# Interaction Between L4 AVs and Human Drivers in Italian Take-over Scenarios

Linda Boscaro[2], Veronica De Guglielmo[1], Andrea Fossati[2], Andrea Galbiati[2], Massimiliano Gobbi[1(✉)], Gianpiero Mastinu[1], Giorgio Previati[1], Edoardo Sabbioni[1], Maria Gabriella Signorini[1], Antonella Somma[2], Luca Subitoni[1], and Lorenzo Uccello[1]

[1] Politecnico di Milano, Milan, Italy
massimiliano.gobbi@polimi.it
[2] Universitá Vita-Salute San Raffaele, Milan, Italy
fossati.andrea@hsr.it

**Abstract.** Automated Driving (AD) technologies are rapidly transforming road transportation, emphasizing the critical role of Human-Machine Interaction (HMI). In this regard, the paper examines the interaction between Level 4 Autonomous Vehicles (L4 AVs) and human drivers in take-over scenarios within Italian traffic environments. Employing the Dynamic Driving Simulator at Politecnico di Milano, the study presents two simulation environments: an urban roundabout and a Ligurian highway. The research aims to measure the driver response during take-over requests. Questionnaires are used to psychologically analyse the participants. Physiological signals, including ECG, EEG, and EDA, are acquired throughout the entire simulation.

**Keywords:** Automated driving · L4 AVs · Dynamic Driving Simulator

## 1 Introduction

The rapid advancement of Automated Driving (AD) technologies and their connection to Intelligent Transportation Systems (ITS) is revolutionizing road transport, promising safer roads, reduced pollution, and human-centred solutions [1,2]. In this regard, Human-machine interaction in Autonomous Vehicles (AVs), particularly during take-over scenarios, emerges as a pivotal research domain. Many are the factors to be carefully studied. The Take-Over Time (TOT) [3] and its relation to the driver state and performance. The Operational Design Domains (ODDs), its correct definition and extension, considering geographical, technological and design limitations [4]. Furthermore, bidirectional human-machine interaction should drive all the technologies related to advanced Automated Vehicles. Specifically, the current trust paradigm, in which the human evaluates the vehicle's ability to drive in a given condition, should be assessed, investigating whether an AV should let the driver regain control [5]. This research aims to study L4 AVs, employing the state-of-the-art Dynamic Driving Simulator at DriSMi Laboratory of Politecnico di Milano [6,7]. Specifically, the paper

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analyzes the take-over manoeuvre, during which the driver is asked to regain control of the vehicle. The study is part of "Interaction of Humans with Level 4 AVs in an Italian Environment - HL4IT" project, stemmed from the necessity to test the admittance of Level 4 AVs in a unique scenario, such as the Italian one. The project, therefore, aims to deploy automated mobility in Italy, pursuing the subsequent objectives:

- the psychophysiological characterization of the driver, interacting with an automated vehicle Level 4 in the Italian environment;
- the definition of an Operational Design Domain adequately representing 80% of the Italian road network and traffic conditions.

Hence three scenarios, representative of the majority of Italian traffic networks, were selected to assess the humans' capability of regaining control after a TOR respectively in an urban, suburban and highway environment:

1. A urban four-leg roundabout replicated from a real one in Milan.
2. The industrial area of a town located in Friuli-Venezia Giulia, near Udine.
3. An highway scenario, modelled on Ligurian motorways.

The paper is organized as follows. Firstly, it presents a brief literature review to frame the topic covered. Secondly, the two currently developed simulation scenarios are described, focusing on the factor causing ODD exit. The last chapter collects the sensors employed to measure the driver's response and interaction with the vehicle and the surrounding road elements.

## 2 Literature Review

L4 AVs, as defined by the Society of Automotive Engineers (SAE), can perform all driving tasks within specific Operational Design Domains (ODDs) [8]. ODDs can be contained by different limitations, such as geographical or technological, making it highly mutable [4]. If an event causes the exit from the ODD, they must give back the control to the human driver or achieve a minimal risk condition. During these events, a Take-Over-Request (TOR) is issued, prompting the driver to take over [9]. The critical period between the TOR and the driver regaining control is known as the Take-Over Time (TOT). Many factors influence the extent of TOT, such as handheld device usage, non-visual tasks, auditory or vibrotactile TORs, and anticipatory cues [3]. Furthermore, studies suggest that a time budget of 10 s is generally adequate for a safe take-over.

Monitoring driver states during this process is complex, possibly involving bio-telemetry systems, such as Electrocardiography (ECG), Electroencephalography (EEG) and Electrodermal Activity (EDA) [10]. Effective warning methods, including auditory, visual, and haptic stimuli, are essential to improve driver response and reduce TOT [11].

### 2.1 Roundabout Scenario

To test the interaction between humans and AVs Level 4 in an urban context, a network constituted by an orbital and intercity roads and a mini-roundabout has been developed, as shown in Fig. 1. Specifically, a four-leg, single-lane mini-roundabout, located in Milan, was selected as one of the most representative scenarios of the Italian urban environment. The following roundabouts' characteristics justified the choice:

- The presence of a crosswalk at each leg, positioned directly before the entrance to the roundabout.
- The high volume of traffic at two of the legs of the roundabout.
- The standard roundabout's configuration, widely spread in Italy.

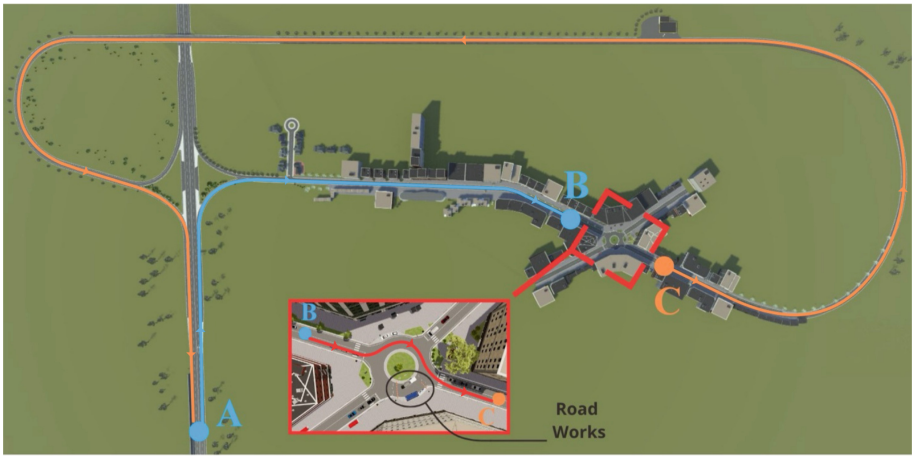



**Fig. 1.** Simulation environment created using VI-WorldSim.

The simulation environment created was divided into three zones:

1. *Zone 1 (blue section in Fig. 1)*: in the initial part of the route, going from point A to point B and corresponding to an orbital road, the DDT is entirely performed by the ADS. Hence the human being is not driving and is, instead, asked to watch a video on a hand-held device.
2. *Zone 2 (red section in Fig. 1)*: the central part of the route, going from point B to point C, corresponds to the roundabout, where the presence of roadworks caused an alteration of the traffic flow. Specifically, the direction of traffic became clockwise, causing the exit from the ODD. Hence the driver is asked to regain control of the vehicle, within the time budget, and to proceed along the route, following the instructions provided on the dashboard. If the driver could not take control of the vehicle, they were asked to remain inside the cockpit, while the Automated Driving System (ADS) achieved the minimal risk condition.

3. *Zone 3 (orange section in Fig. 1)*: the last part of the route, going from point C to point A and corresponding to an orbital road, is travelled solely in the case the driver regained control of the vehicle. While driving in this zone, the driver had to comply with ordinary road rules. An auditory signal warns the driver of exceeding the speed limit, simulating warnings usually installed on the most recent vehicles.

### 2.2 Highway Scenario

To further investigate the interaction between humans and AVs Level 4, a simulation environment representing a Ligurian motorway has been developed, as shown in Fig. 2. Specifically, a three-lane highway has been selected, including the emergency lane. The subsequent motorway's characteristics justified the choice:

- The presence of tunnels and bridges;
- The risk of wind gusts;
- The standard highway configuration, widely spread in the Italian coastline.

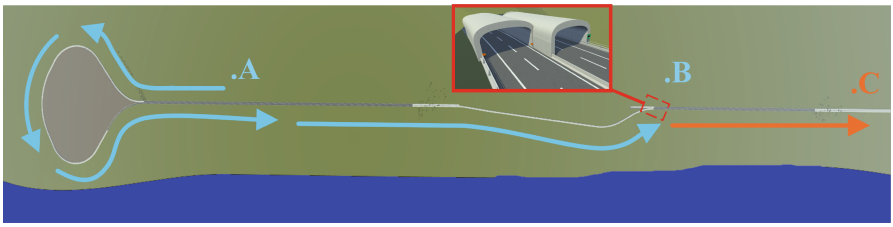



**Fig. 2.** Simulation environment created using VI-WorldSim.

During the simulation, three driving phases are considered:

1. *Phase 1 (blue section in Fig. 2)*: in the first part of the manoeuvre, going from point A to point B and corresponding primarily to a tunnel, the DDT is entirely performed by the ADS. Hence the human being is not driving and they are asked to watch a video on a hand-held device.
2. *Phase 2*: At the exit of the tunnel, corresponding to point B, a wind gust caused the exit from the ODD. Hence the ADS prompted a TOR to the driver, who was asked to regain control of the vehicle within the TOT, proceeding along the route. If the driver could not perform the DDT, they were asked to remain inside the cockpit, while the ADS achieved the minimal risk condition.
3. *Phase 3: (orange section in Fig. 1)*: the last part of the route, starting from point C, was travelled solely in the event the driver regained control of the vehicle.

## 3 Overview of the Collected Physiological and Psychological Measures from Drivers

Drivers' physiological signals are continuously monitored throughout the driving simulation. Figure 3 illustrates the recorded set of data, which includes ECG [12,13], EEG, and EDA [15] signals, as well as eye-tracking data and the forces applied to the steering wheel [14,16]. Additionally, questionnaires are used to describe the drivers' psychological status. Before the driving session, participants completed several psychological measures. Specifically, the Technological Optimism Scale (TOS), assesses views on technology, the Perception of Driving an Automated Vehicles Scale (PDAV) gauges disposition towards automated vehicles, and the Differential Emotions Scale (DES) rates emotional states, based on a 5-point and a 7-point Likert's scale, respectively. Furthermore, the Manchester Driver Behaviour Questionnaire (DBQ) measures self-reported driving behaviours and the Big Five Inventory (BFI) evaluates personality traits are also considered. After the driving session, additional measures, such as the Simulator Sickness Questionnaire (SSQ), the Presence Questionnaire (PQ), measuring the sense of presence in the virtual scenario, and the PDAV and the DES, were administered.

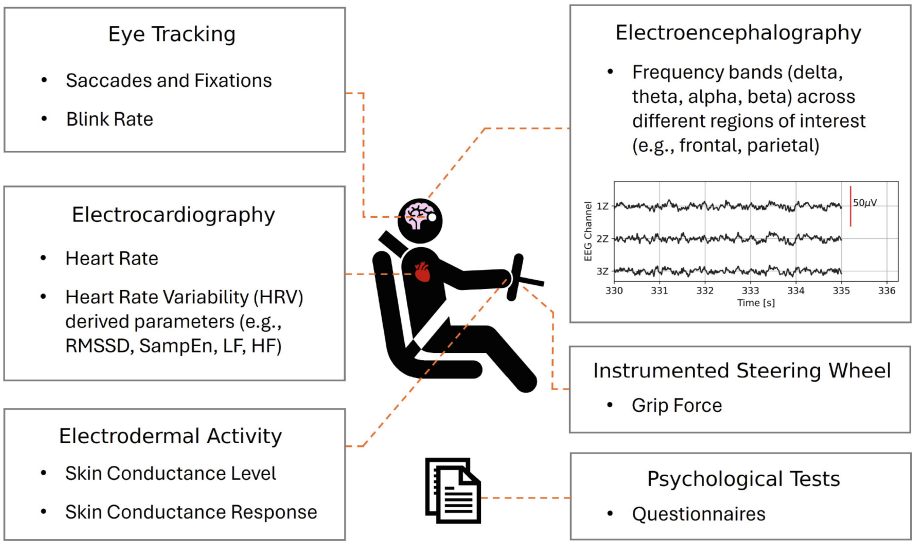



**Fig. 3.** Outline of the physiological and psychological data collected from each subject, along with relevant parameters. The EEG signals shown in the figure illustrate actual pre-processed data from three exemplary midline electrodes, acquired during a driving simulation session.

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