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Legal Frameworks for Autonomous Vehicles in Germany, Brazil and India: A Comparative Analysis

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Abstract: When a driverless car kills someone, who answers for it? That question, deceptively simple on its surface, cuts to the heart of a problem that transport law was never designed to handle. For well over a century, legal systems have allocated responsibility for road accidents by working backwards from a human driver someone held the wheel, made the choices, and bears the consequences. Autonomous vehicles break that logic. At the higher levels of automation, nobody is driving. The machine perceived the road, planned the route, and executed the manoeuvre. If something went catastrophically wrong, the legal chain of causation runs not to a distracted human but to a software algorithm, a sensor array, a training dataset, and the corporate entities that assembled them into a product and released it onto public roads. Existing legal frameworks were not built to answer that question, and the answers being developed across different jurisdictions are, as this paper shows, strikingly different.

Three countries occupy the centre of this analysis Germany, Brazil, and India. Germany enacted the world's first statute specifically governing Level 4 autonomous vehicles in July 2021 and followed it with detailed implementing regulations in January 2022, creating a regulatory architecture that has no equivalent anywhere. Brazil has taken a more tentative path, authorising controlled pilot testing in selected cities while deliberately deferring comprehensive legislation until there is sufficient empirical evidence to write it responsibly. India has neither legislated nor experimented in any formal sense. The Motor Vehicles (Amendment) Act 2019 grants the Central Government power to regulate autonomous technology, but those powers sit unexercised. Senior ministers have publicly opposed autonomous vehicle deployment as a threat to the employment of millions of drivers. The result is neither a framework nor a prohibition but a regulatory silence that the technology will eventually force someone to break.

This comparison is not accidental. These three jurisdictions represent three genuinely distinct regulatory archetypes, each shaped by a different political economy of technology governance. Germany is a proactive industrial state with the administrative depth to write comprehensive rules and enforce them. Brazil is a large emerging economy with innovative capacity but real institutional constraints, making calibrated uncertainty a rational choice. India is the world's most populous democracy confronting the distributional politics of automation in conditions that make the employment consequences immediate and severe in ways that wealthier countries have been able to sidestep. The comparative AV law literature has concentrated almost entirely on North American and European jurisdictions. This paper brings India's experience, with its traffic complexity, its employment politics, and its recently enacted data protection regime, into comparative dialogue with Germany and Brazil. The analysis identifies structural convergence on certain principles alongside deep divergence in regulatory philosophy and institutional implementation. Policy recommendations follow for each country.

Keywords: autonomous vehicles; comparative transport law; product liability; algorithmic accountability; India; Germany; Brazil; data protection; Level 4 automation; regulatory governance.

INTRODUCTION

The development of autonomous vehicles (AVs) is, in the opinion of many analysts, one of the most revolutionary technological disruptions that the automotive and transport industries have ever encountered. These self-driving vehicles are equipped with a range of advanced sensors, artificial intelligence decision-making algorithms, and other enabling technologies. Taken together, these have the potential to make a major positive impact on the way people and goods are transported by making the transport process much safer, more efficient, and providing greater mobility opportunities for people who are often excluded or disadvantaged, such as the disabled, the elderly, and other vulnerable groups. Nevertheless, the deployment of autonomous vehicles on a large scale also presents a range of serious legal, ethical, and practical issues that need to be properly managed. Consider this what if a self-driving car, in fully autonomous mode, gets into a serious accident? It would be naive to believe that autonomous vehicles are infallible. They need to communicate with their environment, including traffic, other drivers, pedestrians, cyclists, and other vehicles, in order to navigate safely and effectively. And who is responsible? The manufacturer, the programmer, the owner, or is it the autonomous system itself? Queries around liability.¹

NITI Aayog-linked discussions (e.g., automotive reports) look to Advanced Driver Assistance Systems (ADAS) and emerging autonomous tech prevalence by 2030. These analyses are about industry trends and not liability laws. By 2040, 33 million autonomous vehicles will be on the Indian roads, emphasizing the need for appropriate legal frameworks.² Meanwhile, Germany has emerged to be one of the world leaders in autonomous vehicle governance, passing the world's first complete automated driving law in July 2021. Brazil, the country with the fifth-largest vehicle market in the world, has started to create the first regulatory frameworks through directives by DENATRAN and pilot projects, thus becoming a potential leader in Latin American autonomous vehicle governance.³

"A case that occurred in a Volkswagen factory in Germany

involved the death of a worker who was ascribed to a robot. This accident, which was reported by foreign newspapers a few years ago, involved a conventional robot and seems to have been caused mainly by human factors and not by the robot malfunctioning. However, it is likely that such deaths will influence discussions on human-robot interaction and the legal implications of the damage inflicted by robots. It is also interesting to note that the language used in the reporting of the accident is significant, as it portrays the robot as an active participant in the accident that "killed" the worker. The AI industry and the automotive industry in Germany together provide more than 770,000 jobs, and the German Original Equipment Manufacturers (OEMs) are responsible for more than 70% of all consider the German and broader EU regulatory environments when developing and implementing their Autonomous Cars strategies.⁴

At lower levels of automation, it is generally expected that the driver is fully responsible, at least from the perspective of insurers. However, in order to accurately assess the driver's guilt at higher automation levels, at least three factors must be known:

- i) whether full robotization was dynamic,
- ii) whether there was a compulsory power change demand and the reaction of the driver to that, and
- iii) whether there was an infringement of traffic rules by people themselves and consequently inclined to mistakes

A third methodology is examined by Nyholm and Smids (2020) An optimal human robot coordination should be pursued, in which human driving is made more similar to robot-like driving, such as through in vehicle technologies aimed at preventing common human errors or violations. Instead of developing a robot-like driving behavior or assuming that the robot-like behavior is ideal,

Autonomous Cars are one of the most popular research

¹ Dong, X., Cappuccio, M., Alnajjar, F., Ali, L., Jassmi, H. A., Debie, E., Ghasrihouzani, M., Lanteri, A., McGregor, T., & Molloy, O. (2025). Why Autonomous Vehicles Are Not Ready Yet: A Munlti-Disciplinary Review of Problems, Attempted Solutions, and Future Directions. *Journal of Field Robotics*. <https://doi.org/10.1002/rob.70108>

² Backhaus, R. (2020). Autonomous Driving and AI - Risks and Opportunities. *ATZ worldwide*, 122(6), 8-13. <https://doi.org/10.1007/s38311-020-0265-2>

³ He, W., Chen, W., Tian, S., & Zhang, L. (2024). Towards full autonomous driving: challenges and frontiers. *Frontiers in Physics*, 12. <https://doi.org/10.3389/fphy.2024.1485026>

⁴ Jung, K., & Yang, J. (2025). Mitigating safety challenges in human-robot collaboration: The role of human competence. *Technological Forecasting and Social Change*, 213, 124022. <https://doi.org/10.1016/j.techfore.2025.124022>

topics in the automotive industry today. As they can exchange data with other devices, both inside and outside the car. “The Society of Automotive Engineers” has classified automation into six levels (SAE). For levels 0 to 2, the operator has complete control over the vehicle. Levels 3 and 4 require the operator to take control of the vehicle only when the autonomous mode requests it. Level 5 cars are fully automated (driverless cars) and require no human intervention. Each of these automations, particularly level provides a completely different driving experience.⁵

Methodology

The approach is doctrinal comparative law. Primary legal sources form the analytical foundation statutes, subordinate legislation, government orders, official policy documents, and judicial decisions where available. Secondary sources include academic commentary, parliamentary debates, and policy reports. Because all three jurisdictions are in active regulatory development, particular care has been taken throughout to distinguish between enacted law, proposed legislation, administrative guidance, and policy aspiration. That distinction collapses easily when working across multiple legal systems with different document conventions and, in the Brazilian and Indian cases, translation challenges.

The tertium comparationis is the allocation of legal responsibility for harm caused by autonomous vehicles operating without meaningful human control. This is

examined through five subsidiary dimensions overall regulatory philosophy and framework; liability allocation; testing and deployment authorisation; data protection and cybersecurity; and safety certification procedures. These dimensions were selected because they represent the areas of greatest legal significance and greatest practical consequence for manufacturers, operators, insurers, and injured parties.

The three jurisdictions were selected on functional grounds rather than geographic proximity or political affinity. Germany represents comprehensive proactive regulation by a technologically advanced industrial state. Brazil represents experimental governance under genuine resource constraints. India represents politically driven regulatory restraint in a large democracy with distinctive socio-economic conditions. This functional spread enables the analysis to address not merely what the law is in each jurisdiction but why it took that form which, in autonomous vehicle governance, turns out to be at least as important as the doctrinal content.

A limitation deserves acknowledgement upfront. Autonomous vehicle law is a fast-moving field in all three countries. The German ordinance of 2022 may be supplemented or revised; Brazil's pilot programme is expanding; India's DPDPA implementing rules had not been issued at the time of writing. The analysis reflects the state of law and policy as of early 2026, and claims about the current state of the law should be read in that light.

The SAE Framework and Its Legal Significance

Society of Automotive Engineers Levels of Driving Automation

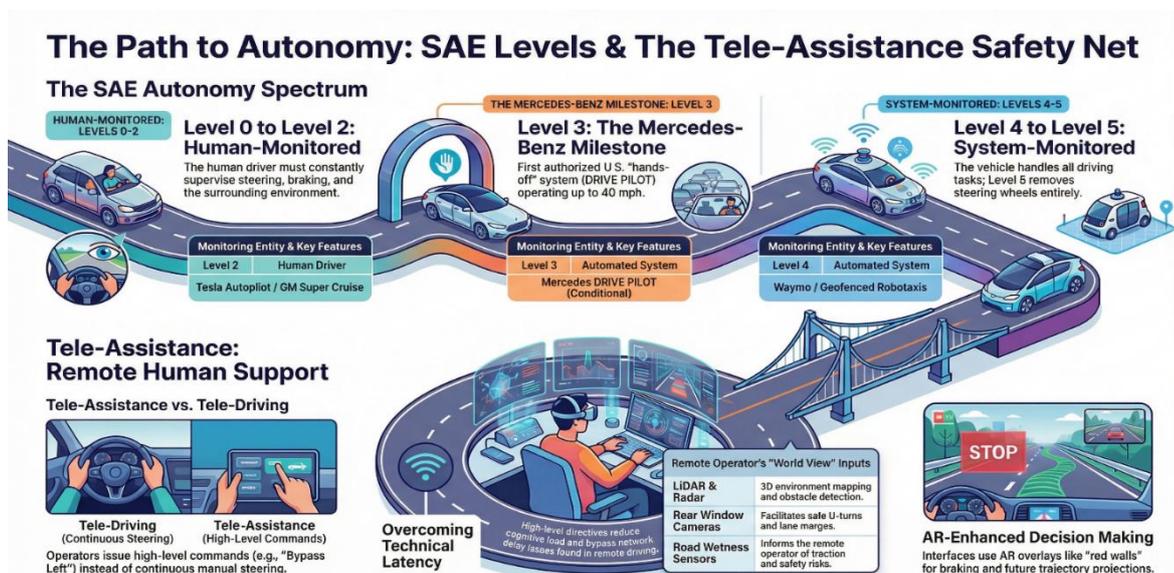
SAE Level	Name	Driver Involvement	System Capabilities	Examples
Level 0	No Automation	Driver performs all tasks	System may provide warnings or momentary assistance but has no sustained control	Basic cruise control, lane departure warnings, automatic emergency braking
Level 1	Driver Assistance	Driver must be engaged at all times	System controls either steering OR acceleration/braking in specific situations	Adaptive cruise control, lane keeping assist (not simultaneously)
Level 2	Partial Automation	Driver must supervise constantly and be ready to take over	System controls both steering AND acceleration/braking simultaneously in specific situations	Tesla Autopilot, GM Super Cruise, Mercedes Drive Pilot (in most conditions)
Level 3	Conditional Automation	Driver must be available to take over when requested	System handles all driving tasks in specific conditions but requires driver intervention when needed	Mercedes Drive Pilot (Level 3 certified), Honda Legend (Japan only)
Level 4	High Automation	No driver attention	System handles all	Waymo robotaxis,

⁵ Kolekar, S., Winter, J. D., & Abbink, D. (2020). Human-like driving behaviour emerges from a risk-based driver

model. Nature Communications, 11(1). <https://doi.org/10.1038/s41467-020-18353-4>

		required in specific conditions	driving tasks within defined conditions (geofenced areas or situations); no human intervention needed	Cruise AVs (in designated areas)
Level 5	Full Automation	No driver needed ever	System handles all driving tasks in all conditions without any human intervention	Currently theoretical - no production vehicles exist

Distinction: Levels 0-2 require constant human supervision. Levels 3-5 are considered “automated driving systems” where the vehicle can perform driving tasks independently under certain conditions.



The situation of autonomous cars, for example, opens up new possibilities for disadvantaged individuals such as the disabled, the elderly, and those who are precocious to drive. A Complete Autonomous car might be unable to act accordingly to an unforeseen crisis, or its sophisticate mechanism may fail completely, likely to result in an accident involving destruction of property, concussions, and even the death of a person. When this occurs, there is bound to be a public uproar, as well as a demand for responsibility, including the allocation of civil and criminal liability.⁶

Legal Framework for Autonomous Vehicles in Germany

Germany is leading the world in autonomous vehicle regulation. This development mirrors Germany’s advanced automotive industry and its steadfast desire to provide clear legal certainty for technological innovation. Important milestones in the legal framework

include:

Three important UN Regulations entered into force in January 2021, of which the 54 contracting parties to the 1958 Agreement will presumably be bound, including Germany and the European Union

- UN Regulation No. 155: Cyber Security and Cyber Security Management Systems
- UN Regulation No. 156: Software Updates and Software Update Management Systems
- UN Regulation No. 157: Automated Lane Keeping Systems (ALKS), the first international standard for SAE Level 3 deployment in limited use cases⁷

Germany passed the first comprehensive law worldwide directly regulating as an amendment to the Road Traffic Act (Straßenverkehrsgesetz) in July 2021 that Level 4 autonomous vehicles can regularly drive on public roads in Germany within defined operating areas. An ordinance approved at the beginning of 2022 further enriched this law. The German federal cabinet adopted the new mandate to control a motor vehicle with automated and autonomous driving controls and to issue

⁶ Calvert, S. C., & Zgonnikov, A. (2025). A lack of meaningful human control for automated vehicles: pressing issues for deployment and regulation. *Frontiers in Future Transportation*, 6. <https://doi.org/10.3389/ffutr.2025.1534157>

⁷ Kriebitz, A., Max, R., & Lütge, C. (2022). The German Act on Autonomous Driving: Why Ethics Still Matters. *Philosophy & Technology*, 35(2). <https://doi.org/10.1007/s13347-022-00526-2>

rules on road traffic on 23 February 2022, completing the public legal framework for autonomous driving in Germany and thus signing the nation's commitment to staying ahead in autonomous vehicle development.⁸

The German legislation regarding autonomous driving is remarkable internationally because of its comprehensive and centralized regulatory approach. A key element of this approach is the technical approval procedure conducted by the Federal Motor Transport Authority (Kraftfahrt-Bundesamt, KBA). In contrast to previous approaches, which were based on a patchwork of regional approvals, the German approach sets up a standardized procedure for the entire country for the approval of vehicles equipped with autonomous driving capabilities. The approval procedure is conducted in a step-by-step manner initially, the submission of comprehensive technical data to the KBA; subsequently, the relevant regional authorities assess and approve the respective areas in which the autonomous vehicle is authorized to operate; and finally, the vehicle is registered, usually by assigning a license plate, which authorizes the vehicle to operate on public roads.⁹

Another characteristic feature of the German system is the use of the “technical supervisor” (Technische Aufsichtsperson), which is a radical departure from the conventional understanding of the human driver. The technical supervisor is a natural person who takes the legal responsibility for the vehicle's compliance with traffic rules, despite the lack of physical presence within the vehicle. This duty includes a number of essential obligations first, the obligation to engage in continuous communication with passengers to keep them informed; second, the obligation to actively assess real-time data being produced by the vehicle to monitor its status and environment; third, the obligation to have the capability to initiate alternative routes for the vehicle when needed to ensure safe and efficient travel; and fourth, the obligation to have the capability to turn off the autonomous system in emergency situations to avoid damage or potential danger. In addition, the technical supervisor has the duty to ensure that the vehicle has sufficient insurance coverage. The governing law sets strict technical and safety standards for autonomous vehicles. In particular, autonomous vehicles must have the capability to comply with traffic rules within their defined operational zones and to transition to a state of minimal risk when emergency situations arise. They must also have the capability to produce and transmit

proposed driving actions to the technical supervisor and to maintain a continuous and auditable record of operational data. To further enhance safety, the law requires the use of redundant systems to avoid accidents, indicating a strong focus on reliability and safety.¹⁰

Data governance and privacy are at the heart of the regulatory framework that surrounds autonomous vehicles. Autonomous vehicles are required to record and process their operational data continuously while ensuring that they have robust measures in place to protect against unauthorized access. GDPR compliance is obligatory to ensure that both personal and operational data are processed in a lawful, transparent, and secure manner throughout the entire lifecycle of the vehicle. The 2022 legal ordinance further clarified the matter by specifying the technical and procedural requirements that are involved in the deployment of autonomous vehicles. The conditions and procedures for the issuance of operating licenses, the approval process for the designated operating zones on public roads, and the role of all stakeholders, including the manufacturers and technical supervisors, were all specified in the ordinance. The ordinance also introduced new rules concerning regulatory offenses and the procedural requirements for enforcement, as well as specific technical requirements for the design, maintenance, and equipment of autonomous vehicles.¹¹

Legal Framework for Autonomous Vehicles in Brazil

Unlike the complex legislative frameworks that other countries such as Germany and the Indian government have developed, Brazil is still in the process of evolving in its approach to autonomous cars. This is according to a set of preliminary guidelines and resolutions that were drawn up by the National Traffic Department (DENATRAN). The autonomous cars are classified on the basis of levels of automation in relation to their development. Additionally, a set of conditions has been put forward for the issuance of testing permits. Furthermore, the safety standards are also set within the framework of testing. The document touches on issues concerning insurance coverage and the liability requirements for the entities that are testing the cars. This is done within set geographical and operational constraints in a manner that does not compromise public safety. The dynamics of these guidelines also allow the Brazilian government to amend the legal standards

⁸ Kirchmair, L. (2023). How to Regulate Moral Dilemmas Involving Self-Driving Cars: The 2021 German Act on Autonomous Driving, the Trolley Problem, and the Search for a Role Model. *German Law Journal*, 24(7), 1184-1208. <https://doi.org/10.1017/glj.2023.83>

⁹ Salvini, P., Kunze, L., & Jirotko, M. (2024). On self-driving cars and its (broken?) promises. A case study analysis of the German Act on Autonomous Driving. *Technology in Society*, 78, 102628. <https://doi.org/10.1016/j.techsoc.2024.102628>

¹⁰ Kriebitz, A., Max, R., & Lütge, C. (2022). The German Act on Autonomous Driving: Why Ethics Still Matters. *Philosophy & Technology*, 35(2). <https://doi.org/10.1007/s13347-022-00526-2>

¹¹ PÜTZ, F., MURPHY, F., MULLINS, M., MAIER, K., FRIEL, R., & ROHLFS, T. (2018). Reasonable, Adequate and Efficient Allocation of Liability Costs for Automated Vehicles: A Case Study of the German Liability and Insurance Framework. *European Journal of Risk Regulation*, 9(3), 548-563. <https://doi.org/10.1017/err.2018.35>

depending on the advancing capabilities of technology.¹² One of the most noticeable aspects of the Brazilian regulatory system is the use of controlled pilot testing as a means of informing prospective regulation. Testing of autonomous vehicles has been approved in selected urban areas, with São Paulo and Rio de Janeiro being identified as key locations for these pilot tests. These activities are often conducted in partnership with various stakeholders, such as universities and other higher educational institutions, research institutions, technology companies, and automobile manufacturers. This collaborative approach helps to create a culture that is inherently supportive of innovation. The empirical data and findings generated from these pilot tests are critical in developing regulatory knowledge, allowing policymakers to fully assess risks and consequences before imposing additional or more stringent regulatory requirements.¹³

The liability regime in Brazil is still in the process of development, and it is quite evident that the Brazilian government plans to rely on existing legal principles rather than developing new ones. This indicates that the Brazilian government prefers to work on existing principles rather than formulating new ones. It appears that the new liability regime will be based on the Brazilian Civil Code regarding product liability, especially in cases of design or production defects, as well as the Brazilian Consumer Protection Code and the Brazilian Traffic Code. Insurance for testing activities is already mandatory, which is a sign of a risk aversion strategy. The new liability regime will be a combination of liability, where the manufacturer will be liable for technological failure, the operator for negligence or misuse, and joint liability during the transition period when human and automated control interact.¹⁴

Data protection and privacy issues play a crucial role in Brazil's evolving regulatory framework. After the implementation of the Lei Geral de Proteção de Dados (LGPD) in 2018, Brazil has been able to create a robust data protection framework that is on par with the General Data Protection Regulation (GDPR) framework of the European Union. As a result, the regulation of autonomous vehicles also needs to take into account the following challenges related to the collection and storage of sensor data, the setting of limits on data storage for safety and operational reasons, and the protection of the privacy rights of pedestrians and other road users. Cybersecurity is another important aspect of the Brazil

policy on autonomous mobility. There is a focus on developing secure software development processes, ensuring strong protection against unauthorized changes to the vehicle, and developing a reliable over-the-air update solution. The government is also looking into procedures for reporting cyber incidents and working together to respond to incidents. While developing these policies, Brazil seeks to align its policies with international cybersecurity standards to ensure that the policies are compatible with global standards.¹⁵

Legal Framework for Autonomous Vehicles in India

Autonomous vehicles (AVs) represent a significant innovation in the manner by which we transport people and goods. They offer a variety of benefits, such as improved road safety, reduced traffic congestion, and optimized transportation networks. Focusing on the Indian context, a country that is notorious for its congested and unpredictable traffic patterns, diverse road infrastructure, and relatively high rate of accidents, AVs have the potential to make a dramatic difference. However, despite the potential, the technology is still in its infancy. The subsequent discussion will elaborate on the current state of affairs and future trends.

Although fully autonomous and self-driving passenger vehicles are not yet available in the market, semi-autonomous systems such as Advanced Driver Assistance Systems (ADAS) – including adaptive cruise control, lane-keeping support, and automatic emergency braking – are increasingly being incorporated into vehicles offered by carmakers such as Tata, Mahindra, and Maruti Suzuki. Startups have become essential players in India's AV ecosystem. For instance, Swaayatt Robots, founded in Bhopal, has shown the ability to modify a Mahindra Bolero to perform in congested Indian traffic, including interactions with cows, pedestrians, and unpredictable traffic, using artificial intelligence and sensor technology. At the same time, pilot projects for autonomous taxis are being explored in technology hubs like Bengaluru and Hyderabad. Barriers to regulation are still present; the Indian Motor Vehicles Act of 1988 cannot support autonomous vehicles (AVs), and the proposed amendments have been delayed. Union Minister Nitin Gadkari has been quoted as opposing the use of AVs, claiming that self-driving cars will never be allowed in the country in order to protect the jobs of 7-8 million drivers. However, innovation initiatives like the IIT Bombay Global R&D Centre for Connected and

¹² Anonymous (Unknown year). Comparative analysis of legal mechanisms to net-zero: lessons from Germany, the United States, Brazil, and China. *Climate Change and Law* Collection. https://doi.org/10.1163/9789004322714_cclc_2023-0094-0443

¹³ Picon, P. D., Beltrame, A., & Banta, D. (2013). NATIONAL GUIDELINES FOR HIGH-COST DRUGS IN BRAZIL: ACHIEVEMENTS AND CONSTRAINTS OF AN INNOVATIVE NATIONAL EVIDENCE-BASED PUBLIC HEALTH POLICY.

International Journal of Technology Assessment in Health Care, 29(2), 198-206. <https://doi.org/10.1017/s0266462313000056>

¹⁴ Brüggemeier, G. (2011). Modernising Civil Liability Law in Europe, China, Brazil and Russia. *Unknown journal*. <https://doi.org/10.1017/cbo9780511835179>

¹⁵ Souza, J. S. D., Abe, J. M., Lima, L. A. D., & Souza, N. A. D. (2020). The Brazilian Law on Personal Data Protection. *International Journal of Network Security & Its Applications*, 12(6), 15-25. <https://doi.org/10.5121/ijnsa.2020.12602>

Autonomous Vehicles are actively working to address India-specific challenges. They address issues such as unstructured road environments and hostile traffic patterns, planning to adapt autonomous technologies to the Indian environment. Until at least 2026, the use of autonomous vehicles is expected to remain mostly within controlled environments, even as new entrants emerge in the market. For instance, Flying Wedge Defence has launched AI-powered drones and unmanned aerial vehicles for similar uses, indicating a growing interest in advanced autonomous technology. The Indian market's unique characteristics, such as highly urbanized road infrastructure, varied rural road infrastructure, and complex and unpredictable traffic patterns, provide a fascinating backdrop for testing the robustness of AV technology. This is evident from startup initiatives to conduct real-world AV demonstrations, indicating the industry's momentum towards field-testing.¹⁶

However, the transition to autonomous vehicles also faces a number of serious challenges that must be overcome before they can be widely adopted. One of the most serious challenges is related to infrastructure currently, there is a lack of standardized road markings and connectivity, which makes it difficult for autonomous technology to work properly and slows down its adoption. Another serious issue is related to the potential loss of employment. It is estimated that millions of people are currently employed in driving-related jobs, and the widespread adoption of autonomous vehicles raises serious concerns about how these individuals will adapt and what kind of support they will need. Ethical issues are also relevant in this case. Concerns about privacy, the safety of autonomous technology in vulnerable or dangerous settings (such as the potential for incorrect driving, which could happen if the vehicle drives on the wrong side of the road), and the general level of public trust in this technology are all serious issues that must be carefully managed. In terms of the timeline, it is suggested that the achievement of full and true autonomy could take up to ten to fifteen years, even in a fully developed and regulated market such as the United States. This is because of the complexity of the technical, legal, and social shifts that would be required for full autonomy to be achieved.

Another challenge is related to the cost of this technology. Currently, the price of sensors and AI-enabled circuitry is very high, which slows down the adoption process because human drivers are still

economically viable in many settings.¹⁷

The Indian autonomous vehicle market is at an interesting crossroads, weighing significant potential upside against significant obstacles that must first be overcome. Market research has predicted that India's autonomous vehicle market is set to rise to about 45.8 USD billion by 2035, courtesy of an astronomical growth rate of over 26%. The prognosis for Indian autonomous vehicles is positive, considering that autonomous cars can help reduce road accidents that kill more than 150,000 people annually and decongest Indian cities. They have the further potential for revolutionizing robotaxi and autonomous truck services. Government policies, such as the Production-Linked Incentive schemes for electric vehicles and the India AI mission, suggest a governmental commitment to development. However, these rosy forecasts face the reality of the situation. Transport Minister Nitin Gadkari's reservations about autonomous vehicles stem from his concerns about job security, owing to the displacement of millions of drivers in the large labour market. Technological hurdles are also quite high Indian roads are far removed from the controlled environments where autonomous vehicles have shown success. Negative factors such as a lack of lane discipline, dangerous overtaking manoeuvres, the use of the horn as a primary means of communication, pedestrians ignoring traffic signals, and animals entering roadways pose challenges that would be difficult to overcome even for highly advanced artificial intelligence.¹⁸

Despite such challenges, some analysts believe that the Indian traffic scenario presents a special testing ground for robust autonomous vehicles. Startups such as Swayatt Robots have demonstrated their modified vehicles functioning in the Indian traffic scenario, and research labs at IIT Bombay are developing Indian-specific solutions to cope with the Indian traffic scenario. The critical question is to develop algorithms based on Indian traffic patterns, where three-wheelers, two-wheelers moving through traffic, and vehicles moving on the wrong side of the road are common sights rather than exceptions. However, it has been observed that the economic argument still lacks clarity, as there are minimal labor cost savings and suboptimal investment returns for costly autonomous vehicle technology. However, the optimistic view is that there will be a gradual path forward, with Level 2 and Level 2+ autonomous vehicles being common by 2030, along with long-term strategies to develop Level 4 autonomous

¹⁶ Rahman, M. M., & Thill, J. (2023). Impacts of connected and autonomous vehicles on urban transportation and environment: A comprehensive review. *Sustainable Cities and Society*, 96, 104649. <https://doi.org/10.1016/j.scs.2023.104649>

¹⁷ Dong, X., Cappuccio, M., Alnajjar, F., Ali, L., Jassmi, H. A., Debie, E., Ghasrihouzani, M., Lanteri, A., McGregor, T., & Molloy, O. (2025). Why Autonomous Vehicles Are Not Ready Yet: A Multi-Disciplinary

Review of Problems, Attempted Solutions, and Future Directions. *Journal of Field Robotics*. <https://doi.org/10.1002/rob.70108>

¹⁸ Rajendran, S., Prakash, C., Shakir, M., Alwetaishi, M., Dhairiyasamy, R., Rajendran, P., & Lee, I. E. (2025). Enhancing competitiveness in India's electric vehicle industry: impact of advanced manufacturing technologies and workforce development. *Scientific Reports*, 15(1). <https://doi.org/10.1038/s41598-025-97679-9>

systems in controlled environments like highways and industrial areas. Success will come with a thorough assessment of technological feasibility, policy frameworks, worker displacement through training initiatives, and major investments in digital infrastructure and traffic management. The critical question is not whether autonomous vehicles can function in India but whether India can develop a scenario where autonomous vehicles are needed.¹⁹

Comparative Analysis of Regulatory Frameworks: Germany, Brazil, and India

Regulatory Models: Permissive vs. Restrictive Model

Nonetheless, a certain group of researchers is of the belief that the chaotic traffic conditions of India offer a uniquely challenging environment to test and prove the efficacy of resilient autonomous systems. Start-ups like Swaayatt Robots have already shown how their altered vehicles can operate in the congested roads of India, while research labs at organizations such as IIT Bombay are working on indigenous solutions that are suited to the traffic patterns of India. The challenge lies in training algorithms on Indian traffic patterns, where three-wheelers, two-wheelers moving in and out of traffic, and vehicles moving on the wrong side of the road are not exceptions but the rule. Critics point out that the economic viability is still unclear, as the cost of labor is relatively low, making the ROI on expensive autonomous systems questionable. However, supporters forecast a gradual rollout: Level 2 and 2+ technologies becoming popular by 2030, culminating in Level 4 autonomous systems in controlled environments such as highways and industrial areas. The question is not whether autonomous vehicles can be made to work in India, but whether India can provide a setting where the deployment of autonomous vehicles is appropriate.²⁰

Brazil takes an intermediate approach, using a permissive framework that is pragmatic in nature and based on administrative flexibility rather than legislative comprehensiveness. Brazilian policymakers have allowed controlled pilot projects and experiments to take place without setting up definitive statutory limits, preferring to coordinate among transport ministries, technology regulatory bodies, and local administrations. This allows for experiments to take place without making contentious policy choices about large-scale commercialization. The approach is reflective of technological uncertainties and administrative prudence, allowing policymakers to watch and wait before setting up binding legislative frameworks. But at the same time,

it leaves manufacturers and investors uncertain about regulatory expectations.²¹

India offers the most restrictive environment, although this is largely due to a lack of regulation rather than any kind of prohibition. Although the Motor Vehicles (Amendment) Act, 2019 can be seen to be accommodating autonomous technology, statements from government ministers, especially Transport Minister Nitin Gadkari's opposition to driverless cars, indicate a certain unwillingness on the part of the government to permit the use of such technology. This is largely due to job security rather than safety, as the government is concerned about replacing millions of drivers in a country where labor is abundant. The lack of operational requirements, testing, and certification procedures can be considered a *de facto* moratorium, even in the absence of a prohibition. This is a reflection of the prioritization of the current socio-economic environment over technological development and, as such, represents a significant barrier to innovation. India is therefore left with neither a permissive environment to facilitate development nor a restrictive environment to foreclose development.²²

Liability Frameworks: Allocation of Legal Responsibility

Liability attribution is arguably the area that diverges most between the three countries, and it has very basic implications for risk distribution and market development. The German system has created the most far-reaching liability system for manufacturers, which is based on the *Produkthaftungsgesetz* and further tightened by amendments to traffic law. The German system imposes strict liability on manufacturers for autonomous system defects, including algorithmic, sensor-related, and insufficient safety validation. This system goes beyond the scope of classic product liability by including criminal negligence criteria in cases where foreseeable design-related defects pose a significant risk to the general public. Manufacturers have specific duties to inform about system limitations, validate systems exhaustively, and initiate recalls when system defects are discovered. The German system is based on the policy choice that manufacturers, as the actors exercising the greatest control over system design and possessing the highest level of technical expertise, are primarily responsible for autonomous vehicle safety. Vehicle owners and operators are held liable only for maintenance deficiencies, illicit modifications, or operation beyond approved design specifications.²³

¹⁹ Parkavi, S., & Parthiban, A. (2025). Assessing urban traffic congestion for sustainable transportation in Chennai, India: a case study of Kathipara and T. Nagar intersections. *Frontiers in Sustainable Cities*, 7. <https://doi.org/10.3389/frsc.2025.1684489>

²⁰ *ibid*

²¹ Chen, W., Chi, W., Ji, S., Ye, H., Liu, J., Jia, Y., Yu, J., & Cheng, J. (2025). A survey of autonomous robots and multi-robot navigation: Perception, planning and

collaboration. *Biomimetic Intelligence and Robotics*, 5(2), 100203. <https://doi.org/10.1016/j.birob.2024.100203>

²² Mishra, B. R., & Malik, S. K. (2025). E-Commerce in India: Issues and Challenges. *TECHNO REVIEW Journal of Technology and Management*, 5(1), 01-07. <https://doi.org/10.31305/trjtm2025.v05.n01.001>

²³ PÜTZ, F., MURPHY, F., MULLINS, M., MAIER, K., FRIEL, R., & ROHLFS, T. (2018). Reasonable,

The Brazilian system of liability is still relatively uncoded and based on general civil liability principles, and not on specific legislation regarding autonomous vehicles. The Brazilian courts are likely to adopt a traditional tort law approach to negligence, using the breach of duty, causation, and damage criteria. Nevertheless, the lack of specific legislation makes it difficult to foresee how liability is to be shared between car manufacturers, software developers, and drivers in complex autonomous vehicle accident situations. The Lei Geral de Proteção de Dados adds a new liability dimension related to data processing errors that may cause accidents, although its relevance in the autonomous vehicle scenario has not yet been ascertained. The Brazilian Consumer Protection Code (Código de Defesa do Consumidor) could be used as a basis for strict liability against the manufacturer, but it is too generic to encompass errors in decision-making algorithms or the degradation of sensors.²⁴

The liability rules in India have the most conceptual clarity in the world, but they are nevertheless employed in only a few cases. The Motor Vehicles (Amendment) Act, 2019, provides straightforward language that gives algorithmic fault its first statutory recognition by providing that the producer of an automated driving system shall pay for the damage caused by defects in the system. The Motor Vehicles (Amendment) Act, 2019, provides almost no information on how to deal with actual world collisions, who has to prove the existence of a defect, and how to share responsibility when more than one party is involved. The Bharatiya Nyaya Sanhita, 2023, which has replaced the Indian Penal Code, provides ordinary rules for penal liability when a person dies or is injured as a result of another's negligence, but no court has yet declared how these rules apply to self-driving cars. The former judge-made law of torts continues to be in force together with the new statutes, creating a set of rules that overlap but do not fit together. The owners and drivers are nevertheless liable under the present motor vehicle law even if the car is self-driving, unless they can prove with absolute certainty that the accident was caused by a defect in the system rather than misuse or poor maintenance. This two-tier system, whereby the producers are liable for design defects and the users are liable for misuse, gets the blame right on paper but is utterly impractical in cases where the sequence of events is complex and the evidence is in the hands of the produce²⁵

Adequate and Efficient Allocation of Liability Costs for Automated Vehicles: A Case Study of the German Liability and Insurance Framework. *European Journal of Risk Regulation*, 9(3), 548-563. <https://doi.org/10.1017/err.2018.35>

²⁴ Brüggemeier, G. (2011). European Civil Liability Law outside Europe. The Example of the Big Three: China, Brazil, Russia. *Journal of European Tort Law*, 2(1), 1-22. <https://doi.org/10.1515/jetl.2011.1>

Testing and Deployment Requirements: Pathways to Market Authorization

Germany has developed a complex testing and deployment process that describes the steps to involve in testing and commercial deployment. Autonomous vehicles must undergo stringent type approval procedures to ensure that they meet the required safety standards before they are approved for use on the roads. Testing is to be conducted under approvals that describes operational design domains, geographic regions and approval procedure, more autonomous vehicles have to meet increasingly strict validation requirements, such as scenario testing, simulation validation, and real-world testing. The regulatory system requires the use of data recording systems (similar to aviation “black boxes”) to facilitate post-event analysis and continuous safety evaluation. Deployment approval requires the manufacturer’s proof that autonomous systems meet safety performance requirements at least equivalent to those of competent human drivers, although the exact standards for such equivalence are a matter of technical and regulatory debate.²⁶

The regulatory system for testing and implementation in Brazil is still quite informal, with administrative agreements being the norm rather than comprehensive legislation. Pilot testing is approved on a case-by-case basis by municipal and state governments and is usually limited to controlled settings such as university campuses, industrial sites, or specific areas of a city. There is a lack of standardized terminology for pilot projects, leading to discrepancies across different regions. There has been a degree of caution shown by regulatory agencies in formalizing testing procedures, choosing instead to watch and wait for the development of this technology before formalizing requirements that may ultimately prove unnecessary or obsolete. While this may promote innovation, it also creates a great deal of legal ambiguity for producers who wish to make long-term investments. The lack of national standards also creates a problem of safety, as local governments may not have the necessary technical knowledge to assess the performance of autonomous vehicles. It would appear that the regulatory attitude in Brazil is one that values flexibility over procedural clarity, tolerating a degree of short-term ambiguity in order to avoid “lock-in” at too early a stage.²⁷

The regulatory framework in which autonomous vehicles are tested and deployed in India is more aspirational than

²⁵ Anonymous (2022). The Question of the Applicable Law in Cross-Border Claims on Product Liability: Reflections from India

²⁶ Aboy, M., Minssen, T., & Vayena, E. (2024). Navigating the EU AI Act: implications for regulated digital medical products. *npj Digital Medicine*, 7(1). <https://doi.org/10.1038/s41746-024-01232-3>

²⁷ Santos, A. A. D. S. (2022). Informal practices in politics and society in Brazil. *Contemporary Social Science*, 17(3), 191-204. <https://doi.org/10.1080/21582041.2022.2042588>

operational. Although the Motor Vehicles (Amendment) Act, 2019 has theoretically established the central government's control over the specification of testing and deployment criteria, the operational regulation has yet to be established. There is no formal system of permitting the testing of self-driving vehicles on public roads or a formal certification process for system safety. The pilot projects conducted by Indian startups and research institutions operate in a gray area, with all parties operating on a gentlemen's agreement with local authorities rather than an operational regulation. This state of affairs is a reflection of the ambivalence of the government towards autonomous technology in general, such that India finds itself with neither a controlled pilot nor a clear way to commercialization. The lack of testing infrastructure, standards, and evaluation capacity for system safety is further exacerbated by the lack of expertise and resources in the relevant regulatory agencies to evaluate the safety of autonomous systems, despite the political will to do so. Thus, the current de facto policy, which is effectively a lack thereof, essentially delegates the regulation of the sector to countries with more developed regulatory systems, which could potentially place Indian manufacturers at the mercy of foreign systems designed for different environments.²⁸

Data Protection and Privacy Standards: Governance of Information Flows

Germany applies the European Union's General Data Protection Regulation (GDPR) to autonomous vehicles, making it one of the strictest data protection frameworks in the world. Autonomous vehicles produce vast amounts of data, such as location tracking, passenger activity, environmental observation, and communication with infrastructure, making it necessary to comply with the GDPR's principles of lawful processing, purpose limitation, data minimization, and storage limitation. The GDPR's principles of privacy by design and privacy by default mandate that autonomous vehicles incorporate data protection concerns into the system design, not as an add-on but as a central consideration. Data subjects enjoy rights to access the processed data, rectify errors, erase data under certain circumstances, and object to automated decision-making with legal or significant consequences. Transborder data flows are subject to more stringent conditions, creating difficulties for global manufacturers. The enforcement of the GDPR combines heavy administrative fines of up to 4% of the global annual turnover with individual rights of action, providing a powerful incentive for compliance. The German GDPR policy considers data protection a basic

right rather than a consumer protection issue, echoing the constitutional concepts of informational self-determination and human dignity in the technological age.²⁹

The Brazilian data protection regime, which is set out in the Lei Geral de Proteção de Dados (LGPD), shows a strong conceptual fit with the GDPR but differs in terms of enforcement and the development of institutional infrastructure. The LGPD applies to the processing of data in autonomous vehicles, which must be based on a legal basis such as consent, legitimate interests, or the performance of a legal obligation. Data subjects have rights of access, erasure, rectification, and portability, as well as the right to object to decisions based solely on automated processing that produces effects for them. The LGPD requires data controllers to adopt adequate security measures, carry out impact assessments for high-risk processing, and designate data protection officers under specific circumstances. However, the enforcement apparatus of the LGPD is less evolved than that of Europe, as the Brazilian data protection authority (Autoridade Nacional de Proteção de Dados) is still in the process of developing its institutional infrastructure and jurisprudence. As a result, autonomous vehicle manufacturers are subject to legal requirements without complete knowledge of the details of compliance and enforcement priorities. The LGPD also includes exemptions for public interest and legal compliance, which may allow public authorities more access to data from autonomous vehicles for traffic management and monitoring than is allowed under the GDPR.³⁰

India offers the most sophisticated emerging data protection regime among the three countries analyzed, although recent legislative trends suggest an increasing recognition of the right to privacy. The Digital Personal Data Protection Act, 2023, marks the beginning of India's first-ever data protection regime, which incorporates principles such as consent, purpose limitation, data minimization, and individual rights, in line with the GDPR and LGPD. The applicability of the Act on autonomous vehicles is still unclear, in the absence of any specific requirements in the regulations. Moreover, the Act provides wide exemptions for government data processing and security, which may facilitate significant government access to autonomous vehicle data without sufficient procedural protections. The Supreme Court's decision that privacy is a fundamental constitutional right offers a normative foundation for data protection; nevertheless, its application is yet to be ascertained. Therefore, Indian autonomous vehicle companies are currently operating in a state of uncertainty regarding data localization,

²⁸ Rahman, M. M., & Thill, J. (2023). Impacts of connected and autonomous vehicles on urban transportation and environment: A comprehensive review. *Sustainable Cities and Society*, 96, 104649. <https://doi.org/10.1016/j.scs.2023.104649>

²⁹ Noia, T. D., Tintarev, N., Fatourou, P., & Schedl, M. (2022). Recommender systems under European AI

regulations. *Communications of the ACM*, 65(4), 69-73. <https://doi.org/10.1145/3512728>

³⁰ Carrillo, A. J., & Jackson, M. (2022). Follow the Leader? A Comparative Law Study of the EU's General Data Protection Regulation's Impact in Latin America. *ICL Journal*, 16(2), 177-262. <https://doi.org/10.1515/icl-2021-0037>

consent, restrictions on cross-border data flows, and enforcement priorities. These are particularly challenging for autonomous vehicles that are continuously processing data for safety-critical applications, thus creating a paradox between operational needs and privacy rights.³¹

Safety Standards and Certification Procedures: Technical Verification Systems

Germany has a relatively advanced safety certification system that integrates the standards for autonomous vehicles with the current type approval procedure, while also specifying clear criteria for higher levels of autonomy. The procedure requires adherence to technical safety standards that cover sensor performance, redundancy design, cybersecurity, and fail-safe design. The safety certification process involves a rigorous documentation process that covers system architecture, testing, and validation. Autonomous systems are required to be able to perceive and respond to traffic participants, environmental conditions, and infrastructure components within the operational design domain certified for the system. The process also includes software update procedures, which require that software updates maintain safety equivalence without requiring recertification for minor updates. Germany is also involved in international standards development, working through the United Nations Economic Commission for Europe (UNECE) to enable the development of harmonized technical standards that can facilitate the global deployment of autonomous vehicles. The regulatory framework is focused on performance standards, which define the outcomes required rather than how they should be achieved, thus allowing manufacturers to choose multiple technical solutions to meet safety requirements. The process of conformity assessment is carried out by independent technical services, which offer a third-party validation service that confirms systems meet regulatory requirements before being authorized for the market.³²

Currently, Brazil does not have a comprehensive safety certification system specifically designed for autonomous vehicles. Rather, Brazil follows a set of general guidelines for the safety of motor vehicles, which were originally developed for conventional cars. The Conselho Nacional de Tránsito (CONTRAN) has the legal power to set technical standards for the authorization of vehicles but has not yet developed standards specifically for autonomous vehicles. Test projects are usually carried out through administrative agreements, which specify safety terms on a project-by-

project basis rather than through a comprehensive certification system. Although this system provides flexibility in terms of regulation, it does not provide a standardized level of safety across various projects and manufacturers. Brazilian participation in regional standards development through MERCOSUR provides an opportunity for regional harmonization with other nations; however, this has been made difficult by discrepancies in the regulation agenda and differences in technical capacity. The absence of institutional infrastructure required for the assessment of complex autonomous systems, such as testing infrastructure, qualified personnel, and effective validation procedures, represents a basic hindrance to the development of certification systems, despite the presence of a regulatory mindset that is inclined to facilitate this process. As a result, Brazilian regulatory bodies are faced with a dilemma: either to develop certification systems for autonomous vehicles in Brazil, to accept foreign certifications from other nations such as Germany or the United States, or to stick with the current ad hoc system of project-by-project authorization.³³

The safety certification system for autonomous cars in India is, in essence, a non-existent reality that has not been implemented in theory, despite legal authorization. The Central Motor Vehicles Rules, which regulate the standards and certification of vehicles, have not been updated to include autonomous technology. The Automotive Research Association of India (ARAI), which performs type approval testing for regular vehicles, does not have the infrastructure or technical know-how to test autonomous technology. There are no standardized testing procedures, simulation requirements, or real-world validation processes that have been developed. The few projects that are being developed in India are not subject to any formal safety certification process and are left to the discretion of the manufacturer and the local transport authorities. This is a reflection of the government's unwillingness to implement the use of autonomous vehicles and the lack of ability to perform complex technical testing. The current Indian strategy for technological development is in stark contrast to its vision.³⁴

Key Similarities and Structural Convergences

Notwithstanding the presence of significant disparities in terms of regulatory development and normative alignment, the three systems share common challenges that are indicative of similar underlying drivers in the regulation of autonomous vehicles. The three systems are faced with the challenge of basic uncertainty in terms of

³¹ Gupta, N., & George, A. (2024). Digital Personal Data Protection Act, 2023. *Data Governance and the Digital Economy in Asia*, 34-53. <https://doi.org/10.4324/9781003505723-3>

³² Kriebitz, A., Max, R., & Lütge, C. (2022). The German Act on Autonomous Driving: Why Ethics Still Matters. *Philosophy & Technology*, 35(2). <https://doi.org/10.1007/s13347-022-00526-2>

³³ Sever, T., & Contissa, G. (2024). Automated driving regulations – where are we now? *Transportation Research Interdisciplinary Perspectives*, 24, 101033. <https://doi.org/10.1016/j.trip.2024.101033>

³⁴ Hakstian, A. R. (1971). A Comparative Evaluation of Several Prominent Methods of Oblique Factor Transformation. *Psychometrika*, 36(2), 175-193. <https://doi.org/10.1007/bf02291397>

the appropriate level of safety, which stems from the fact that autonomous technology is developing at a pace that is faster than the regulatory systems can keep up with. The three systems are also faced with the challenge of epistemology in terms of being able to determine the safety of systems whose decision-making processes may be opaque to their developers, thereby creating questions about the level of testing that is sufficient and the level of algorithmic reliability that is required.³⁵

Each of the three systems recognizes the role of manufacturer liability as a key component of liability regimes, but the application of this tenet to workable legal systems is not straightforward. The issue of allocating responsibility to multiple parties, including manufacturers, software designers, component suppliers, vehicle owners, and infrastructure suppliers, is a transnational issue that represents the inherently distributed nature of autonomous vehicle systems. Additionally, each of the three systems faces the issue of algorithmic transparency, where regulatory bodies need sufficient systemic knowledge to confirm safety and analyze incidents, but manufacturers are averse to information disclosure that could lead to the loss of intellectual property or cyber attacks. This issue is not dependent on data protection laws and likely arises from the nature of autonomous technology.³⁶

The ethical issues related to algorithmic decision-making, such as different versions of the trolley problem and issues of bias, arise in all three systems, although the regulatory measures taken to address them show a great degree of variation. While Germany has attempted to enshrine ethical values in the form of guidelines, which stress the values of human dignity and non-discrimination, Brazil relies on constitutional values without any concrete detail, and India has, in effect, steered clear of ethical issues. However, the underlying questions remain the same, regardless of the regulatory strategy adopted: How are competing safety values to be weighed in autonomous systems? What is the acceptable risk allocation, and how can the fairness of algorithmic decision-making be ascertained and enforced? The universality of these questions suggests that technology regulation is increasingly forced to engage with moral philosophy in a manner that has not been the case with safety regulation.³⁷

Key Differences and Jurisdictional Variations

³⁵ Hansson, L. (2020). Regulatory governance in emerging technologies: The case of autonomous vehicles in Sweden and Norway. *Research in Transportation Economics*, 83, 100967. <https://doi.org/10.1016/j.retrec.2020.100967>

³⁶ Sever, T., & Contissa, G. (2024). Automated driving regulations – where are we now? *Transportation Research Interdisciplinary Perspectives*, 24, 101033. <https://doi.org/10.1016/j.trip.2024.101033>

³⁷ Wang, X., Wu, Y. C., Ji, X., & Fu, H. (2024). Algorithmic discrimination: examining its types and regulatory measures with emphasis on US legal

The differences in jurisdiction are rooted in the philosophy of regulation and the capacity to regulate. Germany shows a strong belief in the state's ability to cope with technological change by means of comprehensive regulation, backed up by a strong administrative tradition and sufficient resources to develop and implement complex standards. Brazil shows a more cautious approach to regulation, preferring a learning-by-experimenting approach to premature legislative action. India shows a clear attitude of skepticism about the social desirability of autonomous technologies, giving more weight to employment protection than innovation. These philosophical stances not only shape the present content of regulation but also the adaptability to new knowledge: Germany can change its specific standards as technology advances; Brazil can adjust its approaches based on the results of pilot projects; while the regulatory void in India does not offer any obvious way to incorporate new knowledge or change the regulatory agenda.³⁸

Institutional infrastructure shows a great degree of disparity among the different jurisdictions. Germany has a strong type approval system in place, testing facilities that are autonomous, technical know-how in the regulatory bodies, and the ability to impose sanctions. Brazil has basic certification capability for traditional vehicles but does not have the capability for autonomous vehicles, and the regulatory power is dispersed at the federal, state, and local levels. India has the most extreme degree of institutional weakness, as the regulatory bodies do not have the technical know-how to assess autonomous vehicles even if they are given the regulatory power to do so.³⁹

The three countries display different tendencies in their engagement with internationalization and the harmonization of regulations. Germany is very much involved in the European Union regulatory process and the UNECE standards process, aligning its autonomous vehicle regulatory system with international efforts. Brazil is selectively involved through MERCOSUR but is not part of international standards development, which limits its ability to shape international standards and tap into international regulatory knowledge. India remains quite isolated in its operations and does not participate much in international efforts for harmonization, despite the advantages that can be derived from cooperation with other nations that are also faced with similar

practices. *Frontiers in Artificial Intelligence*, 7. <https://doi.org/10.3389/frai.2024.1320277>

³⁸ Anonymous (2014). From competing jurisdictions to competing competences (Chapter 1) - The Allocation of Regulatory Competence in the EU Emissions Trading Scheme

³⁹ Tu, Y., Chen, B., Liao, C., Wu, S., An, J., Lin, C., Gong, P., Chen, B., Wei, H., & Xu, B. (2025). Inequality in infrastructure access and its association with health disparities. *Nature Human Behaviour*, 9(8), 1669-1682. <https://doi.org/10.1038/s41562-025-02208-3>

challenges..⁴⁰

Best Practices and Lessons for Regulatory Development

The German experience illustrates the importance of ensuring that there be clear legal channels that minimize regulatory uncertainty while maintaining strong regulatory safeguards with regard to safety. Legal permission for testing and use, together with technical requirements, provides regulatory certainty for manufacturers and ensures public safety. The incorporation of autonomous vehicle regulation into existing motor vehicle law, rather than developing two different systems, builds on existing knowledge and enforcement infrastructure. The German system's focus on manufacturer responsibility properly assigns risk to those best situated to manage system safety, and also provides a clear path to recourse for those injured in accidents. The disclosure framework that provides regulatory agencies with access to the algorithmic logic of autonomous systems for safety assessment, but does not require public disclosure, strikes a balance between transparency and the protection of intellectual property rights.⁴¹

The Brazilian incremental approach offers lessons on the role of regulatory flexibility during times of technological uncertainty and institutional constraints. The use of implementing authorizations for controlled pilot projects before the creation of comprehensive regulatory frameworks allows for ex post assessments of technological feasibility, ease of implementation, and social acceptability, without The process involves the avoidance of premature regulatory decisions. This approach to experimental governance recognizes the limitations of knowledge and promotes the development of evidence-based policies rather than policies based on theory alone. However, the Brazilian experience reveals the negative consequences that can befall regulatory ambiguity: “legal uncertainties may discourage investment, inconsistencies between local regulations may hinder growth, and the lack of clear liability

provisions may leave individuals at risk without sufficient safeguards.” In the context of incremental regulation, it is necessary to move from experimental learning to formalization within a reasonable period of time, which has not yet occurred in Brazil.⁴²

This approach involves choices that may be made before full regulatory certainty. This experimental governance recognizes the limitations of present knowledge and promotes evidence-based policy-making, as opposed to policy-making based on theoretical assumptions. However, the Brazilian experience also shows the negative consequences of regulatory ambiguity. Uncertainty of the law may discourage investment, inconsistencies between local and international regulatory systems may hinder growth, and the lack of clear liability clauses may put people at risk without sufficient safeguards. In the context of incremental regulation, it is necessary to move from experimental learning to formalization within a reasonable time frame, which Brazil has not yet reached.⁴³

Cross-cutting best practices are identified through comparative analysis. First, there must be significant investment in autonomous vehicles, and this cannot be achieved through administrative means. Second, there must be a regulatory framework that defines liability in such a way that it does not attribute responsibility to insufficiently understood technology. Third, there must be safety certification that uses performance-based standards. Fourth, data protection regulations must ensure a balance between the need for data and privacy rights of individuals, based on principles of data minimization, purpose limitation, and security. Fifth, there must be transparency that allows regulatory bodies to access the logical foundations of algorithms for safety certification, without undermining proprietary rights. Sixth, there is a need for international harmonization of regulatory frameworks to facilitate cross-border deployment and learning while recognizing sovereignty over fundamental policy decisions.⁴⁴

The comparative evidence suggests that regulatory convergence may neither be possible nor desirable.

⁴⁰ Singer, D. A. (2004). *Capital Rules: The Domestic Politics of International Regulatory Harmonization*. International Organization, 58(03). <https://doi.org/10.1017/s0020818304583042>

⁴¹ Sánchez-García, E., Martínez-Falcó, J., Marco-Lajara, B., & Manresa-Marhuenda, E. (2024). Revolutionizing the circular economy through new technologies: A new era of sustainable progress. *Environmental Technology & Innovation*, 33, 103509. <https://doi.org/10.1016/j.eti.2023.103509>

⁴² Cunha, B. Q., Pereira, A. K., & Gomide, A. D. Á. (2017). State capacity and utilities regulation in Brazil: Exploring bureaucracy. *Utilities Policy*, 49, 116-126. <https://doi.org/10.1016/j.jup.2017.06.004>

⁴³ [https://www.google.com/search?q=Rao%2C+U.%2C+%26+Nair%2C+V.+\(2019\).+Aadhaar%3A+Governin g+with+Biometrics.+South+Asia%3A+Journal+of+Sou th+Asian+Studies%2C+42\(3\)%2C+469-](https://www.google.com/search?q=Rao%2C+U.%2C+%26+Nair%2C+V.+(2019).+Aadhaar%3A+Governin g+with+Biometrics.+South+Asia%3A+Journal+of+Sou th+Asian+Studies%2C+42(3)%2C+469-481.+https%3A%2F%2Fdoi.org%2F10.1080%2F00856401.2019.1595343&rlz=1C1GCEA_enIN1116IN1118&oq=Rao%2C+U.%2C+%26+Nair%2C+V.+(2019).+A adhaar%3A+Governing+with+Biometrics.+South+Asia %3A+Journal+of+South+Asian+Studies%2C+42(3)%2 C+469-481.+https%3A%2F%2Fdoi.org%2F10.1080%2F00856401.2019.1595343&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQIRiPAjIHCAIQIRiPAAtIBBzUwNGowa jmoAgawAgHxBYHSNtUr7m8N&sourceid=chrome&ie=UTF-8)

481.+https%3A%2F%2Fdoi.org%2F10.1080%2F00856401.2019.1595343&rlz=1C1GCEA_enIN1116IN1118&oq=Rao%2C+U.%2C+%26+Nair%2C+V.+(2019).+A adhaar%3A+Governing+with+Biometrics.+South+Asia %3A+Journal+of+South+Asian+Studies%2C+42(3)%2 C+469-

481.+https%3A%2F%2Fdoi.org%2F10.1080%2F00856401.2019.1595343&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQIRiPAjIHCAIQIRiPAAtIBBzUwNGowa jmoAgawAgHxBYHSNtUr7m8N&sourceid=chrome&ie=UTF-8

⁴⁴ Perleth, M., Jakubowski, E., & Busse, R. (2001). What is ‘best practice’ in health care? State of the art and perspectives in improving the effectiveness and efficiency of the European health care systems. *Health Policy*, 56(3), 235-250. [https://doi.org/10.1016/s0168-8510\(00\)00138-x](https://doi.org/10.1016/s0168-8510(00)00138-x)

Countries face unique infrastructure challenges, traffic patterns, societal values, and institutional capabilities that form legitimate grounds for different regulatory responses. The German system of comprehensive legislation is highly suitable for a technologically developed country with deep administrative capabilities, but may end up being highly counterproductive in settings that lack institutional infrastructure or are faced with more pressing development needs. The Brazilian model of experimentation may suit countries that are middle-income and face technological uncertainty in conditions of resource scarcity, but offers too little structure for developed markets that demand investment predictability. The Indian model of stringency expresses genuine concerns about job displacement that may be undervalued by wealthy countries with adequate social safety nets. The challenge that all three countries, and the international community at large, face is to devise regulatory frameworks that are sufficiently sensitive to local conditions and yet retain sufficient compatibility to facilitate the beneficial transfer of technology.⁴⁵

Synthesis of Regulatory Approaches

Germany has proven to be a world leader in the regulation of autonomous vehicles, and this is made possible by a comprehensive regulatory framework. The Autonomous Driving Act of 2021 is a revolutionary step in the regulation of autonomous vehicles, as it provides the first-ever comprehensive regulatory framework in the world that is specifically designed for Level 4 autonomous vehicles. The regulatory framework is marked by several key features, including a centralized approval procedure that is managed by the Federal Motor Transport Authority (KBA), the use of the “technical supervisor” approach to replace the traditional concept of the driver, a technical and safety framework that requires vehicles to comply with traffic laws and ensure that the vehicle is in a minimal risk state in emergency situations, and a comprehensive data governance framework that is aligned with the General Data Protection Regulation of the European Union. The German regulatory system mirrors the government’s basic trust in its ability to control technological change through comprehensive regulation, which is made possible by a strong institutional framework. However, the system’s comprehensiveness also leads to high compliance costs and could act as a barrier to entry for smaller innovators who cannot afford to deal with the system’s complexities.⁴⁶

Brazil is an intermediate case between the German regulatory system and the Indian regulatory system. The Brazilian regulatory system is marked by administrative

flexibility and experimental governance rather than legislative reform. The National Department of Ground Transportation (DENATRAN) has introduced preliminary guidelines and allowed controlled pilot testing in specific urban areas, with a special emphasis on São Paulo and Rio de Janeiro, often carried out in partnership with universities and technology companies. This allows policymakers to gather empirical information about technological performance, implementation issues, and social acceptance before the establishment of a permanent regulatory framework. The liability framework is still rudimentary and relies on existing rules in the Brazilian Civil Code, the Consumer Protection Code, and the Traffic Code, rather than on autonomous vehicle-specific legislation. Data protection is regulated by the General Data Protection Law (LGPD), which is very similar to the GDPR but has less developed enforcement capacity. Although Brazil’s flexible regulatory system promotes innovation and prevents regulatory lock-in at an early stage, it creates uncertainty for technology manufacturers about long-term regulatory requirements and may leave some gaps in safety standards for different jurisdictions. The Brazilian system is a sensible response to technological uncertainty and institutional capacity limitations.⁴⁷

India represents the most restrictive environment for autonomous vehicles, which is a situation that exists due to a lack of regulation rather than outright ban. The Motor Vehicles (Amendment) Act of 2019 is ostensibly a legal framework for the use of autonomous vehicles, but there are still no operational regulations in place, nor any formal testing or certification process. This lack of regulation is compounded by outright political opposition from the Indian government, led by Transport Minister Nitin Gadkari, who has stated that driverless cars will not be allowed in the country in order to protect the jobs of millions of drivers. This is a legitimate concern regarding job displacement in a labor-saturated economy that currently lacks comprehensive social welfare provisions. At present, the limited number of autonomous vehicle projects in India are functioning in a condition of ambiguity, with the projects running on a sort of understanding with the local government in the absence of a formal regulatory framework. In addition to this, India faces a significant infrastructural challenge, with the absence of standardized road markings, a lack of lane discipline, and complex traffic patterns that include pedestrians, animals, and a variety of vehicles, in addition to a lack of digital connectivity. These factors, taken together, create a challenging environment for the implementation of autonomous vehicles. However, some researchers have argued that the successful handling of

⁴⁵ Simmons, B. A. (2001). The International Politics of Harmonization: The Case of Capital Market Regulation. *International Organization*, 55(3), 589-620. <https://doi.org/10.1162/00208180152507560>

⁴⁶ Salvini, P., Kunze, L., & Jirotko, M. (2024). On self-driving cars and its (broken?) promises. A case study analysis of the German Act on Autonomous Driving.

Technology in Society, 78, 102628. <https://doi.org/10.1016/j.techsoc.2024.102628>

⁴⁷ Oswald, O. R. S., & Burri, M. (2020). India, Brazil, and public health: <sc>Rule-making</sc> through <sc>south-south</sc> diffusion in the intellectual property rights regime? *Regulation & Governance*, 15(3), 616-633. <https://doi.org/10.1111/regg.12355>

traffic patterns in India could result in a significantly robust autonomous vehicle system. The Indian government's policy prioritizes the immediate socioeconomic implications of autonomous vehicle implementation over technological development, effectively establishing a moratorium on the use of autonomous vehicles in the country in the absence of an outright ban.⁴⁸

Critical Gaps and Convergent Challenges

Despite their different approaches to regulation, all three states share common challenges that stem from the nature of autonomous vehicle regulation itself. The issue of liability allocation is still a challenge in all three states. Although the German system of liability allocation is the most advanced, with primary responsibility allocated to the manufacturer in cases of system malfunction, in Brazil, the issue of liability allocation is governed by general tort law and product liability law, which lack specific regulation on autonomous vehicles, and in India, the legislative recognition of manufacturer liability lacks practical detail on the allocation of burden of proof in multi-party accidents.⁴⁹

Transparency and safety verification of algorithms are common challenges. The regulatory body needs enough information about the decision-making process of autonomous systems to ensure safety and analyze any accident, but the industry is averse to information that could lead to the theft of intellectual property or cybersecurity threats. This is a challenge for all three nations, but Germany has made the most progress in setting up guidelines for information disclosure that would allow the regulatory body to access the logic of the algorithm without making it public. Brazil and India have not yet addressed this issue.⁵⁰

The ethical implications of algorithmic decision-making, such as trolley problems and bias in system design, are present in all three countries. Germany has attempted to grapple with these issues through ethical guidelines that focus on human dignity and non-discrimination. Brazil has based its approach on constitutional principles but has not put in place any implementation framework for autonomous vehicles. India has not engaged with these ethical issues, possibly because it is still in the hypothetical stage of implementing autonomous

vehicles. But regardless of how a country chooses to regulate, the questions remain the same: How do autonomous systems balance competing priorities in safety? What is a socially acceptable distribution of risk? How is fairness in algorithmic decision-making measured and enforced? The fact that these questions are universal indicates that technology regulation is entering a realm of moral philosophy that traditional safety regulation has not required.⁵¹

Data protection and cybersecurity are issues of varying intensity in the three countries. Germany has the benefit of full GDPR compliance requirements, although the severity of European data protection regulation makes it difficult to implement systems that must process data continuously for safety-critical tasks. Brazil's LGPD has a similar framework but is less developed in terms of enforcement infrastructure. India's Digital Personal Data Protection Act of 2023 introduces basic principles of protection but has sweeping government exemptions and no implementing regulations specific to autonomous vehicles. Each of the three countries faces the challenge of reconciling operational data needs with individual privacy rights, data retention periods, privacy of pedestrians and other road users in sensor data, and unauthorized access or malicious manipulation of vehicle systems. The knowledge problem the question of how to define sufficient safety in rapidly changing technological systems is a problem that all jurisdictions face. The rate of development of autonomous technology outstrips the ability of regulatory structures to keep up, leading to epistemological problems about how much testing is necessary and what degree of algorithmic safety is required. These problems are exacerbated by the lack of established safety standards: should autonomous vehicles be required to drive as well as the average human driver, the good human driver, or meet some kind of absolute standard of safety? Each country has taken a different tack in dealing with this problem, but no country has fully answered the underlying question of how to regulate a system whose capabilities and limitations may not be fully understood even by its developers.⁵²

Cross-Jurisdictional Best Practices and Future Directions

⁴⁸ Patel, M., Singh, R., Arora, P., & Mahapatra, D. (2024). EV adoption in India: barriers and policy solutions from manufacturers' and consumers' perspectives. *Energy for Sustainable Development*, 83, 101583. <https://doi.org/10.1016/j.esd.2024.101583>

⁴⁹ Orwat, C., Bareis, J., Folberth, A., Jahnel, J., & Wadehul, C. (2024). Normative Challenges of Risk Regulation of Artificial Intelligence. *NanoEthics*, 18(2). <https://doi.org/10.1007/s11569-024-00454-9>

⁵⁰ Cheong, B. C. (2024). Transparency and accountability in AI systems: safeguarding wellbeing in the age of algorithmic decision-making. *Frontiers in Human Dynamics*, 6. <https://doi.org/10.3389/fhumd.2024.1421273>

⁵¹ Lu, W. (2024). Inevitable challenges of autonomy: ethical concerns in personalized algorithmic decision-making. *Humanities and Social Sciences Communications*, 11(1). <https://doi.org/10.1057/s41599-024-03864-y>

⁵² Coche, E., Kolk, A., & Ocelík, V. (2023). Unravelling cross-country regulatory intricacies of data governance: the relevance of legal insights for digitalization and international business. *Journal of International Business Policy*, 7(1), 112-127. <https://doi.org/10.1057/s42214-023-00172-1>

Some principles have emerged from this comparison that are relevant to all three jurisdictions and should inform future regulatory development. First, the regulation of autonomous vehicles is a matter that requires a high level of institutional investment that cannot be accomplished through administrative improvisation. It is necessary to develop technical knowledge in the regulatory agencies, test facilities that are able to verify complex systems, certification procedures that are able to evaluate decision-making algorithms, and enforcement procedures that are able to address violations. This requires years of development.

Second, the regulatory environment should offer clarity on liability issues without unnecessarily assigning liability to a technology that is not well understood. The best way to address this issue seems to be through the assignment of primary liability to the manufacturer for system defects, while also assigning liability to the operator for system maintenance, correct usage, and adherence to operational limitations. Clarity in documentation requirements, data recording systems, and investigation procedures can assist in determining liability in the event of an accident.

Third, safety certification should use performance standards that specify outcomes rather than technical specifications. This method, as seen in the German framework, gives manufacturers the flexibility to achieve safety goals without worrying about the regulatory framework being rigid on the technology used. Performance standards can keep up with technological changes without needing a regulatory overhaul, thus encouraging innovation while ensuring safety.

Fourth, frameworks for data protection must strike a balance between the need to collect data for operational purposes and the privacy rights of individuals through the principles of minimization, purpose limitation, and security. The need for autonomous vehicles to process data on a continuous basis for safety-critical systems is imperative; however, this need does not justify the collection and retention of data without limitations.

Fifth, regulatory structures must establish transparency procedures that allow regulatory bodies to have access to the logic of algorithms for the purpose of verification while ensuring that intellectual property rights are not violated. This can be achieved through secure review facilities where regulatory bodies can review decision-making processes in systems without making this information public, through technical experts who are bound by confidentiality agreements and can verify claims by manufacturers, or through formats that make information about safety publicly available without making the entire system architecture public.

Sixth, international harmonization of regulatory approaches should be considered to enable the international deployment of drones and the exchange of knowledge related to their use. However, international harmonization of regulatory approaches must respect the sovereignty of nations with regard to basic policy choices. For example, technical standards related to

sensor performance, communication, cybersecurity, and data recording can be harmonized without requiring international harmonization of liability standards, testing standards, and deployment approvals.

Conclusion

A comparative analysis of the regulatory regimes for autonomous vehicles in Brazil, Germany, and India illustrates that the regulation of new technologies is intricately intertwined with particular economic, institutional, and socio-political contexts. The differences between the three countries go beyond procedural variations and are rooted in profoundly different views on how technological progress should relate to public security, economic development, and social welfare. Germany represents a comprehensive and proactive regulatory approach, which is facilitated by strong institutional capabilities and a legal culture focused on proactive risk management related to technology. By placing autonomous vehicle technology within a comprehensive normative framework, Germany seeks to promote innovation and maintain legal certainty, accountability, and public confidence. Conversely, Brazil adopts a more incremental and responsive regulatory approach, which is facilitated by regulatory experimentation and limited by infrastructural constraints. This approach seeks to align innovation with social and legal facts in a developing regulatory environment. India represents a developing regulatory approach to autonomous vehicles, in which wider development imperatives influence a cautious and incremental approach to technological integration. Taken together, these examples illustrate the absence of a regulatory template that can be universally applied to autonomous vehicles. For regulatory purposes in this area, it is necessary to have frameworks that are sensitive to context and capable of taking into account the capabilities of nations while also being flexible enough to keep up with the ever-changing nature of technological progress. At the same time, it is important to note that there are certain challenges that are common to this area of regulation. An understanding of the areas of divergence and convergence is highly relevant to the current debate on law, technology, and society.

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