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BERTHA

D2.3. Updated Methodology for Basic Simulation Environment

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IMPORTANT

This document serves as a template for deliverables and follows a proposal structure. The mandatory sections include: Executive Summary, Introduction and Objectives, and Conclusions. The remaining sections are customizable.

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EXECUTIVE SUMMARY

BERTHA's details

Project name	BEhavioural ReplicaTion of Human drivers for CCAM
Project acronym	BERTHA
Grant Agreement number	101076360
Duration and dates	36 months (1 November 2023 – 31 October 2026)
Call and topic	HORIZON-CL5-2022-D6-01-03: Safe, Resilient Transport and Smart Mobility services for passengers and goods
Granting authority	European Climate, Infrastructure and Environment Executive Agency (CINEA), under the powers delegated by the European Commission
Official project website	berthaproject.eu

The BERTHA consortium

N°	NAME	ROLE	COUNTRY
1	INSTITUTO DE BIOMECANICA DE VALENCIA (IBV)	Coordinator	Spain
2	INSTITUT VEDECOM (VED)	Beneficiary	France
3	UNIVERSITE GUSTAVE EIFFEL (UGE)	Beneficiary	France
4	DEUTSCHES FORSCHUNGSZENTRUM FUR KUNSTLICHE INTELLIGENZ GMBH (DFKI)	Beneficiary	Germany
5	CENTRE DE VISIO PER COMPUTADOR (CVC-CERCA)	Beneficiary	Spain
6	ALTRAN DEUTSCHLAND SAS & CO KG (CAP)	Beneficiary	Germany
6.1	VORTEX - ASSOCIACAO PARA O LABORATORIO COLABORATIVO EM SISTEMAS CIBER-FISICOS E CIBERSEGURANCA (VOR)	Affiliated entity	Portugal
7	CONTINENTAL AUTOMOTIVE FRANCE SAS (CON)	Beneficiary	France
8	FUNDACION CIDAUT (CIDAUT)	Beneficiary	Spain
9	AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH (AIT)	Beneficiary	Austria
10	UNIVERSITAT DE VALENCIA (UVEG)	Beneficiary	Spain
11	EUROPCAR INTERNATIONAL	Beneficiary	France
12	F. INICIATIVAS, CONSULTADORIA E GESTAO, UNIPESSOAL, LDA (FI)	Beneficiary	Portugal
12.1	F. INICIATIVAS ESPANA I MAS D MAS I SLU (FI_ES)	Affiliated entity	Spain
13	SMART EYE AB (SEYE)	Beneficiary	Sweden

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Project's summary

The main objective of BERTHA is to develop a scalable and probabilistic Driver Behavioural Model based mostly on Bayesian Belief Networks (BBN). The DBM will be implemented on an open-source HUB (repository) to validate the technological and practical feasibility of the solution with industry, and provide a distinctive approach for the model worldwide scalability. The resulting DBM will be translated into a simulating platform, CARLA, using various demonstrations which will allow the construction of new driving models in the platform.

BERTHA will also include a methodology which, using the HUB, will allow to share the model with the scientific community, in order to facilitate its growth.

The project includes a set of interrelated demonstrators to show that the DBM can be used as a reference to design human-like, easily predictable and acceptable behaviours of automated driving functions in mixed traffic scenarios.

BERTHA is expected to go from TRL 2 to TRL 4. The requested EU contribution is €7,981,801. The consortium, formed by several entities from different countries, deems this Project as vitally relevant to the CCAM industry due to its impact for safer and more human-like CAVs and its market and societal adoption.

Document details

Deliverable type	Document, report
Deliverable n°	D2.3
Deliverable title	D2.3 - Updated methodology for basic simulation environment.
Lead beneficiary	VED
Work package and task	WP2 Task 2
Document version	1.0
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Actual delivery date	
Dissemination Level	PU-Public
Purpose	To outline the updated methodology for the basic simulation environment, detailing the simulation capabilities and experimental plans. This deliverable provides comprehensive guidelines for conducting laboratory tests in the early stages of BERTHA's project, defining scenarios, and implementing Use Cases to assess BERTHA's modules. It guides model development processes essential for advancing the DBM.

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Document's abstract

This document presents the updated methodology for the basic simulation environment in BERTHA's project, emphasizing simulation capabilities and comprehensive experimental plans. It outlines the procedures for laboratory testing, including the objectives and scope managed by the partners responsible for BERTHA's module. Integrating Use Cases from WP1, the document details model implementation and parameters based on specific indicators. By providing an overview of the driving simulator facilities across partners such as IBV, UGE, DFKI, and SEYE, D2.3 elaborates on their respective objectives and approaches to data collection, ensuring the first foundation for the DBM's development.

Additionally, the document establishes a consolidated data-sharing framework, ensuring adequate storage and access among project partners. This framework supports the early-stage development and iterative testing of models. The methodology facilitates identifying and analyzing accident-prone scenarios based on D1.2. The document ensures integration into the broader project objectives by systematically planning and executing the experimental activities.

Document's revision history

The following table describes the main changes done in the document since it was created.

REVISION	DATE	DESCRIPTION	AUTHOR (PARTNER)
V.0.1	2024/07/19	Initial Draft	C. Perdomo (VED)
V.0.1.1	2024/09/04	Changes in structure: Section 3 and 4 have been separated after by partners, allowing each one to present their plans separately.	C. Perdomo and S. Pechberti (VED)
V.0.2	2024/10/17	Inputs in section 3 and 4 by UGE, and DFKI.	Jean-Charles Bonard (UGE), Thierry Bellet (UGE), Shreedhar Govil (DFKI)
V.0.3	2024/11/07	Changes in structure: Section 3 is being focused on the simulation setups, letting the complete description of tests for D2.4 when the experimentation phase will be advanced.	C. Perdomo (VED)
V.0.4	2024/11/22	UGE updates in sections 3 as well as inputs and relationships with other deliverables after BERTHA's 3rd presential meeting. Write of section 5 and first conclusions.	Jean-Charles Bonard (UGE), Thierry Bellet (UGE), C. Perdomo (VED).

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V.0.5	2024/12/04	Final inputs of DFKI and IBV's inputs regarding experiment scope.	Shreedhar Govil (DFKI); Juan-Manuel Belda (IBV), Víctor de Nalda (IBV).
V.0.6	2024/12/09	Final inputs of UGE and IBV. Inputs of CON and SEYE based on the 3rd presential meeting.	Jean-Charles Bonard (UGE), Thierry Bellet (UGE), Juan-Manuel Belda (IBV), Víctor de Nalda (IBV), C. Perdomo (VED).
V.0.7	2024/12/10	Final inputs of CON and SEYE. Reference arrange and last check-in.	Farhood Negin (CON); Martin Bergström (SEYE); C. Perdomo (VED).
V.0.8	2024/12/12	Internal review	Andrés Soler Valero (IBV), Juan-Manuel Belda Lois (IBV), Victor de Nalda Tarrega (IBV).
V.0.9	2024/12/17	Addressing internal review corrections and feedback	C. Perdomo (VED)
V1.0	2024/12/19	Fix layout	IBV

Terminology and acronyms

TERM/ACRONYM	EXPLANATION
CAV	Connected Autonomous Vehicles
CCAM	Connected, Cooperative and Automated Mobility
CINEA	Climate, Infrastructure and Environment Executive Agency
DBM	Driver Behavioral Model
EC	European Commission
HAV	Human Autonomous Vehicle
AV	Autonomous Vehicle
BBNs	Bayesian Belief Networks
UCs	Use Cases
FOT	Field Operational Test
SOPs	Standard Operating Procedures
HR	Heart Rate
HRV	Heart Rate Variability
V-HCD	Virtual Human Centred Design
SURCA	Sécurité des Usagers de la Route et Conduite Automatisée
SUaaVE	SUpporting acceptance of automated VEhicles

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1. INTRODUCTION

1.1. Background information

The advancement of Connected and Autonomous Vehicles (CAV) technologies is fundamentally dependent on a deep understanding of human driver behaviour [1], [2]. To develop safe autonomous vehicles (AV) that exhibit human-like driving characteristics, it is essential to create advanced models capable of predicting and simulating driver actions in diverse scenarios. BERTHA's project, as outlined in previous deliverables [3], [4], [5]; aims to address this need by developing a scalable and probabilistic **Driver Behavioral Model (DBM)** [6] primarily based on **Bayesian Belief Networks (BBNs)** [7], [8], [9], [10].

The DBM is structured around five distinct yet interconnected modules that encompass essential facets of human driving performance:

- **Perception Module**: Processes sensory information to interpret the driving environment, primarily focusing on visual perception—the most important sense for driving [11].
- **Risk Awareness and Decision-Making Modules**: Assess potential hazards, evaluate risk levels in various situations, and determine appropriate driving actions based on perceived information and risk assessment [3].
- **Affective Module**: Incorporates the driver's emotional and cognitive states and their influence on driving behaviour, parametrizing psychological processes related to cognition and emotional arousal affected by internal, external, and environmental factors [3].
- **Motor Module**: Executes the physical actions required to control the vehicle [3], conditioned by the driver's level of expertise [12] and influenced by the affective module [4].

Collecting empirical data from real human drivers is important to achieving BERTHA's project goals. The project involves human participants and collecting personal data across multiple activities in Work Packages WP1, WP2, WP4, and WP5. This data collection is the main source for developing the DBM and introduces complexities related to data sharing, storage, and ethical considerations.

This document is a comprehensive guide for laboratory testing and planning of experiments designed to collect data across BERTHA's modules within our research framework. It emerges from the collaborative efforts of project partners responsible for data collection in modules involving human participants.

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1.1.1. Relation to other Deliverables

This document is integrally connected to several other deliverables within BERTHA. It builds upon the preliminary use cases proposed in WP1. Specifically, **D1.1: Use Cases for the Identification of the Model** [3] and **D1.3: Influencing the parameters that determine driving and outputs of the model** [13]. These deliverables provided the theoretical frameworks and scenario definitions that inform our experimental design involving human participants.

To conduct laboratory tests, we needed to define scenarios that confront drivers with specific situations that can be highly accident-prone in a real environment. Built around the BERTHA's Use Cases (UCs) defined in WP1, **the scenarios correspond to a subset of the information necessary for implementing the model**. For more information, check the end of Section 3 of this document.

A collaborative methodology was applied to choose these scenarios, comprising a workshop co-organized by VED and CID during the BERTHA 3rd committee meeting in Germany. During this workshop, partners could express their thoughts regarding the key parameters that define the scenarios based on the UCs.

This workshop involved individual brainstorming sessions to identify parameters defining scenarios. The objectives were:

- Align on scenario parameters for each UC.
- Ensure parameters are compatible across Field Operational Tests (FOT), simulations, field tests (WP5), and CARLA integration (WP4).
- Strengthen collaboration among all partners.

Partners were asked to think about feasible values based on their expertise and to address any technical constraints or adaptations needed.

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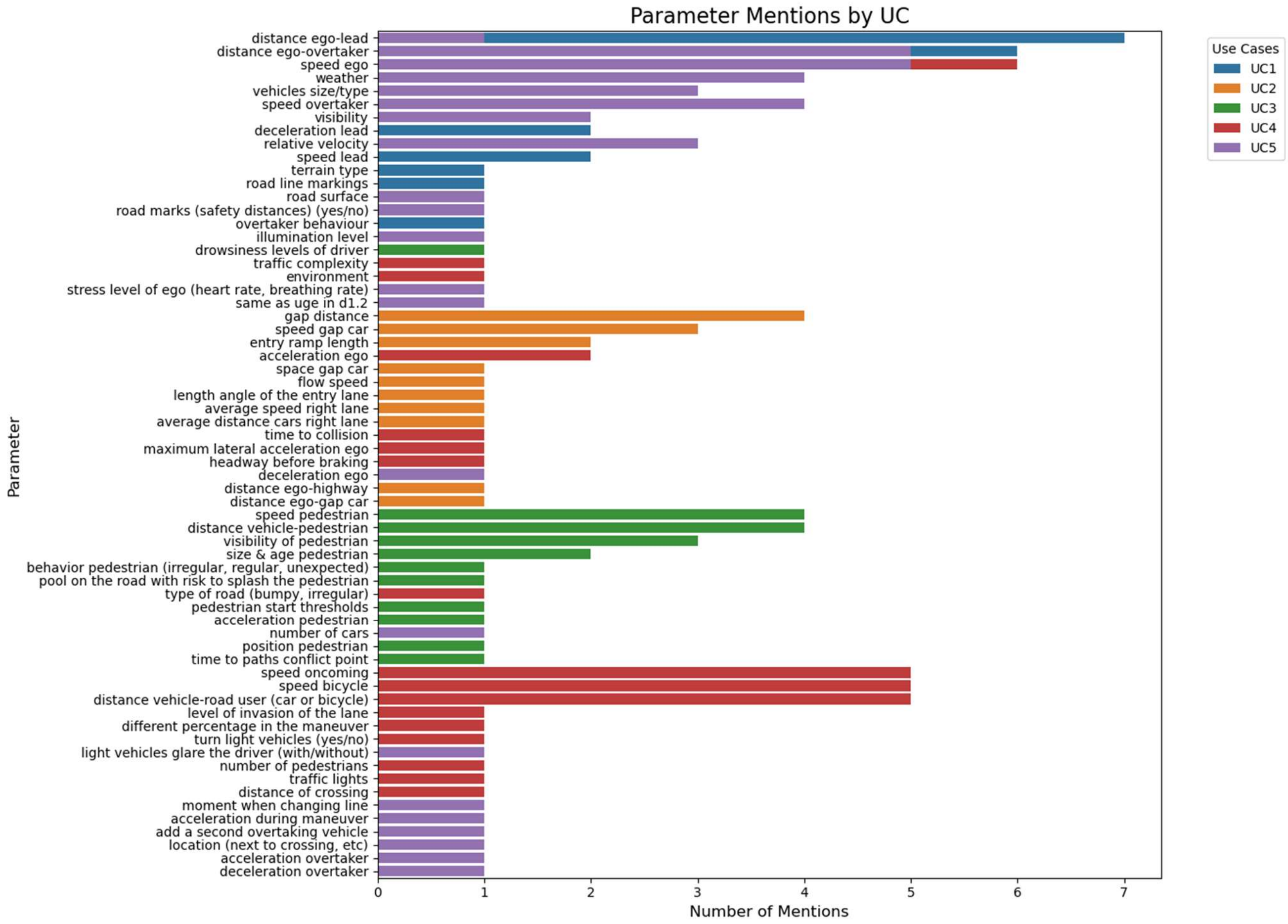

Figure 1. Normalized workshop results across UCs.

After normalizing all the responses, 64 parameters were suggested in total, as it can be seen on Fig. 1. We used the parameters defined in D1.3 and associated keywords to map the partners' suggested parameters to the work already done in D1.3 [13]. A high overlap was observed between the workshop results and D1.3 parameters; out of all the partners' suggested parameters, 57 were already within the scope of D1.3, as shown in Fig. 2. This indicates a strong alignment between partners' suggestions and previously defined parameters for critical scenario developments.

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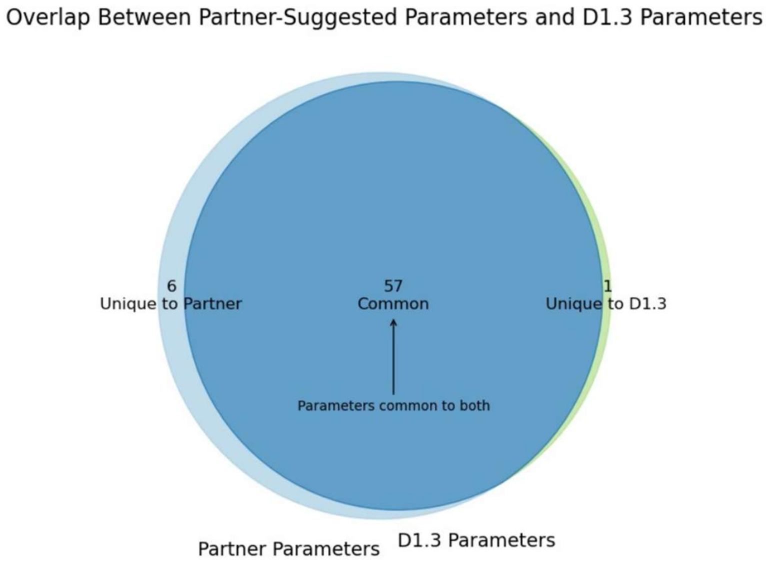

Figure 2. Venn diagram to visualize the overlap between partners-suggested parameters during workshop and D1.3 parameters.

These results were also consistent with D1.2 scenarios [14]. When we examined the top two parameters suggested by partners per UC (see Fig. 3), they matched either the static or key parameters in the video scenario references of D1.2. **This means that the suggested scenarios defined in D1.2 are relevant and effective for our purpose with the laboratory test**. For more information, check Section 3.

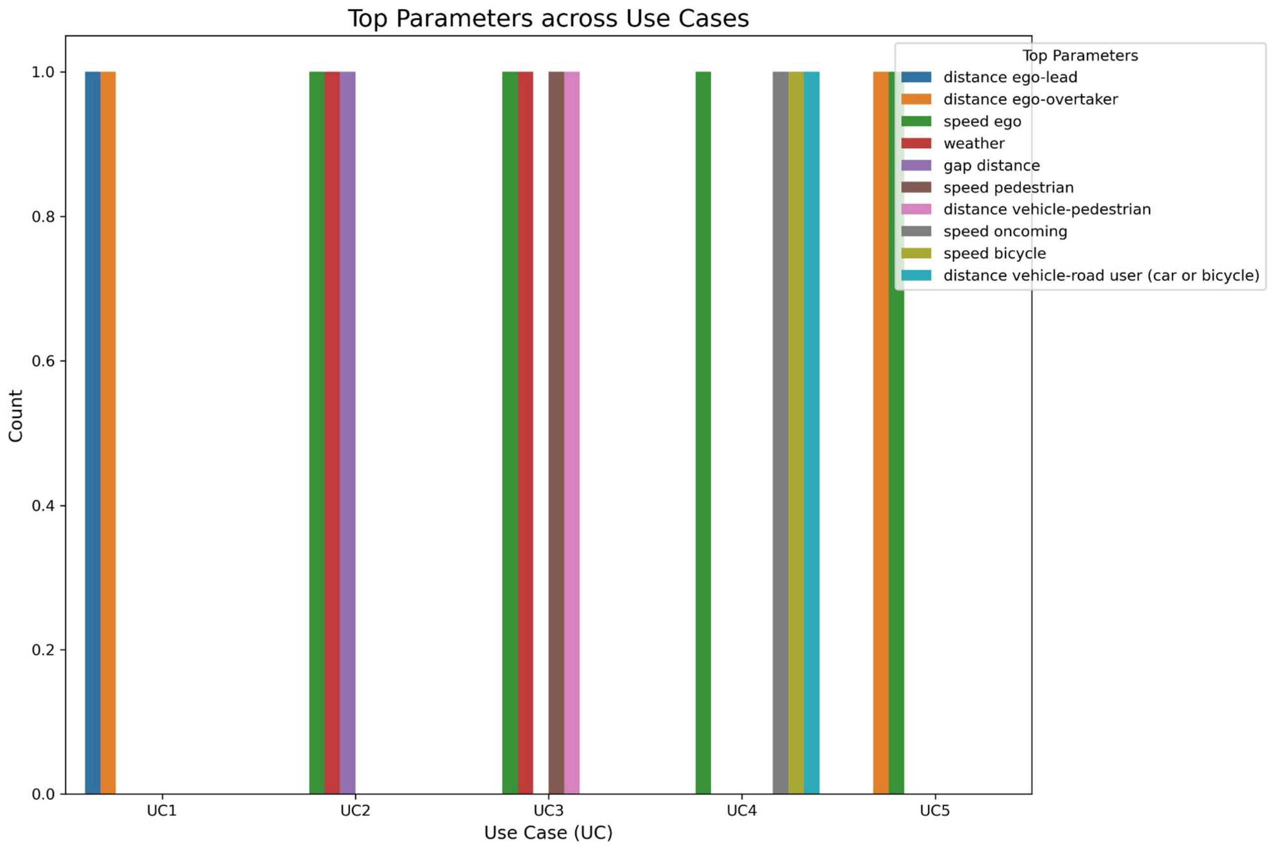

Figure 3. Top parameters suggestion per UC.

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Nevertheless, not all suggestions can be implemented across simulations, CARLA, FOT, and track tests. For example, due to technical limitations, parameter suggestions like weather conditions and the size or age of pedestrians are challenging to implement realistically in CARLA and field tests. As discussed during the workshop, CARLA cannot simulate vehicle grip or wet roads, while field tests cannot safely include actual pedestrians in hazardous scenarios.

Therefore, the video scenarios of D1.2, which already focus on critical situations involving variations of key parameters like distance and vehicle behaviors, remain highly relevant. They cover the UCs defined in WP1, ensuring consistency and relevance to the project's goals. More details are provided in Section 3.

Additionally, the bases of the data acquisition processes were established in D2.2 [5], where we defined the indicators and pre-requirements necessary for the DBM's realisation and validation. As well as data formats, labels, and sharing requirements. This document complements those foundational works by providing a detailed roadmap for implementing the UCs and data acquisition methods in a laboratory setting, as shown in Fig. 4. It facilitates a transition from conceptual design to practical experimentation, ensuring our empirical efforts align with BERTHA's goals.

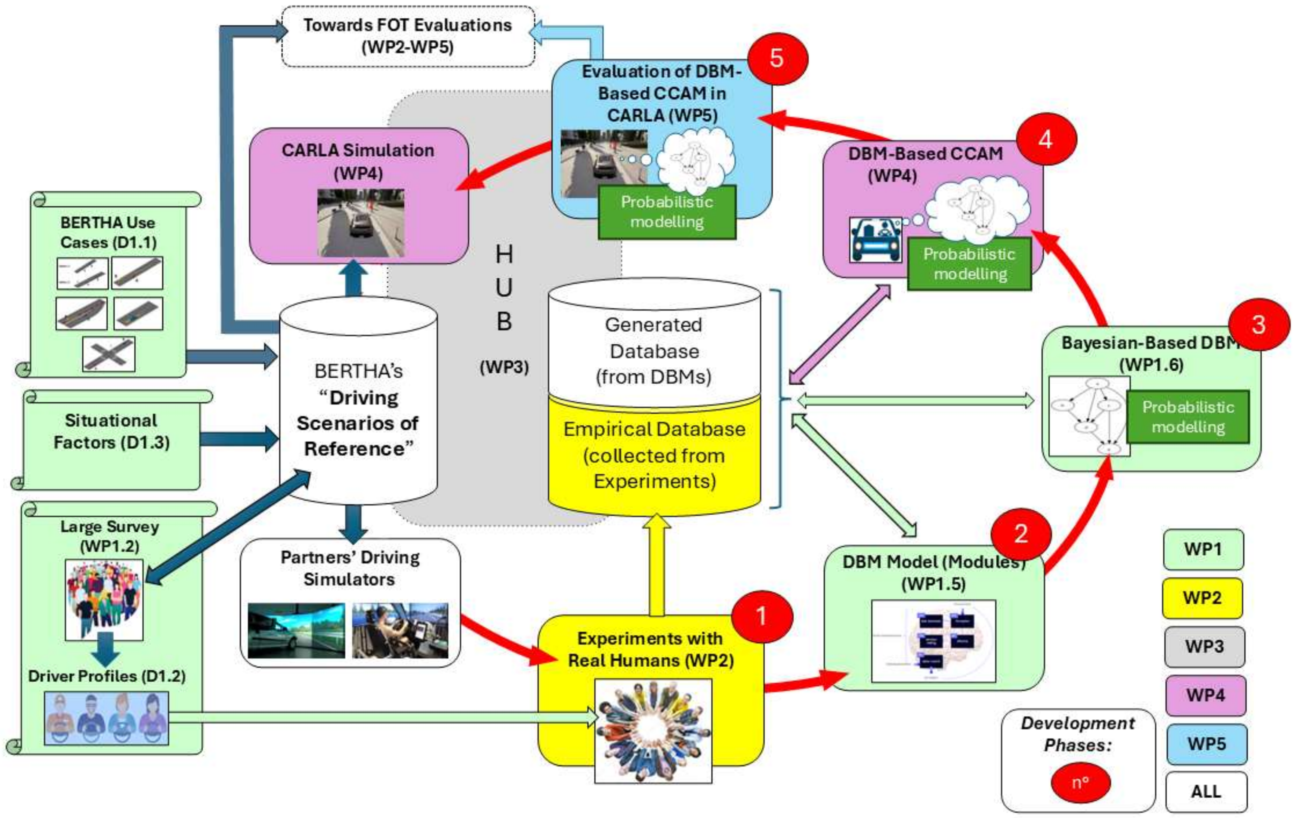

Figure 4. Overview of BERTHA's DBM solution at a glance. Lab tests in simulators are conducted to develop DBM modules. The same data provides empirical evidence for validating the modules by comparing real human behaviors with DBM behaviors.

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1.2. Purpose of the document

The primary purpose of this document is to delineate the simulator capabilities for laboratory testing within BERTHA involving real human drivers, ensuring that all partners involved adhere to a consistent approach. It provides detailed accounts of the objectives, scope, and installation procedures for conducting the first experiments and developing the DBM. Furthermore, it outlines the planning and execution of tests, partners' data-sharing policies, storage procedures and the expected outputs, all within the context of partner technologies.

By doing so, the document seeks to guarantee that the experimental activities are conducted systematically, safely, and in a manner that yields reproducible and valid results. Standardised testing procedures and reproducibility are paramount, given the importance of high-quality data in developing an accurate and reliable DBM. As mentioned in D2.2 in the context of AV [5], reproducibility is not merely an aspect of scientific rigour but a necessity. It involves defining clear protocols and maintaining detailed documentation to ensure that experiments can be replicated under the same conditions across different environments and times and that data can be effectively shared and integrated among partners. This standardisation ensures that any variations in the data can be attributed to the tested variables rather than inconsistencies in the experimental setup.

Ultimately, this document is relevant for coordinating efforts across various partners involved in empirical data collection to support the development of the DBM and its modules, as well as to provide empirical data for their validation. By facilitating effective collaboration and ensuring alignment among partners, we are taking significant steps toward making BERTHA's DBM safer and more human-like in its operation.

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2. OBJECTIVES

2.1. Objectives of Lab Tests

As mentioned in Section 1, BERTHA's primary objective is to develop and validate a comprehensive DBM by integrating five modules. In this context, document D2.3 sets the stage for the detailed Lab Test descriptions with humans in the following sections, outlining their overall scope in the context of the DBM development.

Specifically, D2.3 aims to:

- **Establish the scope of the lab test**: Define the specific requirements and parameters for data collection involving real human drivers, including agreed-upon driving scenarios and data-sharing policies among partners. This ensures that all partners are aligned and that the data collected will be suitable for developing the DBM.
- **Detail the Experimental Setup**: Comprehensively describe each partner's installation, including software settings, instruments, sensor specifications, and participant sampling. This allows for consistency across different setups and facilitates the integration of data.
- **Plan Expected Data Acquisition**: Outline the expected data to be collected during the acquisition campaigns, ensuring it aligns with the objectives of the DBM development. This planning is an update regarding D2.2 content thanks to the Lab Test.
- **Set Milestones and Checkpoints**: Establish milestones for BERTHA, including the definition of experiments and timelines.

These objectives guide the planning and execution of the laboratory tests, ensuring that the expected outputs—high-quality data and results—are achieved by focusing on these goals. **The involvement of real human drivers underscores the need for meticulous planning and coordination**.

In the upcoming sections, we will delve into:

- **Lab Test Facilities (Section 3)**: This section overviews the laboratory test facilities and equipment setups involving human participants across partners that do simulations.
- **Lab Test Planning (Section 4)**: This part provides an overview and a 1st schedule of the planned experiments involving real human drivers.
- **Consolidated data sharing and validation framework (Section 5)**: Finally, this section presents the consolidated data sharing and validation framework, outlining data storage, access guidelines, and general validation processes among partners.

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3. LAB TEST FACILITIES

Creating standardised laboratory test protocols is important for systematically assessing human driver behaviour in controlled environments. In D2.2 [5], we have already defined the Standard Operating Procedures (SOPs) for high-quality data collection and prerequisites for simulations in BERTHA. With this in mind, we continue these discussions in this deliverable. This section delineates the framework employed by BERTHA to conduct preliminary lab tests with humans for the modules, using driving simulators and advanced data acquisition systems. We ensure that our testing procedures align with the project's overarching goals by outlining the simulator facilities, defining clear objectives and scope, and designing relevant scenarios replicating.

The BERTHA project uses various driving simulators, with each partner responsible for human data collection operating within their dedicated simulator setups. These simulators have sophisticated features like motion platforms, high-resolution visual systems, and extensive sensor integrations, enabling realistic and immersive driving experiences.

This deliverable will concentrate on acquiring simulations that integrate the comprehensive set of signals defined in D2.1 [4] and collected by project partners. Additionally, D2.3 will offer detailed information on the shared partner installations responsible for data acquisition throughout the project.

The preliminary lab tests are designed to investigate specific aspects of driver behaviour. The primary aim is to understand how drivers interact in highly accident-prone scenarios. These tests focus on key areas, such as decision-making during complex driving manoeuvres and emergency responses. By aligning these objectives with the use cases defined in WP1 [3], we ensure that our laboratory experiments contribute directly to the BERTHA's strategic goal. Additionally, the data gathered from these laboratory tests will be the foundational input for developing and refining, enabling us to simulate and predict driver behaviour in various constrained environments as the project progresses (D2.4, and D2.7).

With this foundation established, the following sections provide a structured overview of the lab test facilities and guidelines, detailing the simulator, objectives, and data acquisition methods underpinning our preliminary testing efforts and calibrations. We aim to generate reliable and actionable insights by adhering to these guides.

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3.1. IBV

3.1.1. Overview of Driving Simulator Facilities

General description

At IBV, the driving dynamic simulator HAV (Human Autonomous vehicle, Fig. 5) has been developed centered on Human Factors by considering the users' technology acceptance of the system or device being evaluated in each experimentation and assuring a certain level of fidelity and immersivity.

Figure 5. IBV's driving dynamic simulator HAV.

The 3 principles considered when developing the simulator, are the following:

1. **Reduction of simulator sickness**.
2. **Assure the immersivity of the user and simulator's external validity**, ensuring comparable results between simulated laboratory tests and real-world driving scenarios.
3. **Enable a seamless integration of new functionalities or measurement devices**. See Fig. 6.

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Figure 6. Measuring devices installed on top of the central screen

Components of the driving simulator

The dynamic platform used in the HAV is a "*Motion Platform PS-6TM-550 (6DoF, 550kg) - Motion Systems*", see Fig. 7. This system receives the longitudinal accelerations and angular velocities for every frame. It converts this information into the movements of its servomotors, replicating the accelerations.

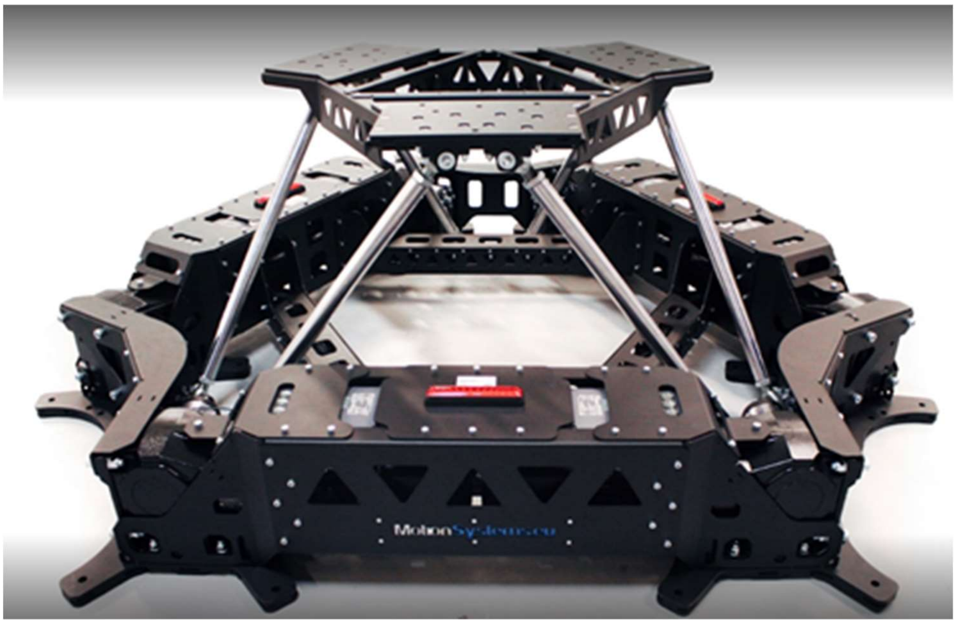

Figure 7. Dynamic platform.

The main software used in the experimentations completed with the driving simulator is CARLA. This software has been adapted to run the scenarios in the IBV Human Factors centered driving simulator. This has been possible by spawning different cameras in the ego vehicle to display the user's POV in an immersive 3-TV system, controlling the vehicle with steering wheels and pedals, mounting a cockpit, displaying additional information in the rear view (Fig. 8), and HUD screens and replicating the accelerations in the dynamic platform.

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Figure 8. Rear-view screen POV.

As shown in Fig. 9, HAV has different measuring devices such as a bio signals data logger, where different measurements can be made (ECG, GSR, EMG, and others), an EEG helmet, respiration rate via laser, and fatigue detection via computer vision. All measurements taken in the different experimentations are previously defined in the experiment protocol, fulfilling a specific purpose, and are subsequently analyzed.

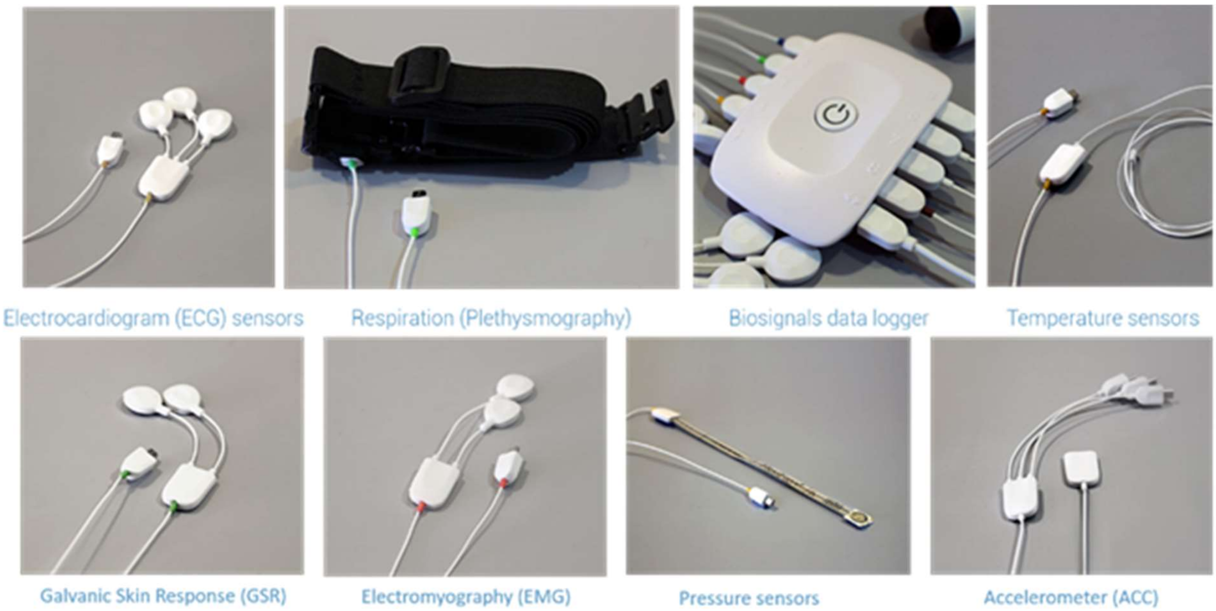

Figure 9. Physiological signals measurement devices.

The dimensions of the whole simulator (considering the dynamic platform and screens) are approximately 2 m long, 3.5m wide, and 2.2 m high. The light intensity and hue of the laboratory's overhead LED system are controlled through an app. The sound of the different environments sounds, and events in the driving scenarios are played through a 5.1 surround sound system. The temperature and humidity levels can also be controlled.

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Simulator scenarios

With the aim of developing a methodology for creating different scenarios that can be easily customized to cover all the needs of the different projects and experimentations, different scenario templates have been defined. Starting from these templates, different parameters can be then edited with the graphic interface, obtaining the easiest way possible, a customized scenario that provides different stimuli to the user. Among the different scenario templates, the Sleep Deprivation, ADAS Validation, and Stress scenarios stand out.

The main objective of the sleep deprivation scenario is to induce sleep in the users. It simulates driving along a straight road with very little traffic at night. This scenario evaluates drowsiness detection systems, alert systems, or any experimentation where inducing sleep to the user can be of interest. As with any of the templates, different events can be programmed and configured to spawn different vehicles or modify the scenario if needed.

The main objective of the ADAS validation scenario is to generate, repetitively and easily, situations in which the different ADAS alerts can be activated and displayed. Example of it on Fig. 10. These alerts, usually being evaluated, can be visual, acoustic, haptic, or a combination of two or more. The most common ADAS to be evaluated are:

- Fatigue detection
- Overspeed
- Adjacent lane invasion
- Blindspot vehicle detection

The scenario consists of a route in which the user can drive throughout several kilometers, overpassing different vehicles and in which different vehicles can overpass them. The weather is normally sunny and dry, with good visibility. The lane width varies, with wider lanes having higher maximum velocity.

Figure 10. ADAS route screenshot.

The scenario in which the main objective is to generate stress for the user has been designed to make the user always feel alert and in a hazardous environment, trying to reach several destinations in a given time. This scenario aims to measure the users' physiological signals under stress. This can become handy for several situations: better understanding of driving behaviors, humanizing driving models, and others. The route combines a rural road and an

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urban neighborhood, as in Fig. 11. The weather is rainy and has low visibility, as the objective is always to make the user feel uncomfortable.

Figure 11. Stress route screenshot.

Different scenarios can be designed to suit every experimentation, as well as these templates and the configuration graphic interface. The scenario can not only be customized by modifying factors such as weather, the number of actors, traffic light behavior, or even programming the routes of specific actors, but also by adjusting the amount of data saved at the end of the simulation for the ego vehicle or all the actors involved. The most common data to be saved and later analyzed is:

- Time information (frame number, elapsed seconds).
- Vehicle position and velocities.
- Vehicle accelerations.
- Intensity of the throttle and brake pedal. Angle of the steering wheel.
- Spawned events log.
- Driving quality indicators.

Environment control

In order to ensure a correct procedure when connecting, controlling, or turning off the simulator, a functioning protocol has been written. Only a limited number of IBV workers have been trained and know how to control the simulator following the guidelines described in the protocol. Every time an update occurs in the simulator, this is reflected in the written protocol, and the workers who need to control the simulator are informed.

The principal guidelines describe the following points:

- How to correctly turn on the simulator.
- How to edit and prepare different scenarios:
- How to launch the scenarios
- How to correctly do an emergency stop
- How to correctly turn off and disconnect the simulator.

Past projects

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The HAV simulator has been utilized and further developed over the past five years through its implementation in various European projects, including "Diamond," "SUaaVE," and "Bertha." Additionally, it has been employed within the framework of the MEDUSA Network of Excellence, which is composed of four Spanish technological centers.

3.1.2. Objectives, Scope, and Data Acquisition Strategy for Laboratory Tests

Primary objective

The primary objective of these lab tests is to validate and enhance the current affective state module by incorporating additional physiological signals such as facial expressions, heart rate (HR), and heart rate variability (HRV), along with behavioral data like blink rate, line of sight, and driving inputs. This work seeks to deepen our understanding of the interplay between driver affective states and simulated driving scenarios, focusing on how environmental factors—such as weather and traffic conditions—shape driver behavior. Furthermore, the robustness of the affective state and driver behavior models will be evaluated by testing their reliability and adaptability in dynamic driving simulator environments.

Scope

These experiments contribute to the broader goals of the BERTHA project by addressing gaps between theoretical modeling and real-world application. The empirical data collected during these tests will refine predictive models of driver behavior and provide insights into the interplay between drivers, vehicles, and their environments. This work enables a systematic exploration of affective states in controlled, but realistic, scenarios. By integrating physiological and behavioral data with environmental parameters, the results will inform the design of more human-centered systems for semi- and fully autonomous vehicles.

The driving simulator enables comprehensive data collection across multiple domains. Physiological signals such as facial expressions are captured via RGB cameras, while HR and HRV are measured using wearable sensors. Behavioral data is also recorded, including blink rate, line of sight, and driving inputs (steering wheel, accelerator, and brake pedal). Simulated environmental conditions, such as weather variations (clear, foggy, or rainy) and traffic density, are systematically controlled alongside vehicle dynamics parameters like velocity, acceleration, and time-to-collision. These diverse data streams are securely stored on a high-capacity server with rigorous version control and metadata standards to ensure integrity and facilitate analysis.

Data processing follows a robust pipeline that includes noise filtering and synchronization across multiple modalities to ensure compatibility for subsequent analysis. Relevant features like HRV frequency components and steering entropy are extracted to build predictive models. These models are further validated using advanced machine-learning techniques and cross-validation procedures to ensure their accuracy and generalizability.

Data Acquisition Strategies

The collected data directly supports the modeling process by enriching the feature set to predict driver affective states and behaviors. Additionally, it enables hypothesis testing on the interaction between environmental variables and driver responses. By varying these conditions in a controlled environment, the tests would reveal the adaptability and limits of the models under complex scenarios. This work ensures the robustness and applicability of the models to diverse real-world conditions, aligning with the BERTHA project's overarching aim of enhancing driver safety and comfort.

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3.2. UGE

3.2.1. Overview of Driving Simulator Facilities

UGE will use either SIMAX or SIMDYNA driving simulators, depending on their schedule and the BERTHA's experiment constraints.

Figure 12. The SIMAX Driving Simulator of UGE.

SIMAX, Fig. 12, is one of the two UGE-LESCOT driving simulators, and its architecture can be divided into three parts.

First, the driving cab is a 3-door Peugeot 308, equipped with input sensors by our teams. A custom-made embedded controller gathers all sensor data streams from the pedals, the steering wheel, and the gearbox. This controller also communicates with the car's internal CAN bus to read input data from the light switches and to display values (e.g., speed, RPM) on the dashboard. The steering wheel also has a custom-made force-feedback, also plugged into the embedded controller. The cabin also includes an "infotainment" touchscreen, monitoring cameras, and many physiological sensors. Around the car, 12 displays cover nearly 360° of horizontal field of view. Nine displays handle the "direct" view from the driver, and two small monitors are integrated in place of the side mirrors.

Additionally, a pull-down screen is installed in the rear to cover both the rear-view mirror and the direct rear view. Finally, adjacent to the simulator is the control room, which hosts a rack of 9 computers. Those are used to feed images to the displays, synchronise and record all experimental data streams, and to serve as conductor of the whole experiment. The simulator is placed in the centre of a large blind room, with an HVAC system allowing the perfect control of the temperature inside the car.

SIMAX driving simulator was used in several French National projects and industrial partnerships, like SAKHAD (for Situation Awareness Keeping and rebuilding during Highly Automated Driving) with Toyota Motor Europe to design innovative HMI solutions aiming to support the drivers in resuming the manual control of their car after automated driving [15]. This simulator is also currently used on a French project that displays a 20-minute manual

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driving scenario in urban areas with numerous vulnerable road users crossing the driver's path.

Figure 13. The SIMDYNA Driving Simulator of UGE

SIMDYNA is the second UGE-LESCOT's mid-range driving simulator, Fig. 13.

It includes a small driving cab from MobSim (based on an Aixam car), equipped with D-BOX actuators, adding extra motion to the platform. The dashboard is displayed on an integrated monitor, and the cockpit includes an "infotainment" touchscreen. The simulated environment is displayed on five 4K TVs, covering around 200° of horizontal field of view. The computer rack powering the simulator has been designed similarly to SIMAX's, allowing easier operations and maintenance across both simulators. This cabin is placed in the centre of a blind room, with spatialized audio, and where the building's ventilation system regulates the temperature. The open-cab design of this simulator offers benefits for some specific studies, such as those requiring accurate body tracking.

SIMDYNA was used in the H2020 European project VI-DAS (Vision Inspired Driver Assistance Systems, under the grant agreement n° 690772; http://www.vi-das.eu) to support the Human Centred design and evaluation of future adaptive ADAS based-on vehicle automation [16]. This simulator is also currently used in a French National project to investigate the effects of non-driving-related postures on takeover performance during conditionally automated driving. A takeover scenario with SAE automation level 3 requiring emergency braking was deployed for different test conditions under different time budgets. [17].

The V-HCD platform [18], [19]: These two driving simulators are connected with the "V-HCD" software (for Virtual Human Centred Design platform) developed at UGE-LESCOT, see Fig. 14.

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This custom-made driving simulator software is based on Unreal Engine 5.4, allowing the creation of well-fitted tailored scenarios in any driving environment.

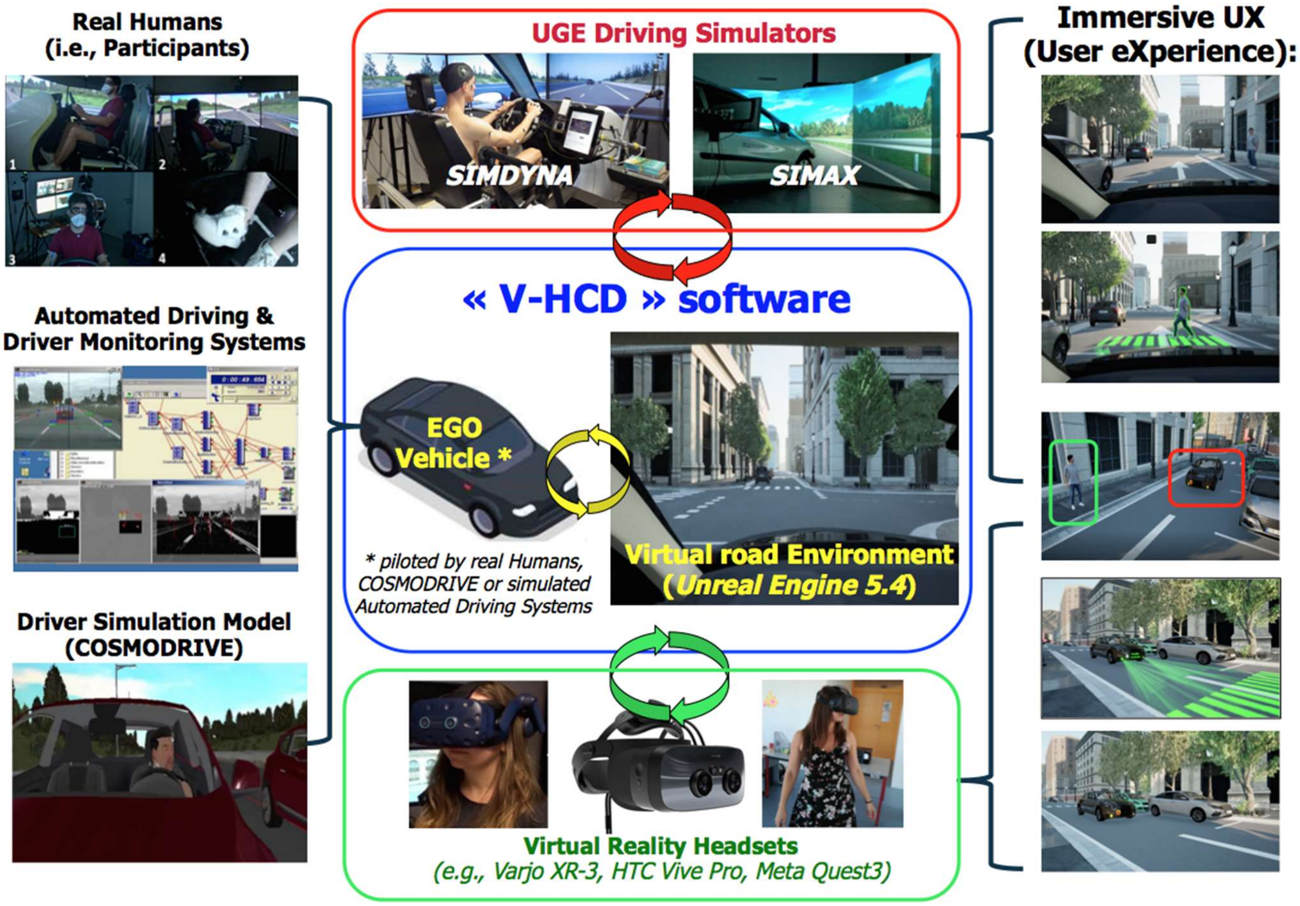

Figure 14. The V-HCD platform (Virtual Human Centred Design) of UGE.

One of the specific features of the V-HCD platform is the inclusion of a virtual "ego vehicle" that can be operated (see Fig. 14) either by a real human manually piloting the ego vehicle of the driving simulator (i.e.; SIMAX or SIMDYNA), by emulated or real algorithms used for automated driving (see [20], [15]) or, finally, by the COSMODRIVE model of UGE - as a digital twin of a human driver when the involvement of human volunteers is not possible. In addition, the V-HCD software is also interfaced with several Virtual Reality Headsets, allowing immersive experiments with external participants (like pedestrians observing or interacting with the ego-car).

The V-HCD was developed at UGE and used in the frame of several French National projects like SURCA (Sécurité des Usagers de la Route et Conduite Automatisée; https://surca.univ-gustave-eiffel.fr/f) and was also shared - as a common simulation platform - between 6 european partners in the H2020 european project SUaaVE (SUpporting acceptance of automated VEhicles, under the grant agreement n° 814999; https://www.suaave.eu), to study interactions between future Automated Cars and Pedestrians [21].

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3.2.2. Objectives, Scope, and Data Acquisition Strategy for Laboratory Tests

The purpose of the driving simulator experiment conducted by UGE is to study risk assessment and decision-making processes during the manual driving of a motor vehicle. To achieve this, participants will be exposed to various driving scenarios derived from the five UCs identified in D1.1 [3] (i.e., collision risk avoidance on highways, highway merging, management of pedestrian crossings in urban areas, turning left at urban intersections with traffic lights, and managing a dangerous cut-in by a third party on an urban highway). The general principle of this experiment will be to confront real human drivers with situations of varying levels of criticality (i.e., presenting a higher or lower collision risk). For each scenario and its associated risk level, the aim will be to examine how participants will assess the situational risk, the decisions they make, and the driving behaviours they adopt to address it (e.g., braking, maintaining their current speed, accelerating, or executing an avoidance manoeuvre).

Link with other BERTHA efforts and deliverables:

The experiment implemented by UGE under the Task 2.3 will be directly based on the work carried out in Tasks T1.1 (selection of five use cases), T1.2 (creation of video scenarios for deploying an online survey to identify different "driver profiles" based on sociodemographic characteristics, behaviours, and driving styles), and T1.3 (focused on identifying situational parameters likely to influence risk assessment and drivers' decision-making).

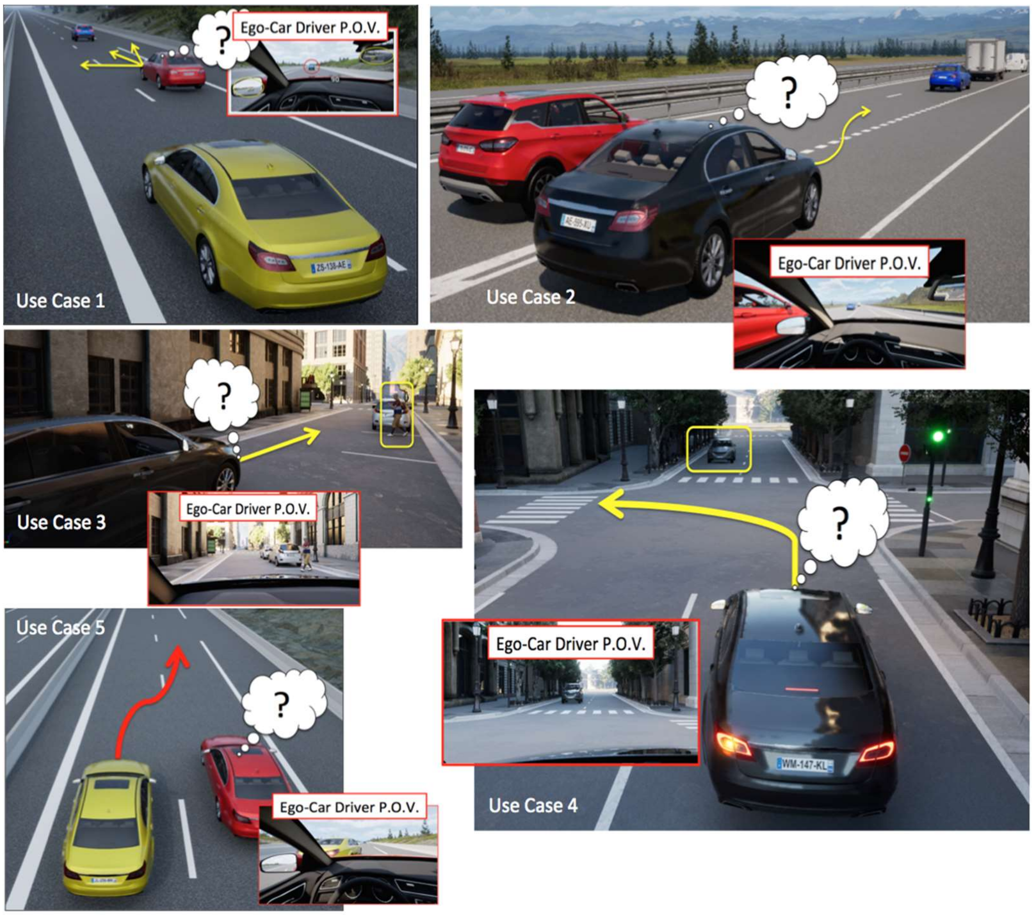

Figure 15. Examples of driving scenarios implemented on the UGE driving simulator with the V-HCD, based on the video demonstrations used in the T1.2 online survey.

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Indeed (cf. figure 15), the scenarios studied by UGE as part of this experiment will be directly based on the video scenarios used in the online survey performed in Task 1.2 (each video scenario having been designed with four variations for a situational parameter impacting its level of criticality). However, unlike the online survey, where participants watched videos and then chose an action between three (or four) proposed alternative behaviours, this experiment performed on a driving simulator will allow us to observe the actual driving behaviours effectively implemented by participants on the ego vehicle commands.

Data collected during the experiment:

The data collected during this experiment will be of four different types and in accordance with the work already performed in WP2 as described in D2.1 [4] (*BERTHA Data Model*) and D2.2 [5] (*Data Format and Common Acquisition Principles*). Thus, at the Université Gustave Eiffel driving simulator, the drivers' actions on the vehicle's commands (pedals, steering wheel, indicators, flashing lights, horn, etc.) will be recorded. Simultaneously, the state of the situation will also be continuously logged (positions and speeds of vehicles interacting with the ego vehicle, inter-vehicular times, time to collision). Additionally, participants will be surveyed using questionnaires to subjectively assess the situational criticality (the subjective risk level as estimated by the participants) and provide a self-assessment of their driving performance. Lastly, eye-tracking data will also be collected using the SmartEye technology, provided it is made available to UGE and is compatible with the technical constraints of the driving simulator used in this experiment.

3.3. DFKI

3.3.1. Overview of Driving Simulator Facilities

DFKI has developed a new advanced driving simulator for BERTHA that combines cutting-edge hardware and software to create an immersive environment for studying driving behaviour, see Fig. 16 and Fig. 17. The simulator setup includes the following features:

Simulator Configuration:

1. **Triple Monitor Display System**: The simulator features three 4K monitors, each running at 30 frames per second (fps), configured to deliver a combined resolution of 5760x1080 pixels. This setup offers a 120-degree panoramic field of view (FoV) for a realistic driving experience.
2. **Rear-view Cameras**: Integrated virtual rear-view cameras allow users to monitor traffic behind them, enabling the study of behaviors like lane changes and rearward situational awareness.
3. **HUD interface**: A heads-up display (HUD) on the middle screen provides critical information, such as driving speed. The speed indicator dynamically changes color based on driving speed, offering users intuitive, real-time feedback.

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4. **Driver Interface**: A cockpit-style seat has a Logitech G923 Steering Wheel and a gear shifter, ensuring precise control and an authentic feel for users.
5. **Frame Rate and Performance**: The system is designed to operate smoothly at 30 fps, optimizing performance for the given hardware and software setup.

Figure 16. DFKI's Driving Simulator Setup.

Figure 17. Eye tracking on DFKI simulator

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Physical Dimensions:

The physical dimensions of the simulator are tailored to accommodate the three large displays, cockpit seats, and adequate user interaction space.

Eye-Tracking Integration:

The simulator employs **Pupil Labs Core eye-tracking glasses** to record user gaze data and egocentric video.

Display of AprilTag Markers:

AprilTag markers are continuously displayed at the bottom of the simulator screens during the session to facilitate accurate gaze alignment within the simulator. The markers are placed strategically to ensure they do not interfere with the user's eye gaze patterns. These markers are fixed spatial references for mapping gaze points within the simulation. The egocentric video captured by the eye-tracking glasses is aligned with the simulator's recording data during post-processing using these markers. This approach enables highly accurate mapping of user gaze and fixation points within the simulated environment.

Temporal Alignment with AprilTags:

The simulator displays a set of AprilTags prominently on the screens just before and after each simulation recording. This step enables temporal alignment between the timestamps of the eye-tracking data and the simulator recordings.

Software and Hardware Components:

Software: The simulator is powered by CARLA, a leading open-source driving simulator widely used for autonomous vehicle research.

Hardware Configuration:

1. **CPU**: AMD Ryzen 9 7950X3D, a high-performance processor designed for demanding simulation workloads.
2. **GPU**: NVIDIA RTX 4090, one of the most powerful graphics cards, ensures high-quality visuals and rendering.
3. **Steering System**: Logitech G923 Steering Wheel offers realistic force feedback and precise controls.
4. **Seat**: Next Level Racing GT Racer seat, designed for comfort and immersion during extended simulation sessions.

Environment Control

The simulator environment is managed using the building's integrated temperature and lighting control systems. This setup allows us to maintain a comfortable ambient room temperature and adjust lighting conditions by operating the automated blinds.

Available UCs:

The simulator can reprogram all currently studied use cases supported by CARLA. Specific scenarios are simulated by leveraging tools such as **Scenario Runner** and **Scenic**, which enable the creation of diverse driving scenarios. These approaches were thoroughly reviewed and endorsed during the Steering Committee meeting in Munich.

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Previous Studies:

The simulator is newly introduced; no prior studies or research have been conducted using this specific setup.

3.3.2. Objectives, Scope, and Data Acquisition Strategy for Laboratory Tests

Primary objective

The main goal of these lab tests is to gather eye gaze attention data in CARLA to develop the perception module for BERTHA. While previous studies [22], [23], [24]) have explored collecting eye gaze data and constructing attention prediction models, they primarily focused on standard driving scenarios and did not address the specific use cases outlined in D1.2. Although [24] did focus on critical situations, the data was selected by maximising KL-divergence from the rest of the dataset. Additionally, earlier research relied on cameras with a narrow field of view. In contrast, these lab tests utilize a wide frontal field of view (120 degrees) and rear-view cameras.

Scope

DFKI simulator is capable of collecting the following types of data:

1. Eye Tracking Data: Includes blink patterns, fixation points, saccades, and other eye movement metrics.
2. Driving Data: Encompasses driving parameters such as speed, angular velocity, and acceleration, as well as driving control inputs like throttle, brake, and steering angle.

Contribution to the Modelling Process

The collected driver fixation patterns, combined with the simulated images, will be used to train a predictive model for the perception module. The module can use this training data to predict where a human driver would focus their attention during driving.

3.4. SEYE

3.4.1. Overview of Facilities

SEYE's research facilities are designed to enable comprehensive driver monitoring and behavior studies under both simulated and real-world conditions. The primary test environment is a CARLA-based driving simulator in the final planning and design phase. This simulation facility (Fig. 18) will feature a multi-screen setup offering a broad field of view utilizing three 75" 4k monitors (total resolution 11520x2160, field of view to be determined after installation), providing a realistic and immersive driving experience. It will incorporate the Smart Eye Pro camera system for advanced eye tracking and driver monitoring and concept development kits to prototype driver and occupant monitoring solutions. Additionally, the

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simulator will be equipped with the full vehicle control interfaces (steering wheel with force feedback, pedals, clutch) Logitech 920 [25][26] and environmental audio effects (e.g., engine revving, collision sounds, wind noise) to enhance authenticity. The simulation environment's detailed climate and lighting are controlled using an air conditioning system and curtains to block out natural light; the design goal is to achieve conditions suitable for replicating scenarios of varying complexity, aligning closely with BERTHA's needs for realistic testing of driver behavior, attention, and decision-making processes.

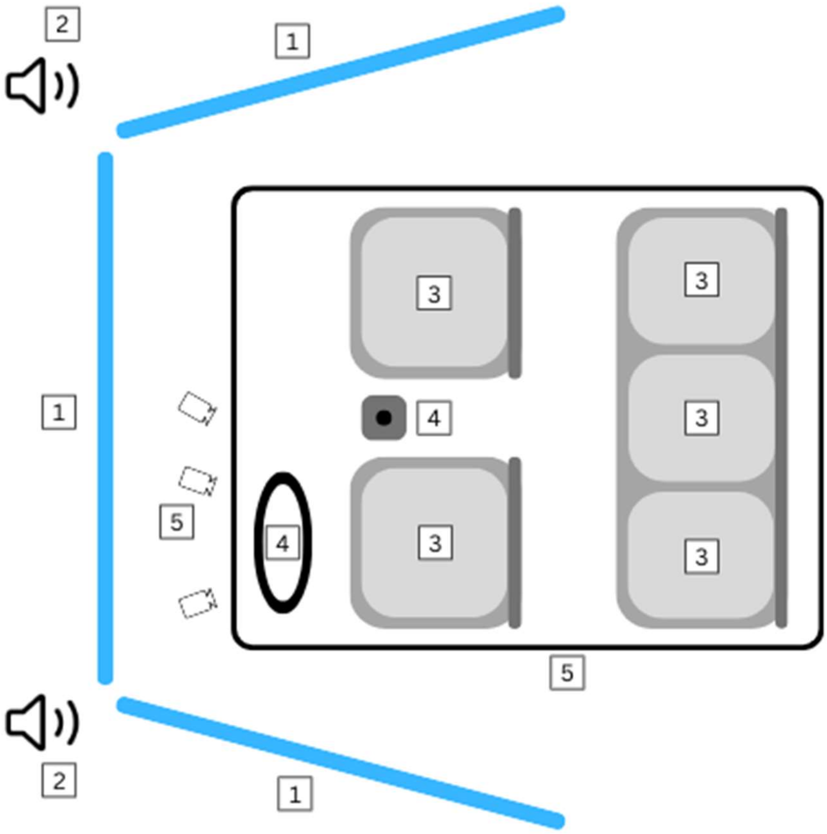

Figure 18. SEYE driving simulator setup sketch. 1. three 75" monitors, 2. speakers, 3. car seats, 4. vehicle control interface (clutch, steering wheel, pedals), 5. SEYE pro cameras.

A key technical component of our setup is the Smart Eye Pro [27], recognized as one of the most advanced remote eye-tracking systems available. With true multi-camera capabilities and research-grade accuracy, it supports the tracking of many driver states, including gaze patterns, head position, and facial expressions. To supplement the driver-centric analysis, SEYE will use iMotions [28], which integrates multiple physiological and behavioral modules (e.g., ECG, EEG, EMG, EDA/GSR, respiration, facial expression, voice analysis) and Affectiva emotion recognition algorithms [29]. These tools can capture a wide array of human responses, enabling the analysis of cognitive load, emotional states, and situational awareness under diverse driving scenarios. The scenario repertoire can range from routine city driving and highway cruising to critical events like sudden pedestrian appearances or complex multi-vehicle interactions—ideal for BERTHA's focus on human-like and context-aware behavior modeling.

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Although the CARLA-based simulator is still under development, previous collaborations and projects within SEYE's ecosystem highlight the facilities' capabilities. For instance, research using the Smart Eye Pro system has been published in multiple transportation safety and human factors studies, demonstrating improved insights into driver attentiveness and workload distribution. Similarly, studies integrating Affectiva's emotion recognition capabilities have been documented in the affective computing literature [30], underlining the system's reliability and relevance for assessing driver emotions and facial cues. While the exact environmental conditions (lighting, sound fidelity, and temperature control) are being finalized, SEYE's ultimate goal is to create a fully instrumented environment that has already been successfully applied to contexts similar to BERTHA's scope—where human-like, context-adaptive driver behavior is paramount.

3.4.2. Expected Data Acquisition

From SEYE's facilities and technologies, it is possible to capture various behavioral, physiological, and performance-related data. Key data types include:

- **Visual Metrics**: Gaze direction, pupil dilation, blink frequency, and facial expressions via Smart Eye Pro and Affectiva.
- **Physiological Signals**: EEG, ECG, EMG, EDA/GSR, respiration, and voice analysis through the iMotions platform.
- **Driver Performance Data**: Steering wheel angles, pedal inputs, reaction times, trajectory planning, and speed profiles were recorded directly from the simulator and, later, from the research vehicle's sensor suite.
- **Environmental and Contextual Data**: Vehicle kinematics, GPS data, IMU readings, lane invasion detection, lidar, radar and interactions with virtual or real traffic participants.

3.5. Driving Simulator Scenarios Standards

In D2.1 [4], we presented time reference and spatial reference systems as essential for data aggregation and standard processing. Additionally, in D2.2 [5], partners provided comprehensive guidelines and best practices for data collection to ensure the success of the driving data acquisition stages, as illustrated in Fig. 4.

Building upon these foundational agreements on references and standard processes, we aim to deepen BERTHA's collaboration by selecting and sharing standardised scenarios among partners for BERTHA based on the five UCs defined in D1.1 [3]. Despite the diversity in our driving simulator setups, as outlined in Section 3, our commitment is to enable comparable results in the Lab Test experiments. Defining these standardised scenarios is essential to ensure all participants have an equal and fair experience during the experiments.

As a reminder from D1.1 [3], a UC provides a generic depiction of a "situational interaction" between the ego-vehicle (to be piloted by the Driver Behavior Model) and other road users (e.g., cars, pedestrians) exhibiting specific behaviours. In contrast, a Scenario is a particular

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instance of a UC, see Fig. 19, specifying concrete parameters such as positions, speeds, and behaviours of the ego-vehicle and other road users. It describes the development of a situation within a traffic context where at least one actor performs a predefined action or is triggered by a predefined event.

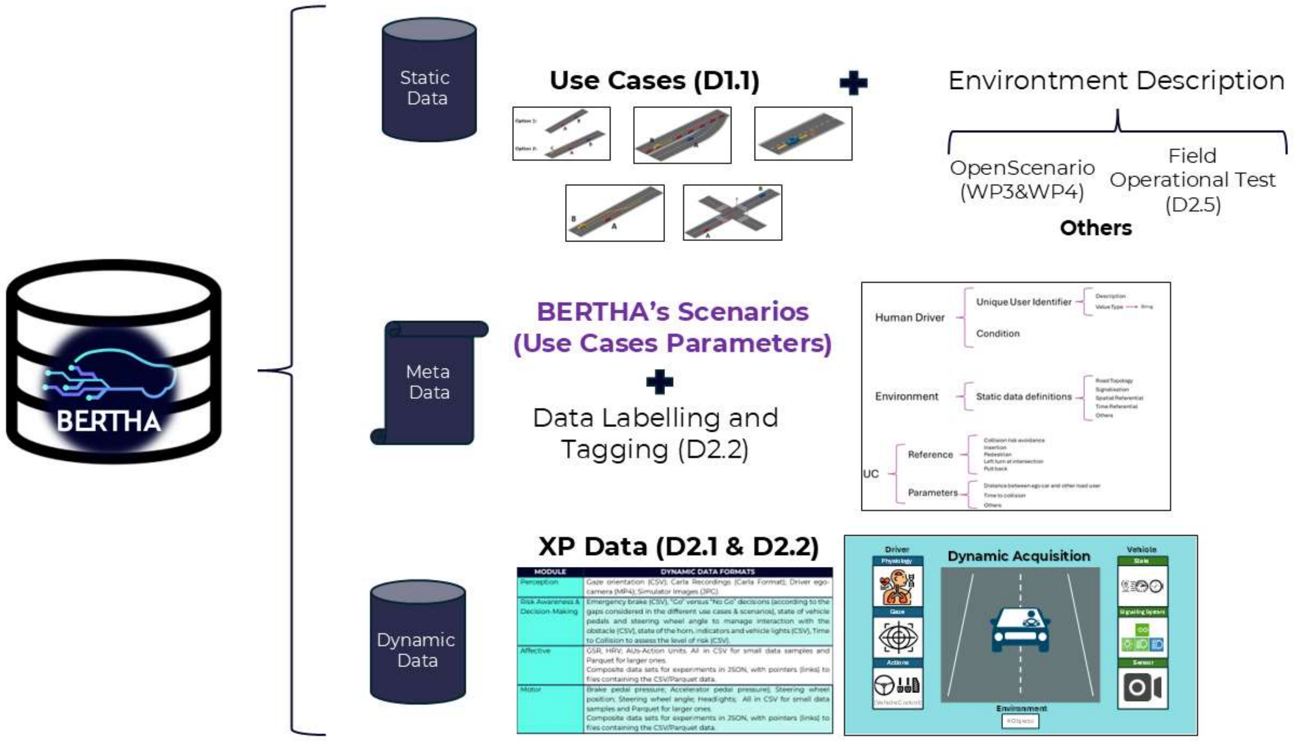

Figure 19. The metadata is particularly significant as it links to BERTHA's scenarios, representing UC variations. The scenarios focus on specific instances, defining concrete parameters like vehicle positions, speeds, and the behaviours of road users.

When conducting the scenario design for the Lab Test, the following aspects should be considered:

- **Alignment with the Five UCs Defined in D1.1**: Ensuring that each scenario corresponds to a specific Use Case to maintain consistency and relevance.
- **Definition of Concrete Parameters**: Specifying positions, speeds, or behaviours for the ego-vehicle and other road users to create precise and reproducible scenarios. Variations in these parameters allow the exploration of different driver responses.

In D1.2 [14], we discussed and selected scenarios based on variations of parameters associated with specific UCs, as shown in Fig. 4. In the current D2.3, we build upon this work by integrating these scenarios into the basic laboratory test.

To develop the framework in D1.2, AIT designed a comprehensive survey about driving habits and preferences administered to 1,200 participants across five countries. The rest of BERTHA's

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partners translated and supported the survey to ensure cultural relevance and accurate representation. In addition to gathering general information and sociodemographic data, the survey aimed to measure drivers' experiences, reactions, and preferences in various driving situations. This data enabled AIT to perform statistical analyses for clustering drivers and identifying patterns.

The video scenes were created by UGE, ensuring homogeneous and immersive environments in which to observe driver behaviour in specific situations. These experiments offered valuable insights into how drivers might react in the five explicitly defined UCs from D1.1 [3]. More details on these methodologies can be found in the corresponding deliverables.

As previously mentioned, the scenarios defined in D1.2 depend on variations of important parameters, precisely the distance between the ego vehicle and dynamic road users such as pedestrians, cyclists, or other vehicles. The variations for each UC are as follows:

- **UC1 Collision Risk Avoidance**: Variation of the **distance** between the ego vehicle and a leading vehicle on the highway right lane. We also consider as variation the **emergency manoeuvre** the driver of the ego-car could execute.
- **UC2 Insertion on Highway**: Variation of the **distance** between the ego vehicle and a gap car (another vehicle creating a slightly more significant gap in traffic).
- **UC3 Pedestrian Crossing**: Variation of the **distance** between the ego vehicle on an urban road and a pedestrian walking on adjacent sidewalks.
- **UC4 Left Turn at Urban Intersection (with Traffic Lights)**: Variation of the **distance** between the ego vehicle making a left turn and an oncoming road user. Uniquely, in this UC, we also vary the type of the oncoming **road user**, whether a vehicle or a cyclist. This dual variation in both distance and the nature of the other road user adds complexity to the scenario, affecting the driver's perception of risk and the decision-making process.
- **UC5 Pull Back in**: Variation of the **distance** between an overtaking vehicle on the left lane of a double-lane road and the leading ego vehicle.

Each variation results in different instances for each UC, as shown in Fig. 20, which is significant because the level of risk and the required reaction time can vary, impacting drivers' situation awareness and decision-making processes. As highlighted in D1.3 [13], situational criticality is crucial in determining driving outputs—especially under time pressure or in high-risk situations. For instance, limited time to react can lead to faster decision-making but may increase the likelihood of overlooking important information, potentially resulting in inappropriate responses by the driver.

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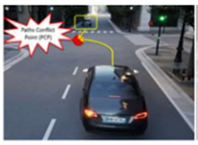
- **Speed of Ego/Lead Car:** 90 kph
- **Lane:** Right lane of a two-lane highway
- **Initial Inter-Vehicular Time (IVT) between Ego Car and Lead Car:** 1.8 s
- **Final IVT before stopping:** 0.55 s
- **Final Time to Collision (TTC):** 0.66 s
- **Speed of Overtaker:** 90 kph
- **Camera angle:** 115° (57.5° per side from center)

- **Speed of Ego Car on entry lane:** 50 kph
- **Speed of vehicle in right lane:** 40 kp
- **Camera angle:** same as UC1.

- **Speed of Ego Car:** 30 kph
- **Speed of Pedestrian:** 5.4 kph
- **Time to Paths Conflict Point (TPCP) for Ego Car:** 0.6 s
- **Camera angle:** 110° (55° per side from center)



- **Speed of Ego Car:** 23 kph when the video stops
- **Speed of oncoming car:** 43.2 kph
- **Speed of oncoming bicyclist:** 21.6 kph
- **Time to Paths Conflict Point (PCP) for Ego Car:** 0.8 s
- **Camera angle:** same as UC3.

- **Speed of Ego Car:** 90 kph
- **Time between Ego Car and Lead Car:** 2 s
- **Overtaker:** 100 kph
- **Camera angle:** same as UC3.

Instance (Critical ↑)	UC1 (Distance Overtaker and Ego car)	UC2 (Gap distance)	UC3 (TPCP)	UC4 (PCP)	UC5 (Distance Overtaker and Ego car)
1	10m (IVT = 0.4s)	IVT of 1s (Gap = 11m)	2s	8m	25cm (IVT = 0.01s)
2	20m (IVT = 0.8s)	IVT of 1.6s (Gap = 17.6m)	2.4s	18m	2.5m (IVT = 0.1s)
3	30m (IVT = 1.2s)	IVT of 2.2s (Gap = 24.2m)	2.8s	28m	5m (IVT = 0.2s)
4	40m (IVT = 1.6s)	IVT of 2.8s (Gap = 30.6m)	3.2s	38m	7.5m (IVT = 0.3s)

Figure 20. Video scenarios for D1.2 [14]. On the table we can see the key parameters that define the scenarios while the static parameters are the ones under each UC image. For a deeper discussion, check D1.2 [14].

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4. LAB TEST PLANNING

This section presents the comprehensive plans for the upcoming laboratory tests by IBV, UGE, DFKI, SEYE, and CON. The planning details include test schedules, key milestones, participant characteristics when possible, and how the collected data will support BERTHA's objectives and potentially contribute to industry standards.

Each partner's breakdown, including timelines, is provided to ensure transparency and coordination. The collected data from these tests will support the homologation process for ADAS/AD systems and may inform potential enhancements to existing standards in BERTHA's WP5.

4.1. IBV

4.1.1. Planning of Tests and Test Schedule

IBV initiated preliminary user testing of the Affective module approximately four months before month 10 (around June 2024). Formal laboratory tests have been ongoing since June 2024, and additional experiments are scheduled over the following months, with data gradually becoming available to partners shortly thereafter during 2025.

Specifically, preliminary user testing of the Affective module was conducted between June and September 2024, simultaneously initiating formal laboratory tests to assess changes in the Central Nervous System (CNS) and Autonomic Nervous System (ANS) for estimating affective states such as fatigue, drowsiness, mental stress, and emotions. Additionally, further experiments are scheduled from January to July 2025, including motor control module identification and additional affective module tests, ensuring comprehensive data collection and validation of the modules. For more information, check the last annexe of this deliverable.

4.1.2. Sampling of Participant Characteristics

Participants are selected with inclusion criteria designed to represent diverse profiles (e.g., balanced gender distribution, a range of ages from younger adult to older adult drivers, and a variety of anthropometric characteristics) to ensure comprehensive calibration and validation of the modules. This approach is intended to capture a realistic sample of driver types, supporting the robustness and applicability of the results across different user groups.

Therefore, IBV's participants will represent a broad demographic range, spanning from approximately 25 to 60 years old. Additional anthropometric criteria (e.g., height, body mass) will be considered to ensure diverse and representative samples, aligned with the experimental protocols approved by the Ethical Review Board.

Additionally, participants must hold an active driver's license for relevant testing phases. Exclusion criteria eliminate individuals suffering from mental illnesses, cognitive disabilities, those taking specific medications (including blood pressure medications, psychostimulants, anxiolytics, or antidepressants), professionals in sensitive occupations (e.g., psychologists,

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doctors, nurses) to avoid biases, among other exclusions. For more information, check the last annexe of this deliverable.

4.2. UGE

4.2.1. Planning of Tests and Test Schedule

UGE plans to prepare the necessary elements for experimentation between late 2024 and the first quarter of 2025, allowing for pre-experimental tests to be conducted in the first quarter of 2025. Following this, the experiments will be carried out during the first semester of 2025.

4.2.2. Sampling of Participant Characteristics

All the participants involved in the UGE experiment (50% women / 50% men) will have a valid driving licence, and will be aged from 20 to 65 years old (with a main sub-group of middle-aged drivers from 25 to 45 years old).

4.3. DFKI

4.3.1. Planning of Tests and Test Schedule

The planned start date for the experiments is December 20th, 2024. It is expected that a total of 25 participants will take part in the study.

4.3.2. Sampling of Participant Characteristics

The selection criteria for participants include a minimum of 5 years driving experience and a valid driving licence. Participants must also be able to drive in the simulator without glasses due to the limitations of the eye tracker. The age range for eligible participants is between 23 and 65 years.

4.4. SEYE

4.4.1. Planning of Tests and Test Schedule

The development and deployment of SEYE's CARLA-based simulator are progressing towards a target operational date of March 2025. A dedicated room has been allocated, and design work is well underway. Planned modifications to CARLA include implementing multi-screen support for enhanced immersion and integrating engine sound effects to improve immersion. These preliminary adjustments will be completed by January of 2025, allowing initial test runs to begin in early 2025. The goal is to finalize core system functionalities and validate the driving scenarios by March 2025.

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For the BERTHAS test vehicle, the timeline targets readiness in May 2025. A suitable base vehicle will be available in February 2025 (final model selection pending). During the following months, SEYE will integrate throttle and brake control modules and incorporate a vision-based system for lane and vehicle detection. Initial calibration and preliminary tests are planned for March–April 2025, with full system testing and data acquisition commencing thereafter. The collected data will be delivered to project partners in mid-2025, following the initial analysis phase.

4.5. CON

4.5.1. Data Review and Validation

CON's primary role is to ensure that the data gathered from lab-based tests directly applies to the homologation and certification processes for ADAS/AD systems. This involves a structured approach to reviewing, filtering, and validating the experimental outputs to align with recognized standards such as Euro NCAP and the evolving requirements of regulatory bodies. By examining relevant test techniques and use cases drawn from BERTHA's developments, CON aims to identify which test procedures and parameters genuinely reflect real-world conditions, particularly in mixed-traffic scenarios and situations that challenge human-driver behavior.

Initial efforts, guided by bi-weekly workshops since February, focus on gathering input from various work packages (notably WP1) to refine scenario selection and ensure that critical aspects of driver-vehicle interactions are thoroughly captured. Although the information collection phase encountered a two-month delay, CON plans to maintain momentum and incorporate these inputs into a first draft of recommendations by early 2025. From these scenarios, CON will identify the potentially needed additions or amendments to existing standards—facilitating the translation of simulated or controlled test results into actionable, industry-wide criteria. As a result, the lab data will not only verify technical system performance but also serve as evidence supporting the homologation process for advanced driver assistance and automated driving functionalities.

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5. CONSOLIDATED DATA SHARING AND VALIDATION FRAMEWORK

5.1. BERTHA's Data Sharing Overview

In the BERTHA project, effective data sharing is crucial for developing the DBM and ensuring the overall success of collaborative efforts. During recent discussions among partners during the third reunion in Germany, it was collectively agreed that while not all data needs to be shared universally, the data integrated into BERTHA's centralized data solution will be accessible to all consortium members. This ensures that essential information for developing the DBM is available to support BERTHA's shared objectives.

5.1.1. Storage and Access Guidelines

VED is developing a solid data solution powered by Big Data technologies to facilitate this. The initial prototype of this database (Deliverable D2.6) is scheduled for completion by Month 18 (M18). Following its delivery, partners will have a two-month period to update and test data integration.

VED's data solution for BERTHA incorporates a suite of tools, as seen in Fig.21, engines, and platforms:

- **Hadoop** [31]: An open-source framework that provides scalable and distributed data storage and processing of large data sets across clusters of computers, managing large volumes of data efficiently.
- **Spark** [32]: A fast, in-memory data processing engine that enables quick and efficient big data analysis, critical for handling the velocity and variety of data we anticipate.
- **Jupyter Notebooks** [33]: Offers interactive data visualization and exploration, aiding in collaborative analysis and understanding of datasets.
- **Apache NiFi** [34]: Automates and manages the flow of information between systems, representing data flows as directed graphs on a web-based user interface, ensuring seamless data integration and transformation between diverse data sources and Hadoop.
- **Docker Containers** [35]: A platform that packages applications into portable containers, ensuring consistent and efficient deployment across various environments, enhancing BERTHA's data solution applications' portability and reliability.

This integrated Big Data framework addresses the challenges characterized by the six V's of Big Data: Volume, Velocity, Variety, Veracity, Vulnerability, and Value [36]. By utilizing these technologies, we can effectively manage the immense datasets required to train BERTHA's DBMs. Such an approach is prevalent in automated vehicles and is employed by leading research institutions like CERN [37], demonstrating its reliability and scalability in complex data environments.

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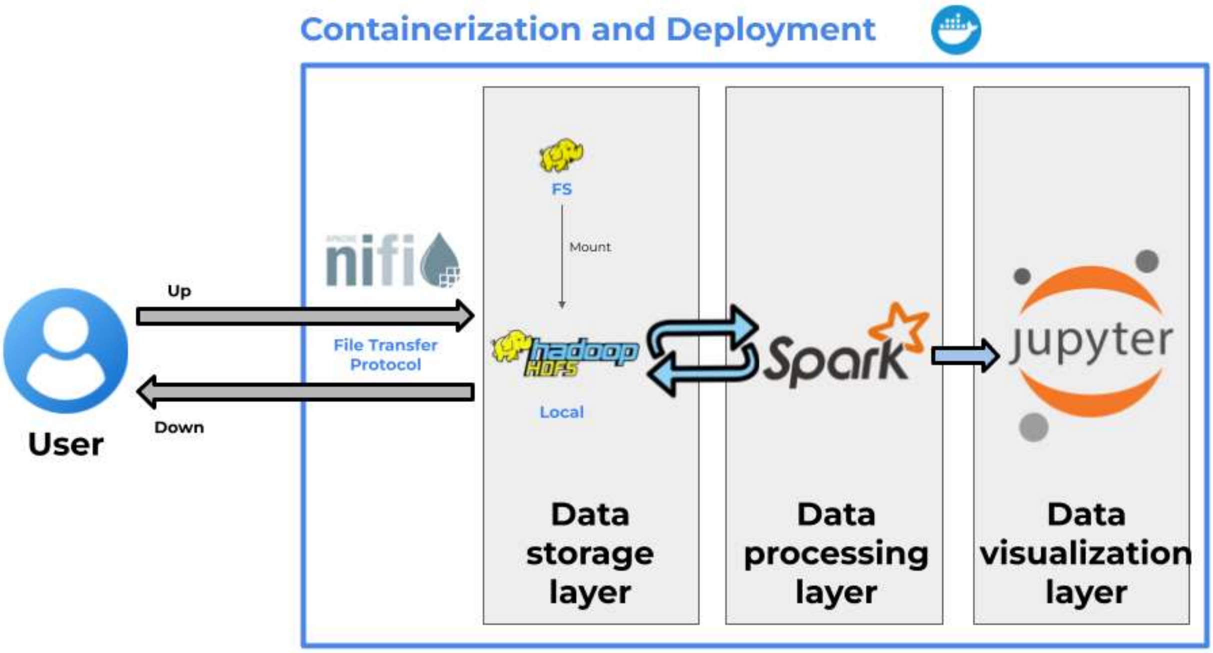

Figure 21. BERTHA's centralized big data solution architecture. Big Data refers to large, complex, multimodal datasets that could come from different signals and sensors. Several tools are needed to process all this information and manipulate this data.

All partners will receive access to the data solution upon finalizing the necessary agreements, promoting transparency and collaboration within the consortium. The data to be shared includes:

- **Type of Data**: Experimental results, simulation data, and relevant metadata necessary for the scenario identification and the DBM development.
- **Format**: Standardized formats compatible with the Big Data tools (e.g., CSV, JSON). For more information, check D2.2 [5].
- **Access Conditions**: Data will be accessible to all partners through secured credentials, adhering to agreed-upon data governance and privacy policies. For more information, check D6.8 [38].

By defining these storage and access guidelines, we aim to establish appropriate sharing protocols that align all parties regarding data management. This ensures that every partner can contribute to and benefit from the collective data resources, ultimately increasing the quality and effectiveness of the BERTHA project's outcomes.

5.1.2. Integration of WP2 and WP3 for Enhanced Functionality

From the HUB to the data solution, a pipeline could be established to access and take the data from both the modules, as seen in Fig. 22. This integration facilitates seamless data exchange, ensuring all relevant information is available for collaborative development and analysis. For more information regarding the HUB, refer to D3.1 [39].

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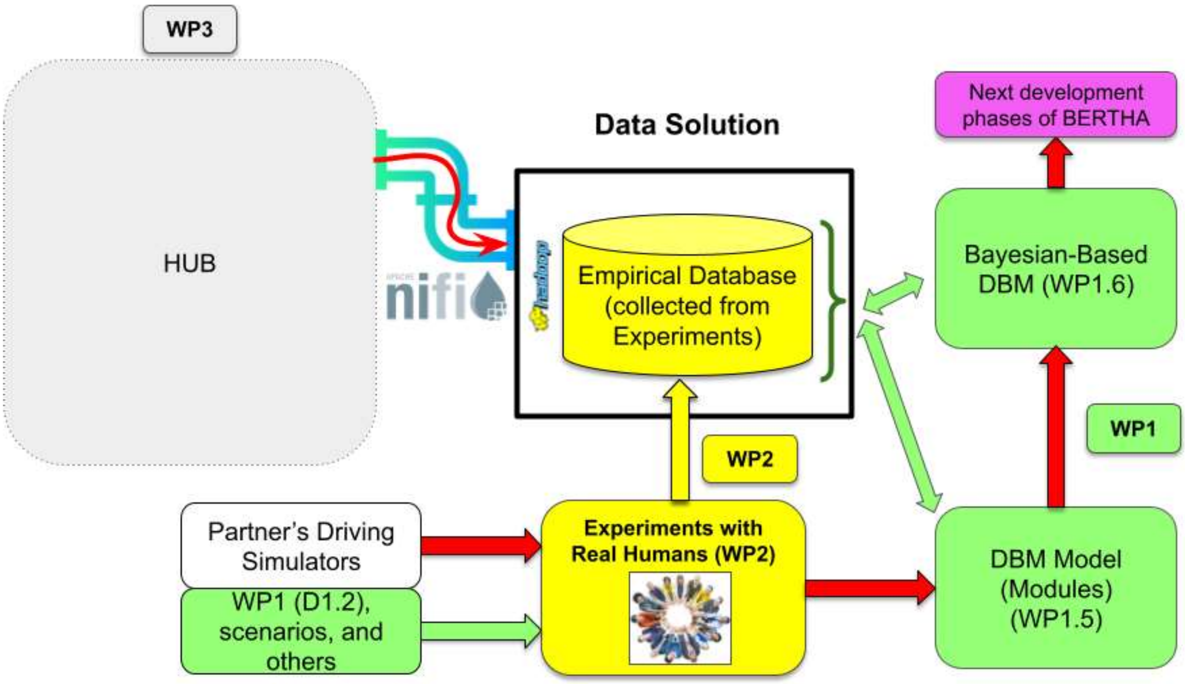

Figure 22. Data Solution Integration with WP3. The data solution enables the utilization of empirical data from WP2 in developing the DBM, particularly during the initial phases of BERTHA in WP1. This solution will comprise the empirical database (data collected from module experiments as explained in this document). A pipeline from the HUB to the database could be established as a new developing phase of BERTHA's data solution, allowing seamless access to data using tools such as NiFi.

This future integration between the HUB and the data solution will provide an efficient and collaborative environment for data sharing that respects privacy regulations and accommodates partners' specific technical requirements. For more information about data sharing requirements, refer to D2.2 [5], and D3.1 [39].

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6. CONCLUSIONS

This deliverable presents a comprehensive framework for the basic laboratory testing and data collection efforts integral to the BERTHA project. Building upon the foundational work outlined in previous deliverables—specifically D1.1 [3], D1.2 [14], D2.1 [4], and D2.2 [5]—we have established standardized guidelines and methodologies to ensure the systematic, safe, and reproducible collection of high-quality data involving human participants in the first phase of the laboratory tests.

By detailing the capabilities and planned activities of IBV, UGE, DFKI, SEYE, and CON, we have outlined a coordinated approach to conducting laboratory tests using advanced driving simulators. Each partner's commitment to aligning their simulator scenarios with the five UCs defined in D1.1 [3] ensures consistency and comparability across different experimental setups. This alignment is crucial for generating relevant and actionable data for DBM development.

A significant milestone achieved in this deliverable is the consensus among partners regarding data sharing and collaboration in the data solution. Recognizing the importance of collective access to data for the successful development of the DBM, partners have agreed that the data integrated into BERTHA's centralized data solution will be accessible to all consortium members. This agreement not only facilitates transparency and cooperation but also increases the efficiency of collaborative efforts.

We are implementing a data solution using advanced Big Data technologies to effectively manage the vast and complex datasets required for the DBM. The integration of platforms such as Hadoop for scalable storage, Spark for rapid data processing, Jupyter Notebooks for interactive data exploration, Apache NiFi for data flow management, and Docker containers for consistent deployment environments. This approach aligns with industry best practices.

In conclusion, this deliverable marks an important step forward in the BERTHA project:

- Establishing standardized laboratory test guides and first reference scenarios aligned with defined UCs
- Detailing the planning and execution strategies of each partner for upcoming laboratory tests.
- Achieving consensus on data sharing policies, ensuring that essential data is accessible to all partners.
- We are implementing an advanced Big Data framework to manage and process the datasets necessary for developing the DBM.

These collective efforts lay a solid foundation for the subsequent phases of the project. The data and insights garnered from these laboratory tests will not only advance the BERTHA project's objectives but may also inform potential enhancements to industry standards and the homologation process for ADAS/AD systems in WP5.

Continued adherence to the established protocols, timelines, and collaborative agreements will be essential as we move forward. More updates are expected for D2.4. The following steps involve executing the planned laboratory tests, as the complete definition of protocols in D2.4.

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8. ANNEXES

8.1. Annex 1: Complete IBV test planning and samplings

8.1.1. Planning of Test and Test Schedule

8.1.1.1. Tests already achieved

Determination of the Affective Module

This test has been carried out between June to September 2024. The objective has been the use of the changes produced in the CNS and ANS to estimate the probability of being in each of these states:

- Active/passive fatigue.
- Drowsiness.
- Mental stress.
- Mental workload (demand level).
- Attention/distraction (concentration level).
- Emotion: anger/sadness/pleasure/calm.

Calibration of the Affective Module in the Simulator

This test has been carried out in November 2024. The objective of the test was to assess whether the affective module was reliable under the simulator. For this reason, a specific test has been carried out on the simulator to elicitate several states:

- Active fatigue.
- Mental stress.
- Mental workload.

8.1.1.2. Coming Tests

Motor Control Module Identification

These tests will take place from January to April 2025.

Determine the state variables of the motor control module under the use cases of BERTHA. The experiments will be block-designed with several changing factors in different use cases. In particular:

- UC2 Insertion on Highway.
- UC4 Left Turn at Urban Intersection.
- UC5 Pull Back in.

Affective Module Identification

These tests will take place from April to July 2025.

Determine how the parameters from the environment influence the affective state of the driver—taking into account driver characteristics of age, skill, and experience.

It will be based on the use cases of BERTHA. Several factors will be taken into account.

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8.1.2. Sampling of Participants Characteristics

8.1.2.1. Tests already achieved

Determination of the Affective Module

The sample will consist of 40 adult participants (men and women) between 25 and 60 years old who meet the following inclusion and exclusion criteria:

Inclusion criteria:

- Participants must be healthy individuals who have not:
- Consumed any stimulant or relaxant substances 4 hours before participating in the study.
- Performed intense physical exercise 24 hours before participating in the study.
- Smoked 4 hours before participating in the study.
- Consumed alcohol 24 hours before participating in the study.

Exclusion criteria:

- Suffering from a mental illness.
- Having a cognitive disability.
- Working shift schedules that involve nighttime hours.
- Possessing electronic implants (e.g., insulin pumps, cochlear implants).
- Taking medications for blood pressure, psychostimulants, anxiolytics, or antidepressants.
- Allergies to components of the sensors (gels, adhesives, etc.) or skin hypersensitivity.
- Facial tattoos or other severe facial skin alterations (burns, keloids, etc.).
- Occupations as a psychologist, doctor, or nurse.

Calibration of the Affective Module in the Simulator

The sample is a sub-sample of 10 adults who have participated in the test of the determination of the affective state.

In addition to the inclusion and exclusion criteria of the previous point, the participants should have an active driver's license.

8.1.2.2. Coming Tests

Motor Control Module Identification

The sample will consist of 12 adult participants (men and women) between 25 and 60 years old who meet the following inclusion and exclusion criteria in the test of calibration of the affective state.

Inclusion criteria:

- An actual valid driver's license.
- Individuals have not:
- Consumed any stimulant or relaxant substances 4 hours before participating in the study.
- Performed intense physical exercise 24 hours before participating in the study.

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- Smoked 4 hours before participating in the study.
- Consumed alcohol 24 hours before participating in the study.

Exclusion criteria:

- Suffering from a mental illness.
- Having a cognitive disability.
- Working shift schedules that involve nighttime hours.
- Possessing electronic implants (e.g., insulin pumps, cochlear implants).
- Taking medications for blood pressure, psychostimulants, anxiolytics, or antidepressants.
- Allergies to components of the sensors (gels, adhesives, etc.) or skin hypersensitivity.
- Facial tattoos or other severe facial skin alterations (burns, keloids, etc.).
- Occupations as a psychologist, doctor, or nurse.

Affective Module Identification

The sample will consist of 12 adult participants (men and women) between 25 and 60 years old who meet the same inclusion and exclusion criteria as in the test of calibration of the affective state.

Inclusion criteria:

- An actual valid driver's license.
- Individuals have not:
- Consumed any stimulant or relaxant substances 4 hours before participating in the study.
- Performed intense physical exercise 24 hours before participating in the study.
- Smoked 4 hours before participating in the study.
- Consumed alcohol 24 hours before participating in the study.

Exclusion criteria:

- Suffering from a mental illness.
- Having a cognitive disability.
- Working shift schedules that involve nighttime hours.
- Possessing electronic implants (e.g., insulin pumps, cochlear implants).
- Taking medications for blood pressure, psychostimulants, anxiolytics, or antidepressants.
- Allergies to components of the sensors (gels, adhesives, etc.) or skin hypersensitivity.
- Facial tattoos or other severe facial skin alterations (burns, keloids, etc.).
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