Human Systems Engineering and Design (IHSED 2026), Vol. 237, 2026, 55–64
https://doi.org/10.54941/ahfe1008145

Development and Verification of a Testing Methodology for Driver Alcohol Intoxication Detection Systems

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ABSTRACT

The development of robust driver monitoring systems for alcohol intoxication detection represents an important advancement in automotive safety technology. Intoxicated driving remains a major contributor to road fatalities worldwide, and regulatory bodies and consumer safety organisations such as Euro NCAP are increasingly encouraging the implementation of technologies capable of detecting driver impairment and reducing alcohol-related risk. However, the development of production-ready detection solutions requires multi-phase data collection and assessment with participants under the influence of alcohol. This introduces significant safety, ethical, operational, and methodological challenges, particularly when moving beyond laboratory conditions towards more realistic vehicle-based validation. Consequently, there is a growing need for structured toolchains and assessment methodologies that build upon existing driver monitoring validation approaches while extending them across virtual and real-vehicle platforms. The specific innovation of this work lies in the development of user testing services that can support automotive product development during a critical phase between laboratory validation and real-world deployment. The proposed framework combines controlled alcohol administration protocols, medical supervision, vehicle and driver monitoring instrumentation, behavioural and subjective data collection, BrAC measurement, and rigorous safety procedures. This paper presents the development and pilot implementation of this testing framework at the IDIADA proving ground in Spain. The methodology is designed to enable controlled, repeatable, and ethically managed evaluation of alcohol intoxication detection systems in a real-vehicle environment, while maintaining participant safety and operational robustness. The standardised approach supports comparative assessment between different technological solutions and contributes to the definition of performance evaluation procedures for emerging impairment detection systems. In doing so, it provides a practical bridge between early-stage system development, simulator-based validation, and future real-world implementation.

Keywords: ADAS, Driver engagement, Driver states, DMS, Driver intoxication

INTRODUCTION

Road traffic accidents remain a pervasive global challenge, resulting in substantial human and economic losses. The World Health Organisation estimates that approximately 1.19 million people die in road traffic incidents

Received July 1, 2026; Revised July 22, 2026; Accepted August 10, 2026; Available online September 25, 2026

each year, with an additional 50 million experiencing non-fatal injuries (World Health Organisation (WHO), 2023). Among the most striking observations in traffic safety research is the central role of human error, which contributes to more than ninety per cent of accidents (World Health Organisation (WHO), 2023). These errors encompass a wide range of factors, including misperception, distraction, fatigue, decision-making under uncertainty, and misjudgement of dynamic traffic situations.

Alcohol intoxication represents one of the most significant and preventable causes of impaired driving performance (Garrisson et al., 2022; Dong et al., 2024). The development of robust driver monitoring systems for alcohol intoxication detection represents a critical advancement in automotive safety technology (National Highway Traffic Safety Administration (NHTSA), 2023). With intoxicated driving remaining a significant contributor to traffic fatalities worldwide, there is growing regulatory push alongside strategy for consumer safety organisations like Euro NCAP towards technologies to minimise associated risks (National Highway Traffic Safety Administration (NHTSA), 2023).

Development of production-ready detection solutions depends on multi-phase data collection and assessment with test participants under the influence of alcohol – presenting significant safety and ethical challenges. In consequence, there is a pressing need to build tool chains for driver intoxication monitoring system evaluation upon existing performance validation approaches across virtual and real-vehicle platforms. Specific innovation focusses upon providing user testing services for implementation during the automotive product development cycle at a critical phase between laboratory validation and real-world implementation.

The present work describes the development and validation of a comprehensive testing framework for alcohol intoxication detection systems, applicable to both proving ground and driving simulator environments. This framework addresses the critical need for standardised, ethical, and safety-focused methodologies to support the automotive industry in developing and validating technologies that can detect and respond to alcohol-impaired driving states.

METHODS

Foundation and Regulatory Context

The methodological foundation relies upon established human factors principles and regulatory frameworks governing driver monitoring systems, accounting for relevant factors including participant selection, controlled intoxication protocols, vehicle instrumentation, safety measures, and data collection procedures. Development has been guided by comprehensive literature review of alcohol's effects on driving performance, crash risk assessment (Fell and Voas, 2014; Compton and Berning, 2015; Blomberg et al., 2005), and international standards for evidential breath analysis (International Organisation of Legal Metrology (OIML), 2021; European Committee for Standardisation (CEN), 2011), providing a robust basis for the standardised testing approach.

Ethical Framework and Medical Oversight

To guarantee ethical compliance and participant safety, a certified research physician is involved in preparation and review of the complete protocol, identifying potential health risks and proposing mitigation strategies including candidate screening, exclusion criteria, and health monitoring variables. All testing activities follow reference guidelines from National Institute on Alcohol Abuse and Alcoholism (NIAAA) for conducting alcohol administration studies (National Institute on Alcohol Abuse and Alcoholism (NIAAA), 2023), and World Health Organisation standards for ethics review of health-related research (World Health Organisation (WHO), 2011). The research physician provides continuous support throughout candidate screening, participant exclusion, and monitoring prior to, during, and after alcohol assumption.

Participant Selection and Screening

The framework is based around a stratified sample of representative drivers selected according to specific criteria including driving experience, alcohol consumption habits, and demographic profile. Eligibility requires participants to be at minimum 18 years of age and **provide a medical declaration of fitness for alcohol consumption.**

Screening employs a questionnaire to assess alcohol consumption patterns, with exclusion criteria encompassing medical conditions incompatible with alcohol intake, medications contraindicated with alcohol, pregnancy or breastfeeding, hazardous drinking indicators (AUDIT-C scores ≥4 for men, ≥3 for women), abstainer status, history of aggressive behaviour when intoxicated, prior conviction for driving under influence, and any medical or behavioural concerns raised by the research team or physician. Participants must refrain from eating for at least 2 hours before the trial, avoid caffeine consumption, and abstain from alcohol for 24 hours prior to testing.

Controlled Intoxication Protocol

The controlled intoxication protocol establishes negative, low-level, and high-level alcohol concentration validated using calibrated breathalyser devices following a within-subject design. Required alcohol doses are determined based on target blood alcohol concentration (BAC) and participant body weight and sex using standard formulae such as the Widmark equation, ensuring appropriate dosing to reach desired BAC levels. All Breath Alcohol Concentration (BrAC) measurements are conducted using evidential breath analysers (e.g., Dräger Alcotest® 6000) with up-to-date calibration certificates complying with OIML R 126-1 and European standard EN 15964:2011, with BrAC converted to equivalent BAC using the blood-to-breath ratio (≈2100:1) to assess impairment and legal compliance.

Instrumentation

Test vehicles and the driving simulator platform are equipped with synchronised recording systems for comprehensive data collection. Measurement equipment includes physiological monitoring systems

(BioSignal Plux) for heart rate, heart rate variability, electrodermal activity, and respiration; fingertip pulse oximeters for blood oxygen saturation and pulse measurements; eye-tracking systems; and cabin video cameras capturing face and cabin views. Vehicle or simulator platform data interfaces are used to acquire steering angle, speed, brake status, and other relevant channels; and data-logging workstations with secure storage and time synchronisation.

For proving ground tests, safety equipment includes auxiliary brakes accessible to safety co-drivers, and monitoring mirrors and displays.

Safety Measures and Oversight

Comprehensive safety measures ensure participant well-being throughout testing, with trained safety drivers, medical supervision, and closed-track conditions validated by external research committee review.

A certified physician is assigned to provide continuous health professional support including protocol review, risk identification and mitigation, candidate screening, participant monitoring throughout alcohol administration and testing, fitness assessment before and after tests, and maintains constant radio contact with safety drivers. Test personnel receive physician training to detect physiological and behavioural decay, with access to 24/7 ambulance and dispensary services.

For proving ground testing safety measures include vehicle technical review, exclusive track access, trained safety co-drivers capable of intervening on longitudinal and lateral control, proving ground safety coordination, and security notification. Safety co-drivers maintain a primary responsibility for monitoring driving behaviour and maintaining radio contact with all safety personnel from proving ground management.

Measurement Requirements

Measurements are conducted systematically throughout testing. BrAC measurements include baseline verification (0.00% $\pm$ device error), measurements at fixed intervals (5–10 minutes) during administration until target BrAC is reached, monitoring at 15–20 minute intervals during testing, and post-test measurements at 5–10 minute intervals until baseline values are reached. Physiological monitoring includes baseline and post-test verification that heart rate lies within 60–100 bpm and SpO_2 within 95–100%, continuous heart rate monitoring during administration (ensuring never drops below 40 bpm), SpO_2 checks every 10–15 minutes during administration (ensuring never drops below 90%), and continuous heart rate and respiration monitoring with SpO_2 checks every 20–25 minutes during testing. Behavioural metrics include participant sensorimotor assessment (alertness, orientation, balance) performed at baseline and post-test, continuous eye-tracking data collection (fixations, gaze dispersion, eye-closure), and driving behaviour measurements (steering angle, vehicle speed, brake activations).

Subjective measures employ standardised scales including the Karolinska Sleepiness Scale and Subjective Intoxication Scale at baseline, during administration (5–10 and 15–20 minute intervals respectively), during

testing (15–20 and 25–30 minute intervals), and post-test assessment including System Acceptance/Trust/Safety Benefit scales when relevant to study objectives.

Test Scenarios

Test scenarios are designed to balance ecological validity with safety requirements on closed courses. These incorporate variable speed highway driving, intersection navigation, low-speed manoeuvres, and scenarios designed to assess specific aspects of impaired driving performance according to test objectives.

For driving simulator implementation, testing is conducted in exclusive-use simulators (e.g., VI-grade Static or DiM250) with adjustable seating, harness, ventilation, and temperature control, considering potential motion sickness and discomfort from alcohol intoxication, with participants following a route within a virtual environment. For proving ground implementation, tracks are reserved for exclusive use for testing with external participants under intoxication inducement with speeds never exceeding 80 km/h, and defined routes. Proving ground management are involved in managing restricted access within an mixed-use facility, and monitoring tests to ensure safety conditions are upheld.

TEST PROCEDURE

Arrival and Briefing

Upon arrival, participants receive a concise briefing delivered by a Human Factors specialist covering: (a) the study procedure, (b) the safety measures in place, and (c) an overview of any subjective scales or questionnaires that will be administered. Participants then provide informed consent and complete privacy documentation in accordance with GDPR requirements.

Transfer to Test Site

Participants are escorted to either the driving simulator suite or the proving ground according to study objectives. For on-track trials, alcohol administration and baseline checks are conducted in the medical dispensary whenever feasible to ensure a rigorously controlled environment and to enhance participant confidence.

Baseline Verification

An initial breath alcohol assessment is performed to confirm a baseline BrAC of $0.00 \pm 0.01\%$, accounting for the breathalyser's margin of error. Prior to measurement, the participant performs a thorough oral rinse with water to avoid sample contamination. When required by study objectives, participants complete validated pre-test subjective questionnaires. The research physician performs sensorimotor assessment of the participant (i.e., alertness, orientation, and balance).

Acclimatisation Drive

Once zero BrAC is verified and the physician approves proceeding, the participant undergoes 15–20 minutes of acclimatisation drive:

- Simulator trials: Participant is seated in the activated simulator and begins driving in the exact scenario to be used during formal testing. At regular intervals, the researcher checks for participant physical and psychological comfort (e.g., absence of motion sickness or visual fatigue).
- On-track trials: The participant, accompanied by the safety driver, drives a familiarisation lap at the prescribed speed on the same circuit and in the correct lane position to be used in the test. During this lap, the safety driver indicates lane discipline, reference markers, braking points, safe areas, and demonstrates how to engage auxiliary systems (e.g., ACC) if relevant to the study.

At the end of the adaptation period, the participant provides a final comfort check; if no concerns arise, they proceed to the formal testing phase.

Alcohol Administration

After completing the baseline driving session, the calculated alcohol dose is administered to the participant in beverage form using standardised glassware, calibrated beverage, and stopwatch for dosing/absorption timing. The dose must be consumed within approximately 10–15 minutes to achieve the target BrAC. During this period, light snacks may be provided, and potable water is available to maintain hydration and comfort.

BrAC Absorption and Target Achievement

Approximately 15 minutes after finishing the drink (to allow for absorption), a second breathalyser test is conducted to measure the participant's BrAC. Prior to this breath test, the participant rinses their mouth with water to eliminate any residual mouth alcohol that could skew readiness. If the measured BrAC is not yet within the target range, the protocol calls for waiting an additional 5–7 minutes and then taking a new measurement. This step is repeated as necessary until the participant's BrAC falls within the target window.

Post-Administration Driving Phase

Once the target BrAC is confirmed, the participant proceeds to the next driving phase of the experiment. This driving session (on track or simulator) lasts approximately 30–40 minutes, during which the participant operates the vehicle or simulator under the influence of the alcohol dose. The driving task is standardised in length and conditions for all participants to allow reliable comparisons. Throughout this phase, continuous monitoring of physiological, behavioural, and subjective measures is maintained according to the defined measurement schedule.

Post-Trial Assessment and Recovery

At the end of the testing session, a final breathalyser measurement is taken to document the participant's BrAC after the driving tasks. Participants then complete the same scales or questionnaires that were administered prior to the trial, for example, repeating the KSS or other surveys used at baseline. This pre-post comparison helps researchers and the research physician to assess any changes in the participant's subjective state, feelings, or health condition from before alcohol consumption to after the driving session.

Behavioural and sensorimotor assessment, such as alertness, orientation, and balance, is also performed on participants before approving their dismissal. This monitoring phase is performed by either the research physician or by the research team member with the supervision of the research physician, who has previously trained the team on how to perform the monitoring.

Recovery and Safe Transport

After all tests are finished, the participant is given time to recover in a comfortable setting. Food and non-alcoholic beverages are provided to help speed recovery and mitigate the effects of the alcohol. Light snacks or a simple meal, along with water or soft drinks, help participants metabolise the alcohol and improve comfort whilst they sober up.

Participants are required to remain under observation at the test location until they are granted approval to leave the test site without risk for their or anyone else's safety and health. The criteria to determine participant dismissal are based upon BrAC, oxygen saturation, and HRV, which are expected to return to pre-administration level, i.e., baseline values. Under no circumstances are participants allowed to leave the testing site if physiological values are over baseline ranges, and/or they exhibit worse sensorimotor functions relative to pre-test assessment.

Once participant dismissal is granted, a member of the research team accompanies the participant to the IDIADA gate. Safe transportation home is arranged—a taxi (pre-paid and arranged by the study organisers) takes the participant home safely. The researcher escorts the participant to the vehicle to ensure a hand-off to a sober driver. The participant is thanked for their cooperation, and the session is formally concluded once they are safely on their way home.

Test Interruption Criteria

The test must be terminated if any of the following conditions occur:

1. Participant withdrawal: The participant decides to quit. Their decision has immediate effect with no need for explanation.
2. Non-compliance or unsafe behaviour: The participant is repeatedly ignoring instructions, performing deliberate reckless manoeuvres, interfering with the equipment, or doing anything that could put themselves or anybody else at risk or affect the quality of the data.

3. Simulator sickness or acute distress: The participant exhibits strong nausea, dizziness, confusion, panic, or other physical or mental symptoms that prevent moving forward with the test safely or comfortably.
4. Clear signs of impairment, lack of focus: The participant shows difficulty staying in lane, drifting, microsleep episodes, or a demeanour that is not compliant with the present and other safety protocols defined for this type of test.
5. Decay of participant's health condition: Participant's physiological values exceed safety/baseline ranges, and/or research physician suggests the interruption of the test based on objective observations suggesting a risky decay of participant's health condition.
6. Safety-driver override (proving ground tests): The safety driver activates brake, steering, or kill-switch after detecting participant decay in cognitive or behavioural performance, as well as health condition.
7. Technical or environmental hazard: Critical simulator/vehicle malfunction, unexpected obstacle on track, or adverse weather (heavy rain, fog, high winds, lightning) that compromises safe operation.
8. Unforeseen/behavioural risk: Any new hazard not foreseen in the protocol, e.g., sudden medical issues, aggressive or confused behaviour due to alcohol.

RESULTS

Results are currently being analysed. The validated framework has successfully enabled integrated and reliable collection of applicable data streams across multiple test sessions.

DISCUSSION

The discussion of results will be presented following completion of ongoing data analysis.

CONCLUSION

This framework provides a basis for rigorous, repeatable methods to validate alcohol detection technologies in a proving ground and driving simulator environment. The defined framework for participant testing under the influence of alcohol provides basis for definition and implementation of proving ground tests whilst meeting safety and ethical standards of a world-leading multi-use facility. The validated test procedure enables integrated and reliable collection of applicable data streams, with collected data correlated between image, physiological, vehicle metrics, and breathalyser-measured alcohol levels.

The standardised approach supports comparative analysis between different solutions and establishes a benchmark for performance evaluation procedures balanced with specific challenges of user testing under alcohol intoxication inducement. The framework successfully integrates comprehensive safety measures, including medical oversight, trained safety personnel, controlled test environments, and rigorous participant screening and monitoring protocols.

Significance extends beyond immediate application, setting a foundation for global adaptation at similar test facilities across differing specific objectives. In addition, it provides a basis to evaluate systems for monitoring of other intoxication states, alongside emerging vehicle response strategies for risk mitigation of alcohol intoxication in drivers (European Commission, 2022; National Highway Traffic Safety Administration, 2023). By supporting development of accurate and robust monitoring systems, this research contributes to road safety and user-technology acceptance, directly aligning with initiatives aimed at reducing alcohol-related incidents by fitment of intoxication detection systems in vehicles.

The methodology demonstrates that complex safety-critical testing involving controlled alcohol administration can be conducted ethically and safely through appropriate application of medical oversight, comprehensive safety protocols, and rigorous adherence to established ethical guidelines (National Institute on Alcohol Abuse and Alcoholism (NIAAA), 2023; World Health Organisation (WHO), 2011). Future work will focus on analysis of collected data and refinement of the framework based on pilot implementation findings.

Ongoing work will focus on analysis of collected data and refinement of the framework based on pilot implementation findings.

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