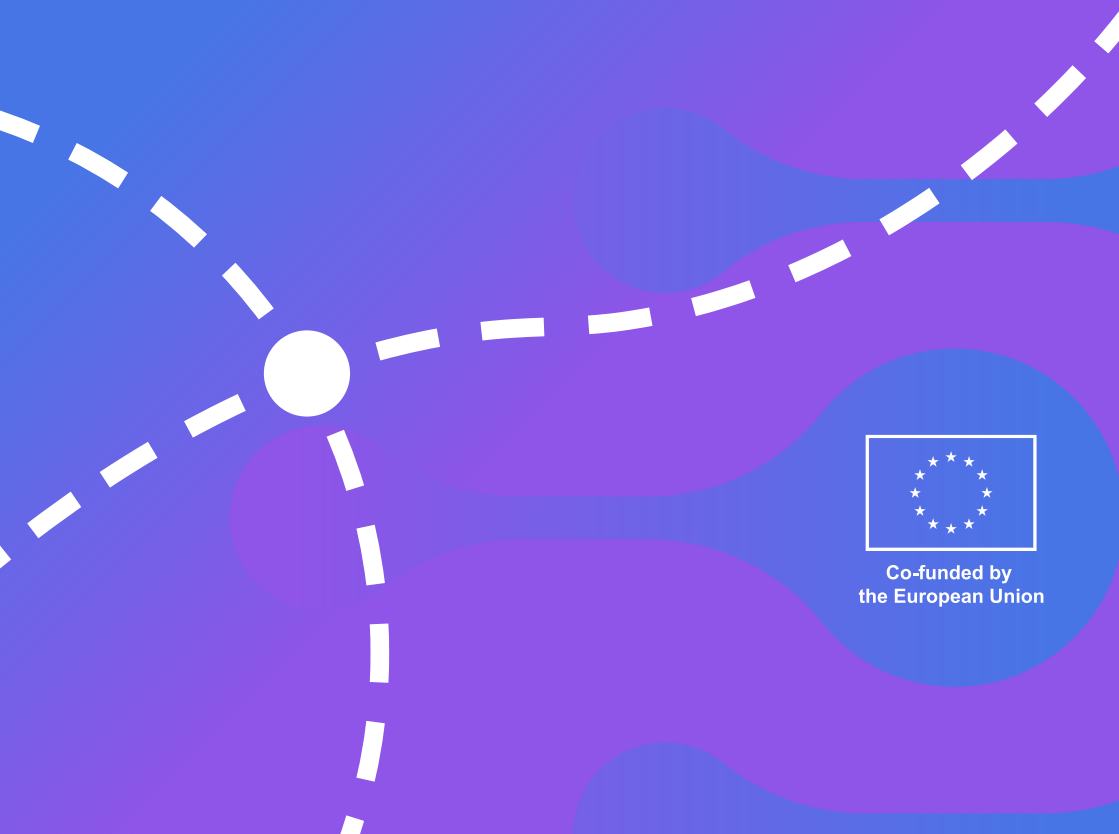
# PODIUM

## ACCELERATING THE IMPLEMENTATION OF CONNECTED COOPERATIVE AUTOMATED MOBILITY (CCAM) TECHNOLOGY



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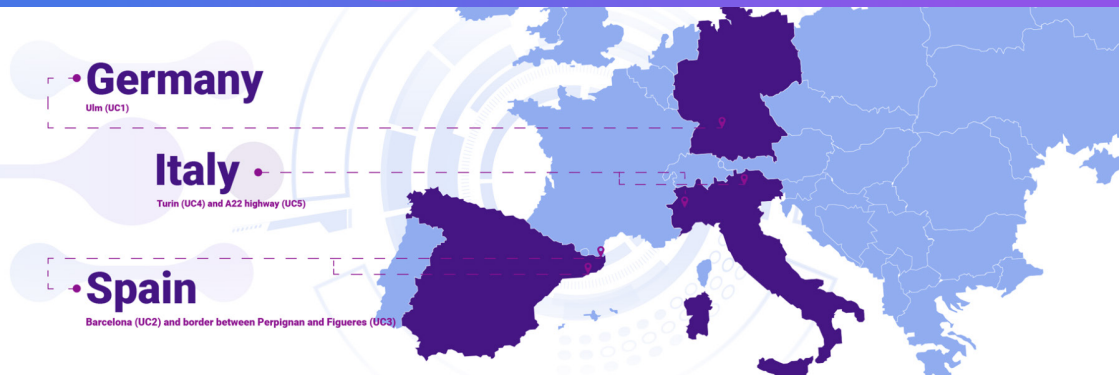
# PoDiUM

PoDIUM advances the integration of Physical and Digital Infrastructure (PDI) to enable safer, more efficient, and more reliable road automation. By addressing key challenges in connectivity, cooperation, data management, interoperability, and reliability, the project paves the way for the large-scale deployment of Connected, Cooperative, and Automated Mobility (CCAM) solutions across Europe.




## Through extensive real-life demonstrations

in three Living Labs — in Germany, Italy, and Spain — PoDIUM has tested innovative CCAM use cases in urban, highway, and cross-border environments, showing how advanced infrastructure can support vehicles and road users alike.

## The PoDIUM Living Labs

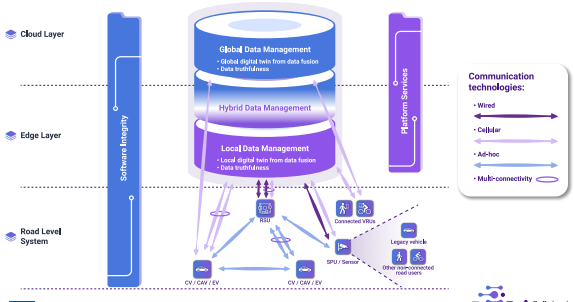
**Germany:** Testing cooperative urban corridor management for improved safety and efficiency in complex city traffic.

**Italy:** Demonstrating enhanced safety and reliability in complex environments — from urban intersections to GNSS-denied motorway tunnels.

**Spain:** Showcasing real-time, data-driven traffic management in urban corridors and on highways, supporting priority vehicles, Vulnerable Road Uses (VRU) protection and cross-border continuity.

**The project's final result is a Reference Architecture for next-generation cooperative systems. This architecture defines how physical and digital infrastructure components can work together seamlessly, offering a scalable, interoperable, and trusted framework adaptable to different road environments and technologies.**

## High-level platform architecture



Use Case #1

# Cooperative Corridor Management in the City of Ulm

**Use Case 1 validates a cooperative local environment model and planner to manage complex urban traffic situations, such as a blocked lane. The focus is on improving safety and efficiency when vehicles and VRUs (e.g., cyclists) must share a constrained road section. The setup combines onboard and infrastructure sensors with different communication technologies (5G cm- and mm-wave, and 60 GHz WiFi) to ensure high availability and reliability.**

## Key results and technological advancements

- A local environment model for the intersection was developed using data from connected road users alone, and in combination with infrastructure sensors, including reliability checks.
- A reliable multi-connectivity approach (5G + 60 GHz WiFi) enabled fast and reliable cooperative decision-making.
- VRU protection improved through coordination between Connected Automated Vehicles (CAVs) and connected VRUs.
- Cooperative corridor management led to improvements in traffic efficiency and/or safety.
- PoDIUM's architecture enabled offloading complex CAV functions to the MEC.

Photo of the test junction. Source: UULM-MRM

## Challenges and recommendations for deployment

- Traffic steering and load balancing across heterogeneous communication technologies can be efficient in transport-layer schedulers, but intensive packet processing for collision-free duplication/deduplication requires hardware support for high throughputs and should be decoupled from transport-layer scheduling.
- Standardised messages only should be used as the interface between different components to facilitate interaction between the server planner and the local vehicle planners.
- Accurate local environment models can be built with minimal infrastructure, enabling manoeuvre coordination using only communication modules and an edge server.
- Vehicles can be augmented with enhanced or even supplementary functionalities by leveraging function offloading to the MEC. This is much improved by high-bandwidth networks like 5G and multi-connectivity.

Demonstration Event on Connected Cooperative Driving in Ulm

Use Case #2

# PDI for Use-Centric, CCAM-enabled Traffic Management in Urban Corridors with High Priority Vehicles and VRUs

**Use Case 2 enhances urban traffic management in Barcelona by enabling real-time data exchange between CAVs and the infrastructure. Three scenarios were demonstrated in a complex urban environment: Emergency Vehicle (EV) priority, traffic optimisation, and VRU protection. Together, they address real-time traffic light priority for EVs, traffic analytics and congestion warning based on connected vehicle data, and proactive collision-risk alerts for CAVs and VRUs.**

## Key results and technological advancements

- The use case succesfully achieved its key objectives of validating the physical and digital infrastructure (PDI), edge computing (MEC), and their integration with Barcelona's traffic management and emergency response systems.
- Scenario 1 successfully anticipated the arrival of EVs and activated the green light early before they reached the road segment, achieving dynamic EV priority.
- Scenario 2 enhanced the MISTRAL Smart Mobility Platform by utilising connected vehicle data (position and origin-destination) to generate traffic metrics and facilitate optimal control strategies.
- Scenario 3 demonstrated clear safety benefits: the C-V2X warning enabled earlier braking and reduced deceleration magnitude, thus validating the targets for low latency and softer manoeuvres.
- Warnings for all scenarios (EV approach, congestion and collision risk) are broadcast as standardised C-ITS DENM messages via a hybrid 5G/C-V2X network. These warnings are relayed to the driver via the Human-Machine Interface (HMI), and CAVs can also react autonomously to them.

Emergency Vehicle (EV) priority scenario (Gran Via, Barcelona)


Elements for protecting VRUs include detection by cameras, roadside infrastructure and an HMI inside the vehicle

## Challenges and recommendations for deployment

- The main challenge was the difficulty of testing the scenario due to heavy mixed traffic and complex VRU patterns at the Barcelona test site (the Gran Via Corridor).
- Ultimately, the CAV was unable to obtain the necessary permits to conduct tests in Spain. Consequently, the CAV trials had to be relocated to a closed circuit in France. Nevertheless, the full set of planned trials involving connected vehicles were carried out in Barcelona, with no impact on the results.
- Recommendations include prioritising the establishment of streamlined, harmonised European regulatory frameworks for CAV testing.

Use Case #3

# Real-time Responsive PDI for CCAM-enabled Traffic Management in the Mediterranean Cross-Border Corridor

**Use Case 3 demonstrates how a responsive PDI system enables real-time cooperation between vehicles, road users, and operators to improve safety and traffic flow under mixed traffic conditions. On the C-32 highway near Barcelona, connected vehicles exchanged data with the infrastructure to receive alerts and manoeuvre recommendations for efficient daily commuting and unexpected safety incidents. The use case also addressed seamless cross-border data continuity and coordination between traffic management centres, an on-demand automated shuttle service, and a VRU Safety application issuing simultaneous alerts to pedestrians and vehicles.**

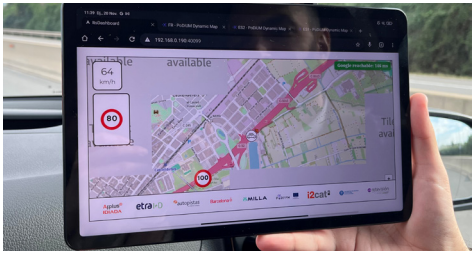
Autopistas Operations and Road Safety Centre

## Key results and technological advancements

- An ETSI-compliant V2X communications protocol stack, including C-ITS messages was implemented in vehicles and the edge server.
- Two V2X gateways enabled the transmissions of C-ITS messages over both C-V2X and 5G networks.
- A Digital Twin based on a Local Dynamic Map (LDM) was implemented to store road-user and infrastructure data and to predict nearby vehicle positions during network interruptions.
- The Traffic Management Centre fused connected vehicle and video analytics data from traffic cameras to detect traffic flows and hazards, launching responsive traffic strategies in real time.
- The VRU Safety app transmits pedestrian locations with C-ITS messages and sends collision-risk alerts to vehicles and pedestrians.
- On-board units and the HMI enabled any vehicle to connect with nearby vehicles (V2V communication) and infrastructure, receiving alerts and recommended strategies; automated vehicles can apply them autonomously.

## Challenges and recommendations for deployment

- Cross-border 5G roaming limitations disrupted seamless connectivity and limited testing of edge–cloud communication across operator domains.; C-V2X antennas were used to bridge coverage gaps and maintain C-ITS message delivery.
- Integrating OBUs, 5G modems, HMIs, and logging equipment required extensive calibration and compatibility checks; modular, standardised interfaces would streamline future deployments.
- Coordinating communication between vehicles, roadside units, and the PoDIUM MEC platform demanded significant integration and tuning; layered testing and orchestration monitoring tools are recommended to ensure robustness and interoperability.
- In-vehicle HMI warnings must be intuitive and non-distracting; UX co-design, system finetuning and usability testing improve clarity.
- The private experimental 5G network used in trials had stability issues; future tests should use commercial networks for carrier-grade reliability.
- CAV testing was not possible due to permit limitations; harmonised EU regulations are needed to enable future cross-border CAV demonstrations.




Driver HMI in a Connected vehicle, showing the active traffic alerts and strategies

Use Case #4

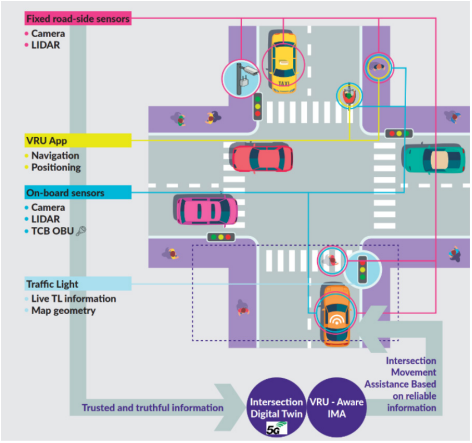
# Trusted Cooperative Perception for Intersection Manoeuvre Assistance

**Use Case 4 demonstrates an infrastructure-based application that assists CAVs at urban intersections while protecting VRUs. Deployed in Turin, the system fuses trusted data from multiple sources, including roadside sensors, C-ITS infrastructure, and traffic lights through a digital twin. It then provides guidance to the CAVs and connected VRUs to safely pass a busy urban intersection. The Use Case demonstrates that the digital infrastructure can provide the necessary information to road users to improve safety at intersections.**


Demonstration day in Turin

## Overview of results and technological advancements

- An infrastructure-based awareness and assistance system, based on a Digital Twin and a dedicated VRU intersection-movement assist application, providing collective perception data, warnings and recommendations to CAVs approaching an intersection.
- An on-board communication unit (OBU) with trust computing capabilities that allows protection of OBU applications and infrastructure data upstream against integrity attacks on C-ITS stations.
- ETSI-compliant protocol stack (GeoNetworking, BTP, C-ITS) on the OBU for seamless communication.
- Precise positioning strategies for CAV sub-meter localization utilizing mass market hardware.
- On-board applications, on the electronic control unit of the vehicle, performing V2X and sensors data fusion and assisting the driver or the automated driving function with enhanced awareness of VRUs and other road users at urban intersections.
- A gateway ensuring low latency and robust data exchange between the intra-vehicle network and the external system, including C-ITS messages and precise positioning data.
- Seamless interaction with 5G MEC applications via SEN platform services, ensuring adequate response times for real-time decision-making.




Smart traffic control solutions in urban conditions

## Challenges and recommendations for deployment

- The performance assessment — particularly the actual advantage over human driving decisions — should be conducted in more controlled environments due to the complexity of real-world manoeuvres.
- Despite several technical and organisational issues that affected integration timelines, the use case reached its final operational state in time for the Turin demonstration.
- A living lab on public roads is very useful for evaluating collective perception, but it needs to be complemented by test-track experiments where VRU trajectories and CAV behaviour can be safely measured.

Use Case #5

# Risk Management in a Highway Tunnel

**Use Case 5 addresses safety and cooperative-awareness challenges in tunnels, where satellite positioning is not available. In a tunnel on the Brenner Motorway, the service monitors traffic, assesses real-time risks and sends warnings to incoming CAVs. Roadside sensors count and classify vehicles in the tunnel, while a Digital Twin processes this data and sends warnings to CAVs in case drivers need to change lane or reduce their speed. Inside the tunnel, indoor positioning is maintained either through a synthetic GNSS signal delivered by dedicated infrastructure or through trilateration using vehicle and roadside units, ensuring cooperative services continue even without open sky.**

## Overview of results and technological advancements

- A real-time risk assessment system integrating multi-source data to generate a digital twin of the tunnel environment.
- Context-aware warnings and risk-mitigating actions based on validated sensor and vehicle data, improving the quality of the outgoing C-ITS messages.
- Secure and trustworthy communication protocols using Trusted Platform Module (TPM) technology.
- Dynamic risk management strategies that can trigger automated responses in CAVs for lane changes or speed adjustments.
- An on-board positioning system using dead reckoning based on maps and lane detection as well as V2I trilateration techniques for lane-level localization of the vehicle inside the tunnel, and GNSS with Real Time kinematics in open sky conditions.
- Development of a vehicle-based collective perception complying with ETSI standard and data fusion system to obtain extended perception even inside the tunnel.
- Integration of positioning system, V2I hazard warning and V2V collective perception and data fusion into CAV prototype for Cooperative Adaptive Cruise Control (C-ACC) and SAE L4 Operational Design Domain in tunnel scenarios.


Traffic jam/Accident warning displayed on roadside infrastructure before a tunnel


In-vehicle HMI notification warning of traffic congestion ahead

## Challenges and recommendations for deployment

- Positioning systems based on V2I trilateration are highly dependent on the relative position of the roadside units. Along the highway, especially in tunnels there is little margin to install them.
- The multi-source positioning system was calibrated and optimised for transitions between open sky and tunnel.
- Extensive tests along the A22 showed good performance in these transitions, though moderate GNSS degradation still occurred in environments characterized by narrow valleys. These cases and the so called “urban canyon” conditions should be addressed when calibrating a production-ready system.
- Experiments on the data fusion of Cooperative Perception Messages (CPM) and sensors performed well under Living Lab operational conditions (10 CPM per second). Through simulations, possible degradation effects were evident when exchanging CPM less frequently (threshold of acceptable error found at around 3 CPM per second). Further studies should be performed, with different kind of data fusion systems involved, to consolidate the value of minimum frequency of CPM fulfilling the cooperative use cases.

*"PoDIUM has strengthened the foundations for CCAM deployment by advancing physical and digital infrastructure technologies and validating connectivity and cooperation enablers in real traffic environments.*
*Project results show measurable improvements in safety-especially vulnerable road user protection, vehicle-to-infrastructure (V2I) communication and traffic efficiency, supporting higher levels of automation across Europe."*

**Dr. Angelos Amditis**
PoDIUM Project Coordinator
Research & Development Director, ICCS

## Consortium

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