BERTHA

D2.4. Updated methodology for advanced technology acquisition

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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°	D2.4
Deliverable title	D2.3 - Updated methodology for advanced technology acquisition.
Lead beneficiary	VED
Work package and task	WP2 Task 2.3
Document version	1.0
Contractual delivery date	M16
Actual delivery date	M17
Dissemination Level	PU-Public
Purpose	This deliverable outlines the framework for BERTHA's high laboratory tests and experimental protocols, detailing the facilities, key technologies, and sensor integration aspects while building on previous deliverables such as D2.3. It provides a comprehensive overview of methodological approaches, including experiment-specific protocols across partners, standardized data acquisition methods, and the sharing and future applications of collected data.

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Document's abstract

This document presents the updated methodology for developing BERTHA's simulation platforms that use advanced technologies to capture driver behavior. It builds upon D2.3, outlines high laboratory test facilities and experimental protocols, and continues the comprehensive data acquisition. The document addresses the technical integration of additional sensors by employing advanced simulation techniques, ensuring the approach is aligned with safety and ethical standards.

A concise analysis of the implemented methodologies reveals the data acquisition across multiple experimental protocols, emphasizing the diverse sensor usage, and the systematic collection of objective and subjective data. The document ultimately provides a strategic framework for collaboration between BERTHA's partners. It serves as a detailed roadmap for further revisions and integration efforts, ensuring that future iterations continue to refine and validate the simulation processes.

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	2025/01/22	Initial Draft after KoM	C. Perdomo (VED)
V.0.2	2025/01/29	Template and guide questions for section 2 and 3. IBV inputs as guide.	C. Perdomo (VED); Juan-Manuel Belda (IBV), Victor de Nalda (IBV)
V.0.3	2025/02/07	Draft of UGE contribution	T. Bellet & J.C. Bornard (UGE)
V.0.4	2025/02/10	Draft of DFKI contribution	Jason Rambach (DFKI)
V.0.5	2025/02/11	Draft of SEYE contribution	Martin Bergström (SEYE)
V.0.6	2025/02/12	Draft of introduction and introduction of section 2.	C. Perdomo (VED)
V.0.7	2025/02/25	Review of inputs in section 2. Re-structure of section 3. DFKI, SEYE, and UGE inputs in section 3. Contributions of AIT and EUR at the end of section 3.	C. Perdomo (VED); T. Bellet & J.C. Bornard (UGE); Martin Bergström (SEYE); Shreedhar Govil (DFKI).
V.0.8	26/02/2025	Input at the end of Section 3 regarding AIT and EUR contribution.	C. Perdomo (VED), Steve Pechberti (VED); Sébastien Lacrampe (EUR); Kristin Tovaas (AIT).
V.0.9	07/03/2025	Final inputs section 3.	T. Bellet & J.C. Bornard (UGE); Shreedhar Govil (DFKI); Martin Bergström (SEYE); Ursula Martinez Iranzo (IBV)
V.0.95	10/03/2025	Final inputs section 3. Last suggestions. First references and image revision. Proof-reading.	Shreedhar Govil (DFKI); Martin Bergström (SEYE); Victor de Nalda (IBV); C. Perdomo (VED).

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V.0.99	12/03/2025	Final inputs for motor control. Final revision of SEYE inputs. Final revision of AIT inputs. Arrange of reference. Changes on titles Section 4. Final proof read before review. Page numeration.	Juan-Manuel Belda (IBV); Martin Bergström (SEYE), Svitlana Finér (SEYE); Martin Zach (AIT); C. Perdomo (VED).
V.1.0	20/03/2025	Fix Layout	Helios De Rosario (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
DBM	Driver Behaviour Model
BBNs	Bayesian Belief Networks
HLTs	High laboratory tests

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1. INTRODUCTION AND OBJECTIVES

For the successful deployment of Connected, Cooperative, and Automated Mobility (CCAM), tools and technologies are required that enable the digital design and analysis of these components through a shared, standardized framework. However, a critical gap in this domain is the lack of a scientifically grounded Driver Behaviour Model (DBM) that comprehensively reflects human driving performance. Consequently, building on insights from previous deliverables [1], [2], [3], the BERTHA project seeks to close this gap by developing a scalable and probabilistic DBM [4] that leverages Bayesian Belief Networks (BBNs) [5], [6], [7], [8] as its foundational methodology.

We established foundational concepts for developing driver behavior models in previous project phases and began preliminary data collection and defining performance indicators. Building on those efforts, this deliverable (D2.4) details the High Laboratory Test and associated experimental protocols, ensuring standardized data acquisition and ethical handling of human data across project partners. By using advanced sensor technologies and well-defined procedures, these High Laboratory Tests provide the empirical basis for refining and validating the project's DBMs in subsequent tasks.

1.1. Purpose and Scope

The principal purpose of D2.4 is to detail the advanced data acquisition procedures employed in controlled laboratory environments. These procedures target the collection of human driver data pertinent to the development of the DBM in the WP1.

This document outlines the necessary equipment, methodologies, and experimental protocols. It ensures that the resulting datasets in the experimental phase of BERTHA capture the diverse scenarios and critical aspects of driver behavior needed to build accurate, probabilistic BBNs. The scope includes the description of key technologies, research questions, and experimental methods. It also addresses how these approaches will facilitate multi-partner collaboration and support subsequent data sharing, and analysis within the broader BERTHA framework.

1.2. Relation to Previous Deliverables

This deliverable continues the work started in earlier project documents:

- **D2.2** [3] sets out important data formats, labeling conventions, and ethical considerations for data collection. Here, we adhere to those requirements while adding detailed experimental protocols to ensure reproducibility and consistency across sites.
- **D2.3** [9] provided an initial overview of the experimental design and sensor technologies. **D2.4** builds on these foundations by detailing how these technologies will be deployed in high laboratory test environments.

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- The work in this deliverable is directly linked to **Tasks 1.5 and Tasks 1.6**, which transform the collected data into model components and probabilistic representations of driver behavior. The resulting datasets and protocols will ultimately feed into **D2.7**, where final data acquisitions and model validations will be consolidated.

By clearly indicating how D2.4 interacts with these previous and forthcoming deliverables, we ensure that the project's experimental efforts align closely with its overall objectives, culminating in a seamless DBM development, as shown in Fig. 1.

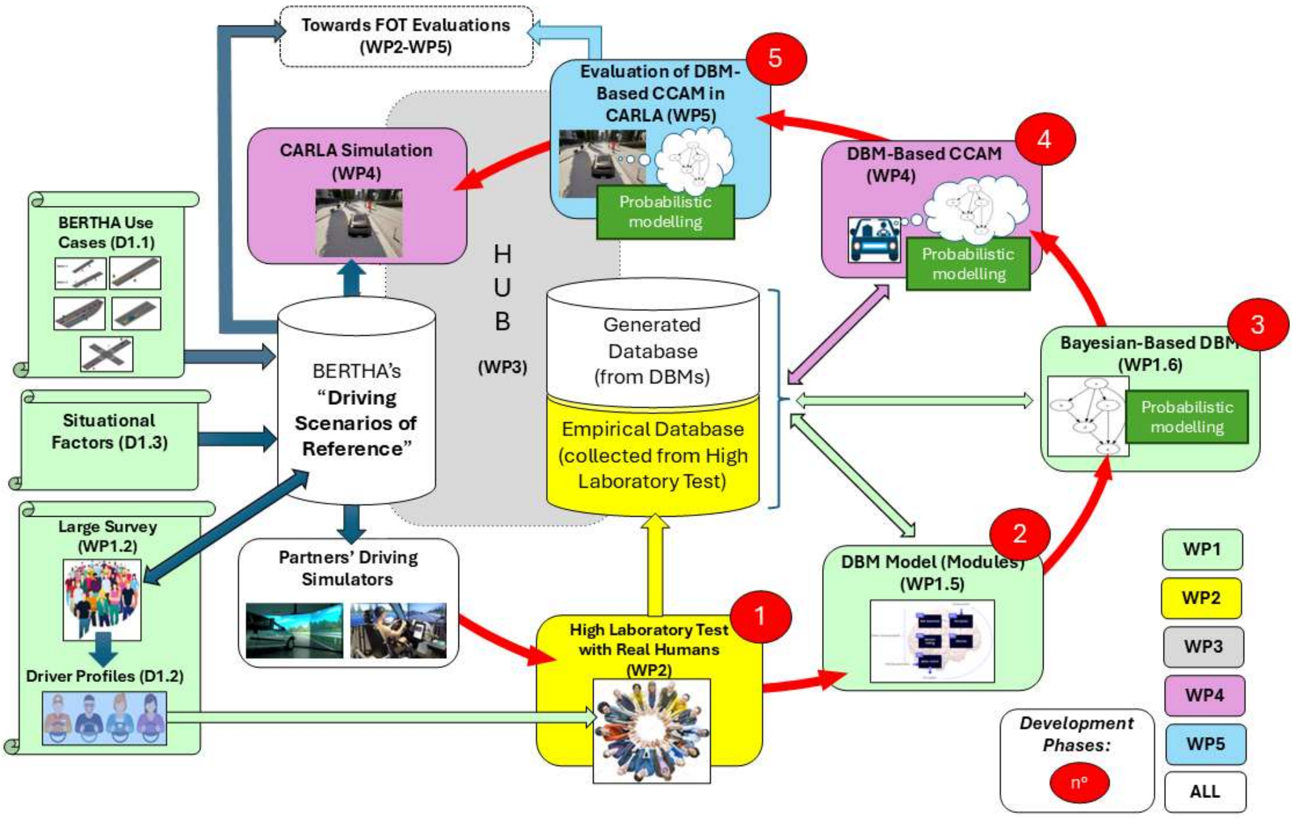

Figure 1. Overview of BERTHA's DBM solution at a glance. Lab tests and High Laboratory Tests in simulators are conducted to develop DBM modules. The same data provides empirical evidence for validating the modules by comparing real human behaviors with DBM behaviors.

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1.3. Overview of High Laboratory Tests

High laboratory tests (HLTs) refer to controlled experiments conducted in specialized facilities using advanced simulation platforms and sensor suites. These facilities:

1. **Enable a wide range of scenarios:** Through simulators and specialized hardware, HLTs can replicate critical driving situations that are challenging or unsafe to test on public roads. This offers an invaluable opportunity to gather high-fidelity data on driver behavior in controlled yet realistic conditions.
2. **Provide data collection:** The instrumentation in HLTs-ranging from physiological sensor to vehicle dynamics logging-capture information about driver reactions, decision-making processes, and potential stress points. Specifically, BERTHA's DBM is structured around 5 interconnected modules that represent these facets of human driving performance. For more information check [1].
3. **Maintain Ethical and Safety Standards:** Given that human participants are at the core of these experiments, comprehensive protocols ensure participant well-being, data privacy, and adherence to ethical guidelines.

Overall, the HLTs serve as a critical step in transitioning from conceptual DBM design to tangible datasets that can be used to refine and validate the models developed in Task 1.5 and Task 1.6 (See Fig. 1).

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2. HIGH LABORATORY TEST FACILITIES

This section introduces the key laboratory test facilities contributed by the project partners, including simulation platforms and sensor integration setups. Building on the foundational overview provided in D2.3 [9], here we expand upon the practical highlighting of these facilities:

- **Partner-Specific Infrastructure**: Each partner's facility has unique capabilities-from full-scale vehicle simulator to wearable sensors-and distinct operational constraints. These infrastructures ensure consistent data collection from simulations, and analysis throughout the project.
- **Key Technologies**: Data logging systems-such as Smart Eye Pro- are integral to capturing the aspects of human driving behavior.

Integrating these specialized facilities and advanced technology allows the BERTHA project to gather a comprehensive dataset under controlled yet realistic conditions. In the following sections, we will describe the specific experimental protocols (Section 3), and then present a cross-analysis of data acquisition approaches used by BERTHA's partners (Section 4).

2.1. Summary of Facilities

2.1.1. IBV

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

1. **Reduction of simulator sickness**:

Simulator sickness is a side effect of driving simulators that may reduce the user's performance and well-being due to its various symptoms, from pallor to vomiting. A simulator that has the capability to reduce these symptoms can improve the results of the studies taking place and increase user comfort. To achieve this, the HAV (Human Autonomous vehicle) simulator replicates the three linear accelerations and three angular velocities in real-time, using a virtual Inertial Measurement Unit (IMU).

The layout of the three main screens (with a dedicated camera for each screen) and the user's seat are calculated so that the distance of the screens and the angle between them simulate the FOV of the simulation scene. Finally, a multi-threading system is used in the main script of the simulator to ensure the best framerate in the screens and make the user's experience as pleasant as possible.

2. **Assure the immersivity of the user and simulator's external validity**.

Achieving a sufficient level of immersivity in the user's experience is critical to validate solutions from the automobile (and other transport industries) for use in the real world. In developing IBV's simulator, a dynamic platform with six degrees of freedom was installed to replicate high accelerations and steep turns in real time using the software's acceleration vector. An HMI and rear-view screens allow users to access relevant driving information as if they were in a real car, making it easier to change lanes, monitor velocity and autonomy, and display various driving alerts.

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Additionally, the laboratory features an overhead LED system that controls light intensity, creating immersive conditions (e.g., sunset, nighttime, tunnels). A surround sound system further enhances realism by accurately reproducing environmental and vehicle sound effects. Together, these features ensure an immersive driving experience that closely approximates real-world conditions, thereby improving the external validity of the research conducted.

3. **Enable a seamless integration of new functionalities or measurement devices**.

Constant improvements, such as adding different scenario features (spawning vehicles, pedestrians) or updating physiological signal measurement devices, allow researchers to adapt the environment and measurements to evolving study requirements.

The simulator scripts are coded with a graphical interface, enabling the straightforward creation of events. Non-invasive devices (RGB/infrared cameras, lasers) can be mounted on the TVs as needed, while physiological sensors (e.g., ECG, EEG, galvanic skin response, temperature sensors) can be incorporated depending on each experiment's objectives.

Besides the Carla driving simulator at IBV, a digital twin of a specific zone in Valencia has been replicated in Unity, in the scope of an intelligent mobility laboratory project, where the users can drive in replicated Valencia streets, where there are different hazards in pedestrian crossings, roundabouts, intersection, among others, can be easily detected.

The wheelbase podium, steering wheel, and pedals are a Fanatec high-end product, with customizable settings such as the force feedback, sensitivity, and the angle range at which the steering wheel can be turned. Besides controlling the vehicle, different events can be spawned from the steering wheel buttons.

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 state-level technological centers.

Besides this, different private projects ordered by different customers have also been executed using experimentations in the HAV. The different types of experimentations developed for private customers were, in most cases, evaluations of the following systems:

- ADAS alerts.
- Autonomous driving models.
- Fatigue detection systems.
- Communication protocols to the user.

Figure 2. IBV - HAV driving simulator.

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2.1.2. UGE

The driving simulator used by UGE to perform the experiment will be SIMAX or SIMDYNA driving simulator (described in D2.3), depending on their schedule and the BERTHA's experiment constraints.

SIMAX is a 3-door Peugeot 308 equipped with input sensors and developed at UGE. 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 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. This driving simulator was/is used in several French National projects and industrial partnerships.

Figure 2. UGE driving simulators (SIMAX on the left and SIMDYNA on the right)

SIMDYNA 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. 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 [10]. 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 [11].

These two driving simulators are connected with the "V-HCD" software (for Virtual Human Centred Design platform) developed at UGE-LESCOT, that will be used to create the driving scenarios investigated in BERTHA during the UGE experiment (described in the D2.3 and in the next section 2.2.2).

2.1.3. DFKI

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 in Fig. 3. The simulator setup includes the following features as described in **D2.3** [9]:

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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.
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.
6. **Eye-Tracking Integration:** The simulator employs Pupil Labs Core eye-tracking glasses to record user gaze data and egocentric video. A marker-based alignment approach allows projecting the gaze data directly on the monitor space allowing retrieval of the context information of the scene with respect to the driver gaze.

The gaze information projection on the monitor is shown in the Figure below.

Figure 3. DFKI's simulator setup.

Currently, extending beyond the state of the experimental setup reported in D2.3, the following actions are in progress:

- **Driving Scenario extension:** In order to obtain a higher level of scene variation for the collection of training data that will allow the generation of a more comprehensive and generalizable perception module, an effort is undertaken to increase the available CARLA simulation scenarios for user data collection experiments. These scenarios will be implemented using the five UCs defined in D1.1 [1] and parameterized using the values given in T1.5 by CVC.

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2.1.4. SEYE

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. 4) will feature a multi-screen setup offering a broad field of view utilizing three 75" monitors (total resolution 5760x1080, field of view to be determined after installation), providing a realistic and immersive driving experience. Furthermore, seats are used that are resembling the setup in a regular car. 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 simulator will be equipped with the full vehicle control interfaces (steering wheel with force feedback, pedals, clutch) Logitech 920 [12][13] and environmental audio effects (e.g., engine revving, collision sounds, wind noise) to enhance immersion. 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.

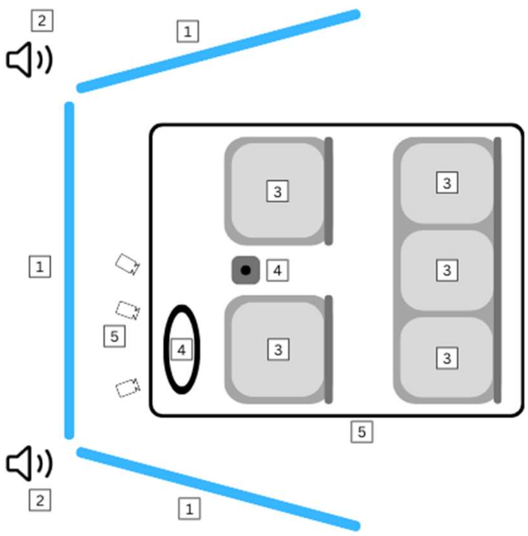

Figure 4. SEYE driving simulator setup.

A key technical component of our setup is the Smart Eye Pro [14], 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 [15], which integrates multiple physiological and behavioral modules (e.g., ECG, EEG, EMG, EDA/GSR, respiration, facial expression, voice analysis) and Affectiva emotion recognition algorithms [16]. 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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The simulator rig supports advanced driver behavior research by utilizing the comprehensive data streams and real-time analysis made available through SEYE Pro. This allows for monitoring and understanding the behavior of the driver to support ADAS algorithms and HMI research.

The data includes 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.

The main standout feature of our simulator rig at SEYE is the research-grade eye tracking system, which provides precise eye and head tracking using the Smart Eye Pro. This system enables detailed analysis of gaze behavior, visual attention, and cognitive workload, offering insights into how drivers process their environment, anticipate hazards, and interact with vehicle interfaces. Another unique feature is the integration of multimodal physiological monitoring through iMotions, which combines eye tracking with biometric data such as EEG, ECG, EMG, and EDA/GSR. This allows an assessment of not only where a driver is looking but also their emotional state, cognitive load, and stress levels in response to different driving conditions. Additionally, the high-resolution multi-screen setup (three 75" monitors) provides a wide field of view, enhancing realism and immersion compared to traditional single-screen simulators. This expansive visual field allows for better peripheral vision assessment, crucial for studying lane changes, merging behavior, and situational awareness. To further support immersion the simulator also features a vehicle control interface, including a Logitech G920 steering wheel with force feedback, pedals, and a clutch, ensuring high-fidelity replication of real-world driving. The addition of (e.g., engine sounds, wind noise, collision impacts), aids in creating an immersive testing environment.

These combined capabilities make our facility well-suited for analyzing complex driver behaviors, including distraction, fatigue, stress, and decision-making under dynamic and unpredictable driving scenarios. Many of these aspects would be challenging to study in real-world settings due to safety concerns and logistical constraints.

To ensure that our laboratory simulations closely approximate real-world driving conditions effort has been put into choosing parts that together creates a setup suitable for advanced laboratory testing of driver behavior and ADAS functions. The hardware creates the conditions for a high level of immersion by utilizing large displays, life-like vehicle control interfaces and sound. Furthermore, the Carla software allows for a realistic simulator environment in total control of the developer.

Since D2.3 the setup has been upgraded from using a Nvidia RTX 2080ti GPU to a Nvidia RTX 4080 GPU to allow for rendering the image streams of several RGB sensors simultaneously.

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2.2. Key Technologies

2.2.1. IBV

As detailed in D2.3 [9], IBV simulation setup relies on Carla and Unity for scenario generation. Through our custom-configured interface, users can easily modify parameters such as weather, traffic light behavior, or actor routes. Different scenarios can also be designed using Scenic, importing Carla's modules and using Carla's Python API and different client scripts to control the dynamic platform, data storage, screens render... The data saved at the end of each simulation includes driving quality indicators (e.g., distance to lane center, adjacent lane invasion, collisions), increasing both the depth of analysis and the alignment with real-world driving metrics.

As mentioned in D2.3 [9], IBV follows a functioning protocol to ensure correct procedures for connecting, operating, and shutting down the simulator. Only a limited number of IBV staff, trained specifically for this purpose, handle the simulator according to these guidelines. The protocol covers some main points such as:

- **How to correctly turn on the simulator**, including:
  - Turning on the screens
  - Activating the Fanatec steering wheel
  - Powering the dynamic platform controller
  - Initializing specific measuring devices for each experiment
- **How to edit and prepare different scenarios**, specifying:
  - Use of the user interface
  - Parameters to consider when defining scenarios

Further operational details can be found in Section 3.

2.2.2. UGE

As detailed in D2.3 [9], the software used to develop the driving scenarios investigated in BERTHA by UGE from our driving simulator experiment is the "V-HCD" (for Virtual Human Centred Design platform; [17] [18]) developed at UGE-LESCOT. This home-made driving simulation software is based on Unreal Engine 5.4, allowing the creation of well-fitted tailored scenarios in any driving environment.

In BERTHA, the V-HCD software was also used to develop the video scenarios required by the on-line survey, in the Task 1.2. From the driving simulator experiment to be now implemented by UGE in T2.3, it is thus expected to have a continuum between the "selection of action" studied from the on-line survey (participants observed videos and have then to select an "action" to be implemented soon) and the risk assessment, the decision-making and the driving behaviour effectively implemented by a human participant when experiencing the same driving scenarios, but at the wheel of the ego car of a driving simulator.

Moreover, one of the specific features of the V-HCD platform (cf. D2.3) is the inclusion of a virtual "ego vehicle" that can be operated either by a real human manually driving the ego

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vehicle of the driving simulator, by emulated or real algorithms used for automated driving or, finally, by the COSMODRIVE model of UGE (as a digital twin of a human driver).

In addition, UGE will also use the *SEYE Pro system,* loaned by SEYE for the BERTHA project, in order to collect eye tracking data during the UGE driving simulator experiment.

2.2.3. DFKI

A notable aspect of the DFKI driving simulator setup is its capacity to gather eye-tracking data from test users that is spatially synchronized with the simulator's data. Gaze information from the PupilLabs device is projected onto the CARLA simulator monitors using AprilTag markers. This method allows the gaze data to be linked to the 3D environment and specific objects within the CARLA simulation through its built-in segmentation capabilities—an essential function for BERTHA's perception module.

The system utilizes Pupil Labs Core to capture eye tracking at a rate of 120Hz, along with an ego-centric view at 30Hz. During post-processing, metrics such as gaze fixations, blink patterns, and head poses are computed. Ultimately, the dataset is sampled at 30Hz and includes information on gaze fixations, driving inputs, car positions, and more.

The data collection pipeline incorporates the following platforms:

1. **CARLA Simulator**: Used for simulating driving scenarios.
2. **Pupil Core Capture/Player**: Pupil Capture records, synchronizes, and calibrates the eye tracker, while Pupil Player processes the recordings to compute gaze fixations, blink patterns, and related metrics.

DFKI Codebase: Responsible for recording driving data, calibrating gaze during post-processing, and generating saliency maps.

2.2.4. SEYE

To create a cohesive system the different technologies a carefully developed protocol will be followed to ensure consistency in the data collection. The system may be separated into three subsystems. SEYE Pro, Carla and physical simulator.

- **SEYE Pro** - The SEYE Pro system integrates its own extrinsic calibration procedure and synchronization of cameras, which is done in the beginning of each data collection session.
- **Carla** – Starting up Carla and running scenarios will be done using scripts which will ensure that each session proceeds indiscriminately from each other, except the potential randomization of scenario order.
- **Physical simulator** - To ensure that the spatial relationship between the objects in the physical simulator stays intact, the placement of each object will be marked and mapped.

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3. DETAILED DESCRIPTION OF EXPERIMENTAL PROTOCOLS

3.1. General Methodological Approach

The general methodological approach of BERTHA across all protocols is structured to ensure consistency and reliability by following a sequential framework: All protocols start by clearly defining the general objectives and research questions, establishing the foundation for each experiment. Participants are first screened and introduced to the experimental environment through an adaptation phase, ensuring they are comfortable and their baseline data is accurately recorded. Following this, controlled scenarios capture objective sensor data (e.g., physiological signals, eye-tracking, vehicle inputs) and subjective feedback via standardized questionnaires. This structured sequence—beginning with overarching research aims, followed by standardized testing—ensures that consistency is maintained across all human participants, ultimately leading to comparable data.

3.2. IBV Protocol

3.2.1. Objectives and Research Questions

The experimental design is oriented along the following main lines:

- Validation of the **affective model**: to confirm the capacity of the model to identify and quantify the mental states defined in the context of the simulator. For this purpose, two specific states have been selected in order to narrow down the study, these have been stress and mental load.
- Evaluation of **environmental** and **situational factors**: in a second phase, the aim is to determine how environmental and situational factors (such as time of day, weather conditions, traffic density, road type and conditions, driving duration and presence of distractors) influence the driver's mental state.
- **Motor Control Module**: Collection of reaction times and actions on the steering wheel and pedals from real drivers in different simulated scenarios, in order to calibrate the **parameters of the motor control module**.
- Comparison of real and modeled actions on the steering wheel and pedals as a means of validation of the motor control module.

The research questions to be answered are the following:

- Is the affective model, developed in controlled situations, applicable to the context of a driving simulator?
- How does the output of the affective module vary in different driving scenarios with different environmental and situational factors?
- In the motor control module, can the actual actions on the controls of the vehicle be adequately imitated by the motor control module using the tactical goals as input,

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with the kind of parametrization that is defined in BERTHA for the driver profile and its affective state.

- Are the parameters of the motor control model affected by the mental state parameters?

- Are the parameters of the motor control dependent on the driver profile (driving experience/gender/age/driving style)?

Each phase of the protocol is designed to answer these questions, allowing the formulation of hypotheses based on previous evidence and ensuring that the findings contribute directly to the development of the DBM within the BERTHA project.

3.2.2. Experimental Methods: Scenarios and Procedures

The main overview of the experimentation protocol is the following:

- Participant reception:
  - Lab technicians make sure the participant has signed the corresponding documentation, understands the purpose of the experimentation, the activities he must perform and the measurements that are going to be completed.
- Application of physiological monitoring devices:
  - ECG signal
  - Respiration rate
- Configuration of measurement equipment:
  - RGB camera (facial expression)
  - SEYE system
  - PLUX device
- Baseline measurements:
  - Throughout 5 minutes, in which the participant stays in the simulator looking forward and without completing any activity, the participant baseline measurements are registered.
- Driving simulator training:
  - A simple driving scenario is displayed to make sure the participant gets used to the driving simulator dynamics and overall functioning.
- Driving characterization slalom test:
  - Participants complete 3 different scenarios described in the UMTRI-2001-43 paper to characterise their driving among fast/slow and precise/imprecise.
- Experimental trial battery:
  - These are the main driving use case scenarios defined previously throughout the Bertha project. The scenarios are launched with Scenic and the driving simulator is controlled with the Python scripts that connect with the Carla server.
- Final driving characterization test with cones:
- Deactivation of the equipment.
- Questionnaire.

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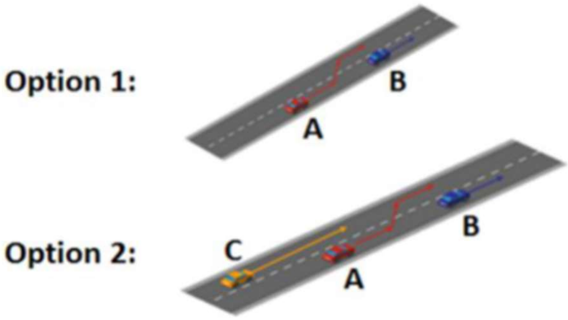
The main protocol lasts for approximately 90 minutes. Each experimentation trial scenario lasts for 1 minute, and in total, each participant will complete 15 scenarios, 3 of each type.

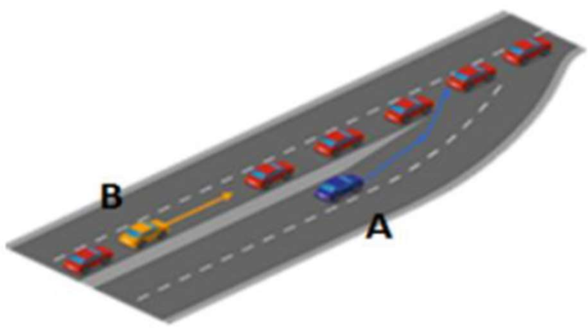
The experimental protocol includes several scenarios designed to evaluate driver response in various traffic conditions previously discussed and designed in the Bertha project.

- **Collision Risk Management on Highway:**



  - The ego-vehicle is following a leading vehicle on the right lane of a highway. Suddenly, the leading vehicle performs an emergency braking, which significantly reduces its speed. To avoid a front collision, the driver of the ego-vehicle must execute an emergency manoeuvre.
  - Scenario variability:
    - Management of collision risk with the other vehicle.
      - Vehicle B brakes suddenly when vehicle A approaches below a certain distance.
      - Vehicle B moves too slowly, requiring vehicle A to overtake while another vehicle approaches at high speed in the adjacent lane.
      - Possibility of another vehicle in the opposite lane with the same direction of travel.
    - Different speed variations of the yellow vehicle in the left lane. Related to the difference of speeds between blue and yellow vehicles.
    - Different speed variations of the blue vehicle.
    - Distances at which the blue vehicle starts breaking. That is, the blue vehicle breaks when the ego vehicle (red car) is at a certain distance.

- **Insertion on Highway**



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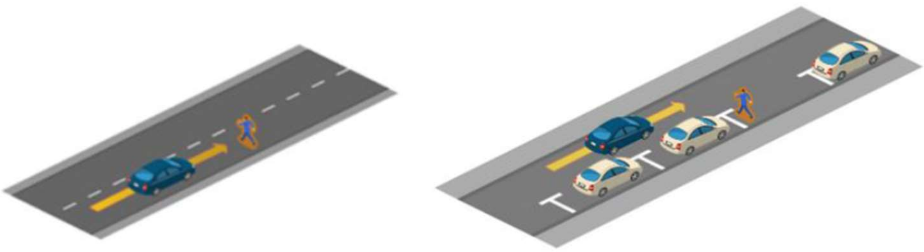
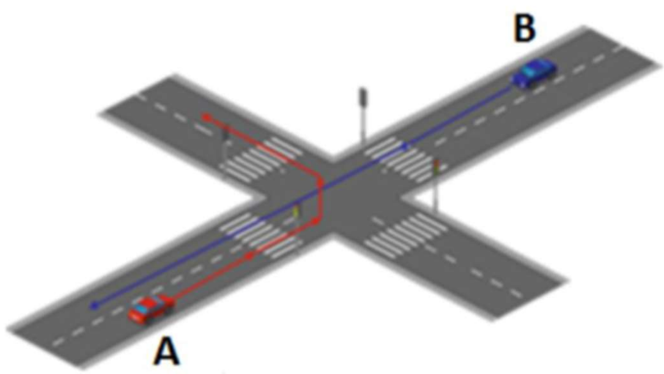
- The ego-vehicle needs to merge into a crowded left lane from an entry ramp on a double lane highway. The ego-vehicle relies on a gap car (another vehicle creating a slightly larger gap in traffic) to create an opportunity for insertion before the entry lane ends.
- Scenario variability:
  - Vehicle A must negotiate the merging from an entry ramp into traffic of varying densities in different situations.
  - Traffic density. Distance between cars.
  - Speed variations of vehicles on the highway

- **Pedestrians avoidance**



- The ego-vehicle is driving on an urban road. Pedestrians are walking on the sidewalks adjacent to the road. While most will follow the proper path and cross the road at the designated zebra crossings, some may attempt to cross the road at an inappropriate location.
- Scenario variability:
  - Pedestrian circulate on the sidewalk and cross unexpectedly in non-designated areas at a distance of X meters.
  - Pedestrian suddenly emerge between vehicles.
  - Speed variation of vehicle.
  - Pedestrian speed: 5Km/h (test NCAP)

- **Left Turn at Urban Intersections**



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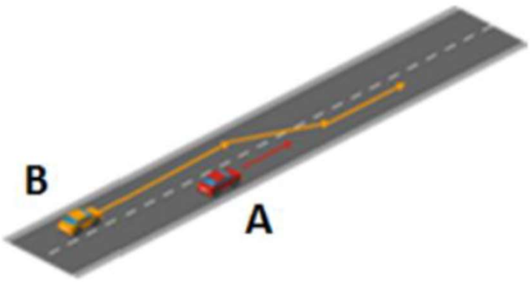
- The ego-vehicle (the vehicle making the left turn) approaching an urban intersection controlled by traffic lights. The ego-vehicle intends to turn left across oncoming traffic, where the traffic lights can influence the decision to proceed or wait.
- Scenario variability:
  - Vehicle B approaches at different speeds: 60, 45, 30 km/h
  - Obstacles when turning:
    - Pedestrian crossing from the left
    - Pedestrian crossing from the right
    - No pedestrian crossing

- **Pull back in / Cut in on Urban Highways**



- An overtaking vehicle (overtaker) on the left lane of a double lane road needs to pull back into the right lane in front of the lead vehicle after completing the overtaking manoeuvre. This type of situation frequently occurs on urban highways when the overtaker decides at the last moment to take the next exit on the right side of the road and then make an abrupt lane change.
- Scenario variability:
  - Vehicle B performs a sudden manoeuvre, overtaking vehicle A to take the next exit.
  - Speed variations of vehicle B (60 – 80 – 100 km/h) and distances at which the manoeuvre occurs (5m–20m–50m) so vehicle A reacts to avoid collision and maintain distance.

3.2.3. Data Collection

Data collection was carried out following a sequence of standardized procedures that ensured the quality, homogeneity and validity of the information obtained. A double adaptation phase was implemented for the participants (firstly to the experimental context and secondly to the driving simulator itself), followed by calibration of the baseline data.

A. Compliance with Inclusion and Exclusion Criteria

In all experimental protocols, it is guaranteed that users meet the established criteria. Inclusion criteria consist of selecting participants with previous driving experience, which ensures a homogeneous sample in terms of skills and characteristics relevant to the task. It is mandatory that participants:

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- Wear comfortable clothing that facilitates access to the thoracic area for instrumentation.
- Refrain from intense physical exercise in the previous 24 hours.
- Avoid alcohol intake during the 24 hours prior to the procedure.
- Do not smoke in the previous 4 hours.
- Do not consume caffeine or other nervous system stimulants (e.g., theine, taurine) during the 4 hours prior to testing.

Exclusion criteria include:

- Individuals with electronic implants (such as insulin pumps or cochlear implants).
- Individuals with a history of epilepsy or light sensitivity.
- Participants under treatment with blood pressure medications, psychostimulants, anxiolytics or antidepressants.
- People with allergies or hypersensitivity to components of the contact devices (gels, adhesives, etc.).
- Subjects with infectious diseases or skin conditions (e.g. atopic dermatitis, rosacea, etc.).
- Individuals with chronic pathologies (such as chronic pain or diabetes) and night shift workers.

In addition, the Motion Sickness Questionnaire is used to confirm that **no participant is predisposed to motion sickness**, ensuring that the simulator experience is not compromised by symptoms of discomfort.

B. Sensory Data

Each experiment begins with an adaptation period divided into two phases:

1. **Adaptation to the Experiment Contex**t: the participant becomes familiar with the general environment and the conditions of the study.
2. **Adaptation to the Simulator Contex**t: a pre-test is offered in the simulator so that the user can get used to its operation and dynamics.

Subsequently, an initial recording is made in the resting state, which acts as a baseline calibration of the physiological signals. From this point, data collection is segmented into two modules:

- **Affective module**: variables related to heart rate variability (HRV) are recorded, obtained using the ECG sensor and the RGB camera. In addition, AUs (Action Units) of facial expression are extracted from the same camera.
- **Motor Control Module:** variables related to dynamics of driving. Participants should perform a slalom drive to determine their dynamic characteristics.

C. Questionnaires and Scales

The protocol includes a battery of questionnaires and scales designed for two main purposes:

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- Verify subject criteria and characteristics: ensure that the sample is representative and collect data on general health status and other individual characteristics that may influence the experimental response.
- Assess affective states: stress and mental workload scales allow subjective measurement of affective and cognitive response at different times during the protocol.

The questionnaires used are:

1. **Initial questionnaires**:
    - Health Scales: evaluate the general state of health to ensure that there are no conditions that interfere with the experimentation.
    - PSS-14 (Perceived Stress Scale): measures the level of perceived stress, fundamental to correlate with physiological responses.
    - FSS (Fatigue Severity Scale): determines the severity of fatigue, allowing the interpretation of changes in the affective response.
    - CFQ (Cognitive Failures Questionnaire): analyzes cognitive failures in daily life, which may be related to mental workload during the test.
2. **Driving style questionnaire**: collects information on the participant's driving style and habits, which allows identifying possible influences on the response to stressful situations in the simulator.
3. **Motion sickness questionnaire**: used to rule out predispositions to motion sickness, ensuring that the simulator experience is not affected.

Timing of administration of the questionnaires:

- **Pre-test**: they are initially applied, together with informed consent, to establish a baseline of the subject's condition.
- **Intermediate**: after each test or trial, stress and mental load scales are collected to assess the evolution of the affective state in response to the experimental conditions.
- **Post-test**: these are administered again to analyze the overall impact of the protocol and to contrast the measurements with baseline values.

D. Privacy Considerations

All protocols have been submitted and approved by the ethics committee of the Universidad Politécnica de Valencia (UPV), complying with current regulations and ethical principles established in the Declaration of Helsinki. Measures have been implemented for the treatment and protection of sensitive data, among which the following stand out:

- **Sensitive data collected**: the images captured by the RGB camera are considered sensitive data. Therefore, specific technical and organizational measures have been adopted to ensure their confidentiality.

Data protection and handling: anonymization and secure storage protocols have been established to ensure that personal information and biometric data are managed in compliance with current data protection regulations.

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3.3. UGE Protocol

3.3.1. Objectives and Research Questions

The research objectives of the driving simulator experiment conducted by UGE are to study risk assessment and decision-making processes among real human drivers during manual driving. To achieve this, participants will be exposed to various driving scenarios derived from the five UCs identified in D1.1 [1]. The general principle of this experiment is to confront human drivers with traffic situations of varying levels of criticality (i.e., presenting higher or lower collision risks). Situation criticality is associated with the likelihood of an accident and the time available to avoid it [19], [20]. In critical traffic situations, drivers must rapidly make decisions and select emergency reactions, such as performing an emergency brake or abruptly steering to avoid a frontal collision. The higher the accident risk and the shorter the time to react, the more difficult and stressful the driving task and decision-making process become [21. Furthermore, in cases where critical hazards are deliberately provoked by dangerous violations of traffic rules by other road users (e.g., critical cut-ins, priority rule violations, or dangerous crossing behavior by inattentive pedestrians), emotions such as fear or anger may arise. These negative emotions can, in turn, lead to aggressive decision-making and behaviors [22], [23].

For each scenario investigated in this experiment, and according to its level of criticality, the aim will be to examine how participants assess the situational risk, the decisions they make, and the driving behaviors they implement to address it (e.g., braking, maintaining their current speed, accelerating, or executing an avoidance maneuver by changing lanes). As discussed in D1.3 [24], various personal factors can impact drivers' risk assessment and decision-making, such as their socio-demographic characteristics, their driving experience and/or familiarity with the situation, as well as their attitudes toward risk and risk-taking. However, building on the driver profiling work carried out in Task 1.2 (cf. D1.2 [25]), the central objective of this experiment will be to study participants' driving styles, both in terms of decision-making and behavior, when confronted with driving situations of varying levels of criticality. Driving style refers to the manner in which a person operates a vehicle, encompassing their decision-making and behaviors while driving. It includes various factors such as speed and time headway, the way vehicle controls are manipulated for acceleration, braking, or steering, adherence to traffic rules, and overall risk-taking behavior [26]. As discussed in D1.2 [25], driving styles can range from "aggressive" and risk-prone to "cautious" and defensive. While driving style is influenced by individual factors [27][28], it can also be locally affected by the level of risk associated with the traffic situation.

In the context of the driving scenarios used in this experiment, based on those developed for the survey implemented in Task 1.2, we hypothesize that only the most aggressive drivers are likely to engage in acceleration maneuvers to manage their interactions (e.g., with a pedestrian or another vehicle) in the most critical variants of these scenarios. Conversely, in the less critical variants, slowing down (braking) or stopping could indicate excessively cautious driving, potentially revealing difficulties in risk estimation, decision-making, or executing a specific driving maneuver. Beyond the tactical decisions made, the way participants manipulate vehicle controls in the simulator will also serve as an indicator of driving style. On the one hand, smoother actions on the controls (especially the steering wheel and brake pedal) will correspond to better control of the situation and a driving style that is

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more smooth and composed. On the other hand, abrupt reactions on the controls will reflect a more "jerky" driving style, potentially revealing greater difficulty in understanding the situation, correctly assessing risks, and/or anticipating the dangers associated with a particular driving decision or behavior.

Beyond evaluating these research hypotheses, the data collected from this driving simulator experiment will be directly used to design and later calibrate and evaluate the Cognition Module (including Risk Awareness and Decision-Making processes) of the DBM, to be developed by University Eiffel for the BERTHA project (cf. D1.5 [29]).

3.3.2. Experimental Methods: Scenarios and Procedures

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

3.3.2.1. Driving scenarios investigated by UGE

Synthetically, the driving scenarios studied on driving simulator correspond to the video scenarios used for the online survey implemented 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 implemented on driving simulator will allow us to observe the actual driving behaviours (and the underlying decisions) effectively implemented by participants on the ego vehicle commands, according to their perceived level of risk. For each driving scenario, four variations will be investigated by manipulating experimentally a key situational parameter impacting its level of criticality (like it was also studied in the on-line survey implemented in T1.2).

The six main driving scenarios to be investigated by UGE during this experiment are the following (scenario “d” performed 2 times, when interacting with another car versus a bicyclist):

a) **Driving scenarios used for UC1 (collision risk on highway)**:

In this traffic situation, the Ego Car piloted by the participants will have to follow a Lead Car (blue car in Fig. 5) in the right lane of a two-lane highway. During the first part of the scenario, the lead car keeps a cruise speed of 90 kph, and the participants are free to adopt a time headway at their convenience. At a random time, the lead car suddenly performs an emergency braking.

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Figure 5. Overview of the scenario developed for the UC1 on UGE driving simulator

To avoid a frontal collision, participants will have to execute an emergency manoeuvre. They can either (1) perform an emergency brake to stop behind the lead car, (2) overtake the lead car by safely changing to the left lane, or (3) implement an evasive manoeuvre by moving to the shoulder to avoid the crash.

Four different versions of this scenario will be studied, by manipulating a key parameter directly impacting the criticality of this traffic situation: the distance of an overtaking vehicle in the left lane of the highway (the yellow car in Fig. 6).

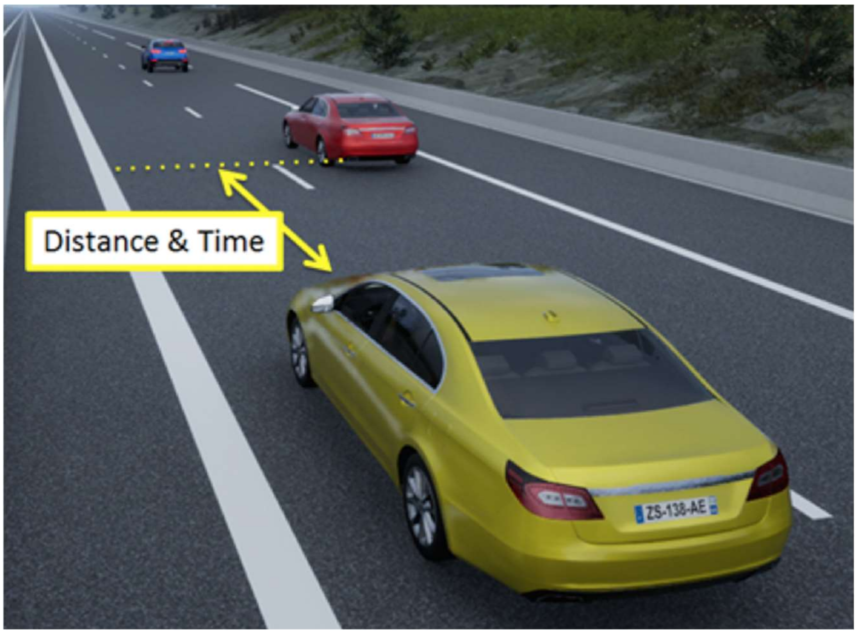

Figure 6. Manipulated parameter regarding the Criticality of the scenario for UC1.

In the most critical variation of this scenario, corresponding to the View 1 in Fig. 7, the Overtaker is 10 metres behind the Ego car, with an IVT of 0.4 second. Alternatively, the second level of criticality (cf. View 2) corresponds to a distance of 20 metres, of the Overtaker (with an IVT of 0.8 s.), the View 3 to a distance of 30 metres (IVT of 1.2 s.), and finally the View 4 (that is the less critical variation of this scenario) to a distance of 40 metres of the Overtaker and an IVT is 1.6 seconds .

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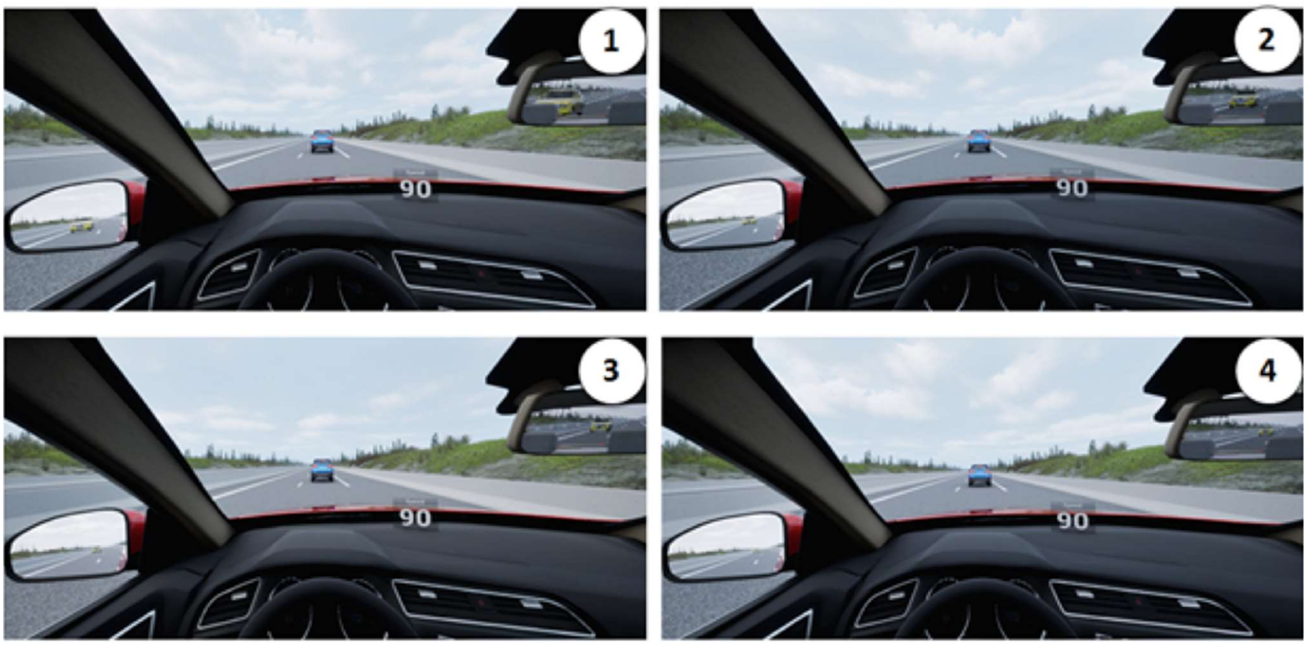

Figure 7. participant's view form the ego-car, according to the Criticality of the scenario (i.e., variations of the overtaker's distance when the lead car start to brake)

b) **Driving scenarios used for UC2 (insertion on highway)**:

In this driving scenario, presented in Fig. 8, the participants (driving the black car) need to merge into a crowded left lane from an entry ramp on a double-lane highway. The decision they must make is whether to merge in front of or behind the red vehicle, travelling in the right lane of the highway at a speed of 40 kph.

Figure 8. Overview of the scenario developed for the UC2 on UGE driving simulator

This merging task will be more or less difficult depending on the gap (i.e., IVT) between this red car and the one ahead of it on the highway (blue car, in Fig. 8): the larger the gap, the more space the participant will have to merge, making the manoeuvre easier. On the other hand, the smaller the gap, the more critical and difficult the merge will be.

The following Fig. 9 presents the four variations of this scenario studied on the UGE driving simulator, corresponding to the four levels of Criticality investigated in the on-line survey implemented in Task 1.2. The View 1, that is the most critical condition, corresponds to an IVT of 1 second between the Red and the Blue car (representing an available gap of 11 metres for the participant), the View 2 to an IVT of 1.6 seconds (gap size of 17.6 metres), the View 3 to an

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IVT of 2.2 seconds (gap size of 24.2 metres) and the View 4, that is the less critical variation, to an IVT of 2.8 seconds (gap size of 30.6 metres).

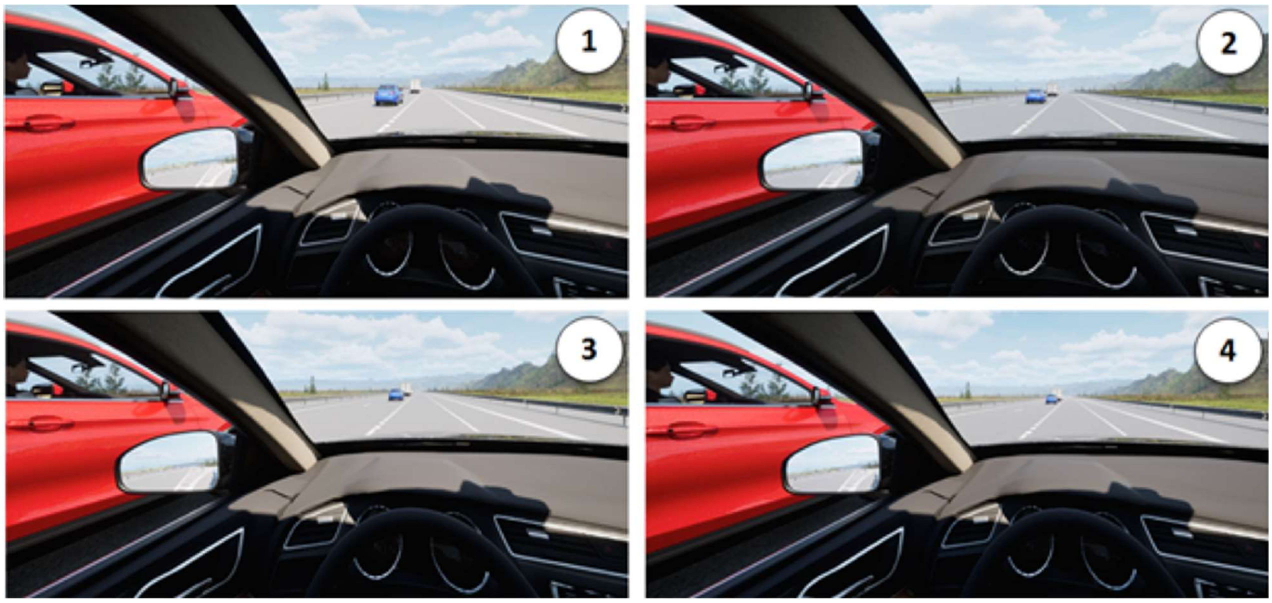

Figure 9. participant's view form the ego-car, according to the Criticality of the scenario used for UC2 (i.e. variation of IVT between the red and the blue car)

c) **Driving scenarios used for UC3 (Interaction with a pedestrian)**:

In this driving scenario, presented in Fig. 10, the participants have to drive on a one-way urban street limited to 30 kph. Suddenly, an inattentive pedestrian distracted by his smartphone decides to cross the road just in front of the Ego Car. In this scenario, the speed of the pedestrian is 5.4 kph (1.5 m/s).

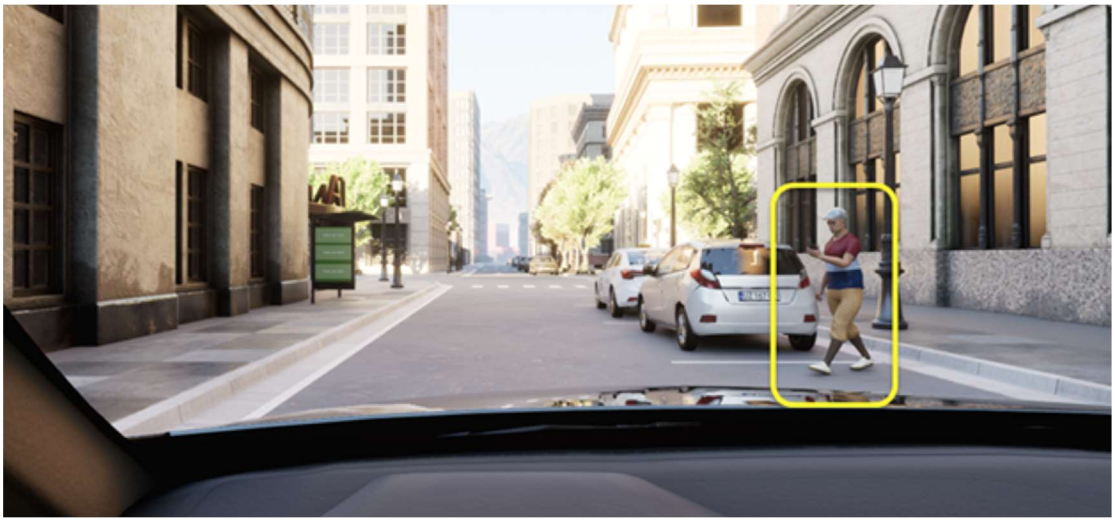

Figure 10. Overview of the scenario developed for the UC3 on UGE driving simulator.

In this driving scenario, the criticality of the traffic situation is dependent on the respective Times to the Inter-Paths Conflict Point between the ego car, from the one hand, and the pedestrian form the other (Fig. 11).

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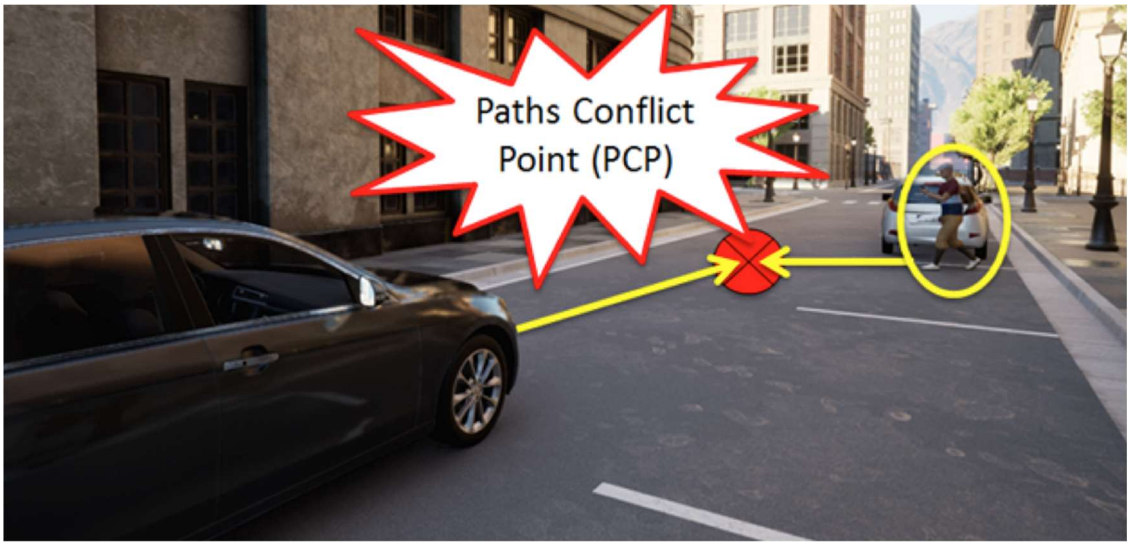

Figure 11. Manipulated parameter regarding the Criticality of the scenario for UC3

The following Fig. 12 presents the four variations studied by UGE (corresponding to the four levels of Criticality studied in the on-line survey for the UC3), when the participant is at a Time to the Paths Conflict Point (TPPC) of 0.6 second. The View 1, that is the most critical variation, corresponds to TPCP of 2 seconds for the pedestrian, indicating a high probability of collision if the ego car driver will not react. The other views present respectively a TPCP of 2.4, 2.8 and 3.2 seconds for the pedestrian.

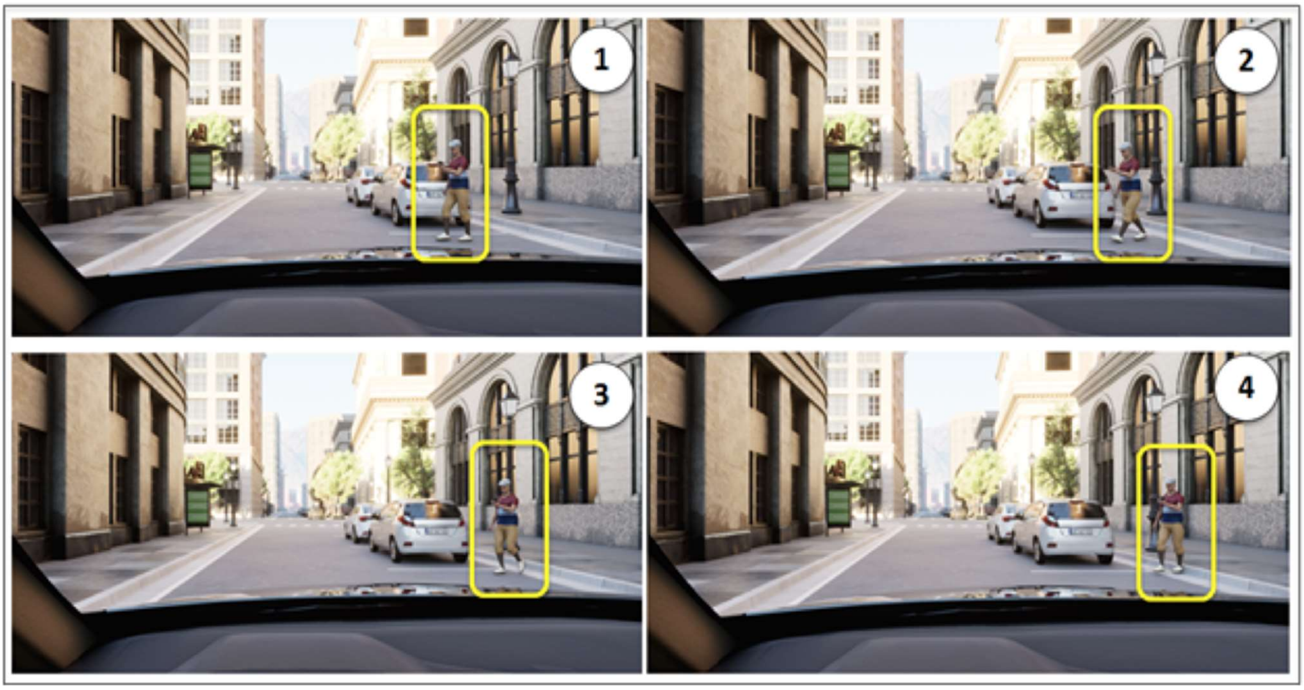

Figure 12. participant's view form the ego-car, according to the Criticality of the scenario used for UC3 (i.e. TPCP of the pedestrian).

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d) **Driving scenarios used for UC4 (Turn Left at a Urban Cross-Roads)**:

In this driving scenario, presented in Fig. 13, participants have to Turn Left (TL) at an urban cross-roads controlled by traffic lights (that are green). To make their decision, they have to assess the (1) distance and the (2) velocity of oncoming traffic to evaluate the level of risk associated with the TL manoeuvre. From this assessment, they have to determine when it is safe to make the left turn, or when it is preferable to stop and wait for the opposite car to cross the intersection before making their turn.

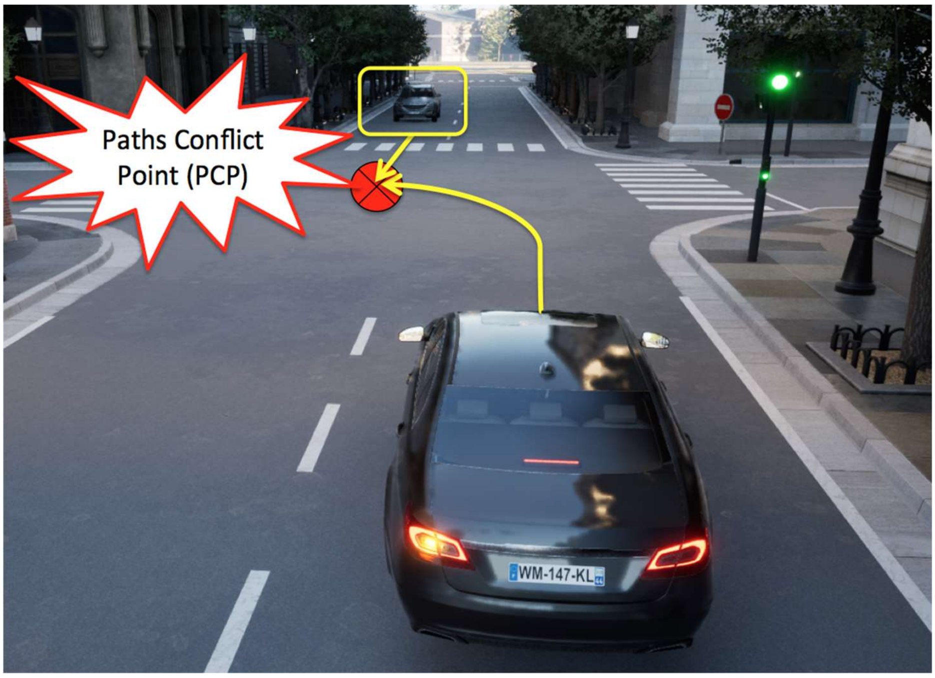

Figure 13. Overview of the scenario developed for the UC4 on UGE driving simulator.

The key manipulated parameter used to create different levels of criticality in this scenario is the Time / Distance of the oncoming car to the Paths Conflict Point (PCP), given a similar position (i.e., at 0.8 second to the PCP) of the participant's Ego car. The closer the oncoming car is, the higher the collision risk if the participant decides to turn left in front of them. Consequently, it is expected that participants will stop their car and wait for the opposite car to cross the intersection before making their turn. Conversely, the farther the oncoming car is, the more feasible and safe it will be for the Ego car driver to turn left before they arrive.

The Fig. 14 presents the four variations of this scenario, according to the distance of the oncoming car to the Paths Conflict Point, when the ego car is at 0.8 s.of the PCP. Views 1, that is the most critical variation, corresponds to a PCP distance of 8 metres for both the oncoming car or the bicyclist, indicating a high probability of collision if the ego car driver maintains the same speed for turning left in front of them. The other views correspond, respectively, to distances to the PCP of 18 metres (level 2), 28 metres (level 3) and 38 metres (level 4) for the other road user

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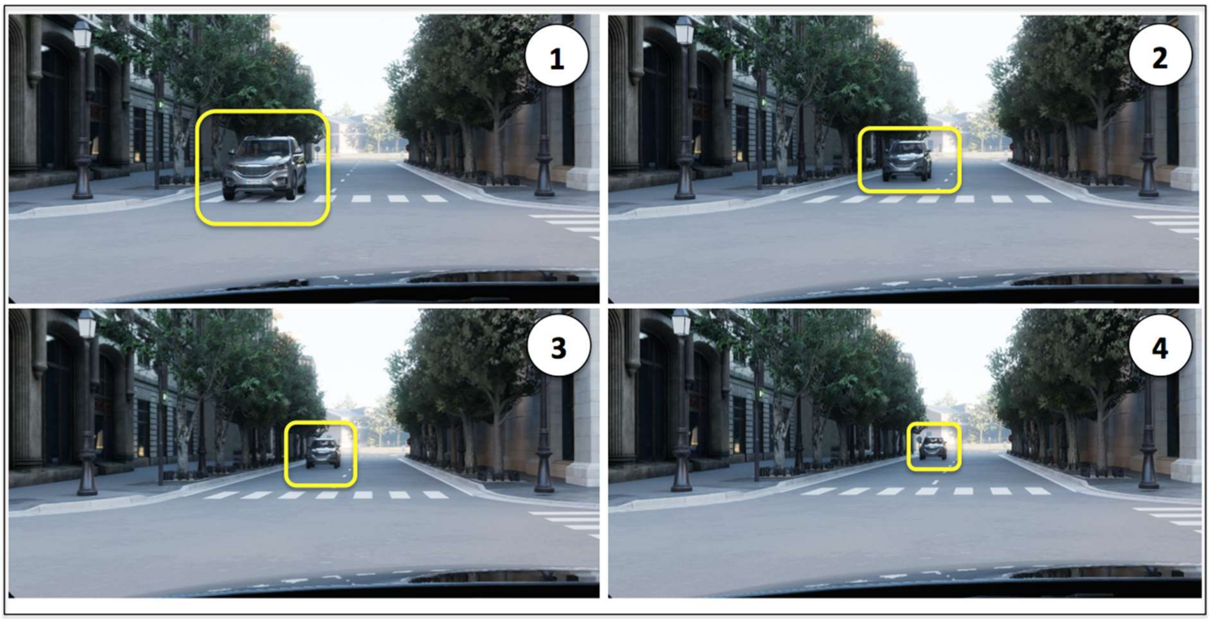

Figure 14. participant's view form the ego-car, according to the Criticality of the scenario used for UC4 (i.e. TPCP of the pedestrian)

Moreover, this scenario (and its 4 variations) will be also replicated in the UGE experiment by using a bicycle (against a car) as the opposite road user, for 4 similar levels of criticality.

e) **Driving scenarios used for UC5 (Pull Back / Cut-In on highway)**:

In this driving scenario, presented in Fig. 15, the participants have to follow a lead car (i.e. the blue car in this Figure) driving at 90 kph on the highway, with a free time headway.

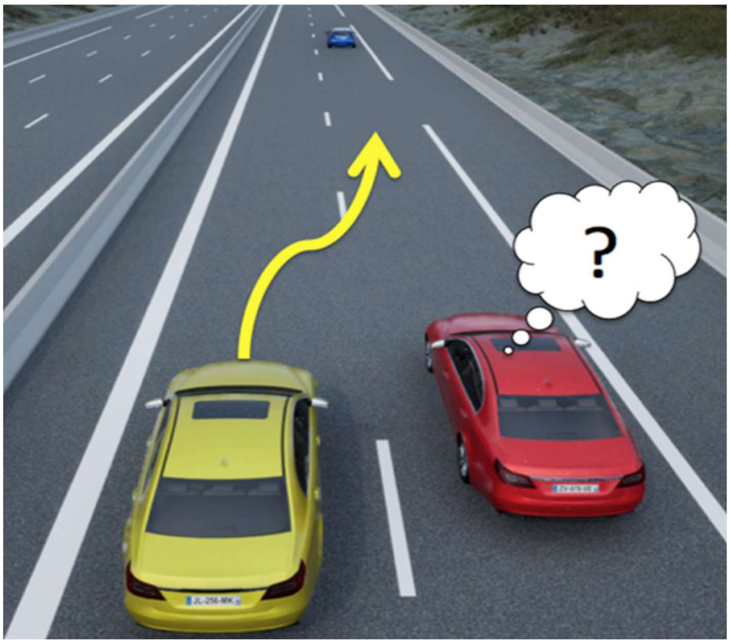

Figure 15. Overview of the scenario developed for the UC5 on UGE driving simulator.

At a randomized time, an overtaking vehicle (yellow "Overtaker") implements a safe pull back versus dangerous cut-in in front of the Ego vehicle, after completing the overtaking manoeuvre. This type of situation frequently occurs on highways when the overtaker decides at the last moment to take the next exit on the right side of the road, and then make an abrupt lane change. In the scenario created for this UC, the speed of the Overtaker is 100 kph.

The situational parameter used to vary the criticality of this scenario is the distance at which the Overtaker merges back in front of the Ego vehicle (Fig. 16). For the most critical version of this scenario, the Overtaker merges 25 cm in front of the Ego vehicle driven by the participant, with an Inter-Vehicular Time (IVT) of 0.01 second. For level 2 of criticality, the Overtaker merges 2.5 metres in front of the Ego car, with an IVT of 0.1 second. For level 3 of criticality, it merges 5 metres in front of the Ego vehicle with an IVT of 0.2 second. Finally, for level 4 of criticality, the merging distance of the Overtaker is 7.5 metres in front of the Ego vehicle, with an IVT of 0.3 second.

None of these merging manoeuvres result in a collision if the participant keep the same speed, as the Overtaker is travelling 10 kph faster than the Ego vehicle. However, the first two criticality levels can be considered as very dangerous cut-ins, while the last two are less critical merges.

The Fig. 16 below shows the Ego driver's view for the four variations of this scenario at the moment when the Overtaker is 75% merged into the Ego car's lane (only its left rear wheel remains in the left adjacent lane).

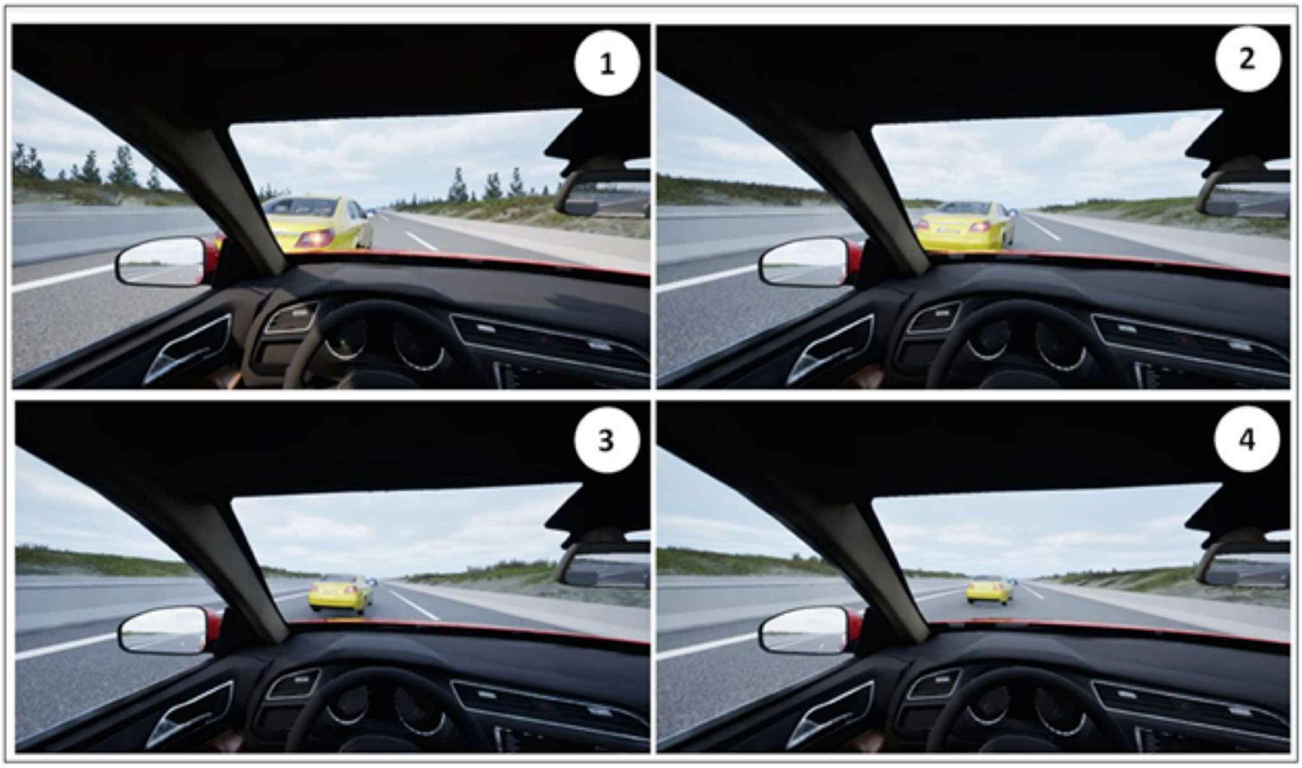

Figure 16. participant's view form the ego-car, according to the Criticality of the scenario used for UC5 (i.e. IVT between the Overtaker and the Ego car).

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3.3.2.2. Procedure of the UGE experiment

The experiment plan to be completed by the participants during the UGE experiment will be carried out in 5 main phases, lasting a total of approximately 1 hour and 45 minutes to 2 hours (including a 10-minute break).

1) Welcoming participants and signing the "informed consent" form:

Upon their arrival at UGE, the experimenters will explain the objectives of the study and the experimental task the participants will perform on the driving simulator. Participants will be free to ask questions. They will then be invited to sign the "informed consent" form, confirming that they have understood the experimental protocol and agree to participate in the experiment voluntarily.

2) Getting familiar with the driving simulator (10 to 15 minutes):

Participants will then sit at the wheel of the simulator to complete a manual driving training session during which they will familiarize themselves with operating the ego vehicle. They will be asked to perform various maneuvers (reaching and maintaining a cruising speed, braking with varying intensity, overtaking a vehicle, turning left at an intersection) in different driving scenarios. Once they feel comfortable with driving on the simulator, they can proceed to the main experiment.

3) Conducting the experiment (80 to 90 minutes, including a 10-min. break):

Participants will manually drive the vehicle to complete 6 blocks of 4 driving scenarios (each scenario lasting 2 to 3 minutes). A "block" corresponds to a specific "driving situation" (as detailed in section 3.3.2), which must be performed under 4 different levels of criticality (in random order). For each scenario, the driver must manually operate the vehicle and make decisions to handle the driving situations they encounter. Experimental data will be recorded during this process. At the end of each scenario, participants will use Likert scales to subjectively evaluate the quality of their decisions and the risk they believe they took. After completing the first 3 blocks of the experimental protocol, participants will take a 10-minute break before continuing with the final 3 blocks of scenarios.

4) Debriefing (5 to 10 minutes):

During this phase, participants will be able to share their feedback on the experiment and ask any questions they may have for the experimenter regarding the collected data and the research objectives.

3.3.3. Data Collection

Objective Data

The objective data collected during this experiment will be of three different types and collected in accordance with the work performed in WP2, as described in D2.1 [2] (*BERTHA Data Model*) and D2.2 [3] (*Data Format and Common Acquisition Principles*):

- **Driving behaviours**: All the drivers' actions on the driving simulator vehicle's commands (i.e., pedals, steering wheel, indicators, flashing lights, horn, etc.) will be recorded.

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- **Visual Metrics**: Eye-tracking data will also be collected using the SmartEye Pro technology.
- **Traffic situation and objective risk:** Simultaneously, the state of the traffic situation will also be continuously logged (positions and speeds of vehicles interacting with the ego car, inter-vehicular times, or time to collision).

Subjective Data

In addition to the objective measures of the driving behaviour, two types of subjective data will be also collected during the experiment:

- **Subjective Evaluations regarding the decision made**: after each scenario, participants will be surveyed using Likert scales to subjectively assess the risk associated with the decision they made and/or to provide a self-assessment about their driving performance.
- **Participant profiling:** Additionally, before the experiment, participants will be also surveyed using a part of the questionnaires defined in T1.2 to profile the car drivers (cf. D1.2 [24]).

Privacy Considerations

The protocol supporting the UGE experiment has been validated by the Ethical Committee of the University Gustave Eiffel. Not any sensitive personal data will be collected. Moreover, to ensure the privacy of the participants, only anonymized data collected during this experiment will be shared with the other BERTHA's partners.

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3.4. DFKI Protocol

3.4.1. Objectives and Research Questions

The objective of the perception module is to develop a model that replicates human driver perception. Given visual inputs from a vehicle, the perception module generates a probability map (saliency map) highlighting areas and objects a human driver is likely to focus on.

This step is critical for Project BERTHA, which aims to create a Driver Behavioral Model (DBM) capable of emulating human driving behavior. By incorporating such a perception model, we enhance the explainability of autonomous agents and accelerate autonomous vehicle development. A DBM equipped with human-like perception can be deployed to test autonomous vehicles in mixed human-AI driving environments, improving their adaptability and safety.

Previous studies have demonstrated the effectiveness of saliency maps in enhancing autonomous driving systems [30][31]. By leveraging this approach, our research contributes to the broader goal of making autonomous driving more interpretable and aligned with human behavior.

DFKI initiated the experiments in January 2025. Additional data will be collected in March and April 2025 using scenario definitions that are more closely aligned with the development scenarios provided by CVC in T1.5 [29]. These scenarios differentiate between weather and town conditions for development and validation, ensuring that the datasets remain distinct and free from data leakage.

Our work focuses on addressing the following research questions:

1. Can human perception for driving be effectively modeled using a simulated environment?
2. What internal and external factors influence the modeling of human perception for autonomous driving, as outlined in D1.2 [25] (internal) and D1.3 [24] (external)?
3. Does incorporating human perception modeling enhance the performance of self-driving systems and make their decision-making processes more explainable?

3.4.2. Experimental Methods: Scenarios and Procedures

Each experiment is divided into the following phases and lasts approximately one hour and fifteen minutes:

1. Participant Introduction and Consent (5 minutes):
   a. Welcome the participant and provide an overview of the study.
   b. Obtain informed consent and explain the use of eye-tracking glasses.
2. Pre-Test Interview (5 minutes):
   a. Administer a short interview to gather demographic information, driving experience, and familiarity with driving simulators.
   b. Include questions on typical driving habits, frequency of distractions, and any vision impairments or conditions.
3. Equipment Setup (5 minutes):

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   a. Fit the participant with the eye-tracking glasses, ensuring proper alignment and comfort.
   b. Calibrate the eye-tracking system to ensure accurate data capture.
4. Driving Simulation (5 minutes):
   a. Guide the participant to the driving simulator.
   b. Explain the driving tasks and the structure of the simulation, emphasizing the need for realistic driving behavior.
   c. The simulation includes different driving environments such as:
      i. Urban Areas: High traffic density, intersections, and pedestrian crossings.
      ii. Highways: High-speed conditions with merging lanes and variable traffic flow.
      iii. Adverse Conditions: Rain, or fog to simulate challenging scenarios.
5. Data Collection (30-40 minutes):
   a. Instruct the participant to drive through each environment while wearing the eye-tracking glasses.
   b. Record eye movement data, gaze patterns, and simulator metrics (e.g., steering, braking).
6. Post-Test Feedback and Questionnaire (10-15 minutes):
   a. Conduct a brief interview to gather qualitative feedback about the experience and driving challenges encountered.
   b. Ask participants to reflect on any moments of distraction or difficulty.
   c. A survey will be conducted to gather information similar to T1.2, profiling the car drivers.
7. Repeat for All Participants:
   a. Reset the simulator and eye-tracking system for the next participant.

Breaks are provided after each driving scenario during the reset of the simulator, with flexibility for longer pauses if needed.

Our driving scenarios consist of several categories:

1. **Test scenarios**: Simple scenarios designed to help users become familiar with the driving simulator.
2. **Normal Driving Scenarios**: Users drive in typical traffic conditions without guidance, allowing them to navigate freely and make decisions, including potential violations, on their own.
3. **Guided scenarios**: Voice navigation guides users through a series of checkpoints to simulate specific situations—such as pedestrian crossings, left turns at intersections, etc. Currently, most data collection occurs through these audio-guided sessions.
4. **Use case specific scenarios**: These will be used in the next phase of data collection and the scenarios will be implemented in accordance with the five use-cases specified in D1.1 and parameterized according to T1.5.

We implement driving conditions:

1. *Urban Areas*: High traffic density, intersections, and pedestrian crossings.
2. *Highways*: High-speed conditions with merging lanes and variable traffic flow.
3. *Adverse Conditions*: Rain, or fog to simulate challenging scenarios.

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Simulating these conditions are relevant to build a diverse dataset for the perception module. Having a diverse dataset with a wide range of conditions makes the perception module more robust to different conditions.

Additionally, we also simulate pedestrians on sidewalks with different densities in some scenarios to get more realistic simulations in urban areas.

Participants navigate through varied traffic scenarios that replicate everyday driving conditions and align with the use cases outlined in D1.1 [1]. To target our research questions, we dynamically manipulate scenario parameters as follows:

1. **Environmental Conditions**: Weather conditions are randomly assigned for each scenario from a predefined set available in Carla, ensuring a diverse range of environmental settings.
2. **Traffic Parameters**: In the initial phase, parameters such as traffic density, inter-car distances, and pedestrian spacing are fixed to maintain consistency across tests. In later phases, these parameters will be systematically adjusted based on the guidelines outlined in T1.5 from CVC to further investigate their impact on driving behaviour.

3.4.3. Data Collection

We collect three main types of data:

1. **Eye Tracking Data**: Collected using the Pupil Lab's Core eye tracker, this includes gaze data, fixations, and the egocentric view.
2. **CARLA Simulation Data**: Recorded from the CARLA simulator, this includes car positions, orientations, pedestrian status, steering, throttle, braking inputs, speed, acceleration, and more. Additionally, this data is used in post-processing to extract further perception modalities such as depth and segmentation.
3. **Personal and Driving Data**: A post-experiment survey will be conducted to gather information similar to D1.2 [24], profiling the car drivers.

To maintain data consistency we use the following inclusion and exclusion criterion for our participants:

1. Inclusion:
   a. Driving experience greater than five years.
   b. Good vision or corrected vision with contact lenses (no glasses used).
   c. Age group between 18 to 65 years.
2. Exclusion:
   a. Predisposition to motion sickness.
   b. Unable to maintain vehicular control in simulation.
   c. Vision correction using glasses.
   d. Invalid driving license.

To ensure the accuracy and reliability of our eye-tracking system (Pupil Core) in conjunction with the Carla Simulator, we implement a multi-step calibration process:

1. **Ego-Centric Camera Calibration**: We begin by calibrating the ego-centric camera using a predefined calibration pattern.
2. **Eye Camera Adjustment**: The eye cameras are positioned to ensure adequate coverage of the eye, capturing the pupil under various conditions.

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3. **Gaze Point Calibration**: Using screen markers in Pupil Core's software, we align the ego-centric and eye cameras for precise gaze tracking.
4. **Temporal Alignment**: Before starting the simulation, we synchronize Pupil Core timestamps with Carla timestamps using screen markers. During post-processing, we maintain this alignment using platform timestamps from the shared PC clock which were saved during the recording.
5. **Gaze Mapping in Carla**: After recording, we map the gaze data from the ego-centric camera onto the Carla simulation environment using AprilTag markers (see Fig. 17). This enables accurate translation of gaze points into the virtual world, allowing us to generate detailed saliency maps (see Fig. 18).

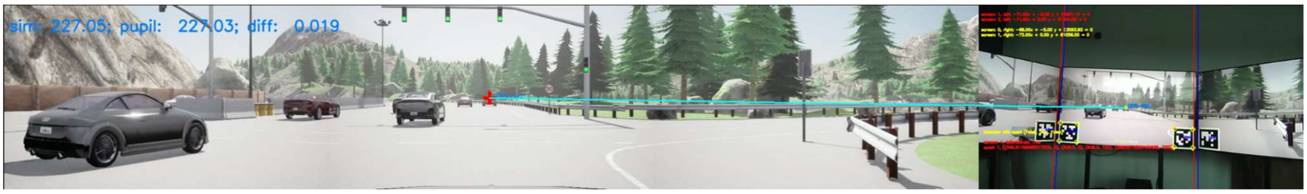

Figure 17. Mapping eye tracking gaze from Pupil Core to Carla using April Tags.

We conduct a survey after the simulation experiments using a part of the questionnaires defined in T1.2 to profile the car drivers (cf. D1.2 [24]). These profiles can be used to parameterize the perception module with different driver types.

Our experimental protocol involves collecting sensitive and identifiable data, including eye-tracking recordings, as well as personal details such as name, age, and sex. The protocol supporting the DFKI experiment has been reviewed and approved by the Ethical Committee and Data Protection Officer of DFKI.

To safeguard participants' privacy, only anonymized data will be shared with BERTHA's partners. This includes aggregated insights such as gaze location heatmaps (see Fig. 18), while raw data—such as eye-tracking videos, ego-centric views, or any information that could identify individual participants—will not be shared.

Figure 18: Saliency map created from data collection.

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3.5. SEYE Protocol

3.5.1. Objectives and Research Questions

The specific research objective is to evaluate the DBM by analyzing how drivers perceive and react to critical situations defined in D1.1 [1], such as left turns with oncoming traffic and highway merging. This evaluation is conducted in a CARLA-based driving simulator and on a test track with an equipped vehicle.

The research follows a two-phase protocol:

- **Simulator Development:** Designing and configuring the CARLA-based simulator to ensure it meets the technical requirements for accurate driver behavior analysis. This includes setting up the multi-screen display, integrating Smart Eye Pro for eye tracking, integrating iMotions for logging, implementing realistic vehicle dynamics, and incorporating environmental and audio effects for immersion.
- **DBM Evaluation:** Investigating driver responses to predefined scenarios using both the CARLA simulator and a test track. The analysis will utilize key measurements listed in 2.1.4, including:
    - Visual Metrics
    - Driver Performance Data
    - Environmental and Contextual Data

By aligning with the overall project goals, this research will provide essential insights into human behavior models used in autonomous systems, ensuring that simulated driving conditions effectively support DBM evaluation. While stationary-base simulators may have limitations in replicating certain dynamic situations, they can still achieve a sufficient level of validity for this research.

The evaluations described in 3.5.1 are expected to take place during mid-project and end-of-project. The simulator validation is planned for summer 2025 and the DBM validation is expected to take place during autumn 2025 (WP5), or when the DBM is ready for evaluation.

The main research questions driving SEYE are:

RQ1a: How does the behavior and performance of the DBM compared to human drivers in terms of driver performance metrics such as longitudinal displacement, lateral displacement, vehicle speed and distance to other road users

RQ1b: How is the performance of the DBM affected by varied conditions such as weather, illumination, road conditions and traffic conditions in terms of performance metrics such as longitudinal displacement, lateral displacement, vehicle speed and distance to other road users.

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3.5.2. Experimental Methods: Scenarios and Procedures

The driving scenarios that will be used are the scenarios UC1-5 that is described in Use Case Definitions 1.1. Furthermore, several environment parameters and other variations will be used in order to capture a wider range of driving conditions and those are the following:

- Weather.
- Light (time of day).
- Amount of traffic.
- Environment (rural, urban or highway).

3.5.3. Data Collection

Sensor data:

To ensure sensor accuracy and reliability, the Smart Eye Pro setup and calibration procedure will be followed. Each camera is placed in a position that captures the subject's head in the camera image center when the subject is sitting in a neutral position, preferably with the subject's face covering a large part of the camera image. The camera should not be placed in an unstable position or in a position that does not put the camera in risk of getting moved by the subject. Once the cameras have been positioned and fixed in the desired positions a camera calibration is required for the software to learn the position and orientations of the cameras. This procedure may be used to verify the camera calibration prior to each recording session and the steps are described below:

- The Smart Eye Pro software is started and camera camera calibration dialogue is chosen which will show the view of all connected cameras.
- A chessboard is held in front of the cameras in an accepted position which is confirmed by red, green and blue bars being drawn on top of the chessboard in each camera video feed in the Smart Eye Pro software.
- Moving the chessboard around using different tilts and positions will fill up a progress bar for each camera in the Smart Eye Pro software. When the bar of every camera is full the application will proceed to the "Verify Camera Calibration" dialogue in which the calibration results are presented.
- If the results are acceptable the calibration may be saved and used for recording.

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3.6. Supporting Contributions from AIT, EUR and CON

Although AIT and EUR are not directly involved in conducting the experimental protocols described in this deliverable, their data contributions significantly shape both the design of BERTHA experiments and the validation of results:

- **AIT's Driver Typology and Survey Data**:
    - **Informing Participant Profiles**: The typology developed in D1.2 [25] (and underlying survey results) helps define which driver profiles or behavioural tendencies to consider in new experimental scenarios, ensuring that the tested conditions reflect realistic variations of the situational risk, impacting cognitive processes (risk assessment and decision-making) and driving behaviours, however dependent on the driver's profile or driving style.
    - **Realism**: By considering these typologies in simulation environments, researchers can more accurately model how different segments of the driving population may respond under certain conditions, improving the validity of the protocols.

- **EUR's Data**:
    - **Real-World Usage Patterns**: EUR's vehicle fleet data offers insights into everyday driving behavior across a large, diverse set of vehicles.
    - **Cross-Checking Findings**: After experimental tests are conducted, the EUR dataset can compare observed behaviors (in controlled settings) against real-world driving patterns, adding a layer of external validation to the experimental outcomes.

AIT's survey data and EUR's records can highlight emerging trends, driver preferences, or anomalies that might inspire further protocol adjustments (e.g., focusing on certain driver groups). In upcoming deliverables (e.g., D2.7, D6.10), the consortium may select specific AIT/EUR data subsets to refine the scenarios or models tested in the lab, ensuring continuous alignment between experimental design and real-world evidence.

In summary, AIT's driver profiles and EUR's telematics insights are complementary resources that increase BERTHA experimental relevance and validity.

Finally, in T5.1 CON is developing several specific scenarios and safety evaluation methods that align closely with the experimental protocols in D2.4. The objective of Task 5.1 is to evaluate and validate a vehicle integrated with a DBM model within a CCAM framework. This assessment aims to ensure the model's reliability, efficiency, and performance under real-world operating conditions. For instance, one key example is the design and validation of critical mixed-traffic scenarios where human-driven and automated vehicles interact under varying conditions. These scenarios were carefully selected to reflect realistic driving contexts and incorporate findings from D1.2 [25].

The work in T5.1 ensures that safety evaluation methods are grounded in established regulatory standards such Euro NCAP. This approach directly supports the objectives of D2.4, illustrating a precise alignment between safety evaluation strategies and experimental protocols.

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4. CROSS-ANALYSIS REGARDING DATA ACQUISITION

In BERTHA's project, each partner employs a structured experimental protocol to capture multiple layers of human driver behavior, visual perception, and actions. The protocols cover various data types—from physiological signals and eye-tracking to subjective evaluations and vehicle dynamics. Standard information across the partners includes rigorous participant screening, simulation environments, and collecting objective sensor data and subjective feedback. In this section 4, we outline the overall framework used for data collection and provide a cross-analysis to ensure consistency, data quality, and complementary insights across experiments.

4.1. Collected Data Across Partners

The table below summarizes each partner's experimental design, including the experiment identifier, data types, and methods of acquisition:

Table 1. Summary table about protocols.

PARTNER	EXPERIMENT ID/FOCUS	TYPE OF DATA/PARAMETERS (for more information, see also D2.1 [2])	METHOD OF ACQUISITION
IBV	Affective and Motor Control Modules	-Physiological signals (ECG, HRV). -Facial expression parameters (AUs). -Reaction times and control inputs (steering, pedals). -Questionnaire responses (stress, mental load, baseline calibration).	- Simulator-based tests with a double adaptation phase. - Controlled environment with pre-/post-test questionnaires.
UGE	Risk Assessment and Decision-Making	-Driving behavior metrics (pedal usage, steering, vehicle commands). -Visual metrics (eye-tracking via SmartEye Pro). -Traffic and risk parameters (vehicle speeds, inter-vehicular times). -Subjective ratings via Likert scales.	- Driving simulator experiments with multiple scenario blocks. - Manual driving training and continuous logging.
DFKI	Perception	-Eye-tracking data (gaze, fixations, saliency maps) -Simulation outputs (vehicle positions, environmental factors). -Post-experiment feedback on driving perception and conditions.	-Use of eye-tracking glasses (Pupil Lab). -CARLA simulation data acquisition and calibration procedures.

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SEYE	DBM validation	-Objective sensor data (gaze patterns, steering inputs, reaction times). -Simulator versus real-life driving comparisons (longitudinal/lateral displacement, speed, safety distances). -Subjective experience via surveys and Smart Eye Pro recordings.	-Dual testing in a CARLA-based simulator and test track. -Camera calibration (Smart Eye Pro) and iterative validation steps.
AIT/EUR/CON	Participant Profiling and External Validation datasets	-Driver profiles (demographic and behavioral data). -Survey data linking driving habits and risk assessment. -Comparison metrics between controlled experimental outcomes and real-world patterns.	- Data from dedicated surveys (as in D1.2). - Integration of external datasets (e.g., EUR dataset) for cross-validation.

As we could see in Table 1, partners utilize real-time sensor data and comprehensive questionnaires to assess human responses (for more details, see following Section 4.2). The primary distinction lies in the research focus as we can see in the second column, and in more detail in Sections 3.2.1; 3.3.1; 3.4.1; and 3.5.1. The support from AIT, EUR, and CON contribute external validation and human participant profiling.

4.2. Cross-Analysis of Future Collected Data

The experimental protocols, while diverse, converge on several core aspects that enable cross-analysis:

- **Common Data Collection Methodologies**: All partners ensure data quality through standardized calibration and participant adaptation phases. The use of baseline recordings and controlled pre-test screenings (including inclusion/exclusion criteria) reinforces the reliability of data across experiments.

- **Objective and Subjective Data Integration**: Each partner collects both sensor-based objective data (e.g., physiological measurements, driving metrics, eye-tracking) and subjective data (questionnaires and interviews) to provide a comprehensive picture of driver behavior. This dual approach allows for cross-validation between measurable metrics and participant perceptions.

- **Overlaps and Complementarity**: The use of similar technologies—such as advanced simulators, and eye-tracking systems—ensures that data are comparable. While IBV and SEYE, focus on sensor accuracy in a simulator environment, UGE expands on risk evaluation through dynamic scenario analysis. DFKI provides a unique perspective by modeling human perception, offering insights that further support the findings from other experimental setups.

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Table 2. Cross-Analysis Summary Table.

ASPECT	OBSERVATION
Calibration & Screening	Uniform use of baseline calibrations and stringent inclusion/exclusion criteria ensures data homogeneity and reliability (Sections 3.2.3 and 3.4.3).
Sensor Data	Common use of physiological sensors, eye-tracking systems, and vehicle control loggers allows cross-referencing of metrics, although specific sensors vary per partner's focus (Sections 3.2.3; 3.3.3; 3.4.3; and 3.5.3).
Subjective Data	Consistent deployment of questionnaires and Likert scales captures participants' perception or cognition, with slight variations in focus (stress, fatigue, risk evaluation, driving style) (Section 3.3.2.2 and Sections 3.2.3; 3.3.3; 3.4.3; and 3.5.3).
Experimental Design	While the overall structure is similar (adaptation, simulation, and debriefing), the duration and specific scenario setups differ to match each partner's research questions.
Data Integration & Validation	Data from simulator-based experiments are cross-validated against real-world driving (SEYE) and externally sourced datasets (AIT/EUR/CON) to ensure broader applicability.

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5. CONCLUSIONS

This deliverable has outlined a comprehensive structure integrating data acquisition across multiple experimental protocols, emphasizing calibration, diverse sensor usage, and the systematic collection of objective and subjective data. Combining these descriptions in Tables 1 and 2, D2.4 recaps the key contributions from each partner while reinforcing the overall strategy for maintaining high-quality data collection. While Section 2 provided a summary of the facilities and key technologies previously addressed in D2.3, in Sections 3 and 4, we focused on synthesizing partner inputs into protocols for a coherent data acquisition and cross-analysis framework.

The integration strategy aligns the diverse protocols from the partners by highlighting standard methodologies and ensuring consistency in the data collection process. This approach facilitates cross-referencing among the different experimental setups. D2.4 thus serves as a cornerstone in understanding the experimental landscape and sets the stage for subsequent research developments phases on BERTHA.

WP2's next phase will focus on data sharing and protection measures based on established protocols based on D2.4. In Deliverable D2.6, we are developing BERTHA's Acquisition Database Prototype that specifies data uploading, downloading, and sharing procedures among project partners. This prototype is instrumental in providing clarity and uniformity in managing and accessing data. Further developments about the experiments and data sharing protocols are anticipated also for Deliverable D2.7.

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