Final Presentation

NAVISP-EL1-115

ADAS TECHNOLOGY AND PNT

Date: 02.09.2026

The consortium

Prime Contractor:

KENOTOM P.C - Greece-based embedded systems engineering company delivering high-reliability solutions across automotive, automation, aviation, and medical domains, with strong emphasis on safety, security, and engineering quality. The company has solid expertise in standards-driven development, including AUTOSAR, ISO 26262, ISO 21434, Automotive SPICE, and ASAM. Its ADAS background includes Level 3+ development, NVIDIA DRIVE AGX integration, functional safety, connected vehicle cybersecurity, simulation-based validation, and functions such as LKAS and ACC.

Subcontractors:

Geosystems Hellas S.A. - a Greek SME delivering advanced geospatial software, remote sensing, Earth observation, data analytics, and AI solutions. It supports sectors including safety, security, critical infrastructure, and climate resilience, while also providing value-added services for the space market in Earth Observation, Navigation Applications, business development, and project management.

The National Technical University of Athens (NTUA) - a leading technological university with strong research activity and participation in national and European projects. Its School of Rural Surveying and Geoinformatics Engineering specializes in geoinformatics, remote sensing, GIS, and spatial data analysis. The Dionysos Satellite Observatory (DSO) provides expertise in GNSS, satellite geodesy, and advanced navigation applications.

Project objectives

4 strategic objectives, grounded in 4 backbone documents (D1-D4) and progressively matured across 3 milestones.

1. **Assess PNT relevance in AD/ADAS**

   Evaluate the current and emerging role of PNT technologies across automotive and adjacent automation sectors.
   Covered through D1 & D2: baseline and PNT dependency Mapping

2. **Map the development landscape**

   Build a structured view of the market, technologies, actors and regulatory environment shaping AD/ADAS.
   Covered through D1 & D2: market, ecosystem, emerging applications

3. **Identify gaps and opportunity areas**

   Highlight technology gaps, development priorities and ecosystem opportunities where NAVISP can enable innovation.
   Covered through D3: limitations, gaps, mitigation paths

4. **Turn evidence into recommendations**

   Convert findings into actionable NAVISP directions across NAVISP Element project types
   Covered through D4: NAVISP project roadmap

D1 — State of the art of PNT usage in AD/ADAS

Overview

D1 establishes the baseline understanding of how Positioning, Navigation, and Timing (PNT) technologies support current AD/ADAS systems across sectors.

1 AD/ADAS Market & Technology Baseline

Analysis of deployed AD/ADAS functions across vehicle sectors

2 PNT Dependency Mapping

Classification of commercial AD/ADAS features based on PNT requirements

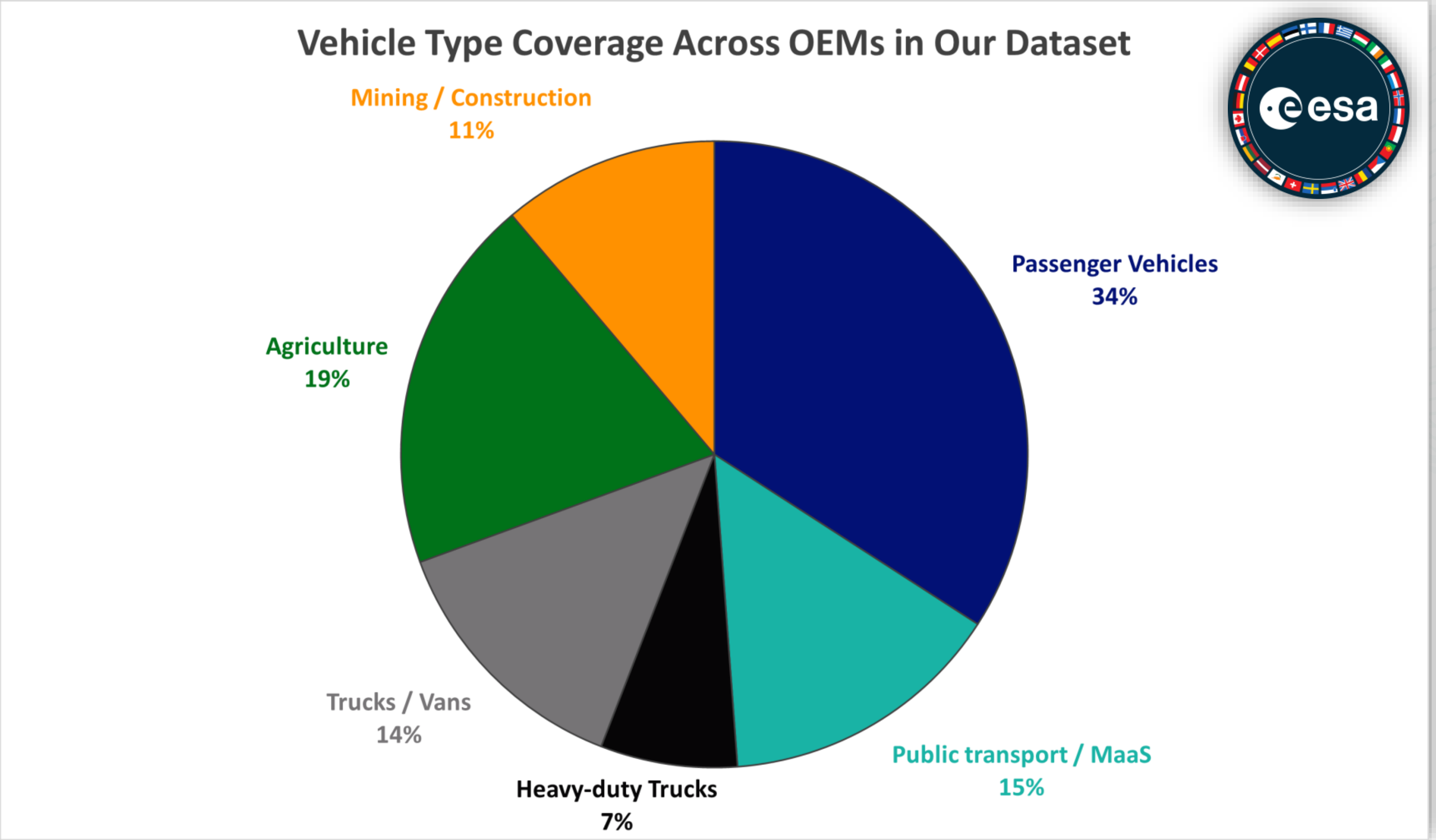
3 Ecosystem Mapping

Overview of OEMs, suppliers, and key players in the European and Canadian AD/ADAS landscape

D1 — State of the art of PNT usage in AD/ADAS

Current AD/ADAS baseline sectors

- Passenger Vehicles
- Public transport / MaaS
- Heavy-duty Trucks
- Trucks / Vans
- Mining / Construction
- Agriculture

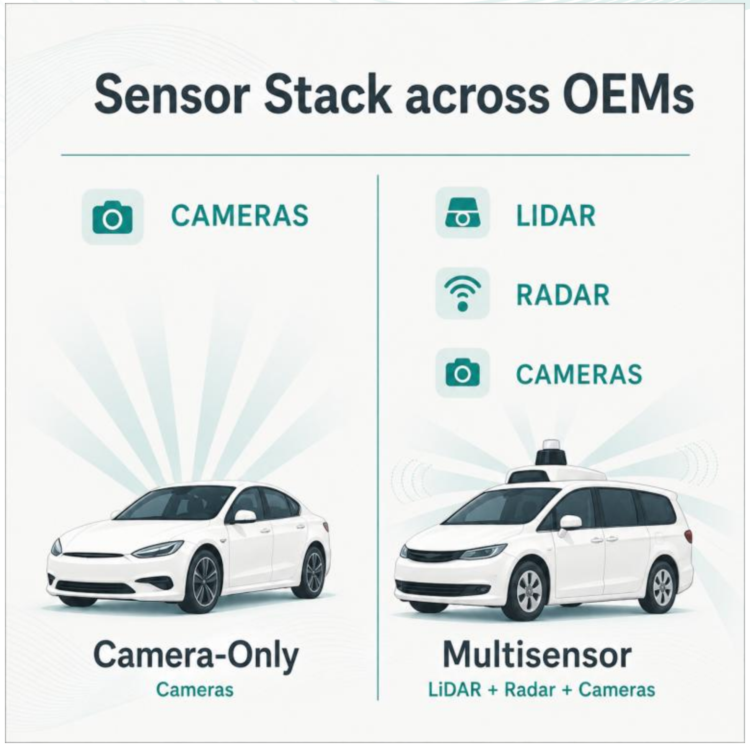


D1 — State of the art of PNT usage in AD/ADAS

Deployed ADAS Features: Classification Logic

Same feature ≠ same tech stack across OEMs

Different commercial names map to similar core functionalities



Core Input Domains

	Environment sensing	Global positioning	External frame	Ego-vehicle frame
Input Sources	Cameras, radar, LiDAR, ultrasonic	GNSS, HD maps, IMU/INS	GNSS/map-based world reference	Wheel speed, steering, yaw, pedals
Derived Context	Object, lane, sign, VRU detection	Absolute localisation and map matching	Road segment, lane, geofence, ODD logic	Local vehicle state and relative surroundings
Example Features	FCW, AEBS, LDW/LKA, BSM, TSR, APA	ALKS, AVP, ISA, CSW, PCC	ISA, PCC, CSW, ALKS, AVP	ABS, ESC, TPMS, ACC, FCW, AEBS

D1 — State of the art of PNT usage in AD/ADAS

Deployed ADAS Features: PNT Dependence

Low PNT Dependency

Mostly ego-vehicle sensing

- Anti-lock Braking System (**ABS**)
- Electronic Stability Control (**ESC**)
- Tire Pressure Monitoring System (**TPMS**)
- Emergency Brake Assist (**EBA**)
- Adaptive Headlights (**AH**)
- Night Vision Systems (**NVS**)
- Surround View Camera System (**SVCS**)
- Driver Drowsiness & Attention Warning (**DDAW**)
- Hill Descent Control (**HDC**)

Mid PNT Dependency

Navigation-aware ADAS

- Adaptive Cruise Control (**ACC**)
- Forward Collision Warning (**FCW**)
- Advanced Emergency Brake System (**AEBS**)
- Autonomous Emergency Steering (**AES**)
- Lane Departure Warning (**LDW**)
- Lane Keep Assist (**LKA**)
- Blind Spot Monitoring / Blind Spot Detection (**BSM/BSP**)
- Rear Cross-Traffic Alert (**RCTA**)
- Intersection Assist System (**IAS**)
- Rear Collision Warning (**RCW**)
- Side Collision Warning (**SCW**)
- Traffic Sign Recognition (**TSR**)
- Automatic Parking Assist (**APA**)
- Vulnerable Road Users Detection (**VRUD**)
- Exit Warning/Door Opening Warning (**DOW**)
- Emergency Stop Assist (**ESA**)
- Lane Change Assist (**LCA**)

High PNT Dependency

geo-fenced / automation-oriented functions

- Automated Lane Keep System (**ALKS**)
- Traffic Jam Assist (**TJA**)
- Intelligent Speed Adaption (**ISA**)
- Automated Valet Parking (**AVP**)
- Curve Speed Warning (**CSW**)
- Predictive Cruise Control (**PCC**)

D1 — State of the art of PNT usage in AD/ADAS

Current AD/ADAS baseline sectors – Passenger Vehicles

Passenger Vehicles

Historically

Safety adoption used to be slow

The first ADAS, ABS introduced ~50 years ago and it took **>20 years** to become standard.

AEB reached near-universal adoption in under a decade—roughly 2–3× faster than ABS.

Modern ADAS

Software-driven vehicles

Modern ADAS adoption cycles are much faster due to software-driven vehicles.

Today

ADAS shift from optional to standard

Nearly all new vehicles now include multiple ADAS features, often standard even in entry-level models.

EU Regulation 2019/2144 mandates key ADAS (including AEB and emergency lane keeping), accelerating baseline adoption.

OEMs

Latest integrated systems target L2-L3 Automation

Commercial Examples:
L2: Tesla Autopilot, GM SuperCruise, Ford BlueCruise, Toyota Safety Sense, VW Travel Assist, others.
L3: Mercedes Driver Assistance, BMW Personal Pilot, Honda SENSING Elite, Hyundai Highway Driving Pilot.

Note on L3+ Systems

A clear pullback from first generation L3 systems

In 2026, the automotive industry showed a clear pullback from first generation L3 systems, as OEMs shift investment toward a more scalable Level 2+ and "Level 2++" ADAS platforms.

OEMs now seem to increasingly favor supervised driving systems with broad geographic coverage over "eyes-off" L3 systems limited to constrained ODDs.

D1 — State of the art of PNT usage in AD/ADAS

Current AD/ADAS baseline sectors – Public transport / MaaS

Public transport / MaaS

Autonomous Buses (L4)

L4 starts where complexity is bounded

- Autonomous buses are first deployed in predictable domains such as BRT corridors, airports, campuses, and fixed public routes.
- Controlled environments allow L4 systems to operate safely and reliably.

L4 Deployments

Commercial examples that show maturity

Baidu Apolong, WeRide Robobus, Navya Autonom® Shuttle, EasyMile EZ10.
Europe milestone: Karsan e-ATAK operating on public city routes (since 2025).

Technology Stack

The technology is domain-focused

Sensor fusion + GPS RTK + AI/Deep Learning for navigation in geo-fenced predefined domains

Robotaxi Expansion

Large fleets are scaling globally

- Waymo (US) + major Chinese players (Baidu, Pony.ai, DiDi, etc.) are operating large fleets globally
- Enabled by regulatory support + platform partnerships.

Market Outlook

L4 deployment is the key growth driver

- The market is projected to grow from $1.19B in 2024 to $174B by 2045, driven by broader L4 adoption (Source: IDTechEx).
- Autonomous shuttles and robotaxis become increasingly part of multimodal, on-demand mobility ecosystems.

D1 — State of the art of PNT usage in AD/ADAS

Current AD/ADAS baseline sectors – Heavy-duty Trucks, Trucks / Vans

Heavy-duty Trucks | Trucks / Vans

Baseline Adoption

Regulation-led safety baseline

- Trucks, vans, and heavy vehicles use the same core ADAS (ABS, ESC, AEBS, ACC, LDW/LKA, etc.), largely driven by regulation
- Rather than customer driven, adoption is largely driven by regulation

Operational Impact

Safety becomes a business case

With AD/ADAS deployment:

- Accident rates & collision severity (↓) goes down
- Protection for drivers, road users, and cargo (↑) goes up
- Insurance costs & legal exposure for fleets (↓) goes down
- Driver comfort and operational safety (↑) goes up

Sector investment & Systems

Blind-spot risk drives dedicated systems

Specialized systems include:

- MOIS (front blind spot)
- BSIS (side blind spot during turns)
- REIS (rear blind spot when reversing)

Major suppliers such as ZF, Bosch, Continental and Kodiak develop truck-specific ADAS solutions

Beyond ADAS

Next step: L4 Autonomy

- L4 driverless commercial delivery has been demonstrated on constrained logistics routes since 2021.
- Deployments remain mainly limited to fixed, predefined routes between logistics nodes, typically within tightly controlled ODDs.

D1 — State of the art of PNT usage in AD/ADAS

Current AD/ADAS baseline sectors – Mining / Construction

Mining / Construction

Operating Environment

Controlled sites enable faster adoption

Mining and construction sites are more controlled than public roads, enabling faster adoption of advanced safety and automation.

ADAS Focus

Hazard prevention is the primary driver

ADAS here is less about road rules and more about hazard prevention.
Core functions: Collision avoidance, AEBS-like braking, blind-spot detection, operator monitoring.

Leading Sector

Early automation leaders

- Komatsu introduced Autonomous Haulage System in 2008.
- Caterpillar and others now operate large L4 autonomous fleets globally.

Key Safety Systems

The safety stack is built around proximity and response

- GNSS, radar, cameras, and V2X detect risks, trigger real-time alerts, and enable automated braking or slowdown.
- Designed for repetitive industrial operations.

Worker Safety & Operation Monitoring

People remain central to the safety case

- Pedestrian detection combines wearables and AI vision, designed for harsh environments: dust, low visibility and vibration.
- Fatigue and attention monitoring are critical during long, repetitive shifts.

Bottom Line: Autonomy scales first where environments are bounded, the safety case is strong, and operations are repetitive

D1 — State of the art of PNT usage in AD/ADAS

Current AD/ADAS baseline sectors - Agriculture

Agriculture

Adoption Stage

Earlier stage compared to mining

- Agriculture is behind mining in autonomy adoption, but the driver is different.
- Rather than safety as a primary driver, automation is mainly used to improve efficiency, accuracy, and workload management.

Strategic Driver

Food demand makes automation critical

- Global cereal demand is projected to rise by 40-50% by 2050, making scalable automation increasingly important.
- Automation is becoming critical for scalable food production.

Technology Evolution

The next step: perception and decision-making

- GNSS-based auto-steering and path planning are already common, typically at L1/L2 with human supervision.
- Guidance systems are evolving and now integrate perception sensors and automated decision-making.
- **Key milestone:** John Deere autonomous tractor (2022): GPS + stereo vision + AI → It enables L4 driverless operation in confined fields with remote supervision.

Emerging Ecosystem

From precision to supervised driverless operation

- Agricultural autonomy is becoming an ecosystem, not a single-OEM effort.
- Trimble, Naio, Pellenc, and others are developing similar autonomy solutions.

D1 — State of the art of PNT usage in AD/ADAS

Ecosystem mapping

Objectives:

- Map the European & Canadian AD/ADAS supply chain
- Identify companies contributing across ADAS development domains

Work Logic

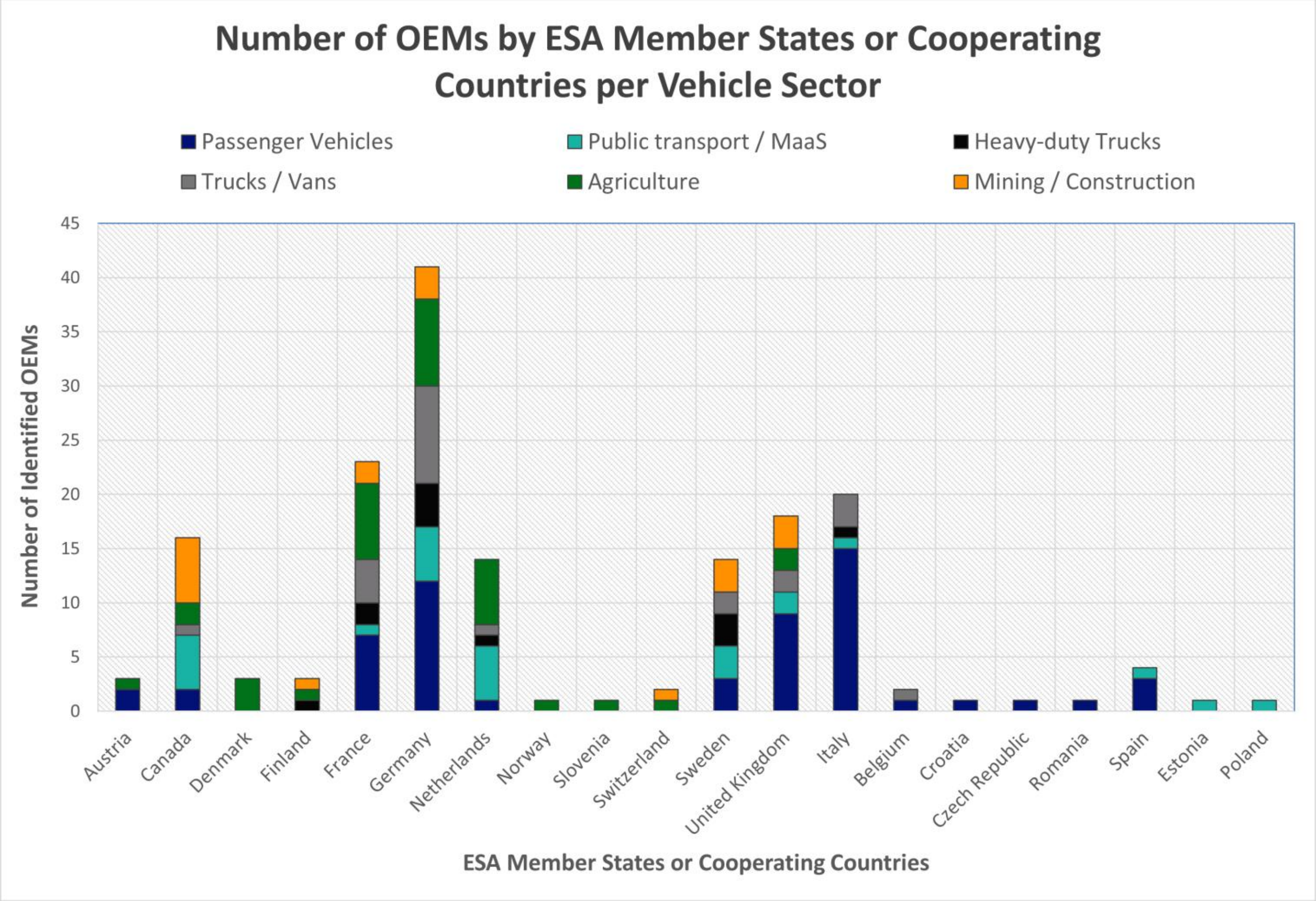
- Compiled a list of OEMs and suppliers relevant to the AD/ADAS ecosystem, grouped by geographic location
- Excluded companies that are not headquartered in ESA Member or Cooperating States or do not have relevant R&D activities in these regions
- Companies were classified as Suppliers and OEMs
- Classified suppliers by supply-chain tier based on publicly available evidence (e.g. product portfolio, OEM collaborations, company disclosures)
- Categorized OEMs by vehicle sector of operation (e.g. passenger vehicles, trucks, agriculture, multi-sector)

Supplier Tiers
- Tier 1
- Tier 1-2
- Tier 2

Vehicle Sectors
- Multi-Sector
- Trucks / Vans
- Public transport / MaaS
- Passenger Vehicles
- Mining / Construction
- Heavy-duty Trucks
- Agriculture

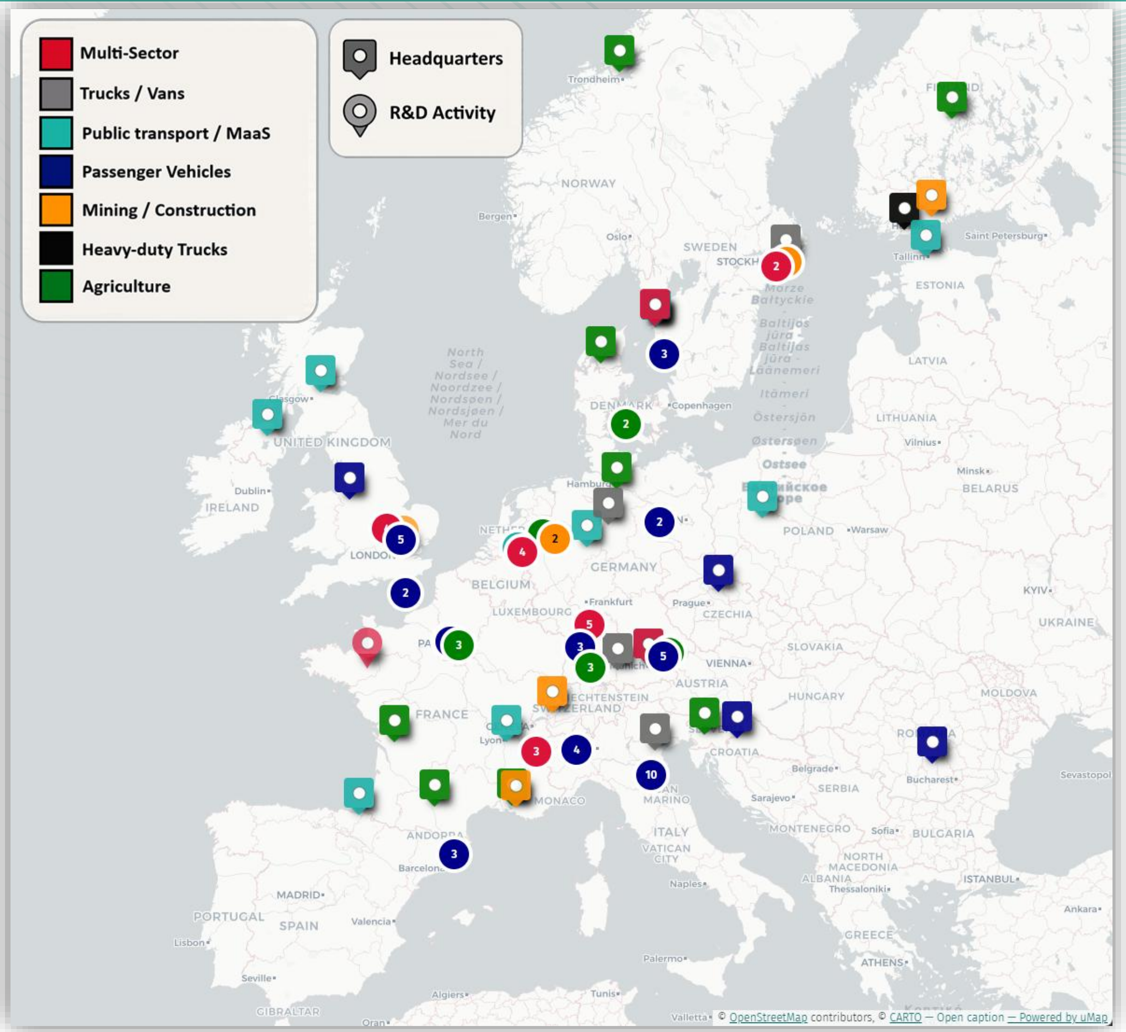
D1 — State of the art of PNT usage in AD/ADAS

Ecosystem mapping – Data Statistics



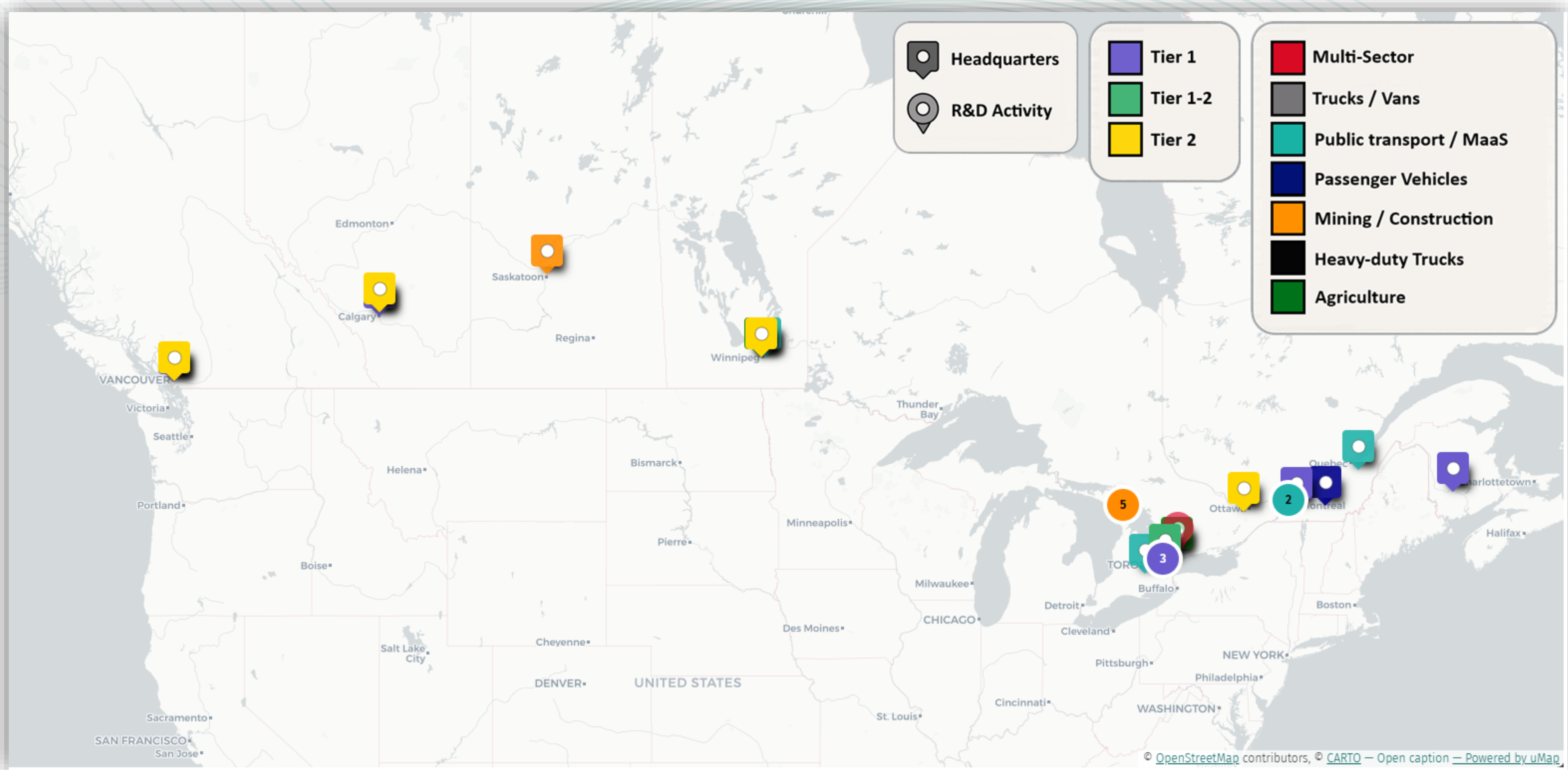
D1 — State of the art of PNT usage in AD/ADAS

Ecosystem mapping – Europe Suppliers & OEMs



D1 — State of the art of PNT usage in AD/ADAS

Ecosystem mapping – Canada Suppliers & OEMs



https://umap.openstreetmap.de/en/map/ad-adas-ecosystem-map-data_131099

D1 — State of the art of PNT usage in AD/ADAS

Ecosystem mapping – Companies List

OEMs (137)

MS · T/V · PT/M · PV · M/C · HDT · A

2getthere
Abarth
Agrifac
Agrointelli
AgXeed
Aigro
Alexander Dennis
Alfa Romeo
Alke
Alpine
AMAZONE
Andela
Ant Robotics
Aprilia
Aramine
Aston Martin Lagonda
Audi
Aurrigo
AutoAgri AS
Auvetech
AVL motion
Benelli Q.J.
Bentley
BMW
BRP
Bugatti Automobiles
Caterra
Citroën
CLAAS
Cupra
Dacia
DAF Trucks
Daimler Truck AG
Deutz-Fahr
Digital Workbench
DS Automobiles
Ducati
Ebusco
Einride
Epiroc
Fantic Motor
FarmDroid
Fendt
Ferrari N.V.
Fiat
Ford Motor
General Motors
GHH
Goldhofer
Gregoire
Hardi
H. Paus Maschinenfabrik
Hitachi
Holon
Honda Motor Co.
Horsch
Husqvarna Motorcycles
Hyundai Motor Group
Irizar
Iveco
J&S Manufacturing
Jaguar Land Rover
JCB
Koenigsegg Automotive AB
Korechi
Kovatera
Krone
KTM
Kuhn
Lamborghini
Lancia
Liebherr
Lion Electric
Lohr
Lotus Cars
MacDon
MacLean Engineering
MAN
Maserati
McLaren Automotive
Mercedes-AMG
Mercedes-Benz
MineMaster
Mini
Mitsubishi Motors
Moto Guzzi
MV Agusta
Naïo Technologies
Navya
Neoplan
New Flyer
New Holland
NIO
Nissan Motor Co.
Normet
Nova Bus
Opel
Pagani Automobili
Pek automotive
PELLENC Group
Peugeot
Piaggio
Pixelfarming Robotics
Polestar
Porsche
Prévost
Raeda Dynamics
Renault
Renault Trucks
Rieju
Rimac Automobili
Rokion
Rolls-Royce Motor Cars
Sandvik
Scania
Seat
Sisu
SITIA
Skoda
Solaris Bus & Coach
Stellantis N.V.
Steyr Landmaschinentechnik
Tecnoma
Tes Inc
Toyota Group
Triumph Motorcycles Ltd
Valtra
Vauxhall
VDL Bus & Coach
ViTiBot
Volvo Buses
Volvo Cars
Volvo Construction Eq.
Volvo Trucks
VW Commercial Vehicles
VW Passenger Cars
Wrightbus

Suppliers (58)

1 · 1-2 · 2

Applanix
Aptiv
AUMOVIO
Baidu
Bosch Mobility
Digital Workbench
HERE
Hexagon AB
Magna
Mobileye
Pony.ai
Potential Motors
SBG-Systems
Suncor
Synopsys
TorcRobotics
Valeo
VBOX Automotive
Wenco International Mining Systems, Ltd
WeRide
ZenduIT
ZF
ZYT

Avisense
AVL
Geoflex
GMV
OXA
Provizio
Qualcomm
Waabi
Waveye
Wayve
Xylon

Agreenculture
ams-OSRAM AG
Calian Group Ltd.
Focal Point
Horizon Robotics
Infineon Technologies AG
JCA Technologies
Lyft
Microchip
Momenta
Moovee Innovations
Nordic Inertial
NovAtel
NXP Semiconductors
Onocoy Services AG
OXTS
Parkopedia
Q-CTRL
Septentrio
Spirent
STMicroelectronics
Texas Instruments
TopoTronics
u-blox

D2 — Survey of Emerging AD/ADAS applications

Overview

D2 is focused on identifying emerging AD/ADAS applications, expected deployment timelines, and the regulatory, commercial, and technological factors influencing adoption.

1 Identify emerging AD/ADAS applications

Identification and analysis of emerging AD/ADAS applications, including extensions of current capabilities and entirely new functions across on-road and off-road sectors

2 Estimate deployment timelines

Classification of emerging applications by expected deployment horizon and technology readiness to support short-, mid-, and long-term NAVISP planning

3 Assess drivers and PNT opportunities

Examination of commercial, regulatory, and technological drivers to identify where PNT technologies can enable or improve future AD/ADAS functions

D2 — Survey of Emerging AD/ADAS applications

Classification AD/ADAS Applications

Emerging AD/ADAS applications are compared through a common framework spanning sectors, Operational Design Domains, automation levels, and PNT dependency

Automation Level

Applications are assessed at system level, mainly across:

- L2/L2+ supervised assistance,
- L3 conditional automation, and
- L4 high automation within a defined ODD.

Operational Design Domain

Each application is described by its:

- operating environment,
- speed range,
- traffic complexity,
- infrastructure support, and
- regulatory context.

PNT Dependence Scale

Each application is assigned a qualitative PNT class from P0 to P3:

P0 – **PNT-independent**: Functions do not depend on PNT technology, such as ABS, ESC, or DDAW.

P1 – **PNT-assisted**: PNT can improve performance but is not critical to safety.

P2 – **PNT-critical**: Loss or degradation of PNT may degrade the function and force fallback, (ALKS, PCC, AVP, autonomous mine haulage, or GNSS-guided tractors).

P3 – **PNT-mission-defining**: The application's core value depends on continuous high-precision PNT, such as agriculture swarm coordination or fully automated yards and ports.

D2 — Survey of Emerging AD/ADAS applications

Changing Role of PNT Across Automation Levels

As AD/ADAS functions progress from basic assistance to higher levels of automation, PNT shifts from being **non-essential**, to a **performance enhancer**, and finally to a **mission-critical enabler** for defining and enforcing the Operational Design Domain.

PNT-independent

Early stabilisation and safety functions

Early ADAS functions such as ABS, ESC, and basic emergency interventions operate mainly in the ego-vehicle frame and do not require external positioning to deliver their safety function.

Basic ADAS

PNT Not Required

PNT-assisted

Comfort, prediction & contextual awareness

For functions such as Intelligent Speed Assistance, curve-speed warning, predictive cruise control, and navigation-enhanced assistance, PNT improves anticipation and contextual awareness, but the function may still degrade safely if positioning quality is reduced.

Predictive ADAS

PNT Enhances Performance

PNT-critical

L3/L4 automation and ODD enforcement

For L3/L4 functions such as ALKS, automated valet parking, robotaxis, hub-to-hub trucking, and autonomous off-road operations, PNT becomes safety-relevant because the system must know where it is, whether it is inside its approved ODD, and when fallback is required.

L3/L4 Automation

PNT Defines and Protects the ODD

D2 — Survey of Emerging AD/ADAS applications

PNT Performance Dimensions for AD/ADAS

For emerging AD/ADAS applications, PNT performance is not defined by accuracy alone;
Safe deployment also depends on integrity, availability, continuity, and sufficiently low latency / high update rate.

Accuracy

Determines how precisely the vehicle knows its position, supporting lane-level localisation, geo-fencing, map matching, path planning, and manoeuvre execution.

Example: Lane-level localization

Integrity

Ensures misleading or degraded positioning information is detected and flagged in time for the automation stack.

Example: ALKS / Robotaxis / Safety functions

Availability

Indicates whether the required PNT service is present when and where the function needs it, especially in GNSS-challenged environments.

Example: Urban-canyons & Tunnels

Continuity

Measures whether positioning performance can be maintained without interruption during operation.

Example: Mining & Logistics automation

Latency

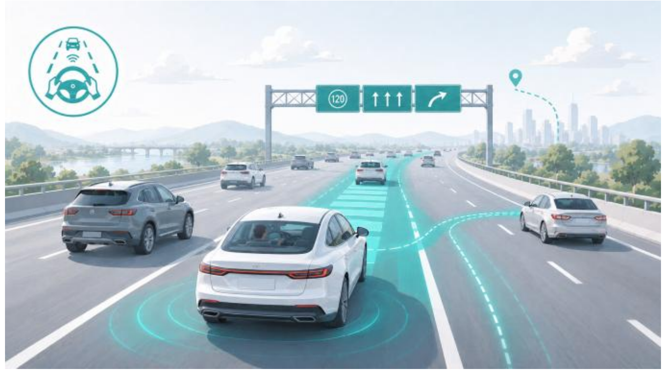
Determines whether PNT information arrives fast enough to support real-time perception fusion, control decisions, fallback triggering, and coordination.

Example: Real-time sensor fusion

D2 — Survey of Emerging AD/ADAS applications

Emerging AD/ADAS Applications: Passenger Vehicles – From L2+ to L3/L4

Passenger vehicle automation is moving from driver-assistance features toward ODD-bounded automation, where the vehicle can assume more of the driving task only under clearly defined road, speed, infrastructure, and environmental conditions. Autonomy grows where the operating domain can be clearly constrained.



Supervised Highway Automation

Supervised L2+ highway assistance

Supervised highway automation combines ACC, lane centering, automatic lane change, and predictive functions to provide near-continuous motorway support. Driver remains responsible for supervision.

L3 Automated Lane Keeping Systems

Transition to Level 3 conditional automation

ALKS extensions move from limited single-lane operation toward higher-speed and multi-lane motorway ODDs, increasing reliance on HD maps, GNSS/IMU fusion, lane-level localization, and integrity monitoring.

Automated Valet Parking

Low-speed L4 in controlled environments

AVP extends parking assistance toward driverless operation in structured car parks, requiring digital maps, infrastructure support or onboard perception, and robust indoor or hybrid localisation where GNSS may be degraded or unavailable.

D2 — Survey of Emerging AD/ADAS applications

Emerging AD/ADAS Applications: Public Transport / MaaS - Shuttles, Buses, Robotaxis

Public transport automation is moving toward geo-fenced Level 4 services, where buses, shuttles, and robotaxis operate within defined urban, campus, airport, or peri-urban ODDs and require reliable positioning to maintain safe and continuous service. This sector places a stronger emphasis on PNT continuity and availability.

Low-Speed Shuttles

Campus and airport operations

Low-speed shuttles operate in closed or semi-closed environments such as campuses, business parks, and airport zones, where restricted access, speed limits, fleet supervision, and infrastructure support reduce traffic complexity.

Autonomous Public Transport

Urban buses and shuttles

Autonomous public transport targets fixed or flexible routes in urban and peri-urban areas, often using dedicated lanes or controlled corridors where lane-level localisation and reliable geo-fencing are operationally necessary.

Urban L4 Robotaxis

Driverless MaaS in city ODDs

Urban L4 robotaxis provide on-demand ride-hailing in dense urban districts, facing mixed traffic, vulnerable road users, complex road geometry, and GNSS-challenged environments that drive very high PNT dependence.

D2 — Survey of Emerging AD/ADAS applications

Emerging AD/ADAS Applications: Heavy-duty & Logistics - Corridors, Hubs, Depots

Heavy-duty automation is evolving along a staged operational pathway: from driver-supervised highway assistance, to L4 autonomous hub-to-hub corridors, and finally to low-speed automation in restricted depots, yards, ports, and terminals.
In this sector ODD is easier to define, and the commercial case is often clearer than in private passenger vehicles.

Long-Haul Assisted & Automated Trucking

Highway efficiency and driver support

Long-haul assisted trucking combines ACC, lane keeping, predictive powertrain control, and fleet-level monitoring to improve safety, comfort, and fuel efficiency on motorways while the driver remains responsible for supervision and fallback.

L4 Hub-to-Hub Autonomous Trucking

Mapped corridor automation

Hub-to-hub autonomous trucking targets SAE Level 4 operation between logistics hubs, using predefined motorway corridors and access links where high-integrity lane-level localisation is required for safe driverless operation.

Depot & Yard Automation

Restricted-site autonomy

Depot automation covers low-speed autonomous manoeuvring in depots, distribution centres, ports, and intermodal terminals, where trucks perform parking, trailer positioning, and internal transfers within geo-fenced and access-controlled sites.

D2 — Survey of Emerging AD/ADAS applications

Emerging AD/ADAS Applications: Off-road automation - Agriculture, Mining, Construction

Off-road automation is advancing fastest in controlled or restricted operational domains, where access, routes, speeds, and work zones can be more tightly managed than on public roads. In this sector, shared positioning and timing become especially valuable when multiple machines operate together under one mission plan.

Tractor Autosteer & Precision Automation

GNSS-guided and precision automation

Agriculture applications range from GNSS-guided tractor assistance to higher automation for field operations, where accurate positioning supports path following, coverage optimisation, repeatability, and reduced operator workload.

Agriculture Fleet coordination

Multi-machine field operations

Agriculture fleet coordination depends on shared positioning and timing references so multiple machines can operate safely and efficiently in the same field under common mission plans.

L4 Autonomous Haulage Systems

Multi-machine field operations

L4 Autonomous haulage systems operate in controlled-access mine environments, using site-specific routes, procedures, and positioning infrastructure to support safe and productive driverless material transport.

Assisted Earthmoving & Site Logistics

semi-autonomous machines

Construction automation focuses on semi-autonomous earth-moving equipment and all-terrain site logistics, where robust localisation is needed for machine guidance, site coordination, and safe operation around workers and other assets.

D2 — Survey of Emerging AD/ADAS applications

Emerging & Enabling Applications

Emerging Applications (15)

Passenger Vehicles	Supervised Highway Automation; L3 ALKS; Infra-assisted AVP
Public transport / MaaS	Autonomous Transit; Low-speed Shuttle; Urban Robotaxi
Heavy-duty Trucks	Long-haul Truck Automation; Hub-to-Hub Trucking
Logistics / Freight	Yard Automation; Off-road Site Logistics
Mining / Construction	Autonomous Mine Haulage; Assisted Earthmoving
Agriculture	GNSS Tractor Autosteer; Precision Automation; Fleet Coordination

Enabling Applications (8)

360° Surround Perception	Passenger Vehicles
Off-road Site Coordination	Mining / Construction
Smart Vehicle Routing; V2X Safety Alerts; V2X Sensor Sharing; Traffic Orchestration; Urban PNT Fusion; Fleet Timing & Positioning	Multi-Sector

Legend

Primary Environment: On-road | Off-road / Mixed

D2 — Survey of Emerging AD/ADAS applications

Enabling Technologies Beyond Classical ADAS

Beyond vehicle-only ADAS functions, higher automation depends on enabling technologies such as connected navigation, cooperative perception, infrastructure coordination, fleet-level timing, and high-integrity localisation.

Intelligent Vehicle Navigation (IVN)

Combines GNSS, IMU, HD maps, V2X, and perception inputs to support dynamic routing and context-aware automated driving.

V2X safety and cooperative perception

Enables vehicles and infrastructure to exchange warnings and sensor information, extending awareness beyond the ego vehicle's direct perception range.

Traffic and fleet coordination

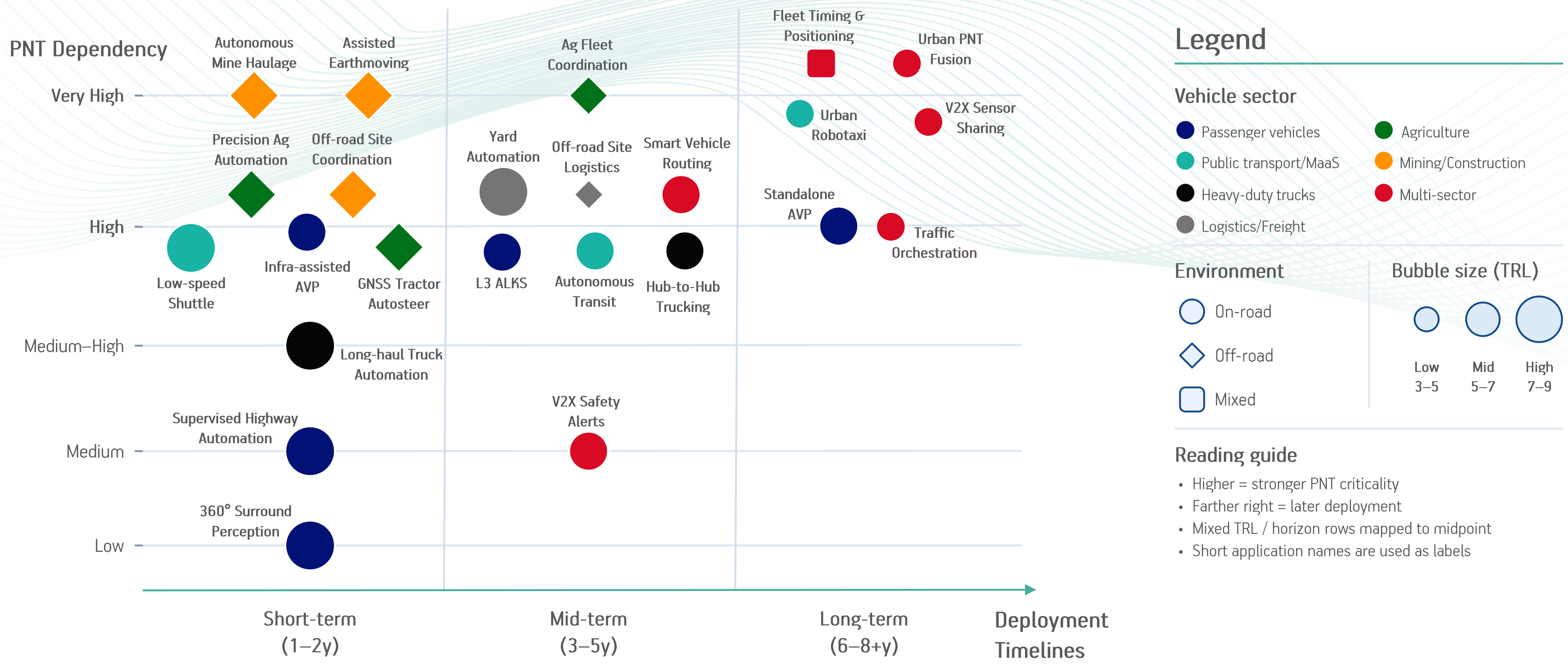
Includes intelligent traffic management, off-road site coordination, and common timing/positioning layers for distributed fleets operating under shared mission plans.

Enhanced perception and urban localisation

Includes 360° surround perception and high-integrity urban PNT/perception fusion to improve robustness in complex, GNSS-challenged ODDs.

D2 — Survey of Emerging AD/ADAS applications

PNT Dependency, Deployment Timelines & TRL



D2 — Survey of Emerging AD/ADAS applications

What Slows or Accelerates TRL Advancement – Barriers & Enablers

TRL maturity depends on more than the core automation function; localisation, perception, regulation, cost, and user acceptance must all be ready for safe deployment.

Technical

- **Blocker**: PNT/GNSS outages, multipath, weak signals, complex sensor fusion, HD-map updates, localisation drift, and AI robustness gaps.
- **Accelerator**: Reliable localisation and perception within a controlled ODD.

Regulatory

- **Blocker**: Safety-case burden, ISO 26262/SOTIF evidence needs, fallback/liability issues, fragmented AD approvals, and V2X interoperability gaps.
- **Accelerator**: Clear ODD, simpler assurance path, and aligned regulatory drivers.

Commercial

- **Blocker**: High sensor/hardware cost, infrastructure dependency, uncertain ROI, and unclear business model.
- **Accelerator**: Clear ROI, especially in fleet-oriented and scalable deployment economics.

User Acceptance

- **Blocker**: Consumer trust and acceptance may lag technical readiness; liability exposure and perceived safety risk can slow OEM prioritisation.
- **Accelerator**: Clear user benefit, predictable behaviour, and phased trust-building rollout.

D2 — Survey of Emerging AD/ADAS applications

Regulatory Landscape

ADAS deployment is strongly shaped by the European regulatory framework, especially EU General Safety Regulation requirements and UNECE/WP.29 vehicle regulations, which define what functions must be available, how they are approved, and where automation can operate.

KEY UNECE REGULATIONS IN SCOPE

Perception & driver assistance	Control & dynamics	Lifecycle & higher automation
R046, R130, R131, R151, R152, R158, R159	R079, R139, R140	R155, R156, R157

Mandatory safety and assistance functions

Regulations cover core ADAS functions such as lane departure warning, advanced emergency braking, brake assist, electronic stability control, blind spot information, reversing detection, and moving-off information systems.

Automation and driver-control boundaries

UNECE R079, R157, and DCAS-related work define where assisted or automated control is allowed, including ODD limits, driver supervision, fallback, and approval conditions.

Cybersecurity and software updates

UNECE R155 and R156 make cybersecurity management and software-update governance mandatory lifecycle requirements for ADAS approval.

Off-road and machinery regulation

Agricultural and machinery regulations extend the regulatory scope beyond passenger cars, relevant for autonomous tractors, construction equipment, and other off-road automation.

D2 — Survey of Emerging AD/ADAS applications

Commercial Models Driving ADAS Adoption

ADAS adoption is no longer driven only by vehicle hardware sales.
It is increasingly shaped by software-enabled business models that allow OEMs, suppliers, fleets, and service operators to monetize functions over the vehicle lifecycle.

Vehicle Sale

Legacy

ADAS features are bundled into the vehicle at purchase, usually through trim levels or optional packages.

Software Unlock

Feature on-demand

Functions can be activated after purchase through subscription access, one-time licenses, or permanent software unlocks.

Fleet Service

Usage-based access

OEMs can package ADAS capabilities into capability tiers or time-bound / usage-based services, aligning feature access with customer needs and willingness to pay.

Data & MaaS Platform

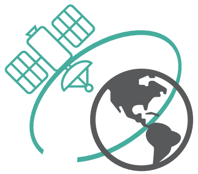
Fleet, data & MaaS models

B2B services, data-as-a-service, and OEM-led mobility platforms monetise automation and operational data.

D2 — Survey of Emerging AD/ADAS applications

Technology Innovation Themes

Six technology innovation themes are identified that can shape future AD/ADAS deployment and create NAVISP-relevant opportunities for resilient, high-integrity PNT and sensor-fusion solutions.

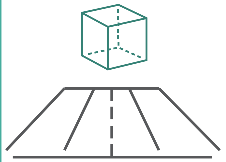


1. LEO-augmented GNSS / hybrid LEO-PNT

Improves positioning resilience, availability, and convergence in challenging environments where classical GNSS alone may be insufficient.

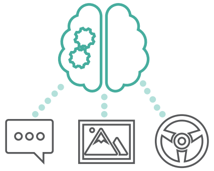
2. HD-map-free and map-lite localisation

Reduces dependency on costly HD-map maintenance by combining onboard perception, GNSS/IMU, and lighter map layers for scalable assisted driving.



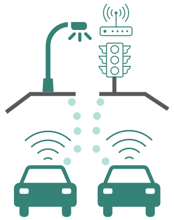
3. 3D occupancy and BEV perception

Strengthens environment understanding by representing free space, obstacles, and drivable areas around the vehicle in a structured 3D / bird's-eye-view format



4. Vision–Language–Action models

Introduce multimodal AI approaches that may support more context-aware driving behaviour and improved interpretation of complex road scenes.



5. V2X cooperative perception

Extends vehicle awareness beyond onboard sensors by sharing perception and safety information between vehicles, infrastructure, and connected systems

6. Next-generation radars

Improve robust perception in adverse weather, low visibility, and complex operating environments where camera- or lidar-only perception may degrade.

D2 — Survey of Emerging AD/ADAS applications

Key Takeaways for NAVISP

Emerging AD/ADAS is moving toward defined-ODD automation, where higher autonomy depends on reliable localisation, safety-relevant PNT performance, and robust sensor-fusion architectures.

Automation is becoming ODD-bound

Future AD/ADAS functions are increasingly deployed within defined highways, urban zones, logistics corridors, depots, farms, mines, and other controlled environments.

PNT becomes safety-critical

As systems move toward L3/L4 operation, PNT shifts from a performance enhancer to a safety-relevant input for ODD enforcement, fallback decisions, and service continuity.

NAVISP opportunity areas are clear

Priority areas include high-accuracy and high-integrity localisation, continuity in GNSS-challenged environments, timing for V2X and fleet coordination, and scalable GNSS/IMU/perception fusion

NAVISP can add most value where PNT becomes a deployment bottleneck: enabling safer automation, wider ODD expansion, and more reliable AD/ADAS services across road and off-road sectors.

D3 — Gaps Identification in PNT Technologies

Overview

D3 analyses how PNT-related limitations affect the deployment of emerging AD/ADAS applications and identifies technologies and services that can support future NAVISP R&D priorities.

1 Link AD/ADAS Functions to PNT Gaps

Assess how technical, environmental, regulatory, and security constraints in current PNT systems limit emerging AD/ADAS functions.

2 Identify and Prioritise Emerging PNT Solutions

Survey novel PNT technologies, services, and developers addressing AD/ADAS challenges.

D3 — Gaps Identification in PNT Technologies

Where PNT Failures Matter Most In AD/ADAS

PNT errors translate directly into control, safety and routing failures in four high-dependence ADAS functions.

Lane Keep Assist (LKA)

Requires accurate vehicle positioning to remain inside the lane. When positioning is wrong or corrupted, the vehicle may drift from the intended lane path, creating unintended lane-departure risk.

Risk Note: Misalignment under spoofing or CAN injection.

Adaptive Cruise Control (ACC)

Depends on precise distance and timing information to maintain safe following distance. PNT inaccuracies can cause inappropriate speed adjustments.

Risk Note: In connected scenarios, corrupted V2V synchronization can create unsafe headway.

Autonomous Emergency Braking (AEB)

Relies on exact positioning and trustworthy perception inputs to detect potential collisions and brake in time. Positioning errors can delay or misfire braking responses.

Risk Note: Manipulated perception inputs can also cause AEB failure.

Navigation & Route Planning

Requires reliable positioning for accurate turn-by-turn guidance. PNT errors can create navigation mismatches, especially in complex urban environments.

Risk Note: Compromised augmentation streams or maps can propagate route-planning errors.

Bottom Line: The critical issue is not only positioning accuracy.
Deployment depends on trustworthy PNT integrity across GNSS, IMU, sensor fusion, vehicle networks, V2X, augmentation services and maps.

D3 — Gaps Identification in PNT Technologies

Families of PNT Limitations

AD/ADAS deployment is blocked by a combined PNT gap—not a single technology gap.

Technical constraints

GNSS, IMU and sensor-fusion limitations reduce positioning accuracy, integrity and continuity. GNSS is affected by weak signals, limited satellite visibility, multipath and spoofing; IMUs drift without correction; advanced fusion improves robustness but adds cost, compute and calibration burden.

Environmental constraints

Real-world ODDs degrade PNT performance. Urban canyons create NLOS and multipath errors; tunnels fully disrupt GNSS; rain, fog and snow reduce LiDAR/camera reliability and weaken perception-assisted localisation.

Cybersecurity constraints

PNT data can be corrupted across the signal, vehicle and cloud layers. Key risks include GNSS spoofing/jamming, false odometry or correction injection through CAN/V2X, manipulated perception inputs, compromised HD maps, correction streams and OTA updates.

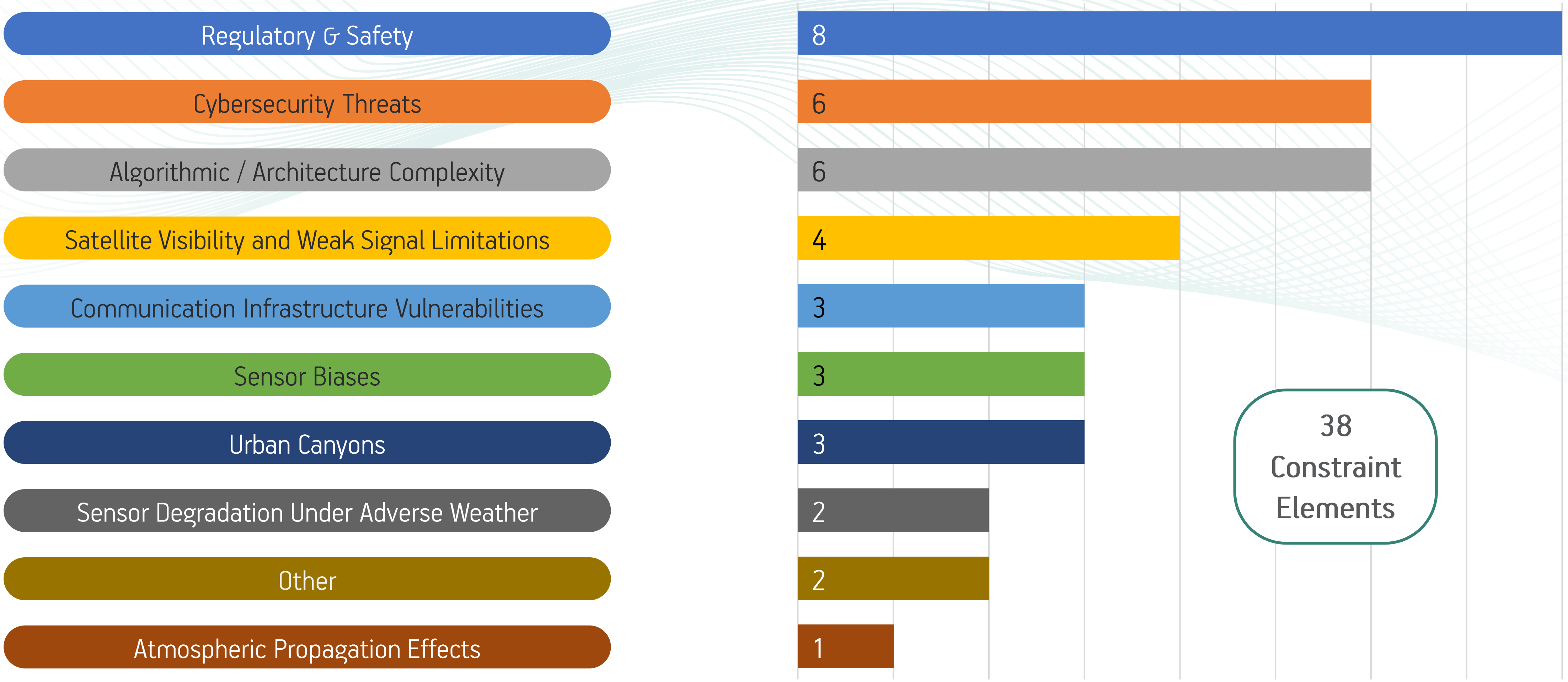
Regulatory / legal constraints

PNT reliability is now part of the deployment evidence chain. Safety, cybersecurity, liability, spectrum and data-governance requirements can delay type approval when PNT integrity, resilience and responsibility are not demonstrably controlled.

Bottom Line: The deployment bottleneck is trustworthy PNT: accurate enough, continuous enough, cyber-secure enough, and evidence-ready for safety and regulatory approval.

D3 — Gaps Identification in PNT Technologies

Constraint Families & Elements Count

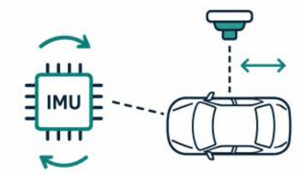


D3 — Gaps Identification in PNT Technologies

Finding 1: GNSS alone does not meet high-integrity road-ADAS needs

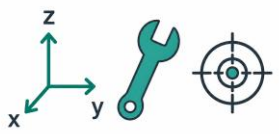
GNSS provides global positioning, but standalone GNSS is not sufficient for safety-critical road ADAS where both accuracy and integrity must be proven.

GNSS performance is degraded by atmospheric delays, weak signals, blocked visibility, foliage, buildings, tunnels and high-noise environments. Accurate GNSS positioning typically requires line-of-sight to at least four satellites, but this condition is not reliably met in dense or obstructed road environments.



ADAS Impact

For road vehicles, positioning accuracy alone is not enough. D3 states that decimetre-level positioning with high integrity — for example, ≤10 cm error 95% of the time — remains unattained by GNSS alone, especially with low-cost mass-market receivers.



Deployment Implications

High-integrity ADAS localisation requires GNSS to be reinforced by integrity monitoring, sensor fusion, multipath/NLOS mitigation and resilience against spoofing or jamming.

Bottom Line: GNSS is necessary, but not sufficient: road-ADAS deployment depends on trusted, fused and integrity-aware PNT.

D3 — Gaps Identification in PNT Technologies

Finding 2: IMU holdover helps, but drift and calibration remain deployment risks

IMUs are essential for maintaining positioning when GNSS becomes weak or unavailable, but inertial holdover is time-limited: Without correction, IMU errors accumulate and can degrade ADAS localisation performance.

Failure Chain

IMU acceleration / angular-rate measurements → Integration into velocity & position → Accumulation of drift & bias → Degraded lane-level localisation → ADAS risk during GNSS outages, tunnels, urban canyons or re-acquisition phases.

Main Technical Risks

Low-cost MEMS IMUs suffer from integration drift, static and dynamic sensor biases, and lever-arm effects when the IMU and GNSS antenna are not co-located. Through turns, different mounting locations can introduce additional positioning error unless modelled or calibrated.

Deployment Implications

GNSS/IMU fusion usually requires full 6-DOF pose estimation and precise knowledge of IMU orientation relative to the vehicle frame. Misalignment, sensor replacement, mechanical shocks or sensor movement can trigger re-calibration needs and reduce scalability for vehicle deployment.

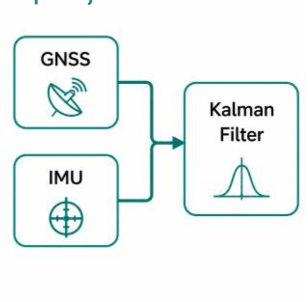
Bottom Line: IMU holdover is a necessary fallback, but it is not a standalone solution. Reliable AD/ADAS deployment requires calibrated GNSS/IMU fusion, drift monitoring, fault-tolerant fallback logic and evidence that performance remains bounded during GNSS loss.

D3 — Gaps Identification in PNT Technologies

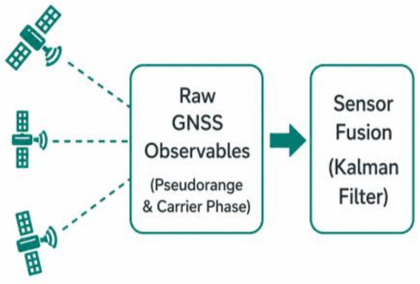
Finding 3: Sensor fusion improves robustness but adds compute and integration burden

Sensor fusion is the practical path to more reliable AD/ADAS positioning, but there is a clear trade-off: stronger fusion improves robustness when GNSS is weak, sparse or jammed, while increasing modelling effort, compute load, calibration needs and deployment cost.

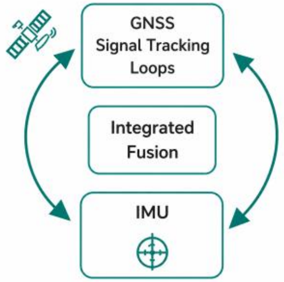
Coupling Trade Offs



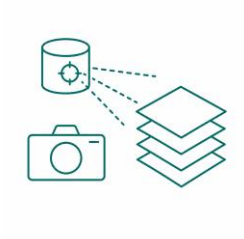
Loose coupling is simpler
It fuses GNSS position/velocity outputs with IMU data through a Kalman filter. Its weakness is that it underperforms when GNSS data is sparse or unreliable.



Tight coupling is stronger
It uses raw GNSS observables, such as pseudo ranges and carrier phase, allowing correction even with fewer than four visible satellites.



Deep coupling
Goes further by integrating GNSS signal tracking loops with IMU data, improving robustness under weak or jammed signals.



Scaling Issue

Adding LiDAR, cameras, SLAM and AI-guided calibration improves robustness, but requires substantial computation and tuning. D3 also notes that tightly coupled GNSS/IMU/LiDAR fusion is still progressing and remains research-focused.

Deployment Implications

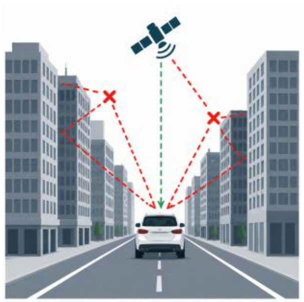
Real-time tight coupling and multi-sensor fusion are demanding for embedded automotive platforms. High-performance GNSS, high-grade IMUs and LiDAR increase cost; multi-sensor systems require periodic calibration; sensor failures require redundancy and fault-tolerant strategies.

Bottom Line: Sensor fusion is necessary for resilient AD/ADAS PNT, but production deployment depends on controlling compute, calibration, cost, fault tolerance and evidence that the fused solution remains stable in real driving ODDs.

D3 — Gaps Identification in PNT Technologies

Finding 4: Urban canyons are the primary accuracy / continuity stress case

Dense urban environments expose the weakest point of GNSS-based AD/ADAS localisation.
The vehicle sees fewer satellites, satellite geometry worsens, and reflected signals create biased position estimates.

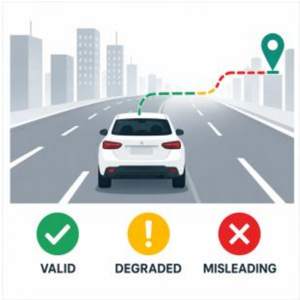


Why it fails

Tall buildings block GNSS line-of-sight, reducing satellite visibility and worsening GDOP. At the same time, reflections from building façades create multipath and NLOS signals that arrive late or distorted, corrupting pseudo range measurements.

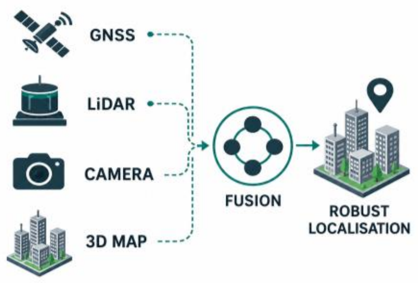
Measured Impact

Multipath errors can reach multiple metres for coarse code measurements and decimetres for carrier-phase measurements.
NLOS errors are also biased and heavy-tailed, especially in deeper urban canyons.



ADAS Impact

This directly affects lane-level localisation, route matching, ISA, LKA, Traffic Jam Assist and urban autonomy. The risk is not only lower accuracy, but unstable continuity: the system may switch between valid, degraded and misleading position estimates within seconds.



Mitigation Evidence

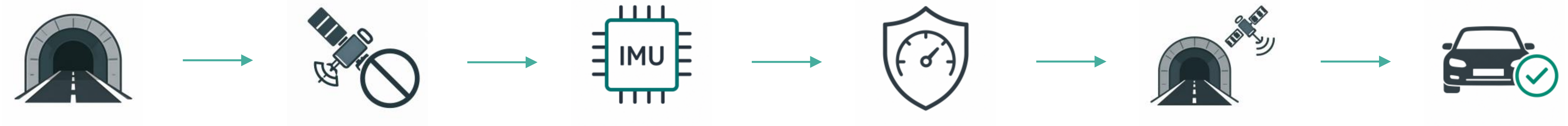
Mitigations include multi-constellation GNSS, 3D-city shadow matching, LiDAR-aided NLOS detection, multipath filtering, and hybrid sensor fusion. Trials showed that 3D LiDAR-assisted GNSS NLOS mitigation achieved sub-metre urban accuracy and improved RTK fix rates from ~14% to ~30%

Bottom Line: Urban AD/ADAS deployment depends on proving robust localisation under blocked, reflected and unstable GNSS conditions—not only on improving open-sky accuracy.

D3 — Gaps Identification in PNT Technologies

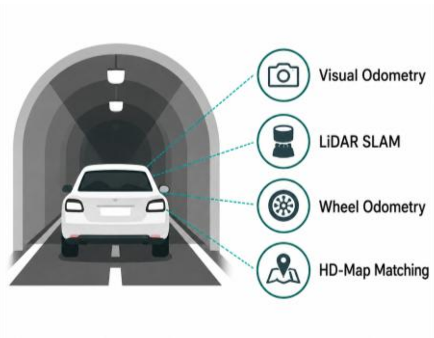
Finding 5: Tunnels turn GNSS failure into a holdover and re-acquisition problem

In tunnels and underpasses, GNSS is not degraded—it is effectively unavailable. This is a continuity problem.
The vehicle must maintain a bounded position estimate during the outage, then safely re-acquire GNSS at the tunnel exit without accepting false or unstable fixes.



Tunnel entry → Satellite visibility loss / GNSS loss → GNSS unavailable / IMU holdover → IMU drift accumulation → Exit re-acquisition → Function restored

Why fallback methods are not enough



Each fallback has limits: visual odometry can fail in darkness or featureless tunnels; LiDAR SLAM requires sufficient tunnel structure; odometry error grows over time; sensor fusion helps but remains constrained by compute, noise modelling and environmental vulnerabilities.

Mitigation Evidence

1. INS + wheel odometry + lane constraints: (1) INS + wheel odometry with lane / kinematic constraints and protection-level management, assessed at TRL 6.
2. UWB / 5G: (2) Sparse UWB / 5G-NR positioning updates where infrastructure exists, assessed around TRL 5.
3. (3) Fast, clean GNSS re-acquisition at exits using INS-aided Doppler / clock propagation and admission checks, assessed at TRL 6.

Bottom Line: Tunnel performance is a test of AD/ADAS continuity: success depends on controlled holdover, bounded drift, trusted transition logic and clean GNSS re-entry—not open-sky positioning accuracy.

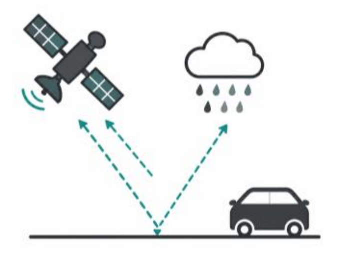
D3 — Gaps Identification in PNT Technologies

Finding 6: Weather degrades the perception side of PNT fusion

Adverse weather does not only reduce visibility; it weakens the sensor inputs used to support localisation, perception and ADAS decision-making.

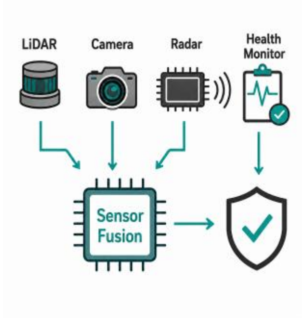
Sensor Impact

Fog, rain and snow degrade LiDAR by scattering and reflecting laser returns, reducing range, point density and measurement accuracy. Cameras are also affected by poor lighting, glare, snow and fog, which reduce image clarity, feature visibility and algorithm reliability.



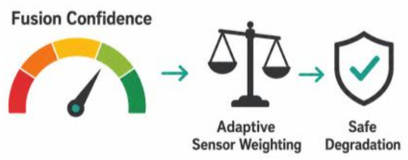
GNSS Impact

Rain has limited direct effect on GNSS signals, but weather-related atmospheric changes can introduce tropospheric delay. Wet road surfaces can also increase reflected signals and minor multipath effects.



Mitigation Evidence

- Weather-aware sensor weighting
- cross-modal fusion
- radar retention under poor visibility
- sensor self-health monitoring
- heaters/defoggers, coatings
- wipers/air jets
- condition-tagged regression testing



Deployment Risk

The key risk is unstable fusion confidence: ADAS must know when camera/LiDAR evidence is degraded, shift weight to more reliable sensors, and degrade safely when protection thresholds are exceeded.

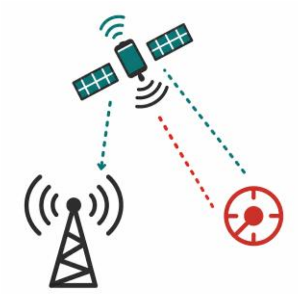
Bottom Line: Weather resilience is not just a perception issue; it is a PNT integrity issue for real-world AD/ADAS deployment.

D3 — Gaps Identification in PNT Technologies

Cybersecurity – PNT is attackable across signal, vehicle and cloud layers

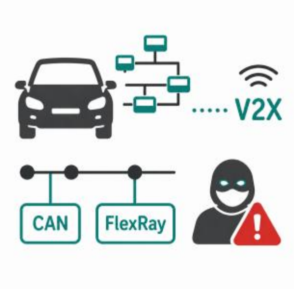
PNT trust can fail at multiple points: the GNSS signal, the vehicle network, the sensor-fusion stack, V2X links, cloud correction services, HD maps and OTA updates.

Attack Surface



GNSS spoofing can generate false position or time; jamming can remove GNSS availability entirely. Low-cost spoofers can displace vehicles by tens of metres, while consumer jammers under €50 can disable GNSS-based ADAS such as ISA.

Vehicle-level Risk



False PNT can enter via unauthenticated CAN/FlexRay buses, injecting odometry or GNSS-correction errors. V2X adds MitM/Sybil exposure, corrupting cooperative messages and weakening platooning or Cooperative ACC.

Service-layer risk

ADAS increasingly relies on PPP-RTK correction streams, HD maps and OTA updates. DoS, ransomware, malicious OTA updates or cloud-side tampering can cut corrections, misdirect fleets or corrupt navigation behaviour.

ADAS Impact

LKA
Can misalign under spoofing or CAN injection

ACC
Can create unsafe headway if V2V timing is corrupted

AEB
Can fail when perception inputs are manipulated

Navigation
Can fail when maps or augmentation services are compromised

Bottom Line: PNT cybersecurity is not only RF protection. Deployment requires end-to-end trust across signal authentication, secure vehicle networks, resilient fusion, correction-stream assurance, HD-map integrity and governed OTA updates.

D3 — Gaps Identification in PNT Technologies

Regulation – PNT evidence is part of the safety case

PNT is not only a technical enabler for ADAS/AD. It becomes part of the compliance evidence needed to prove that safety-critical functions are reliable, secure and ready for type approval.

Evidence Chain

1. PNT input → 2. Safety case → 3. Cybersecurity case → 4. Type approval → 5. Deployment readiness

Why this matters

ADAS and automated functions require functional safety and cybersecurity. Validated, reliable PNT data are critical for hazard analysis and risk assessment. Spoofed, jammed or corrupted inputs weaken the safety case

Regulatory pressure

The EU General Safety Regulation mandates ADAS features such as ISA, ALKS and AEB from 2024 onward. These functions rely on accurate positioning and timing, so unresolved PNT limits can complicate compliance.

Type-approval risk

UNECE R155 and R156 require cybersecurity resilience, controlled software updates and protection of navigation data. Unsecured PNT inputs may cause non-conformance and delay type approval.

Bottom Line: For ADAS/AD deployment, PNT is no longer a black-box input. It must be evidence-ready for safety, cybersecurity and regulatory approval.

D3 — Gaps Identification in PNT Technologies

Solutions Maturity – Technical PNT mitigations

Mixed maturity landscape: some technical mitigations are already near deployment, while others remain research-stage and need validation in real AD/ADAS operating conditions.

Highest maturity
TRL 8

Governed OTA update processes show strong readiness for controlled software evolution and compliance support.

Near-term technical enabler
TRL 7

Multi-constellation / multi-frequency GNSS with Galileo HAS is one of the most mature positioning upgrades for ADAS localisation.

Assurance layer
TRL 6-5

Correction freshness monitoring and estimator integrity are promising but still validation-dependent readiness for safety-critical use.

Fusion & calibration layer
TRL 5

Factor Graph Optimisation, noise adaptation and self-calibration are important for robust GNSS/IMU fusion but still need stronger evidence under automotive ODDs.

Early-stage innovation
TRL 3

Diffusion-model IMU bias priors show research potential but not deployment maturity.

Bottom Line: The technical path is not blocked by lack of concepts; it is blocked by maturity gaps, field validation and evidence that these mitigations work reliably in safety-critical AD/ADAS deployment.

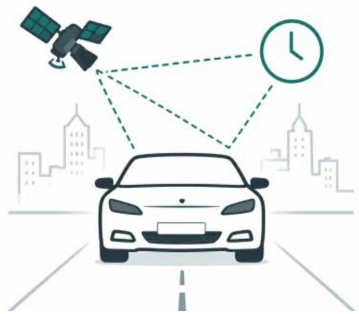
D3 — Gaps Identification in PNT Technologies

Solutions Maturity - LEO-PNT

LEO-PNT is a resilience layer for road ADAS localisation, not a replacement for GNSS. Its value is strongest when GNSS is degraded by urban masking, interference or outages.

LEO Benefit

LEO satellites are closer to Earth than MEO GNSS, enabling higher received power. Their fast orbital motion creates faster geometry change and stronger Doppler signatures, which can support faster estimation, PPP convergence and re-convergence after outages.



ADAS Impact

LEO-PNT can improve continuity, time-to-recover and timing resilience. Independent LEO timing can also provide a cross-check against GNSS timing faults or spoofing, provided authentication and monitoring are treated as safety-relevant functions.

Maturity Status

Iridium STL timing / resilient cross-check	Commercial new GNSS in LEO	LEO-assisted PPP convergence	NTN-based positioning for 5G/6G satellite access
TRL 5	TRL 4	TRL 4	TRL 3

End-to-end ADAS maturity remains at early stage

Integration Risks

- Frequent satellites handovers
- High Doppler & Doppler rate
- Ephemeris / Clock governance
- Spectrum compatibility
- Integrity monitoring & anomaly detection
- Logging & bounded fault detection

Bottom Line: LEO-PNT is promising for resilience and recovery, but it is not yet a deployable ADAS localisation solution on its own. Its near-term role is as an additional trusted layer inside a fused GNSS / IMU / sensor / timing architecture.

D3 — Gaps Identification in PNT Technologies

Solutions Maturity – Environment Mitigations

The most mature environmental mitigations are practical vehicle-level protections, while urban integrity solutions remain mid-maturity and still need stronger ODD-level validation.

Highest maturity

TRL 8

Hardware hygiene and self-protection are the most deployment-ready measures: heaters, defoggers, coatings, wipers, air jets and sensor self-health monitoring help maintain sensor performance under rain, fog, snow and icing.

Operational continuity

TRL 7

Tunnel and outage handling is more mature than dense-urban integrity. INS + wheel odometry constrained holdover, protection-level / covariance management, and fast clean GNSS re-acquisition at exits.

Weather-aware fusion

TRL 6-5

Weather classes, cross-modal re-admission checks and tagged regression logging help keep degraded-sensor behaviour auditable.

Urban-integrity

TRL 5

Sky-mask + 3DMA GNSS, C/N_0 time-series gating and integrity-constrained FGO are promising for urban canyon NLOS / multipath but still need stable performance across diverse road ODDs.

Early-stage weather modelling

TRL 3

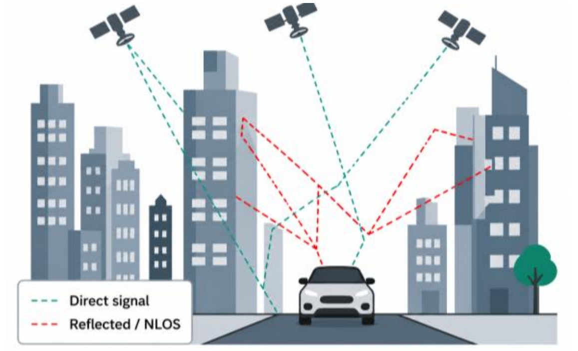
Advanced tropospheric inputs such as NWP assimilation, smartphone ZTD and ML wet-delay prediction remain early-stage for road-ODD localisation.

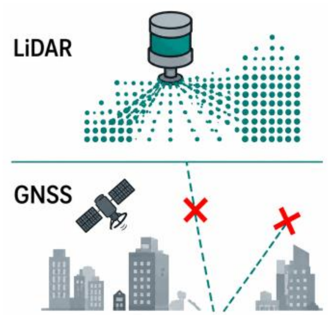
Bottom Line: Environmental resilience is closest to deployment at the hardware and controlled-holdover level; the remaining gap is proving integrity-aware localisation in dense urban, weather-degraded and transition-heavy ODDs.

D3 — Gaps Identification in PNT Technologies

Urban NLOS Mitigation

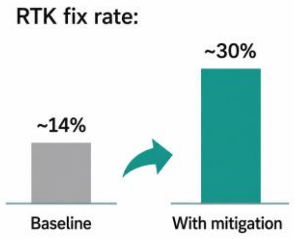
Urban NLOS / multipath mitigation is no longer only conceptual: quantified gains exist.
However, the strongest techniques remain at TRL 5, meaning they still need stable validation across diverse road ODDs before they can be treated as deployment-ready.

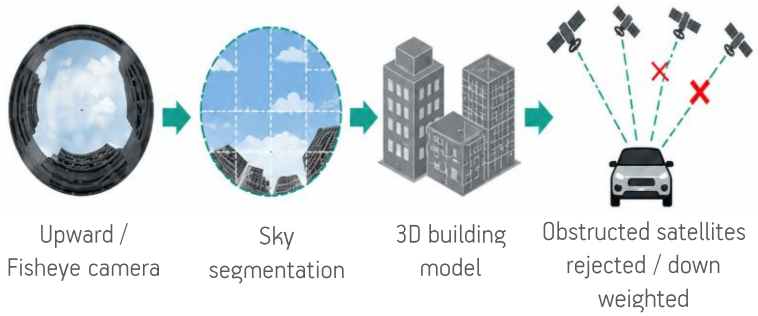




Quantified Mitigation Result

3D LiDAR-assisted GNSS NLOS identification can use point-cloud maps to identify NLOS-affected signals and integrate LiDAR-derived virtual satellite constraints into RTK / factor-graph frameworks.
In cited trials, this achieved sub-metre accuracy in urban canyons and increased RTK fix rates from ~14% to ~30%.





Complementary mitigation path

Sky-mask + 3DMA GNSS combines upward / fisheye camera sky segmentation with 3D building models to reject, or down-weight satellites predicted to be obstructed. This results in improved urban positioning quality and fix availability versus GNSS/INS/Vision without a sky mask.

TRL 5

- Sky-mask + 3DMA GNSS
- C/N_0 time-series
- Integrity-constrained FGO

Bottom Line: Urban NLOS mitigation has measurable performance gains, but deployment readiness depends on proving the same gains consistently across real urban geometries, sensor setups, traffic conditions and integrity requirements.

D3 — Gaps Identification in PNT Technologies

Cybersecurity & Regulatory Maturity

Cyber/regulatory governance controls are already mature, but several detection and anomaly-screening techniques still require stronger automotive field validation.

High Maturity Controls

TRL 8

UNECE R155/R156 governance, ISO/SAE 21434 + NIST CSF evidence-by-design, and AUTOSAR SecOC are assessed at TRL 8. These are deployable foundations for cybersecurity management, software-update control, message origin protection and freshness checks.

Secure Transport Layer

TRL 7

NTRIP over TLS, Automotive MACsec and IEEE 802.1ASdm resilient time synchronisation are assessed at TRL 7, showing strong maturity for protected correction streams, in-vehicle Ethernet security and stable timing.

Mid-maturity Assurance Layer

TRL 6-5

OSNMA freshness checks, crypto-aware admission, V2X PKI validation, correction-stream monitoring and controlled step-down chains sit around TRL 5–6. These provide practical assurance but still depend on integration evidence and stable transitions.

Lower-maturity Detection

TRL 5-4

Rotating-antenna DoA spoofing detection is TRL 4–5 and lightweight ML/XAI anomaly scoring is TRL 4. The main gap is not conceptual feasibility. The remaining challenge is proving them in practice through field evidence, mature packaging, repeatable calibration and subsystem-level demonstration

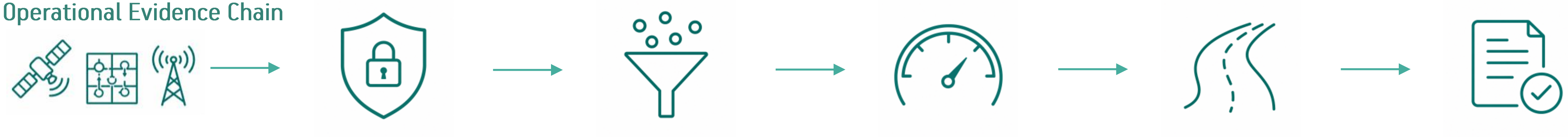
Bottom Line: The governance framework is ready; the remaining risk is proving that detection, admission and fallback logic work reliably in real AD/ADAS operating conditions.

D3 — Gaps Identification in PNT Technologies

Conclusion – Auditable Evidence for AD/ADAS Deployment

AD/ADAS deployment cannot rely on one sensor, one algorithm or one correction service.
Deployment readiness comes from an auditable evidence chain: trusted inputs, controlled fusion, bounded degradation and replay-able logs.

Operational Evidence Chain



GNSS / IMU / maps / V2X / corrections → Security and freshness checks → Fusion admission → Protection-level monitoring → Controlled fallback → Logged recovery

What must be proven:

- ✓ Correction streams are fresh, authenticated and monitored.
- ✓ Fusion only uses inputs that pass plausibility, timing and trust checks.
- ✓ Degraded modes follow predefined step-down paths: RTK → RT-PPP → PPP-float → dead reckoning.
- ✓ Protection levels widen when confidence drops.
- ✓ Step-up only occurs after stability windows and independent monitors agree.

Why this matters:

In tunnels and urban canyons, it is expected to have timed holdovers, widened protection levels, slower map-matching and delayed use of cooperative cues until trust returns.

Bottom Line: The deployable result is not "better positioning" alone. It is a traceable safety/cyber package that OEMs, suppliers and authorities can audit, replay and approve.

D4 — Synthesis & Recommendations for NAVISP

Overview

D4 converts the D1–D3 evidence base into a NAVISP-oriented roadmap: it prioritises the PNT gaps and translates them into project recommendations, partner opportunities, and implementation-ready actions.

1 Consolidate the evidence base

Bring together the AD/ADAS baseline, emerging application landscape, PNT gaps and relevant ecosystem actors into one coherent synthesis.

2 Define NAVISP priorities

Identify the research gaps, technology development needs and deployment opportunities that should guide future NAVISP investment.

3 Recommend NAVISP projects

Propose structured project recommendations for NAVISP Elements 1, 2 and 3, including relevant stakeholders and potential industry or research partners.

D4 — Synthesis & Recommendations for NAVISP

Project Synthesis Approach

Synthesis Chain

Applications → Limitations → Solutions → Strategic Gaps → NAVISP Projects → Partnerships

Applications

Prioritization starts from application value

- PNT dependency
- Deployment horizon
- TRL maturity
- ODD relevance

Limitations

Constraints are mapped to real use cases

- Linked to applications
- Assessed through sector
- Environment and ODD define the constraints

Solutions

Solutions are matched to the gaps they solve

- Each solution addresses specific limitations
- Creates traceability from need to response

Strategic Gaps

Recurring limitation families with plausible mitigations

- Based on deployment horizon
- Paired with mitigation pathways
- Fitted to NAVISP Element investment portfolio

NAVISP Projects

The output is a traceable project portfolio

- Evidence backed project opportunities
- Clear links across applications, gaps, solutions and partners

Partnerships

Partnerships are filtered by fit

- Mapped through industry sector
- Aligned to the relevant ADAS layer

D4 — Synthesis & Recommendations for NAVISP

Strategic Gaps for NAVISP Projects: G1 – G4

Strategic Gaps for future NAVISP projects

G1 – Urban GNSS

LOS blockage, multipath, and NLOS effects degrade positioning performance in dense urban environments

NAVISP Priority

Resilient lane-level urban positioning for short–mid-term, and high-integrity urban PNT/fusion as the long-term enabler for dense-urban autonomy.

G2 – Trust Framework

Lack of harmonised admission, interoperability, and validation framework for cooperative perception and V2X

NAVISP Priority

Secure, interoperable V2X cooperative perception validation and creation of evidence-based trust frameworks for city-scale and cross-border rollout

G3 – Deployment Cost

Cost and operability barriers limit commercial multi-sensor PNT deployment for vehicle ADAS

NAVISP Priority

Establishment of independent European vehicle PNT cost landscape, and validation of algorithmic and augmentation-based cost-reduction paths.

G4 – GNSS Continuity

Maintaining localisation continuity in GNSS-denied areas while managing IMU drift and bias

NAVISP Priority

Tunnel/portal continuity demonstrator for highway, corridor, and urban transit ODDs, with auditable holdover and re-admission criteria

D4 — Synthesis & Recommendations for NAVISP

Strategic Gaps for NAVISP Projects: G5 – G8

Strategic Gaps for future NAVISP projects

G5 – Integrity Monitoring

Integrity quantification and monitoring remain bottlenecks for safety-case approval

NAVISP Priority

Automotive PNT integrity-metric and evidence-pack project, tied to ALKS, robotaxi, mining, and agriculture safety cases

G6 – Weather Robustness

Localisation and perception stacks lack reliable all-weather performance

NAVISP Priority

An all-weather validation and robustness framework for outdoor on-road/off-road ODDs

G7 – Cyber Resilience

Spoofing, jamming, and cyber exposure threaten localisation and the wider service ecosystem

NAVISP Priority

A secure PNT assurance stack for automotive deployment

G8 – Governance Barriers

Regulation and governance constraints act as first-class blockers to deployment

NAVISP Priority

A NAVISP Element 3-style regulatory/evidence framework for PNT-dependent ADAS, including reusable safety/cyber/data governance templates

D4 — Synthesis & Recommendations for NAVISP

NAVISP Project Portfolio Overview

Portfolio structure

Element 1

Foundational PNT-ADAS Projects

5 Projects

Build the core PNT enablers and validate feasibility at Lower TRL Level.

Element 2

Mid-term AD/ADAS Enabling Projects

8 Projects

Advance promising solutions toward validation and productization.

Element 3

Deployment, Governance & Ecosystem Projects

2 Projects

Enable deployment frameworks, pilot corridors and stakeholder coordination.

Portfolio logic

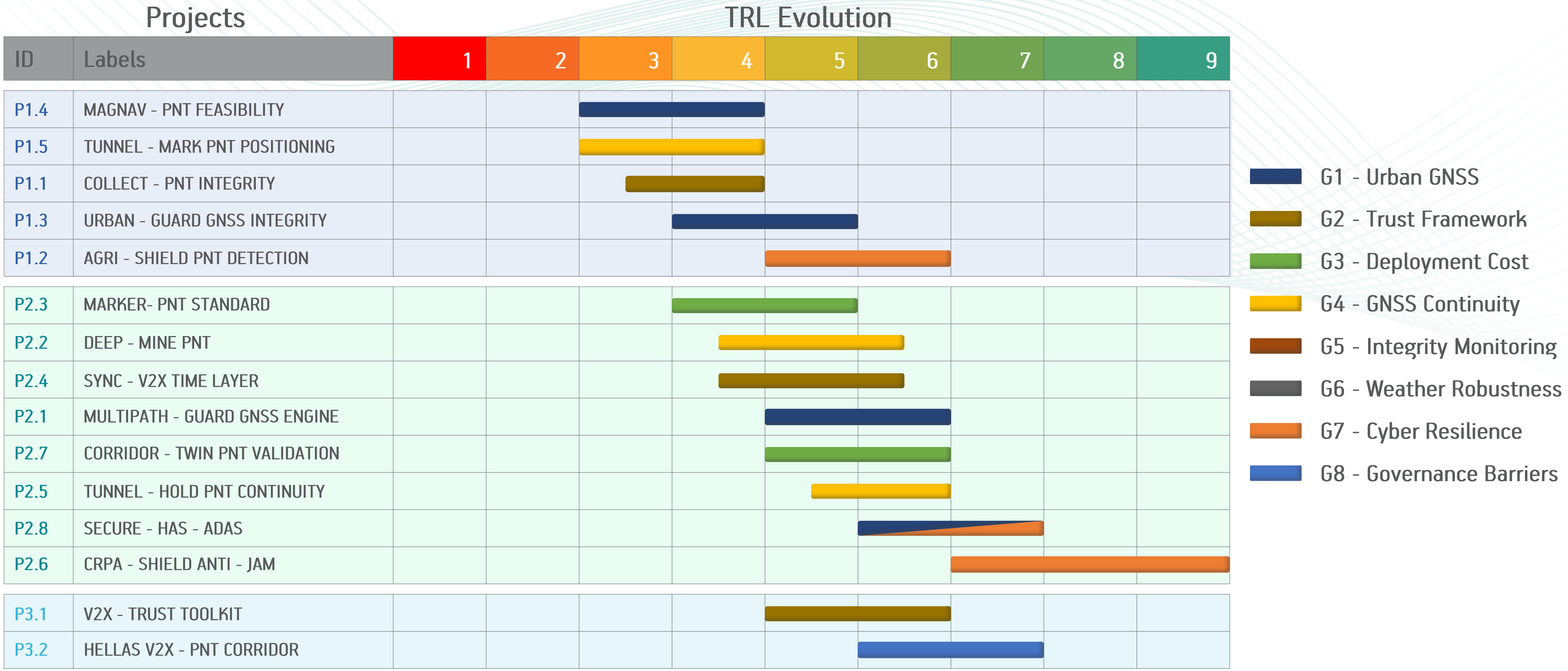
Element 1
Addresses lower-TRL feasibility and foundational innovation.

Element 2
Moves promising solutions toward validation and productization.

Element 3
Supports deployment frameworks, pilot corridors, and stakeholder coordination.

D4 — Synthesis & Recommendations for NAVISP

Portfolio Maturity View: TRL Evolution and Primary Gap Coverage



D4 — Synthesis & Recommendations for NAVISP

Element 1: Foundational Feasibility and Early-TRL PNT Concepts

P1.1 COLLECT-PNT INTEGRITY

Cooperative PNT Integrity for Collective Manoeuvring and L5-Ready Automation.

Perception & Sensor Fusion | Connectivity

P1.2 AGRI-SHIELD PNT DETECTION

DoA-Based GNSS Spoofing Detection System for Autonomous Agricultural Applications with Rotating Antennas.

Localization & Mapping | Sensing Hardware

P1.3 URBAN-GUARD GNSS INTEGRITY

Lightweight ML/XAI Anomaly Scoring for Real-Time GNSS Integrity in Urban Environments.

Compute | Localization & Mapping

P1.4 MAGNAV-PNT FEASIBILITY

Fundamental Assessment of Magnetic Navigation for Resilient Positioning in GNSS-Challenged Environments.

Sensing Hardware | Localization & Mapping

P1.5 TUNNEL-MARK PNT POSITIONING

Magnetic Marker-Based Positioning for Resilient PNT in Extensive Tunnel Networks.

Localization & Mapping | Sensing Hardware

D4 — Synthesis & Recommendations for NAVISP

Element 2: Validation and Productisation of Mid-TRL AD/ADAS Enablers

P2.1 MULTIPATH-GUARD GNSS ENGINE

Commercial Deployment of Adaptive Multipath Mitigation techniques for High-Precision GNSS Positioning Engines.

Localization & Mapping

P2.2 DEEP-MINE PNT

Exploratory Alternative PNT solutions for Deep Underground and GNSS – Free Industrial Autonomy.

Localization & Mapping

P2.3 MARKER-PNT STANDARD

Standardisation of 2D Marker Fiducial for Resilient Positioning.

Perception & Sensor Fusion

P2.4 SYNC-V2X TIME LAYER

Common Time & Reference Layer for Cooperative V2X Safety and Fleet Automation.

Connectivity

P2.5 TUNNEL - HOLD PNT CONTINUITY

Tunnel – resilient PNT holdover and reacquisition for highway and corridor automation.

Localization & Mapping

P2.6 CRPA-SHIELD ANTI-JAM

CRPA - Enabled Interference Mitigation techniques for Civilian-grade Autonomous Vehicles.

Sensing Hardware

P2.7 CORRIDOR-TWIN PNT VALIDATION

Digital Twin PNT Validation Corridor for European Highway ADAS.

Compute

P2.8 SECURE-HAS-ADAS

Resilient High-Accuracy and Authenticated GNSS for Safety-Critical ADAS.

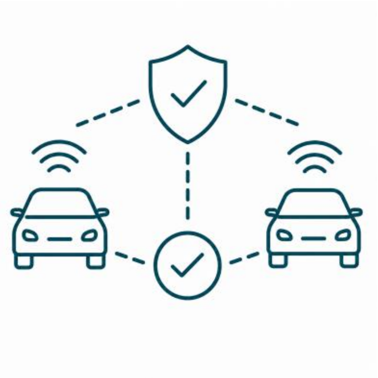
Perception & Sensor Fusion

D4 — Synthesis & Recommendations for NAVISP

Element 3: Deployment Frameworks, Pilots and Institutional Evidence

P3.1 V2X-TRUST TOOLKIT

V2X Cooperative Perception Trust & Interoperability Validation Toolkit



Strategic Objectives:
Establish a harmonised validation framework for V2X-enabled cooperative perception, enabling trusted, reproducible and cross-border evidence for ADAS procurement, regulatory assessment and deployment readiness. The activity should support Member State authorities, road operators, C-ITS bodies, standardisation organisations, OEMs, Tier-1 ADAS integrators and V2X suppliers in assessing whether shared positioning, timing and perception data are reliable enough for operational use.

Expected Impact: Safer, auditable and scalable V2X-enabled ADAS deployment by preventing corrupted positioning data from entering cooperative perception pipelines and reducing the validation burden across Member State pilots.

Compute | Perception & Sensor Fusion | Connectivity

P3.2 HELLAS V2X-PNT CORRIDOR

Greek V2X-PNT Pilot Corridor for Cooperative ADAS, Timing Integrity, and Institutional Evidence

Strategic Objectives:
Establish a Greek Element 3 pilot capability for validating trusted PNT in connected and automated mobility, using existing Greek C-ITS motorway and automated urban-mobility infrastructure as the baseline. The project adds timing integrity, correction monitoring, position consistency and evidence-generation for cooperative ADAS, involving public authorities, road/site operators, C-ITS/V2X providers, PNT suppliers, ADAS integrators, fleet/AV operators and validation bodies.

Expected Impact: A Greek Element 3 pilot that turns prior C-ITS and automated-mobility experience into trusted PNT evidence for safer cooperative ADAS deployment, national scaling and European interoperability.

Localization & Mapping | Perception & Sensor Fusion | Connectivity

NAVISTAR Synopsis

From evidence base to actionable NAVISP project roadmap

1. Evidence base established

One decision framework consolidates the evidence

- Current AD/ADAS deployment and emerging applications consolidated
- PNT dependency, technology gaps, and mitigation pathways linked in one framework
- Evidence base is structured for traceable decision-making

2. Project portfolio defined

15 candidate NAVISP projects are identified

- 5 foundational PNT-ADAS projects
- 8 mid-term AD/ADAS enabling projects
- 2 deployment, governance, and ecosystem projects

3. Implementation pathway prepared

Projects are ready for prioritisation and action

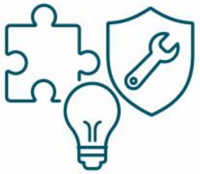
- Each project is linked to strategic gaps and maturity evolution
- Relevant technology areas and candidate partner categories are mapped
- The roadmap is ready to support NAVISP project selection

Traceable Action Chain

1. Applications

→ 2. PNT Limitations

→ 3. Mitigation Pathways



→ 4. Strategic Gaps

→ 5. NAVISP Projects

→ 6. Candidate Partners

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