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The Path of Autonomous Vehicle Deployment for Indian market

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Abstract:
Automotive industry has made considerable progress of introducing and deploying different technologies which improves safety of road users and vehicle occupants. The global race toward Autonomous Vehicle is accelerating rapidly, but in India, the journey is far more complex. As countries like the United States, China, and Germany approving to evaluate driverless cars on public roads, India finds itself grappling with fundamental questions: Is the country ready for autonomous vehicles, and what will it take to make them a reality? Indian market stands at pivotal moment being both one of the fastest-growing economies globally and home to the world's most extensive youth demographic, which is a key driver for adaptation and deployment of new innovation in automotive domain. This paper presents a brief overview of the current state, limitation of autonomous vehicle deployment, implications, and potential solution of autonomous vehicle deployment in the Indian market.
Indian major cities densely populated, diverse traffic conditions, complex road structures and affordability, India presents unique and key challenges and opportunities for the deployment of autonomous vehicles. Autonomous vehicle technology has the potential to address critical issues such as road safety, reduce the crash due to human error, congestion, and pollution while transforming the mobility experience for millions of people. However, several hurdles must be overcome to fully harness its benefits.
The paper explores key considerations for the path of implementation of autonomous vehicles in India. These include adapting the phase wise deployment of technology while addressing the current challenges of infrastructure limitations, regulatory frameworks and ready for future fully autonomous vehicle deployment.
The paper also highlights ongoing initiatives from Government and private OEM's or key players for pilot projects in India, highlighting the progress made in integrating autonomous vehicles into the transportation ecosystem.

Keywords
Electronic Control Unit (ECU), Compute hardware, Advanced Driver Assistance Systems (ADAS), vehicle safety, Autonomous Vehicles (AV), regulatory framework, emerging technologies, case studies, Society of Automotive Engineers (SAE), National Highway Traffic Safety Administration (NHTSA), Lane Keep Assist (LKA), Lane Departure Warning (LDW), Adaptive Cruise Control (ACC).

1. Introduction

The continuing innovation and emerging technology in automotive industry aims to deliver even greater safety, comfort benefits than earlier technologies. Automotive industry is advancing the towards,

automated driving systems, which also refer to as automated vehicles, may be able to manage the whole task of driving when we do not want to or cannot do it ourselves. These vehicles are equipped with high precision compute platforms or ECU which processes the signal form different sensors such as Radar, LIDAR, Camera, High-Definition Maps, Telematics controller communicate over advance communication network protocols (ethernet).

The global Autonomous vehicles (AVs) market is on a steep upward trajectory. Valued at USD 207.38 billion in 2024, it is projected to reach USD 4450.34 billion by 2034, growing at a compound annual growth rate (CAGR) of 36.3%. North America leads, driven by robust technological infrastructure and investments from companies like Waymo and Tesla. Asia-Pacific follows closely, with China and Japan pushing for self-driving technology integration in smart cities. Europe emphasizes safety and regulatory frameworks, contributing to steady growth. Key drivers include advancements in AI, rising demand for safer roads, and urban mobility challenges, with luxury cars (Level 1 and 2) and robotaxis fueling early adoption in emerging economies.

Moreover, Driver assistance technologies hold the potential to reduce traffic crashes and save thousands of lives each year. National Highway Traffic Safety Administration (NHTSA) published in 2023, 40,901 people died in motor vehicle crashes — many of these crashes were tied to human error. The Autonomous Vehicle emerging technology helps to reduce accidents and fatalities by the human error which save the life and reduce the economic costs of roadway crashes through deployment of safe autonomous vehicles.

The potential of autonomous vehicles in India is undeniable. AVs could revolutionize mobility by reducing traffic congestion, cutting down road accidents, and offering new transport solutions for the elderly and people with disabilities and improve the quality of life as well as ease of transportation. With India's push toward a $5 trillion economy and its Smart Cities Mission, driverless technology could play a key role in shaping future urban mobility.

2. Fundamentals of Autonomous Vehicles:

Autonomous vehicles are self-contained vehicle equipped with advanced sensors (Radar, LIADAR.), high performing compute (System on Chip) unit which performs, High-Definition maps and network connectivity which perform necessary deriving functions without any human interference or interaction, by using its ability to sense its environment.

The autonomous vehicle uses a fully automated self-driving system which allows the vehicle to participate in its surrounding conditions and make decisions that the human driver can perform and controls.

There are various five automation levels specified by the Society of Automotive Engineering commonly referenced as the Society of Automotive Engineers (SAE) levels of Driving Automation, has been the industry's most-cited source for driving automation. With a taxonomy for SAE's six levels of driving automation, SAE J3016 defines the SAE Levels from Level 0 (no driving automation) to Level 5 (full driving automation) in the context of motor vehicles and their operation on roadways.

Society of Automotive Engineers (SAE) levels of Driving Automation:

- **SAE Level 0**: the car has zero self-control over its operation. It is fully managed and driven by human drivers.
- **SAE Level 1:** The ADAS vehicle (Advanced Driver Assistance System) is present on vehicle. Example Cruise Control, Adaptive Cruise Control (ACC), Lane Keep Assist etc.

- **SAE Level 2**: The vehicle Advanced Driver Assistance System can control the steering, acceleration and braking, lane change etc. While the human drivers give his attention "eye on" to vehicle's surrounding throughout the entire journey. The Level 2 hands-free self-driving works on limited mapped roads or defined road freeways or express lanes.
- **SAE Level 3**: The vehicle Advanced Driver Assistance System can control perform all the driving tasks till a particular level. You are not driving when these automated driving features are engaged – even if you seated in the driver's seat. The driver is allowed to disengage "eye off "(look away, read, watch infotainment, or check a phone) from continuous visual monitoring of the road while the automated driving system (ADS) is active. When ADAS (Advanced Driver Assistance System) feature requests or notified via warning, driver must drive or take the vehicle control. Mercedes-Benz DRIVE PILOT meets SAE level 3 autonomous driving requirements.
- **SAE Level 4**: The vehicle operates fully on its own but only within a specific environment defined by factors like road type, or weather. These automated driving features will not require driver to take over driving. Examples Waymo.
- **SAE Level 5**: These automated driving features will not require driver to take over driving.Though the benefits of AVs are considerable, there are some challenges in adopting this innovative technology for real time specifically for developing countries like India.

3. Obstacles for Autonomous Vehicles for India Market

There are several challenges that needs to be addressed before full deployment of the Autonomous Vehicle. These problems cover a wide range of limitations, including those pertaining to technology, infrastructure, regulations, social acceptance, and affordability of Autonomous Vehicle in Indian Market. This section will thus, discuss the obstacles for autonomous vehicles.

3.1 Infrastructure limitations

- **Road Infrastructure:** Infrastructure major limiting factors of Autonomous Vehicle deployment in Indian market. The lack of well-marked lanes, non-standardized road signs, lack of traffic lights, unpredictable traffic with mix of cars, auto-rickshaws and pedestrian sharing the same road. Numerous potholes and non-standard road design. In these circumstances Autonomous Vehicles would struggle to make the precise decision and navigate.
- **Communication Networks:** Even though Indian made major progress in the telecommunication by rolling out 5G technology still areas where the network connectivity is poor. Autonomous Vehicle required high speed and stable network connectivity for the real time operations.

3.2 Lack of Regulatory framework

As of now, India does not have a comprehensive legal framework.
specifically designed for autonomous vehicles. The existing regulations, including the Motor Vehicles Act, do not address the unique requirements and challenges posed by self-driving technologies. This regulatory gap presents significant obstacles for the development and deployment of autonomous vehicles in India. However, there have been some preliminary steps toward creating a legal structure for autonomous vehicles. The Ministry of Road Transport and Highways (MoRTH) has shown interest in the development of autonomous vehicle technology and has initiated discussions on drafting appropriate guidelines. In

2021, MoRTH released a draft notification amending the Motor Vehicles Act to include provisions for automated testing [1] and certification of autonomous vehicle technology.

3.3 Ethical and Social Implications

Autonomous Vehicles raise complex ethical questions, such as how to prioritize passenger safety versus the safety of pedestrians and other road users in the event of an unavoidable accident. Addressing ethical dilemmas and societal implications related to Autonomous Vehicle technology requires careful consideration and dialogue among stakeholders.

3.4 Technological limitations

Even the advancement of technology in Autonomous Vehicles still technical limitations that need to be addressed before deploying the Autonomous Vehicles. Considering environmental factors in India and managing the edge case scenarios (unmarked roads, low visibility, congested traffic etc.).

3.5 Cost and affordability

Autonomous Vehicles uses high computational electronics ECUs are extremely expensive which eventually increase the cost of vehicle. The Autonomous Vehicle can be affordable by market penetration of Autonomous Vehicle.

4. Autonomous Vehicle Case Studies and global trends

Many developing countries are advancing and deployment of Autonomous vehicle by easing the phase wise rollout approach of Autonomous Vehicles to different cities. Local government agencies engage in checking the key issues such as accidents due to Autonomous Vehicles error, acceptance of Autonomous Vehicles in the society.

A per the KPMG Autonomous Vehicle Readiness Index [3] studied twenty countries including developed and developing (including India) by assessing countries' openness and preparedness for autonomous vehicles in 2020. The study shows India stand at 20th position based on poor infrastructure, technology and innovation and openness of government.

United States: A per the KPMG Autonomous Vehicle Readiness Index the United States leads in AV innovation and ranked at the top of the technology and innovation pillar of this index.

As per the latest report published [4] in November 2025 from Insurance Institute for Highway Safety (IIHS). Many states allowed use of SAE level 4 and 5 Autonomous Vehicle deployment in major cities and freeways with defined liability and coverage requirements. Few states such as Michigan, Massachusetts, Maryland allowed only testing of Autonomous Vehicles in defined areas.

Singapore: Singapore tops KPMG Autonomous Vehicle Readiness Index two pillars of this index, policy and legislation and consumer acceptance. Singapore's Land Transport Authority (LTA) takes a safety-first approach with AV trials starting on lightly used roads and graduating to more congested environments only after they have proved readiness. All test AVs will have to log travel data to enable accident investigations and liability claims.

Netherlands: The Netherlands is the clear leader in this first Autonomous Vehicles Readiness Index. It is within the top four of each of the four pillars and ranked number one on infrastructure, due to its heavily used, well-maintained road network, rated as being among the world's best by the World Economic Forum and the World Bank. It also has by far the highest density of electrical vehicle charging points, with 26,789 publicly-available points in 2016 according to the International Energy Agency's Global EV Outlook — more than Japan has for a road network more than eight times the length. The Netherlands also has high-quality wireless networks too.

5. Path of Autonomous vehicle deployments

The global semi-autonomous vehicle market size was valued USD 58.17 billion in 2024 and is expected to reach USD 172.2 billion by 2030, growing at a CAGR of 18.8% from 2025 to 2030. The rising need for safer and more efficient driving systems promotes the development and adoption of semi-autonomous vehicles [6].

Despite the challenges discussed above the long-term future of autonomous vehicles in India stays promising. The approach of phase wise deployment of Autonomous Vehicle is important and suitable considering the infrastructure, cost, and social acceptance of challenges.

India's automotive industry is slowly adopting advanced technologies such as Lane Keep Assist (LKA), Lane Departure Warning (LDW), Adaptive Cruise Control (ACC) etc. to improve road safety. Advanced Driver Assistance Systems (ADAS) help drivers by reducing errors that cause accidents. Automakers are adding ADAS to vehicles because it improves safety and prevents collisions.

The basis of Handsfree driving lies in heightening a vehicle's understanding of its path by taking data collected from the front ADAS camera and combining with different vehicle control modules such as telematic module, High-definition maps to define engagement of handsfree driving system. The SAE level 2 category enhances level1-2 driver assistance safety features with location intelligence, providing greater utility to drivers in all driving environments.

Pursuing the path of Autonomous Vehicle (AV), automotive industry and technology partners start investment in enhancing current ADAS technology by integrating ADAS Semi-Autonomous features such as automatic lane change, handsfree driving (hands-off, eyes-on) as per the SAE level.

Handsfree driving is key features which requires the Telematics module, High-definition maps, camera, radar, driver monitoring camera and ADAS compute unit.

6. Comparison study of semi-autonomous vs autonomous vehicle system

Semi-autonomous and autonomous systems required the different sensors. and computational platforms to perform the prescribed functions. This section covers the key differences of sensors and compute requirements for both vehicles.

Sensors and Compute unit	**Semi-Autonomous vehicle (SAE level 2)**	**Autonomous vehicle (SAE L4 and 5)**
Radar	Required (limited based on vehicle architecture)	Multiple radars required as per vehicle architecture

High-Definition Maps	Required (Based on mapped areas)	Required
Driver Monitoring	Required	Not- required
GPS/ Telematics controller	Precise location (Based on mapped areas)	High precision GPS antennas.
Front Camera	Required	Required
Surrounding view Camera	Minimum one required	Multiple surround view cameras with high processing power.
LIDAR	Not required	Multiple LIDAR required for precision
Ultrasonic sensors	required	Uses high frequency sound waves to measure distance between objects
High processing power central compute	Low-cost high processing compute platform required.	Expensive high processing central compute required.
Artificial Intelligence and Machine learning data.	No required or limited use.	High dependency of system on Artificial and machine learning.

SAE level 2 systems still fulfill the functional safety (ISO26262) requirements to maintain the safety of driver and passenger when system unable to make the decision in the environment such as system component failure, undefined operational areas of the self-driving etc.

7. Phase wise roll out of semi-autonomous vehicles

Many express ways in India are already functional in parts and are nearing full completion for example Mumbai-Delhi, Mumbai-Nagpure etc. Considering the completeness of road, line marking, network connectivity and road accessible only for four wheelers and commercial vehicles makes road more suitable for the SAE level 2 semi-autonomous handsfree driving features deployment. This section talks about the proposed phase wise deployment of autonomous vehicle deployment in Indian market.

Proposed Potential phase wise deployment of semi-autonomous and autonomous vehicle in India.

Phase	**Vehicle Autonomous state**	**Target deployment areas**
Phase 1	Semi-autonomous Hands-free driving (SAE level 2)	Pilot program for specific test areas.

Phase 2	Semi-autonomous Hands-free driving (SAE level 2)	Defined national highways and express ways (roads meeting requirement of clear line marking and connectivity.
Phase 2.1	Semi-autonomous Hands-free driving (SAE level 2)	Defined national highways and state highways and express ways (roads meeting requirement of clear line marking and connectivity.
Phase 2.2	Semi-autonomous Hands-free driving (SAE level 2)	Enable low speed (example 25Kmph speed) semi-autonomous for city areas which meets the semi-autonomous driving requirements.
Phase 3	Semi-autonomous Hands-free driving (SAE level 3)	Defined national highways and express ways (roads meeting requirement of clear line marking and connectivity.
Phase 3.1	Semi-autonomous Hands-free driving (SAE level 3)	Enable low speed (example 25Kmph speed) semi-autonomous for city areas which meets the semi-autonomous driving requirements.
Phase 4	Autonomous vehicle (SAE level 4+)	Defined cities (Once all autonomous vehicle requirements fulfilled.

The crucial factor of the deployment of semi-autonomous hands-free driving feature on expressways because expressways are only open for four wheelers and commercial trucks which avoid the traffic issues due motorbikes and the pedestrians. Expressways are the best roads to implement the SAE level 2 autonomous driving Indian roads.

8. Future Directions and Innovations

- **Legal Framework:** Adaption of semi-autonomous vehicles are subject to regulatory frameworks safety and security. Compliance with regulation such as Federal Motor Vehicle Safety Standard (FMVSS) and European Union General Safety Regulation (GSR) is important to ensure the safety, legality and standardization of semi-autonomous vehicle development and deployment.

- **Cost Optimization:** The semi-autonomous vehicle ecosystem—sensors, chips, software—drives the cost of vehicle. Development required for low-cost sensors and hardware compute platform which reduced the cost of overall semi-autonomous vehicle. Technology companies explore option of local manufacturing and government of India's while "Make in India" initiative to reduce the cost of overall semi-autonomous vehicles.
- **Sensor fusion:** Semi-autonomous vehicle performance and safety depend on different sensor and the accuracy and high processing power.

Development high precision sensor fusion techniques and algorithm development effort required considering the diverse climatic conditions in Indian market such as dust, heavy rain etc.

9. Case Studies of Semi-Autonomous Vehicle

Real-world case studies offer valuable insight of challenges, limitations and practical application and effectiveness of semi-autonomous vehicle. This section highlights the practical real world case studies of semi-autonomous (SAE level 2) handsfree driving vehicle deployments.

9.1. General Motor SuperCruise System

The SuperCruise is the hands-free driver assistance technology for Super Cruise utilizes advanced technologies to provide the ease and convenience of hands-free driving on compatible roads. This technology uses precision radar, map data in addition to real-time cameras, sensors, and GPS to maintain control of the vehicle under certain conditions on compatible roads, which can help make long drives and commutes more comfortable and enjoyable. Supercruise technology handles steering, acceleration, braking, lane centering (stay vehicle at center of the lane), automatic lane change, drives the vehicle when handoff the wheel and eyes on the road.

SuperCruise enable feature is popular on General Motors vehicles. Currently the 600,000+ miles [5] of compatible roads in United States and Canda mapped or enabled for the SuperCruise operation. Further expansion of roads and freeways in progress.

9.2. Ford Motors BlueCruise System

The BlueCruise is the handsfree driving assistance technology available on the Ford Motors vehicle. This technology supports the adaptive cruise control, lane centering assistance, accelerate, brake, lane change assistance.

BlueCruise features works on blue zone networks or roads defined for handsfree operation. This technology available 97% controlled accessed highways (130,000miles) across United States and Canada.

9.3 BMW Driving Assistant Pro

BMW has long history of safety and reliability. BMW developed Driving Assistant Pro with hands free driving along with other ADAS safety feature.

10. Pilot Program in India for Semi-auto and Autonomous vehicles

- **ARAI:** The Automotive Research Association of India (ARAI) is developing an autonomous vehicle as part of its "SwayamGo" program.
- **IIT Bombay:** The Global R&D Center for Connected and Autonomous vehicles at IIT Bombay focused on developing solutions specifically for Indian conditions.

Multiple OEMs are currently working on the developing smart solution for the mobility including the semi-autonomous and autonomous vehicles for their future portfolio. Pilot programs, better data sharing, investment in infrastructure upgrades, and clear regulatory policies will be crucial. Partnerships between government, industry, and academia can also help create a roadmap tailored to India's unique needs.

11. Conclusion

Autonomous Vehicle technology is developing very rapidly. It is rare for a week to pass without a major manufacturer, city, or regions in developing countries announcing a new product alliance, trial, or investment.

Despite the challenges, the long-term future of autonomous vehicles in India remains promising. While fully autonomous cars on Indian roads may still be a distant dream, semi-autonomous features like lane-keeping assist, adaptive cruise control and automatic braking are already making inroads through premium vehicle models. The next step is to introduce the semi-autonomous Handsfree driving feature in Indian market. Industry experts suggest starting with semi-autonomous (Hands free driving) development, testing and deployment approach is steppingstone towards the adaption of full autonomous vehicle.

To implement the Autonomous Vehicle in Indian market, need to "Plan today" for an autonomous vehicle future, by revising national and local transport strategies and regulations. Advancing the current infrastructure and consider the Autonomous Vehicles needs while building new infrastructure.

Real case studies, including General Motors SuperCruise and Ford Motors BlueCruise and BMW Driving Assistant Pro offer tangible examples of the widespread coverage of semi-autonomous in United states, Canada, and Europe. These case studies highlight the semi-autonomous vehicle importance and growing acceptance of technology in developing countries.

In conclusion, the development, testing and deployment of semi-autonomous vehicles in Indian market will be transformative shift towards safer, efficient and reduces the possibility of human error and accidents on roads. Successful integration of semi-autonomous helps to pursue the ultimate goal of Autonomous Vehicle deployment on Indian roads.

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