tsdsi
India's Telecom SDO

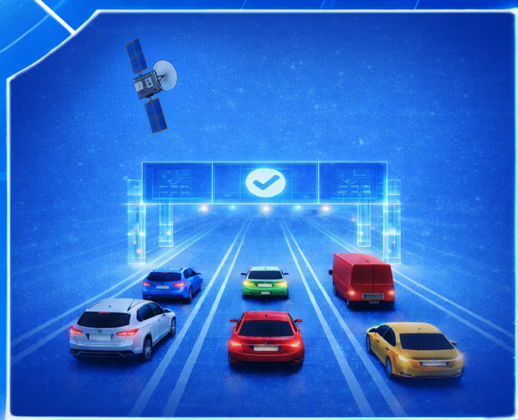
Telecommunications
Standards Development
Society, India

Whitepaper

PLATOONING

ADAS SAFETY &
COLLISION AVOIDANCE

TRAFFIC SIGNAGE DETECTION



GNSS-BASED TOLLING

AUTOMATED ELECTRIC ROAD TRANSPORTATION

Use case-based approach for Indian Context

January 2026

Important Notice

Copyright Notification

Telecommunications Standards Development Society, India (TSDSI)
Registered Office Address
C-DOT Campus, Mandi Road, Mehrauli,
New Delhi, India – 110030
www.tsdsi.in

Foreword

India's transport system faces significant challenges related to road safety, congestion, sustainability, and logistics, necessitating innovative and future-ready mobility solutions. Rapid urbanization and the exponential growth in vehicle ownership have led to increased congestion, road accidents, and environmental pollution. Conventional approaches, such as lane expansion, are proving inadequate to address these complex and interlinked issues.

To study technical solutions to these challenges and to enable the adoption of electric and automated road transport solutions to address road safety, traffic congestion, and high-speed intercity transportation needs, TSDSI established a discussion forum namely **Automated Electric Road Transportation (AERT) TRIP Forum** with the objectives such as:

I. to improve road utilization and efficiency
II. to develop relevant use cases
III. to study key technology aspects
IV. to identify gaps in existing standards and standardization efforts

The Forum met periodically to deliberate and brainstorm on various technical and operational aspects. A dedicated workshop to gather ideas and information on the directions of technology was organized which was attended by a range of stakeholders. The efforts finally culminated in the development of this whitepaper.

This White Paper proposes the deployment of Automated Electric Vehicles (AEVs) through a use-case-driven approach to address the identified challenges. Twelve use cases, broadly categorized under Platooning, ADAS-specific applications, and Satellite Communications have been described. The paper identifies gaps in current standards and infrastructure, along with suggested solution directions.

Automated Electric Road Transportation (AERT) integrates automation, electrification, and digital infrastructure to enable safer, cleaner, and more efficient mobility.

In the Indian context, electric vehicle adoption is gaining strong momentum, while vehicle automation is progressing gradually, beginning with assisted driving features. The advent of 6G is expected to play a pivotal role in enabling safe and reliable connected mobility, particularly through reduced latency. Automation in commercial vehicles is advancing globally, and India is making steady progress in this direction.

We express our sincere gratitude to all contributors who, despite their demanding schedules, devoted their time and expertise to contribute to, review, and refine this Whitepaper. We also acknowledge the guidance and support provided by the Roadmap Committee throughout this effort.

As technologies continue to evolve, sustained and collaborative efforts are essential to translate technological advancements into real-world impact. Standards-driven innovations in the AERT domain, tailored to India's unique requirements and enriched through expert collaboration, will strengthen Indian Standards and transform our roads into truly smart infrastructure.

We hope that this whitepaper will provide useful inputs towards policy formulation, further research activity and realization of AERT in India. We also request suggestions from stakeholders for carrying out technical studies and develop standards to meet the national requirements for AERT. TSDSI is a platform where the stakeholders can join hands to achieve this objective.

AK Mittal

Director General, TSDSI

Table of Content

List of Figures

List of Tables

1. Executive Summary

India's transportation landscape is at a critical juncture, grappling with persistent challenges in road safety, traffic congestion, environmental sustainability, and logistics efficiency. This white paper presents a visionary, use-case-driven framework for addressing these issues through the deployment of automated electric vehicles (AEVs) in dedicated, well-separated lanes.

Use cases have been categorized as Platooning, ADAS specific and Satellite communication related covering a total of thirteen use cases. Current gaps in standards and infrastructure have been identified with potential solutions and need for further work towards implementation of the use cases.

The study underscores the urgent need for scalable, high-capacity, and resource-efficient mobility solutions that leverage India's expanding highway infrastructure. Findings indicate that automation and electrification, when combined, can maximize vehicle and infrastructure utilization, lower emissions, and improve safety—a priority given India's alarming highway accident rates for passenger vehicles as well as commercial vehicles.

For passenger vehicles, AEV deployment can deliver safer and more convenient personal mobility through features such as lane keeping assist, collision avoidance, and traffic signage detection, directly reducing accident risks and improving traffic flow.

For commercial vehicles, AEV-enabled capabilities like platooning, intelligent tolling, and real-time traffic management hold significant promise in enhancing freight efficiency, reducing logistics costs, lowering fuel consumption, and improving fleet safety.

To enable these advancements, the paper proposes a multi-layered technology stack combining multi-GNSS systems (including NavIC), AI/ML-based perception, radar and LiDAR sensor fusion, and V2X communication. Together, these technologies support precise navigation, efficient toll collection, and dynamic traffic coordination.

The white paper also highlights validation efforts at TiHAN and ARAI testbeds, while stressing the need for India-specific standards, robust policy frameworks, and strong public–private partnerships to ensure safe, efficient, and economically viable implementation.

The paper examines current gaps and requirements for AEV deployment in separated lanes, while recommending further research into India-centric operational models for both passenger and commercial vehicle segments.

2. Definitions and Abbreviations

S. No	Acronym	Abbreviation
1	ADAS	Advanced Driver Assistance System
2	AERT	Automated Electric Road Transportation
3	AEV	Autonomous Electric Vehicles
4	ARAI	Automotive Research Association of India
5	CCB	Centralized Computing Board
6	CFAR	Constant False Alarm Rate
7	C-V2X	Cellular Vehicle-to-Everything
8	ECU	Electronic Control Unit
9	FMCW	Frequency Modulated Continuous Wave
10	GNSS	Global Navigation Satellite System
11	GSM	Global System for Mobile Communications
12	ISRO	Indian Space Research Organization
13	LKA	Lane Keep Assist
14	MGIS	Multi-GNSS-Integrated System
15	MGIS–AERT	Multi-GNSS-Integrated System for Automated Electric Road Transportation
16	MoRTH	Ministry of Road Transport & Highways
17	NaVIC	Navigation with Indian Constellation
18	OBU	Onboard Unit
19	OOI	Objects of Interest
20	RFID	Radio-Frequency Identification
21	RTO	Regional Transport Office
22	SatComm	Satellite Communication
23	TiHAN	Technology Innovation Hub on Autonomous Navigation
24	VNAS	Vehicle Navigation Assist System

3. Introduction and Context

With a rapidly growing economy, expanding urbanization, and increasing vehicular density—particularly from passenger cars and commercial vehicles—India faces mounting transportation challenges. The surge in personal mobility and freight movement has led to high accident rates, severe traffic congestion, environmental degradation, and inefficiencies in logistics. Traditional interventions such as lane expansion and conventional public transport systems have proven inadequate in addressing these multifaceted issues, especially given the diverse operational needs of passenger and commercial vehicle segments.

This whitepaper proposes a forward-looking solution: Automated Electric Road Transportation (AERT) in Separated Lanes, which leverages automation, electrification, and digital infrastructure to create a scalable, high-capacity, and resource-efficient transportation model tailored to India's unique needs. By envisioning dedicated corridors for autonomous electric vehicles (AEVs)—including both passenger cars and commercial vehicles—this approach enables high-speed, low-emission travel while optimizing road and vehicle utilization.

AERT in separated lanes enhances safety and operational efficiency across both personal and freight transport, supports last-mile connectivity, delivers superior unit economics, and promotes environmental sustainability. The whitepaper adopts a use case–driven methodology to explore the technological, infrastructural, regulatory, and business model requirements for successful deployment of AERT systems across India, with specific attention to the distinct roles and needs of passenger and commercial vehicle ecosystems.

Global Trends – Automated Electric Passenger Cars

Worldwide, electrification has become the foundation for the future of passenger mobility, with autonomy now being built on top. Automakers are divided between a camera-first vision approach (like Tesla) and a lidar-plus-mapping approach (like Waymo), but both rely on vehicles evolving into software-defined platforms that receive constant improvements via over-the-air updates.

A silent race is underway for power-efficient, high-performance computing that can process massive sensor data streams in real time. Here, the coming era of 6G will be transformative. With ultra-low latency, multi-gigabit speeds, and integrated AI at the network edge, 6G can enable near-instant decision-making for autonomous vehicles, richer V2X (vehicle-to-everything) communication, and real-time collaboration between vehicles and infrastructure. This means smoother coordination for traffic, safer navigation in complex environments, and faster updates from cloud-based AI models.

RoboTaxi pilots are expanding in tightly geofenced cities, while battery innovations and faster charging are extending operational ranges. Regulation and public trust remain the gatekeepers, but as 6G matures, the ability to share vast amounts of data reliably and securely between vehicles, infrastructure, and the cloud will help unlock the next level of safe, scalable autonomy.

3.1 India Trends – Automated Electric Passenger Cars

In India, policy momentum is strongest on electrification, with automation in a preparatory phase. Government incentives, state EV policies, and a push for local manufacturing are building the EV base. Guidelines for AV testing corridors are emerging, but the country's mixed traffic, varied road quality, and high proportion of two-wheelers make full autonomy for private cars a longer-term goal.

The immediate opportunity lies in incremental automation — assisted driving on highways, parking automation, and semi-autonomous fleet operations in controlled environments. Fleets for ride-hailing, logistics, and campus mobility are likely to be the first beneficiaries.

This is where 6G could be a game-changer for India. With its promise of sub-millisecond latency and intelligent network orchestration, 6G can make connected, automated fleets far more responsive and safer, even in unpredictable traffic. High-capacity, real-time data exchange between vehicles and smart city infrastructure could improve navigation in dense urban settings, enhance collision avoidance, and enable AI-powered traffic management tailored to India's unique mobility patterns.

3.2 Global Trends – Automated Electric Commercial Vehicles

Across the world, commercial vehicles are undergoing a double transformation: they are going electric, and they are becoming increasingly automated. The first big wave is visible in electric buses and urban delivery vans, where predictable routes and depot-based charging make electrification practical today. Medium and Heavy trucks will follow, supported by the development of megawatt charging systems that can cut downtime and make long-haul electrification feasible.

On the automation front, the hub-to-hub trucking model is gaining traction. Some companies are already running driverless pilots in defined highway corridors in the U.S., proving that autonomy works best where duty cycles are repetitive and environments are controlled. Fleet operators are also beginning to see vehicles as software-defined assets, with over-the-air updates, predictive maintenance, and AI-powered routing becoming standard parts of operations.

Regulation is another driver: stricter CO_2 and fuel economy rules in Europe, the U.S., and China are pushing fleets to adopt zero-emission solutions faster. Overall, the global trend is clear — automation and electrification are converging first in commercial applications where efficiency, safety, and economics matter most.

3.3 India Trends – Automated Electric Commercial Vehicles

In India, the story begins with buses. Programs like PM e-Bus Sewa and FAME-II are putting thousands of electric buses on the road, making public transport the spearhead of commercial electrification. For freight, momentum is slower but emerging — particularly in captive fleets, mines, ports, and industrial hubs, where vehicles run fixed routes and charging infrastructure can be centrally managed.

Automation in Indian commercial vehicles is still at an early stage. The complexity of mixed traffic, road conditions, and regulation makes full autonomy challenging in the near term. Instead, India is likely to see incremental automation — driver assistance, platooning pilots on highways, and semi-automated vehicles in controlled industrial settings.

Electrification of heavy commercial vehicles (HCVs) in India remains commercially and technically unviable due to battery energy density limits that reduce payload capacity, prohibitively high upfront costs, and the absence of ultra-fast charging infrastructure capable of supporting long-haul operations.

At the same time, India is laying the digital groundwork. Cybersecurity regulations like AIS-189 are aligning with global standards, and smart city projects are beginning to explore how connected infrastructure could one day support automated mobility. With its strengths in software and engineering, India is also positioning itself as a technology contributor to the global AEV ecosystem, even as large-scale domestic deployment remains focused on e-buses and controlled-use freight.

4. Categorization of Use Cases

The whitepaper organizes the use cases into the following categories, each addressing specific functional and operational aspects of AERT.

S. No	Use Case	Category
4.1.1	Platooning	Platooning
4.2.1	Lane Keeping Scenario	ADAS Specific
4.2.2	Road and Traffic Object Monitoring – Speed Bump Detection	ADAS Specific
4.2.3.1	Lane Keep Assist (LKA) – Eco Vehicle Driving Straight	ADAS Specific
4.2.4.1	Collision Avoidance – Object on the Intended Path	ADAS Specific
4.2.4.2	Collision Avoidance – Ego Vehicle Approaching a Vehicle	ADAS Specific
4.2.5	Traffic Signage Detection – T-junction, Bus Stop, Speed Limit	ADAS Specific
4.3.1	Location Granularity (NaVIC)	SatComm

4.3.2	GNSS-Based Tolling	SatComm
4.3.4	Multi-GNSS-Integrated System for Automated Electric Road Transportation (MGIS–AERT)	SatComm
4.3.5	Digitized Mapping of Roads and Lanes using Multi-GNSS-based Equipment	SatComm
4.3.6	Multi-GNSS-based Vehicle Tracking System for AERT in Separated Lanes	SatComm
4.3.7	Multi-GNSS-Integrated Tolling System for Automated Electric Road Transportation (MGITS-AERT)	SatComm

4.1 Platooning Use Case

4.1.1 Use Case 1 - Platooning

Scenario Description

Platooning is an important use case that has the potential to improve the capacity utilization of the road infrastructure. Platooning includes vehicles driving close together at a fixed small gap between vehicles maintained at all speeds. The vehicle is being driven with a leader and one or more follower vehicles automatically following at a small gap between each other. Additionally, when in the platooned mode, the follower vehicle drivers are completely relieved of the dynamic driving tasks. The platooning is accomplished in a phased architecture with radar and wireless communications between the vehicles. Additionally, with a network guided platooning, platooning is commanded through the wireless connection with the communications infrastructure. Platooning can be accomplished in itself as a service through the telecom network operator as "Platooning as a Service". The core architecture for platooning is based on radar and wireless control link between the vehicles in platoon mode using which the dynamic state of the vehicles is exchanged between the vehicles for synchronized control of the platooned vehicles in tandem so as to maintain the fixed gap between the vehicles in the platoon.

Platooning

The platoon formation can be split up into 3 distinct phases depending on the guidance model applicable in each phase.

1. Target Search Phase
2. Homing Phase
3. Rendezvous Phase

As the vehicle is moving through the pathway whenever the front facing radar detects a potential platoon target, a search is initiated by each of the front facing radar to try and detect the corresponding reflector and lock into it. The beam steering capabilities of the phased array radar are put to use to help in the search. Once the radars lock to their targets, the homing phase is initiated and the guidance system is put into homing mode. During the homing mode, the guidance system uses the range information obtained from the front facing radars. A suitable vehicle dynamic control algorithm based on Model Predictive Control is employed to achieve the rendezvous at a preset inter-vehicle platooning gap. During this phase a hard real-time wireless control link is also established between the vehicles as well as video links for sharing backup camera information or other video information from the follower vehicles with the lead vehicle. Once the rendezvous is achieved at the desired inter vehicle gap, the vehicle-to-vehicle wireless control link is used to exchange the vehicle dynamic state with followers to control the follower vehicle dynamics in tandem with the leader and the dynamic driving task is ceded to the lead vehicle. The inter vehicle gap is periodically shared with the lead vehicle to plan its dynamic control.

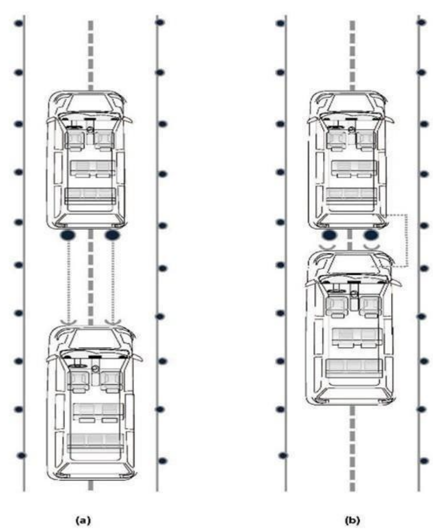


Figure 1. Illustration of platooning with front facing radars detecting the corresponding rear reflectors and achieving rendezvous. The wireless control link is shown as a dotted line in (b)

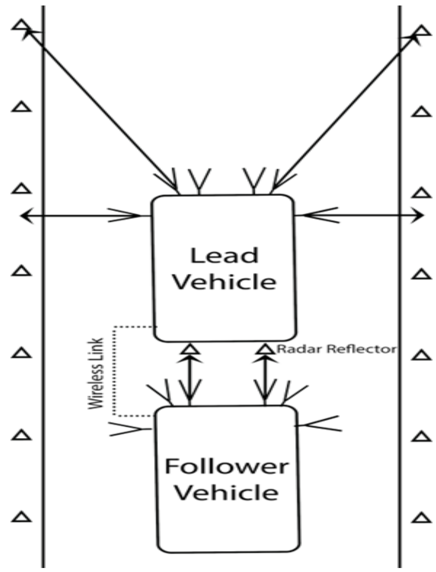


Figure 2. Platooned Vehicles

The command to platoon or disengage can be received from the network through a communications link with the infrastructure. When platooning is provided as a service by the network operator, the platooning service can be billed providing revenues for the network operator. C-V2X with suitable extensions can potentially provide all the required communications functionality including network operations and inter-vehicle communications for platooning.

4.2 ADAS Use Cases

4.2.1 Use Case 2 - Lane Keeping Scenario

The Lane keeping function makes use of millimeter wave FMCW phased array radar with digital beam forming for high specificity and low false alarm rate sensing and accurate ranging and azimuth and relative velocity estimation. The reflectors placed along the pathway are designed to provide high radar return and clutter rejection that allows high specificity detection with a low false alarm rate using a constant false alarm rate (CFAR) based detection algorithm. A two-dimensional Range and Doppler processing are performed to obtain the relative distance and azimuth of the target reflector detected. For path planning purposes, two side looking radars with directional beam forming capabilities are placed on each side of the vehicle. One of the sides looking radars is placed perpendicular to the vehicle's x axis while the other is placed at an angle with the vehicle's x axis. On each side of the roadway, reflectors that lie between the LOS of each of the side looking radars would be used for determining the look-head horizon for path planning purposes. The look-ahead horizon is updated as the vehicle moves through the guided pathway. See Figure 4.

Figure 3. Radar Optimized Corner Cube Reflectors placed behind the rear of the vehicle

The vehicle also would have two front-facing electronically steerable radars for platooning guidance purposes. See Figure 1. There are 2 radar reflectors with unique signatures placed at the back of the vehicle for lateral guidance during platooning.

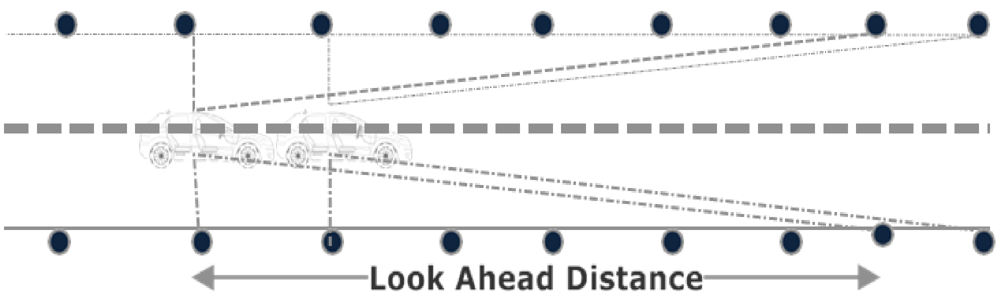


Figure 4. Illustration of the Shifting Look Ahead Window as the vehicle moves

Additionally, the vehicle has an on board IMU to provide for inertial guidance when tracking the trajectory in-between the radar measurements. It is a combination of inertial and non-inertial navigation to control integration errors and provide accurate trajectory tracking. The pole mounted wayside reflectors for lane keeping will be ruggedized for robust operation in all-weather scenarios as well as physically protected from any vandalism or theft.

4.2.1.1 Gaps

Following are the gaps of Lane Keeping Scenario.

A. **Business Models**

With current government operated roads, there is a lack of incentive to adopt and deploy a technology like platooning that is a force multiplier and can improve utilization of the capacity of the roads. Additionally, exclusive and well separated lanes for automated vehicles are needed to improve lane capacity utilization as well as safety. We need to define business models where involvement of private sector in road operations and market competition leads to greater incentive to adopt technologies like automated lane keeping and platooning that would increase speeds and capacity utilization of the roads and thereby leading to greater revenues from tolls and other value-added services and in turn contributing to higher ROI for the road operator.

B. **Architecture and Technology Standards**

We need to develop a reference architecture and associated technology standards that are open, modular and extensible and would be adopted by multiple vendors to develop products and services needed for deploying automation technology like platooning and lane keeping.

C. **Regulations and Legal Frameworks for Safety Liability**

As safety will be paramount, we need new regulations and a legal framework with well-defined liability and certifiability of the products for safety for operating roads with automation and electrification.

D. **Safety Assurability and Insurability**

We additionally need to define system level safety requirements and assurability with appropriate metrics for safety that can be insured against any catastrophic incidents or accidents.

4.2.2 Use Case 3 - Road and Traffic Object Monitoring – Speed Bump Detection

The ego car travels along the road with a speed bumper in its route. The speed bumper can be either marked or unmarked. The primary purpose of the ego vehicle is to maintain traveling straight.
Schematic representation is given in Figure 5.

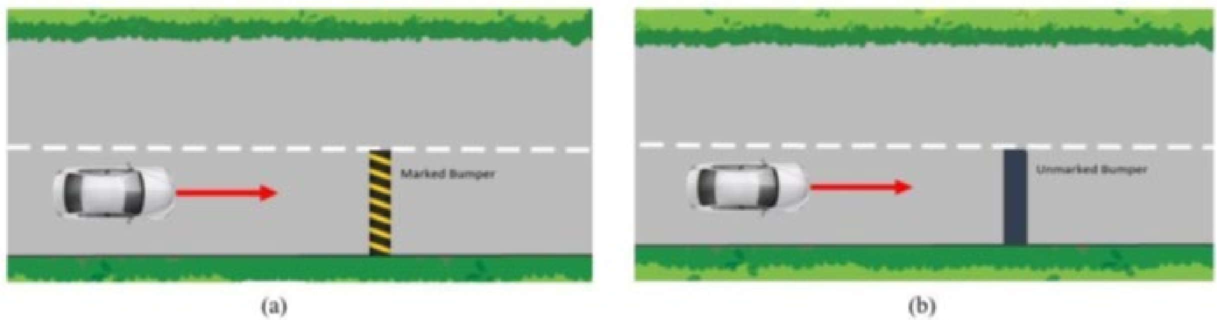


Figure 5. Schematic representation of (a) Marked speed bumper on the intended path and (b) Unmarked speed bumper on the intended path.

When the ego vehicle approaches a speed bump (Marked or Unmarked), the ego vehicle needs to slow down to cross over the speed bump. However, when oncoming vehicle approaches from the other lane, priority rules apply to maneuvering over the speed bumper.

4.2.2.1 Standards & Gaps

In the Indian context, road and traffic object monitoring systems are increasingly being incorporated into modern vehicles to enhance safety and automation. However, the available systems and their associated standards are primarily derived from global benchmarks with minimal localization for Indian road conditions. As, Indian roads have vast road infrastructure diversity and traffic composition where different types of roads objects which includes different vehicle classes, different types of road signage and different types of road markings. However, the current AIS standard -053 titled "Automotive Vehicles-Types-Terminology" includes the motorized vehicle categories (M, N, L, A, C and special purpose vehicles) but does not include E-rickshaws, Agricultural & Rural utility vehicles which are predominantly found in suburban and rural areas of Highways. Also, merely 2% is the percentage of national highway out of the total road transportation network of India. Hence, these kinds of vehicles should also be considered due to the variation in the traffic composition. Apart from this, the Indian roads exhibit significant variability in terms of road quality, lane markings and signage (IRC:67) which again makes it challenging for vision-based systems to accurately identify lanes & boundaries.

4.2.3 Use Case 4 - Lane Keep Assist (LKA)

The following scenarios are designed and developed at TiHAN Testbed.

4.2.3.1 Use Case 4.1 - Eco Vehicle Driving Straight: Lane Keeping Assist (LKA)

The ego vehicle is driving on a straight road. The goal of ego vehicles is to continue driving in the same direction.

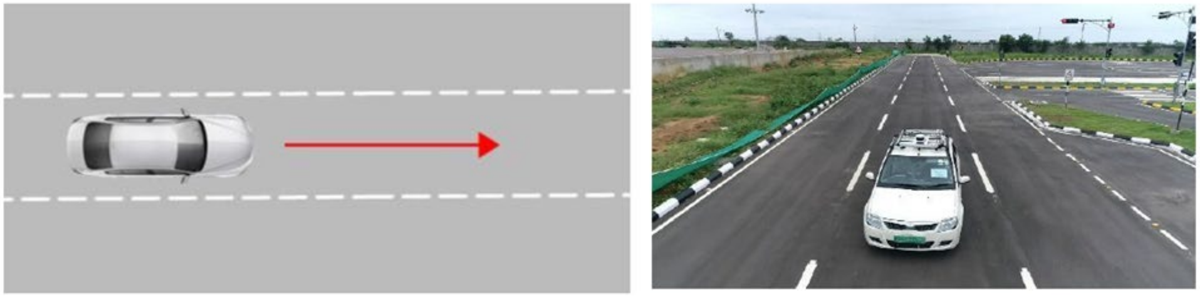


Figure 6. Schematic representation of Ego vehicle driving straight and Real-time testing at TiHAN testbed

When the ego vehicle is driving on a straight road, maintaining its lane and direction is a critical task, and this is where the Lane Keeping Assist (LKA) system comes into play. LKA is designed to ensure that the vehicle stays centered within its lane and does not drift unintentionally due to external factors, such as road conditions or minor distractions. Here's an elaboration of the scenario with respect to Lane Keeping Assist.

4.2.3.1.1 Sensor-based object detection and tracking (Standalone unit)

Two short-range radars were installed at the rear of the vehicle, while a long-range radar was mounted at the front. A Centralized Computing Board (CCB) processes data from these radar sensors and executes object detection and tracking algorithms. The radars communicate with the CCB via a CAN network. Based on the detected information, the CCB sends signals to the Electronic Control Unit (ECU), which activates the turn indicators and warning LEDs. If a vehicle is detected within or approaching the warning zone, the system operates seamlessly under the control of a unified ECU to ensure safety and proper functionality.

4.2.3.1.2 Warning Zone depiction

The system operates by detecting objects within the warning zone and identifying any speeding vehicles approaching it. All vehicles within a medium detection range of 0.75m to 40m are tracked, with those following a trajectory that intersects the warning zone designated as Objects of Interest (OOI). In subsequent radar frames, the system recalculates the trajectories of both previously identified OOIs and any new objects, continuously refining the tracking process and repeating the evaluation cycle.
Schematic representation is given in Figure 7.

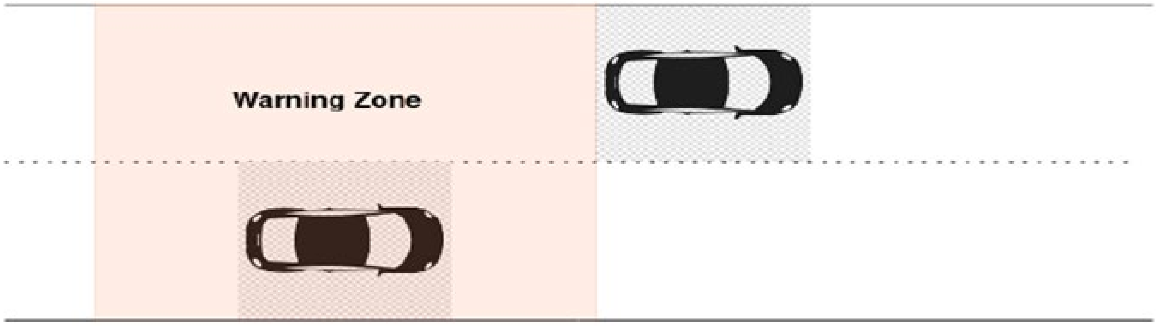


Figure 7. Warning Zone Depiction

4.2.3.1.3 Steering Adjustments for Lane Centering

Lateral Control: Upon detecting a vehicle in the warning zone, the PWM signal from the Centralized Computing Board (CCB) prompts the vehicle to adjust its lateral position. This is achieved through small, continuous steering corrections that are subtle and precise, ensuring the vehicle remains centered within its lane while traveling in a straight line.

4.2.3.1.4 Way forward

The future of Lane Keeping Assistance (LKA) lies in advancing camera-based solutions tailored for highway scenarios. By ensuring cutting-edge camera technology, these systems aim to enhance vehicle safety and navigation by providing robust driver support in high-speed highway environments.

4.2.3.1.5 Standards & Gaps

The integration of Automated Lane Keeping Systems (ALKS) into Indian roadways presents unique challenges, given the distinct nature of traffic conditions, infrastructure, and regulatory frameworks. While the development of ALKS standards, such as those outlined in Draft D1/AIS 191, emphasizes global uniformity through alignment with international regulations like UN R157, fair research gaps remain in the Indian context. The existing sensing and Object and Event Detection and Response (OEDR) systems described in the Draft D1/AIS 191 standards may not be sufficient to handle the variability of Indian roads. For instance, the document specifies a forward detection range of 46 meters and lateral detection requirements for adjacent lanes are not mentioned (Draft D1_AIS_191). As they can be suitable for standardized road conditions, these parameters need to be recalibration to accommodate India's dynamic and diverse road scenarios. Another aspect is related to operational design domain which needs to be dynamic as in India majorly highways often accommodate pedestrians, cyclists, and a mix of slow-moving and fast-moving vehicles, creating a more complex operational environment for ALKS. Also, UN R157 regulations assumes well-maintained highways with clear lane markings, signage, and physical separations to guide the ALKS, where in Indian scenario many roads' lacks in consistent or visible lane markings, physical separations between opposing traffic flows, standardized traffic signs and markings, which are crucial for ALKS to function effectively and hence the system must be adapted to operate in ambiguous road conditions as well.

4.2.4 Use Case 5 - Collision Avoidance

The following scenarios are designed and developed at TiHAN Testbed proving grounds.

4.2.4.1 Use Case 5.1 - Object on the Intended Path

An object in the ego vehicle's route is blocking the ego vehicle's path. There are no other vehicles on the road. If a sound object is on the route, the ego car may swerve around the object, but it may have driven over it. However, when an oncoming vehicle approaches from the other lane, priority rules apply to maneuvering around the obstacle. If the object is impassable, the ego vehicle must avoid the impassable item. The ego car may shift lanes to avoid the item in this instance. However, if an oncoming car arrives from the other lane, the approaching vehicle gets priority over the ego vehicle's passing maneuver.
Schematic representation is given in Figure 8.

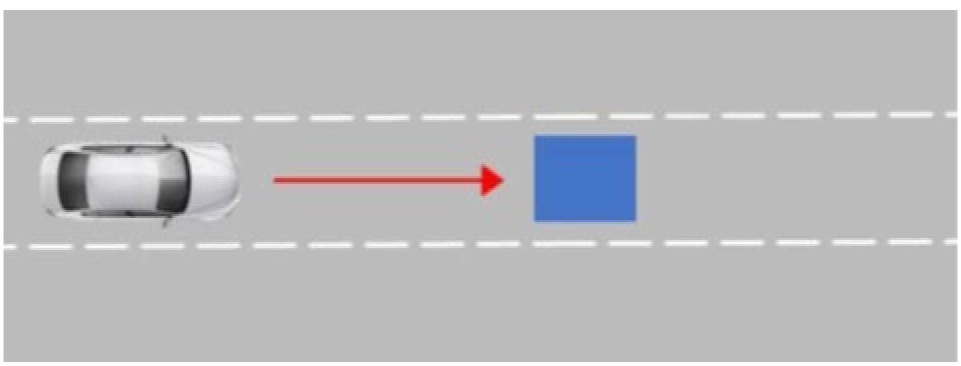


Figure 8. Schematic representation of an object on the intended path

4.2.4.2 Use Case 5.2 - Ego Vehicle Approaching a Vehicle

In front of the ego vehicle, another vehicle (lead vehicle) is going slower or has come to a halt. As a result, the other car appears in the ego vehicle's field of view. The ego car may use the brakes to avoid collision. Another option for the ego car is to make a lane shift. If the lead vehicle brakes, the ego vehicle must alter its speed to keep a safe distance from the lead vehicle.
The use case scenario can be seen in Figure 9.

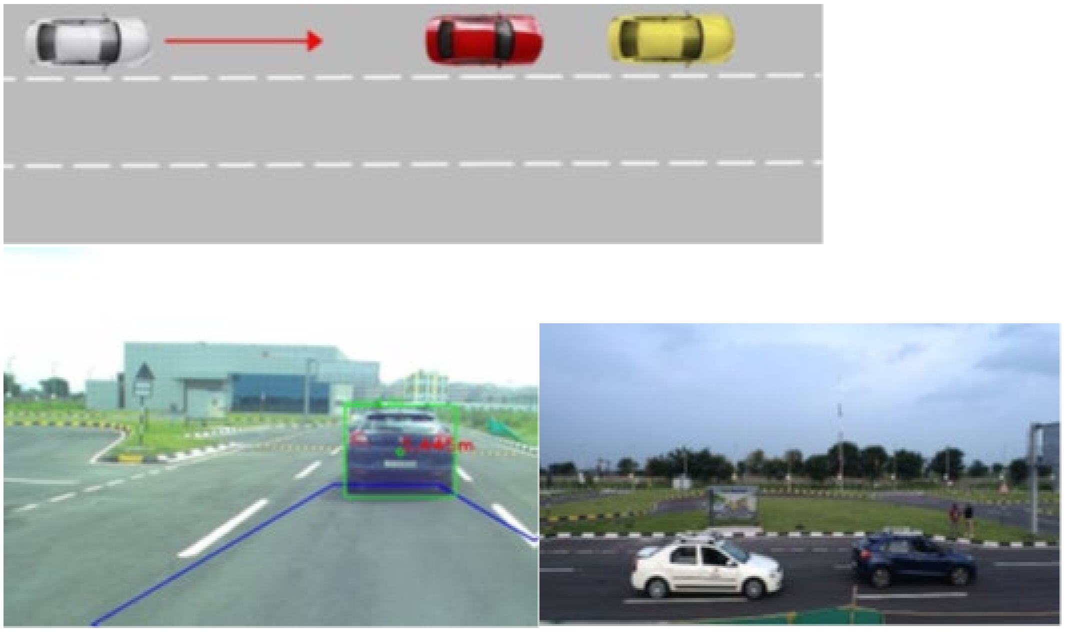


Figure 9. Schematic representation of ego vehicle approaching another vehicle and real-time testing at TiHAN testbed

4.2.4.3 Standards & Gaps

In Indian context, there exist automotive industry standard 162 in draft stage (AIS 162/DF) titled, "*Type Approval of Motor Vehicles of categories M2, M3, N2 and N3 with regard to the Advanced Emergency Braking Systems (AEBS)"* for providing uniformity in provisions to test the AEBS in the vehicles of aforementioned categories on straight roads only [15A]. The following observations can be made to the draft document.

A. **Vehicle Category**

One of the key elements of standardized parameters is the time to collision (TTC) warning and actuation time instants upon potential collision scenarios on a driving straight condition. Although the considered road type is the major source of accidents [15B], the vehicle types considered in AIS 162 are at least four-wheelers. It is known from the reports that 2-wheeler category vehicles are a major source of fatalities.

B. **Sensor Types**

Considered sensors in the AIS 162 are camera and radar and for AEBS type approval, the tests are to be conducted in high visibility. It is not clear, as per the standard, how the sensor data analytics addresses the actual scenario of low visibility conditions.

C. **Brake Types**

It is also not clear on provided uniformity of provisions on the sensitivity of TTC to various brake types, such as drum vs disc brakes, etc.,

4.2.5 Use Case 6 - Traffic signage detection

Scenario Description

Traffic signs play a critical role in modern transportation by leveraging advanced technologies to improve safety, efficiency, and sustainability. Their major functionalities include accident prevention, emergency response, traffic management, speed monitoring, violation detection, sustainable transportation, and providing information to autonomous vehicles.

The following traffic sign detection use case has been designed and developed at TiHAN testbed proving grounds.

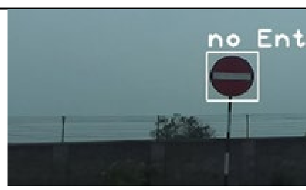
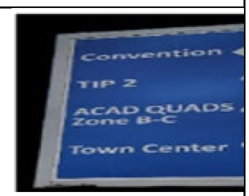
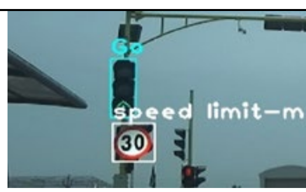
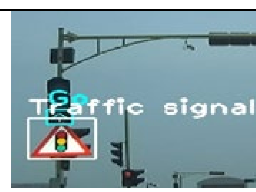
Figure 10. Schematic representation of (a) T-junction and Traffic Signal Detection and (b) Bus Stop and Speed Limit Detection on Driving Path

Figure (a) detects a T-junction where two roads intersect. At the junction, a traffic signal sign is presented. Through this object monitoring, we can control traffic and reduce accidents effectively. Figure (b) presents bus stop and speed limit signs. Based on this information, the ego vehicle can observe and make decisions such as slowing down, changing lanes, and stopping accordingly.

For Road and Traffic Object Monitoring purposes, 3 types of sign boards are available mandatory, cautionary, and informative.

The table below depicts various traffic signage categories. Mandatory sign boards convey essential instructions that drivers must adhere to. These include speed limits, lane usage, or compulsory turns, ensuring safe and orderly traffic flow. Cautionary sign boards alert drivers to potential hazards ahead, including sharp curves, pedestrian crossings, or slippery roads, prompting them to exercise caution and reduce speed accordingly. Informative sign boards provide helpful information to drivers about the road ahead, such as upcoming landmarks, distance to destinations, or services available, enhancing navigation and driving convenience.

Table 1. Different objects monitoring sign board's significance towards road and traffic management

Mandatory	Cautionary	Informative
Stop, Give Way, U-turn prohibited, No Entry, No Parking, Speed Limit Compulsory keep left, etc.,	Traffic Signal. Round-about, T- Junction, right reverse bend, Pedestrian Crossing, Y- Junction, etc.,	Informatory Board Bus stop. Parking lot Parking lot bike-car Parking lot cycles, Direction sign, etc.,
		
		
		

Annexure 2 provides a detailed account of the initiatives undertaken by TIHAN and ARAI towards Traffic sign detection as a use-case for ADAS and autonomy for India.

4.2.5.1 Standards and Gaps

The ISO 14823:2017 document specifies a graphic data dictionary with encoding and decoding message protocols framework for delivering Traffic and Traveler Information (TTI) messages, as part of Intelligent Transportation Systems. The ISO 3166-2:IN delineates the country and state codes for India and the ISO 14823:2017 consists of the category codes for the traffic signs in the three categories of warning, regulatory and informative signs. The TTI message framework allows the interoperability of vehicles between Countries/States. Although the document elucidates TTI-based the in-vehicle signage or in-vehicle information system, the automation technology behind the detection and classification of signs has not been discussed.

As noted in [16], the standardization and homologation processes for the automated driving technologies, including the computer-vision based traffic sign detection and classification under various visibility and weather conditions, are under testing and development all over the world. In the Indian context as well, there exists no automotive industry standard (AIS) in the Ministry of Road Transport and Highways repository that address the traffic sign detection and classification system requirements.

Beyond these foundational ADAS functions, several emerging use cases build on V2X communication, predictive analytics, and cooperative driving principles to enhance efficiency and safety. Features such as Cross Traffic Alert, Predictive Cruise Control, Green Light Optimal Speed Advisory (GLOSA), Intersection Movement Assist, Cooperative Merging, and Cooperative Collision Alerts represent the next layer of innovation. While closely aligned with the core categories, these advanced applications extend their capabilities by enabling vehicles to anticipate, communicate, and coordinate with their surroundings—paving the way toward fully connected and automated transportation ecosystems. The advantages of V2X communication extended to emerging use cases are summarized in Table 2.

Table 2. The advantages of V2X communication for emerging use cases

Platooning	Cooperative Merging	Extends platooning by enabling smooth lane merging of trucks/cars into convoys using V2V communication.
	Predictive Cruise Control	Enhances platooning efficiency by using map/topography/traffic data to optimize acceleration & braking in convoys.
Collision Avoidance	Cross Traffic Alert (CTA)	Warns of vehicles/pedestrians crossing perpendicularly.
	Cooperative Collision Alerts	V2V/V2X communication warning system to prevent crashes beyond sensor line-of-sight.
	Intersection Movement Assist (IMA)	Detects risks from other vehicles at intersections, prevents side-impact collisions.
Traffic Signage Detection	Green Light Optimal Speed Advisory (GLOSA)	Uses traffic signal phase/timing info to suggest optimal speeds; reduces idling, emissions, and improves flow

4.3 SatNav Use Cases

These use cases focus on the use of Satellite Navigation (SatNav) Technology (based on NavIC) for achieving vehicle coordination, inter-vehicle communication, and convoy-like behavior.

4.3.1 Use Case 7 – Location Granularity (NaVIC)

A. **Enhancing Automated Electric Road Transportation with GNSS Granularity**

Global Navigation Satellite Systems (GNSS) like GPS, GLONASS, Galileo, BeiDou, and NavIC are crucial for providing accurate location data needed for automated road transportation. Combining GNSS with local sensors provides a comprehensive view, where local sensors handle immediate surroundings and GNSS offers a broader perspective of the entire journey.

B. **Achieving High Location Granularity**

Positioning accuracy depends on the number of available satellites and their transmission frequencies. A multi-constellation approach boosts satellite numbers, increasing robustness, especially where signals may be obstructed. Dual-frequency GNSS enhances accuracy by reducing ionospheric errors, while local sensors fill in details for local scenarios, such as lane changes or obstacles. Together, they provide a full picture of the vehicle's journey.

By merging multi-constellation and dual-frequency GNSS, typical positioning accuracy improves to 2-5 meters. For even greater precision, differential GNSS techniques like Real-Time Kinematic (RTK) or using high accuracy services enhancements like Precise Point Positioning (PPP) can provide submeter accuracy, essential for dense traffic and complex road conditions.

C. **NavIC's Role in India**

NavIC (Navigation with Indian Constellation), developed by ISRO, is India's regional satellite system, contributing significantly to global GNSS capabilities. NavIC's geostationary and geosynchronous satellites offer a higher elevation angle over the Indian region, ensuring better line-of-sight visibility in dense urban environments compared to lower-elevation GNSS constellations. This minimizes signal blockages caused by buildings and flyovers, making NavIC particularly effective in urban canyons. The constant visibility of NavIC satellites in the Indian region enhances signal availability, reducing positioning gaps and improving reliability for automated transportation, real-time navigation, and critical applications like toll management in India's complex road networks.

Figure 11. NavIC Constellation

When integrated with other GNSS constellations, NavIC provides a more resilient positioning framework. In India's diverse landscapes and congested urban areas, NavIC and local sensors offer reliable navigation, ensuring that both the larger environment and the local environment are accounted for, especially for toll management or complex traffic situations.

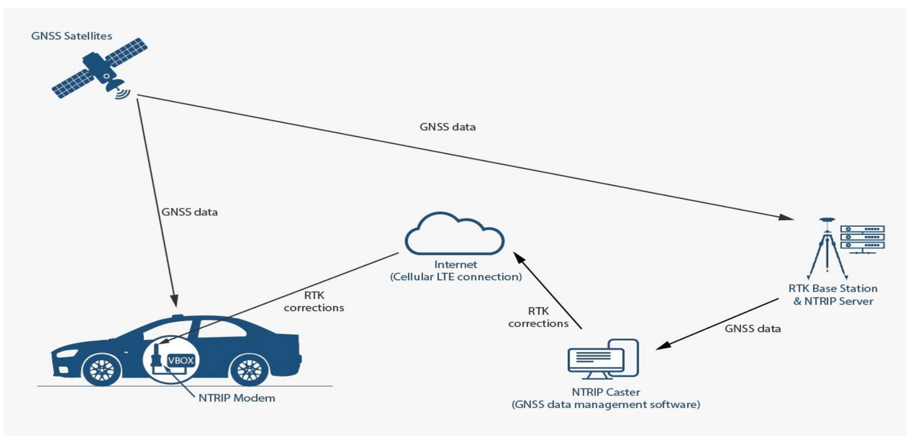


Figure 12. GNSS RTK corrections through Network

4.3.1.1 Key Benefits of Enhanced GNSS Granularity

Key benefits of enhanced GNSS granularity are mentioned below.

i. Broader and Localized View: GNSS provides the broader perspective of the entire route, while local sensors focus on immediate scenarios like vehicle proximity and road conditions.

ii. Improved Accuracy: Dual-frequency capabilities and local sensors work together, enhancing precision for safer and more efficient vehicle operations.

iii. Regional Adaptation: NavIC's integration ensures a reliable solution tailored to India's geographic challenges, making automated transportation more effective.

iv. Enhanced Traffic Management: Combining GNSS and local sensors ensures better navigation in critical areas, improving overall safety and traffic flow.

v. Gaps related to GNSS granularity in the context of automated transportation in India, several areas of concern and opportunities for improvement can be identified:

A. **Limited Satellite Coverage in Urban Canyons**

The gap and solution of the limited satellite coverage in urban canyons are given below.

i. Gap: GNSS signals can be obstructed in urban areas with tall buildings or underpasses, creating blind spots where accurate positioning becomes challenging.

ii. Solution: Integrating more advanced local sensors like inertial systems and additionally utilizing ground-based augmentation systems (GBAS) can enhance the accuracy in urban settings.

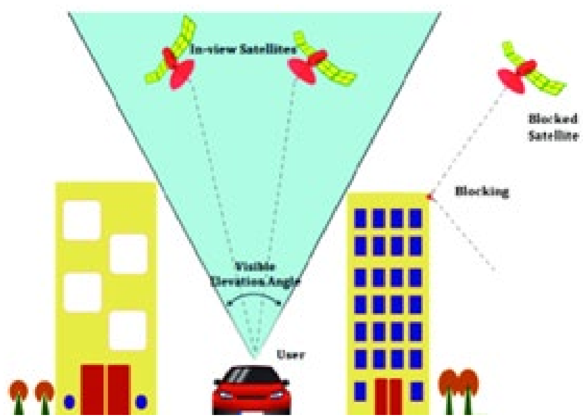


Figure 13. Satellite Signal blocking in urban canyons

B. **Challenges in Complex Road Networks**

The gap and solution of challenges in complex road networks are given below.

i. Gap: On India's complex road networks, such as multi-layered highways, GNSS granularity may struggle to differentiate between vehicles travelling on different levels (e.g., elevated roads vs. ground-level roads).

ii. Solution: Using multi-sensor fusion (GNSS, inertial sensors, and camera-based navigation) can help in distinguishing complex road structures and provide a more precise location understanding.

C. **Limited Adoption of High-Precision GNSS**

The gap and solution of the limited adoption of high-precision GNSS are given below.

i. Gap: High-precision GNSS technologies like RTK or PPP have not yet been widely adopted, limiting the granularity necessary for automated vehicle platooning or close-proximity navigation.

ii. Solution: Greater investment in high-precision GNSS infrastructure, along with scaling the availability of affordable dual-frequency receivers, can bridge this gap and support more precise navigation.

D. **Interoperability Issues Between GNSS and Local Sensors**

The gap and solution of interoperability issues between GNSS and local sensors are given below.

i. Gap: Integrating GNSS data with local sensors, such as LiDAR, radar, and cameras, presents interoperability challenges due to differing data formats, timing issues, and the need for synchronization.

ii. Solution: Development of standardized communication protocols and algorithms for sensor fusion to ensure seamless interaction between local and GNSS-based positioning systems.

Observations

The convergence of multi-constellation GNSS technologies with local sensors enhances the granularity of location data, providing both a big-picture view and precise local detail. NavIC's integration with global systems ensures that India has a resilient GNSS framework, supporting automated electric vehicles and helping to create safer, more efficient transport systems. This combination will be crucial as India moves towards intelligent, automated roadways in the 21st century, driving both technological progress and regional adaptability.

4.3.2 Use Case 8 - GNSS-Based Tolling

Global Navigation Satellite System (GNSS)-based tolling represents a modern and advanced method for Electronic Toll Collection (ETC). Unlike traditional systems reliant on physical toll booths, GNSS-based tolling would be barrier-free and calculate toll fees based on the exact distance travelled by a vehicle on tolled roads. By utilizing satellite navigation technology, the system would enable efficient, real-time tolling without requiring vehicles to stop or slow down at toll points, aligning with global trends in road management.

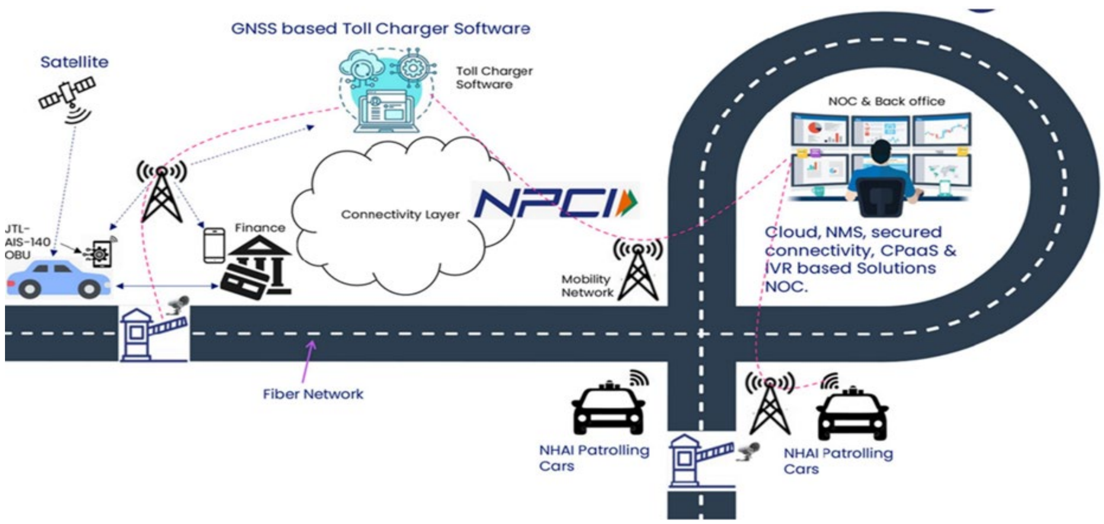


Figure 14. Components of GNSS based tolling

4.3.2.1 Key Components of GNSS-Based Tolling in India

A. **On-Board Unit (OBU)**

Vehicles are to be equipped with GNSS-enabled OBUs, such as AIS 140 VLT devices, that would send anonymized pings (location and time stamps) to a centralized toll charger. These pings would be transmitted at defined intervals (1 to 5 seconds) for accurate tracking of the vehicle's journey on tollable roads. *(Read in Conjunction with para 4.3.4 of Use Case 9 - Multi GNSS Integrated System MGIS AERT)*

B. **Centralized Toll Charger**

This system will play a central role in the tolling process by.

i. Map Matching: Accurately identifying the vehicle's position on the tolled network using pings from the OBU.

ii. Distance Calculation: Using advanced algorithms to calculate the exact distance travelled by vehicle, distinguishing between main carriageways and adjacent service roads.

iii. User Fee Calculation: Calculating toll fees based on vehicle type, road type (e.g., elevated sections), and time of day. This process can be triggered by vehicle entry/exit points or irregular behavior (e.g., U-turns or stopping).

C. **Payment and Notification**

i. Toll fees are processed through an acquirer bank, akin to the FASTag ecosystem.

ii. Road users notified of toll charges via SMS, with details such as the distance travelled and a link to view the vehicle's route on a map.

D. **Data Privacy and Security**

The system prioritizes data privacy by transmitting anonymized pings, ensuring that only toll-relevant data is processed while adhering to stringent data security protocols.

4.3.2.1.1 India's GNSS Tolling System: Unique Aspects and Benefits

Following are the unique aspects and benefits of India’s GNSS tolling system.

A. **Use of NavIC**

India’s GNSS-based tolling system seeks to leverage its indigenous satellite navigation system, NavIC, developed by ISRO. This provides several advantages, including reducing dependency on foreign satellite services and offering improved coverage and accuracy, especially in challenging environments such as urban canyons and areas with dense foliage or flyovers.

B. **Hybrid Model**

India is adopting a hybrid approach, integrating GNSS tolling with the existing FASTag system. This allows for a gradual transition, minimizing disruption and ensuring stakeholders have time to adapt.

C. **Phased Rollout and Scalability**

The GNSS-based tolling system is scalable and will expand from an initial focus on commercial vehicles to eventually cover private vehicles, aiming to span 100,000 kilometres of roads over the next decade.

4.3.2.1.2 Addressing Current Gaps

Following are the gaps of GNSS-Based Tolling.

A. **Integration with Existing Systems**

Seamless integration between GNSS and FASTag is essential to avoid issues like double charging, ensuring a smooth user experience across both systems.

B. **Technological Adaptation**

The AIS 140 devices used in vehicles may require modifications, such as increased memory and enhanced communication protocols, to support the GNSS system.

C. **Scalability and Accuracy**

As the system scales to 100,000 km of roads, smooth and reliable functioning of the GNSS system is to be ensured.

D. **Data Privacy and Security**

Compliance with data privacy laws is essential while ensuring that accurate, real-time tracking and toll collection are maintained.

E. **User Adoption and Awareness**

Road users, particularly commercial vehicle operators, need to be educated on the new system to ensure smooth onboarding and widespread adoption.

4.3.2.1.3 GNSS Tolling and India's Infrastructure Vision

By integrating GNSS with the existing FASTag framework, India would be aligning with global best practices while addressing local requirements and fostering self-reliance. The GNSS-based system will enhance tolling efficiency, reduce congestion, and improve revenue collection by providing a reliable and scalable solution across India's extensive highway network. It also aligns with the country's vision for a digitally driven infrastructure capable of supporting future growth while ensuring a seamless, efficient experience for road users.

4.3.4 Use Case 9 - Multi-GNSS-Integrated System for Automated Electric Road Transportation (MGIS–AERT)

Integrating multi-GNSS technology forms the cornerstone of a comprehensive framework for Automated Electric Road Transportation (AERT). This system addresses the critical requirements of precise road mapping, real-time vehicle navigation assistance, and intelligent tolling solutions. Accurate and detailed digital mapping of roads across urban, rural, and highway networks provides the foundational data for enabling autonomous vehicle navigation and traffic management. By leveraging multi-GNSS systems (based on NavIC), this mapping enables the seamless integration of road layouts, bends, crossings, and entry/exit points into vehicle control systems, ensuring safe and efficient maneuvering for autonomous vehicles. Consequently, integrating multi-GNSS-enabled vehicle navigation assist systems empowers stakeholders such as fleet operators, transport departments, toll authorities, and law enforcement by enabling efficient traffic management, congestion reduction, and enhanced security with real-time vehicle monitoring. Besides, it provides valuable insights into traffic flow and mitigates oversight of unauthorized or unlawful vehicles.

One of the advantageous applications is a multi-GNSS-based tolling system that revolutionizes toll collection by enabling a usage-based pricing model that calculates toll charges based on distance travelled. This system mitigates the limitations of RFID-based tolling, eliminates the need for physical toll plazas, reduces congestion, and ensures a seamless experience for drivers. Integrating AI/ML technologies further enhances operational efficiency, enabling dynamic and scalable tolling solutions while providing actionable insights for infrastructure planning and policy formulation.

This use case demonstrates how multi-GNSS technology synergistically addresses the core requirements of automated electric road transportation—accurate mapping, intelligent tracking, and efficient tolling—paving the way for a transformative future in transportation infrastructure. A suggested business model for a multi-GNSS-integrated system for automated electric road transportation is presented in 4.3.4 Use case 9. This use case demonstrates the way in which multi-GNSS-based solutions for automated transportation systems can facilitate stakeholders, such as RTOs, MoRTH, NHAI, government regulatory bodies, toll operators, fleet managers and individuals involved in contactless tolling systems, in planning, implementing, and managing automated transport systems.

* Electrification in heavy commercial vehicles remains in its early stages, primarily due to limitations in charging infrastructure and the current constraints of battery chemistry. As a result, the industry is actively exploring alternative fuel options such as hydrogen, compressed natural gas (CNG), and other low-emission technologies to bridge the gap toward sustainable transportation.

4.3.5 Use Case 10 - Digitized Mapping of Roads and Lanes using Multi-GNSS-based Equipment

The accurate digital mapping of roads and highways using multi-GNSS systems like NavIC, GPS, and GLONASS is discussed below. It focuses on creating detailed road layouts, including bends, crossings, and entry/exit points, to support autonomous vehicle navigation and safe traffic management. Though mapping with multi-GNSS is beneficial, it has limitations like limited satellite coverage in urban canyons and challenges in complex road networks. However, these challenges can be mitigated with ground-based augmentation systems (GBAS) and multi-sensor fusion. Refer to Points 1 and 2 of the "Gaps Related to GNSS Granularity in the Context of AERT in India" of the Section "Enhancing AERT with GNSS Granularity".

4.3.5.1 Key Features of the Multi-GNSS-Based Survey System

The multi-GNSS-based survey system will be based on static and mobile survey stations, server units, and QGIS maps. Figure 1 shows the schematic of the multi-GNSS-based survey system.

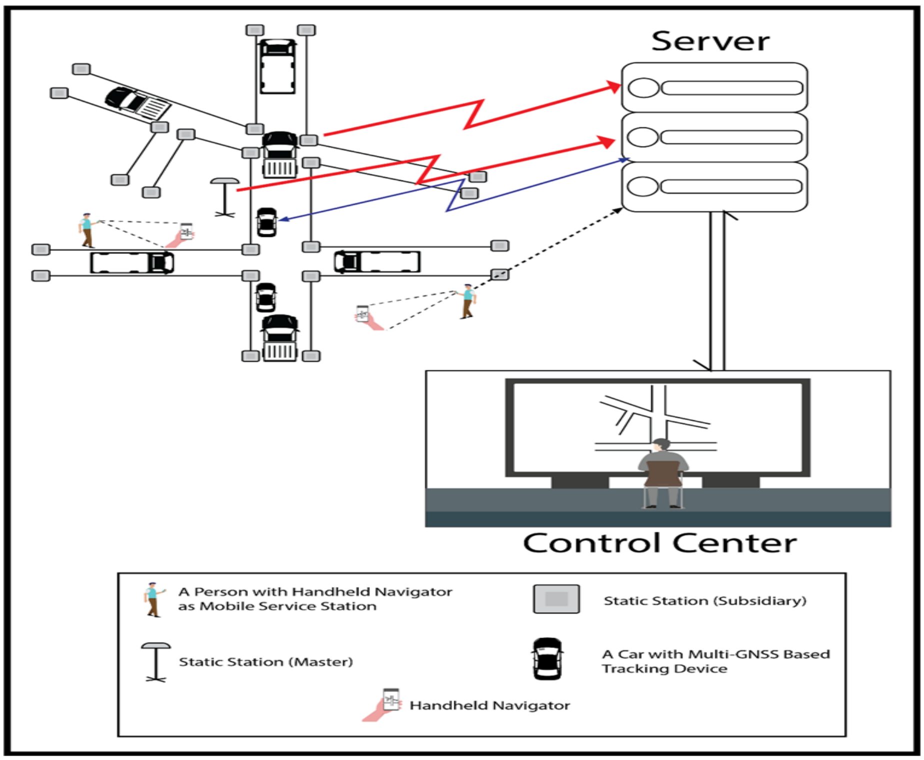


Figure 15. Schematic Representation of the Digitization of Mapping System for AERT

The details and functional requirements of these systems are as follows.

A. **Static Survey Station**

The static survey station will consist of a dual-band antenna, a multi-GNSS receiver, a server, a software application with static IP connectivity to the Internet, and a UPS-based power connection.

The nodal static station with accurate Lat Long coordinates will continuously obtain position information to determine error correction and mitigate the effect of ionospheric disturbances. The error correction transmitted to the mobile survey stations ensures accurate positional data for surveying roads and lanes. Besides, there will also be subsidiary static stations to record positional data, if required. Figure 16 shows the schematic of the utilization of mobile and static survey stations for position updates.

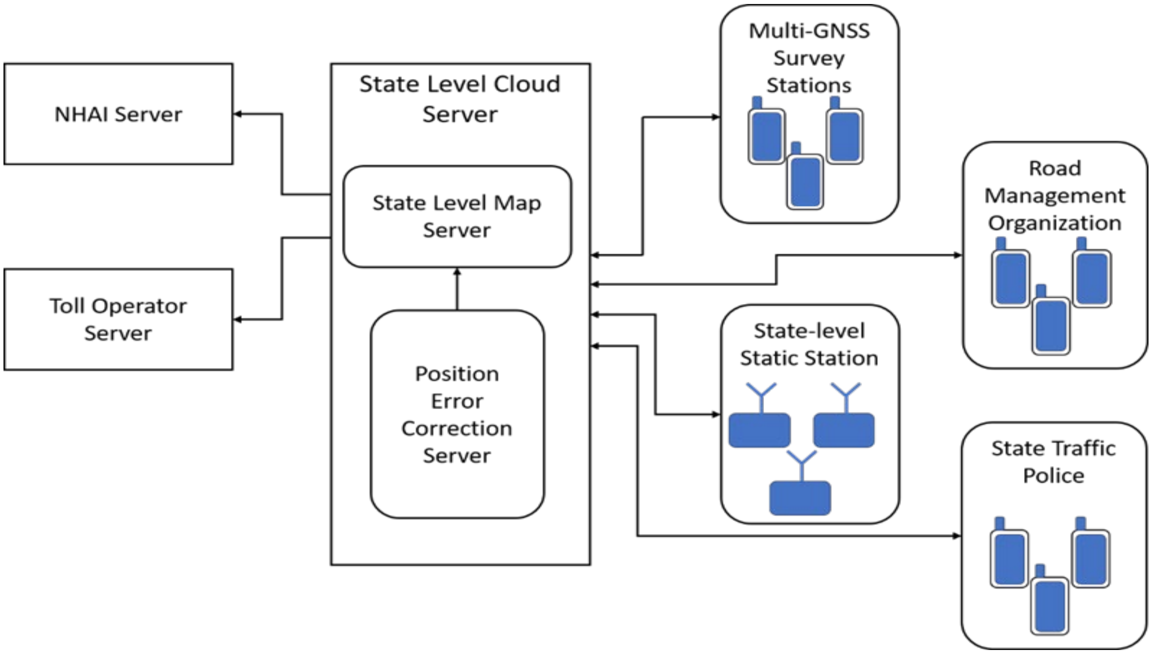


Figure 16. Schematic for Utilization of Mobile and Static Survey Stations for Position

B. **Mobile Survey Station**

Routes will be over undulating ground and/or with twisting paths at certain places. In such planes, a lightweight handheld device will be required for mapping. A mobile survey station is a handheld device with a suitable software application to record the position information continuously, which would be used by survey personnel. This mobile survey station would connect to the network through an IoT SIM or other media like LoRa. It will be able to connect to the nearest static survey station within 50 km to obtain applicable error corrections for processing the corrected positional information with sub-meter accuracy and storing it on a mobile device. The mobile survey station will get instantaneous error correction data from the cloud server. The mobile device can enable data collection for digital marking lanes. These handheld devices will also be used by traffic police, road management services, and toll service providers to update events like accidents, road or lane closures due to gas line work, telephone cables laying, electric cables laying, etc.

C. **Servers**

Cloud-based servers enable large-volume data processing, storage, and need-based sharing with the control centre and connected devices. Several cloud-based servers will be used for efficient data management for GNSS-based surveying. These servers will be helpful for local police, fleet operators, AERT vehicle management operators, toll operators, etc. Refer to Table 1 for the list of cloud-based servers and their applications for surveying. Figure 3 shows the schematic of cloud-based servers used in digitized mapping and surveying.

Table 2. Types of Servers and Their Functions in Lane Surveying

S. No.	Type of Server	Function in Lane Surveying
1	Map Server	A. Stores and processes GNSS survey data B. Corrects inaccuracies and updates data for mapping C. Manages digital maps, geospatial layers, and road network data
2	Road Transportation Management Server	Uses AI to detect Lane changes, Road variations and Survey anomalies
3	Traffic Police Server	D. Update road anomalies E. Provide inputs to avoid congestion
4	Toll Operator Server	A. Charge users for the exact distance travelled

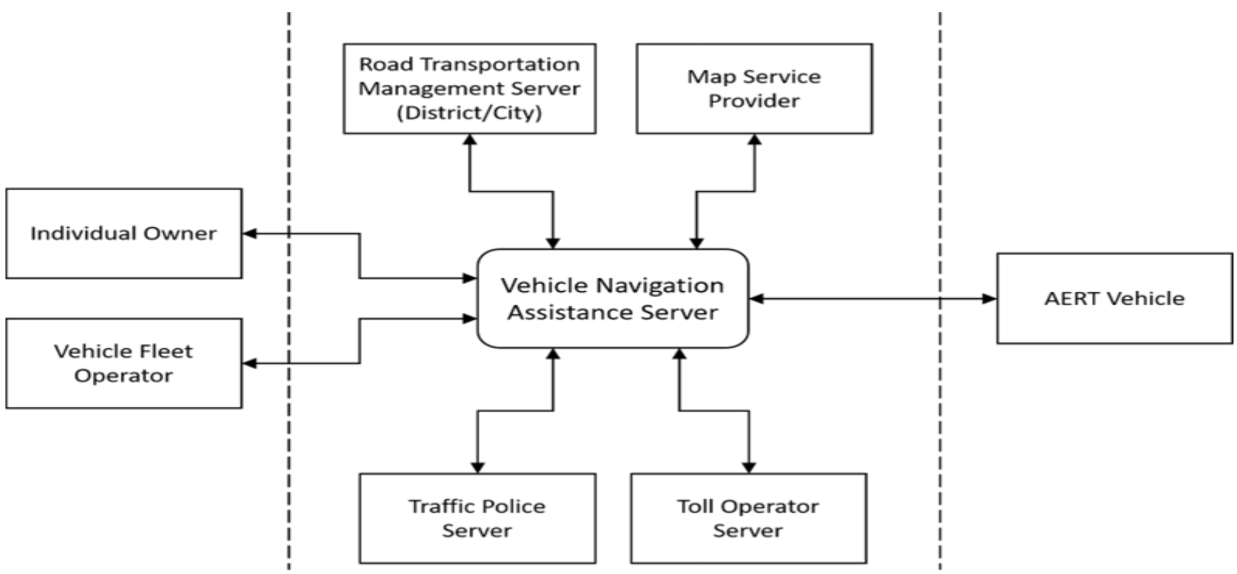


Figure 17. Schematic of Cloud-based Servers used in Digitized Mapping

D. **Mapping Systems**

The digitized maps will be updated with inputs from the survey stations. QGIS-based digitized maps made available in the cloud will have High-Precision Positioning, Real-Time Map Updates, and Geofencing (Geofencing capabilities allow vehicles to operate within predefined areas). These digitized maps would provide the basic template for planning the move of autonomous vehicles. All other data, like charges for toll roads and expressways, would be based on the entry and exit of vehicles in respective geofenced areas to calculate toll charges to be imposed. The respective roads and transport departments of states and private licensed map service operators can maintain the mapping systems. All operators should have similar maps from survey teams in their respective states.

4.3.5.2 Key Benefits of the Multi-GNSS-based Survey System

The Multi-GNSS Survey System will provide several benefits for developing infrastructure to facilitate the final deployment of autonomous vehicles.

A. **Enhanced Speed of Survey**

The use of handheld mobile survey stations programmed to record the accurate positional information of road and lane boundaries can easily facilitate the precise marking of roads or lanes on each road by mobile means, increasing the speed of survey and marking of road infrastructure on digitized maps eliminating the present measurement using metal chains and ropes.

B. **Reduction of Manpower**

The handheld mobile survey devices will save the manpower required to survey road infrastructure.

C. **Cost Efficiency in Survey of Land**

There would be a need to complete the survey across the entire country and use handheld survey devices, saving in manpower and faster conduct of the survey would enhance the cost efficiency to the state and local governments in conduct of overall survey and creation of digitized land records.

D. **Better Revenue Generation**

The availability of accurate land details will help provide a clear understanding of land ownership, leading to efficiency in land and property tax collection and enhancing revenue generation at municipal and district levels.

E. **Cross-sectoral advantages**

As enumerated here, a digitized map developed and deployed will be a force multiplier with cross-sectoral advantages in multiple domains. These maps and the information therein will be helpful for law enforcement agencies, emergency services, logistic agencies and town planning.

F. **Virtual Lanes**

The lane marking may be erased over time. Virtual lanes can be created to enable vehicle movement to be depicted.

G. **Optimized Utilization of 5G & 6G Technologies**

Such detailed digitized maps will enable the deployment of IoT devices and optimally exploit the 5G and 6G Technologies.

4.3.5.3 Advantages of Multi-GNSS-based Survey System

The multi-GNSS-based Survey System will create digitized QGIS maps for autonomous vehicle implementation. These maps can be produced either by government departments or licensed Indigenous agencies. The deployment of autonomous vehicles will only be possible after completing road surveys and making detailed digitized maps publicly available. Digitized roads and lane markings will help in the absence of a physical marking on the roads. Digitized roads and lane marking will also help with other use cases like 'Platooning', 'Lane Keeping', and *'Traffic Signage Detection'*.

4.3.6 Use Case 11 - Multi-GNSS-based Vehicle Tracking System for AERT in Separated Lanes

A multi-GNSS-based vehicle tracking system will enable precise navigation for Automated Electric Road Transport. It will conform to the requirements mentioned in clauses 3.0, 5.0 and 6.0 of AIS-140 as amended until February 2024. It supports efficient traffic management, fleet tracking, and distance-based tolling. Integrated with the *Vahan* database, it aids law enforcement in monitoring vehicle movements, detecting congestion, and improving signal timing to reduce delays.

4.3.6.1 Key Features of the Multi-GNSS-based Vehicle Tracking System

Figure 18 shows the schematic of the multi-GNSS-based VNAS. The vehicle navigation assist system will incorporate the following key features.

A. **Onboard Unit (OBU)**

The OBU will consist of a dual-band antenna, multi GNSS receiver, communication element (GSM/non-GSM options), and a rechargeable power pack. The installation of OBU will follow the requirements given in clause 5.0 of AIS 140. Refer to the Subsection "Key Components of GNSS-Based Tolling in India" from the section "GNSS-based Tolling" in the white paper [18].

B. **Communication System**

Communication systems with low latency and high integrity to ensure real-time navigation and control and to support connectivity of IoT devices. It will conform to the requirements mentioned in clauses 4.0 and 7.0 [18].

C. **Servers**

Both cloud-based and stand-alone options with the capability for large-volume storage and processing to enable cloud computing with allied options such as distributed cloud computing. Each VNAS will connect with the vehicle control system server to relay its instantaneous position, and the system will be passed on to other stakeholders for updates. The centralized server will follow functionalities given in clauses 3.0, 4.0, 5.0, and 6.0 [18].

D. **Mapping Systems**

QGIS-based digitized maps for High-Precision Positioning, Real-Time Map Updates, and Geofencing (Geofencing capabilities allow vehicles to operate within predefined areas).

E. **Sensor Inputs**

It may include Lidar, Radar, Cameras, and Ultrasonic Sensors. It can enable obstacle avoidance systems and effective lane maintenance.

F. **Interactive Panel**

An interactive panel can provide real-time actionable inputs for effective traffic management and easy driving at the user end.

4.3.6.2 Key Benefits of the Multi-GNSS-based Vehicle Tracking System

Numerous benefits can be accrued by deploying the multi-GNSS-based vehicle tracking system. Some of them are as follows.

A. **Optimized Traffic Management**

Controlled traffic flow, reduced congestion, and prevented accidents.

B. **Capitalizing benefits of Autonomous Vehicles**

Efficient navigation can benefit from the ability of autonomous vehicles to operate without long breaks, such as on-demand services.

C. **Environmental Benefits**

Reduced emissions from electric vehicles (EVs) and reduced noise pollution will contribute to a healthier urban environment.

D. **Cost Efficiency**

Autonomous transport with efficient navigation reduces operational costs, providing more affordable and sustainable services.

E. **Digitized Lanes**

Enable lane-keeping on unmarked roads.

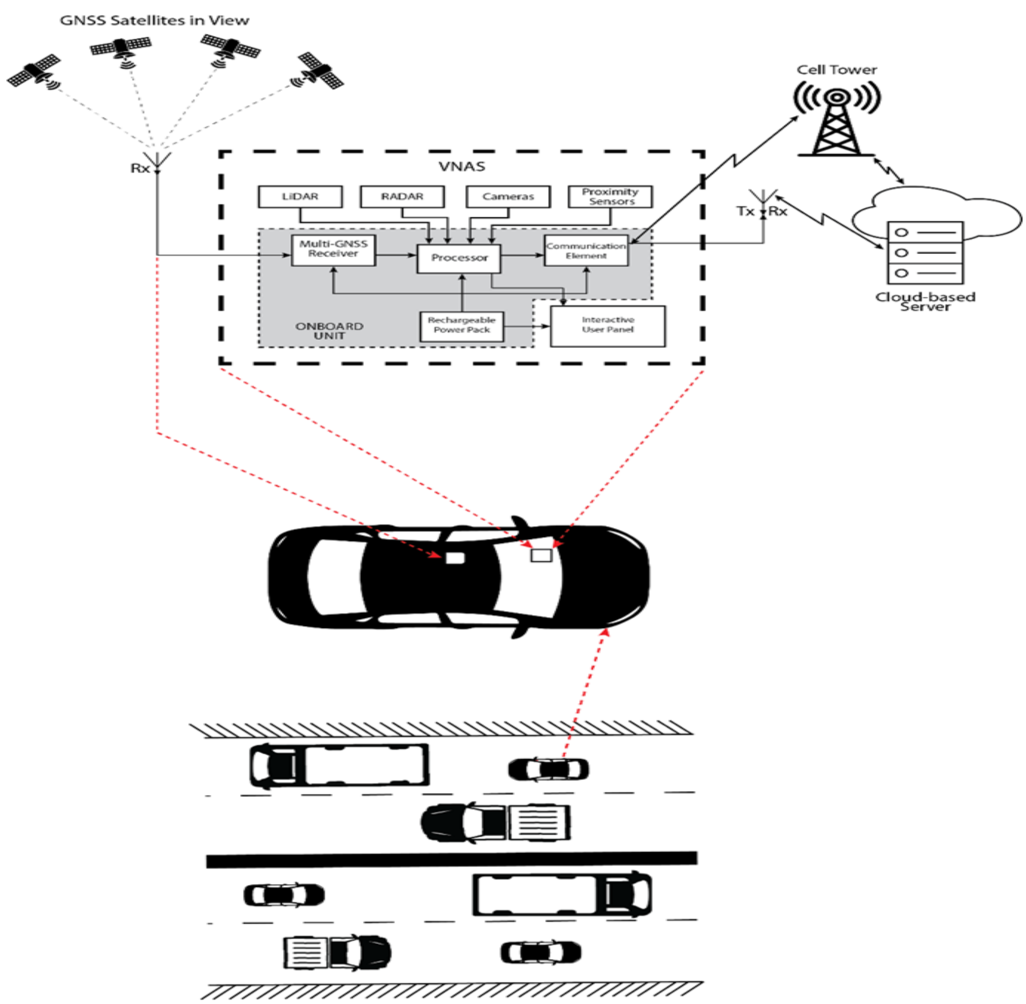


Figure 18. Schematic of the Multi-GNSS-based Vehicle Tracking Systems for AERT

4.3.6.3 Advantages of Multi-GNSS-based Vehicle Tracking System for AERT in Separated Lanes

The multi-GNSS-based VNAS, equipped with integrated applications, will streamline traffic management for Automated Electric Road Transport. It provides private users and commercial fleet owners with precise vehicle tracking capabilities while supporting law enforcement in monitoring activities and enabling efficient use of toll-based road networks. The multi-GNSS-based VNAS will help use cases like *'Road and Traffic Object Monitoring'* and *'Automated Toll Vehicle Tracking'* of the AERT white paper.

4.3.7 Use Case 12 - Multi-GNSS-Integrated Tolling System for Automated Electric Road Transportation (MGITS-AERT)

Multi-GNSS-Integrated tolling systems are crucial for AERT, offering distance-based charges, improved traffic flow, and reduced congestion compared to RFID-based systems. By leveraging satellite navigation technologies and integrating AI/ML, this system ensures seamless tolling, fair pricing, and efficient roadway management, enhancing India's transportation infrastructure.

4.3.7.1 Key Features of the Multi-GNSS-Integrated Tolling System for AERT

The schematic for a multi-GNSS-integrated tolling system for AERT has been shown in Figure 19.

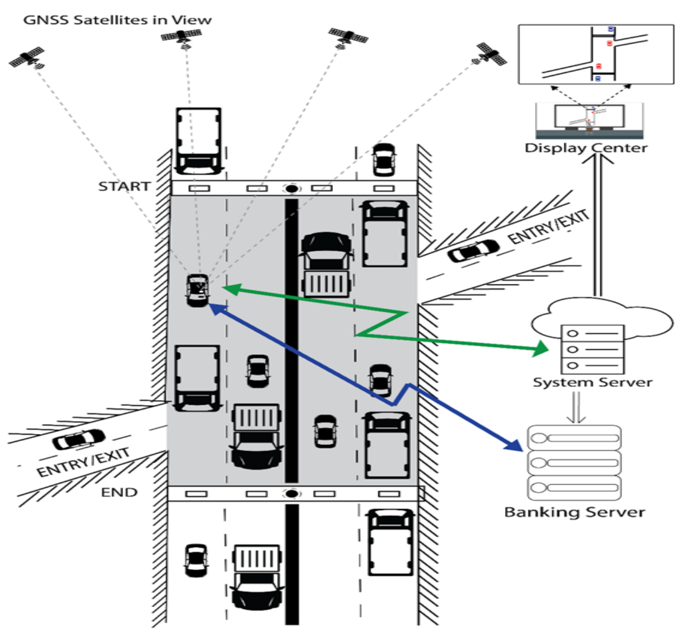


Figure 19. Schematic for Multi-GNSS-Integrated Tolling System for AERT

The multi-GNSS-integrated tolling system consists of a ground-based system and a vehicular system. The ground-based system assists the vehicular system with automated tolling. The multi-GNSS-integrated tolling system will incorporate the following key features.

i. Ground-based System: It consists of Multi-GNSS-enabled Virtual Toll Booths that are marked for the start and end of the tolled road. The precise location of the toll booth is obtained using a highly precise multi-GNSS receiver to mark it on the GIS map. The digitized mapping of the area covered by tolled roads between the consecutive toll booths is required for efficient toll collection. This can be achieved by geofencing the tolled road area with the inputs obtained using multi-GNSS-based handheld navigators.

ii. System Server: A cloud-based server capable of large-volume storage and vehicle data processing, enabling effective toll management. The central server will follow the functionalities in clauses 3.0, 4.0, 5.0 and 6.0 [17]. The system server sends the data to the display centre and banking server to map the vehicle position and the toll amount transaction. Moreover, it sends data to the vehicle to avoid probable collisions and to maintain the lanes.

iii. Banking Server: It obtains the toll amount data from the system server and ensures the secure toll amount transaction is done by vehicles.

iv. Display Centre: It displays the vehicle traffic on the maps and identifies vehicles in and out of toll zones. Moreover, it also shows the congestion or accidents on the road with the help of information from the system server.

v. Composition of Vehicular System: Refer to section 4.3.6.1 for the composition of the vehicular system. The VNAS will also interact with the tolling system through its control server.

4.3.7.2 Key Benefits of the MGITS-AERT

The tolling system has been broadly addressed in Use Case 8 – GNSS Based Tolling (4.3.2). Following up on the aspects mentioned therein, MGITS-AERT has been proposed in this section. The multi-GNSS-integrated tolling system for AERT addresses the limitations of traditional models while paving the way for a more innovative, sustainable, and equitable transportation infrastructure. The benefits of deploying a multi-GNSS-integrated tolling system for AERT are as follows.

A. **Fair Usage-Based Tolling**

Users pay only for the exact distance travelled on toll roads. It eliminates the "flat rate" model, ensuring users pay only for what they use.

B. **Seamless Traffic Flow**

It removes the need for physical toll booths, reducing bottlenecks and congestion. It enables uninterrupted driving, especially during peak hours or high-traffic seasons.

C. **Enhanced Efficiency**

Automatic toll calculation and payment minimize delays compared to manual or RFID-based systems.

D. **Environmental Benefits**

It helps to decrease fuel consumption by avoiding long waits at toll booths. It reduces vehicle emissions associated with idling and stop-and-go traffic near toll booths.

E. **Cost Savings for Authorities**

It eliminates the need to build and maintain toll plazas, lowering operational costs.

F. **Transparency and Accountability**

It offers detailed vehicle movements and toll payment logs, reducing fraud or toll evasion. Also, it enables better enforcement and compliance with toll regulations. It will conform to the standard of secure data transmission [SM1] from clause 3.0 [18].

G. **Convenience for Drivers**

It eliminates the need for physical tags or toll tickets and integrates seamlessly with digital wallets or payment systems for instant transactions.

H. **Real-Time Data and Insights**

It provides accurate data on road usage, traffic patterns, and peak usage times. In addition, the collected data will support data-driven decisions for road maintenance, upgrades, and infrastructure investments.

I. **Integration with Smart Transportation**

It aligns with modern smart city initiatives, contributing to intelligent transportation systems. This can also be integrated with GNSS-based services like fleet management or emergency services.

4.3.7.3 Advantages of MGITS-AERT

MGITS-AERT can facilitate the implementation of Platooning as addressed in Para 4.3.7 and Modular Lane Keeping. Adopting MGIT-AERT offers a transformative solution to modernize India’s tolling system, enabling distance-based pricing, seamless traffic flow, and real-time data collection. Despite challenges like public acceptance, infrastructure development, and data security, coordinated efforts can address these issues. The system promotes reduced congestion, cost savings, and alignment with smart city initiatives, paving the way for equitable and sustainable transportation. The MGITS-AERT will also help in the 'Automated Toll Vehicle Tracking' use case.

4.3.7.4 Gaps for Implementation of MGIS-AERT

The advantages of a multi-GNSS-integrated system for automated electric road transportation have been enumerated above. However, in practically realizing the same, some gaps may exist. These are as follows:

A. **Government Executive Orders**

The use of a multi-GNSS survey needs to be approved by both the Central, State /UT Governments. The Central government needs to pass orders for a method to conduct the multi-GNSS survey for all roads for uniformity. State governments would have to pass executive orders to conduct this survey in their respective states, which would have to be done by the respective state governments and Union Territories, since land is a state subject.

B. **Conduct of GNSS-Based Survey**

The survey would involve multiple departments, including land and revenue, state road and transport, forests, municipal authorities, panchayat officials and organizations like NHAI, toll companies, etc. This exercise would be a massive effort and needs monitoring at the highest levels of the state and central government to ensure it is done promptly.

C. **Creation of an Organization for Map Data Management**

The necessary organization with the required IT manpower will need to be created for the management of the map data generated during the survey, which will be stored in Map servers and be made available in the public domain within each state/UT for use by multiple user organizations who would be implementing the deployment and management of autonomous vehicles. These would also be linked to applications built for traffic police, toll companies, and other stakeholders in transport management.

D. **Information Security and Data Security**

There would be a need to ensure the security of data stored in the map servers and the encryption of data being transferred to the users of map data information. To prevent misuse, there will be a need to ensure the privacy of vehicle location and travel data. Moreover, protecting GNSS infrastructure and tolling systems from cyber threats, including spoofing and hacking, will play an essential role in adopting the automated tolling system. For additional details, refer to the paragraph *'Addressing Current Gaps'* from the Section "GNSS-based Tolling" of the white paper.

E. **Acceptance and Incorporation**

Substantial efforts will be required to create awareness of the advantages of using a multi-GNSS-based tracking system. Similarly, the concerns regarding data security will have to be convincingly addressed. Authorization for facilitators involved in incorporating the system will have to be advertised. Users, toll operators, transport associations, and other stakeholders can resist transitioning from systems like FASTag.

F. **Infrastructure Development**

Additional infrastructure on roads and lanes will be needed. These will include cameras, radars and assistance indicators. Equipping vehicles with GNSS-enabled devices and ensuring compatibility across diverse vehicle types is challenging. Robust backend systems for real-time toll calculation, transaction processing, and account management will be required.

G. **Setting Standards**

There is a need to define standards for using the telecom network, employing manpower, and developing infrastructure. Developing and enforcing standards to ensure GNSS devices work uniformly across the country is challenging. There will be a need to define consistent data formats for data exchange between vehicles, toll systems, and regulatory bodies.

H. **Promulgation of Instructions**

Governmental departments must ensure adequate lead time while promulgating instructions on the subject. Issuing clear guidelines for stakeholders, including toll operators, enforcement agencies, and technology providers, is difficult.

I. **Survey and Mapping**

Nationwide surveys need to be conducted to map toll roads accurately, including entry and exit points, to enable precise tolling. Incorporating GNSS data with geographic information systems (GIS) for comprehensive road mapping is required.

J. **Financial Viability**

High upfront investment in GNSS infrastructure, device installation, and system development is challenging.

K. **Technological Gaps**

We must ensure the widespread availability of affordable and reliable GNSS-enabled devices and address challenges like signal latency, outages, or inaccuracies that could impact toll calculation.

4.3.7.5 Observations

Adopting a multi-GNSS-based framework integrates accurate road mapping, efficient vehicle navigation assistance, and innovative tolling solutions, forming the foundation for AERT. Digitized mapping of roads and lanes emphasizes the creation of digitized QGIS maps and features, such as digitized lanes, enabling autonomous vehicles to operate safely and efficiently. A multi-GNSS-based VNAS highlights the benefits of real-time vehicle tracking for traffic management, law enforcement, and optimized use of toll-based road networks. The suggested business model for MGIS-AERT (refer to *Annexure 1)* brings out the sustainability factors and economic advantages. A multi-GNSS-integrated toll system underscores the transformative potential of MGIT-AERT, addressing limitations of existing systems like FASTag, promoting distance-based pricing, seamless traffic flow, and sustainable urban development. This use case establishes a comprehensive, equitable, technologically advanced transportation ecosystem for India's future.

A tabular segmentation of use cases is given in Table 3.

Table 3. Segmentation of use cases

Serial Number	Primary Segment	Secondary Segment
4.1.1	Long haul Commercial vehicles (Trucks and Buses)	Passenger Cars
4.2.1	Passenger Cars and Heavy Commercial Vehicles	Utility Vehicles and Light commercial vehicles
4.2.2	All Classes Passenger Cars and Commercial Vehicles	--
4.2.4.1	All Classes of Passenger Cars and Heavy Commercial Vehicles	--
4.2.4.2	Passenger Cars and Heavy Commercial Vehicles	Two wheelers
4.2.5	Passenger Cars and Heavy Commercial Vehicles	Two wheelers
4.3.4	All Classes of Passenger Cars and Heavy Commercial Vehicles*	Two wheelers

5. Test Methodologies

5.1. TiHAN Test Methodologies

Section No.	Test Methodology Description	Category
4.1.1	Platooning scenario testing using radar and wireless communication	TiHAN
4.2.2	Road and Traffic Object Monitoring – Speed bump detection	TiHAN
4.3.2	GNSS-based Tolling	TiHAN
4.2.3	Lane Keep Assist (LKA) – Real-time testing at TiHAN testbed	TiHAN
4.2.4	Collision Avoidance – Object on path and vehicle following	TiHAN
4.2.5	Traffic Signage Detection – Detection of T-junctions, bus stops, speed limits	TiHAN
6.1	Technology Stack – Sensor fusion, localization, navigation, and control	TiHAN
Annexure 3	TiHAN Testbed – Proving grounds, simulation tools, smart poles, V2X infra	TiHAN

5.2. ARAI Test Methodologies

Section No.	Test Methodology Description	Category
Annexure 4	ARAI Testbed – Smart City Test Track with Indian road features	ARAI
Annexure 4	ADAS Test Track Equipment – Robotic platforms, ISO 19206 dummies	ARAI
Annexure 4	Driver-in-Loop Simulator – Human-in-the-loop ADAS testing	ARAI
Annexure 4	AV V&V toolchain at simulation level and laboratory level	ARAI
4.2.3.1.5	Standards & Gaps – Draft D1/AIS 191 for ALKS (ARAI involvement)	ARAI
4.2.4.3	Standards & Gaps – Draft AIS 162 for AEBS (ARAI involvement)	ARAI

6. Technology

This section describes the key technologies and architectural components enabling autonomous ground vehicle operations. It outlines the sensing, perception, localization, navigation, and control mechanisms used in different autonomous driving configurations, along with their capabilities and limitations.

6.1. Technology Stack in Autonomous Ground Vehicles

The technology stack of autonomous ground vehicles comprises a combination of sensors, computing platforms, perception algorithms, localization techniques, and control systems. These components work together to enable environment perception, decision-making, and safe vehicle motion under diverse operating conditions. The stack may vary depending on the level of autonomy, operational design domain, and sensor configuration.

6.1.1. Standalone Unit Based Autonomous Navigation

Standalone unit–based autonomous navigation relies primarily on onboard sensing and processing capabilities without continuous dependence on external infrastructure or connectivity. In this approach, perception, localization, navigation, and control are performed locally using sensors such as cameras, radar, LiDAR, GPS, and IMU. This configuration enables autonomous operation in environments where external assistance may be limited, while placing higher emphasis on sensor accuracy, robustness, and real-time processing.

6.1.1.1. Image Acquisition (Perception)

The system uses stereo cameras with (depth perception) mounted on the vehicle to capture high-resolution images or video of the surrounding environment. These cameras can be positioned in different areas of the vehicle, such as the front, rear, and sides. The cameras continuously capture images at a high frame rate to provide real-time visual data to the system.

6.1.1.2. Object Detection and Scene Understanding

Once the camera captures the images, computer vision algorithms (often powered by deep learning models) are used to detect and classify various objects in the scene, such as.

i. Vehicles: Cars, buses, trucks, motorcycles, etc.

ii. Pedestrians Intent: Not crossing, Crossing, Standing

iii. Road Signs: Stop signs, yield signs, speed limit signs, etc.

iv. Traffic Lights: Detecting the state of the traffic light (red, yellow, green)

v. Pothole & Speed bumps

These algorithms detect objects by drawing bounding boxes around them and assigning class IDs (e.g., car, pedestrian, cyclist) along with confidence scores. A set of detected objects with bounding boxes, object classifications (vehicle, pedestrian, etc.), and confidence scores for each detection. The system understands the scene by identifying the objects and their positions related to the vehicle.

i. Real-time Localization: The system uses visual data along with information from other sensors (like GPS, IMU) to determine the vehicle's location and orientation on the road. This step is critical for keeping the vehicle aware of its position within a map.

ii. Navigation and Control: Path planning using waypoint-based navigation. Algorithms are developed to control the lateral motion of the vehicle. Waypoints on a route path are first collected which in respective order from starting point to end point. This waypoint list is used as reference in the algorithm to navigate.

The vehicle follows the planned path, based on the control algorithm which controls the actuators like (steering angle and braking) as it moves through the environment.

Following are the limitations of camera data sensors.

i. Autonomous navigation relying solely on camera data is susceptible to errors caused by changing or noisy contexts (e.g., fog, snow, pixelation).

ii. Models may misclassify objects due to over-reliance on background cues instead of focusing on intrinsic object features.

iii. In this regard *"Lost in Context: The Influence of Context on Feature Attribution Methods for Object Recognition"*, different experiments have been conducted using various datasets under different weather conditions, including fog, snow, motion blur, Gaussian noise, and pixilation for pre-trained models like ResNet50, ResNet101, Efficient Net, and Vision Transformer.

Our key findings regarding model performance under weather perturbations are as follows.

i. Context perturbations (e.g., fog, snow) result in a moderate accuracy drop of around 2.5% to 5.4% across models.

ii. Complete context changes have a greater impact, causing an accurate drop of 8.6% to 15%.

iii. Models trained on larger datasets (e.g., ResNet101) exhibit better robustness to these conditions than those trained on limited data (e.g., ResNet50-IN9L).

6.1.1.3. Integrated Unit Sensor fusion Based Autonomous Navigation

This involves the three major modules: Software & Hardware components; Temporal and Spatial synchronization of sensor data; Navigation & Control; Use case implementation (Object detection; distance measurement; velocity estimation).
A brief description of hardware components, synchronization and navigation and control is provided below.

A. **Hardware Components**

i. Radar Sensor

a) Type: Short-range radar & Long-range radar sensor.

b) Role: The radar sensor captures Point Cloud Data (PCD), which contains information about objects in the environment such as their distance, angle, and velocity. The sensor works even in adverse weather or low-visibility conditions (e.g., fog, rain).

c) Data Output: Radar objects (position, velocity, distance in 3D space) are collected as spare point cloud data in RGB form.

ii. Camera Sensor

B. **Time & Spatial Synchronization**

i. **Sensor data Collection**

The camera and radar are both connected to the ROS framework, which is a middleware for handling sensor data and communication between them.

ii. **Time synchronization**

Owing to the different frame rates of radar and camera synchronizing the radar and camera frames plays a crucial role in associating the scenes captured by two different sensor modalities. Since radar has a higher frame rate, two consecutive radar frames are compared with a single camera frame and the least close timestamps among the two radars and camera are associated.

iii. **Spatial synchronization**

Though the radar and camera data are synchronized in time, but they represent data in different spaces, the radar has the data in BEV(Bird-Eye-View) space and the camera in the 2d image space, so there is also a need to synchronize them spatially for a clear association of the radar points with the camera points. The radar points are converted from radar coordinates into camera pixel coordinates using a projection matrix, that is pre-calibrated. The transformed radar points are projected onto the camera's image in real-time, creating a fused sensor output.

iv. **Localization**

The vehicle needs to determine its exact position on the map and relative to its surroundings. This step integrates sensor fusion using data from the camera, radar, GPS, and IMU (Inertial Measurement Unit).

C. **Navigation & Control**

The planned path is executed by the vehicle's navigation and control system using algorithms. These control systems adjust the vehicle's steering, throttle, and brakes to ensure it follows the planned path while avoiding obstacles.

6.1.1.4. Standalone Unit based Autonomous Navigation

Lidar based autonomous navigation involves three steps Creation of a 3D Map, Real-time Localization on the created Map, path planning & navigation.

A. **Creation of 3D Map**

LiDAR sensor scans the environment and creates a detailed 3D point cloud. SLAM algorithms generate a high-resolution 3D map of the surroundings.

B. **Real-time Localization on the Created Map**

The system matches real-time LiDAR data with the pre-existing 3D map.

C. **Localization algorithms**

Determine the vehicle's precise position and orientation within the map. This localization process provides vital real-time data regarding the vehicle's position and orientation, enabling seamless and accurate autonomous navigation.

D. **Path Planning and Navigation**

i. Path planning algorithms calculate the safest and most efficient route. It involves creating waypoints from source to destination, obstacle detection and emergency braking. Obstacles are detected using front facing LiDAR.

ii. Once the path is planned, the navigation module follows this path using control algorithms. The navigation system sends commands to the vehicle's actuators (steering, throttle, and brakes) to follow the planned path precisely.

iii. The vehicle follows the path by sending commands to its actuators, continuously adjusting to dynamic changes using real-time sensor data. The speed of the shuttle is controlled as per the obstacle distance and steering angle.

6.2. Open and modular architecture for automated lane

A. Modular Lane Keeping and Platooning Technology

High reliable lanes are kept in a well separated lane for operating automated vehicles is a core functional requirement for achieving safety of operations. Additionally, platooning is a function that enables making effective use of the lane capacity increasing lane utilization. Being dynamic in nature as compared to fixed size trains, it offers elasticity and extensibility along with multiple fleet interoperability. The lane keeping and platooning are to form a foundation for a modular and extensible architecture for developing an automated vehicle guidance system for automated vehicle operations. The technology stack for lane keeping consists of a navigation module, guidance module and a control module.

B. Navigation

The navigation module collects the sensor information from the on-board radars and IMU as described in section 7.4 and processes them into kinematic measures. The radars provide non-inertial kinematic information and IMU provides the inertial yaw rate and position information from dead-reckoning. In the case of platooning, this information is used to create a waypoint that is tracked and follows the ego vehicle at a desired gap.

C. Guidance

The guidance module calculates the optimal path and kinematic trajectory for the vehicle to follow within a finite preview horizon provided by the waypoints created from the navigation information provided. The optimal trajectory-planning is accomplished considering the waypoints and constraints on stability and tolerances along with desired kinematic trajectory within the preview horizon. In the case of platooning, this involves the optimal kinematic trajectory to track and close the gap with the ego vehicle if in homing phase or follow the ego vehicle at the desired gap if in platooning phase as described in section 7 earlier.

D. Control

The control module calculates the control input to be provided to the drive-by-wire actuators to track the trajectory as calculated by the guidance module. The control law is based on an MPC based algorithm with constraints based on tolerances on straying from trajectory and waypoints and a cost function based on Linear Quadratic Regulator.

The architecture is modular in nature and uses a separation of concerns paradigm and can form a layered design with well-defined inputs and outputs from each layer to the next.

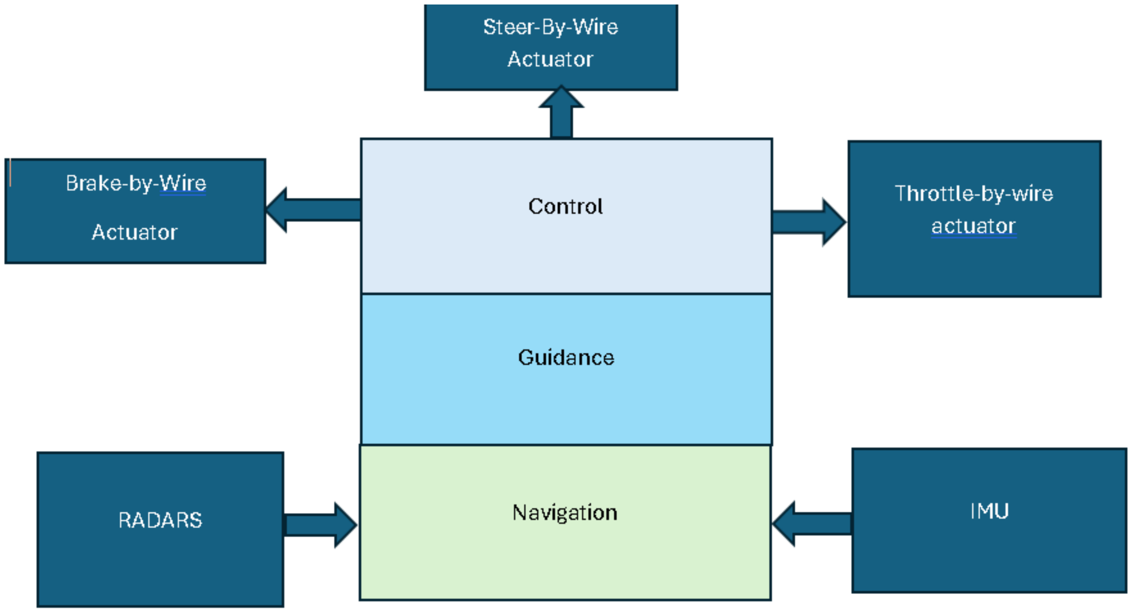


Figure 20. Open and modular architecture for automated lane

7. Current Challenges and Opportunities in Road Transport

7.1 Safety/ Road Accident information

As per the report, "Road Accidents in India 2022", from the Transport Research Wing, Ministry of Road Transport and Highways (MORTH), Government of India [1], India has a road network covering a length of 63.32 lakh kilometers. Out of this, only 4.99% is covered by National and State Highways, and more than 50% of accidents and fatalities are reported on the Highways. The report observes that in over 70% of the accidents and fatalities, over-speeding is the cause and in terms of road users, around 60% of the accidents involve two-wheelers and light motor vehicles (Cars and Vans) with 69.4% of cases the drivers had a valid driver's license. Whereas in terms of road features, around 67% of the accidents were on straight roads. The report suggests the "*engineering of vehicles and roads along with emergency care may also play an important role in road safety.*" Although there exist road accident mitigation measures in place, including education, engineering, enforcement, and emergency care, there has been no significant reduction in accidents, fatalities, and number of persons injured from 2018 to 2022.

A more detailed analysis of road accidents under different conditions and their societal impact can be seen in Annexure 5 which is based on extracts from the report of Ministry of Road Transport and Highway.

There is a dire need to enhance mitigation measures. Banking on state-of-the-art computer vision and big data analytics-based technologies, Automated Driving (AD), Advanced Driver Assistance Systems (ADAS), and vehicle-to-everything (V2X) based connected vehicles technologies can enhance road safety by aiding the mitigation measures.

In recent times, the automotive industry has seen explosive growth in the research and development of AD, ADAS, and V2X technologies. To improve the technology readiness level (TRL) of the hardware and software stacks, there exists a dire need to test and validate the technologies in use case-specific real scenarios under controllable environments to expedite the technology integration into the vehicles for public road usage. In other words, there exists a need for the utilization of smart live test tracks or proving grounds for testing and validation of the vehicles enabled by the technologies.

7.1.1. Traffic Congestion

Roads are around the world and in particular urban roads including highways are plagued by traffic congestion. Roads being government owned and operated around the world lacked technological innovation and the only method that was tried to address the traffic congestion has been lane expansion which has not been very effective in many cases. A holistic approach that addresses the business models of road operations coupled with technology and automation can address many of the challenges with traffic congestion.

7.1.2. Affordable high speed intercity travel

While multilane highways are laid out and operated and can support high speeds, the overall travel times and speeds possible over the length of the trip are hampered due to lack of suitable solutions through automation for intercity travel. Roads are cheaper than rail from both capex and opex and with application of technology and automation, a much more affordable highspeed solution that can compete with highspeed rail or airlines is possible. Key desirable attributes for a scalable and affordable high speed intercity travel solution that are enabled with the proposed solution are as follows.

A. **Safety**

Having a well separated exclusive lane for automated vehicles can be designed with adequate guard rails designed after a systematic assessment of risks. This improves safety very much by enabling anticipation of risks and their mitigation after careful and systematic analysis.

B. **Higher Speeds**

Today's cars and buses are capable of speeds in excess of 150 kmph. And the road surface is capable of supporting such speeds. However, without automation the effective speeds achieved for intercity travel are much lower primarily due to slowing down due to encountering lower speed vehicles ahead in the same lane or adjacent lanes that can swerve in an unanticipated way. With an exclusive and well separated lane that is automated, much higher operational speeds are possible due to harmonization of speeds of all vehicles operating in the lane.

C. **Operational Resiliency**

The proposed solution supports heterogenous vehicles and fleets unlike a single operator solution like trains. This leads to operational resiliency as any single vehicle or fleet operator disruption can be easily compensated by other fleets and operators. In fact, there is decoupling of road space and time usage from vehicle types or fleets that enables any vehicle or operator to make use of the resources based on demand.

D. **Last Mile Advantages**

Road vehicles have last mile advantages as they can be operated in non-automated mode after exiting the automated lane with a dual mode operation. This offers a unique advantage as the same vehicle can get the passengers to their destination unlike trains or airplanes which need the passengers to disembark and find a different mode of transport in the last mile. This saves door-to-door travel times which matter for the passengers.

E. **Superior Unit Economics**

Due to reduced capital expenses of road infrastructure, lower operational costs of operating a lane and adding incremental vehicles or fleets and efficient usage of lane capacity, leads to much superior unit economics measured in terms of cost per passenger mile compared to other solutions like highspeed rail or airlines.

7.1.3. Environmental pollution

Vehicular pollution due to gasoline and diesel vehicles is one of the biggest problems with today's road transport. It is well understood how vehicular pollution is contributing to global climate change and its adversarial effects on the environment and human health. While electric vehicles and other low/zero emission vehicles have arrived, one of the key factors limiting their scale is low utilization of the vehicles.

As per the International Energy Agency, there has been an emission of 5.6 Gigatons of carbon dioxide (CO2) globally in 2020, of which road transport contribution is 78%. India is one of the fastest-growing economies in the world and road transport has been the major contributor to the CO_2 emissions in India. Total CO_2 emission per capita in the transport sector can be seen in Fig [22]. India is one of the key parties of the United Nations Framework Convention on Climate Change (UNFCCC). As part of the 26th Conference of Parties (COP26), the Government of India (GoI) has updated the Nationally Determined Contribution (NDC) to the UNFCCC and committed to a five-fold plan *(Panchamrit)* to aid restriction of global temperature rise to 1.5 deg Celsius. One of the action items of the plan is to reduce emissions by 1 billion tons by 2030, in contrast to the forecasted value of 3 billion tons in 2030. Currently, by fuel category, gas/diesel oils and motor gasoline are the major sources of energy use in transportation [22].

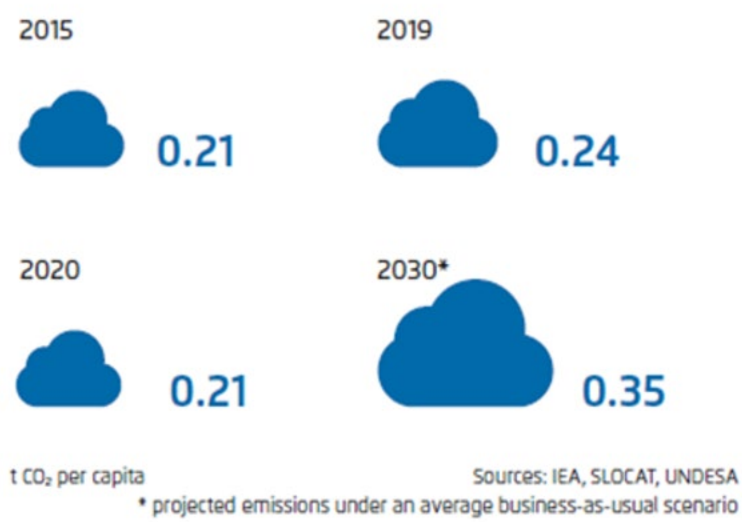


Figure 21. Total Carbon Dioxide emissions in India

Given the recent initiatives of the GoI in electric transportation and non-fossil fuels-based energy generation, there exists an urgent need for intervention of novel technologies and new paradigms in existing inter and intra-city/urban/rural road transportation operations wherein electric/hybrid vehicles and conventional vehicles can co-exist and operate to meet the overarching goal of meeting COP26 commitments.

Electrification will have a bigger impact and scale if coupled with automation leading to better vehicle utilization rates as well as road utilization leading to lower traffic congestion and faster travel. Additionally, electrification and electrical charging infrastructure deployment can be better planned and optimized for usage through well implemented automated road transportation that goes together with electrification.

7.1.4. Logistics

Logistics play a crucial role in economic operations as it relates to the supply chain and transportation of goods. It notably influences energy usage and plays a part in greenhouse gas emissions. These effects are addressed in the objectives outlined in the whitepaper, with a specific focus on advancing autonomous electric vehicles.

Logistics is fundamental to economic growth as it comprises a substantial share of a nation's GDP. Enhancing transportation infrastructure and technological innovations to reduce inefficiencies can lead to significant benefits. For instance, logistical costs account for 14.4% of India’s GDP, whereas in developed nations this figure is only 4 to 6%. Sectoral Plans for Efficient Logistics (SPEL) (outlined in National Logistics Policy Document 2022).

The Ministry of Road Transport and Highways is expected to propose initiatives for the establishment of digital systems to ensure track and trace abilities and full visibility of goods, alleviation of compliance burdens on roadways, and assessment of the reliability of truck operations. It must also create strategies to remedy the shortage of truck drivers, including provisions for rest stops, social security, and digital monitoring of work and rest hours.

The transportation sector is responsible for almost 14% of India’s aggregate greenhouse gas (GHG) emissions, with freight transportation alone utilizing over 40% of total energy in the transport domain. GHG emissions from the freight transportation sector are increasing rapidly, and immediate action is necessary to adhere to India’s Nationally Determined Contributions (NDCs) and to reach net-zero emissions by 2070 (reference: Freight GHG Calculator India Logistics).

Table 4. Summarizing the Societal impact of the use cases

	Context	PC	HCV	Buses	LCV	2W
Platooning	Global	Moderate benefit: smoother highway driving, EV fuel efficiency Global: 5–10% fuel savings,	Maximum benefit: trailing trucks fuel savings up to 10%, lead trucks 5%; CO_2 ↓ ~37.9 Mt globally;	High benefit: synchronized platooning reduces fuel use & enhances passenger safety		

		CO_2 ↓ ~37.9 Mt annually	synchronized braking enhances safety			
	India	long-haul fuel savings, emissions reduction	long-haul fuel savings, emissions reduction, safer freight operations			
Lane Keeping Assist (LKA)	Global	Prevents lane-departure crashes Global: 19% crash reduction	Moderate benefit: lane assistance reduces highway accidents	High benefit: prevents lane departure on highways & urban corridors		
	India	reduces urban lane-departure accidents				
Collision Avoidance (FCW & AEB)	Global	High benefit: reduces rear-end and intersection crashes Global: FCW 22%, AEB 12% crash reduction	Maximum benefit: prevents catastrophic rear-end collisions; reduces fleet liability & insurance	High benefit: reduces passenger injuries in rear-end collisions	High benefit: reduces rear-end collisions in stop-go traffic	Emerging benefit: collision warning under development
	India	mitigates urban collisions	prevents catastrophic rear-end collisions;			
Speed Bump Detection	Global	Moderate benefit: smoother ride, protects		smoother ride improves passenger comfort	protects cargo & suspension	

		suspension Global/				
	India	injury reduction 53–60%, crash ↓ 20% in speed-bump zones				
Ego Vehicle Approaching (ACC & Emergency Braking)	Global	High benefit: adaptive cruise & emergency braking Global: crash ↓ 29%	Maximum benefit: prevents chain-reaction crashes; essential for platooning & fleet safety	High benefit: adaptive braking improves city & highway passenger safety	High benefit: prevents collisions in dense city traffic, improves fleet safety	Emerging benefit: forward-collision warning & emergency braking in development
	India	reduces dense traffic accidents				

Unlike ADAS-driven use cases such as platooning, lane keeping assist, and collision avoidance which are highly vehicle- and segment-specific, SATCOMM-related use cases are more generic in nature, providing ubiquitous connectivity and operational resilience that extend beyond automotive applications into logistics, infrastructure, and multimodal transport ecosystems.

The journey toward safer, smarter, and more efficient mobility is not a solo endeavor—it's a collective mission. As Automated Electric vehicles become increasingly central to modern transportation, a diverse group of stakeholders must come together to make these technologies a reality. From the engineers designing vehicles to the policymakers shaping regulations, each player has a unique and vital role.

A. Vehicle Makers and Their Technology Partners: The Innovators

At the heart of this transformation are the vehicle manufacturers, who are reimagining how cars, trucks, and buses interact with their surroundings. These OEMs work hand-in-hand with Tier-1 and Tier-2 suppliers, who provide the sensors, software, and control systems that power features like lane keeping, emergency braking, and adaptive cruise control. Together, they ensure that AEV systems are not only technically sound but also tailored to the needs of different vehicle types—from compact city cars to long-haul freight trucks.

B. **Connectivity and Infrastructure: The Enablers**

AEV features like platooning and collision avoidance rely on seamless communication between vehicles and their environment. This is where telecom providers step in, offering high-speed, low-latency networks, especially 6G—that allow vehicles to "talk" to each other and to roadside infrastructure. Meanwhile, infrastructure developers—from highway authorities to smart city planners—are laying the groundwork with intelligent traffic signals, high-definition lane markings, and roadside sensors. These upgrades are essential for enabling real-time decision-making and enhancing road safety.

C. **Testing and Certification: The Gatekeepers of Safety**

Before AEVs hit the road, they must be rigorously tested. Agencies like ARAI, ICAT, and GARC simulate real-world conditions to ensure these systems perform reliably. Once validated, regulatory bodies such as MoRTH and BIS step in to certify vehicles and set the standards that guide safe deployment. These organizations are not just rule-makers—they're safety champions, ensuring that every AEV feature meets the needs of Indian roads and driving behaviors.

D. **Tech Companies and Academia: The Thinkers and Builders**

Behind the scenes, technology providers and software developers are crafting the brains of AEV—AI models that help vehicles perceive, predict, and respond to their environment. They also build simulation platforms that allow virtual testing, speeding up development cycles. Academic institutions play a complementary role, conducting research on human-machine interaction, developing indigenous algorithms, and collaborating with industry to solve real-world challenges. Their work ensures that AEV technologies are not only cutting-edge but also contextually relevant.

E. **Fleet Operators and Drivers: The Real-World Testers**

AEV systems come to life on the roads, where fleet operators and mobility service providers deploy them in delivery vans, taxis, and buses. These users provide invaluable feedback, helping refine systems for better performance and usability. Finally, drivers and passengers, the everyday users, are central to this ecosystem. Their experiences, behaviors, and feedback shape how AEV evolves. With proper awareness and training, they become active participants in making roads safer for everyone.

F. **Business models: Driving Value from Data**

Across millions of vehicles, this translates into petabytes of structured and unstructured data digital goldmine for stakeholders. AEV data is not just a byproduct of intelligent mobility, it's a strategic asset. With the right ecosystem, governance, and innovation, stakeholders can unlock new business models, improve safety, and accelerate the transition to smarter transportation. The key lies in balancing monetization with responsibility, ensuring that data serves both commercial and societal good.

G. Key Monetization Opportunities

i. Predictive Analytics and Insights: OEMs and fleet operators can monetize data by offering predictive maintenance services, driver risk profiling, and vehicle health monitoring. These insights reduce downtime and improve operational efficiency.

ii. Insurance and Risk Assessment**:** Insurance companies can leverage data for usage-based insurance (UBI) models, dynamic premium pricing, and fraud detection. Real-time driving behavior and incident data enable more accurate risk assessment.

iii. Smart Infrastructure Planning**:** Governments and urban planners can use aggregated data to identify accident-prone zones, optimize traffic flow, and plan infrastructure upgrades. This data can be sold or shared under public-private partnerships.

iv. In-Vehicle Experience and Personalization**:** Tech providers can monetize behavioral data to offer personalized infotainment, navigation, and driver assistance services. This opens up new revenue streams through subscriptions and targeted advertising.

v. Data-as-a-Service (DaaS) Platforms: OEMs and Tier-1 suppliers can create anonymized data marketplaces, offering access to mobility data for research institutions, startups, and AI developers. This fosters innovation while generating licensing revenue.

H. Stakeholder Roles in Data Monetization

i. OEMs: Custodians of vehicle data; can monetize through partnerships, subscriptions, and analytics services.

ii. TELCOs: Enable secure data transmission; potential to bundle connectivity with data services.

iii. Fleet Operators: Use data for operational optimization; can resell insights to insurers or logistics partners.

iv. Technology Providers: Build platforms for data aggregation, visualization, and monetization.

v. Regulators: Define frameworks for data privacy, consent, and ethical monetization.

I. Challenges and Considerations

While the potential is vast, monetizing data must navigate key challenges.

i. Data Privacy and Consent: Ensuring user consent and compliance with data protection laws (e.g., India's DPDP Act).

ii. Standardization: Harmonizing data formats across OEMs and systems.

iii. Security: Protecting data from breaches and misuse.

iv. Ethical Use: Avoiding discriminatory or manipulative practices in data-driven services.

Effective utilization of vehicle and ecosystem data can accelerate technology adoption by lowering development costs, enabling faster validation, and supporting continuous improvements through over-the-air updates. Shared data platforms foster collaboration across OEMs, suppliers, and regulators, reducing fragmentation and creating economies of scale. Real-world data insights also optimize hardware and software lifecycles, making solutions more affordable and accessible. Together, these factors help democratize advanced mobility technologies, ensuring that innovation reaches the market faster, more economically, and on a scale.

8. Recommendations

The white paper's scope has grown due to the complex nature of the issue, evolving technologies, a broader ecosystem, and increasing demands for certification and homologation. These factors have led to a more comprehensive use case-based approach as applicable for Passenger and Commercial Vehicle segments.

This paper takes a practical approach, presenting key use cases with matching test methodologies and certification requirements. These elements are intended to support broad adoption and deliver lasting social and economic benefits.

This study can evolve in two main ways: by expanding the technological focus and by engaging with government bodies such as MORTH, MeitY, DoT, and DST to help shape policies that support technology development. These efforts may include creating dedicated AEV corridors, democratizing AE datasets, and channelling government funding into industry, academia & startup ecosystems to foster cost-effective innovation.

Annexure 1

Suggested Business Model for Multi-GNSS-Integrated Tolling System for Automatic Electric Road Transportation [MGIS-AERT]

This annexure briefly presents the stakeholders involved: revenue generation, cost distribution, financial flow, share, and beneficiaries.

A. Stakeholders Involved

The envisaged stakeholders are government agencies, service providers, the private sector, vehicle owners and technology providers. Figure 6 summarizes the envisaged stakeholders from various entities.

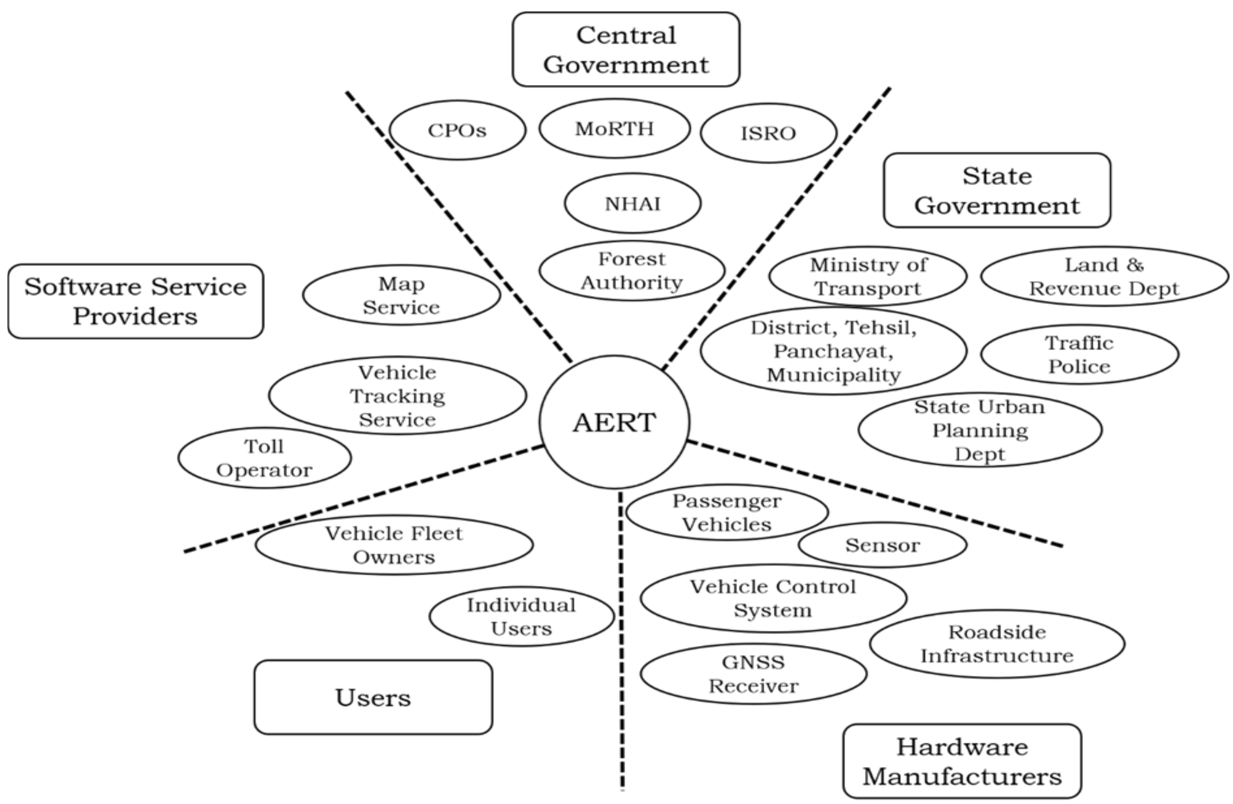


Figure 22. Stakeholders, Software and Service Providers

B. Revenue Sources and Models

This section briefly discusses the anticipated sources of revenue generation, implementation models, beneficiaries, and the role of the government. Following are the revenue sources followed by revenue models:

i. Surveying and Mapping

a) Revenue Source: Licensing fees from indigenous surveying agencies or direct government contracts.

b) Beneficiaries: Survey companies and technology providers.

c) Government Role: Funds initial infrastructure and mapping projects; recovers investment through road usage charges or taxation.

ii. Vehicle Navigation Assistance

a) Revenue Source: Subscription fees for GNSS-enabled tracking services paid by fleet operators and private users.

b) Beneficiaries: GNSS solution providers and government agencies.

c) Added Value: Efficient fleet management, real-time tracking, and data insights for law enforcement and traffic management.

iii. Dynamic Tolling

a) Revenue Source: Distance-based toll charges paid by vehicle owners.

b) Beneficiaries: Toll operators, banks, GNSS providers, and government agencies.

iv. Revenue Sharing

a) Toll Operator: Base toll amount.

b) GNSS Providers: Service fee for location tracking.

c) Government: Tax revenue and a share of toll fees.

v. Fixed Model

a) Build & Transfer (BT): In this model, a government or private entity funds the setup of the GNSS-based tolling infrastructure. Once completed, ownership is transferred to the government or designated authority.

b) Build, Operate & Transfer (BOT): A private player builds and operates the system for a defined concession period, recouping investments through toll revenues before transferring ownership to the government.

vi. Dynamic Model

a) Deploy & Maintain: A vendor deploys the GNSS tolling infrastructure and provides maintenance services for a recurring fee. The government retains ownership and operational control of the system.

b) System as a Service (SaaS): The tolling system operates on a subscription-based model, where the vendor provides end-to-end services, including hardware, software, and analytics. The government or stakeholders pay based on usage or agreed terms.

vii. Hybrid Model

Combines aspects of fixed and dynamic models. For instance, infrastructure deployment may follow a BOT approach, while software and analytics are offered as SaaS. This model provides flexibility, ensuring efficient operations and scalability.

C. **Economics**

This section briefly summarizes the projected capital investors, financial flow and final share. The expected capital investment will be borne by the following stakeholders.

i. Government:
   a) Funds infrastructure for multi-GNSS systems, including satellite constellations, ground stations, and road infrastructure.

   b) Invest in data security and standardization.

ii. Private Companies:
   a) Fleet operators bear costs for installing GNSS devices and subscribing to tracking services.

   b) Toll operators invest in integrating GNSS systems with existing tolling infrastructure.

iii. End-Users:
   a) Pay for GNSS-enabled devices and dynamic toll charges based on road usage.

   b) The finance flow and shares foreseen are summarized below:

iv. Toll Revenue Distribution:
   a) Toll Operator: Base amount of toll revenue.

   b) GNSS Providers: Service fees for enabling real-time tracking and distance-based tolling.

v. Government: Taxation and additional revenues for road development.

a) Program Management Fee: A nominal percentage of toll revenue to GNSS providers, system integrators, and maintenance stakeholders.

D. **Beneficiaries**

The predicted beneficiaries of the multi-GNSS-integrated system for AERT are as given below.

i. Government

a) Gains through efficient toll collection, reduced traffic congestion, and better road usage data.

b) Facilitates smart city initiatives and sustainable urban planning.

ii. Service Providers and Technology Developers

Earn licensing, subscriptions, and hardware/software sales revenues.

iii. Vehicle Owners

Benefit from reduced congestion, fuel savings, and accurate tolling.

iv. Toll Operators

Enhanced revenue generation with dynamic pricing and reduced operational costs.

Annexure 2

Traffic sign detection as a use-case for ADAS and autonomy for India

A. Introduction

Traffic signs play a crucial role in managing traffic on the road, disciplining the drivers, thereby preventing injury, property damage, and fatalities. Traffic sign management with automatic detection and recognition is very much part of any autonomous ecosystem. In this era of self-driving vehicles, calls for automatic detection and recognition of traffic signs cannot be overstated. Specifically, traffic sign recognition system is crucial for safely operating an autonomous driving car and efficiently managing road facilities. Studies on traffic sign recognition tasks show significant advances in terms of accuracy on several benchmarks. However, they lack performance evaluation in driving cars in diverse Indian environments of geography. Because of the diversity, shape and size along with road presence which keeps on changing with respect to demography poses a huge challenge towards development of a traffic signage detection system.

This calls for a traffic sign recognition framework for an AV to evaluate and comparable deep learning-based object detection and tracking models for practical validation for Indian case scenarios. Technically there are many ways to consider the traffic detection framework, broadly speaking two main types can be described on the basis of the type of planning that the AV architecture follows. While path planning in a dynamic environment mainly focuses in dynamic planning which makes the system robust to uncertainties but at the same time increases the frame per watt of the overall system. Coming to the operation of vehicle on road over Indian scenario, versatility of the model over a large case sample is much more needed to suite the changing demographics for a robust model of the AV sign detection. As life is at a paramount risk which implies development of hardware and software should focus on a robust actuation, explain ability and control strategy that holds resilience. This calls for the need for a standard pipeline to channelize the whole development and validation process, the same is discussed in the following article.

B. Traffic Signage Detection pipeline

B.1. India specific Dataset creation

An image dataset for sign recognition would typically consist of collection of images representing various signs such as traffic signs, street signs or any other sign that are needed to be recognized for maintaining the versatility of the dataset with respect to the demography and geography. Each image in the dataset is typically labelled with the type of sign it represents which again depends upon the number of strategic classes defined from the domain analysis.

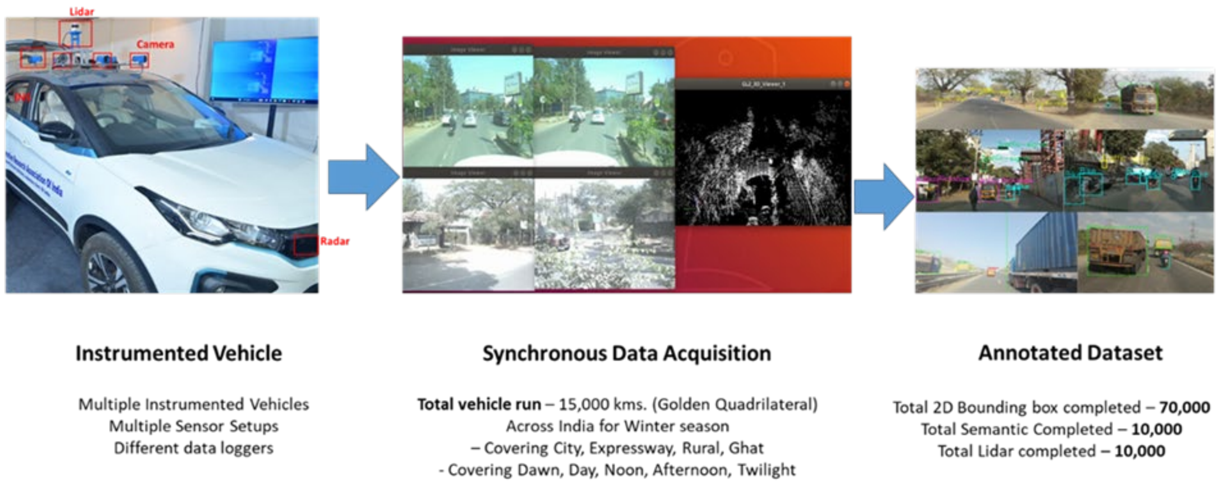


Figure 23. Steps in model creation

A good data collection strategy firstly includes an instrumented vehicle which includes strategically mounted sensors for the need, namely include the high RGB feature camera, LiDAR, Radar, INS etc. The instrumented vehicle is supposed to be calibrated and cross calibrated before collecting data. The calibration needs to be cross verified regularly to maintain uniformity of data collected and use of one sensing modularity over another whenever needed. Over an on-field data collection system (mainly vehicle in most cases) the data should be synchronized at lowest level of time accuracy possible to maintain the uniformity of the scene captured. Next the data is needed to be collected over a vast range of scenario to maintain the versatility over the test scenarios, a big problem that generally faced when dealing with a country like India is the definition of different classes is often seem to overlap on the data, thus it's always recommended to have very tight and collective boundaries of the class definition of every particular object in the scene. Lastly comes the data annotation part where each class is labelled in regard to the kind of task of detection and segmentation. Again, if done in a detailed and correct way can hugely leverage the capability of the AI model.

Figure 24. Traffic sign detection for Indian use case (detection of traffic signs, bikes and trucks as per Indian roads)

B.2. **Data Centre for ADAS/AV**

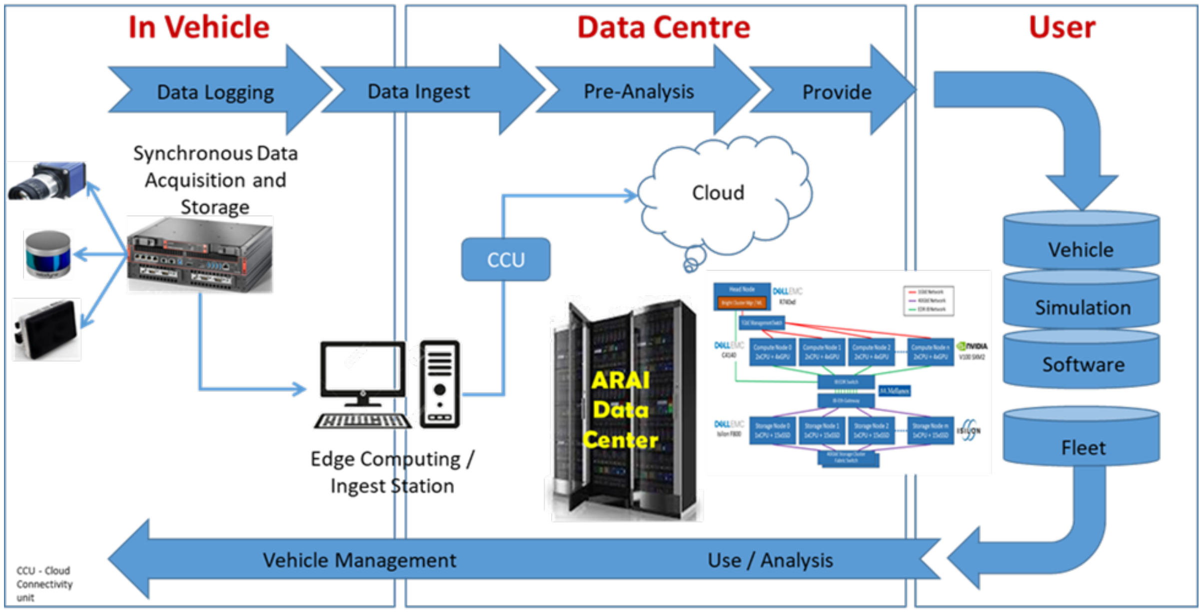


Figure 25. Framework for Data Digitalisation

In the context of the ADAS/AV the need for a dedicated data center is of prime importance. These systems rely heavily on real time data processing such as sensor data from vehicle and traffic infrastructure, high-definition maps and AI algorithm for decision making. The workflow mainly includes logging of data through various modal sensors as previously described synchronously and pushing the data to cloud via ingestion station to data center over which the dynamic annotation and training of the data is done. The data center stack is broadly divided into two main parts, hardware stack and software stack.

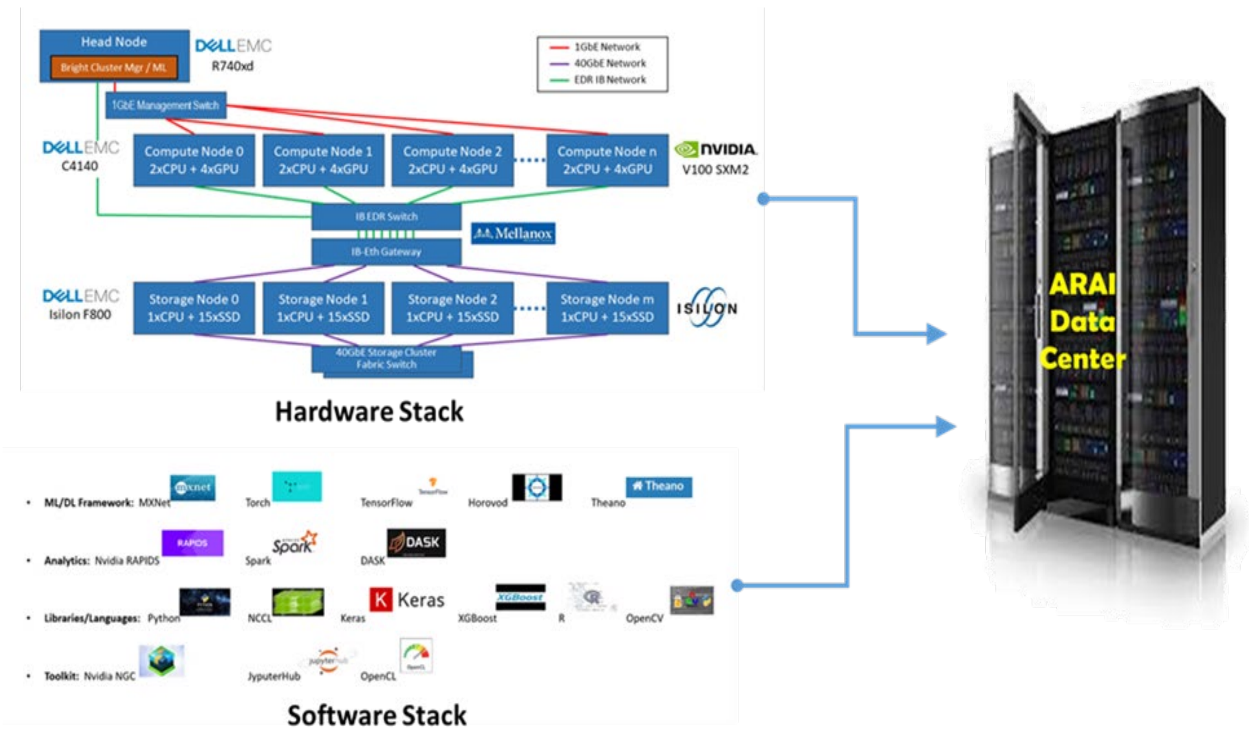


Figure 26. Software/Hardware pipeline for data processing

The hardware stack comprises of the accelerated hardware capable of fast computation and software stack comprise of ML/DL framework for analysis, training and deployment of the trained models. Then comes the real time operation of the model over the edge from the user side and the standardization of the whole process. A robust data center can ensure low-latency processing, which is critical for timely response in dynamic Indian condition. Additionally, India's diverse road infrastructure and traffic pattern require extensive data collection and analysis to develop effective ADAS/AV system tailored to local needs. A dedicated data center can facilitate the storage, processing and analysis of this data, enabling the development and deployment of safe and efficient ADAS/AV solutions to India.

C. AV V&V toolchain at simulation level and laboratory level

The requirement for an ADAS Verification and Validation (V&V) toolchain at the simulation level and laboratory level are critical for ensuring the safety and effectiveness of these systems. At the simulation level the toolchain should be able to accurately simulate real world driving scenarios, including various environmental conditions, traffic situations and vehicle interactions. This requires high fidelity sensor models, realistic physical simulation and the ability to scale simulations to handle large scale scenarios. Additionally, the tool chain should support scenario-based testing, allowing for the systematic evaluation of the ADAS/AV functions under different conditions.

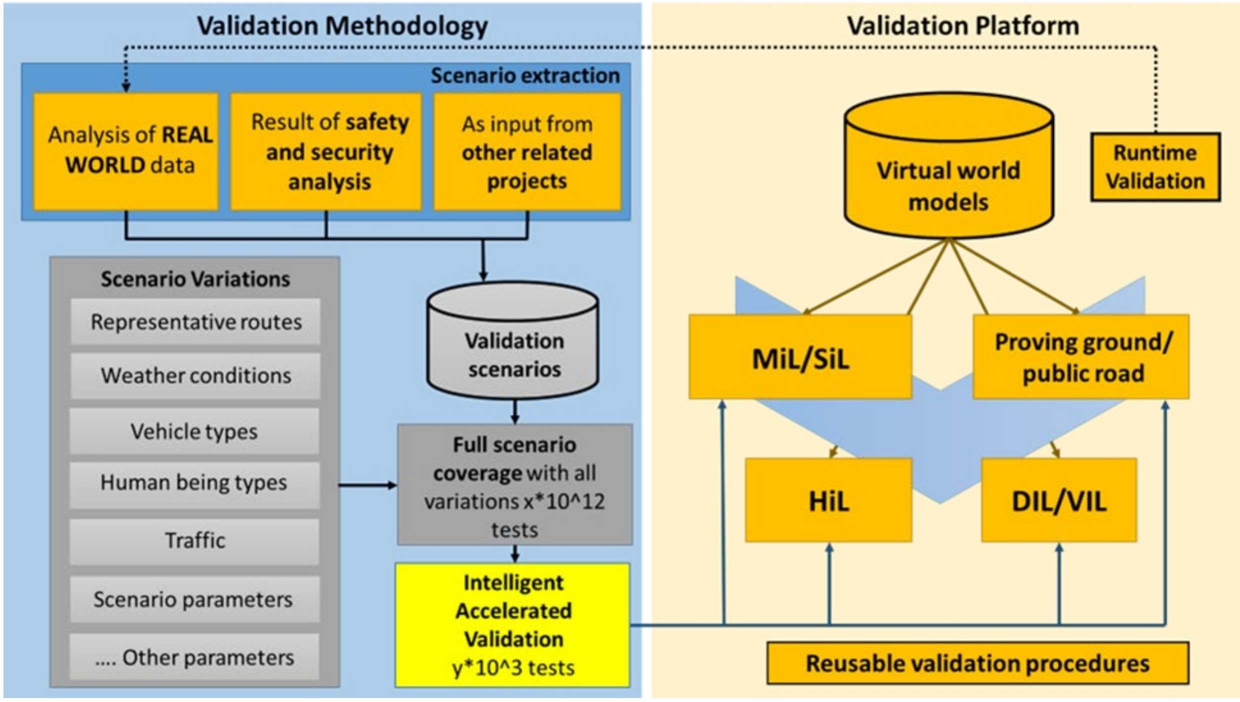


Figure 27. A global approach towards Validation

At the laboratory level, the tool chain should support hardware in loop (HIL) testing, which involves testing ADAS components in a simulated environment that includes physical components such as sensors and actuators. This requires the toolchain to interface with the real hardware and provide accurate sensor and actuator emulation. The efficiency of the system can be evaluated seeking that iterating over all the full scenarios would require a total of 10^{12} multipliers but at the same time with a laboratory tool chain the no iteration multipliers reduce drastically to 10^3. Furthermore, the toolchain should support the integration of the ADAS software with other systems, such as the vehicle's communication network and control systems, to ensure seamless operation.

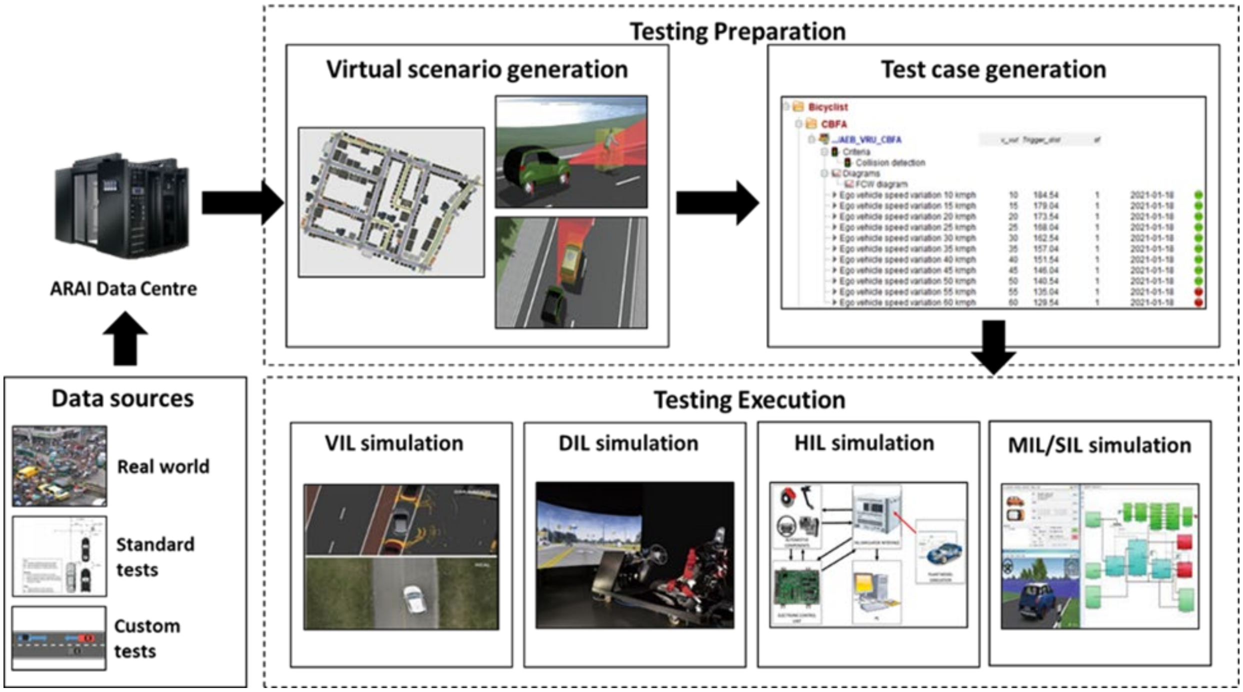


Figure 28. V&V workflow

Overall, an effective ADAS V&V tool chain at both simulation and laboratory levels should provide a comprehensive testing environment that can accurately simulate real world driving scenarios and seamlessly integrate with the physical components for thorough evaluation of the ADAS functions.

D. Gaps in current scenario

The field of traffic sign detection in India is evolving, yet significant gaps remain in the datasets available for training and validating detection models. Here are ten key gaps identified in current datasets relevant to Indian traffic sign detection.

i. Limited Diversity of Traffic Sign Classes in available datasets and insufficient image volume: Most datasets, such as the IRTSD-Datasetv1 and others, contain a limited number of traffic sign classes (e.g., 37 classes in IRTSD-Datasetv1) which may not encompass the full spectrum of signs used across different states with urban and rural scenarios in India. This limitation affects the methodology's ability to generalize across various regions where signs may differ significantly in design and meaning locally [16]. While some datasets provide thousands of images (e.g., over 5000 images in IRTSD-Datasetv1), this may still be inadequate for generation of robust machine learning models that can work with local signage detection, especially for deep learning applications that typically require large datasets to achieve high accuracy and reduce overfitting.

ii. Variability in environmental conditions: Datasets often lack comprehensive coverage of diverse environmental conditions such as extreme weather (heavy rain, fog) and different times of day (night vs. day). Alongside this, gathering data of signage in rural and urban areas along with their placement and the representation of this signage in various language and weather conditions is difficult. These factors can significantly impact the visibility and recognition of traffic signs, making it crucial for datasets to include images captured under varied conditions of topography and weather.

iii. Lack of Real-World Contextual Data and underrepresentation of rural signage: Many existing datasets do not include images that reflect real-world driving scenarios where multiple objects and distractions are present. Including contextual data would help improve the robustness of detection algorithms by simulating more realistic conditions. Current datasets tend to focus more on urban environments, leading to an underrepresentation of rural traffic signs, which can differ significantly from urban signage. This gap can hinder the effectiveness of models trained primarily on urban data when deployed in rural settings.

E. **Limited Multilingual Sign Representation and inadequate temporal variability**

India is a multilingual country with many regional languages; however, most datasets do not adequately represent traffic signs in these languages. Including multilingual signs would enhance model applicability across different linguistic regions [16]. Traffic signs can change over time due to new regulations or updates in design standards. Datasets need to be continuously updated to reflect these changes, but many existing datasets are static and do not account for temporal variability.

F. **Lack of Annotations for Obscured Signs and absence of Adverse Conditions Data**

Traffic signs may often be partially obscured by vegetation, vehicles, or other obstacles. Current datasets typically do not include sufficient examples of obscured signs, which are common in real-world scenarios and pose challenges for detection systems. Datasets often lack images captured during adverse conditions such as heavy traffic or construction zones where visibility might be compromised. Including such scenarios is vital for developing robust detection systems that can operate effectively under challenging circumstances [16].

Annexure 3

TiHAN Testbed

Globally, proving grounds/living labs exist to develop Autonomous Navigation technologies for aerial/terrestrial vehicles. The M-city [9] in the University of Michigan, USA, serves as a living lab with proving grounds enhancing the safety and reliability of highly automated vehicles. Centre of Excellence for Testing and Research of Autonomous Vehicles (CETRAN) at Nanyang Technological University [10], Singapore, develops autonomous vehicle technologies for efficient operations, and for curating regulatory frameworks. Japan Automobile Research Institute (JARI, [11]), Japan develops, tests, and validates autonomous navigation technologies for vehicles at high speeds.

Department of Science and Technology (DST), under the National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS), has sanctioned the prestigious Technology Innovation Hub (TIH) in the technology vertical of Autonomous Navigation and Data Acquisition Systems (UAVs, ROVs, etc.). Technology Innovation Hub on Autonomous Navigation (TiHAN) at IIT Hyderabad (IITH) is a multi-departmental initiative at IIT Hyderabad with collaboration and support from reputed institutions and industry. As part of the project, a first-of-its-kind integrated testbed [12, 13, 14] has been set up on Autonomous Navigation (Aerial/Terrestrial) technologies in the IITH campus and the testbed was inaugurated by Honorable Minister of Science and Technology, Dr. Jitendra Singh in 2022. Testbed has state-of-the-art facilities such as Proving Grounds, Test tracks, Mechanical integration facilities like Hangers, Ground control stations, State of the art Simulation tools (SIL, MIL, VIL), Road Infra – Smart Poles, signalized & unsignalized Intersections, Environment Emulators like Rainfall Simulators, V2X Communications, Drone Runways & Landing area, Control Test center. Pictorially the testbed is shown in Figure 29.

Figure 29. TiHAN testbed at IIT Hyderabad campus. On the left is the front view and on the right is the bird's eye view

The fundamental objective of the testbed is to investigate how connected and unmanned vehicles react and adapt to different roadway types to maintain safe speeds, perform smooth navigation, etc. In addition to the basic roadway layout, as described above, several additional features such as, roundabouts, bus stops, bus bays, pedestrian crossing facilities, speed management measures (such as speed humps and rumble strips), parking zones, etc., are also available for emulating real environmental scenarios and corner cases [14].

Annexure 4

ARAI Test Bed

Framework for the Verification & Validation (V&V) of Advanced Driver Assistance Systems (ADAS) from Indian perspective

A. **Abstract**

Autonomous vehicles are a promising technology to help achieve the goal of zero accidents. But to achieve this goal, autonomous vehicles must perform better than human drivers. This requirement makes these technologies very complex. Uncertain and complex traffic scenarios where these technologies will operate add to the complexity.

Benefits of autonomous vehicles will be realized only when they are deployed on a large scale. However, it will be of prime importance to ensure that the technologies are very safe and robust, having the ability to perform in a variety of driving scenarios, and be very secure, being immune from any external cyber-attacks. This calls for performing extensive testing of such technologies.

Advanced Driver Assistance Systems (ADAS) are a steppingstone to fully autonomous vehicles. Global efforts are being undertaken to help accelerate the implementation of ADAS in vehicles. For e.g. Euro NCAP has framed test and assessment protocols for Autonomous Emergency Braking Systems (AEBS). These protocols form the basis for the development and testing of AEBS for a majority of organizations in the ADAS and Autonomous Vehicle market space.

These systems are slowly being incorporated in Indian vehicles as well, as is evident from the current draft regulations that are being formed for Advanced Emergency Braking systems (AEB) where the vehicle automatically brakes if it senses an impending collision. The systems being developed cannot be deployed directly on the road, even for testing purposes. Methodologies and facilities need to be established to verify and validate the systems so that the systems themselves don't pose any threat to the environment. The complexities involved in testing and validation of such Driver Assistance systems are given in the schematic below.

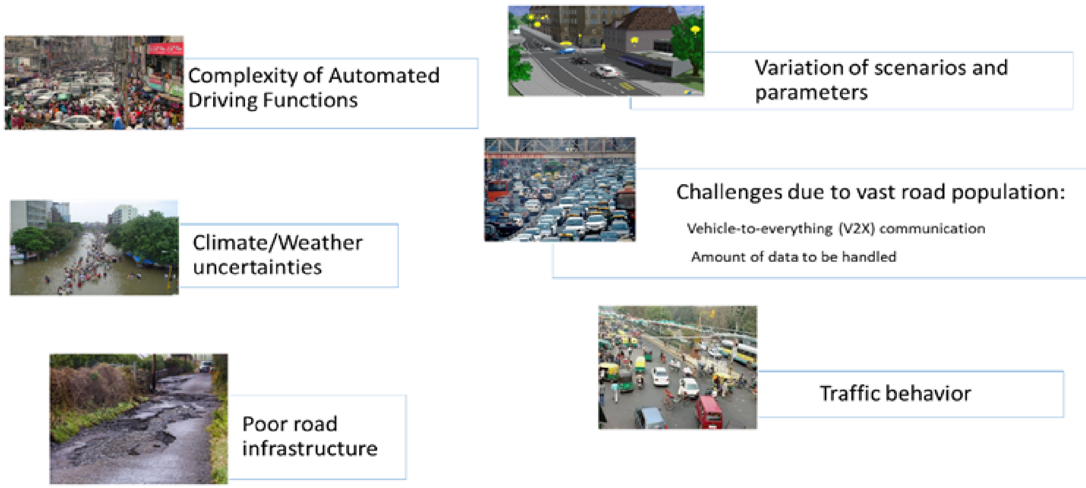


Figure 30. Complexities involved in testing and validation of ADAS Functions

They need to be validated for safe operation in Indian traffic conditions, should not intervene unnecessarily during extreme uncontrolled traffic scenarios like bumper-to-bumper driving. Also, the software needs to validate for fail safe operation. For this purpose, the control system needs to undergo a rigorous verification and validation exercise to deem it safe for Indian operation.

E. **Test Setup for Verification and Validation**

A test setup for verification and validation of safety critical driver assistance systems, typically needs to have following multi-pillar approach as per recommendation from UNECE GRVA. It is a Working Party on Automated/Autonomous and Connected Vehicles (GRVA) under WP 29 Harmonization of world regulations.

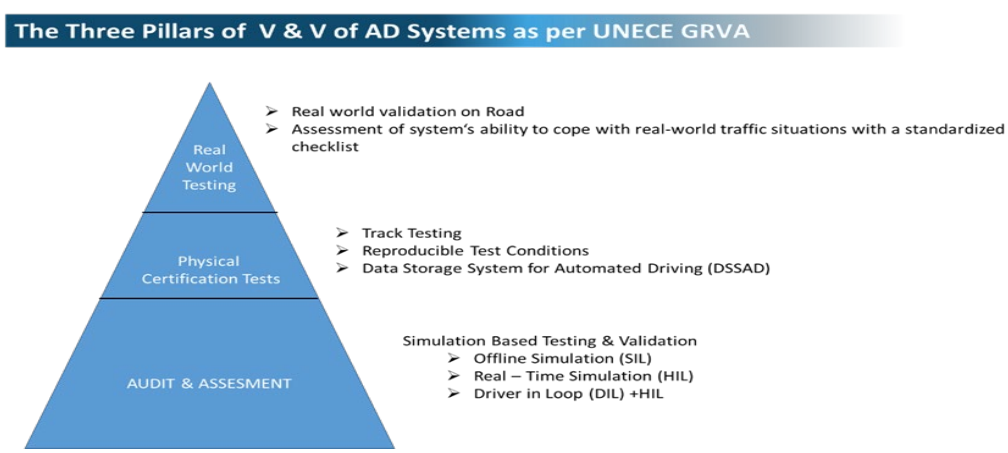


Figure 31. Multi-pillars approach for ADAS testing

Similar setup needs to be established for verification and validation of Driver Assistance systems in India too. For establishing a test setup, the following integrated approach is being proposed by ARAI.

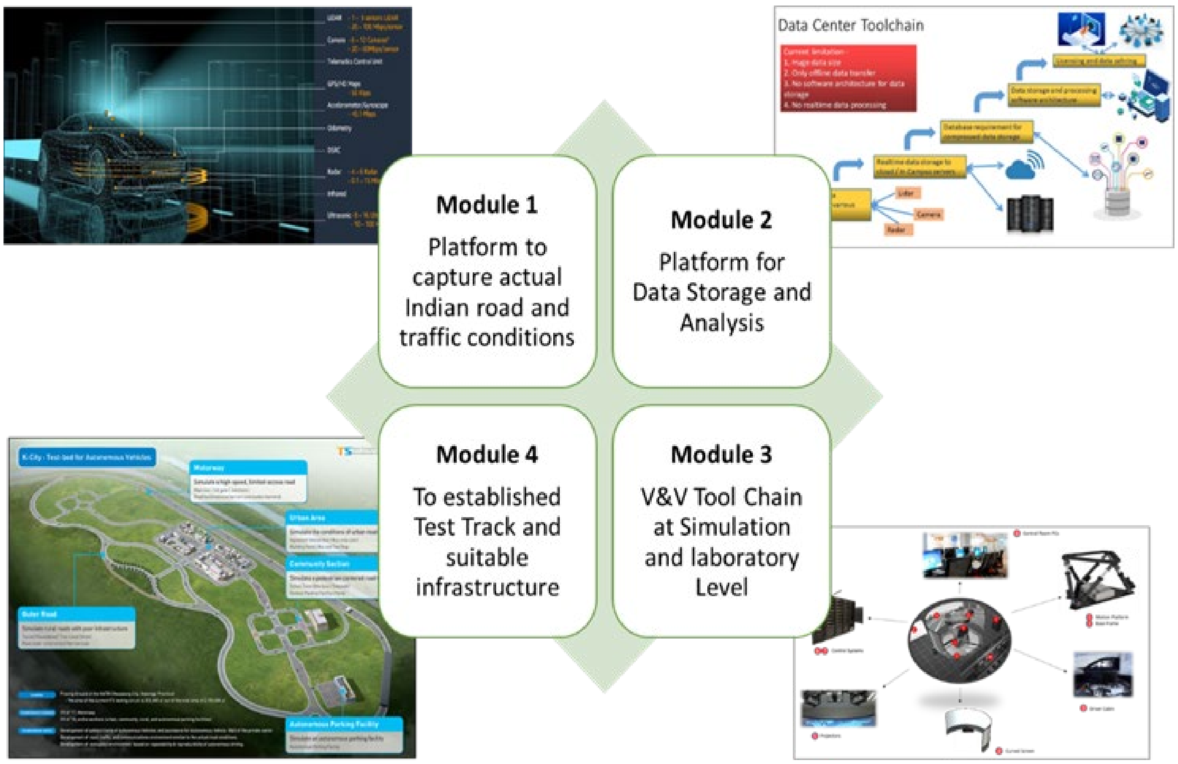


Figure 32. Integrated approach for ADAS V & V

The different modules that need to be established for effective validation of Driver Assistance Systems in India context.

F. ARAI Initiative

Under the Intelligent Vehicle Technology Program, The Automotive Research Association of India (ARAI) is spearheading the development, testing, verification & validation of ADAS technologies for Indian use cases. Team is actively working on establishing complete ADAS V&V toolchain from the lab to the proving ground. The following figure highlights the approach undertaken by ARAI for ADAS V&V.

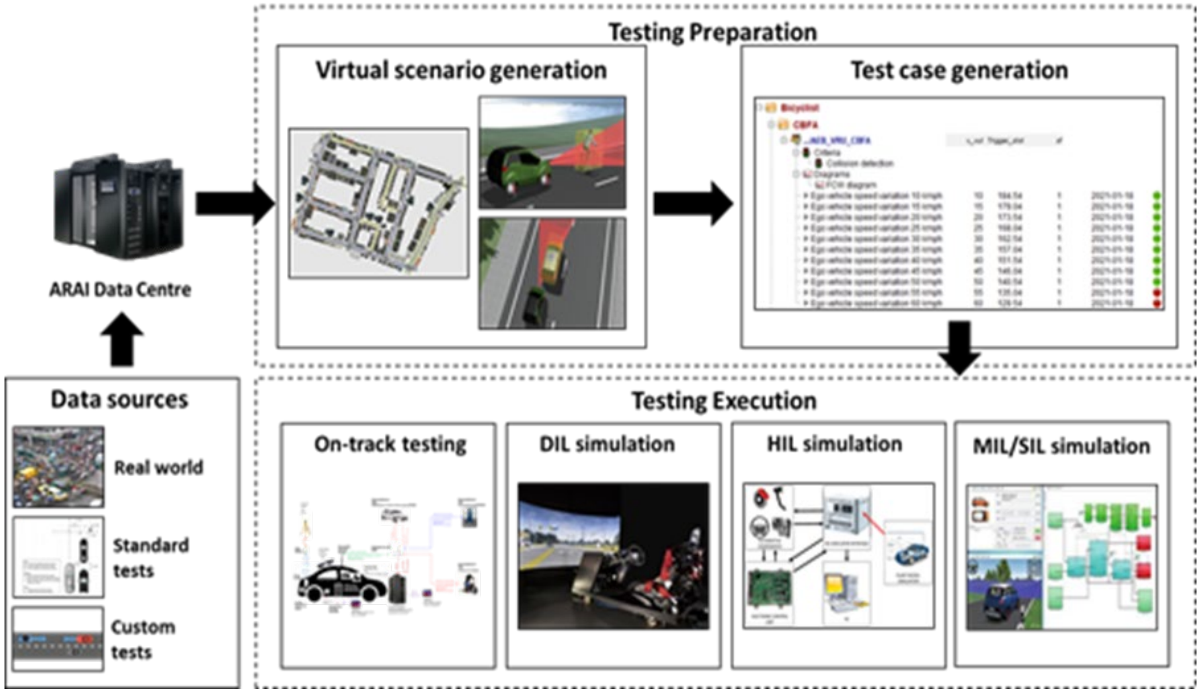


Figure 33. Different platforms for ADAS V & V

ARAI is setting up a Driver-In-Loop simulator setup to enable human-in-loop testing of ADAS in the lab. With regards to on-track testing, ARAI is building a state-of-the-art smart city test track to enable testing of ADAS against complex Indian traffic scenarios with the help of a comprehensive set of special test track equipment such as robotic motion platforms, ISO 19206 standard series compliant dummies, networking equipment and driving robots.

G. **ADAS Smart City Test Track**

In order to enable thorough on-track testing of ADAS against Indian driving scenarios, ARAI has conceptualized an ADAS Smart City Test Track. Spread over an area of over 20 acres, the test track incorporates various features reminiscent of typical Indian roads, thus emulating a fake city environment. Highlighting a few key features, the test track consists of Inner city roads complete with Indian lane markings according to IRC 35 and surrounded by foot-paths & streetlights, Round-about junction with approaches designed according to IRC 41 standard, small and large S-curves with lane markings designed according to IRC 35 standard, 4-way junction with 2 lane roads, Unpaved rural roads , Man-hole covers on roads, Iron bridge usually found on small roads to cross a river, Bus stop, Traffic signals and Movable Traffic signs.

In addition to simulating complex Indian driving scenarios, the ADAS Smart City Test Track can also be leveraged to conduct test scenarios specified under various regulatory and NCAP testing.

Figure 34. ADAS Smart City Test Track Facility

H. **ADAS Test Track Equipment**

To conduct on track testing of ADAS, ARAI possesses a comprehensive set of special ADAS Test Track Equipment to enable end-to-end closed-loop testing. For simulating complex scenarios involving moving as well as stationary objects on the road, the equipment set consists of purpose-built soft test dummies which comply to ISO 19206 series standards. This enables dummies to be detected by sensors such as cameras and RADARs which are commonplace in various ADAS. Among dummies, we have a Global Vehicle Target, an Articulated Adult dummy, an Articulated Child dummy, an Adult Bicyclist dummy, a Child Bicyclist dummy and a Global Motorcycle Target. These dummies are designed in such a way that upon a crash with the Vehicle-Under-Test, they disassemble without causing any damage to the test vehicle. The dummies are also very easy to reassemble.

To freely move the above dummies, the equipment set consists of three battery-powered robotic motion platforms. All robotic motion platforms are equipped with integrated inertial navigation systems capable of receiving RTK corrections, thus allowing them to position with centimeter-level accuracy on the test track. The large robotic motion platform is meant for moving the Global Vehicle Target with a maximum speed of 100 kmph. The other dummies, also termed as Vulnerable Road User dummies, are mounted on two small robotic motion platforms, one capable of a maximum speed of 20 kmph and the other capable of a maximum speed of 100 kmph.

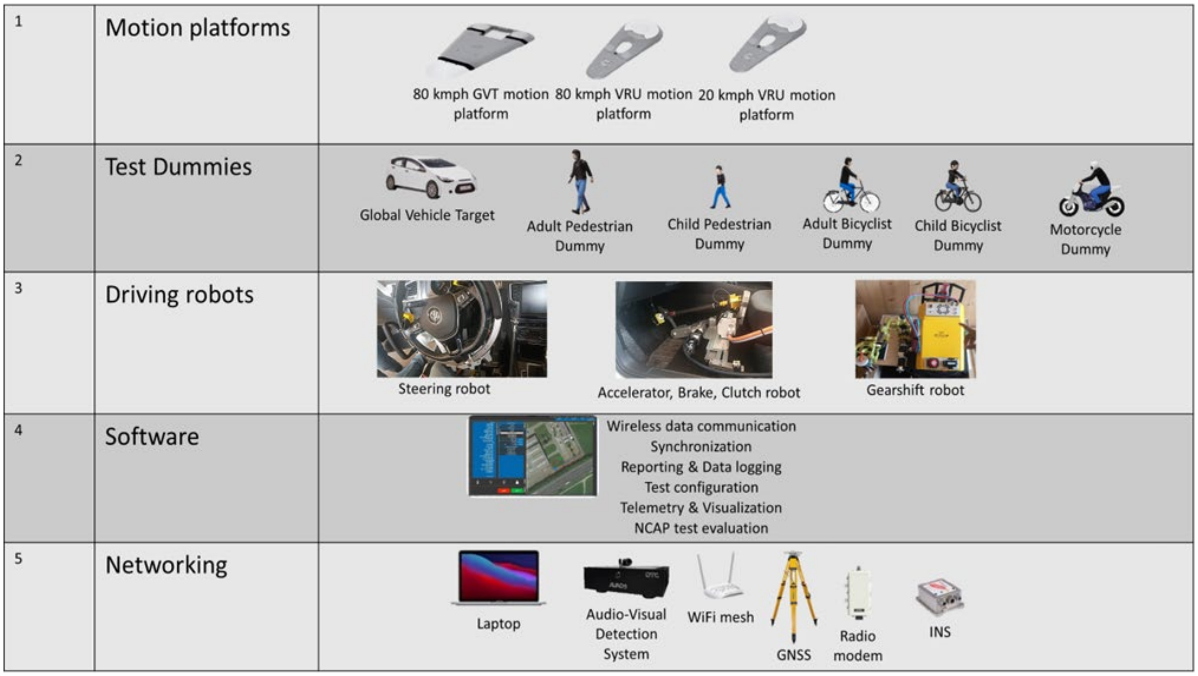


Figure 35. Available ADAS Test Track Equipment

The following figure showcases a representative architecture of the test track equipment setup.

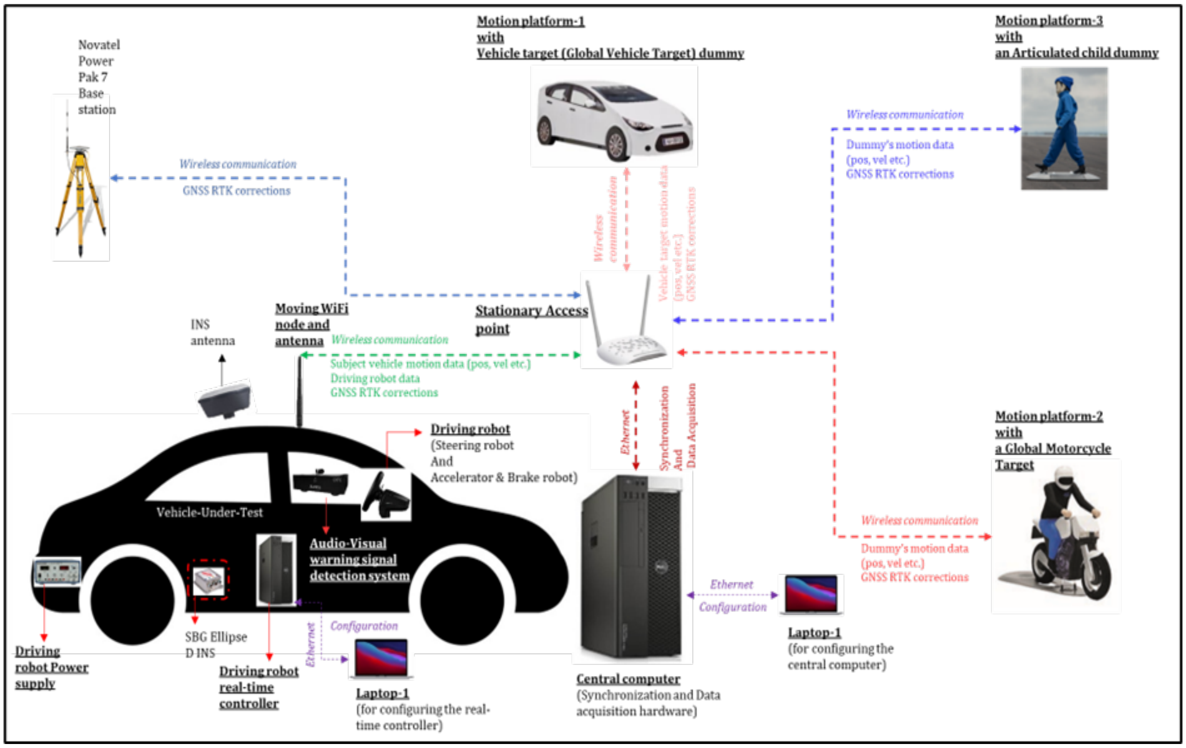


Figure 36. Architecture of the test track equipment setup

The equipment set also consists of a comprehensive set of driving robots, complete with steering robot, accelerator, brake & clutch pedal robots and a gearshift robot with the ability to be configured for both manual and automatic gearboxes. The driving robot controller is connected to an inertial navigation system with the ability to receive RTK corrections, thus allowing to position the Vehicle-Under-Test with centimeter-level accuracy on the test track.

All the above equipment is connected wirelessly to each other to allow for precise synchronization. Test scenarios are configured through centralized test configuration software and uploaded wirelessly to all the equipment set. RTK corrections are also wirelessly transmitted via a dedicated GNSS base station.

The above comprehensive set of ADAS Test Track Equipment allows to simulate complex test scenarios on a test track for thorough evaluation of ADAS in close-to-real-world scenarios.

I. Observations

When it comes to advanced vehicle automation technologies like Advanced Driver Assistance Systems, ensuring their safety before their release into the market requires a completely different approach to verification & validation as compared to traditional automotive testing. With the operating domain being complex, especially given the Indian driving conditions, exhaustive ADAS Verification & Validation can only be achieved with a mix of simulation based, lab-based and track-based verification & validation initiatives.

In line with the same, ARAI is undertaking initiatives to set up state-of-the-art verification & validation setups, from the lab to the proving ground. State-of-the-art ADAS simulation software is being used to enable XiL simulation from Model-In-Loop to Driver-In-Loop simulation. To extend the verification & validation capabilities to the track, the ADAS Smart City Test Track with its India-specific feature set, provides a unique opportunity to simulate close-to-real world Indian driving scenarios thus exposing ADAS to complex test scenarios. To add to that, a comprehensive set of ADAS Test Track Equipment helps ensure smooth and repeatable execution of such complex test scenarios in addition to standard test scenarios.

Annexure 5

A. **Road Accident and its distribution across Road types**

The country registered 4,61,312 accidents in 2022, of which, National Highways (NH) including Expressways had 1,51,997 (32.9%), State Highways (SH) had 1,06,682 (23.1%) and Other Roads had 2,02,633 (43.9%). Out of the total deaths of 1,68,491 in 2022, National Highways accounted for 61,038 (36.2%), State Highways for 41,012 (24.3%) and Other Roads for 66,441 (39.4%).

Out of the total, 1,55,781 fatal accidents in 2022, **National Highways witnessed 55,571 (35.7%), State Highways witnessed 37,861 (24.3%)** and Other Roads witnessed 62,349 (40%).

Category	**Accidents**	**Percentage of Accidents**	**Deaths**	**Percentage of Deaths**	**Fatal Accidents**	**Percentage of Fatal Accidents**
National Highways	1,51,997	32.9%	61,038	36.2%	55,571	35.7%
State Highways	1,06,682	23.1%	41,012	24.3%	37,861	24.3%
Other Roads	2,02,633	43.9%	66,441	39.4%	62,349	40%

Source: Road accidents in India 2022 by TRW of MORTH, GOI

E. **Road Accident and statistical skew towards Highways**

India has 63.31 lakh km of roads (as of 31 March 2019), which include 1.32 lakh km of National Highways, 1.80 lakh km of State Highways and 60.59 lakh km of Other Roads (such as District Roads, Rural Roads, Urban Roads and Project Roads). The share of National Highways, State Highways and other roads in the total road length is 2.1 per cent, 2.8 per cent and 95 per cent, respectively. This is a very uneven distribution, and so is the distribution of the number of road accidents, fatality and injury in 2022 among these road categories.

Road Type	**Length (km)**	**Percentage of Total Road Length**
National Highways	1.32 lakh	2.1%
State Highways	1.80 lakh	2.8%
Other Roads	60.59 lakh	95%
Total	63.31 lakh	100%

Source: Road accidents in India 2022 by TRW of MORTH, GOI

F. Causes of Road Accidents

Road accidents have many causes and often involve the combination of different factors such as (i) human error, (ii) road environment and (iii) vehicular condition. In 2022, among the Traffic Rule Violations, driving too fast is the main cause of death, responsible for 71.2 percent of the fatalities followed by driving on the wrong side (5.4 %).

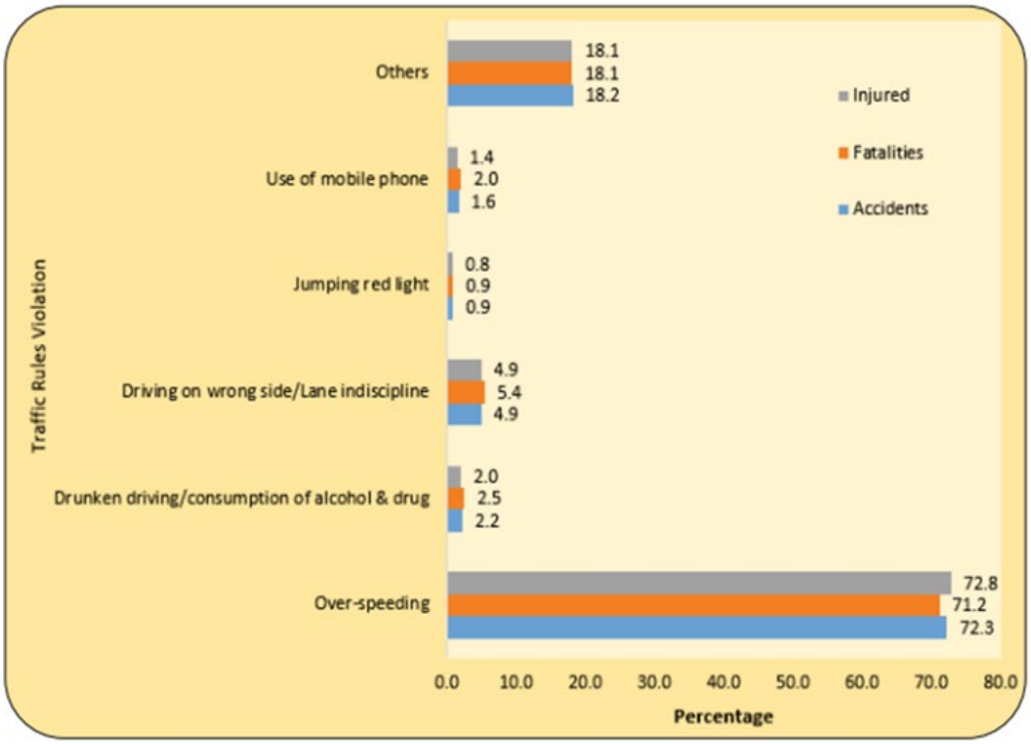


Figure 37. Road Accidents by type of Traffic Rules Violation during 2022

Source: Road accidents in India 2022 by TRW of MORTH, GOI

The report shows that for the neighborhoods categories, 47.7 percent of accidents, 55.1 percent of death and 48.2 percent of injuries happened in open area, i.e., locations where there is usually no human activity nearby. For the road feature category, 67 per cent of accidents occurred on straight roads, while accidents on curved roads, pothole roads and steep grade combined made up only 13.8 per cent of the total road accidents in 2022.

G. Weather condition influence on Road Accidents

Road surface condition and drivers' visibility are influenced by weather condition, which can increase the likelihood of accidents. Driving under bad weather conditions like heavy rain, thick fog and hailstorms is more dangerous as visibility is low and the road surface is slippery. However, the data of road accidents for 2022 showed that almost 75 percent of the accidents and deaths happened under sunny/clear weather (Figure 37). Accidents that occurred under bad weather conditions such as rainy, foggy and hail/sleet made up 16.6 percent of total road accidents in 2022.

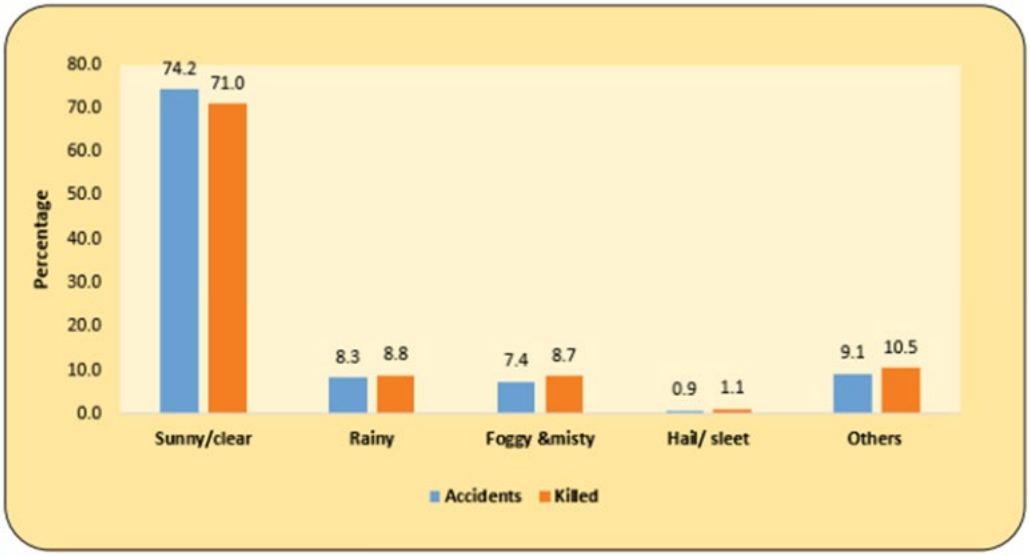


Figure 38. Road accidents by weather conditions during 2022

Source: Road accidents in India 2022 by TRW of MORTH, GOI

H. **Societal impacts based on the age group of accident victims**

Most of the accident deaths in 2022 (Figure 39) were from the 18-45 age groups, which made up 66.5 percent of the total. Road accidents mostly affect young people in the productive age, which has a significant impact on the socio-economic cost of the nation, as well as their emotional and psychological effect on family, society and nation. The working age group of 18-60 made up 83.4 percent of the total road accident deaths (Figure 39) in the country.

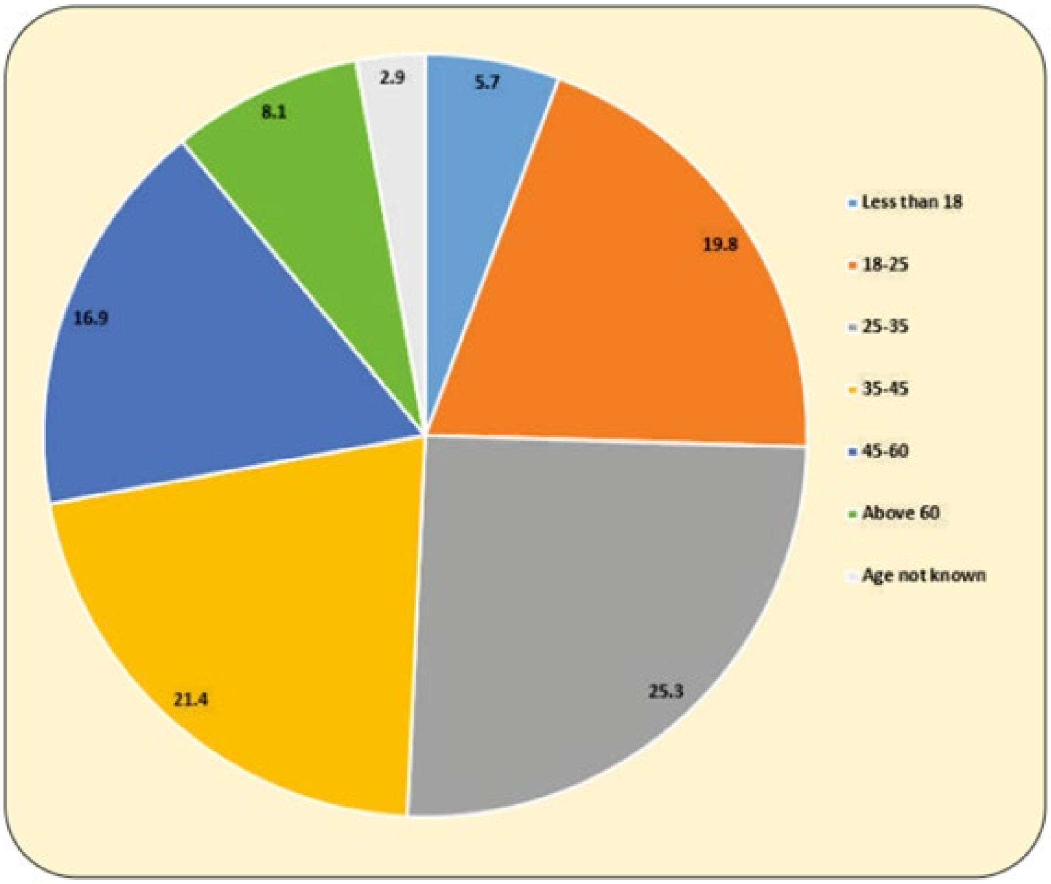


Figure 39. Age profile of fatal Road Accident victims during 2022 (in percentage)

Source: Road accidents in India 2022 by TRW of MORTH, GOI

References

[1] Road Accidents in India 2022, Annual Report 2022-2023, Ministry of Road Transport and Highways, Government of India, New Delhi.

ARAI Test Bed References

[2] Jackulin Mahariba A, Aryan., July 8, 2024, "(IRTSD-Datasetv1)-Indian Road Traffic Sign Detection dataset", IEEE Dataport, doi: https://dx.doi.org/10.21227/ap4b-c439.
[3] https://universe.roboflow.com/datacluster-labs-agryi/indian-traffic-sign-vvx9y
[4] Hegde, Chandan & T, Manjunatha. (2022). Real Time Indian Traffic Sign Detection using Image Processing and CNN. International Journal of Advanced Research in Science, Communication and Technology. 403-409. 10.48175/IJARSCT-5363.
[5] https://paperswithcode.com/dataset/indian-traffic-sign-image-dataset
[6] https://insaan.iiit.ac.in/datasets/
[7] https://doi.org/10.1016/j.ijtst.2022.06.002
[8] https://doi.org/10.1016/j.eswa.2023.121836

TiHAN Test Bed References

[9] Peng, H. (2019). Mcity ABC test: A concept to assess the safety performance of highly automated vehicles. Retrieved from March 22, 2023, from https://mcity.umich.edu/wp-content/uploads/2019/01/mcity-whitepaper-ABC-test.pdf
[10] https://cetran.sg/
[11] https://www.jari.or.jp/en/
[12] https://tihan.iith.ac.in/
[13] Pawar, D.S., Singh, A., Pachamuthu, R. (2023). Connected Autonomous Vehicles (CAV) Testbed at IIT Hyderabad. In: Rastogi, R., Bharath, G., Singh, D. (eds) Recent Trends in Transportation Infrastructure, Volume 1. TIPCE 2022. Lecture Notes in Civil Engineering, vol 354. Springer, Singapore. https://doi.org/10.1007/978-981-99-3142-2_28
[14] P. Rajalakshmi "Autonomous Driving and Connected Vehicles – TiHAN Testbed Usecase Manual", January 2023.

Reference for Use Cases

[15] Collision Avoidance

[A] AIS 162 link: https://morth.nic.in/sites/default/files/ASI/4_Draft_AIS_162_AEBS_DF.pdf
[B] Morth report: https://morth.nic.in/sites/default/files/AR-MoRTH_Annual%20Report_2023-24_English.pdf

[16] Warning Zone depiction

[A] Yadav, S., NT, S. K., & Rajalakshmi, P. (2023, June). Vehicle detection and tracking using radar for lane keep assist systems. In *2023 IEEE 97th Vehicular Technology Conference (VTC2023-Spring)* (pp. 1-4). IEEE
[B] P. Rajalakshmi "Autonomous Driving and Connected Vehicles – TiHAN Testbed Use Case Manual", January 2023.

[17] Traffic signage detection

[A] International Organization for Standardization: Intelligent Transportation Systems – Graphic data dictionary. ISO 14823:2017(E), 2017.
[B] Düser, T., Abdellatif, H., Gutenkunst, C. et al. Approaches for the Homologation of Automated Driving. ATZ Electron Worldw 14, 48–53 (2019). https://doi.org/10.1007/s38314-019-0107-4
[C] https://morth.nic.in/ais

[18] Multi-GNSS-Integrated Tolling System for Automated Electric Road Transportation (MGIT-AERT)

[A] Clause 3.0: ITS Functions and Requirements from AIS-140.
[B] Clause 4.0: Communication Protocol from AIS-140.
[C] Clause 5.0: Construction and Installation from AIS-140.
[D] Clause 6.0: Functional, Performance, Durability, Environmental and Protocol Tests from AIS-140.
[E] Clause 7.0: Device to Backend Communication Mechanism from AIS-140.

[19] Technology

[A] Srikanth, H. N., Reddy, D. S., Sonkar, D. K., Kumar, R., & Rajalakshmi, P. (2023, May). Pothole Detection for Autonomous Vehicles in Indian Scenarios using Deep Learning. In *2023 IEEE 26th International Symposium on Real-Time Distributed Computing (ISORC)* (pp. 184-189). IEEE.
[B] Aishwarya, P. V., Reddy, D. S., Sonkar, D. K., Koundinya, P. N., & Rajalakshmi, P. (2023, May). Robust Deep Learning based Speed Bump Detection for Autonomous Vehicles in Indian Scenarios. In *2023 IEEE 26th International Symposium on Real-Time Distributed Computing (ISORC)* (pp. 201-206). IEEE.
[C] Dutta, T., Reddy, D. S., & Rajalakshmi, P. (2024, January). Real-Time Deep Learning Based Safe Autonomous Navigation. In *2024 8th International Conference on Robotics, Control and Automation (ICRCA)* (pp. 400-406). IEEE.

[D] Adhikari, S., Kumar, R., Mopuri, K. R., & Pachamuthu, R. (2024). Lost in context: The influence of context on feature attribution methods for object recognition. Proceedings of the Indian Conference on Computer Vision, Graphics and Image Processing (ICVGIP 2024), December 13–15, 2024, Bengaluru, India. ACM.

[20] Integrated Unit Sensor fusion Based Autonomous Navigation

[A] Kumar, N., Dasgupta, A., Mutnuri, V. S., & Pachamuthu, R. (2024). An Efficient Approach for Calibration of Automotive Radar-Camera with Real Time Projection of Multimodal Data. *IEEE Transactions on Radar Systems*.
[B] Samuktha, V., Abhilash, S., Kumar, N., & Rajalakshmi, P. (2024, July). A Framework for Object Classification via Camera-Radar Fusion with Automated Labeling. In *2024 IEEE Sensors Applications Symposium (SAS)* (pp. 1-6). IEEE.

[21] Standalone Unit based Autonomous Navigation

[A] Thakur, A., & Rajalakshmi, P. (2024, April). Real-time 3D Map Generation and Analysis Using Multi-channel LiDAR Sensor. In 2024 IEEE 9th International Conference for Convergence in Technology (I2CT) (pp. 1-5). IEEE.
[B] Thakur, A., & Rajalakshmi, P. (2024). L3D-OTVE: LiDAR-Based 3D Object Tracking and Velocity Estimation Using LiDAR Odometry. IEEE Sensors Letters.
[C] Rajalakshmi, P. (2022). Real Time Lidar Odometry and Mapping and Creation of Vector Map**.**

[22] Environmental pollution

[A] Towards Decarbonising Transport 2023, A Stocktake on Sectoral Ambition in the G20, NITI Aayog report.
[B] https://www.worldbank.org/en/country/india/overview
[C] Dr. Venkat TiHAN will provide text about task 4 and 5 from the report https://mohua.gov.in/upload/uploadfiles/files/CMP%20Report%20Revised.pdf

[23] Lack of Annotations for Obscured Signs and absence of Adverse Conditions Data

[A] Jackulin Mahariba A, Aryan ., July 8, 2024, "(IRTSD-Datasetv1)-Indian Road Traffic Sign Detection dataset", IEEE Dataport, doi: https://dx.doi.org/10.21227/ap4b-c439.
[B] https://universe.roboflow.com/datacluster-labs-agryi/indian-traffic-sign-vvx9y
[C] Hegde, Chandan & T, Manjunatha. (2022). Real Time Indian Traffic Sign Detection using Image Processing and CNN. International Journal of Advanced Research in Science, Communication and Technology. 403-409. 10.48175/IJARSCT-5363.
[D] https://paperswithcode.com/dataset/indian-traffic-sign-image-dataset
[E] https://insaan.iiit.ac.in/datasets/
[F] https://doi.org/10.1016/j.ijtst.2022.06.002
[G] https://doi.org/10.1016/j.eswa.2023.121836

[24] Reference from Annexure

[A] Road Accidents in India 2022, Annual Report 2022-2023, Ministry of Road Transport and Highways, Government of India, New Delhi.
[B] Test Bed References ARAI References:
[C] Jackulin Mahariba A, Aryan., July 8, 2024, "(IRTSD-Datasetv1)-Indian Road Traffic Sign Detection dataset", IEEE Dataport, doi: https://dx.doi.org/10.21227/ap4b-c439.
[D] https://universe.roboflow.com/datacluster-labs-agryi/indian-traffic-sign-vvx9y
[E] Hegde, Chandan & T, Manjunatha. (2022). Real Time Indian Traffic Sign Detection using Image Processing and CNN. International Journal of Advanced Research in Science, Communication and Technology. 403-409. 10.48175/IJARSCT-5363.
[F] https://paperswithcode.com/dataset/indian-traffic-sign-image-dataset
[G] https://insaan.iiit.ac.in/datasets/
[H] https://doi.org/10.1016/j.ijtst.2022.06.002
[I] https://doi.org/10.1016/j.eswa.2023.121836

List of Contributors

TSDSI acknowledges with thanks, participation from the following people and organizations in the meetings of the forum chaired by Mr. Surya Satyavolu (Sirab Technologies) and Mr. Niranth Amogh (Nokia) and intensively contributed by Mr. Raja Gopalan (Tata Elxsi) with secretarial support from A.K. Mittal, Sweta Singh and Vaishali Upperwal.

Name of the Contributor	Company
Afjal Das	ISRO
A.K. Mittal	TSDSI
Chandra Murthy	IISc, Bangalore
Col. Suresh Warrier	Elena Geo
Dr. Lenin	IEEE
Dr. P Rajalakshmi	TiHAN
G. Kale Jyoti	ARAI
Jishnu Aravindakshan	Tejas Networks
Hari Krishna Atluri	ERNET India
Mohan Raju	Rjio
Niranth Amogh	Nokia (Co-chair)
Pradeep Hirisave	Rjio
Priyanka Dey	CEWiT
Raja Gopalan Rajappa	Tata Elxsi
Rashmi Kamran	IIT, Bombay
Sai Dhiraj Amuru	WiSig Networks
Samar Shailendra	Intel
Sarvendranath Rimalapudi	IIT, Guwahati
Saurabh Mittal	Airtel
Sourav Mukherjee	IISc, Bangalore
Sudipta Ghosh	Wipro Ltd.
Surya Satyavolu	Sirab Technologies (Co-chair)
Sweta Singh	TSDSI
Vinay Shrivastava	Rjio
Vivek S	Cisco
Vaishali Upperwal	TSDSI

tsdsi

India's Telecom SDO

Telecommunications Standards Development Society, India

Registered Office Address

C-DOT Campus, Mandi Road, Mehrauli,

New Delhi, India – 110030

www.tsdsi.in