講演番号	122

Multi-pillar Framework for the Assessment of Human Machine Interaction in Automated Vehicles

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KEY WORDS: **human engineering (C2)** human-machine interaction, type approval, ADAS, AD

The deployment of partial (SAE Level 2) and conditional (Level 3) vehicle automation redefines the division of roles between the human driver and the automated vehicle, necessitating a clear mutual understanding of system capabilities, limitations, and transitions. Empirical evidence highlights persistent challenges in user comprehension, including misinterpretation of automation states, overreliance, and mode confusion—where system behavior diverges from user expectations. Existing regulatory and standardization frameworks (e.g., ISO, UNECE) offer limited operational guidance, resulting in inconsistent human–machine interface (HMI) implementations. To address these gaps, this paper presents a structured, multi-dimensional framework for evaluating human–automation interaction.

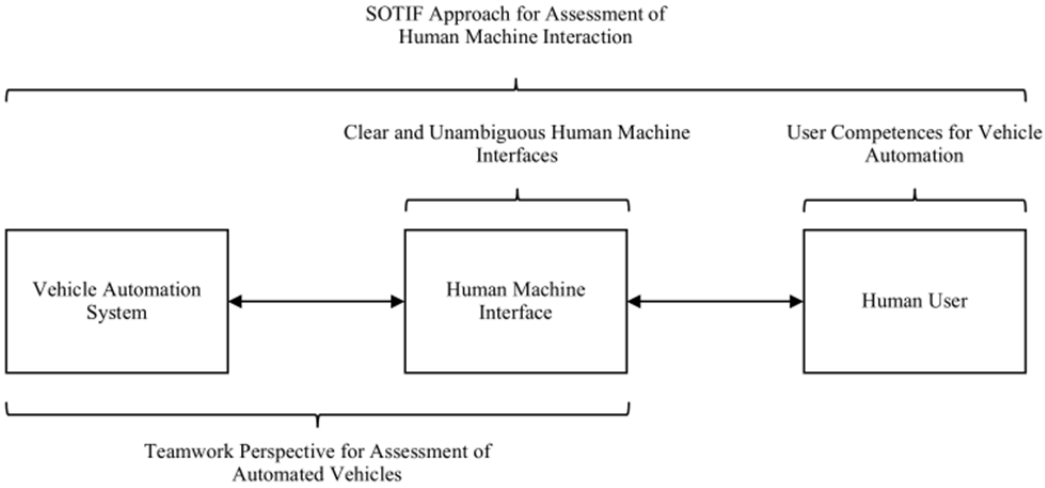

Fig 1: Overview of TNO's multi-pillar framework for the assessment of human machine interaction in automated vehicles.

Developed by TNO in collaboration with Dutch regulatory authorities and other stakeholders, the proposed framework comprises four interdependent methodological pillars:

1) **Clear and Unambiguous HMIs –** This pillar introduces a validated questionnaire (CUQ) to quantitatively assess the clarity and comprehensibility of HMI designs. The tool enables systematic evaluation of user perception and understanding across varying automation levels and user experience profiles.
2) **Teamwork Perspective for Assessment of Automated Vehicles –** Drawing on principles of human teamwork, this pillar conceptualizes the driver and automation as a cooperative team. It defines interaction patterns and shared mental models to assess coordination, predictability, and transparency, offering a structured vocabulary for system evaluation.
3) **SOTIF-Based HMI Assessment –** This component adapts the Safety of the Intended Functionality (ISO 21448) framework to identify potential mode confusion hazards. Through interaction flow modeling, it enables pre-deployment analysis of functional insufficiencies in the communication between driver, HMI, and automation.
4) **User Competences for Automated Vehicles –** This pillar investigates the evolving nature of driver tasks and required competencies in the context of DCAS and ALKS. A theoretical task model is being empirically validated through on-road studies, identifying observable behaviors and providing input to future training and licensing strategies.

Collectively, these pillars constitute a comprehensive methodology for evaluating human–automation interaction. The Clear and Unambiguous HMI pillar was validated through driving simulator studies, where the CUQ reliably differentiated among high-, medium-, and low-quality HMI designs across user experience levels. The Teamwork pillar is applying structured interaction patterns to identify coordination breakdowns and inform design improvements. The SOTIF-based assessment successfully identified potential mode confusion scenarios in a Level 3 highway pilot vehicle, with several hazards confirmed during on-road testing. The Driving Competences pillar yielded empirical insights from a pilot field study, revealing which theoretical driver tasks are observable in practice and highlighting the influence of driver instruction on task engagement. Together, these findings confirm the framework's utility for both OEMs and regulatory bodies in supporting the design, evaluation, and approval of safe and user-centered automated driving systems.