Validation of CAV functions exploiting positioning data: the P-CAR's XiL Testing Framework

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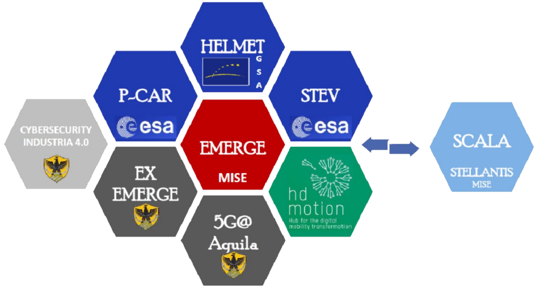
P-CAR: The context

- The roadmap towards autonomous mobility is progressing across the industrialized world and Europe is at the forefront.
- The Abruzzo Region in Italy hosts important automotive and satellite poles and in 2018, a strategic research initiative called **EMERGE-Navigation** has been launched for the **geo-localization**, **communication** and **cybersecurity** technologies for autonomous driving. The initiative, together with the establishment of the **Centre of EXcellence EX-EMERGE**, prepared the path for the creation of a CCAM eco-system in the region.
- Successful experiences in the railway sector demonstrate the importance of accredited laboratories in supporting the validation and certification process.



P-CAR: The context

In this frame, the **P-CAR** (PNT Center for Automated Road-Transport) project – financed through ESA's NAVISP program - aims to realize an **independent and accredited laboratory** for assessing, verifying, **validate** the new technologies for the **CCAM** (Cooperative, Connected and Automated Mobility) applications giving access to OEMs, Tier 1 and Subsystem suppliers.

Funded under the **ESA NAVISP Element 3 program**.

P-CAR: Objectives

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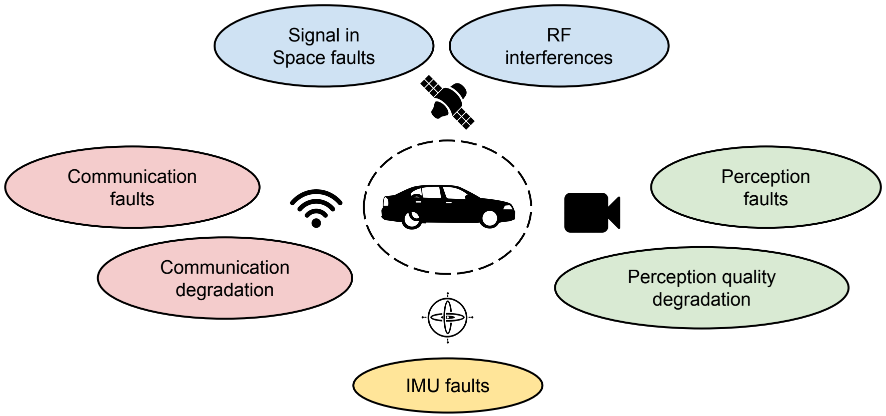
P-CAR AIMS TO

- **reproduce the operational environment** where the system is to be tested
- **inject faults/degradation** typical of the selected environment
- **analyse the results**
- integrate the customer **hazard and safety risk** analysis
- collect the results into a **report**.

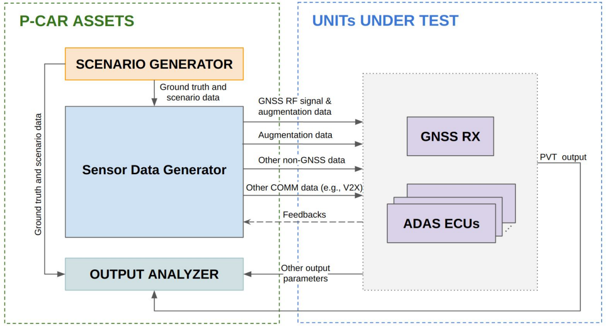


* **FuSa** - Functional Safety (ISO 26262); **SOTIF** - Safety of the Intended Functionality (ISO 21448); **General Safety regulations** (EU 2019/2144, 2022/1426); **UNECE regulation** (e.g., R151, R152, R155, R157)

P-CAR: Approach

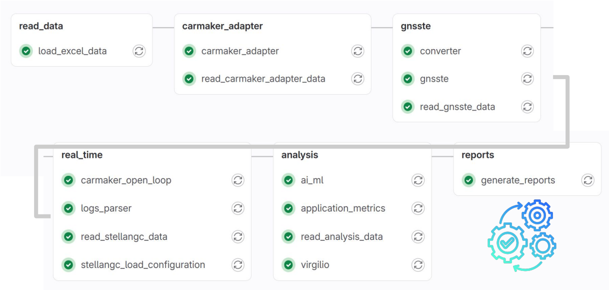
HARDWARE-IN-THE-LOOP PLATFORM

The platform is flexible and allows to include also **software** or **models** in the loop (everything-in-the-loop).



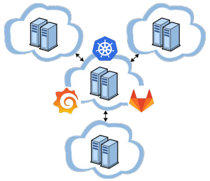
TEST AUTOMATION

Dedicated workflows automation with i) test execution/repetition, ii) results analysis, and iii) test reports.



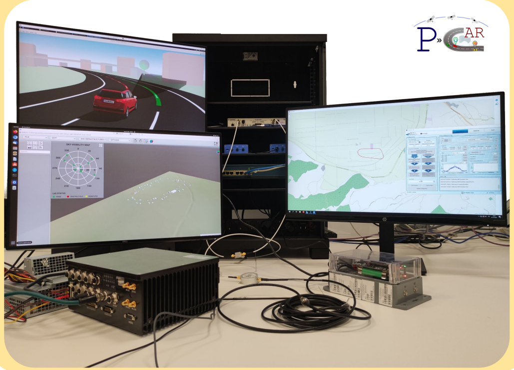
GEO-DISTRIBUTED ARCHITECTURE

Virtualized cloud-based platform to involve other test-beds and laboratories creating a unique and skilled network.

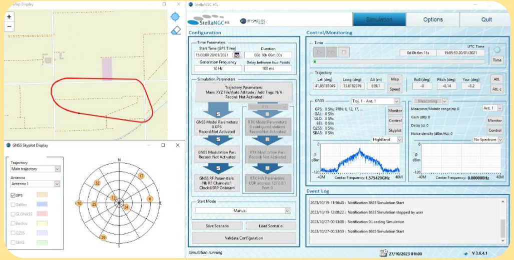


P-CAR: Features

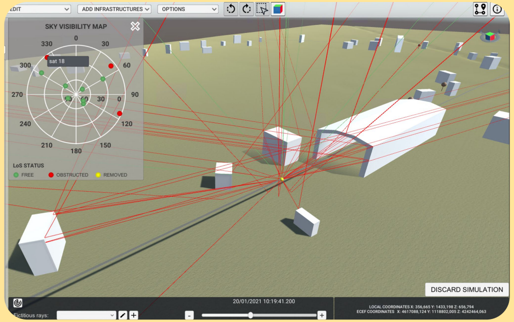
Hardware-in-the-Loop setup for GNSS and ADAS testing



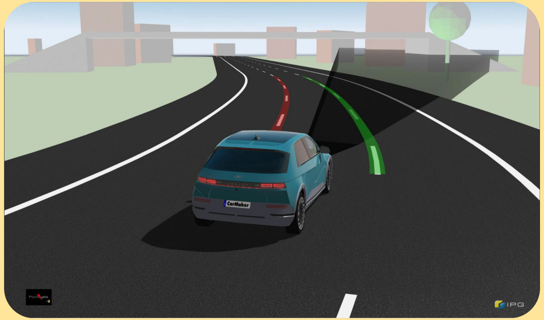
GNSS constellation emulation with SBAS and multipath (e.g, StellaNGC)



Environment-based GNSS deterministic multipath (*GNSSTE*)



Environment and vehicle modelling including perception sensors (e.g., *IPG CarMaker*)



Example of **CCAM applications:**

- Lane Departure Warning (LDW)
- Automated Lane Keeping (ALK)
- Automatic Emergency Braking (AEB)
- Intelligent Speed Adaptation (ISA)
- Adaptive Cruise Control (ACC)

Example of **supported sensors:**

- GNSS and inertial sensors
- Camera, Radar, LIDAR

P-CAR: Testbed

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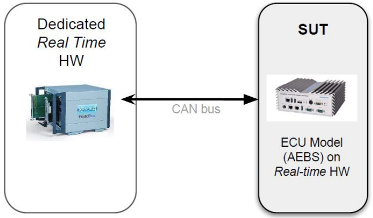
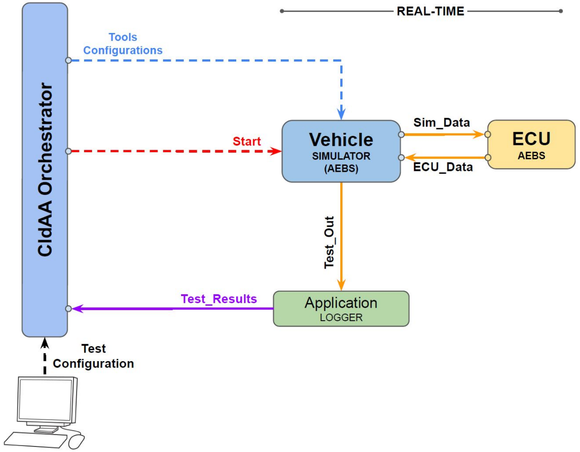
- The **AEBS** and **ISA** functionalities have been selected as a **test bed** for the P-CAR laboratory at the **closure of the Phase I** of the project.
- The test procedures and technical requirements specified in the related regulations have been taken as reference for definition and execution of tests:
  - AEBS: UN Regulation No. 152
  - ISA: Regulation (EU) 2021/1958
- Tests have been conducted in both controlled (**nominal**) and challenging environments (**safety aspects**).

P-CAR: Testbed - AEBS - Setup

- Setup:
  - HiL simulation (closed-loop)
  - ECU model (AEBS) running on real-time HW (i.e., Speedgoat - Baseline)
- AEBS:
  - Data from the radar sensor model
  - Forward Collision Warning (FCW) and braking based on the relative quantities (position, velocity) of the Most Important Object (MIO)



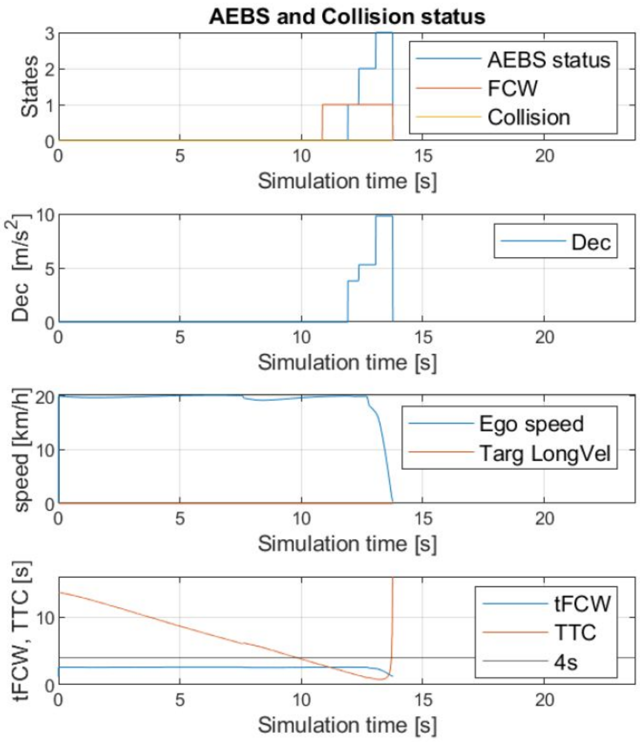


P-CAR: Testbed - AEBS - Scenarios

- Scenarios:
  - C2C and C2P
  - controlled (nominal) and challenging environments (safety aspects)
  - different ego/target speeds (more than 30 test iterations)
- Environments:
  - nominal: unobstructed target in good weather and illumination conditions
  - safety aspects: partially obstructed target in poor weather and illumination conditions

P-CAR: Testbed - AEBS - Test report

- **Pass/fail 1 (FCW):** AEBS braking is coupled with a timely FCW;
- **Pass/fail 2 (DecDemand):** AEBS braking, the braking demand is at least of 5 m/s^2;
- **Pass/fail 3 (Safety):** the test ends in a safety state (i.e., impact velocity compliant with regulation, or negative TTC, or tFCW≤TTC).



P-CAR: Testbed - AEBS - Test report

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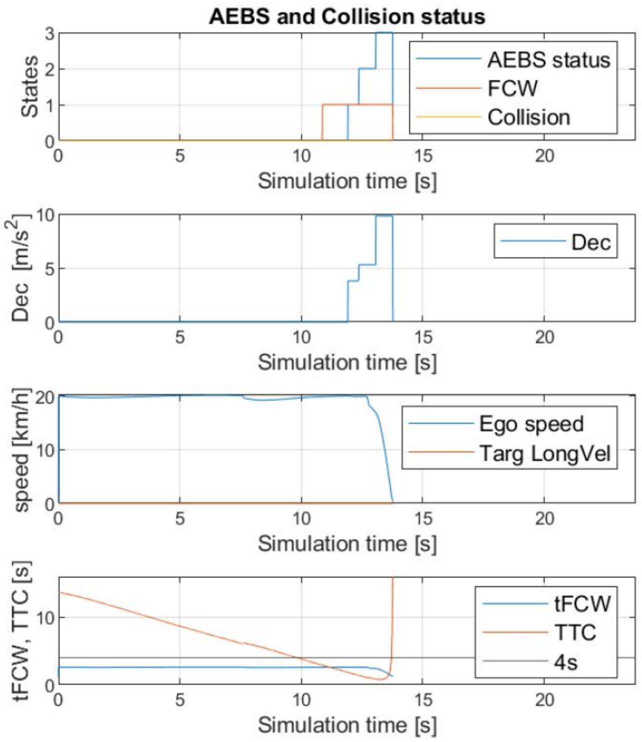
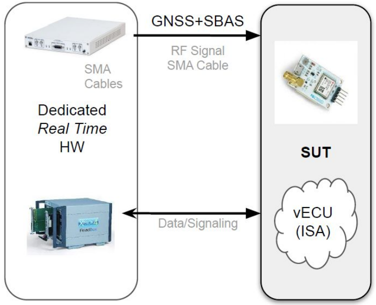
➢ **Pass/fail 3 (Safety):** the test ends in a safety state (i.e., impact velocity compliant with regulation, or negative TTC, or tFCW≤TTC).

AEBS test outcomes:

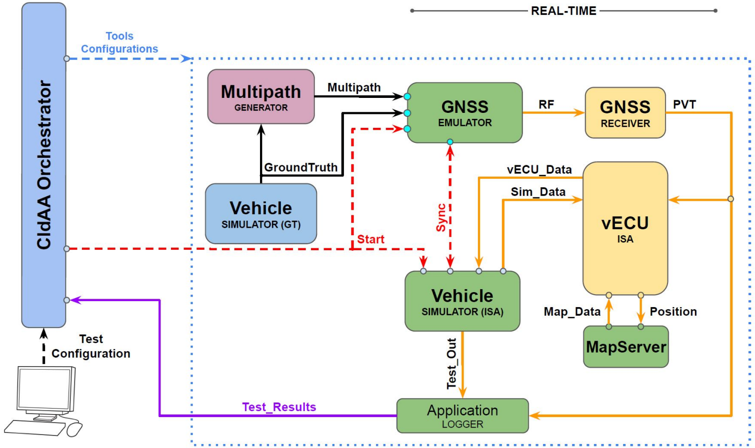
- A single collision has been observed however, the simulation ends in a safety state (i.e., impact velocity compliant with regulation).
- The C2P scenario appears to be challenging even in a "controlled environment".



P-CAR: Testbed - ISA - Setup



- Setup:
  - open-loop simulation
  - GNSS receiver: HiL
  - ISA logic: SiL
- ISA:
  - Data from both camera sensor model and digital map. GNSS emulation in RF.
  - SUT with *Speed Limit Information Function* (SLIF) always active and *Speed Limit Warning Function* (SLWF) with only haptic warning



P-CAR: Testbed - ISA - Scenarios

➢ **Table I** summarizes the adopted test cases for both nominal tests ("open sky") and tests under challenging conditions ("urban").

➢ Tests in the "urban" scenario have been conducted in foggy conditions limiting the camera visibility.

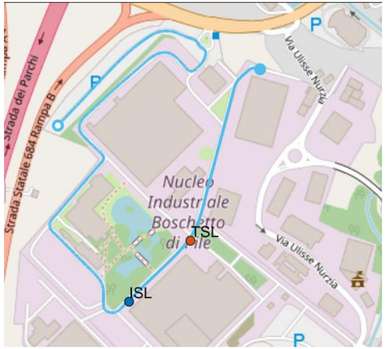
TABLE I
TEST CASES

Test ID	Scenario	Fault	Additional Degradation
1	Open sky	none	none
2	Urban	none	none
3	Urban	**camera:** FoV= 1° 1°	none
4	Urban	none	**map server:** Prop. Delay ($\mu = 80$ ms $\sigma = \pm 10$ ms); PL=5%
5	Urban	**map server:** PL=100%	none

TABLE II
TEST ITERATIONS [a]

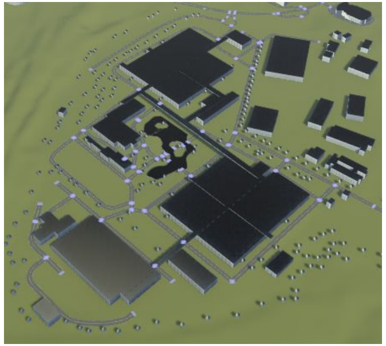
ISL	TSL	Test Speed
70	50	60
60	40	50
50	30	40

[a] All values in km/h.



"Open sky"

"Urban"



P-CAR: Testbed - ISA - Test report

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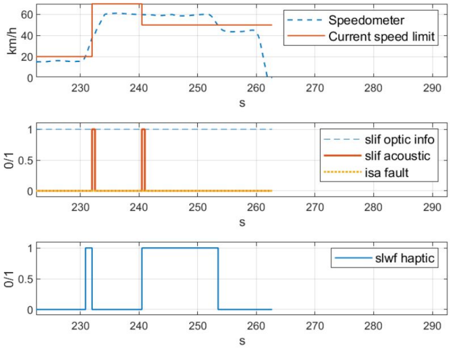
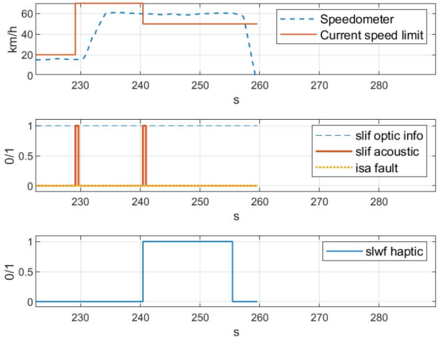
- ➢ **Pass/fail 1:** SLIF correctly and promptly (i.e., in 2 s)
- ➢ **Pass/fail 2:** SLIF no misleading info
- ➢ **Pass/fail 3:** SLIF soft warning
- ➢ **Pass/fail 4:** SLWF activation (i.e., in 1.5 s)
- ➢ **Pass/fail 5:** SLWF deactivation for both “Mod a” and “Mod b”

Mod a



Mod b



P-CAR: Testbed - ISA - Test report

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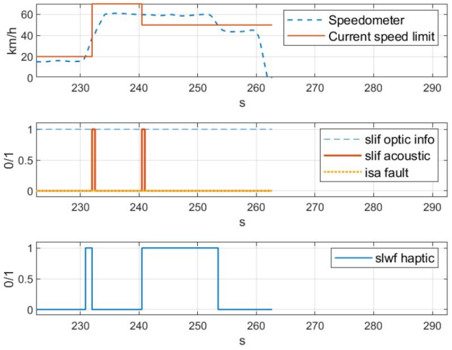
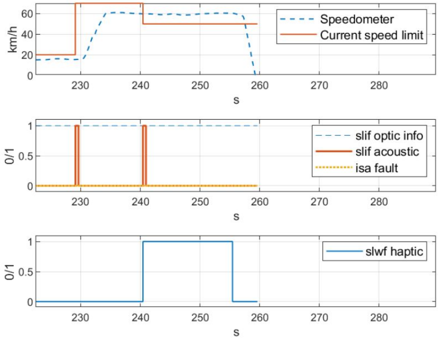
ISA test outcomes:

- The runs for the “open sky” scenario, obtaining the totality of successes in the evaluation of the pass/fail criteria.
- The joint use of camera and GNSS plus digital map demonstrate (in “urban” scenario) the potential in terms of robustness of such a system compared to the de facto camera only.

Mod a



Mod b



P-CAR: Roadmap

2021 – 2024

Phase 1 - Laboratory baseline

- ★ **Assessment for a first set of CAD function**

We are here

2025 – 2027

Phase 2 - Smart road use cases evolution

- ★ **Use cases evolution** (Smart road)
- ★ **COMM. extension** (terrestrial and non-terrestrial)
- ★ **Cybersecurity**
- ★ **Lab assessment with field tests**

Phase 3 - Pilot exploitation

- ★ Partner with OEM and/or Tier Xs in order to have a **concrete exploitation**
- ★ **Laboratory qualification**

The End

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