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Resilient and Continuous Safety Assurance Methodology for CCAM and its HMI Components

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Objective

This paper presents the CERTAIN project, that defines a comprehensive Safety Assurance Framework (SAF) for Cooperative, Connected, and Automated Mobility (CCAM) systems that extends beyond pre-deployment validation to include continuous lifecycle monitoring. The framework addresses critical gaps in safety validation for SAE automation levels L2-L4, focusing on human-centric aspects, trustworthy AI requirements, and post-deployment monitoring while supporting regulatory harmonization across UNECE member countries.

Methodology

The framework integrates four technical pillars:

- Human-Machine Interaction (HMI) Validation: STAC-based (Safety, Trust, Acceptance, Comfort) evaluation with quantifiable pass/fail criteria addressing diverse user populations and mode confusion prevention.
- Trustworthy AI Validation: Scenario-based methodologies incorporating data-driven Operational Design Domain (ODD) extension, Explainable AI (XAI) strategies aligned with EU AI Act requirements, and lifecycle monitoring for AI perception and decision-making systems.
- In-Service Monitoring and Reporting (ISMR): Continuous assessment platform with on-board monitoring units, anomaly detection algorithms, unknown scenario identification, and feedback mechanisms.
- Vehicle-to-Everything (V2X) Validation: Technology-agnostic co-simulation frameworks for connected systems including collective perception, cooperative driving, and connected vulnerable road users (VRUs).

The framework extends the UNECE New Assessment Test Method (NATM) with scenario-based validation following ISO 34503, using hybrid testing across X-in-the-Loop (XiL) simulation, proving grounds, and field operational tests.

Future Key Results:

- Validated through 11 sub-use cases covering automation levels L2-L4 across diverse vehicle types (passenger cars, trucks, delivery robots) and operational environments
- Demonstrated technical maturity progression from TRL 2-3 to TRL 4-5
- Successfully integrated pre- and post-deployment validation with continuous learning mechanisms
- Established quantifiable metrics for HMI, AI robustness, explainability, and V2X communication reliability
- Addressed stakeholder-specific transparency requirements for developers, regulators, and users

Conclusions

The framework addresses critical validation gaps through an integrated, human-centric approach combining pre- and post-deployment safety assurance. Its technology-neutral and scenario-based methodology positions it for regulatory adoption, supporting safe and scalable CCAM deployment. Alignment with UNECE frameworks and EU regulations (including EU AI Act 2024/1689) represents a significant advancement toward trusted, human-centric automated mobility. The continuous learning mechanism addresses the fundamental challenge that exhaustive pre-deployment validation is infeasible given the virtually infinite scenario space.

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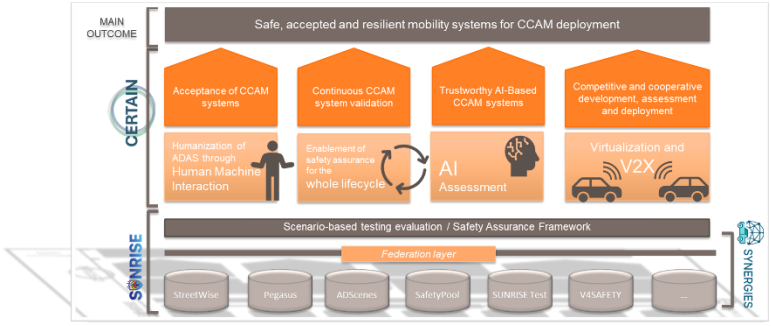

Fig. 1 Safety Assurance Framework in CERTAIN project

Fig.2 Examples of use-cases