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NAVISP Element 3
Final Presentation

EL3-033 "A Confidence Validation Framework for PNT"

17th June 2026, 10:30 – 12:00 CET

Time	Topic	Speaker
10:30-10:35	Welcome	ESA NAVISP Element X Manager
10:35-10:40	Project Introduction	**Xurxo Otero Villamide** Technical Officer, ESA
10:40-11:30	Project Implementation and Results: • Introduction to the project • WMG Safety Pool • PNT Attributes and ODD • Loops implementation • Metrics of interest • Discussion of Results • Conclusion and Next steps	**Presenter 1 Prof. Matthew Higgins** Communications and Navigation Research Group Lead, Data and AI Theme Lead of WMG, University of Warwick **Presenter 2 Dr Jasmine Zidan** Research Fellow, WMG, University of Warwick
11:30-12:00	Question and Answers	Moderator: **Xurxo Otero Villamide** Technical Officer, ESA

NAVISP Element 3
Final Presentation

A Confidence Validation Framework for PNT

WMG, Vodafone, NPL, Spirent

17/06/2026

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NPL

Spirent Is Now Part of Keysight

Acknowledgments

Project Team

- Prof. Matthew Higgins (PI, Reader, WMG, University of Warwick)
- Dr Jasmine Zidan (Co-I, Research Fellow, WMG, University of Warwick)
- Dr Tony Mo (Lead Engineer, WMG, University of Warwick)
- Patrick Irvine (Project Engineer, WMG, University of Warwick)
- Prof. Paul Jennings (Head of IV group, WMG, University of Warwick)
- Prof. Siddartha Khastgir (Head of Safe Autonomy at WMG, University of Warwick)
- Alex Schofield (PhD Candidate in Assured PNT, WMG, University of Warwick)
- Dr Tony Sammut (Senior RD Manager, Vodafone Group Services Limited)
- Sami Gabriel (Vodafone)
- Dr Maurizio Bevilacqua (Senior Engineer, NPL)
- Maryna Antonova (Project Manager, NPL)
- Dr Raphael Grech (Technical Strategist (PNT) - Emerging Technologies, Spirent)
- Chrissie Hillyer (Spirent)

WMG Introduction

- Department at the University of Warwick
- Founded by Professor Lord Bhattacharyya in 1980
- Mix staff delivers academic rigour and industrial implementation
- Focused on Industry Impact from R&D and Skills
- Innovation and skills programmes to meet real business needs
- Strong relationships with >1000 companies – of all sizes
- UG, PG and Research degrees, short courses and work-based learning
- WMG are also a High Value Manufacturing Catapult Centre which is a collaborative environment for innovation- cross sector, cross technology and across the whole supply chain

WMG Configurable Capabilities

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Project Needs

Facility / Laboratory





Spectrum / Standard

- 5G Experience (100 MHz R14)
- 5G NSA (R15)
- 5G SA (R16)
- Beyond 5G (R17)
- FR1 sub 6GHz
- FR2 (mmWave) 24 – 53 GHz
- THz / Optical
- GPS / Galileo

Equipment / Instrumentation

- 5G SA Core / Slicing / MEC
- gNB / eNB / UE
- Signal, Spectrum Analysers
- Vector Signal Generators
- GNSS / Timing
- Antenna Arrays
- L4 CAVs / Robots / Energy Storage

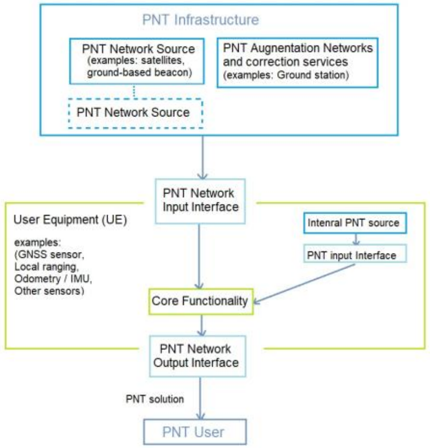
Additionality / Partnership

- IEEE 802.11 / IEEE 802.3 / TSN
- Cyber Security / HMG Links
- RF Metrology
- PNT / Quantum
- OEM / Operator
- Ofcom Licensed
- SME Accelerator
- Catapult Support

Plus an internationally renowned research team


Introduction to the Project

- Positioning Navigation and Timing (PNT) systems underpin many critical infrastructures, leveraging technologies such as Global Navigation Satellite Systems (GNSS), terrestrial networks, and alternative PNT solutions.
- Standards governing these systems play a pivotal role in ensuring availability, accuracy, reliability, resilience and security, but do not always provide a view on validation and hence trust in the methodologies of assuring PNT.
- This compared to the automotive domain where standardised testing procedures such as ISO 34503 (amongst others) exist for example.



Confidence Validation Framework (CVF)

bsi. *

UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE *

ASAM *

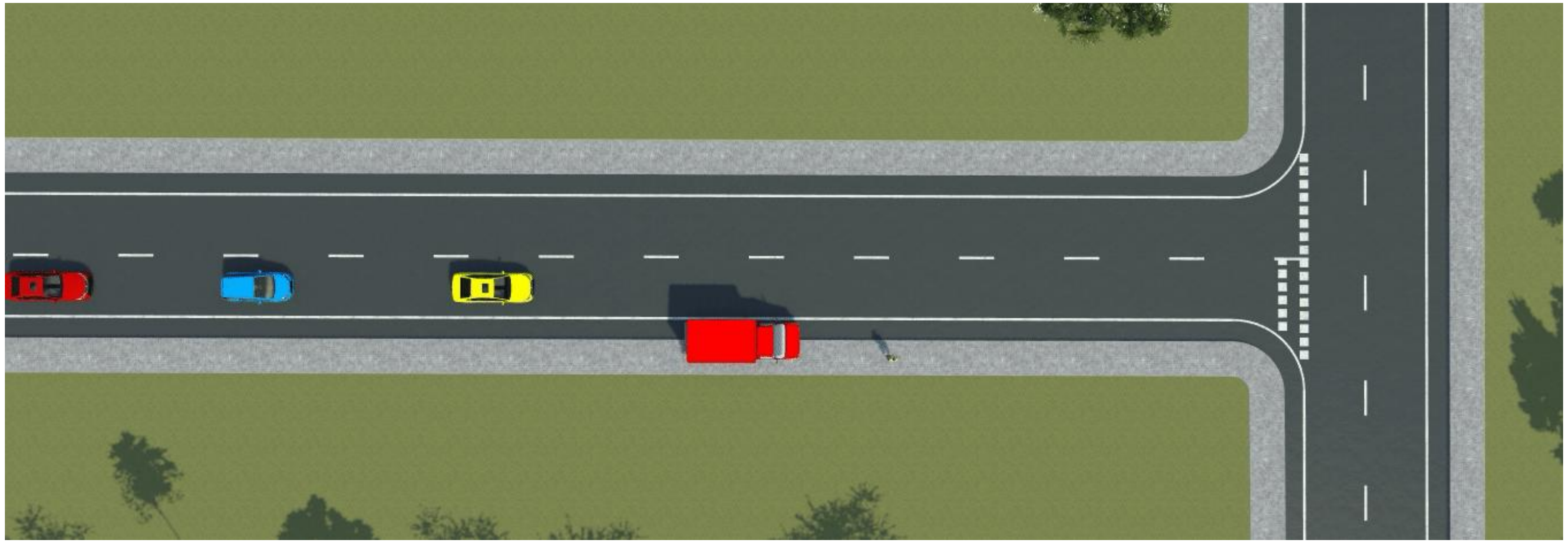
ISO *

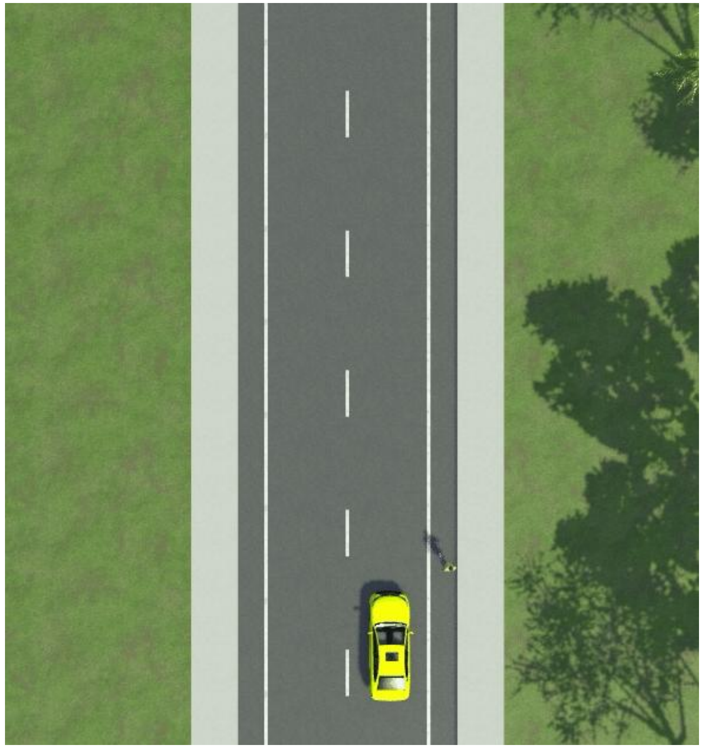
SAE INTERNATIONAL *

Law Commission Reforming the law

Scenarios of Interest

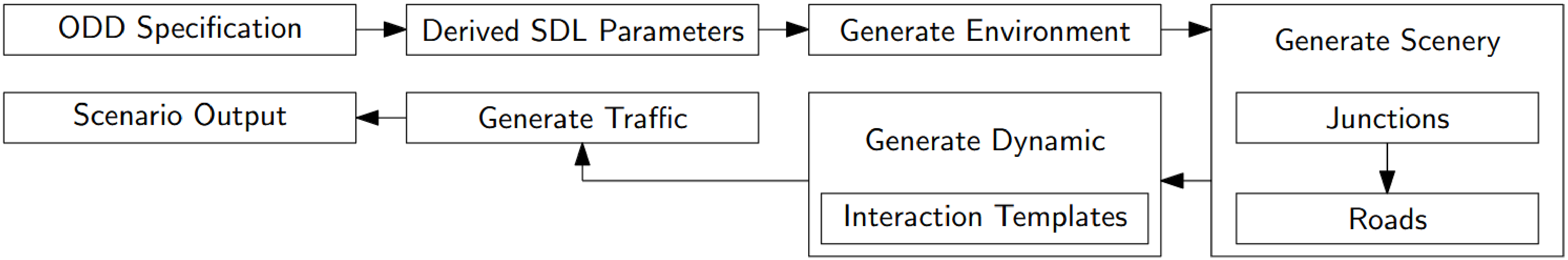
- Naturally, the wider deployment of CAV and uptake of PNT within the sensor fusion suite is quite broad, but this project has an initial focus on the potential interaction(s) between the vehicle and a Vulnerable Road User (VRU)
- Such exploitation of a PNT solution alongside the wider communication network can be coupled to enhance safety in line with 5GAA
- <u>Assuming we have trust in the system</u>





Translation of Scenarios

- The goal of the ODD & behaviour-based scenario generation is to generate scenarios based on a given ODD definition, together with the behaviour capabilities of the system.
- WMG have developed a robust toolchain that follows the below process to go from an ODD definition to the generation of scenarios within said systems capabilities.
- These toolchains have been deployed across a number of EU, IUK and Industrial projects in the autonomy and safety space.



WMG Safety Pool

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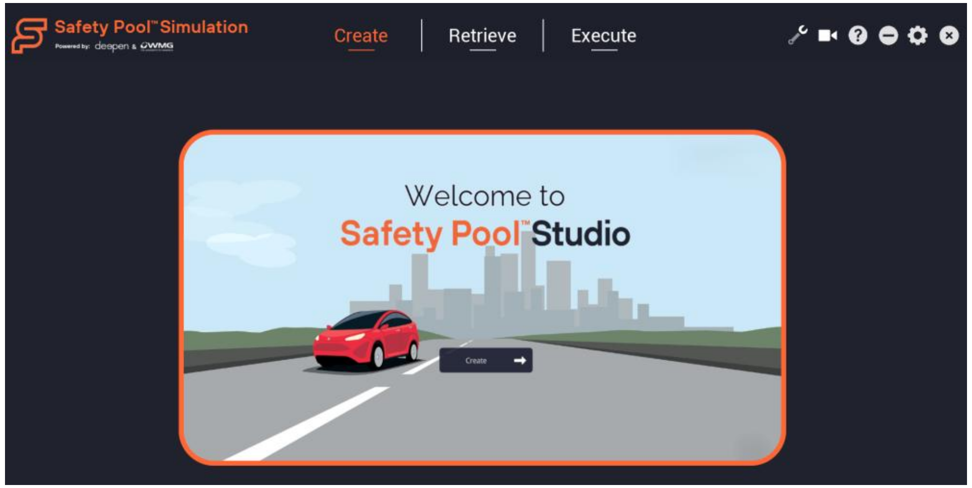
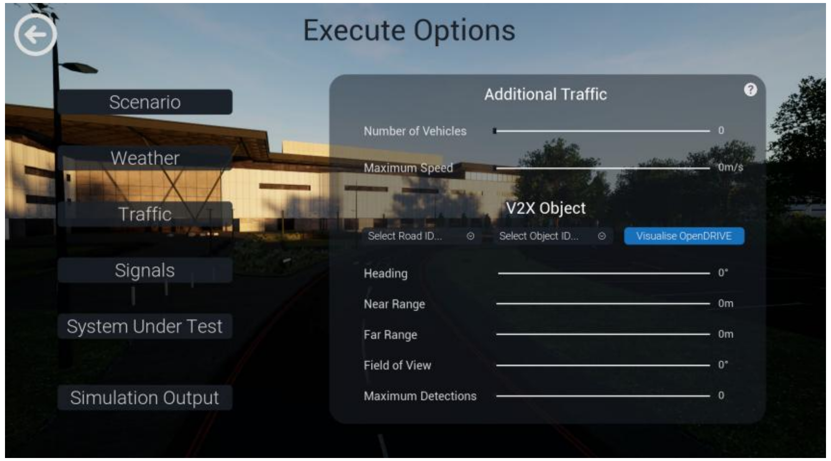
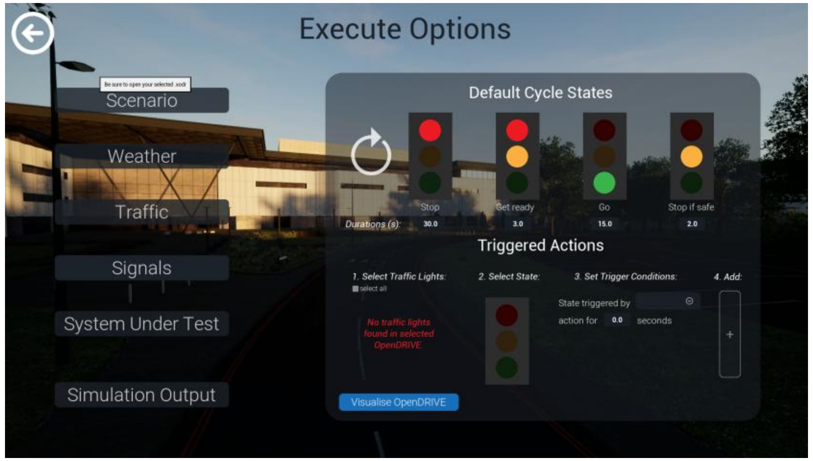
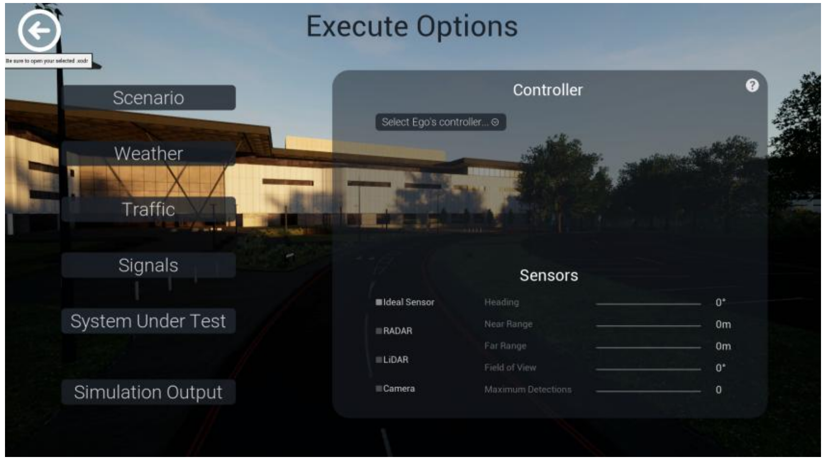
- Safety Pool™ mission is to unite stakeholders from industry, academia, and policymaking all around the world under a common ecosystem that bolsters transparent, certifiable safety for Automated Driving Systems.
- A database of curated driving scenarios shared across stakeholders and geographies.
- Scenarios are organized and tagged based on their specific Operational Design Domain (ODD) following the BSI PAS 1883 ODD Taxonomy and the ASAM Open ODD standard

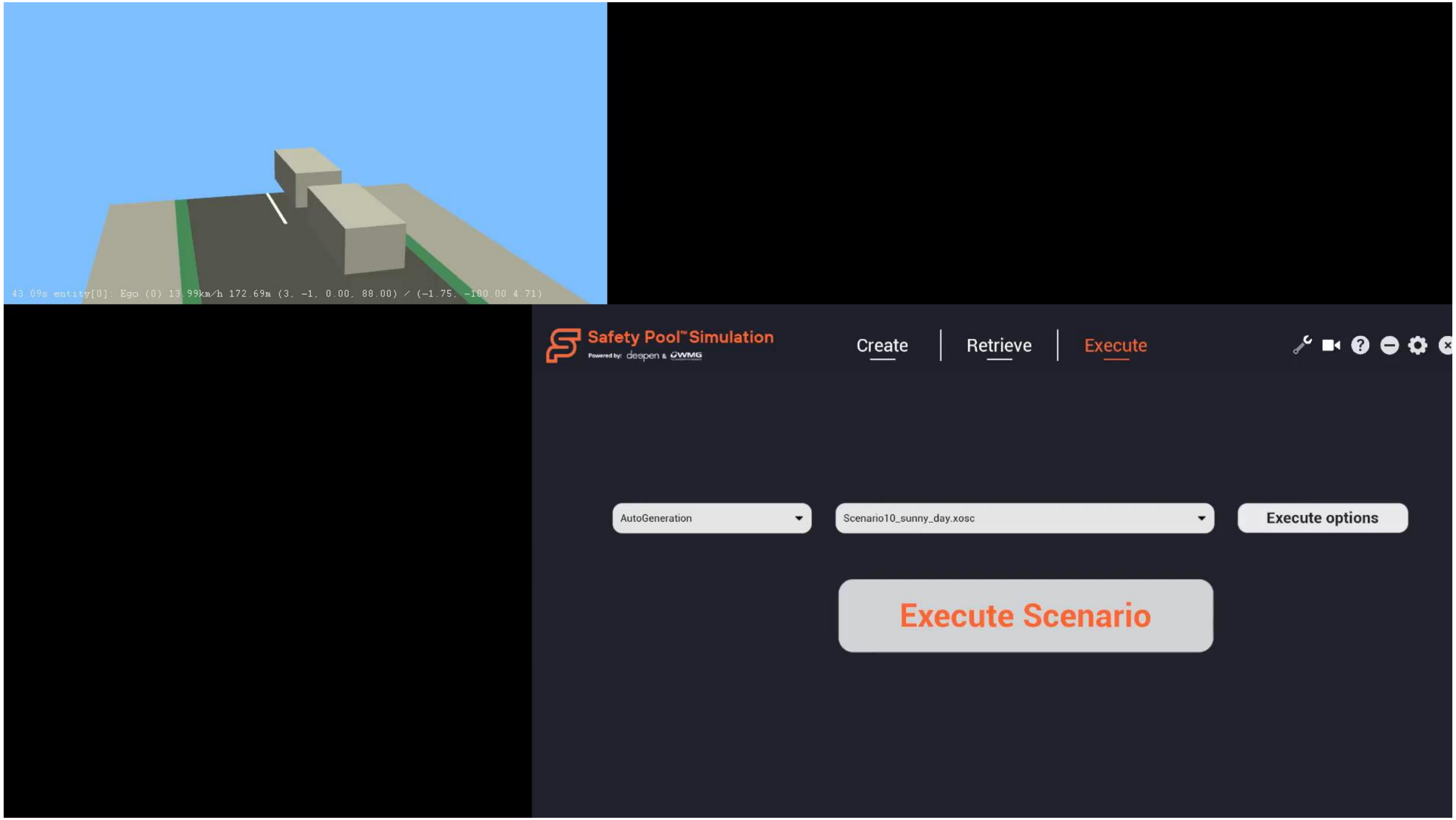








WMG Safety Pool

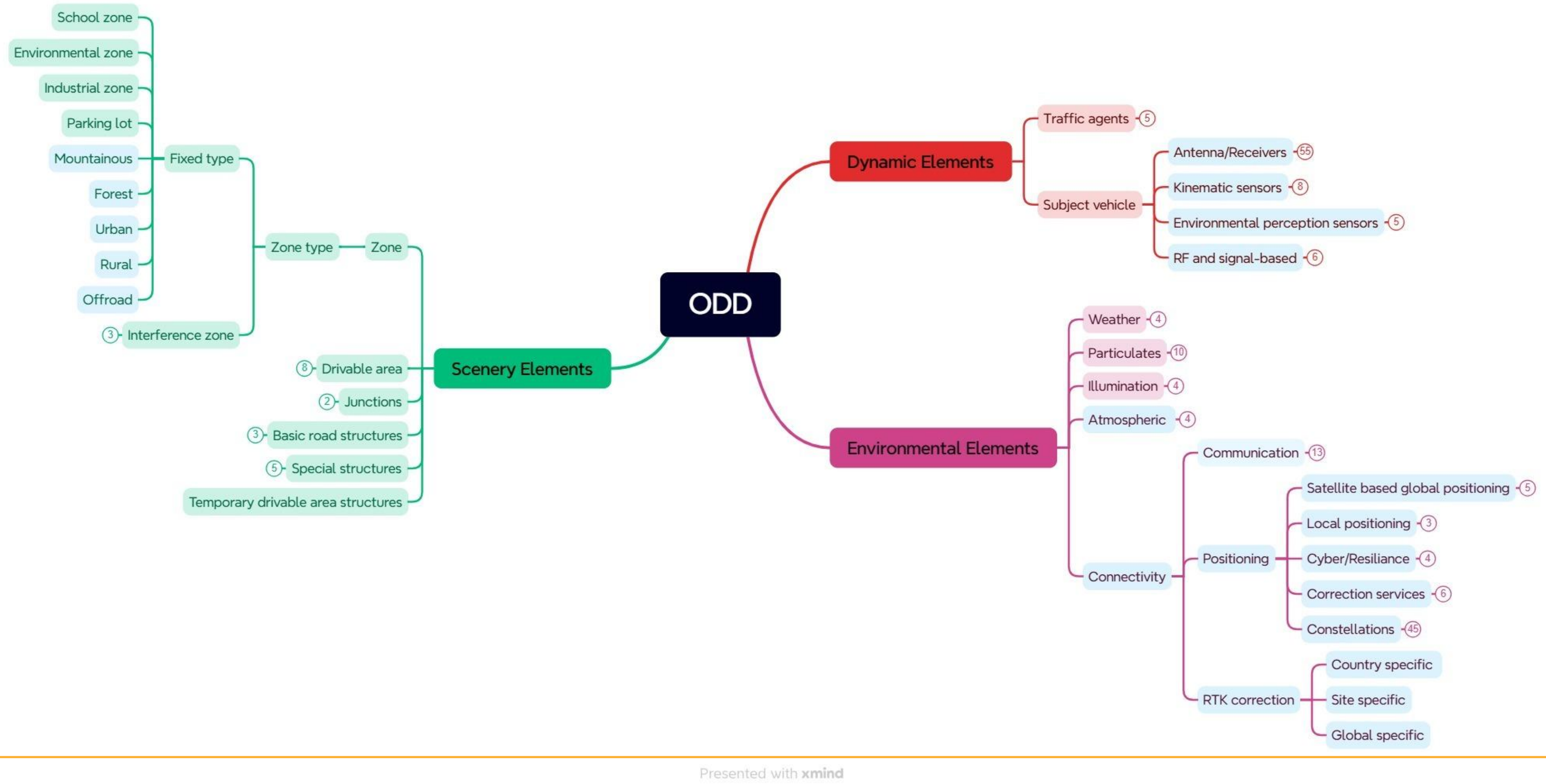


PNT Attributes and ODD

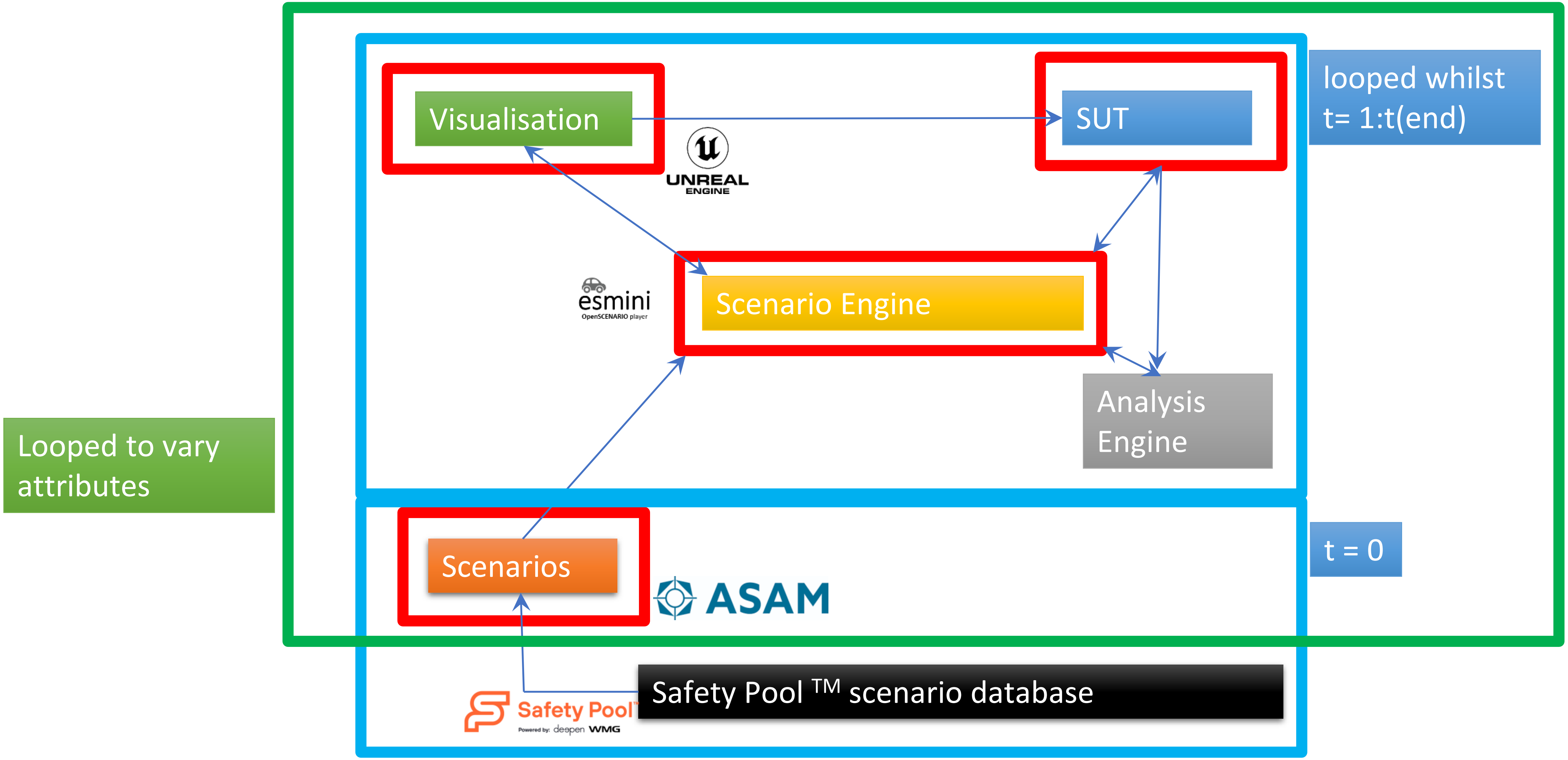
- A series of workshops were held to understand and develop the possible long list of attributes.
- Approximately 90 attributes of note were proposed, ranging from:
  - Constellation type and or bands of interest, i.e. GPS (L1,L2,:5) /Galileo (E1, E5a, E5b, E6) etc.
  - Correction Services, i.e. RTK, DGNSS, SBAS etc.
  - Receiver Capabilities, i.e. C/N0, SNR, CSD, DoP etc.
  - Antenna Characteristics, i.e. Patch, Helix, Polarisation, etc.
  - Atmospheric Phenomena,
  - Built Environment,
  - Cyber Resilience, i.e. under jamming, spoofing etc.
  - Alt. PNT capabilities, i.e. Inertial Sensors, RF-Based Sensors etc.

PNT Attributes and ODD

- The project is approaching a view on recommendations to the hierarchical structure of the attributes of ISO 34503, where the elements in blue are those either new to PNT



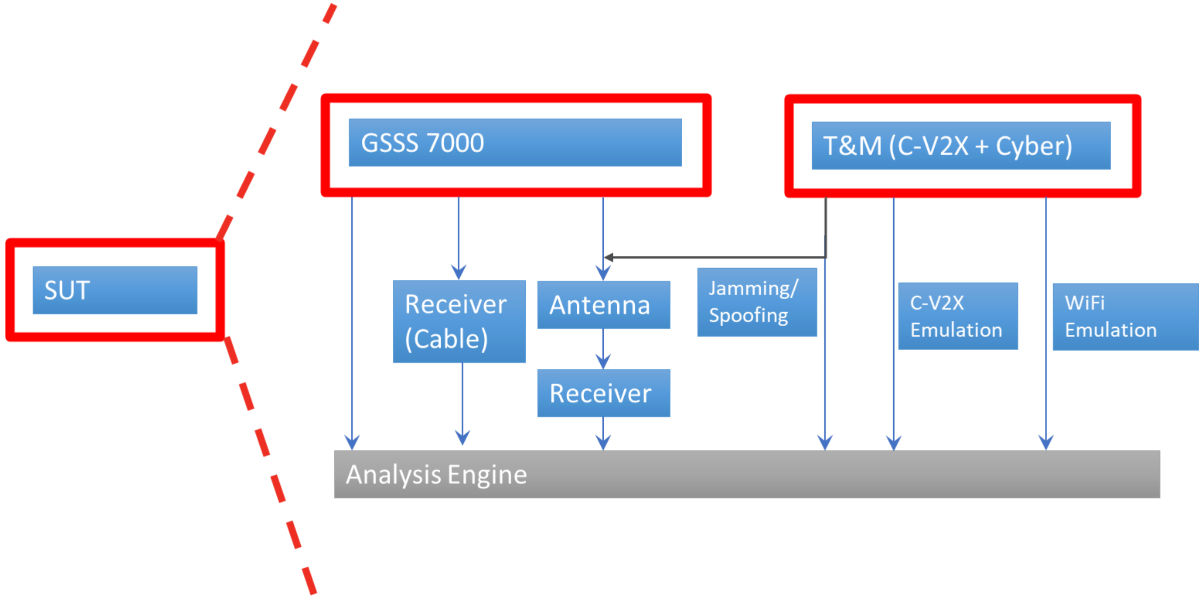
Loops Implementation



Loops Implementation

Laboratory Set Up: 1- Wired Setting

- The WMG scenario engine drives the Spirent GSS7000 with SIMGEN (and Sim3D where appropriate) to provide the cabled and OTA testing.

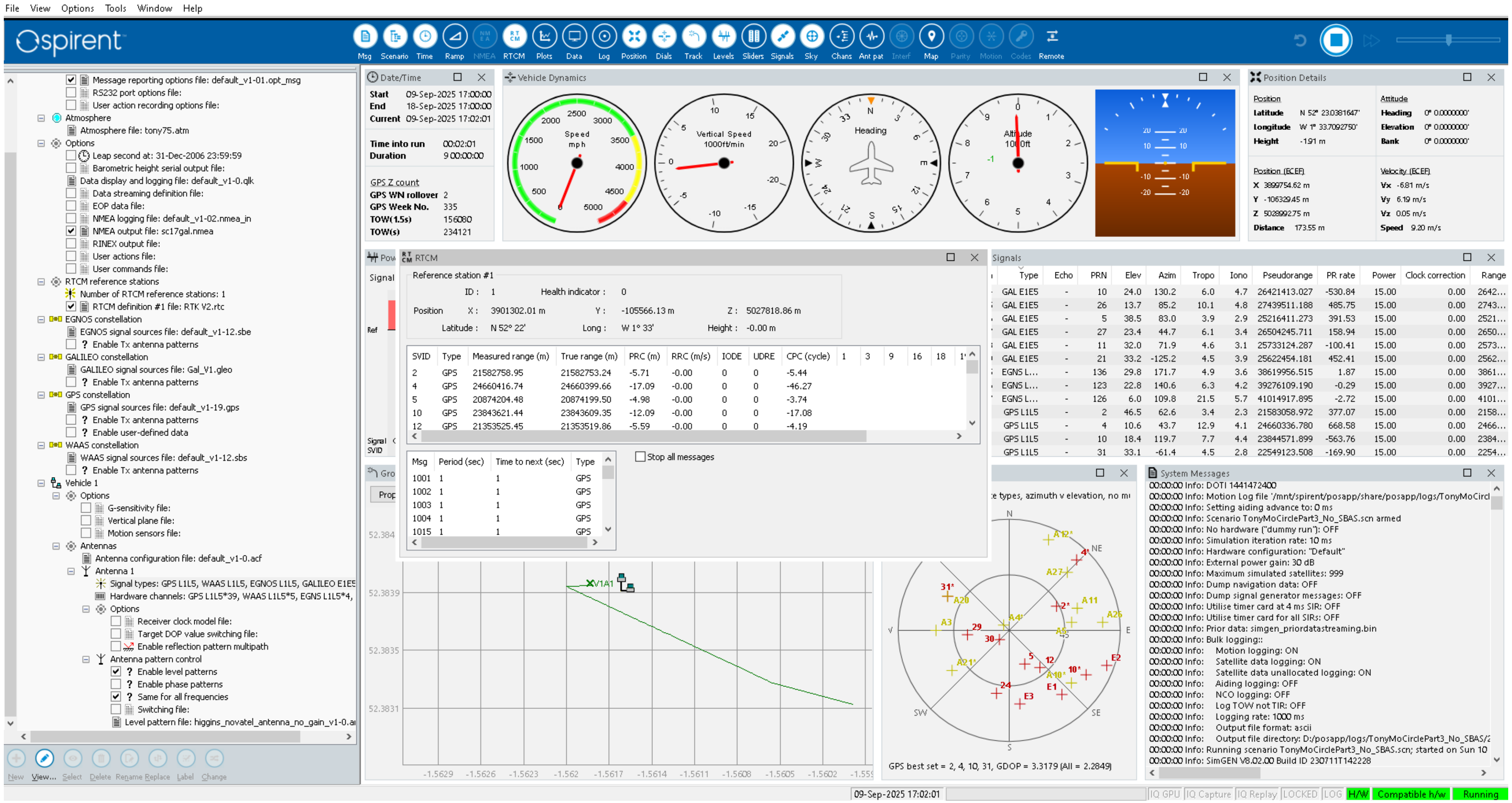


Loops Implementation

Laboratory Set Up: 2- Over the Air Setting

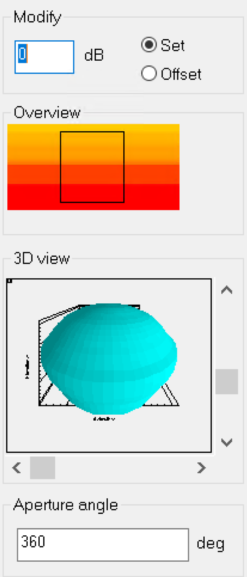
Loops Implementation

Spirent SimGen GNSS7000 configuration baseline time, location, constellation, satellite visibility, signal power levels

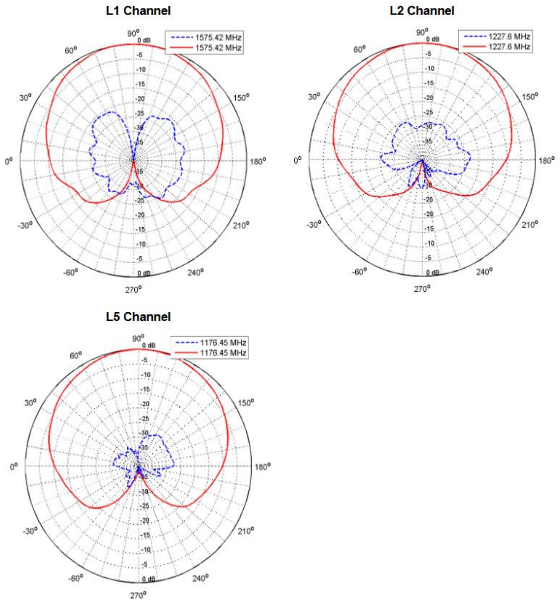


Loops Implementation

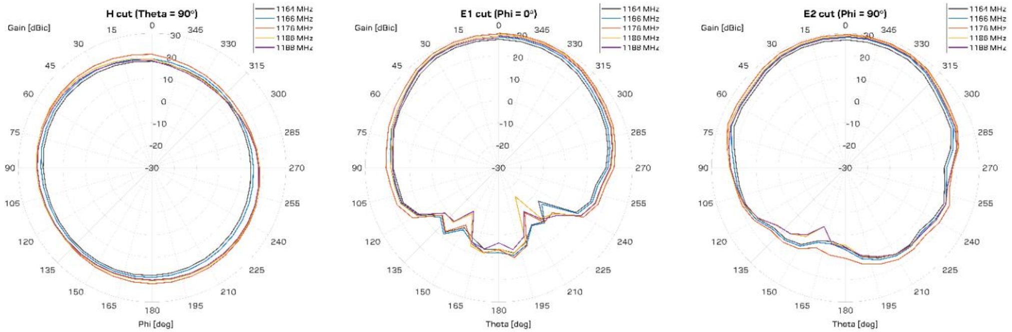
Antenna Profile for Wired Setting



	-67.50	-62.50	-57.50	-52.50	-47.50	-42.50	-37.50	-32.50	-27.50	-22.50	-17.50	-12.50	-7.50	-2.50	2.50	7.50
72.50	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.0
67.50	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.0
62.50	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.0
57.50	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.0
52.50	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.0
47.50	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.0
42.50	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.0
37.50	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.0
32.50	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.0
27.50	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.0
22.50	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.0
17.50	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.0
12.50	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.00	-7.0
7.50	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.0
2.50	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.0
-2.50	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.0
-7.50	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.0
-12.50	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.0
-17.50	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.0
-22.50	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.0
-27.50	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.00	-14.0



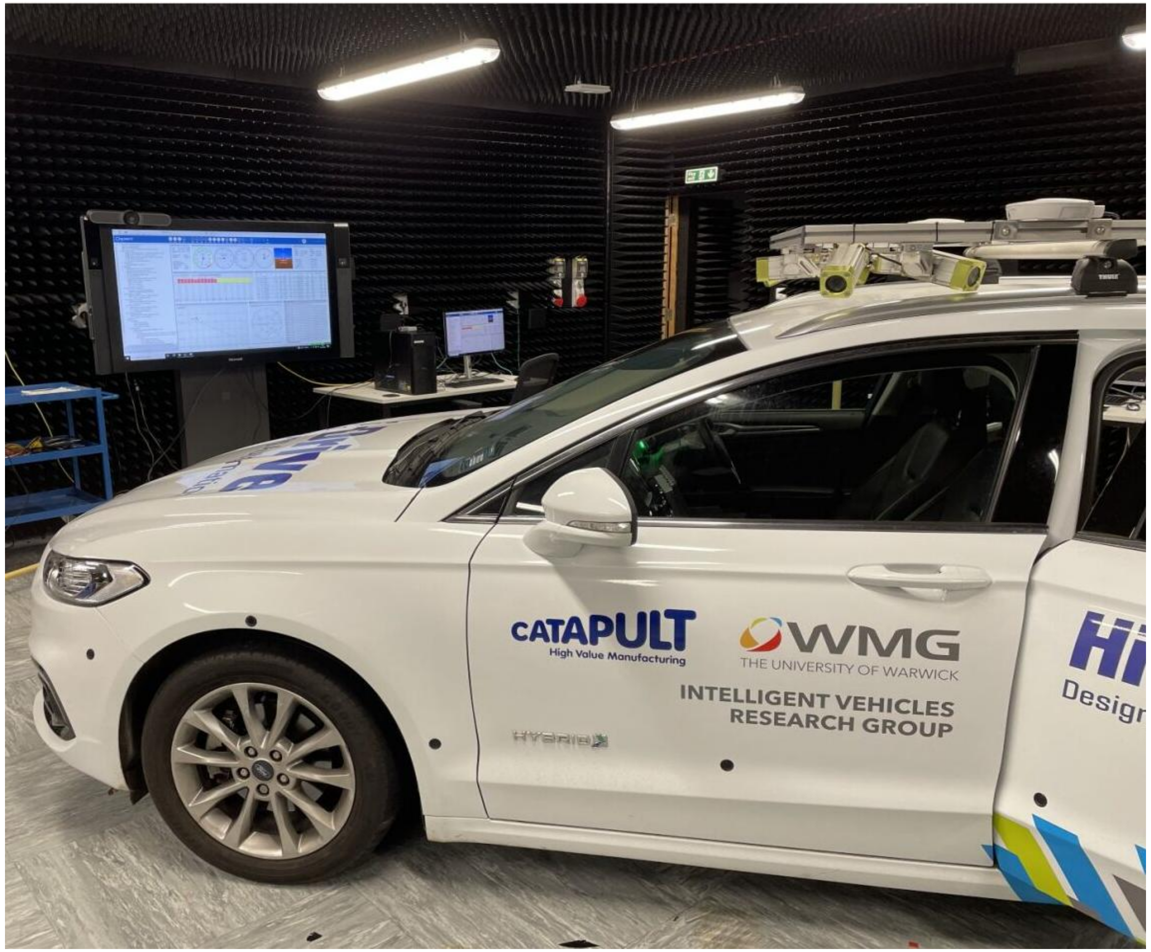
NovAtel GNSS-800 antenna profile



UBlox MB1 Antenna Profile for L1 band

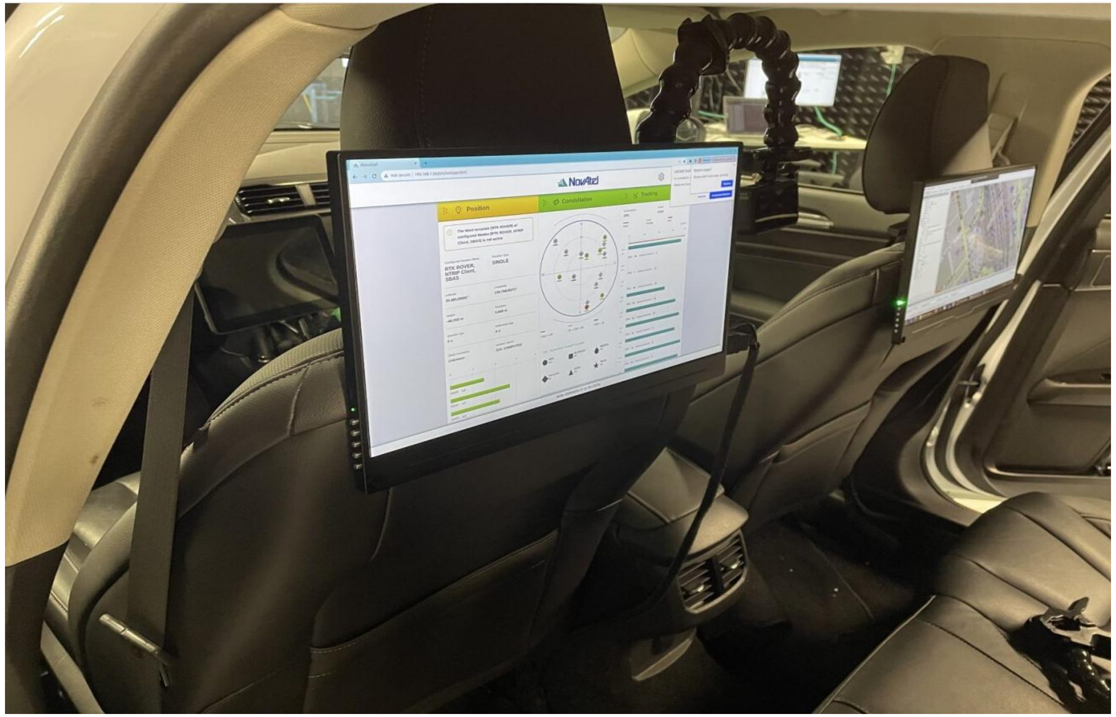
Loops Implementation

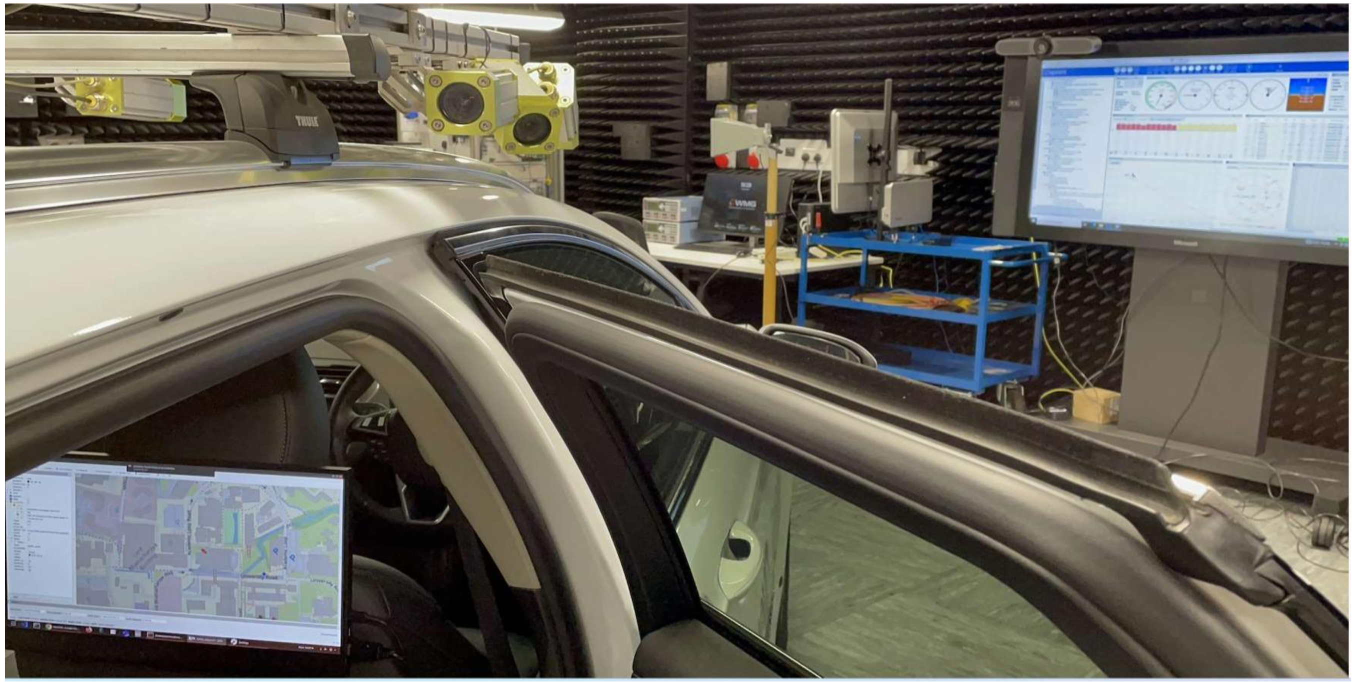
Over the Air Photo Demo



Loops Implementation

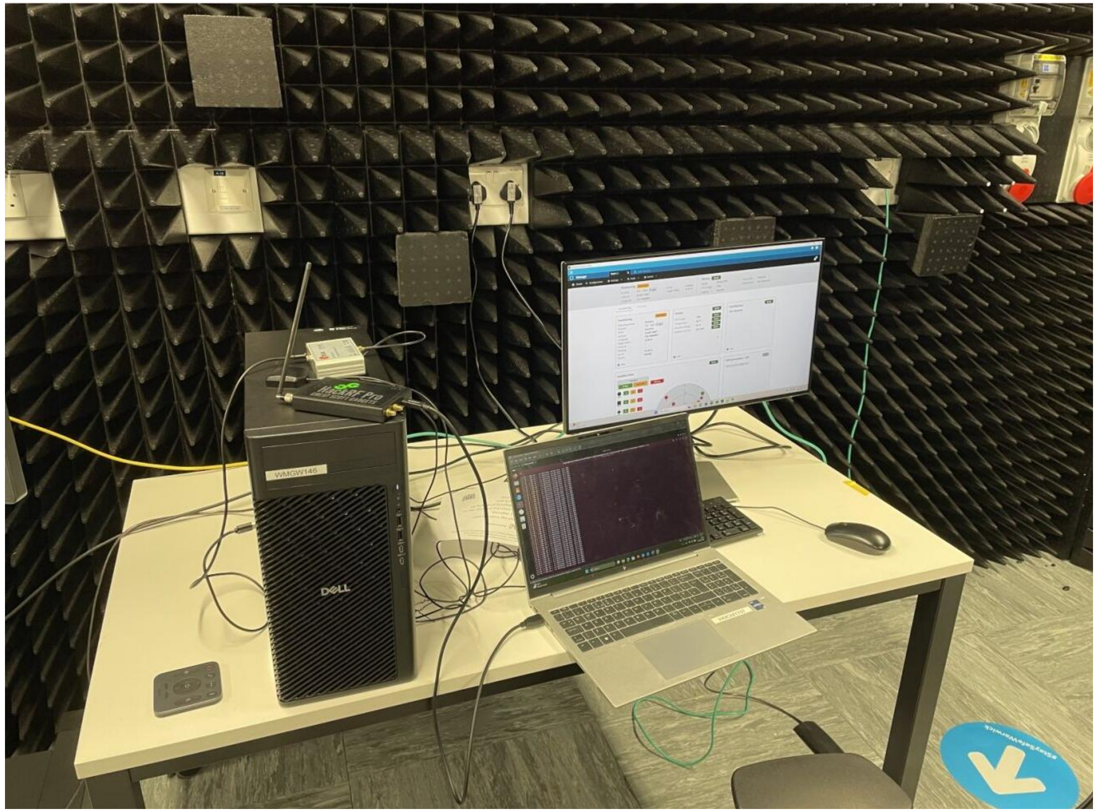
Over the Air Photo Demo

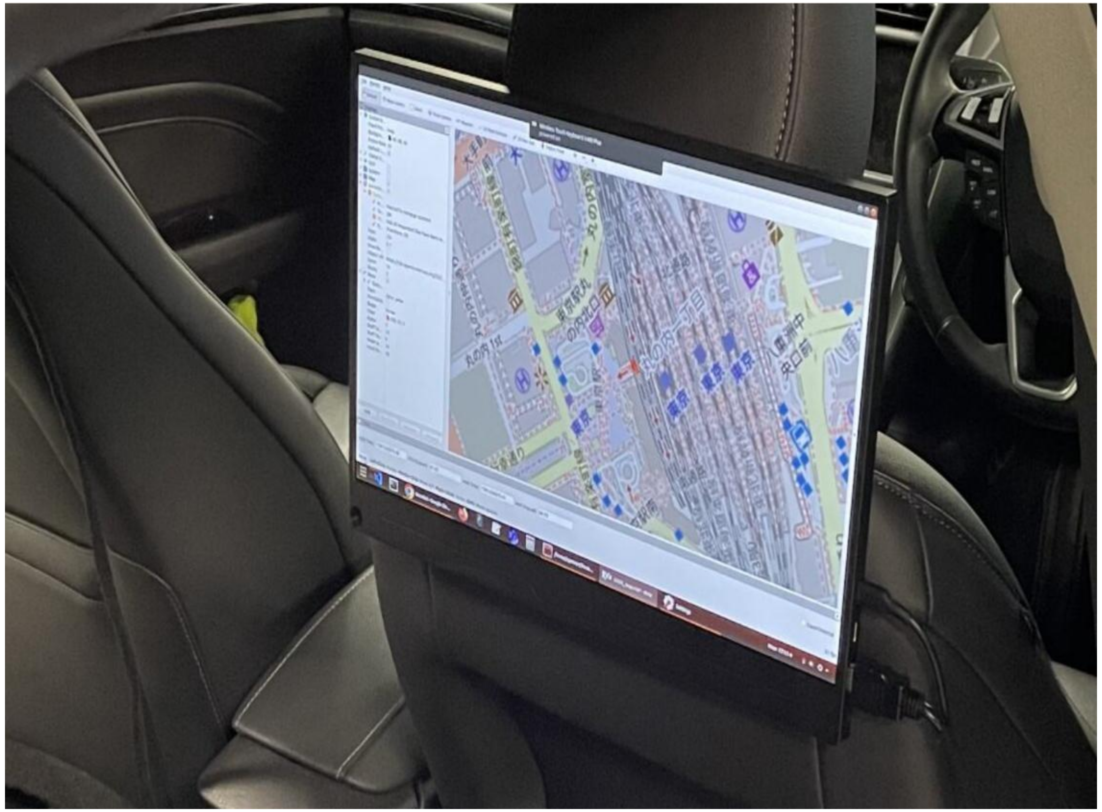




Loops Implementation

Over the Air Photo Demo (RF Stress Capability)





Loops Implementation

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Over the Air Photo Demo (RF Stress Capability)

Dimention	PoM scope	Role in the CVF workflow
Scenario context	Crossroad left-turn reference case, with selected comparative manoeuvre cases	Defines the operational context for interpreting PNT behaviour
Receiver family	u-blox M91 and NovAtel receiver cases	Tests whether the workflow can compare different receiver capability classes
Antenna configuration	U-blox patch antenna MB1 NovAtel antenna GNSS-800	Captures receive-chain configuration effects
Antenna orientation	Controlled orientation/elevation sweep	Tests sensitivity to receive-chain geometry
Correction-service configuration	Baseline, SBAS-enabled, RTK-enabled and SBAS+RTK-enabled states	Compares receiver behaviour under configured service states without validating the services themselves
Environmental/ Weather related parameters	Selected humidity and temperature variation runs	Showing that environmental parameters can be represented and tested within the workflow
Signal-delivery mode	Cabled baseline, with OTA/interference-path extension	Provides a controlled reference and a limited step towards RF-path/stress testing

The purpose was to demonstrate the CVF method and its capability to generate interpretable evidence within a controlled PoM scope.

Metrics of Interest: From Test to Evidence

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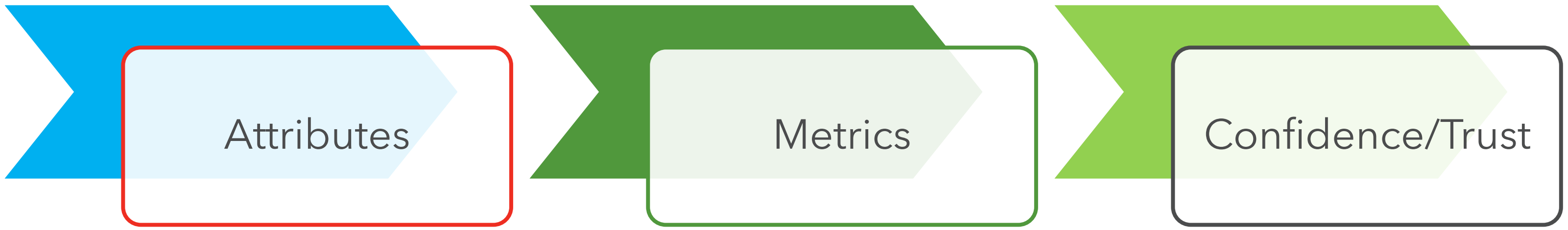
The CVF links **test conditions** to **measured behaviour** to support **confidence statements**



Metrics of Interest

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Nominal Performance

Accuracy
Precision
Latency

Service Behaviour

Availability
Continuity

Decision Level: Trustworthiness (Derived Assurance Outcome)

Not directly measured, derived from combined quadrant evidenced within the CVF

Risk & Detction

Integrity
Reliability

Behaviour under Stress

Robustness
Resilience

How to interoperate the Results Slides

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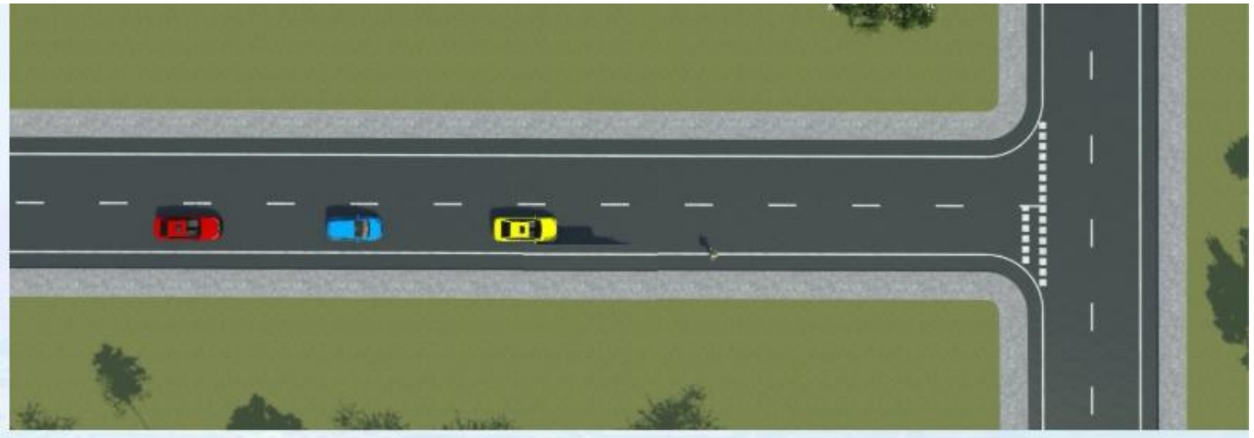
The selected results are interpreted using metric classes rather than a single performance number.

Evidence shown in results	**Metric role in CVF**
2D / 3D RMS and p95 position error	Nominal performance: accuracy and upper-tail error
3D step p68 / p95 or ENU step behaviour	Nominal performance: precision / short-term stability
Valid-fix rate and valid epochs	Service behaviour: availability of usable solution
HDOP, satellites used and C/N_0	Supporting diagnostics for interpretation
OTA / interference-path observations	Behaviour under stress / future CVF extension

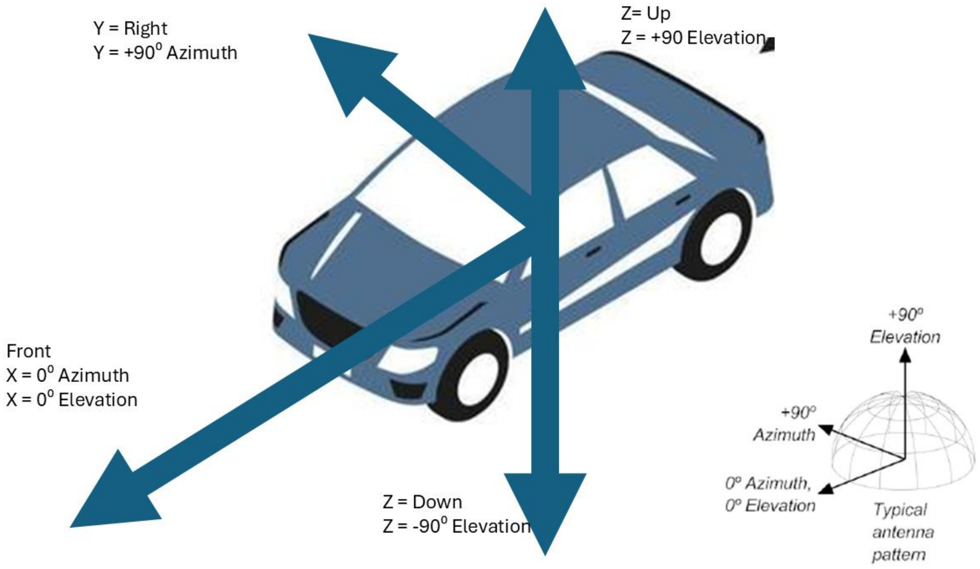
Reference Test Case for Selected Results (1)

- **Attribute under test:** antenna elevation sweep (u-blox_M91 with u-blox MB1 Patch Antenna)
- **Scenario:** T Junction manoeuvre (ground truth referenced ENU errors)

- In this PoM, the 0°–180° sweep represents a controlled antenna-orientation condition in the vehicle/test frame. It is not the received satellite elevation angle which can only be between 0 to 90 degrees.

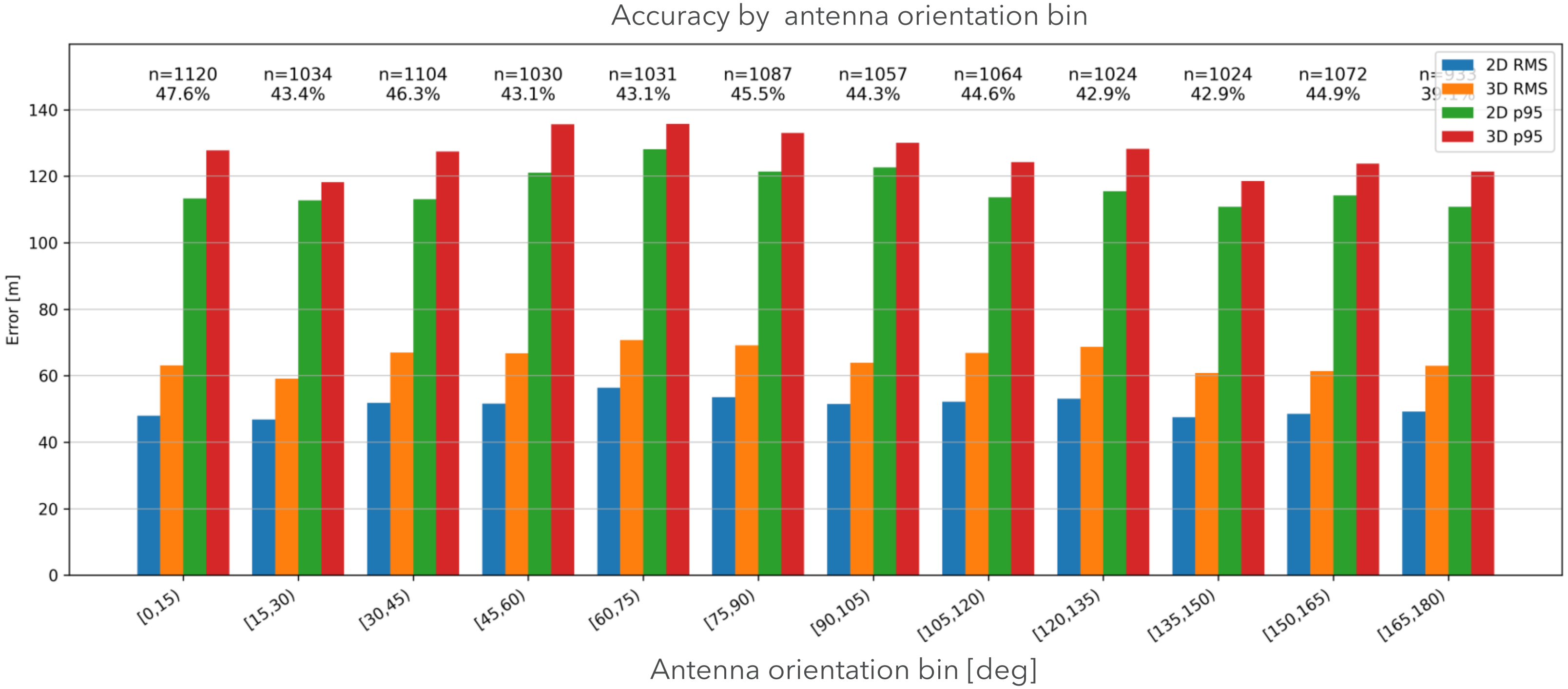


Scenario under test (T Junction, Vehicle turning right)

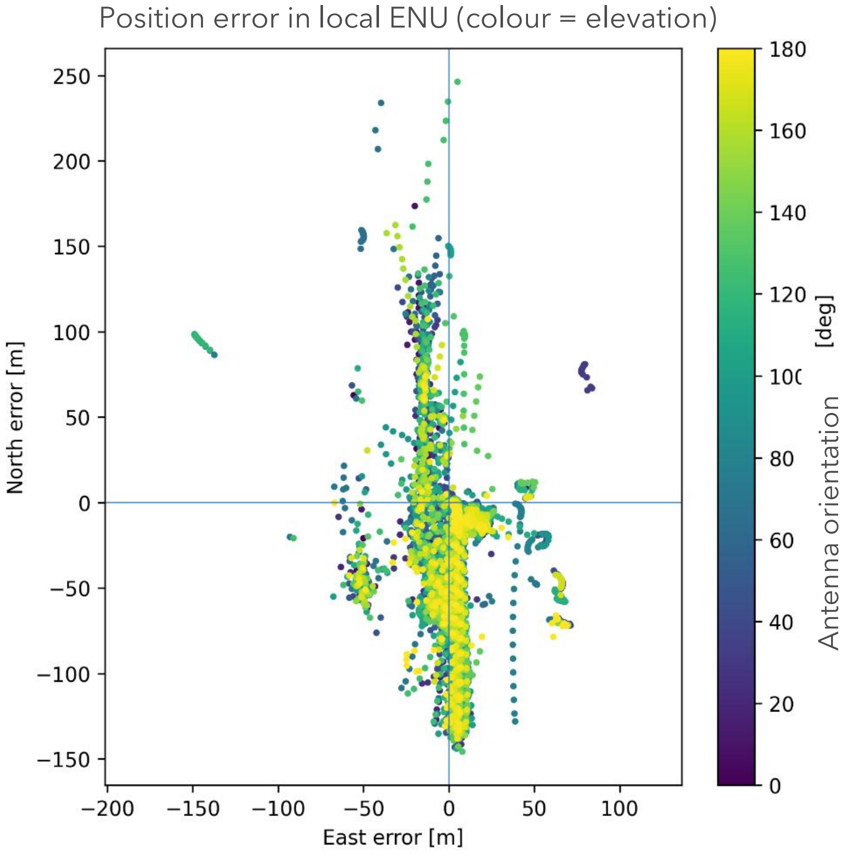


Results 1: Orientation Dependent PNT Behaviour

- **Accuracy vs antenna elevation (valid fixes only): RMS and 95th percentile error**



Accuracy by antenna orientation bin showing 2D RMS, 3D RMS, 2D p95, and 3D p95. The annotations above each bin indicate the number and percentage of valid epochs contributing to the reported metrics.



Position Error (Accuracy) of a u-blox M91 under varying antenna orientation

Results 1: Orientation-Dependent PNT Behaviour

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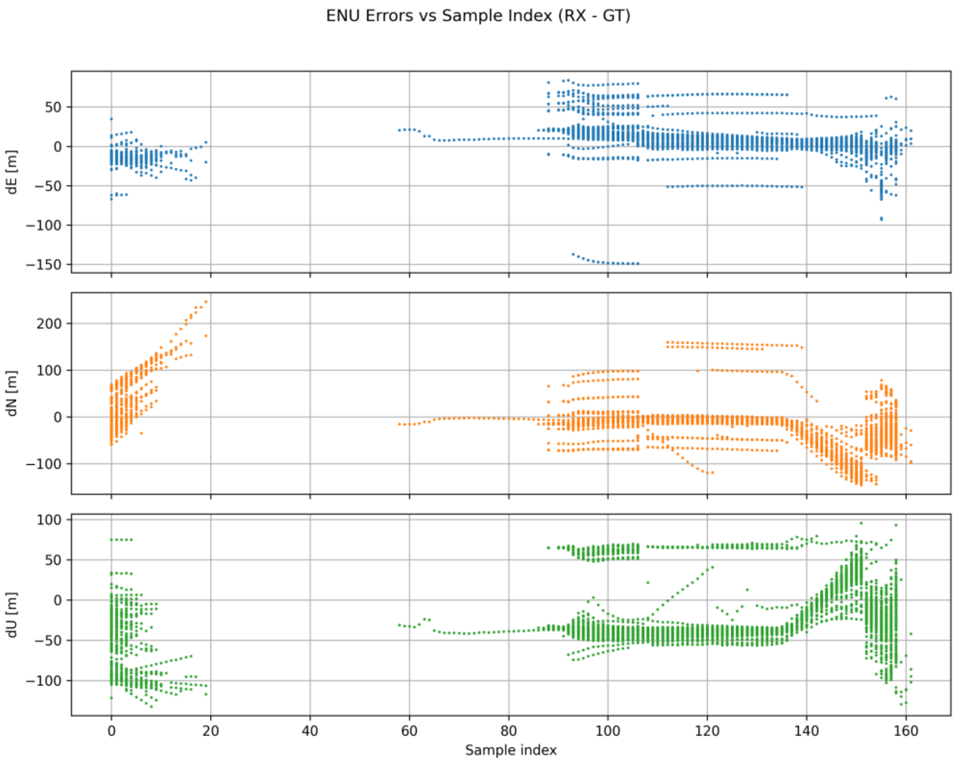
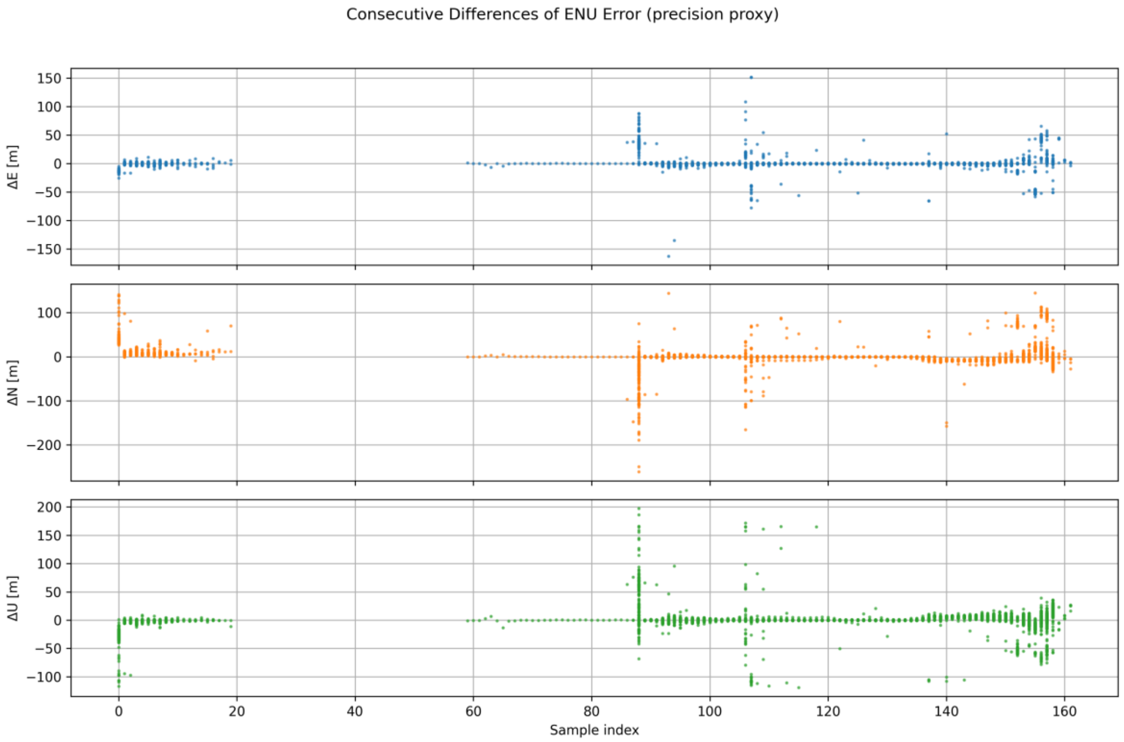
Accuracy (ENU residuals vs time index)



Position Errors of a u-blox M91 referenced against the time index of the scenario.

Precision proxy (consecutive ENU differences)



Precision of the u-blox M91 referenced against time index of the scenario.

Results 1: Orientation-Dependent PNT Behaviour

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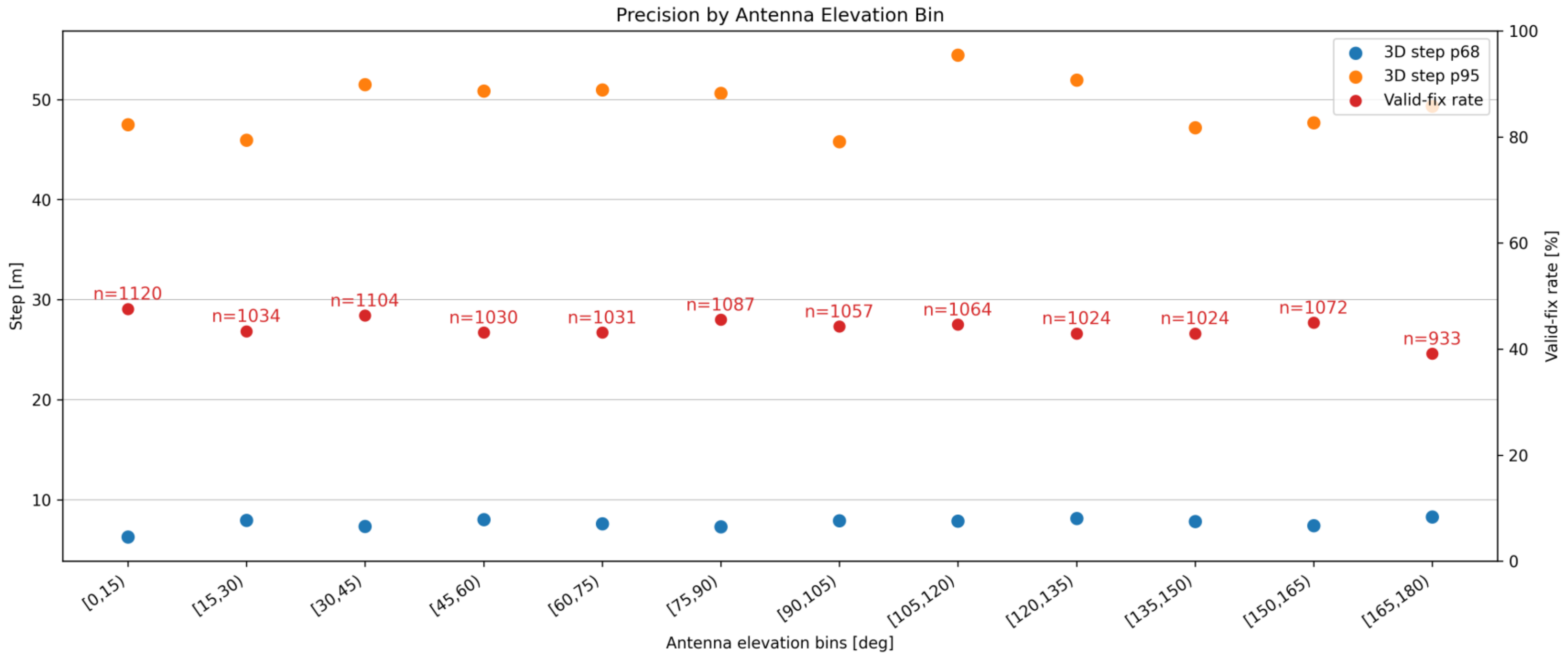
Precision vs orientation :3D step p68/p95 with valid fix rate (availability)



Precision by antenna orientation bin showing 3D step p68, 3D step p95 and the number of valid epochs contributing to the reported metrics.

Reference Test Case for Selected Results (2)

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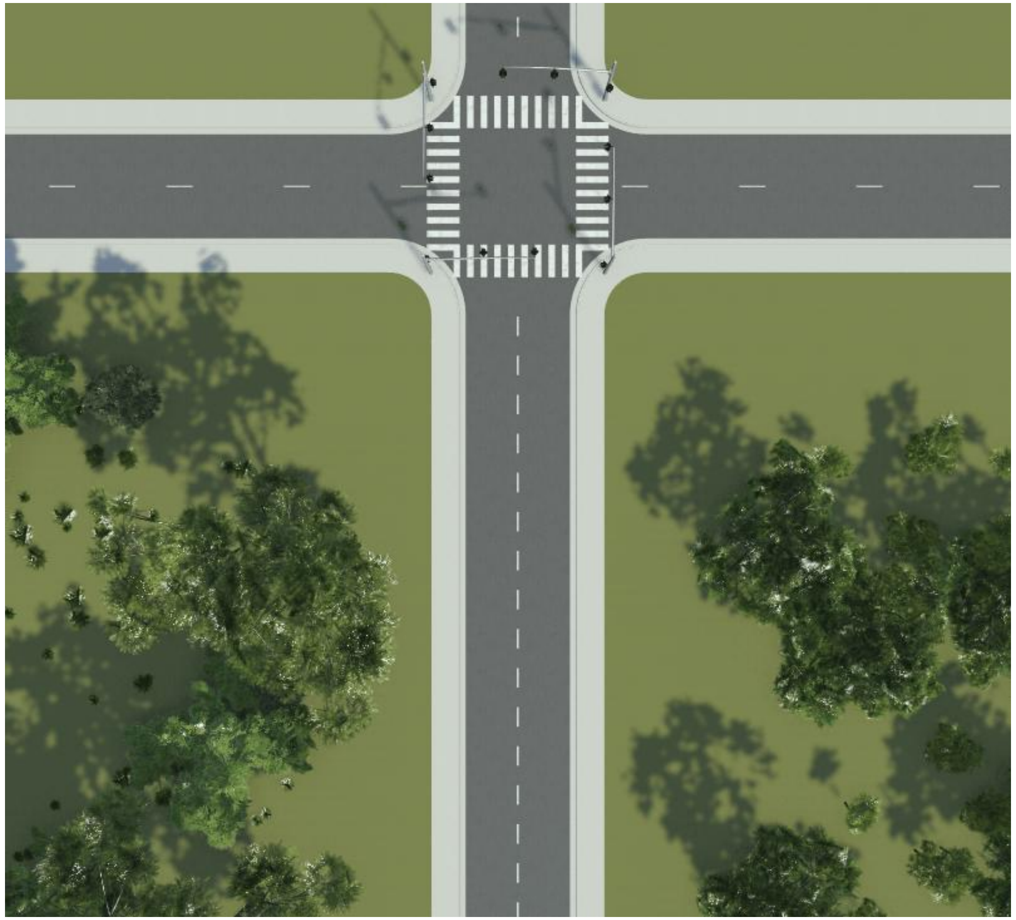
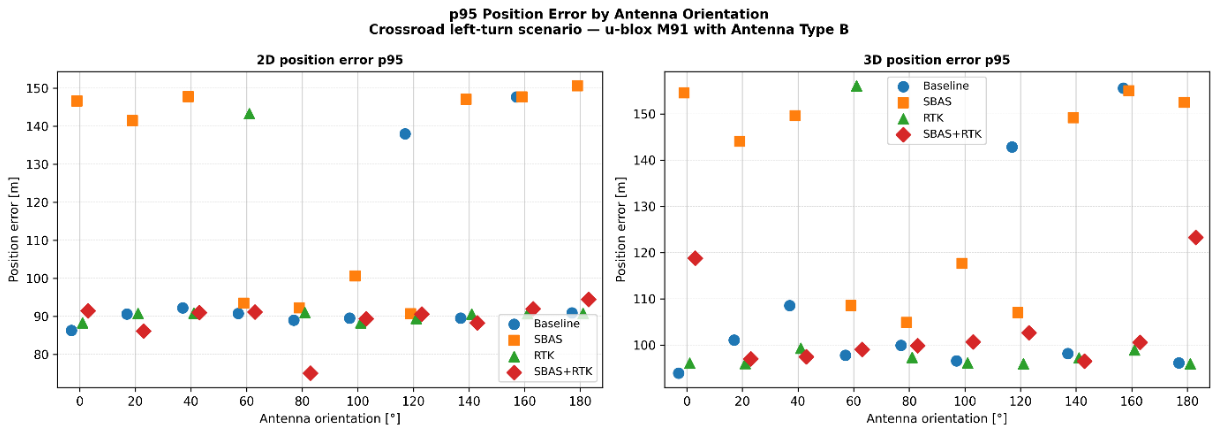
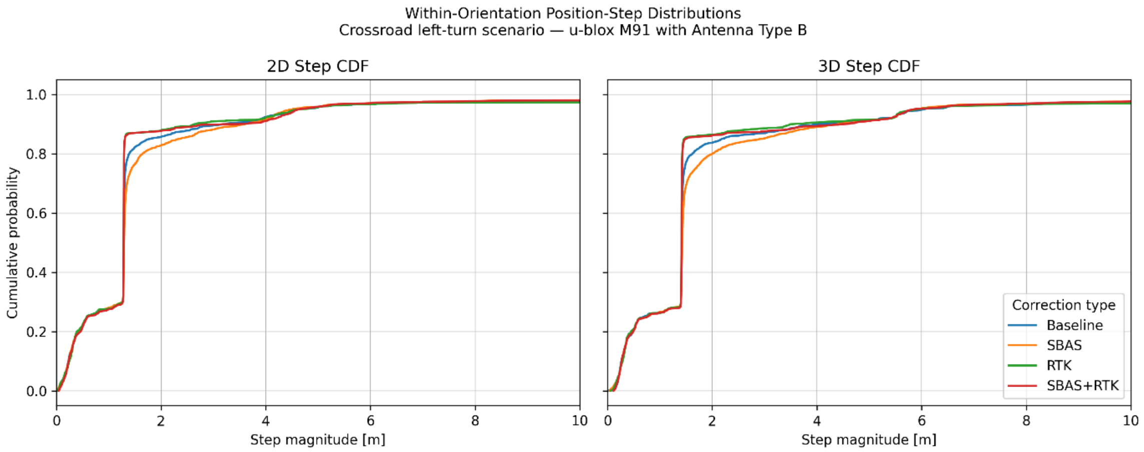


- Scenario: crossroad left turn with two pedestrians.
- Receiver / Antenna: u-blox M91 with a Novatel antenna
- Antenna orientation sweep with configured service states: baseline, SBAS-enabled, RTK-enabled and SBAS+RTK-enabled

Results 2: u-blox M91 receiver with NovAtel antenna



Orientation-binned 2D/3D p95 position error

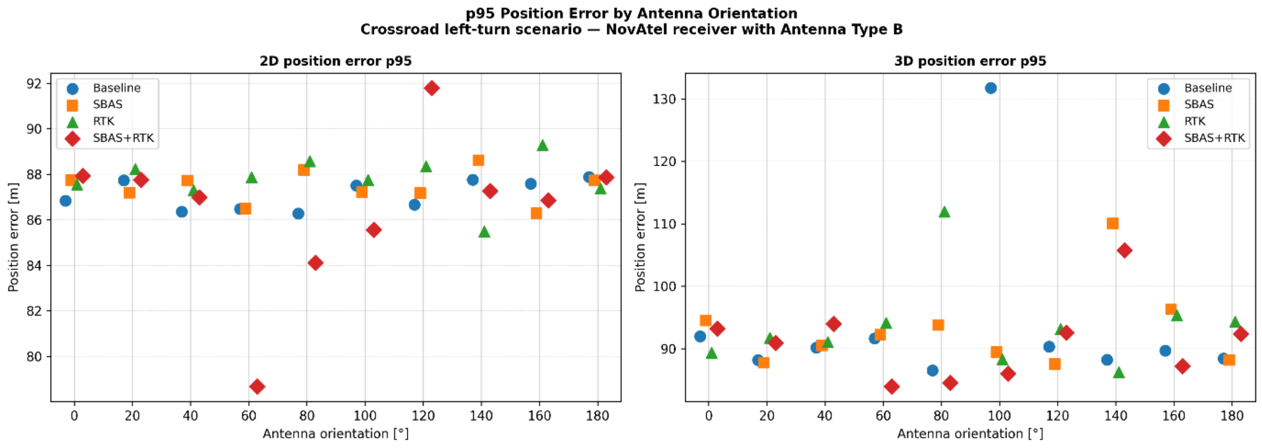


Empirical CDFs of 2D and 3D within-orientation step magnitudes

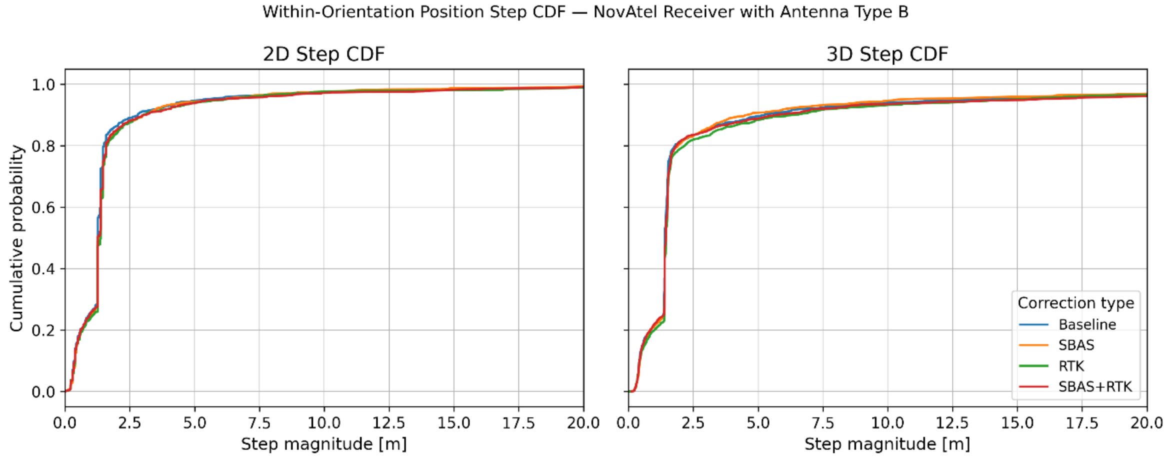
- The orientation-binned accuracy and step-stability results show that realised PNT behaviour cannot be represented by a single nominal accuracy value. Different configurations affect error tails and short-term stability differently, supporting the CVF need for multi-metric interpretation.

- PoM implication: confidence evidence should combine accuracy, tail behaviour and stability metrics within the tested configuration context.

Results 2: NovAtel receiver with NovAtel antenna



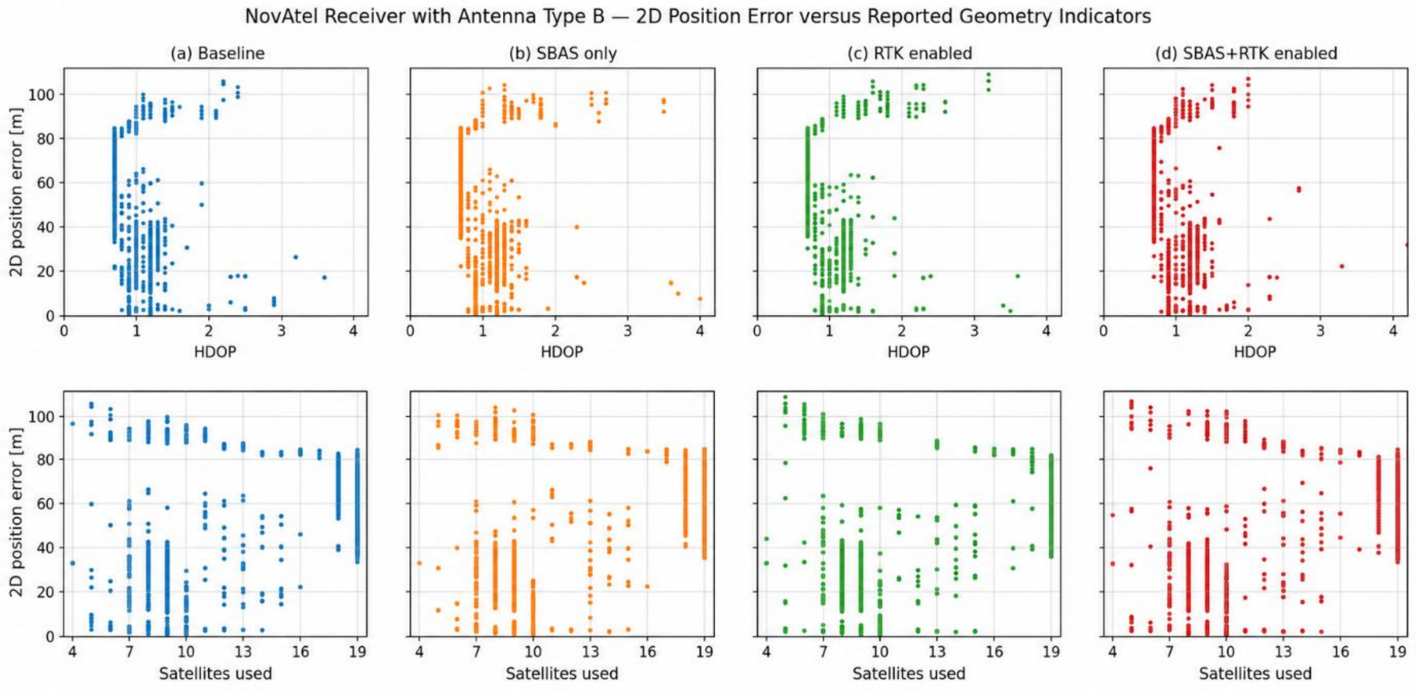
Orientation-binned 2D/3D p95 position error



Empirical CDFs of 2D and 3D within-orientation step magnitudes

- The NovAtel case provides a second receiver configuration under the PoM workflow. Comparing this behaviour with the u-blox M91 case shows why confidence evidence should be configuration-specific and not assumed transferable between receiver setups.
- PoM implication: the CVF can apply the same scenario, attribute and metric structure across receiver configurations.

Results 2: NovAtel receiver with NovAtel antenna



- The plot shows that large 2D errors can still occur under apparently acceptable HDOP and satellite-count conditions. Therefore, they are useful supporting diagnostics, but not sufficient on their own for confidence assessment.
- CVF implication: diagnostics should support the evidence chain; confidence interpretation still needs a combination of the identified metrics.

What the PoM Demonstrated

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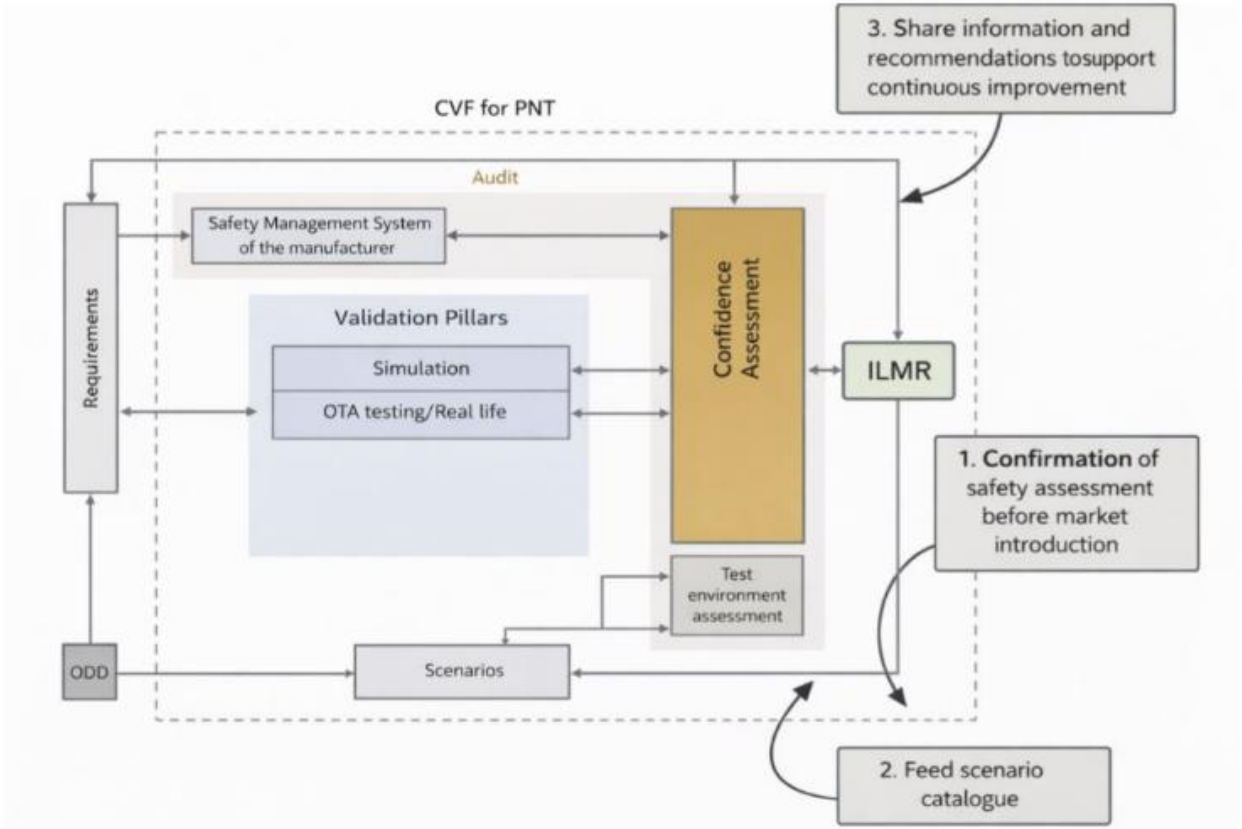
- 1- Scenario-to-signal workflow
  Scenario execution was connected to GNSS stimulation, receiver logging and post-processing.
- 2- Repeatable OTA E2E execution
  The workflow was extended from the cabled baseline to OTA while preserving run control, time alignment and comparable outputs.
- 3- Controlled attribute variation
  Selected PNT attributes and configurations were varied in a structured and repeatable way.
- 4- Ground-truth-based metrics
  Receiver outputs were compared with ground truth and interpreted through accuracy, stability, availability and diagnostic metrics.
- 5- Future extension pathway
  The same workflow provides a basis for wider RF-stress testing, richer observables, broader PNT attributes/architectures and ILMR.

In-Life Monitoring and Reporting (ILMR)

Future extension from controlled evidence to operational monitoring

- ILMR extends the CVF logic beyond initial testing by considering how confidence in PNT behaviour can be monitored during operational life.



Project Recommendations

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The PoM supports taking the CVF forward as a scenario-based evidence-generation method for PNT confidence assessment.

Recommendation theme	Project recommendation
Scenario-based validation	Extend CVF testing across wider ODDs, manoeuvres, additional PNT attributes and RF environments
Metrics and observables	Use combined metrics: accuracy, precision/stability, availability, diagnostics and stress-response indicators
Standards engagement	Use the CVF evidence chain to inform BSI, SAE, ISO, ASAM and ETSI discussions on PNT validation
Threshold development	Treat thresholds as ODD- and automation-level conditioned
In-life monitoring	Develop ILMR approaches so that confidence evidence can be monitored beyond initial testing
Future PoM expansion	Increase PNT attributes coverage such as GNSS alternative , LEO constellations, receiver diversity, environmental coverage, RF stress cases and logging of receiver-state observables

Conclusion and key Messages

The project delivered a scenario-based CVF for PNT that links operational context, controlled testing, metrics and confidence interpretation.

- The project addresses the need for confidence in realised PNT behaviour, not only the availability of a position or timing output.
- The CVF provides a traceable route from operational context and ODD to PNT attributes, controlled testing, metrics and confidence interpretation.
- The PoM demonstrated a practical and repeatable evidence-generation workflow, including OTA E2E execution within the tested scope; it does not constitute universal validation or deployment certification.
- The project outputs provide a basis for future standards engagement, wider empirical testing and deployment-context-dependent in-life monitoring.

Thank you.

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