extremely useful for sharing experience, reporting about the progress, and supporting the project's advancement. After two years of massive efforts, by the end of February 2021, the partners of the L3Pilot project concluded the Piloting of Automated Driving Functions on public roads across Europe. At the same time, some of the Pilots, on a voluntary basis, continued to collect data for upcoming R&I activities beyond February 2021.

Altogether, fourteen partners – among them, car makers, automotive suppliers and research institutes - conducted the Pilots on motorways, urban roads and in parking scenarios. The Pilots, started in spring 2019, involved seven countries: Belgium, Germany, France, Italy, Luxemburg, Sweden and the United Kingdom and included two cross-border activities (Germany – Luxemburg and Germany – Belgium – United Kingdom). The Pilot Sites have been led by: Volkswagen, Aptive, Audi, BMW, CRF, FEV, FORD, HONDA, IKA/FKA, JaguarLandRover, Toyota Motor Europe, Group PSA, Renault, Volvo Cars, overall the L3Pilot Piloting activities have been led by CRF (Luisa Andreone).

750 people participated as test subjects in totally 70 cars, driving more than 400,000 kilometres on motorways (including 200,000 km in automated mode and 200,000 km in a manual mode, as a baseline for comparison of the user experience and evaluation of the impacts) and more than 24,000 km in automated mode in urban scenarios (including 1,800 km driven in the manual mode, as the baseline). The test subjects experienced Automated Driving of SAE L3 either as a driver or on the passenger seat.

All vehicles have been specifically designed for the tests: in particular, they were equipped with sensors detecting the road environment (including camera, radars, lidars) and control systems enabling the lateral and longitudinal control of the vehicle in all different scenarios. During the driving sessions, the data on the system performance and driving experience were collected. Data are currently being processed to evaluate 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 is used to evaluate the interaction between the driver and the vehicle. Data have also been collected to evaluate how the vehicles behave in traffic: for example, the interaction with other vehicles, cyclists and pedestrians, approaching traffic lights or a motorway junction and the use of vehicle-to-x communication.

In addition to data recording, before and after the test drives, the subjects' opinions, attitudes and experiences were recorded by means of questionnaires. This information will provide insights into users experience on driving vehicles with ADFs.

The anonymized and aggregated data collected in the Pilots were shared among the partners for the evaluation process. By a coordinated approach the project succeeded in developing a Common Data Format (CDF) for the data collection, and also implemented a Consolidated Database for storing the processed data. The proposed CDF enabled a uniform procedure for sharing all the Pilot data and user questionnaires and promotes the development of tools for AD functions testing, verification and validation. Based on the L3Pilot-CDF, it was possible to compare the required performance indicators across all the Pilot Sites in the various driving scenarios. Therefore, the format is considered a useful specification item for follow-up projects and is expected to contribute to the harmonization of future AD tests in Europe. [1]

The entire anonymized process for the data collection, conversion and evaluation was subject to the strictest European and national guidelines for data protection.

The following evaluation phase will exploit the complete data sets from the Piloting phase. By a comprehensive analysis, L3Pilot will provide technical parameters characterising the vehicle's behaviour within different traffic scenarios, evaluate the user acceptance, traffic safety and conduct a cost-benefit evaluation. Finally, the overall impact of vehicle automation technology on the environment and mobility will be assessed.

The investigation will be complemented by Wizard of Oz studies, drone datasets and simulator experiments. In addition, a series of large-scale surveys with 36,000 respondents will allow to investigate attitudes towards vehicle automation and the effects on mobility.

The evaluation results will be publicly available as part of the L3Pilot evaluation reports by the end of the project, in the fall 2021.

The L3Pilot Pilot Sites activities also included the promotion of the project work to maximize the impact. This includes dissemination of the project results and communication to the public, through scientific and technical papers and showcases, targeting as an ultimate goal to accelerate the deployment of automated vehicles.

3.2 Piloted AD functions

L3Pilot focused on SAE L3 AD functions in motorways and urban scenarios, while SAE L4 targeted exclusively to parking and close distance scenarios. The SAE L3 features Conditional Automation, which requires that the human driver will respond appropriately to a request to take-over the driving task for a fall-back manoeuvre. In case the driver is not

[1] Data analysts interested to use L3Pilot-CDF may visit the published code under https://github.com/l3pilot/l3pilot-cdf.

responding properly to a take-over request, the vehicle automated function performs a minimum risk manoeuvre to safely stop the vehicle. (Figure 3.1).

Figure 3.1: Graphical representation of the SAE L3 automation level.

The ADFs piloted in the project are still in a prototypal phase, however, they reflect the state-of-the-art the industrial partners, and have been designed to take into account the characteristics of the different vehicles, specifically upgraded for the project.

Particularly, the L3Pilot functions tested in the different Pilot Sites were the following:

Traffic Jam Chauffeur

The Traffic Jam Chauffeur 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 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 the lane to react to a slower vehicle ahead or to the road infrastructure, like in case of exit lanes.

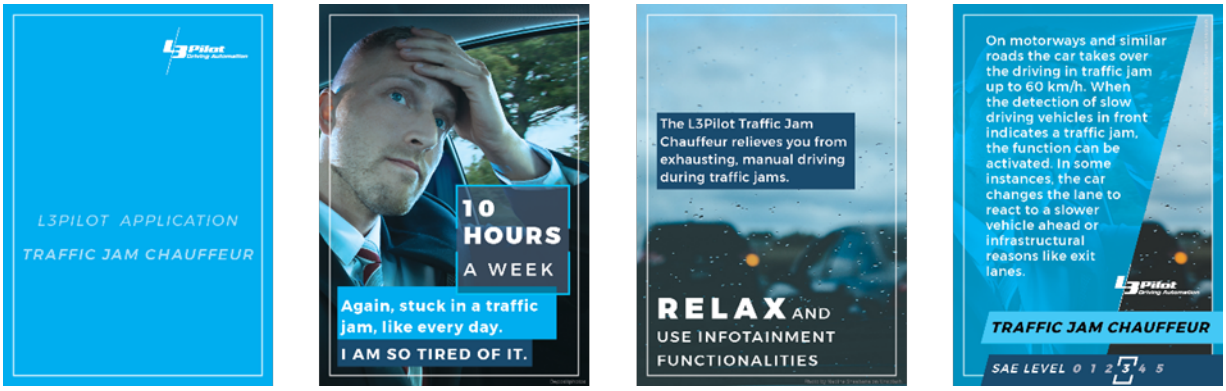

Figure 3.2: SAE L3 Traffic Jam Chauffeur.

Motorway Chauffeur

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

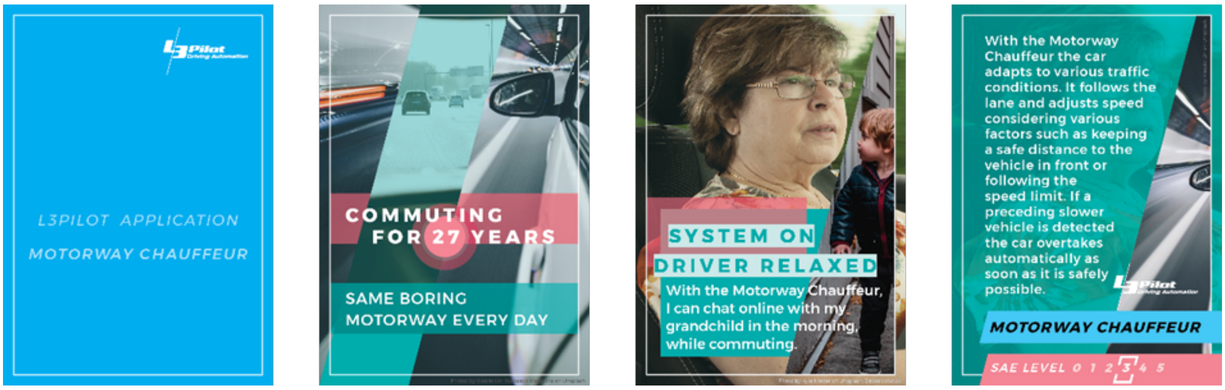

Figure 3.3: SAE L3 Motorway Chauffeur.

Parking Chauffeur

The 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 Operational Design Domains, the Parking Chauffeur has also been tested at SAE L3 or L4, namely without the need for handing over to the human driver the vehicle control in case a fall-back manoeuvre is required.

Figure 3.4: SAE L3-4 Parking Chauffeur.

Urban Chauffeur

The Urban Chauffeur targets stress-free driving in urban areas. With the Urban Chauffeur the vehicle automatically follows the lane, starts and stops and handles overtaking within cities. When coming to 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 marking is present.

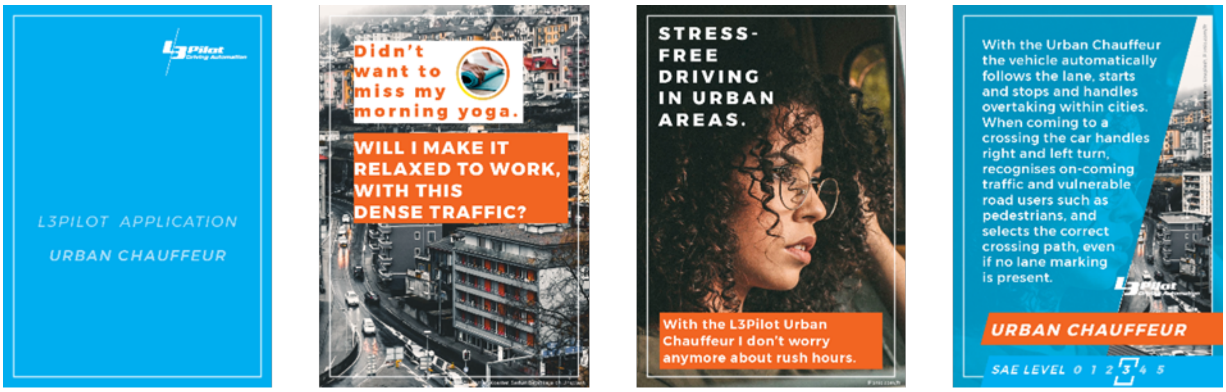

Figure 3.5: SAE L3 Urban Chauffeur.

3.3 Vehicles

The project equipped a total of 70 vehicles, of which 56 for the motorway environment, 8 for parking and 6 for urban situations. Figure 3.6 shows the distribution of the vehicles across the driving contexts, considering that traffic jam chauffeur Piloting sessions have been conducted in motorways scenarios.

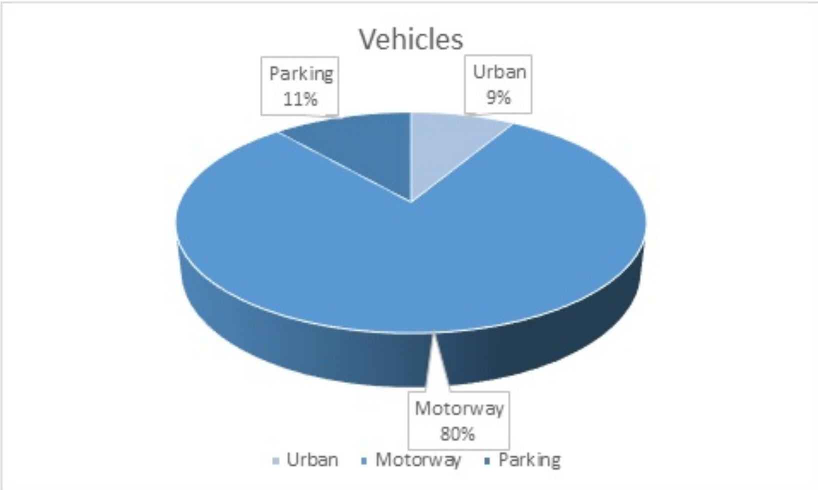

Figure 3.6: Distribution of the vehicles across the driving contexts.

Figure 3.7: Distribution of the vehicles across the driving contexts.

3.4 Subjects

The L3Pilot D6.1 deliverable "Pilot Execution Plan" specified the requirements for the test subject recruitment in the frame of the general methodology of the project. They mainly concern two points: selection criteria in order to have a balanced representation of the target users, and a sample size which has been defined for each one of the contexts (i.e., motorway, traffic jam, urban and parking).

L3Pilot identified two main categories of drivers: ordinary and professional. Ordinary drivers are characterized by low familiarity with the system. On the other hand, L3Pilot envisaged professional drivers, who have a more significant familiarity with the system and high driving experience. During the road tests, a professional driver can also act in the same way as a driving instructor either with double controls on the passenger sit or with other means to actively intervene. This '*safety driver'* serves as a supervisor or a backup in case of emergency. Such a setup was mandatory in some cases considering that the Pilots included prototype systems operating in normal traffic environments.

L3Pilot involved a total of 750 subjects, of which 587 drivers and 163 passengers. Table 3.1 provides a breakdown of the number of drivers across the different driving contexts. Figure 3.8 shows that almost three fourth of the drivers are ordinary. More specifically, a majority of the drivers were ordinary in the motorway and parking environments, while the urban environment involved only professional/safety drivers.

Table 3.1: Breakdown of the test subjects per driving context.

Scenario	Professional & safety drivers	Ordinary drivers	Users on a passenger seat
Urban	17	0	160
Motorway	143	338	0
Parking	4	85	3

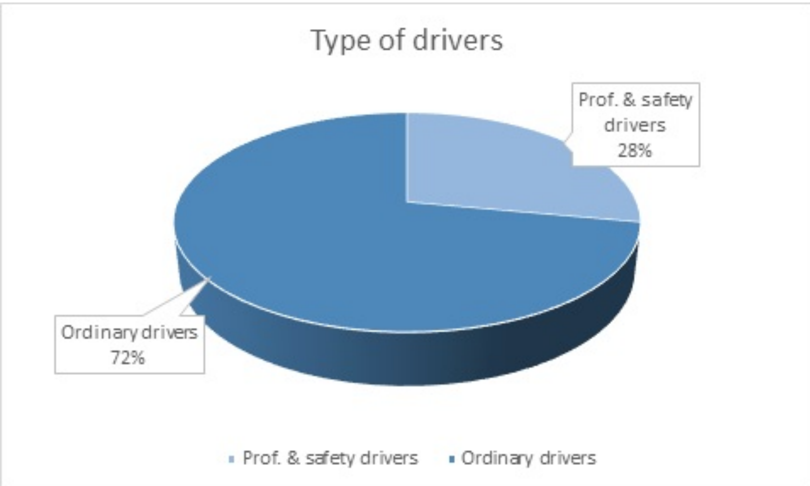

Figure 3.8: Distribution of the type of drivers across the driving contexts.

Figure 3.9 and Figure 3.10 show the distribution of the drivers and passengers, respectively, across the different driving contexts. In particular, Figure 3.9 shows that urban trips involved users sitting at passenger seat in order to allow a safe assessment of this more complex environment as well. Using subjects as passengers was not necessary in motorway conditions.

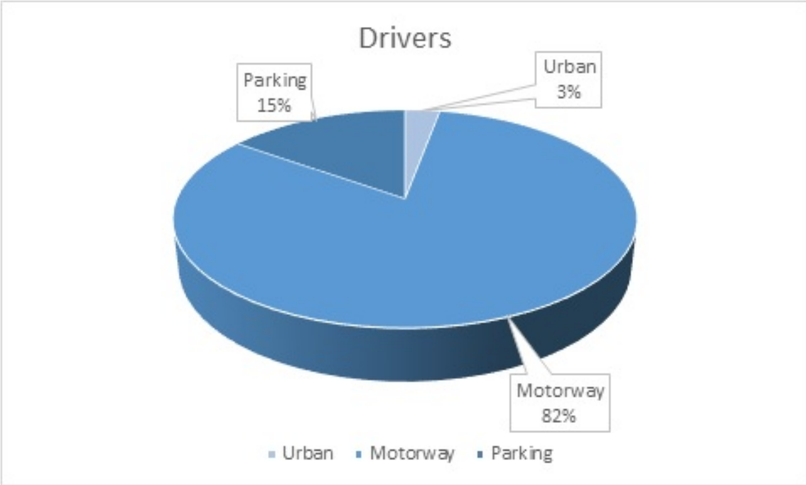

Figure 3.9: Distribution of the number of drivers across the driving scenarios.

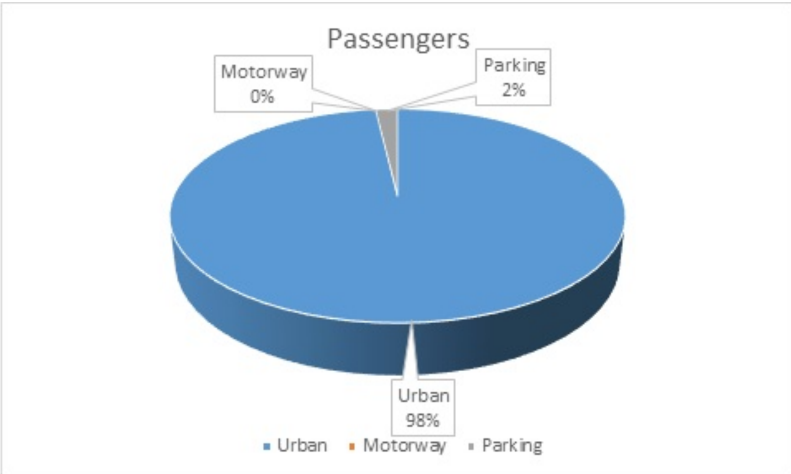

Figure 3.10: Distribution of the number of passengers across the driving contexts.

3.5 Driven kilometres and hours

As already mentioned, L3Pilot collected data from a total of around 400.000 kilometres driven in the motorway environment, of which a half in the automation mode, and another half in the baseline mode.

In the urban environment, the L3Pilot vehicles travelled a total of around 1.120 hours, of which the vast majority (990 h) in the automation mode. The Pilot experimental design defined that a smaller percentage of driving in the manual mode for the baseline has been needed for the urban scenarios with respect to the motorway scenarios (Figure 3.11).

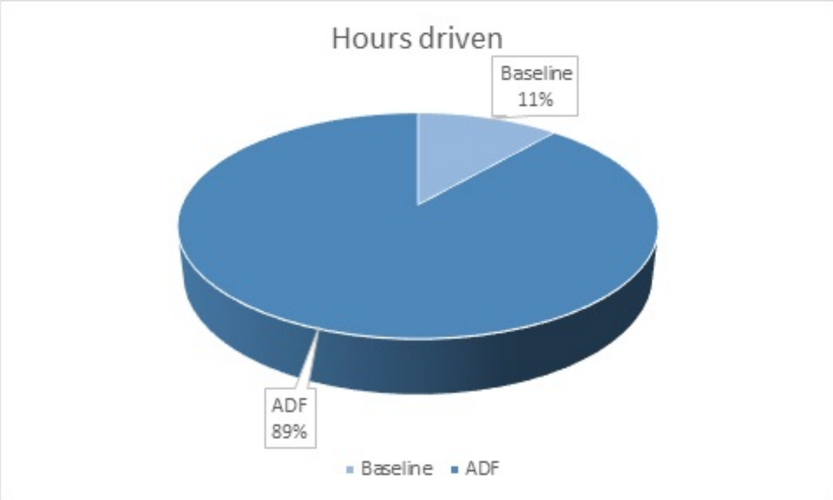

Figure 3.11: Distribution of the number of driven hours in urban environment by experimental condition.

3.6 Pilot Outcomes

As described throughout this document, the key outcomes obtained in the Piloting phase are:

- The collection of objective and subjective data.
- The creation of the digital environment able to manage the resulting huge data set.
- The translation of Pilots raw data in a common data format, and
- The data upload into the consolidated database for a delivery to the evaluation experts.

Clearly, the ultimate goal was the in-depth data analysis planned for the subsequent phases of the project.

However, already from the Piloting execution it was possible to derive a number of considerations on challenges and research needs that are reported hereafter. The challenges can be mapped within the building blocks specified in the White Paper: “Safety First for Automated Driving” (ed. Sep. 2019). According to this document, two major challenges require a special consideration: they concern the “perception” and “prediction” building blocks of vehicle automation and are related to *the perception in severe weather conditions* and *the prediction of the intentions of pedestrians*. There are a number of technologies that can help in this context, and in particular: perception sensors able to afford the variety of weather conditions, dynamic high resolution digital maps, precise localization techniques, use of communication providing redundancy and extending the situation awareness, and advanced machine learning techniques. In the following, for each ADF type tested in L3Pilot, the main challenges are highlighted.

The Parking Chauffeur function includes automated parking in a parking slot and manoeuvres at a low speed in parking areas. The basic principles included: trajectory learning and simultaneous localization and mapping (SLAM) for localization, particularly needed when positioning satellites are not visible, for example in a garage silo. This function is the most mature among the L3Pilot functions, and from perception and prediction no major challenges were encountered, except for the need to further develop the SLAM techniques in complex close-distance scenarios, possibly by means of advanced machine learning techniques.

The Traffic Jam Chauffeur is designed to operate at a speed up to 60 km/h and the function can automatically manage lane changes when feasible. Here the major challenge is lane changing in very dense traffic, as the calculation in real time of a collision-free and lawful manoeuvre is quite demanding, as well as for a human driver.

The Motorway Chauffeur provides longitudinal and lateral control of the vehicle inside the lane, including the capability to automatically undertake a lane change manoeuvre. The function is made available by a voluntary activation by the driver, provided that the automated function is inside its operational design domain. The function operates at a speed up to 130 km/h, and the driver can take over the control anytime. The challenges here are mostly related to severe weather conditions, like heavy rain or snow, which can significantly limit sensors' detection and performance. Therefore, these conditions are not yet included in the operational design domains. Other driving situations like toll gates, construction zones, accident areas, and exchange routes are also not yet included in the operational design domains.

The Urban Chauffeur performs lane following and lane keeping up to 50 km/h, and handles stop and go manoeuvres, intersections, recognition of pedestrians, and overtaking when feasible. Intuitively, this is the most challenging scenario, not only for the variety and unpredictability of the dynamic traffic situations, but also for the number of obstructions (e.g., buildings) that do not let the vehicle sensors see a specific traffic situation. A particularly critical issue for the Urban Chauffeur regards predicting the trajectory of pedestrians or other road users. It can be remarked that this challenge is not necessarily related to the detection and classification aspects but involves especially the understanding of human behaviour and intentions. One example is: what if a pedestrian is standing at a side of the zebra stripes, but for any reason he/she has no intention to cross the road?

A human driver is likely able to intuitively understand pedestrian's intention, but how can an automated system sort out this situation? Can the new generation of machine learning techniques handle this challenge? This is an open question that deserves more research.

The following considerations on further research needs are relevant for all the traffic scenarios investigated in the project. One evidence, resulting from the Piloting activities, is the need to understand the extent to which connected vehicles can improve the ability to capture the environmental situation. Communication with other vehicles, road infrastructure, or traffic control centres, could extend the operational design domains of the automated functions, particularly in situations where sensors alone cannot see through obstacles or behind curves. Data exchange based on connectivity could improve the sensing capabilities in two directions: redundancy within the sensors range and extended understanding beyond the sensors range. A specific topic to be investigated in this area is the role of traffic control centres, which could send to an automated vehicle anticipatory data related to dynamic changes in the traffic and environmental conditions, directly affecting the operational design domain.

Machine learning is expected to play an essential role in the future of vehicle automation. Piloting activities may allow to acquire a large dataset of traffic scenarios derived from dynamic vehicle sensors, as well as Camera, Radar, and LiDAR. These data can represent a significant basis to train machine learning models applied to vehicle automation.

Furthermore, in a sensor system development there is under way a new, promising a high-resolution adaptive multi-sensor suite building on a novel Artificial Intelligence perception-processing scheme for low visibility conditions. The result will be a robust, fault-tolerant perception system functional in practically all lighting conditions. The system will make use a combination of novel sensors of a gated SWIR-camera (Short-wave Infrared Camera), 4D MIMO Radar prototype with a dense point cloud for an effective data fusion, a short-wave infrared (SWIR) LiDAR and a further developed High-Definition dynamic map to support environment perception. The development of this system still takes some years before a market introduction, but in time it will solve several of today’s environment perception issues limiting the operational design domain of automated vehicles.

4 Data management and Consolidated Database

4.1 Confidentiality

The Consolidated database (CDB) aims at sharing the data from all the Pilot Sites to answer the project's research questions concerning the expected impacts of the novel L3 automated driving functions (ADF). Particularly, L3Pilot targeted to four impact areas: technical performance of the tested L3 ADFs, user acceptance and behaviour, impact on traffic and mobility and societal impacts. The research questions aimed at an analysis of the vehicle/driver performance in different experimental conditions (ADF, 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 is simple, the actual sharing automotive data from advanced automated driving functions is a complex task, given the heterogeneity of the proprietary vehicular environments and the obvious confidentiality-related issues. Thus, a collaboration has been set up since the beginning of the project among the evaluation team expressing the data needs, the Pilot Site Leaders (who provide and share the data) and those responsible for developing the processing tools.

L3Pilot investigates the overall impact of new AD systems on the road, not of a single manufacturer. Thus, it is important to extract meaningful general information, while preserving confidentiality of vehicular raw data. The manufacturers or their tested systems should not be identified, ranked or compared through any information shared within the project.

Three main constraints have been thus applied to data uploaded to the CDB:

- Within each scenario, it should not be possible to identify which Pilot Site the data came from. For example, attention has been paid not to insert metadata, such as temperature and date, which might give a hint to identify the location of the Pilot Site.
- No personal data about the driver, passengers nor other test participants have been uploaded.
- No possibility to characterize in detail the behaviour of a specific vehicle function. This has been achieved by the fact that vehicular sensor data are not uploaded to the CDB as time series but as summarised performance indicators,

With an ID of the trip and of the user, data owners should be enabled to track their data in the CDB (also to update the data if needed), a SHA-256 hashing-based pseudonymization technique has been implemented (Hiller & al., 2020). Knowing the encrypted IDs, the data owners could track their data in the CDB, while such IDs are not decipherable by the other users.

4.2 Performance Indicators

L3Pilot did not share in the CDB the original vehicular signal time series both for confidentiality reasons and for the enormous amount of data that would have been shared. As a factual basis for quantitatively answering the project research question, we thus defined a set of four types of performance indicators (PIs). PIs are constituted by statistical aggregations (e.g., average/min/max) in significant intervals of a trip.

Two PI types (Trip_PI and ScenarioSpecific_PI) were computed at whole trip level, while the other two (ScenarioInstance_PI and Datapoints) are much more specific, as they are computed for each instance of driving scenarios detected during a trip. An overview of the types of PIs are provided in Table 4.1.

Table 4.1: Outlook of the L3Pilot CDB Performance Indicators.

Coverage	Performance Indicator (PI)	Description
Trip level PI	Trip_PI	General synthesis of a whole trip.
	ScenarioSpecific_PI	Synthesis of a whole trip, but considering segments from a single type of scenario.
Scenario instance level PI	ScenarioInstance_PI	General synthesis in a driving scenario instance.
	Datapoint	Scenario-specific synthesis in a driving scenario instance.

The analysis of all the research questions thus defined a set of vehicular signals to be provided by all the Pilot Leaders as the basis for the PIs. Such signals have been translated in the common data format (CDF) (Hiller et al., 2019) to allow a homogeneous processing of all the data across all the Pilot Leaders and Pilot Sites (Hiller et al., 2020).

The CDB PI computation step consists in synthesizing the vehicular time series into the needed PIs to be stored in the CDB. This stage is undertaken by the CDB Aggregator module which processes HDF5 files (one per each trip), containing the original time series formatted in the CDF. The output of the CDB Aggregator module is represented by a set of .json files storing the computed PIs. The .json files are ready to be uploaded to the CDB. The same information contained in the .json files is also saved in corresponding .csv files, which are more easily readable by the analysts.

The CDB Aggregator module consists of a set of Matlab scripts. The processing loop is the core of the programme, as it processes the time series and segments the computation of the PIs based on experimental condition, road type and driving scenarios. An example of the resulting segmentation is reported in Figure 4.1, where we can see eight different scenario instances. The slice indicated as Unrecognized 1 (U1), will not produce Scenario Instance PIs, nor Datapoints, nor Scenario Specific Trip PI, as a scenario could not be detected there. However, the signal values contained in that segment will contribute to the Trip PI indicators in the “ADF on” condition.

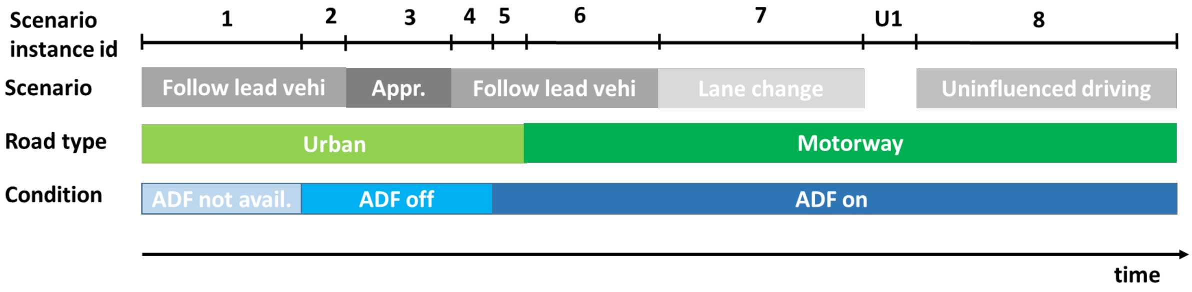

Figure 4.1: Example of a scenario segmentation during a trip.

4.3 Subjective data

While the focus of the first implementation has been on vehicular sensor related data, a complete assessment of vehicle automation functions also requires processing subjective data concerning the user opinions and acceptance evaluation areas. Thus, the CDB also includes subjective data, obtained through questionnaires that have been distributed to all the test subjects before and after each drive with the ADF. The designed questionnaire included questions to assess various aspects of participants' initial reactions to using automated functions. Participants have been re-asked questions about vehicle use, driving history, in-vehicle system usage, and engagement with non-driving tasks, trip choices and mobility patterns.

Following the completion of all questionnaires, each Pilot Site exported the test participants' response results to the SPSS file format, to ensure a common data format in the CDB.

4.4 Uploader

The previous two steps prepare the files with the vehicular or subjective PIs to be uploaded to the CDB. For this step, we decided to develop an ad-hoc tool, namely the Uploader, to enhance usability, according to the specifications. This solution for uploading has been preferred to a browser-based one, as it allows full access to the local file system. Another functionality implemented by the Uploader concerns the support of post editing the csv files output by the CDB-aggregator. Post editing of PIs can be made by analysts on .csv files as well. The Uploader is a NodeJS Command Line Interface (CLI).

4.5 Measurement Application Programme Interface (API) Back-End

For the data storage, we used Measurify (formerly, Atmosphere), an open-source Representational state transfer (RESTful) application programming interface (API) dedicated to measurement management (Berta et al., 2020). Measurify is implemented in NodeJS and built atop MongoDB, a state-of-the-art non-relational database.

Measurify is a generic measurement API, which can be configured for different applications in different installations. The system performs data integrity check at each measurement upload. Different user roles have been defined in order to tailor the data accessibility to the actual needs of each type of user (e.g., supplier, impact analyst, technical analyst, subjective analyst).

4.6 Graphical User Interface (GUI)

A web-based Graphical User Interface (GUI) application has been created to facilitate an access to the data available in the CDB. Although data can be downloaded using the Uploader described in the previous subsection, the user interface provides a mean to query data from a web browser as shown in Figure 4.2.

The Query functionality is split into Vehicular and Subjective data, each with its respective page. The first is based on five query parameters: Query type (also known as a Performance indicator), Experimental condition, Road type, Driver type and Scenario type. The available options for each query parameter are dynamically loaded from the CDB API and filtered according to constraints indicating possible combinations of the query parameters. All parameters except for the first have a null choice, which ignores filtering records by that parameter.

A download page allows users to download all data available to the current user typology in the database, by compressing results for all queries into a single .zip file.

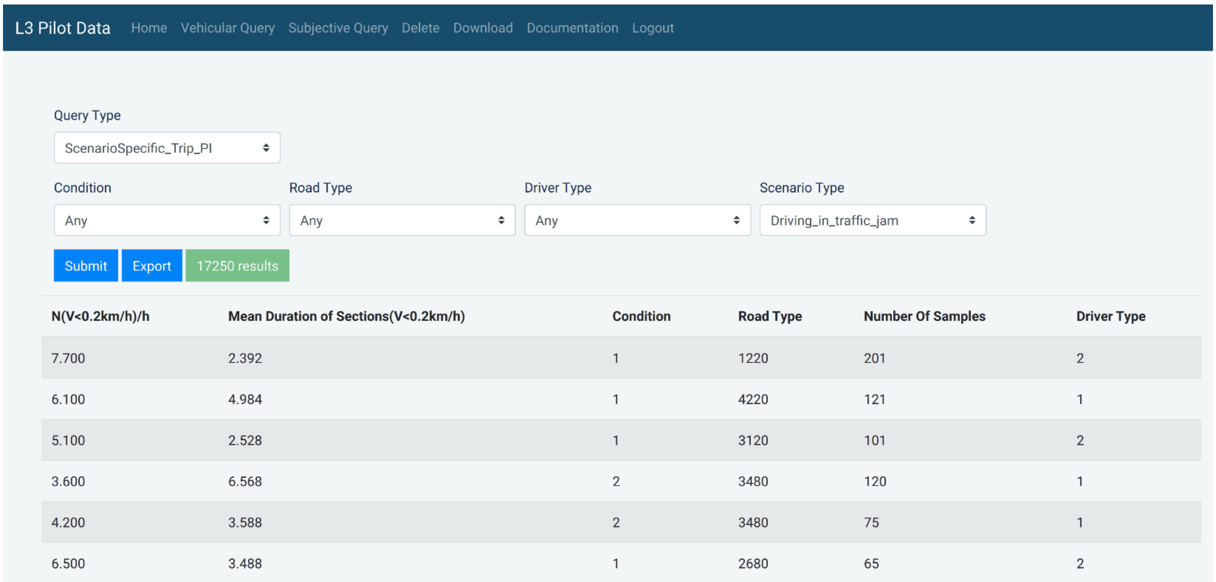

Figure 4.2: Example of vehicular query with (dummy) results displayed in a table.

4.7 Consolidated Database Deployment

After the laboratory tests, the CDB was deployed in the cloud together with the web user interface. In parallel, the Uploader has been distributed to all Pilot Sites.

In order to make tests on the data and get familiarity with the process, the Pilot leaders and the corresponding data processing partners asked for the possibility of having own instances of the CDB, beside the common cloud database which has been reserved for official data, shared with the Evaluation partners. Thus, the Local CDB concept has been defined.

Given the complexity of the overall system, some partners asked for simplifying the set-up process. This led to the development of a single Docker containing the Measurify API, with automatic configuration based on Postman scripts, the MongoDB and the GUI accessible through the local host.

These different architectural options allowed every partner involved in the Pilot Sites to get familiarity with the process according to their different roles. Various patterns of use could be observed. Pilot Leaders uploaded and checked their data and Evaluation partners accessed and analysed data from all the Pilot Sites but only concerning features for specific research questions.

The cloud-CDB is hosted on a cloud operator. A variety of hardware (CPU, memory, storage) and software (operating system) solutions could be considered based on the project's requirements. This solution allows achieving a state-of-the-art level in terms of infrastructure performance, scalability and security.

4.8 Data Delivery to Evaluation

Data delivery of the Piloting results from the Pilot Leaders to the Pilot data processing partners were done in a close collaboration between the involved partners. All data processing partners are also contributing to the overall evaluation by using the aggregated results shared via the consolidated database. By this, they have an insight in how the vehicle data look like in detail from their collaboration with different Pilot Leaders which allows for a good understanding of how the pseudonymised performance indicators are derived.

Data delivered to Pilot data evaluation partners consists of data stored in the Common Data Format (Hiller et al. 2019) and questionnaire data. For an in-depth analysis and validation of the driving scenario detection in the data processing toolchain, the video data have been shared as well. Depending on the implementation of GDPR and the use of the video data for the evaluation, this has been either shared together with the CDF data directly or could be accessed by Pilot data processing partners on a given premises of the Pilot Leaders or remote access. The questionnaire data have been shared in a digital format utilizing the online questionnaire tool LimeSurvey. A high-level data workflow is pictured in Figure 4.3 which integrates the tools introduced above.

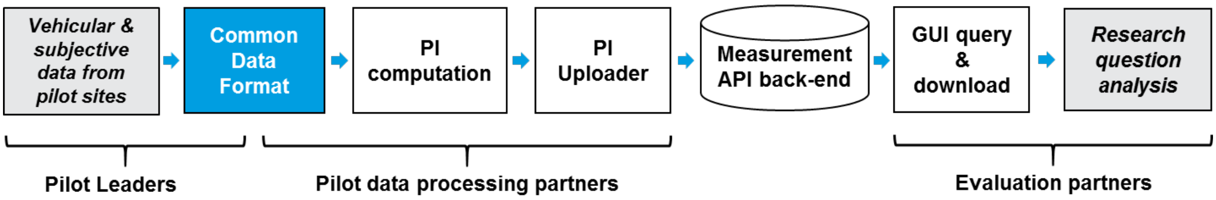

Figure 4.3: CDB data workflow. (PI = performance indicators, API = application programming interface, GUI = graphic user interface).

Overall, the Pilot data processing partners provided with 2267 hours of data from the Pilot Sites operating the motorway ADF. The Urban ADF Pilot Sites provided with 638 hours of data for the analysis excluding some data collected in test environments not considered for the evaluation. Of this data delivered, a fraction of the data had to be disregarded for the analysis as being out of the operational design domains of the piloted ADF or not allowing a proper scenario detection by the data analysis toolchain. Of this data for motorway Pilot Sites, 1808 hours were processed to instances of driving scenarios and uploaded to the CDB. For parking ADF, data on 686 parking manoeuvres were delivered for analysis by Evaluation partners.

In order to ensure the data quality for the evaluation, quality checks of the data have been made at various stages. As the data have been delivered in the form of the Common Data Format, an identical data processing framework has been applied with only minor adaptations for the data handling and pre-processing for different Pilot Leaders. The processing framework was hosted within a shared code repository. The initial version of the data processing framework was implemented by L3Pilot data management experts and handed over to the Evaluation partners. Necessary adaptations of the processing toolchain were discussed and inserted into the toolchain.

The first step of data quality assurance took place at the data exchange between the Pilot Leaders and the Pilot data processing partners. For batches of data delivered to the Pilot data processing partner the data processing toolchain has been applied to verify that data can be processed accordingly. An important step to validate is the correct detection of driving scenarios using video validation. When data could be successfully processed by the evaluation toolchain at the different data evaluation partners, batches of processed data were uploaded to the consolidated database.

The contents of the consolidated database were then analysed by the Evaluation partners. Inconsistencies and unexpected values were identified, and the necessary changes to the data processing toolchain were applied. Depending on the impact of the changes applied to the toolchain, the entire dataset in the database could be then reprocessed and re-uploaded.

After all processed data have been delivered to the Pilot data processing partners and the data were processed with the final version of the data processing toolchain, the final dataset was uploaded to the consolidated database. As a final step the Evaluation partners discussed any filter criteria that are to be applied before the actual evaluation. These filter criteria may concern too short instances of driving scenarios which cannot be considered stable states for evaluation, as well as unexpected values which may result from edge cases that cannot entirely be eliminated while processing the data. This final dataset will be then used for the data evaluation that will be reported in fall 2021, in D7.3 – Pilot Evaluation Results, and in D7.4 – Impact Evaluation Results. Further details on the data management and processing and related lessons learnt in the process, will be reported in D5.2 – Guidelines and lessons learnt.

4.9 Driving scenarios

The evaluation of the Pilot data for deriving the impacts on automated driving requires segmenting the collected time series data into different driving scenarios. For these scenarios, the appropriate performance indicators can be analysed in order to answer the research questions defined by the L3Pilot methodology and the evaluation experts. For motorway data, eight types of driving scenarios were derived from the data. The distribution of instances for these scenarios is reported in Figure 4.4.

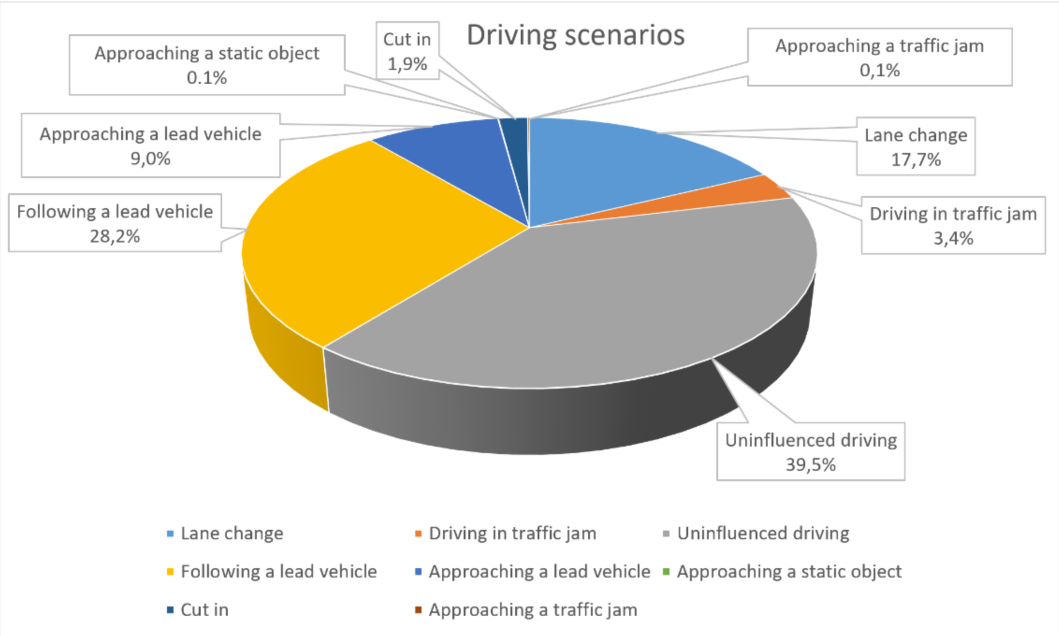

Figure 4.4: Distribution of the measurements across the different driving scenarios.

4.10 Subjective measurements

L3Pilot collected a total of 647 subjective measurements from all subjects who experienced a drive using one of the piloted ADF. Each measurement corresponds to a trip by a driver or a passenger, and includes detailed information from the pre-experience and post-experience questionnaire. Of the 647 subjective Consolidated Database entries, the majority (365) concern the motorway environment. The percentage distribution is reported in Figure 4.5.

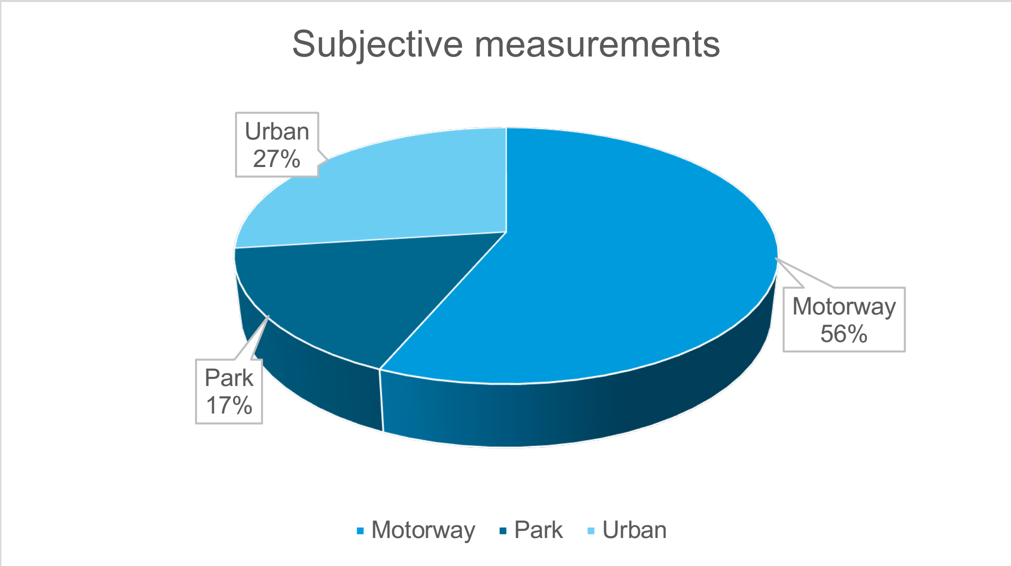

Figure 4.5: Distribution of the subjective data across the driving contexts.

5 Lessons Learnt

5.1 On the management and execution of the Pilots

In general, a key factor in the L3Pilot Piloting phase has been the establishment of a community of researchers and developers. This team has been vital to allow a full understanding and a proper handling of all the issues that emerged during the actual operations in all the Sites. The L3Pilot Piloting phase leveraged on the defined methodology, on the data tool chain, on the vehicles prepared for testing and on a structured pre-test phase. However, it is necessary to stress the complexity of the process and system allowing to share data among different providers and to answer various research questions. Thus, time and effort need to be carefully planned to assure a smooth overall process. Iterations and flexibility/availability are needed since specifications need to be refined during the project.

Instructions were provided on the Confluence collaboration tool and, for more technical detail, on Gitlab together with the source code: this approach was useful in facilitating the Piloting phases. Feedback from the users is important to improve communication and worked as an iterative process. The related lesson learnt is that the collaborative activities of a project of high complexity like L3Pilot would be hard without a workspace with the features offered by a powerful tool.

The following main recommendations have been given for the Pilots and for further work in the area:

- L3Pilot learnt, that any problem is not resolved, any new plan is not concrete until all details on possibilities and on consequences of the planned solutions have been discussed with the involvement of all experts.
- Planning testing and Pilots requires not only a powerful collaborative tool, but also a powerful and trustful methodology and data toolchain; without these ingredients the Piloting phase would have never be started.
- Drivers are newcomers to vehicle automation: this is the case also for company professional drivers, and the possibility to plan commonly agreed professional driver safety courses for testing and Piloting vehicle automation is recommended.
- The legal framework of permission to perform the test in the different countries shall possibly be harmonized.

Additionally, it should be mentioned that the biggest challenge L3Pilot had to face in its Piloting phase, was the pandemic situation. The L3Pilot Piloting phase faced the unprecedented situation of a pandemic that practically blocked the whole world. In the spring 2020 Pilot Sites Leaders had to cope with the new situation and had to understand and plan how to conduct a Pilot trial during a pandemic. L3Pilot partners wanted to continue testing despite COVID-19 crisis.

The vehicles were fully equipped, ready to go and Piloting was ongoing. But then, in the second quarter of 2020 the execution of Pilot studies was critically threatened.

How could driving a car be realised while keeping all occupants safe? How could safety and health of all the participants be protected? Protecting safety and health of the participants in the L3Pilot tests has been the top priority during the pandemic. Therefore, partners took all measures to meet the needs for protecting the people performing the tests: vehicles needed modifications to be COVID-19-compliant. For some Pilot Sites to collect meaningful in-cabin video data, the facial expressions of the subjects needed to be recorded. In this case, it was necessary to complete the test drives without a mask. So, separating transparent screens were used to isolate the driver and passenger areas from each other. Additionally, special ventilation concepts have been developed. For interviews inside rooms, tablet gloves and masks have been distributed and the distance between participants has been ensured.

All Pilot Site Leaders in L3Pilot took the effort to make sure they could meet the project goals. “It shows the outstanding commitment of our partners that we managed to pursue Piloting and the related targets despite the COVID-19 situation”, says L3Pilot Co-ordinator Aria Etemad, Volkswagen AG. After the lock-down in spring 2020, all Pilots managed to restart in September and October last year, and Piloting continued until Feb. 2021.

5.2 On Pilots data acquisition, management and delivery

Before entering the pre-test phase, the expectation of Pilot partners has been to encounter a number of technical problems or even roadblocks in data acquisition, verification and delivery to the evaluation phase. However, this eventually was not the case thanks to the huge work carried out in the preparation of the vehicle functions and the data tool chain. The cooperation and the exchange of information on "how to solve the problem" acted as grounds to help each other on solving problems at hand. In the Piloting pre-test phase all Pilot Site Leaders dedicated a specific effort to the selection and the adaptation of on-board data loggers. This activity highlighted that a Common Data Format had to be achieved being the only possible way to guarantee uniformity and usability of Pilots data. The lesson learnt for future projects is to leverage on the availability of a Common Data Format at a an early stage of the project. A starting point is the Common Data Format defined by L3Pilot which is publicly available. In addition, it is necessary to select data logging tools that are compatible with the chosen approach, meaning that the data acquired by the specific data logger should be easily translated, online or offline, into the Common Data Format. The Common Data Format has a unique value as L3Pilot project outcome, a value that is being brought to the worldwide community of experts dealing with automated driving functions.

5.3 On the constraints in recruiting Piloting drivers/users

An important lesson learnt is related to the fact that in several cases legislation related to testing of vehicle automation in real traffic does not allow to recruit drivers that are not company professional drivers specifically trained to deal with the new technologies related to

SAE L3 automation. This fact created a barrier to the recruitment of so-called naive subjects, but at the same time, it represented an opportunity to the Pilot Site Leaders as it led to the understanding that the courses for professional drivers driving AD vehicles are an essential part of the testing toolchain. In particular, L3Pilot organized a team of experts among OEMs to discuss on the opportunity to harmonize the professional drivers' courses at European or even possibly at worldwide level.

All Pilot recorded data respected the GDPR rules while the data delivery to a third party for analysis required additional effort with the preparation and signature of bilateral agreements among Pilot Leader and its related evaluation partner that is supporting the Pilot Leader to prepare the dataset ready to be uploaded in the consolidated database.

5.4 On the Consolidated Database for Data Management

The L3Pilot Consolidated Database has been conceived to be a unique opportunity for the project to collect and analyse data from all Pilot Sites preventing any benchmarking among parties involved. At the same time, its design and development revealed to be a huge challenge since its definition at an early stage of the project. In particular, the design had to guarantee an easy data loading, easy accessibility for data processing in the evaluation phase and the impossibility to trace which data are coming from which Pilot Sites, the latter to prevent any cross-Pilot comparison.

Major achievements and takeaways on the Consolidated Database are as follows:

- The definition of a tool for efficiently uploading data to the database, guaranteeing each Pilot to access, update and manage its own data and giving evaluation experts full access to the Piloting data without the possibility of cross-Pilot comparison.
- The development of a web-based, open-source GUI for supporting a proper user experience when querying the database.

A key component of the system is the Measurify measurement-oriented API back-end, which has been appreciated for several reasons, such as:

- Efficient storage and sharing of complex measurements, thanks to the underlying MongoDB non-relational database management system.
- Easy configurability by specifying the features to be supported. In the L3Pilot CDB, the features correspond to the types of vehicular and subjective data to be uploaded. Changes in the data and structure are easily managed by changing the Feature records.
- Ability to seamlessly deal with both vehicular and subjective data.
- Platform-independence, given by the use of the intrinsically platform-independent NodeJS technology and MongoDB open-source tool for the data storage.

- Different with respect to the typical cloud-based data management solutions, Measurify does not depend on vendor APIs. This makes the service easily portable across cloud providers.
- The CDB has been deployed in a cloud installation and locally in all the Pilot Sites, also on laptops.

The experience and the achievements of L3Pilot on the Consolidated Database, combined with the definition of a Common Data Format, is a best practice that is recommended to be followed in vehicle automation projects that are dealing with extensive field trials. Further improvements beyond the timeframe of the L3Pilot project are also envisaged to leverage on the most recent SW tools for developers.

5.5 On the legal constraints to get permissions and to deliver data to other parties

Legislation to get the permissions to conduct tests and Pilots of vehicle automation is new and needs to be harmonized at the European level or even beyond to prevent the risk that future Pilots will be carried out only in those countries where Legislation is asking for less steps. This is a risk that will be avoided as already the L3Pilot outcomes are showing the need to test L3 vehicle automation across borders, as a key essential element for the future market deployment of vehicle automation.

Timing to organise the needed documentation to get permission to conduct Pilots and to prepare, agree and sign bilateral agreements among partners for sharing Pilots' raw data revealed to be time consuming. The recommendation is to carefully plan these actions always at the very beginning of any Piloting planning phase.

While an extraordinary work has been done by each Ministry of Transport of all countries to rapidly issue - for the first time - the rules to conduct Pilots in real traffic, a huge difference in legislation to access the permission to drive exist among the countries. This is varying from a simple "authorities shall be informed that a Pilot of SAE L3 automation is being performed" to a considerable number of permissions and in-depth documentation needed to get the permissions. This fact led to a diversity in the timing to get the permissions among the different partners. This is critical especially for planning cross-border testing.

Hopefully, the Member States would be willing to take on board this task, as it would accelerate the timing to activate large-scale testing of vehicle automated functions. The Hi-Drive European Project, starting in July 2021, has already taken this task among its objectives. However, an evolution towards the harmonization of the rules to get permission for testing can happen only with a clear commitment of the Ministries of Transports of the countries.

6 Highlights and Conclusions

L3Pilot set ambitious goals concerning the extent of Piloting: 1000 test drivers, 100 automated vehicles in 10 European countries from south to north. However, the project had to face the unexpected: the pandemic situation forced L3Pilot partners to re-schedule the original goal. Considerable efforts have been done to respect the timing of the project, achieving 750 drivers, 70 automated vehicles Piloted in 7 European countries. In this light, the outcome of Piloting can be regarded as a success in this exceptional pandemic time that severely restricted all face-to-face communication and challenged conventional road tests.

The main practical goals of the Pilots are the data collection, the creation of the digital environment for the huge data set management, the translation of Pilots raw data in a common data format, and finally their upload on the Consolidated Database for the evaluation. These tasks constitute a basis for the ultimate goal of the project which is the outcome of data analysis. However, already from Piloting execution a number of considerations could be derived, especially related to the key aspects of the operational management.

Designing, planning, organising and executing Pilots is a huge challenge. Even before the actual Piloting could be started, several preparatory activities have been needed to enable Piloting and data collection on public road networks. An integral aspect has been that relevant ethical, safety, legal and privacy issues have been identified from the very beginning and related risk mitigation plans integrated in the test plans. The work on safety and ethics benefitted from large-scale user trials of intelligent vehicle tests over the past two decades, and established guidelines created by the field operational test community in Europe.

Together with creating the guidelines for Piloting, equally important has been to gather 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 suitable permission from the authorities. The negotiations with national and local authorities were rather time-consuming, and for future testing activities these negotiations must be initiated early enough also considering cross-border activities to ensure the road tests can be launched as planned.

The ethical and privacy principles have been considered throughout L3Pilot. Another issue to be faced concerned the general procedures for recruitment: these included checklists for instructing the subjects before the tests and a legal consent form, which has been adjusted to the specific needs of each Pilot Site. The consent form described the main details on treating data and handling participants, 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 recorded some personal data, these have been only collected and analysed 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 setups have been designed by observing appropriate safety procedures, based on the partners' experience, consolidated in several years of research and development. Using trained professional drivers, safety instructions and supervised driving along with consideration on the Pilot Site infrastructure allowed to address effective risk mitigation methods for all the trials.

In the project, personal data have been anonymised deriving specific indicators from collected data for statistical work and assessment of societal impacts. The impact assessment will be done using scientific methodology and principles, ensuring that the focus is on the behaviour of large user groups instead of focusing on individuals and their data.

Another challenge has been to handle the huge amounts of generated data from the Pilots while preventing any comparison among vehicle automated functions developed by L3Pilot partners. This required special techniques and a solution to make it happen. At the same time, the data analysts shall be able to provide answers to more than 100 research questions posed by the methodology development team. The Consolidated Database (CDB) innovated the way to treat the dataflow from the raw signals of single vehicles, each one in a proprietary format. The CDB brought data all the way to the consolidated data for the impact analysis – and even further, a part of the data will be made available as 'open data' after the end of the project. This Consolidated Database method will save a lot of time in upcoming large-scale road tests and serves as a model on how to manage large amounts of data.

Thanks to the Piloting data, it is now possible to fully exploit the advanced evaluation methods and answer the research questions from user behaviour all the way to societal level impacts and provide data-led analysis on the impacts of automated driving to be reported towards the end of the project.

Overall, European wide Piloting needed precise rules and procedures on how to conduct the tests to ensure that valuable data can 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 main things is to make behavioural scientists and research engineers to speak the same language and agree on the principles of experimental testing in addition to focus on the technical functionality of the test vehicles. Here, it has been essential to observe the principle of collecting extensive baseline measurements to have data and knowledge on how users and vehicles behave without automation. When we have this knowledge, it is possible to compare the automation to non-automation driving and draw conclusions from the impacts of automated driving. The consortium followed this methodology basic principle enabling meaningful analysis of the data.

The L3Pilot project is organizing its Final Event and Showcase at the ITS Word Congress 2021 in Hamburg in October 2021, in this event the full set of the Pilots' evaluation outcomes will be presented and the Congress Attendees will have the opportunity to experience the L3Pilot automated vehicle functions in the city and motorways traffic scenarios.

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List of abbreviations and acronyms

Abbreviation	Meaning
AD	Automated driving
ADAS	Advanced Driver Assistance System
ADF	Automated Driving Function
API	Application Programme Interface
AV	Automated vehicle
CDF	Consolidated data format
CLI	Command Line Interface
CoP	Code of Practice
CPU	Central processing unit
FESTA	A handbook on FOT (Field operational tests) methodology
GDPR	General Data Protection Regulation
Gitlab	Web-based DevOps lifecycle tool
HMI	Human Machine Interaction, Human Machine Interface
ID	Identification (e.g., of a trip in the data)
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
Naïve subject	A person participating in a test and having no prior experience on the testable matter (here automated driving and functions)
NodeJS	JavaScript runtime built on Chrome's V8 JavaScript engine
ODD	Operational design domain
OEM	Original Equipment Manufacturer (here auto manufacturer)
PI	Performance indicator (like speed, deceleration)
RESTful	An open-source Representational state transfer
R&I	Research and innovation
RQ	Research question
SAE	Society of Automotive Engineers
SDV	Software Defined Vehicle
SLAM	Simultaneous localization and mapping

Abbreviation	Meaning
SPSS	Statistical package for social sciences
Subject	A person participating in a test (here in a pilot)
SWIR	Short-wave infrared
VRU	Vulnerable road user
Wizard of Oz	An experimenter (the “wizard”) not present to the subject
zip.file	File compression, encryption concept