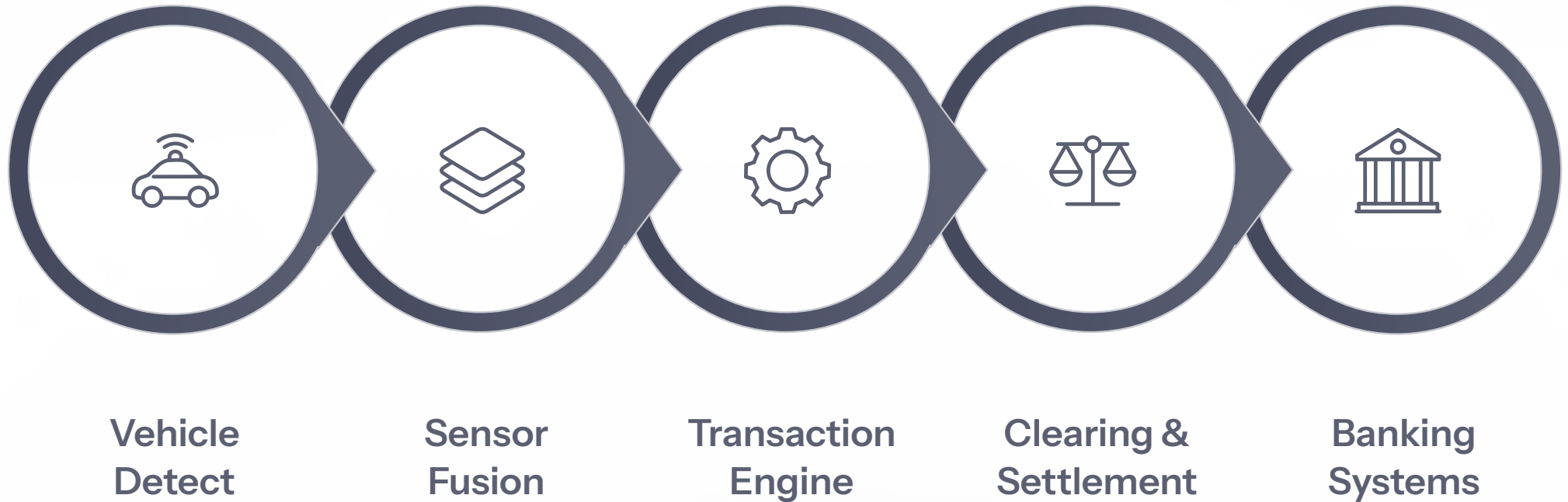




RITAIS MLFF: Multi-Lane Free-Flow Tolling Architecture

A deep-dive into sensor fusion, LiDAR technology, 4D radar, and intelligent tolling infrastructure

Understand the System in 30 Seconds



From vehicle detection to payment settlement — all at highway speed, with zero stopping required.



What is Multi-Lane Free-Flow Tolling?

No Barriers

Vehicles pass at full highway speed – no toll plazas

All Lanes

Every lane tolled simultaneously under a single gantry

Multi-Modal

Cars, trucks, motorcycles – every vehicle class

Automated

AI-driven transaction without human intervention

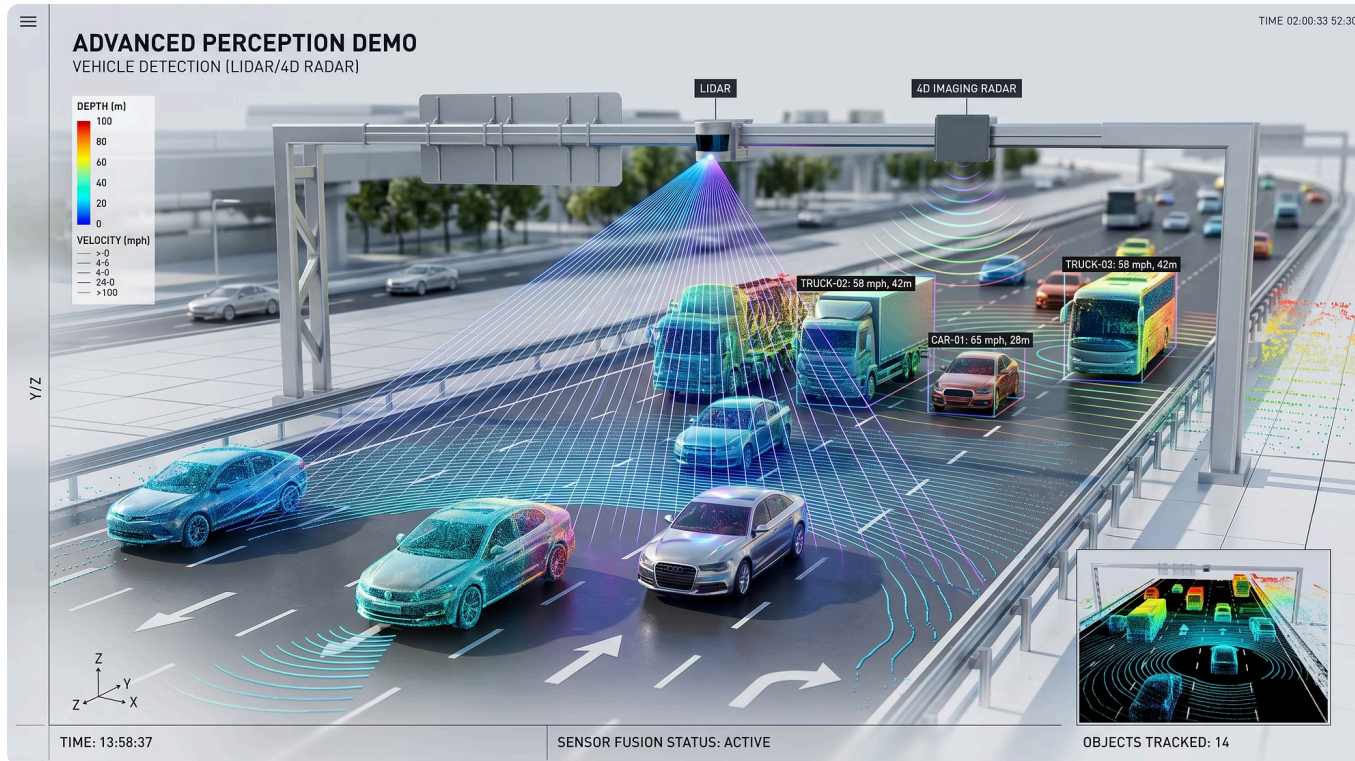
MLFF Sensor Suite on the Gantry



Four Sensing Technologies

- **RFID Reader**
Reads transponder at >200 km/h
- **ANPR Camera**
License plate capture, all lanes
- **4D Radar**
Position, velocity, height tracking
- **LiDAR**
3D point cloud, vehicle geometry

How LiDAR Works



Light Detection and Ranging

LiDAR fires **pulsed laser beams** across the scan zone. Timing the return of each pulse (Time-of-Flight) yields precise 3D coordinates for every reflection point.

Pulse Rate

Up to 1.2 million points/sec

Accuracy

± 2 cm range precision

Output

X, Y, Z + intensity per point

LiDAR Point Cloud — What the System Sees

Vehicle Separation

Distinguishes truck + trailer from passenger car from motorcycle — even in convoy

Height Mapping

Measures vehicle height to ± 3 cm — determines toll class without driver input

Axle Estimation

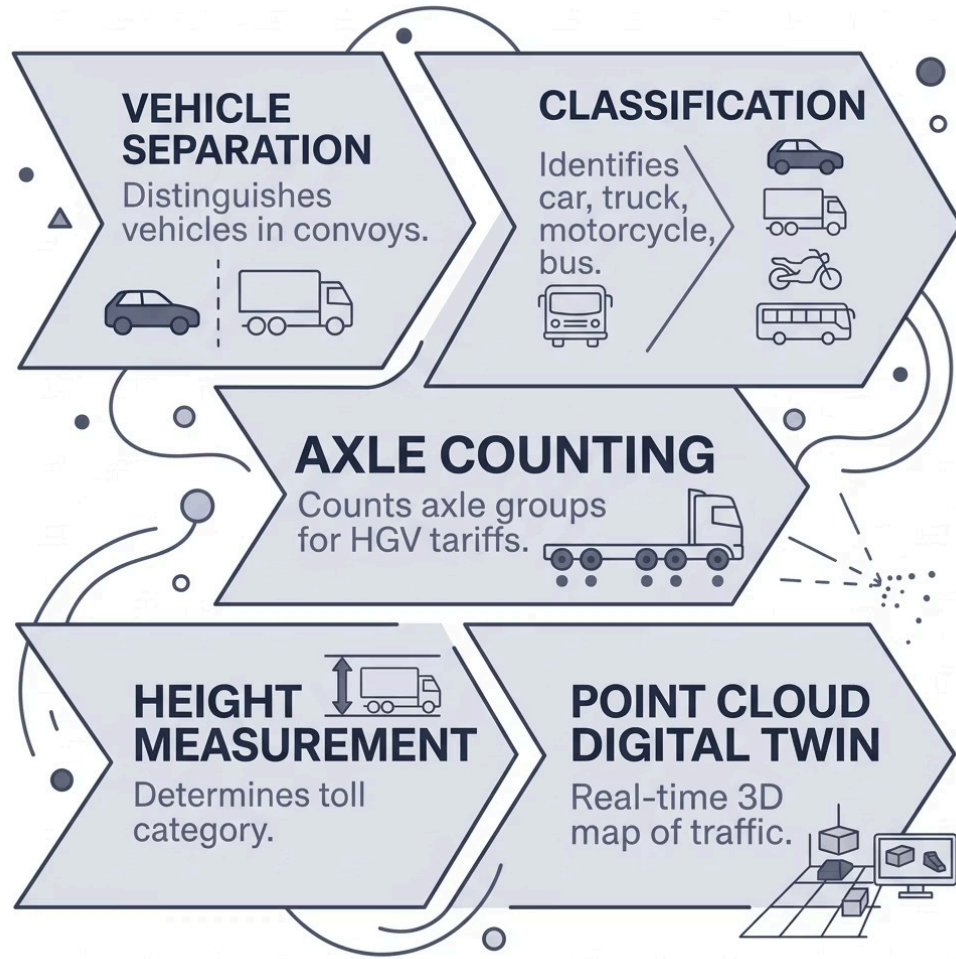
Point cloud analysis counts axle groups — critical for HGV toll categories

Geometric Fingerprint

Length, width, height profile creates a unique vehicle silhouette



LiDAR in MLFF: Role by Role



Why LiDAR is Indispensable

Cameras fail in glare and darkness. Radar lacks geometric resolution. **LiDAR delivers millimeter-accurate geometry in all conditions** – rain, fog, direct sunlight, night.

- 📍 Gantry-mounted LiDAR scans a full 8-lane carriageway every 10 ms – producing a continuous, real-time 3D traffic map.

DEEP DIVE

What is 4D Radar?

Range (X)

Distance to target, 0.5–300 m

Azimuth (Y)

Lateral position across lanes

Elevation (Z)

Height – separates trucks from cars

Doppler Velocity (V)

Instantaneous speed per target



4D Radar: Technical Performance

250+

km/h

Maximum vehicle speed tracked accurately

64

Targets

Simultaneous vehicles tracked per sensor

±0.1

m/s

Doppler velocity resolution

300

Meters

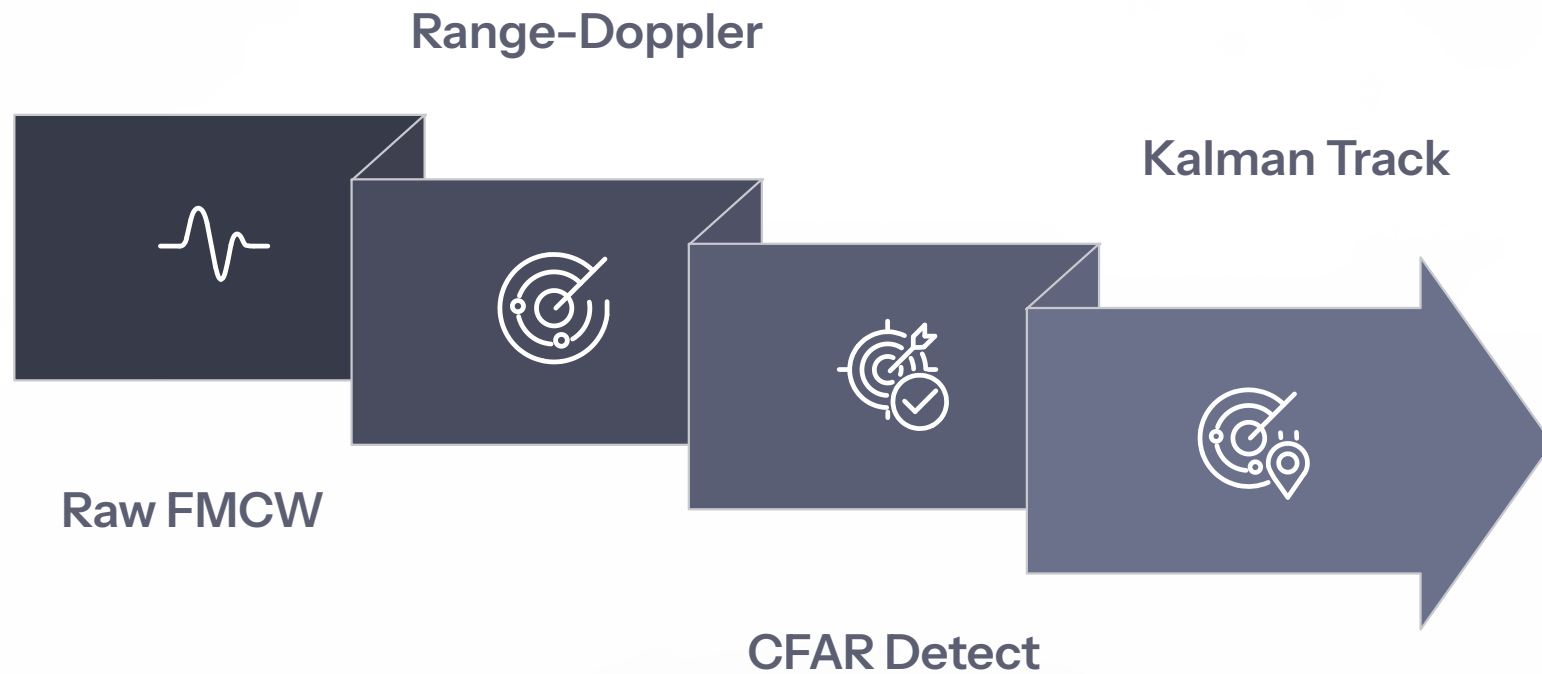
Detection range ahead of gantry

Why 4D Beats Traditional Radar

Legacy 2D radar detects presence and speed only. 4D radar adds **elevation dimension** — enabling vehicle height classification and multi-lane target discrimination without LiDAR assistance.

- ✔ 4D radar operates in all weather: rain, snow, dust, fog — where cameras and LiDAR degrade, radar maintains full performance.

4D Radar: Multi-Target Tracking Architecture



Each detected target is assigned a unique track ID, associated across sensor frames at up to 100 Hz update rate — maintaining identity through lane changes and occlusion events.

RITAIS MLFF: Engineering Architecture

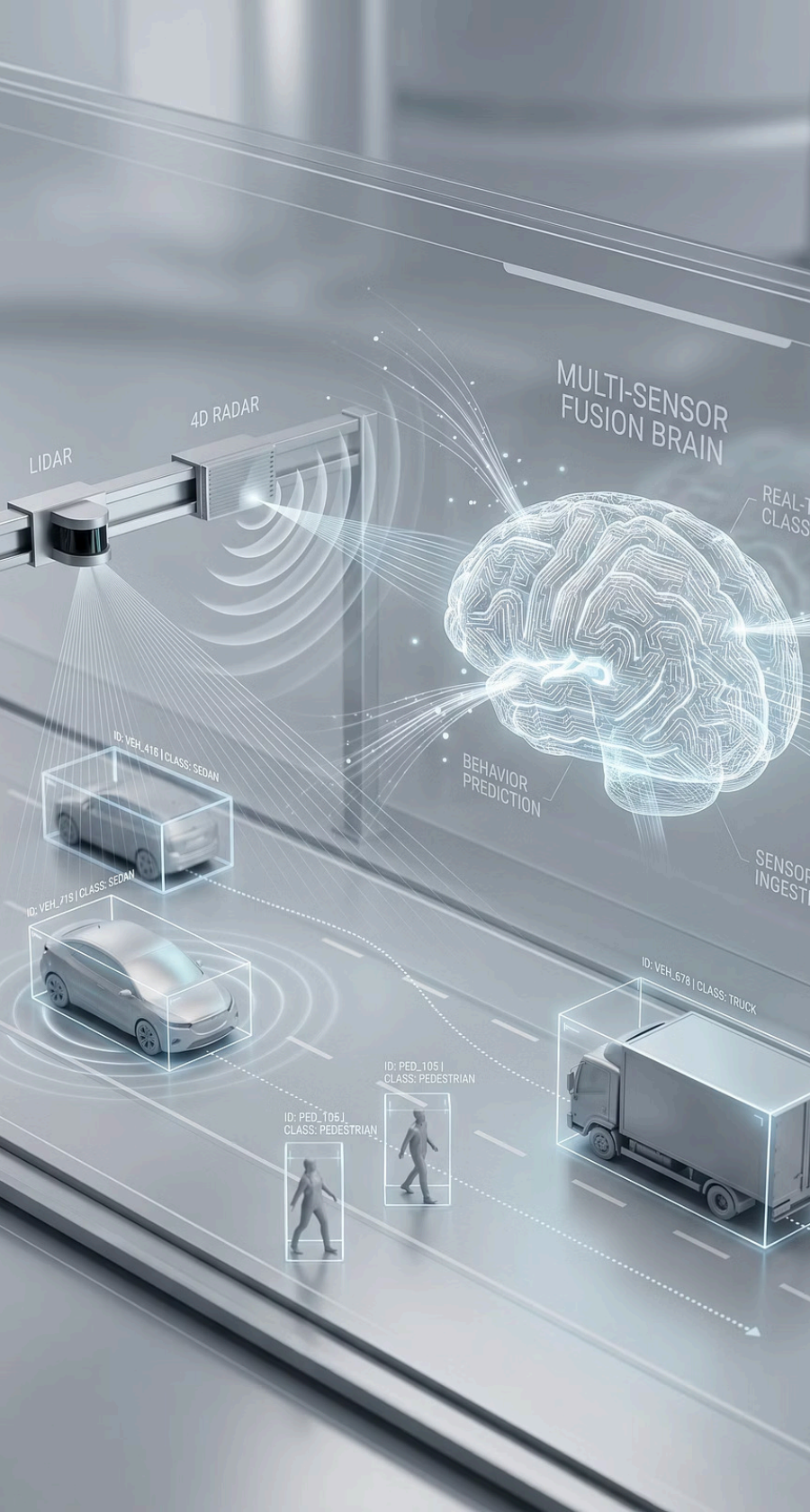


Audience: Technical Evaluators & System Integrators

Every sensor feeds a dedicated pipeline stage. No single sensor failure causes a transaction loss – the fusion engine compensates.

i Designed to meet EN 15509 and ISO 17575 interoperability standards.

Sensor Fusion Engine – The Brain



Vehicle Tracking Engine

Fuses radar + LiDAR tracks into a single ground-truth trajectory per vehicle across the gantry zone

Association Engine

Links RFID tag reads and ANPR plate captures to the correct vehicle track – even in dense traffic

Classification Engine

Combines LiDAR geometry + radar height + ANPR image to assign toll category with >99.5% accuracy

Violation Engine

Detects no-tag, no-plate, and unclassifiable vehicles – triggers enforcement workflow automatically

High-Speed Free-Flow Tolling

1

4D Radar Acquisition

Vehicle detected 150 m ahead, track ID assigned

2

RFID Read

Transponder captured at >200 km/h, 99.9% read rate

3

ANPR Capture

License plate imaged with <5 ms exposure

4

LiDAR Classification

Geometry confirms vehicle class in real-time

5

Transaction Issued

Correct toll posted to account within 500 ms

Use Case 1: Outcomes

120+

km/h

Full tolling accuracy at legal highway
speed

3x

Throughput

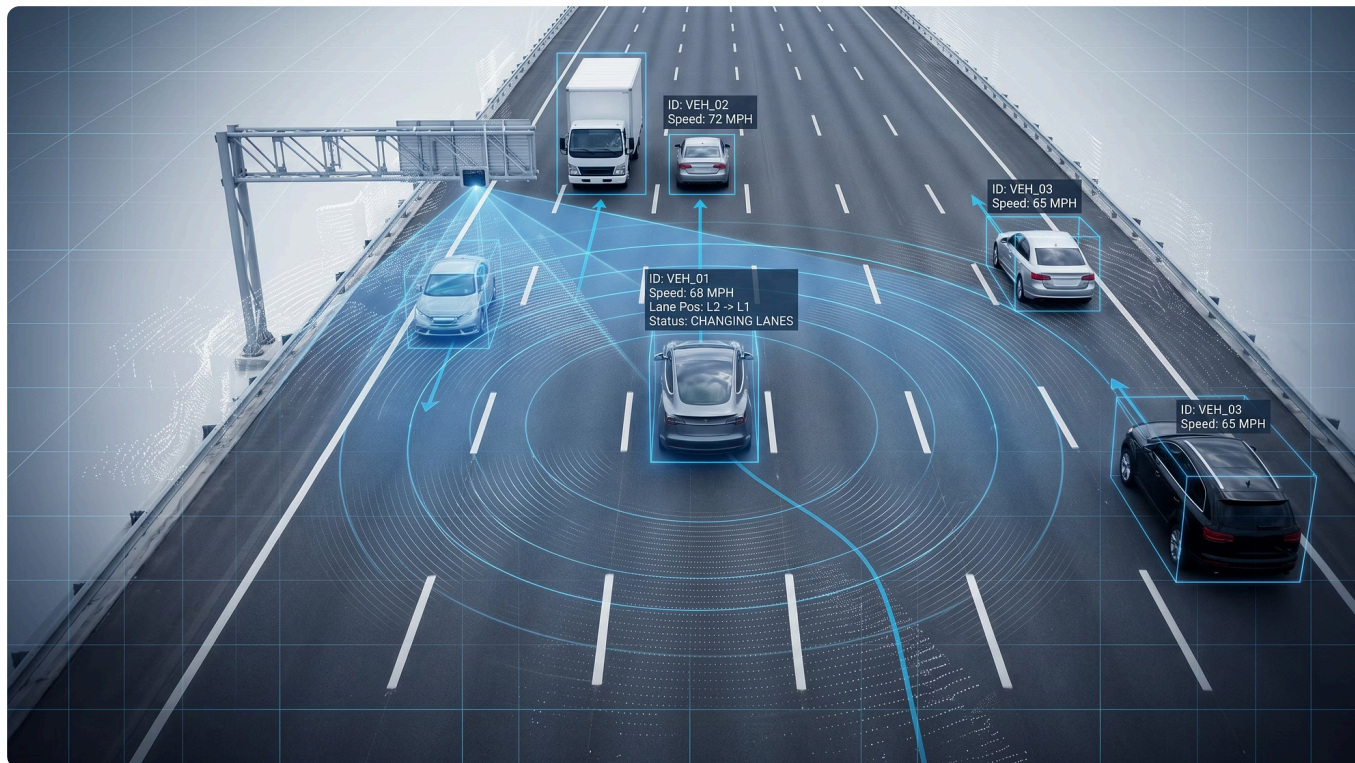
vs. traditional stop-and-pay barrier
systems

42%

Emissions

Reduction vs. barrier toll — no idling, no
queues

Lane Change Under the Gantry



The Problem

Vehicle enters Lane 2 → switches to Lane 3 **under the gantry**. Camera zone shifts. Traditional systems lose the vehicle identity — wrong toll or no toll posted.

The RITAIS Solution

4D Radar maintains a **continuous kinematic track** across all lanes. LiDAR confirms geometry continuity. ANPR re-acquires in new lane. Association Engine links all observations to the original track ID.

- ✔ Zero identity loss — transaction remains valid even with mid-gantry lane switch.



USE CASE 3

Truck Occluding a Car

✗ Camera Fails

Truck body completely blocks ANPR view of adjacent car. Plate cannot be read. Traditional ANPR-only systems record a miss.

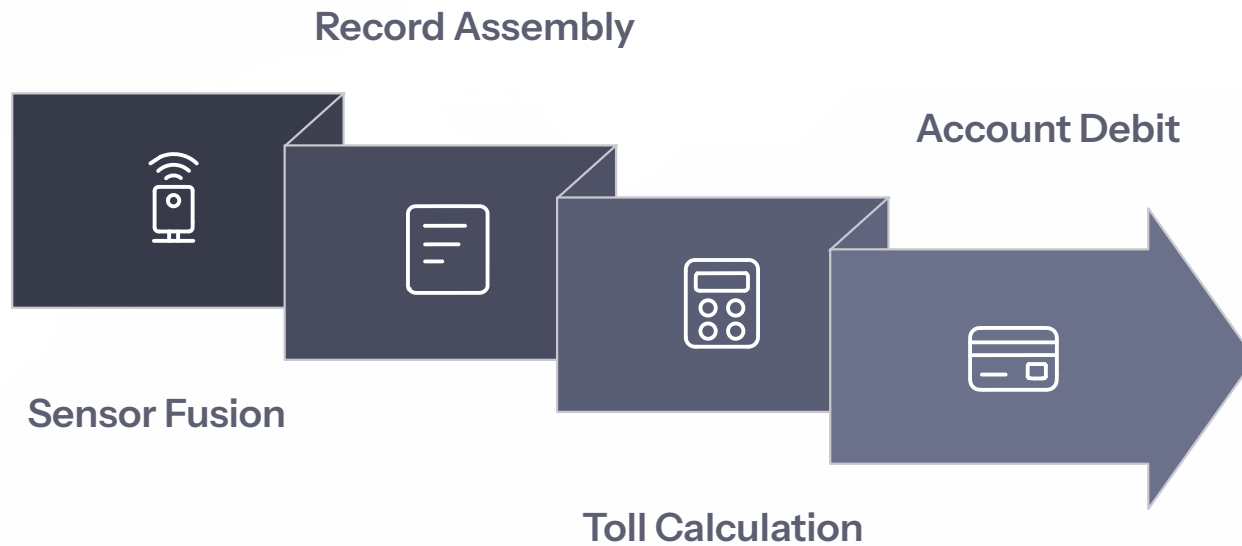
✓ Radar Continues

4D Radar sees through the occlusion — tracks both vehicles as separate point targets. Car track remains live throughout gantry transit.

✓ LiDAR Resolves

Point cloud separates the two vehicle silhouettes spatially — classification proceeds independently for each target.

Transaction Engine

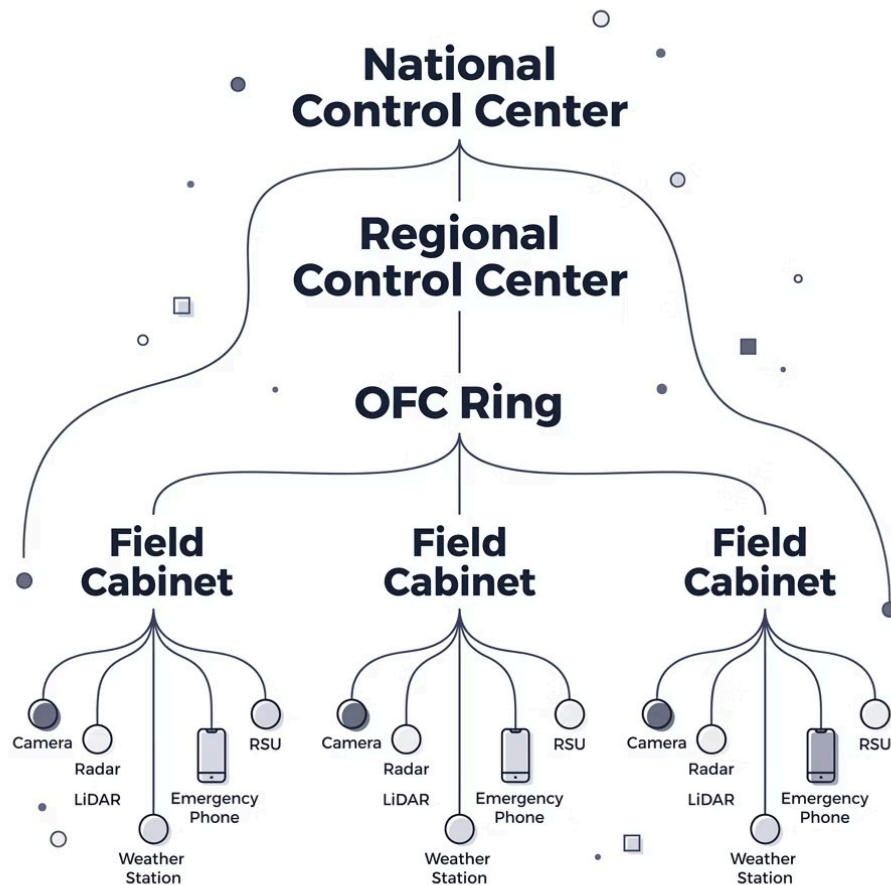


Sub-500ms End-to-End

From gantry detection to account debit in under half a second. Supports:

- OBU prepaid accounts
- Post-paid invoicing
- Video-only enforcement billing
- Interoperability with national clearing houses

Physical Deployment Architecture



Audience: Highway Operators & EPC Contractors

All field equipment connects to a **ruggedized field cabinet** at the gantry base. OFC rings provide redundant backhaul to regional and national control centers.

i Designed for hot-standby redundancy — single field cabinet failure does not interrupt tolling operations.

Field Cabinet: The Gantry Edge Node

Industrial PC

Real-time sensor fusion processing at the edge — <math><1\text{ ms}</math> latency

Managed Switch

Gigabit PoE+ for all field sensors, VLAN segmented

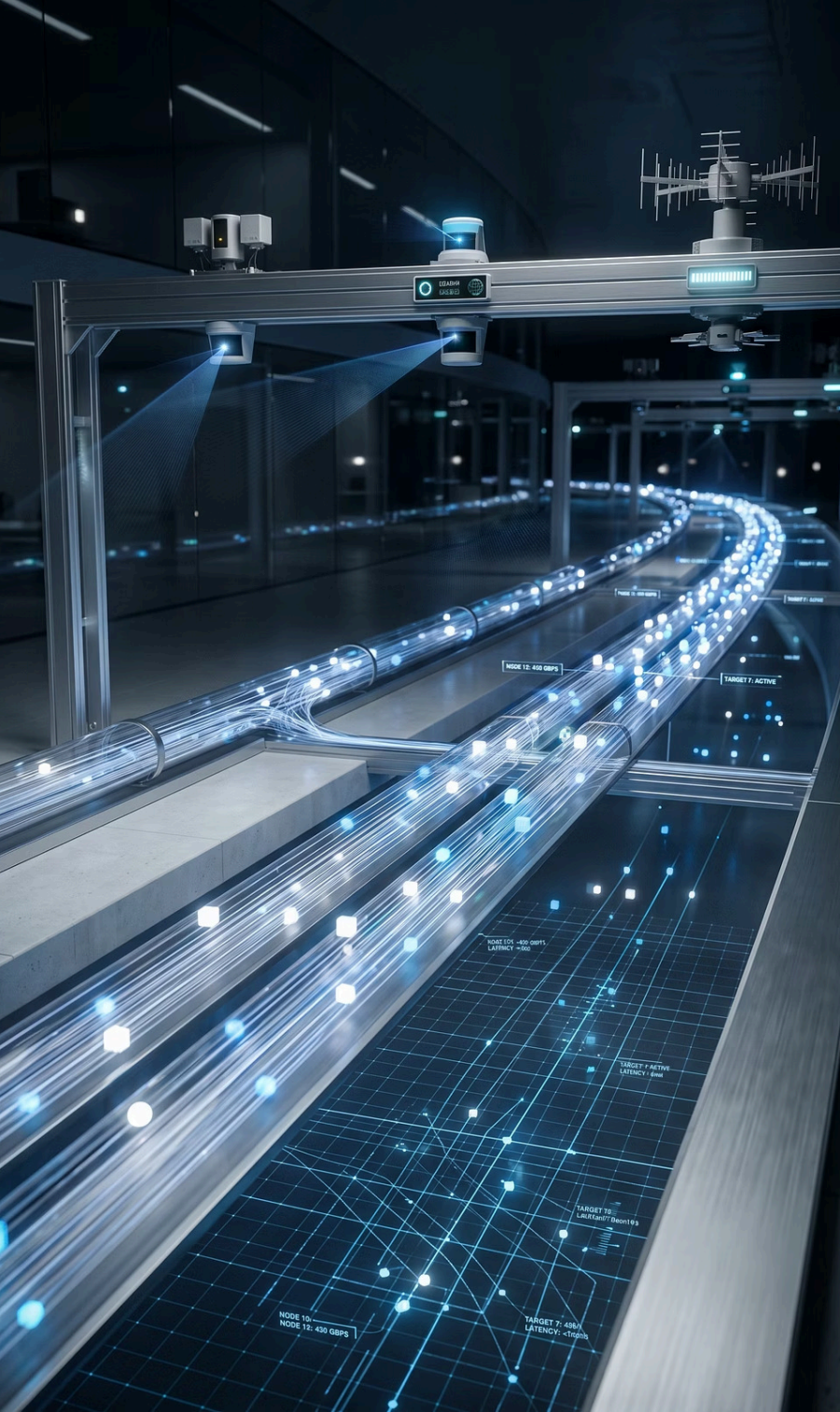
UPS Module

4-hour battery backup — tolerates mains outage events

Environmental Control

IP55 enclosure, active cooling, -40°C to $+70^{\circ}\text{C}$ operation





OFC ARCHITECTURE

Smart Highway Optical Fiber Communications

MLFF Gantries

Primary tolling nodes — highest bandwidth priority, QoS guaranteed

CCTV & VMS

Surveillance and variable message signs on shared OFC ring

Weather Stations

Micro-environmental data streamed to AI analytics platform

Emergency Phones

SIP-based, carried over OFC — no separate cabling required

OFC Ring Topology



Self-Healing Ring

OFC ring topology provides **automatic rerouting in <50 ms** on any fiber cut — tolling continues without interruption.

- 10 Gbps backbone capacity
- Supports 100+ field nodes per ring
- MPLS traffic engineering for QoS
- Encrypted transport (MACsec)

CONTROL CENTERS

Regional & National Control Center

Regional Control Center

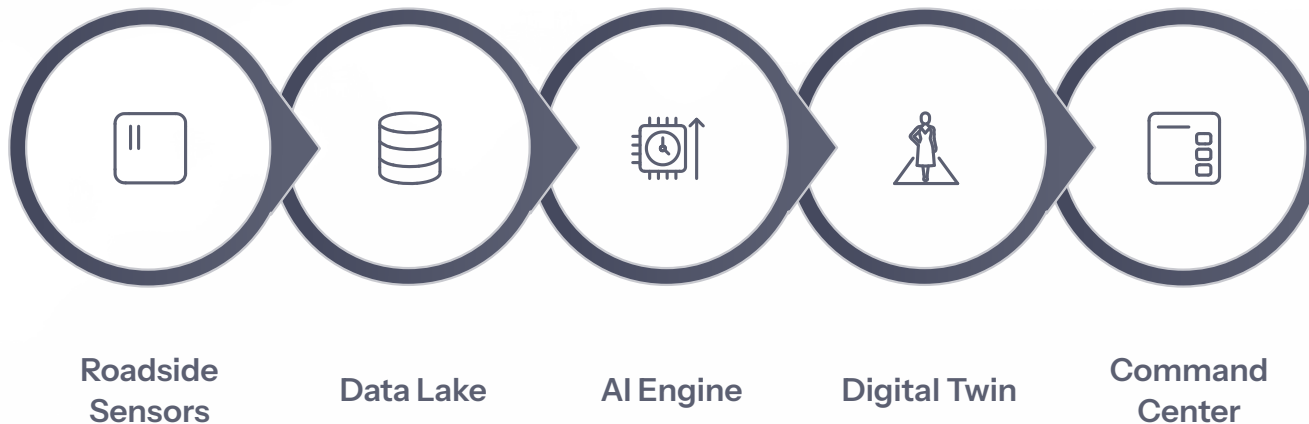
Aggregates data from all gantries in a highway corridor. Manages incidents, VMS messaging, CCTV, and field maintenance dispatch.

National Control Center

Consolidates all regional data. Hosts clearing, settlement, reporting, interoperability gateway, and national traffic analytics.



Digital Twin Architecture



Living Model of the Highway

Every sensor — LiDAR, radar, weather, CCTV — feeds a unified **Data Lake**. The AI Engine runs inference continuously, updating the Digital Twin in real time.

- i** The Digital Twin enables predictive maintenance, incident simulation, and traffic demand forecasting — not just monitoring.

AI Engine Capabilities



Anomaly Detection

Identifies wrong-way drivers, stopped vehicles, debris — in real time from sensor fusion data



Traffic Demand Forecasting

ML models predict congestion 30–60 min ahead — feeds adaptive VMS and ramp metering



Predictive Maintenance

Sensor health scoring flags degraded LiDAR or radar units before failure occurs



Vehicle Re-ID

Cross-gantry vehicle re-identification for origin-destination analytics and OD matrix generation

Micro Weather Station – RITAIS Edition

Rainfall Sensor

Tipping bucket + optical – mm/hr intensity, detects black ice risk

Wind Sensor

Ultrasonic anemometer – speed and direction, no moving parts

Visibility Sensor

Forward scatter – reports MOR in metres, triggers fog alerts

PM2.5 Sensor

Particulate monitoring – air quality index for tunnel and urban segments

Temperature / RH

Road surface and air temperature – pavement condition modelling

Weather Data Flow to AI Platform



From Sensor to Decision in Seconds

Weather data is streamed via the **RSU over OFC** to the Traffic Control Center at 1 Hz. The AI Analytics Platform correlates weather with traffic speed to issue adaptive speed limit recommendations and road condition alerts.

RSU: Road Side Unit



The Field Intelligence Node

The RSU aggregates all co-located field sensors and acts as the local edge compute and communications hub.

DSRC / C-V2X

Vehicle-to-infrastructure messaging

4G/5G Backup

OFC failover cellular path

Edge Compute

Local pre-processing reduces backhaul load

RITAIS MLFF: Key Performance Parameters

250

km/h Max

Highest vehicle speed at which full toll transaction is guaranteed

64

Targets/sec

Simultaneous vehicles tracked by a single 4D radar sensor

1.2M

Points/sec

LiDAR point cloud density across full carriageway

99.5%

Classification

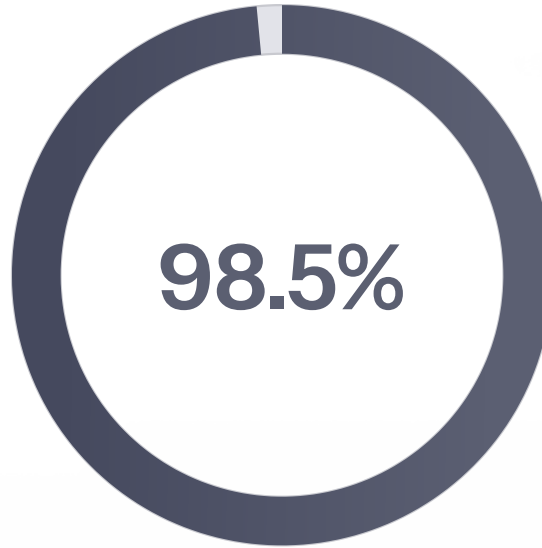
Vehicle class accuracy across all weather conditions

Accuracy & Reliability Benchmarks



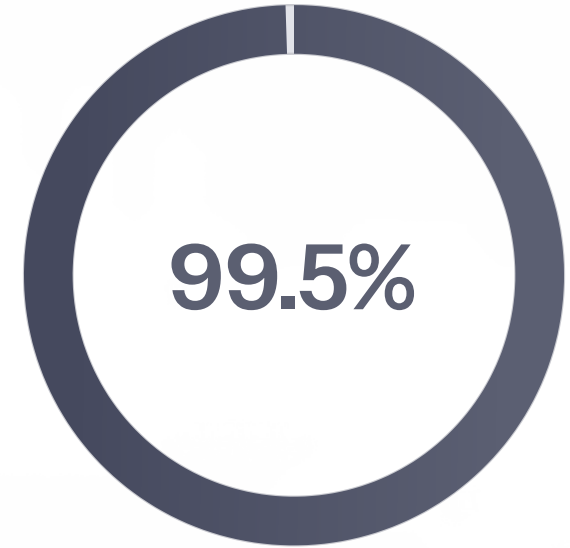
RFID Read Rate

At speeds up to 250 km/h



ANPR Accuracy

All weather, day and night



Classification

LiDAR + Radar fusion

Fallback Hierarchy

When one sensor degrades, the fusion engine seamlessly promotes the next best data source — no operator intervention required.

→ **Primary**

RFID + ANPR + LiDAR + Radar (all four)

→ **Secondary**

ANPR + LiDAR + Radar (no RFID)

→ **Tertiary**

ANPR + Radar only — enforcement mode

Violation Detection & Enforcement



Automatic Violation Workflow

- No RFID tag detected → ANPR plate lookup
- Unregistered plate → photographic evidence package assembled
- LiDAR geometry confirms vehicle class for penalty calculation
- Evidence posted to enforcement back office within 2 seconds
- Infringement notice auto-generated and dispatched

⚠️ Violation Engine maintains a separate chain of custody log — admissible in legal proceedings.

Clearing & Settlement Architecture



RITAIS supports multi-operator corridors — a vehicle with Country A OBU can be correctly tolled on Country B infrastructure with automated cross-border settlement.

Cybersecurity Architecture

Field Layer

MACsec encrypted OFC, certificate-based sensor authentication, tamper-evident enclosures

Transport Layer

TLS 1.3 for all backhaul, VLAN isolation between tolling, CCTV, and management traffic

Application Layer

Role-based access control, full audit logging, SOC 2 Type II alignment

Data Layer

AES-256 at rest, GDPR-compliant PII handling, license plate data retention policies enforced



Project Delivery Phases



Why RITAIS MLFF

Proven Sensor Stack

4D Radar + LiDAR + ANPR + RFID — no single point of failure

All-Weather Operation

Radar maintains tracking where cameras and LiDAR degrade

Standards Compliant

EN 15509, ISO 17575, EETS-ready interoperability

AI-Native

Digital Twin, predictive maintenance, and demand forecasting built in



Next Steps

For Technical Evaluators

- Request RITAIS sensor fusion API documentation
- Schedule lab demonstration — live point cloud and radar tracking
- Review ICD for system integrator onboarding

For Highway Operators & EPC Contractors

- Site survey and OFC route assessment
- Reference site visit — operating MLFF corridor
- CAPEX / OPEX modelling workshop

📄 Interactive architecture diagrams available on the RITAIS portal. Contact your regional RITAIS representative to schedule a technical deep-dive.