Science & Technology Policy Brief

Autonomous Vehicles

Summary

- Advances in AI, sensors, and hardware have enabled automated driving of road vehicles.
- Driverless vehicles are being piloted in pre-defined design scenarios such as city roads.
- Infrastructural improvements may be needed to make driving environment more predictable for autonomous vehicles.
- Safety and productivity gains could be key advantages; however, new safety risks may emerge due to the nature of technology.
- Policy questions include assigning liability in case of accidents, and addressing privacy and cybersecurity concerns.

Background

Vehicles across air, water, and land are still largely manned by humans for driving. Human drivers are prone to fatigue, stress, and variance in skills.[1,2] Humans may also consciously violate regulations or make errors, posing safety risks.[2,3] Safety and productivity concerns have driven the interest in replacing human drivers with automation.[4] Around the world, driverless trains and metros have been in operation.[5] Driverless vehicles are also in use in controlled environments such as factories.[6] Airplanes use 'autopilot'.[7] However, achieving a similar level of automation on public roads has been harder. This is due to a more complex environment, constant interactions with other vehicles and pedestrians, diverse terrains, and weather conditions.[8]

Advances in sensors, AI, and computing hardware have brought autonomous road vehicles closer to reality.[9,10,11] Advanced driving assistance systems that are currently available commercially, automate some driving functions but still require a driver.[12,13] Driverless vehicles are being piloted in pre-defined design scenarios such as city roads and highways.[14,15,16] However, fully autonomous road vehicles capable of driving in all scenarios are still considered a frontier.[17,18] Automation of driving may incur costs in implementing technology and building adequate physical and digital infrastructure.[3,19] These costs could potentially be offset by savings from eliminating a human driver. With re-allocation of driving responsibilities between the driver and the system, there could also be concerns around: (i) safety, (ii) apportioning liability and (iii) data security.[20,21,22]

Autonomous Vehicle Technology

Automation Levels

Driving involves several tasks such as monitoring the environment, changing direction and speed, adhering to road regulations, and avoiding collisions. Many of these tasks need to be performed simultaneously and in real-time. Vehicles with varying level of automation of driving functions are available today. SAE International provides a widely referred classification of driving automation (Table 1).[4,23]

Table 1: Automation level in road vehicles

Level	Description	Examples
Level 0: Momentary Assistance	Driver operates, system may provide warnings and alerts	Traditional vehicles
Level 1: Driver Assistance	Driver operates, system assists with functions such as speed control or lane keeping	Honda Civic (2018)[24]
Level 2: Partial	System can control both speed and steering; driver must monitor and remain in control	Tesla Model 3 (2017)[25]
Level 3: Conditional	System can drive autonomously; driver must be ready to take control when requested	Mercedes Benz S Class (2022)[26]
Level 4: High	No driver needed in defined scenarios such as highways or city streets	Waymo in USA (2018)[27]; Baidu in China (2021)[28]
Level 5: Full	No driver needed in any scenario	-

Source: SAE International; PRS.

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As shown in Table 1, vehicles up to Level 3 are operational. There are trials being conducted for Level 4 automation, such as Robotaxis in city streets in various places such as San Francisco and Wuhan (see Box 1).[14,15] The developer specifies that in a specified design scenario, such as streets of a city, no human driver will be needed.[27,28]

These are different from Level 5 fully autonomous vehicles that can operate without human intervention at all.[4] This means that they should be able to operate under all road conditions in which a skilled human driver will be expected to operate a traditional vehicle. These vehicles are still considered a technological frontier.[8,17,18] Predictions regarding their realisation range between 2025 and 2050 and later.[18] A key challenge is the complexity of the driving environment due to: (i) the risks of unpredictable behaviour of other human drivers and pedestrians on roads, and (ii) diverse terrains, dynamic road conditions, and traffic rules across regions.[29] This note focuses on issues related to operationalising Level 4 and Level 5 autonomous vehicles.

Box 1: Pilot of driverless cars in San Francisco

California has permitted the operation of driverless cars in certain areas.[32] Waymo, a driverless car developer, has been deploying these vehicles in the city of San Francisco.[32] These do not require any human operator to supervise them.[32] General public can hail them for daily commute.[32] These cars can operate on all roads in the city, in all weather conditions, and throughout the day.[14]

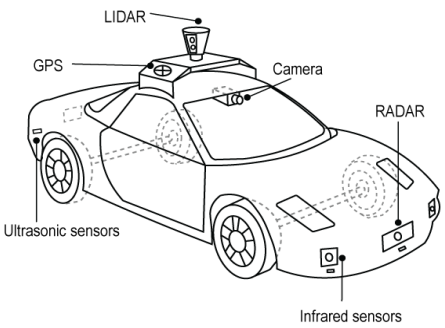
Waymo has reported that its fleet of taxis have driven 22 million miles in USA without a human driver, as of June 2024.[33] The data collected was compared to a human driven vehicle that has driven the same number of miles.[33] Waymo reported: (i) 84% fewer airbag deployment crashes, (ii) 73% fewer injury causing crashes, and (iii) 48% fewer police reported crashes with their fleet.[33] It also reported fewer incidents per million miles traveled as compared to the benchmark set by a human driven vehicle.[33]

Other states in USA, and countries such as China and Germany have also permitted pilot of driverless vehicles on public roads.[34,35,36] Vehicle types include cars, buses, and trucks.[34,35] Permits have conditions on operating in designated areas, and during certain times and weather conditions. Regulations may require presence of a human observer, either in-seat or remotely.[16,32]

Observing surroundings

A pre-condition for vehicles to drive autonomously is the ability to observe the surroundings continuously. Autonomous vehicles use a variety of imaging technologies for this. Vehicles typically come equipped with video cameras, lidar (laser-based imaging), radar (radio wave-based imaging), and ultrasonic sensors.[10,30] These are used to generate information about the presence of objects in the surrounding and their shapes, sizes, and distances.[10] Some of the data captured by these sensors include: (i) information about pedestrians, vehicles and other objects on the road, and (ii) road signs and lane markings. Cameras and lidar are less effective in adverse weather and long ranges than radar.[31] The data is processed by a machine learning-based software in the vehicle, which interprets the surroundings.[11] Machine learning systems learn from patterns in large datasets, and feedback from their developers.[11]

Figure 1: Sensors in an autonomous vehicle



Source: Center for Sustainable Systems, University of Michigan. 2024. "Autonomous Vehicles Factsheet."; PRS.

Sensors have a finite range and may face obstruction due to: (i) unpredictable weather or (ii) blind spots on the road. Hence, vehicle-to-vehicle communication and vehicle-to-infrastructure communication are being considered.[19,37] This involves vehicles relaying information such as their speed, position, and trajectory to each other.[37] Vehicles can receive information about traffic signals rather than depending on their cameras to scan them.[19]

Navigation

High-definition maps are needed to provide vehicles with precise information about the road network as well as other road infrastructure such as lane boundaries and traffic signs.[19,30,38,39] Positioning systems like GPS help determine the exact location on the map in order to navigate to the destination.[10]

Decision making

Autonomous vehicles need to make decisions to navigate safely, such as reacting in real time to pedestrians and other vehicles.[10,11,29] Such decisions include predicting behaviour of various actors.[11] Machine learning systems are used for making such decisions.[11]

Issues to Consider

Cost

The capital cost of an autonomous vehicle is likely to be higher than a traditional vehicle.[40,41] This is due to the need for advanced sensors, software, and computational hardware. These costs may moderate with widespread adoption as economies of scale kick in.[42]

Additionally, autonomous vehicles may require special physical and digital infrastructure for their operation. Costs for such public infrastructure

would have to be allocated across general government spending, road users (through road tax) and autonomous vehicle users (specific cess).

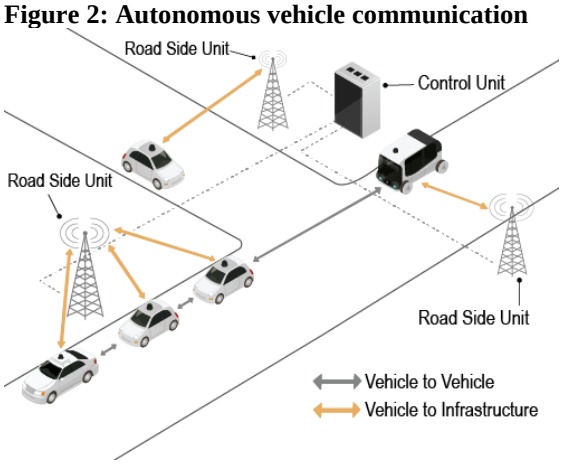
On the other hand, there would be some savings. The time freed by disengaging from driving a vehicle could be spent on productive work.[41] There may be reduced need for parking spaces in busy areas as vehicles no longer need to be in the proximity of their drivers.[43,44]

Autonomous taxis would not incur the cost of a driver. Taxis also have a higher capacity utilisation than owner driven cars as they are on the road for a longer time, resulting in lower capital cost per unit of distance covered. These factors may make taxi usage more cost attractive than owning a car. Long distance trucks could also save time as there would be no need for breaks for food and rest.

Infrastructure improvements

Adoption of autonomous vehicles may necessitate certain improvements in infrastructure.[45] Accurate and detailed maps and reliable maintenance of road and traffic infrastructure are crucial.[19] Roads may need clear and harmonised lane markings.[45] Road signs may have to be placed in open and visible areas.[45] Potholes, unmarked road works, and stray animals may increase risks. Smart traffic systems relaying information about traffic rules and signals could make the road environment more predictable.[45] They could reduce risks for errors. Vehicles will require fast communication networks to allow exchange of data with these systems.[19] USA is considering allocating a separate spectrum band for autonomous vehicle communications.[46]

Figure 2: Autonomous vehicle communication



Source: Sanguesa, J.A.et al; Sensing Traffic Density Combining V2V and V2I Wireless Communications. Sensors 2015, 15, 31794-31810; PRS.

Safety

Autonomous vehicles have the potential to enhance both safety and efficiency.[47] Road accidents often result from human errors, suboptimal road and vehicle conditions, or a combination of these factors.[48] An analysis of road crash data in USA from 2005 to 2007 attributed human error as a critical reason in 94% cases, while road and vehicle conditions were critical reasons in 2% cases each.[1] Human errors included inattention, mis-judgement of speed and gap, and falling asleep.[1] In India, 73% of accidents in 2022 involved over-speeding, and 5% involved lane indiscipline.[48]

Where human drivers are still involved, automation can: (i) reduce fatigue by taking over driving functions, (ii) provide enhanced awareness through sensor inputs and alerts, and (iii) improve reaction time in emergencies.[49] The European Union has mandated several driver assistance technologies for road vehicles since 2022.[12]

Driverless vehicles (SAE Level 4 and Level 5) may eliminate the scope for error and negligence of human drivers.

While autonomous vehicles have the potential to improve safety, risks may emerge due to the nature of technology behind autonomous vehicles. These vehicles use machine learning-based software to observe the surroundings and make decisions.[11] They learn from patterns in datasets. If the datasets do not adequately represent real-world scenarios, these systems may make errors.[20,29,50] Such risks increase with uncertain road and adverse weather conditions.[19,51] Difficulty in predicting human behaviour may emanate from variation in driving styles, unpredictable risks, and negligence by human drivers and pedestrians.[29]

At automation levels where the drivers and observers are still needed, their attention can wane due to boredom or distraction.[52,53] Reduced alertness can delay responses.[52] As systems perform driving tasks, driving skills may also worsen over time due to less practice.[54]

For permitting commercial use, regulators may require autonomous vehicles to be at least as safe as human drivers. One approach to ensure this may be to allow testing on public roads. Accidents are not very common and therefore to collect data, a large number of kilometres need to be driven by these vehicles.[20,55]

Liability

In case of traditional vehicles, human drivers are held responsible for driving decisions.[3] If they fail to exercise reasonable care, laws hold them liable for any harm caused. Liability on the vehicle owner for compensation for harm is met through mandatory insurance.[56] In some cases, criminal liability may also apply. For instance, negligent or rash driving in India is punishable with imprisonment up to six months.[57] Additionally, harm can sometimes result from manufacturing defects. In such cases, manufacturers are held liable to pay compensation (product liability).[58]

With autonomous vehicles, responsibilities could change.[59] For instance, at SAE Level 3 automation level, the system may request the driver to take control in certain circumstances. This may necessitate case by case evaluation of whether the system functioned correctly and the driver fulfilled

his obligation. At SAE Level 4 and Level 5 automation levels, all driving decisions are made by the system. In such cases, regulations may have to add certain additional obligations on developers.[60] For example, in UK, manufacturers must ensure that their autonomous vehicles drive safely and legally (see Box 2).[61] Authorisation may be suspended or withdrawn if their vehicle commits a traffic violation.[61]

Privacy

Vehicles with varying level of automation process a lot of data including personal data to provide assistance and interpret the surroundings.[62,63] Personal data includes high resolution imaging of passengers, and people in the vehicle's field of view, and location and behavioural data of passengers.[64] In vehicle-to-vehicle or vehicle-to-infrastructure communication, vehicle's movements and location may be shared.[65] Such data collection raises privacy concerns.[65] Retaining such data could enable building profiles of individuals. These profiles may be valuable for third parties such as insurers. Availability of such data may lead to data requests for law enforcement purposes. Manufacturers may also want to retain data for training and improving their machine learning models. Innovation in these areas depend on availability of datasets.[66]

Existing data protection laws like Digital Personal Data Protection Act, 2023 in India and GDPR in European Union will apply to the collection of personal data in case of vehicles.[67,68] These laws mandate individual consent for data processing. However, individuals may struggle to provide informed consent due to the complexity of data flows. These laws mandate minimising data collection and retention, potentially conflicting with the need for data to improve technology. To balance benefits, laws permit unrestricted processing after data anonymisation. Anonymisation refers to removing personally identifiable information from datasets so that individuals cannot be identified.[69]

Cybersecurity

As vehicles are connected to networks to receive information from other vehicles, maps, traffic systems, and software updates, they may be prone to cyber-attacks.[62,70] Such attacks may include: (i) hacking a vehicle to take control and cause deliberate collision, or (ii) jamming sensors and vehicle communication to cause malfunction.[62] Hence, autonomous vehicles will need to adhere to the highest standards of cybersecurity.

Employment

As per the Periodic Labour Force Survey (2022-23), about 1.5 crore persons in India (3% of the workforce) are employed as drivers of two-wheelers, three-wheelers, and four-wheelers for commercial purposes.[71,72] Another 1% are employed as truck and bus drivers.[71,72]

Box 2: UK Law on Autonomous Vehicles

The Automated Vehicles Act, 2024, passed by the UK Parliament in May 2024, establishes a legal framework for self-driving vehicles.[61] Key provisions are as follows:

Self-driving vehicle: A self-driving vehicle is a vehicle that travels autonomously, without direct or remote human control, and does so safely and legally. Capability will be assessed by location and circumstances, and may differ. An entity must seek authorisation for rolling out self-driving vehicles. Such a vehicle may either have a user in charge or no user-in-charge (NUIC) model. User in charge means that the vehicle has a feature to transfer driving control to an individual. NUIC operators need a licence, and passenger services using NUIC vehicles need a permit.

Obligations and liability: The authorised entity (a manufacturer or a developer) is liable to ensure that the vehicle continues to satisfy the self-driving test all the time. User in charge is not liable for the manner of driving when the vehicle is self-driving or for the transition period in taking back control. NUIC operator will be required to oversee the operation as per the conditions in the licence. Offences under the Act include: (i) using or causing another person to use a vehicle without a driver or a licensed oversight, (ii) withholding or falsifying information for authorisation, and (iii) supply of defective or unsuitable software.

Insurance: An earlier Act passed in 2018 had put obligation on insurers to cover damages in accidents involving automated vehicles.[73] Insurers can recover costs from developers if the accident was caused by a failure of the vehicle to function as designed.

SAE Level-4 and Level-5 vehicles may have an adverse impact on these jobs.[74] On the other hand, automation may create higher-skilled jobs in the development and maintenance of technology.[74]

Legislative changes

To address the issues related to autonomous vehicles, laws across sectors may need to be amended (Table 2).

Table 2: Laws that may need amendments

Laws	Concerns
Motor Vehicles Act, 1989	▪ Registration and licensing of autonomous vehicles ▪ Liability and insurance ▪ Rules of the Road
Consumer Protection Act, 2019	▪ Product based liability
Information Technology Act, 2000	▪ Data privacy, security, and personal data protection
Digital Personal Data Protection Act, 2023	
Bharatiya Nyaya Sanhita, 2023	▪ Rash and negligent driving
Telecommunications Act, 2023	▪ Communication networks and services

Source: PRS.

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