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Article

Criminal Responsibility for Harm Caused by Autonomous Vehicles: A Doctrinal Study

Qianwen Zhu [1,*]

[1] Faculty of Law, Minzu University of China, Fengtai District, Beijing, China
* Correspondence: Qianwen Zhu, Faculty of Law, Minzu University of China, Fengtai District, Beijing, China

Abstract: With the rapid advancement and deployment of autonomous driving technology, autonomous vehicles (AVs) have increasingly integrated into daily life and modern transportation systems. While these innovations offer substantial societal benefits, they simultaneously raise the likelihood of unprecedented traffic accidents, thereby complicating the traditional allocation of legal responsibility. The inherent diversification of potential criminal subjects, the intricate complexity of causal relationships between human operators and machine algorithms, and the glaring inadequacy of existing legal frameworks collectively pose significant challenges to the accurate determination of criminal liability in autonomous vehicle-related incidents. To address these critical jurisprudential gaps, this doctrinal study aims to systematically clarify the scope of criminal responsibility for the various different actors involved in AV accidents. It fundamentally argues that the human driver's liability must be dynamically determined based on the specific level of vehicular automation. Specifically, in non-highly or partially autonomous driving scenarios, the driver should continue to bear standard negligence liability for operational failures. Conversely, in highly or fully autonomous driving contexts, the driver's role is substantially diminished, limited strictly to a residual duty of care. Furthermore, the manufacturer's liability should be meticulously delineated across both the production and application phases, accompanied by the enforcement of improved, rigorous safety standards. Ultimately, in cases where manufacturers deliberately refuse or negligently delay fulfilling their statutory safety management duties, and the resulting circumstances are demonstrably serious, strict criminal liability should be unequivocally imposed to ensure public safety and corporate accountability.

Keywords: autonomous driving; driverless vehicles; criminal liability; duty of care; product liability

1. Introduction

The rapid advancement of artificial intelligence has precipitated a paradigm shift in the transportation sector, with autonomous vehicles (AVs) emerging as one of the most transformative applications of AI technology. Unlike conventional automobiles that necessitate continuous human operation, AVs are capable of perceiving their environment and navigating safely with minimal or no human intervention, fundamentally altering the traditional driver-vehicle relationship. This technological evolution has progressed from theoretical conception to practical implementation in numerous jurisdictions worldwide. In China, the commercialization of autonomous driving services has advanced considerably, exemplified by the deployment of the nation's first autonomous taxi in Guangzhou in November 2018 and Beijing's landmark initiative in November 2021 to launch the country's first commercial pilot program for automated driving services, authorizing the operation of up to one hundred AVs within designated pilot areas. Similarly, Baidu's "Apollo Go" autonomous ride-hailing service has expanded its operations to multiple major cities including Wuhan and Shanghai, accumulating over one million total orders [1]. These developments signify a decisive shift from experimental testing toward large-scale commercial deployment, positioning autonomous vehicle technology at the threshold of mainstream societal integration.

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However, the proliferation of AVs introduces unprecedented challenges for legal systems, particularly in the domain of criminal law. Despite the sophisticated information processing capabilities and enhanced safety features attributed to autonomous driving systems, empirical data reveals that accidents involving these vehicles remain a significant concern. The United States National Highway Traffic Safety Administration reported that between July 2021 and May 2022, there were approximately four hundred crashes involving vehicles equipped with advanced driver-assistance systems or automated driving technologies, resulting in six fatalities and five serious injuries. Notably, Tesla vehicles operating on Autopilot or full self-driving software accounted for 273 of these incidents, while Waymo's autonomous vehicle fleet reported sixty-two crashes during the same period. These statistics underscore a fundamental reality: notwithstanding continuous technological refinement, AVs remain susceptible to operational failures and cannot guarantee absolute immunity from traffic accidents. The attribution of criminal responsibility for harm caused by AVs consequently emerges as an urgent doctrinal question demanding systematic examination within the framework of criminal law.

The complexity of this inquiry stems from several interrelated factors. First, the diversification of criminal subjects involved in autonomous vehicle accidents, encompassing human drivers, manufacturers, software developers, and potentially the vehicles themselves complicates traditional paradigms of criminal attribution. Second, the intricate causal relationships between human conduct, algorithmic decision-making, and technological malfunctions render conventional causation analysis substantially more difficult [2]. Third, existing criminal law frameworks, developed within the context of human-operated vehicles, lack doctrinal apparatus adequate to address the distinctive features of autonomous driving scenarios. These challenges are further compounded by the graduated nature of vehicle automation, which ranges from driver assistance systems requiring continuous human supervision to fully AVs capable of operating without any human intervention.

The Society of Automotive Engineers' classification standard J3016, which has been substantially adopted by China's national standard Taxonomy of Driving Automation for Vehicles (GB/T 40429-2021), delineates six levels of driving automation from L0 to L5. Levels L0 through L3 remain predominantly human-centric: L0 involves no automation with full manual operation; L1 provides driver assistance through isolated functions such as adaptive cruise control or lane keeping assistance; L2 entails partial automation where the vehicle can control both steering and acceleration simultaneously while requiring continuous driver monitoring; and L3 represents conditional automation wherein the automated driving system performs all aspects of the dynamic driving task but expects the human driver to respond appropriately to intervention requests. At these levels, the human driver retains operational responsibility and traditional legal frameworks offer serviceable, if imperfect, analytical tools for determining criminal liability. However, Levels L4 and L5 designated highly automated driving and full self-driving respectively fundamentally reconfigure the human-machine relationship. L4 vehicles can perform all driving functions autonomously within defined operational design domains without expecting human intervention, even when encountering system limitations. L5 vehicles achieve full automation across all road types and environmental conditions, effectively rendering human driving superfluous [3]. These highest automation levels, which constitute the focus of this study, present genuinely novel legal questions that resist resolution through conventional doctrinal approaches.

A preliminary threshold question concerns whether AVs themselves might possess criminal legal personality capable of bearing responsibility. Scholarly discourse reveals divergent positions on this issue. Proponents of recognition theory contend that fully AVs, supported by sophisticated artificial intelligence and big data analytics, have developed capacities for identify and control that render subjective culpability theoretically conceivable, thereby qualifying as potential subjects of traffic accident crimes. Conversely, negation theory maintains that AVs remain fundamentally products of human programming, lacking the independent thinking capabilities and genuine normative

understanding essential for criminal responsibility. This study aligns with the negation perspective. Notwithstanding their operational autonomy, AVs are instruments of human design and intent, executing programmed algorithms rather than exercising moral agency. Moreover, even if algorithmic malfunctions or emergent behaviors contributed to accident causation, vehicles inherently lack capacity to bear criminal sanctions or participate in criminal proceedings. The denial of criminal personality to autonomous vehicles necessitates, therefore, a comprehensive examination of responsibility attribution among human actors, particularly drivers and manufacturers whose conduct intersects with automated systems in producing harmful outcomes [3, 4].

2. Overview of Criminal Responsibility in AV Accidents

2.1. Defining Autonomous Driving

Autonomous driving refers to the capability of a vehicle to execute dynamic driving tasks, including acceleration, deceleration, steering, and environmental monitoring without continuous human intervention. The Society of Automotive Engineers' classification standard J3016, which has been substantively adopted by China's national standard Taxonomy of Driving Automation for Vehicles (GB/T 40429-2021), delineates six levels of driving automation ranging from L0 to L5. Levels L0 through L3 remain predominantly human-centric: L0 requires full human control; L1 provides isolated support functions such as adaptive cruise control; L2 enables the vehicle to control both steering and acceleration simultaneously while requiring constant driver supervision; and L3 allows the automated driving system to perform all aspects of the dynamic driving task but expects the human driver to respond appropriately to intervention requests. At these levels, the human driver retains operational responsibility, and traditional criminal law frameworks, though not without difficulties, offer serviceable tools for determining liability. Levels L4 and L5 fundamentally reconfigure the human-machine relationship [5, 6]. L4 vehicles can perform all driving functions autonomously within defined operational design domains without expecting human intervention, even when system limits are reached. L5 vehicles achieve full automation across all road types and environmental conditions, effectively rendering human driving superfluous. Because the distinctive legal questions arise primarily at these highest automation levels, this study focuses on L4 and L5 vehicles, which are hereafter referred to as "autonomous vehicles" for the purposes of criminal responsibility analysis.

2.2. Subjects of Criminal Responsibility

The intelligent and autonomous nature of these vehicles enables them to make independent decisions and execute driving tasks, yet accidents remain possible [7, 8]. This reality necessitates a systematic identification of the potential subjects of criminal liability. Chinese legislation has not granted AVs legal personhood through legal fiction, nor do they possess the capacity to bear criminal responsibility; they lack the requisite legal personality and the ability to participate in criminal proceedings. Accordingly, the criminal subjects in autonomous vehicle-related accidents must be sought among human actors. The literature generally distinguishes three categories of potential responsibility: driver responsibility, product responsibility, and the criminal implications of algorithmic intervention. Each category involves distinct legal relationships, causation chains, and normative expectations, and a refined allocation of responsibility is essential both for doctrinal clarity and for ensuring that victims can obtain redress. The following subsections examine the two most contentious categories, driver responsibility and manufacturer responsibility, while the question of whether AVs themselves could ever be considered criminal subjects is addressed separately.

2.3. Negation of Criminal Legal Personality for Autonomous Vehicles

A threshold theoretical debate concerns whether fully autonomous vehicles might possess criminal legal personality. Proponents of recognition theory argue that, supported by big data and advanced artificial intelligence, L5 vehicles have developed capacities for

recognition and control that render subjective culpability theoretically conceivable, thereby qualifying as potential subjects of traffic accident crimes. For instance, some scholars suggest that the ability of AVs to process environmental information and make decisions approximates human cognition, making it possible to impute a form of machine mens rea. Opponents of this view maintain that AVs remain fundamentally products of human programming and lack the independent thinking capacity and genuine normative understanding essential for criminal responsibility. According to this negation theory, even when an autonomous vehicle executes an operation that leads to harm, it is merely executing algorithms designed by humans; the vehicle itself cannot form intent or negligence in any legally meaningful sense.

This study aligns with the negation perspective [3, 9]. Notwithstanding their operational autonomy, AVs are instruments of human design and intent, executing pre-programmed algorithms rather than exercising moral agency. Moreover, even if algorithmic malfunctions or emergent behaviors contributed to accident causation, vehicles inherently lack the capacity to bear criminal sanctions or participate in criminal proceedings. Criminal punishment presupposes a subject capable of understanding the wrongfulness of its conduct and of being deterred by sanctions—qualities that machines do not possess. The denial of criminal personality to AVs necessitates, therefore, a comprehensive examination of responsibility attribution among human actors, particularly drivers and manufacturers whose conduct intersects with automated systems in producing harmful outcomes. The following sections address the contentious issues surrounding driver and manufacturer liability in greater detail.

3. Difficulties in Attributing Criminal Responsibility

The allocation of criminal responsibility for harm caused by AVs is fraught with doctrinal difficulties, which arise primarily from the diversification of actors involved, the opacity of algorithmic decision-making, and the inadequacy of existing legal frameworks designed for human-driven vehicles [10, 11]. Two areas have generated particularly intense debate: the responsibility of the human driver across different automation levels, and the responsibility of manufacturers whose products embody the algorithms and hardware that enable autonomous operation. Each of these areas presents distinct challenges that resist straightforward resolution through traditional criminal law concepts such as actus reus, mens rea, and causation.

3.1. Disputes over Driver Responsibility

The question of driver responsibility is intrinsically linked to the level of automation. While L0-L2 vehicles require continuous human control and therefore fit comfortably within conventional liability models, the conditional, high, and full automation levels introduce novel complexities. At L3, the automated driving system performs all dynamic driving tasks but expects the human driver to respond appropriately to system requests for intervention. In such scenarios, criminal responsibility may arise only if the driver acts with intent or negligence [12]. Intentional use of an autonomous vehicle to cause harm would clearly be attributable to the driver as a tool of crime, so the primary controversy concerns negligent conduct. The core difficulty lies in defining the precise scope of the driver's duty of care in the L3 context. Current legislation does not specify what actions a driver must take to discharge that duty, nor does it clarify whether a driver's reliance on the system can ever excuse a failure to intervene. For example, if the system issues a warning but the driver, trusting the vehicle's capabilities, delays taking control and an accident ensues, should the driver be held criminally negligent? The answer hinges on whether the driver's reliance was reasonable under the circumstances—a determination that lacks clear statutory guidance.

A further complication arises in scenarios where a driver forcibly overrides the autonomous system, either because of distrust or a perceived imminent danger. Suppose a driver, believing that the autonomous vehicle is about to execute a risky manoeuvre, manually disengages the automation and assumes control. If a collision then occurs,

should the driver bear full criminal responsibility? Some scholars argue that once the driver intervenes, the vehicle ceases to operate autonomously and ordinary traffic offence principles apply, making the driver liable. Others contend that the accident may be a consequence of a dangerous situation created before the takeover—for instance, a latent system error that placed the vehicle on a collision course—and that attributing sole responsibility to the driver would be unjust. The causal chain in such cases is rarely linear, and the interplay between system behaviour and human reaction complicates the determination of fault.

At L5, the vehicle is capable of operating without any human intervention, and the driver becomes a mere passenger. The prevailing view holds that in such circumstances the human occupant owes no duty of care and cannot be held criminally liable for accidents caused by the autonomous vehicle [13]. This conclusion rests on the principle of reliance: the occupant is entitled to trust that the autonomous system will perform safely. Moreover, since the occupant performs no driving acts, there is no actus reus to support a conviction for a driving offence. However, a minority of scholars caution that, given the current developmental stage of autonomous vehicle technology and the possibility of system failures, it may be premature to entirely exempt the occupant from any residual duty, such as the obligation to monitor the vehicle's performance or to intervene in obvious emergencies. This dissenting view emphasises that the law should not create a responsibility vacuum, especially while autonomous vehicles remain imperfect.

3.2. Disputes over Manufacturer Responsibility

Manufacturer responsibility encompasses the obligations of developers, producers, and sellers. In civil law systems, product liability for defective vehicles is well established, but the extension of such liability into the criminal domain is far more contentious. Criminal law traditionally requires personal fault and a direct connection between the defendant's conduct and the harm, yet manufacturers, particularly developers and producers, are typically removed from the scene of an accident and may have no contemporaneous awareness of the specific incident.

The most fundamental debate concerns the developer's duty. Developers design the algorithms that govern autonomous vehicle behaviour; in a sense, the vehicle's actions are the embodiment of their prior programming choices. Some commentators argue that if an algorithmic flaw causes a foreseeable accident, the developer could be held criminally responsible for a form of negligence [14]. However, this position confronts a formidable obstacle: existing criminal offences, such as traffic accident crimes, presuppose conduct occurring at the time and place of the incident. A developer who wrote code months earlier cannot be said to have caused a collision in the sense required by traditional causation doctrines. Charging a developer with a traffic offence would violate the principle of legality because the offence was not designed to encompass remote conduct of this nature. Moreover, many developers are employees working within complex organisational structures; imposing criminal liability on individuals who merely followed design specifications could be unduly harsh and might stifle innovation. Consequently, scholars increasingly suggest that criminal responsibility for developers, if any, should be addressed through specially crafted offences rather than by stretching existing traffic laws.

The producer's obligations have generated even more diverse opinions. Producers are responsible for manufacturing vehicles that comply with safety standards, and they exercise ongoing control over the product's lifecycle through updates and maintenance. One school of thought maintains that producers should bear a duty to prevent accidents by ensuring that their vehicles are safe when placed on the market and remain safe through post-sale monitoring. This duty, if breached with sufficient gravity, could give rise to criminal liability for negligence. However, critics point out that producing a vehicle that merely meets regulatory standards does not amount to a criminal act; liability would require proof that the producer knew or should have known of a defect that created an unreasonable risk of harm. In many cases, the producer may lack such knowledge, and the very concept of negligence in this context is contested. Some scholars invoke the theory

of permitted risk to argue that certain accidents are inevitable in any transportation system and should not automatically trigger criminal consequences for the producer. Others advance a new negligence theory, suggesting that producers, by virtue of their expertise, are best placed to foresee and mitigate risks and therefore owe a heightened duty of care. Yet this approach has been criticised as result-oriented and insufficiently grounded in existing criminal doctrine.

A further strand of thought proposes a joint duty of care, allocating responsibility among developers, producers, and sellers according to their respective roles in creating or failing to correct defects. However, this theory struggles to satisfy the requirements of complicity, because in L4 and L5 scenarios none of these actors is present at the accident and none can be considered a principal offender in the traditional sense. The absence of a direct perpetrator makes it difficult to apply joint criminal enterprise principles, and the solution may instead lie in creating new, specific offences that capture the distinct nature of corporate fault in the autonomous vehicle context.

The seller's role is generally viewed as the least problematic. Sellers are parties to a commercial transaction and lack the technical expertise to conduct substantive safety assessments of the vehicles they sell. Their duty of care is primarily civil in nature and does not extend to the criminal domain, except perhaps in cases of intentional concealment of known defects. Given their limited control over the vehicle's design and operation, imposing criminal responsibility on sellers for autonomous vehicle-caused accidents would be both doctrinally unsound and practically unfair.

4. Proposed Framework for Criminal Responsibility

In light of the doctrinal difficulties analyzed above, a coherent framework for allocating criminal responsibility in autonomous vehicle-related accidents must be calibrated to the level of automation and must distinguish clearly between the roles of drivers and manufacturers. Such a framework should respect existing criminal law principles while adapting them to the novel features of autonomous systems.

4.1. Driver Responsibility Based on Automation Level

The driver's criminal responsibility should be determined primarily by the extent to which the human retains control over the vehicle's operation. At automation levels L0 through L3, the driver remains actively involved in the driving task, either continuously or as a fallback ready to respond to system requests. Consequently, the driver should bear a duty of care commensurate with that involvement and may be held criminally liable for negligence if a breach of that duty causes harm. In L0-L2 vehicles, the driver is essentially operating a conventional vehicle with assistance features; ordinary traffic offences and negligence principles apply without substantial modification. At L3, however, the duty of care requires careful definition. The driver must monitor the driving environment and be prepared to take over control within a reasonable time when the system issues a takeover request. Failure to do so that results in an accident could constitute criminal negligence, provided the driver's inattention was unreasonable under the circumstances. Importantly, the driver's reliance on the system is not absolute; it must be balanced against the obligation to remain vigilant. The content of this duty should be specified through a combination of legislative guidance and judicial interpretation, taking into account factors such as the system's known limitations, the driving conditions, and any warnings issued by the vehicle. Where a driver forcibly overrides the autonomous mode, the ensuing operation reverts to manual control, and the driver assumes full responsibility for any subsequent negligence, unless the accident was inevitable due to a pre-existing dangerous situation created by the system.

At levels L4 and L5, the vehicle is capable of performing the entire dynamic driving task without human intervention, and the human occupant is effectively a passenger. In such scenarios, the occupant owes no duty of care with respect to the driving function and cannot be held criminally liable for accidents caused solely by the autonomous vehicle. This conclusion is grounded in the principle of reliance: the occupant is entitled to trust

that a properly functioning L4 or L5 vehicle will operate safely within its operational design domain. Moreover, because the occupant performs no driving acts, there is no actus reus to support a conviction for a driving offence. However, a narrow exception may exist where the occupant has actual knowledge of a malfunction that creates an imminent risk of serious harm and fails to take reasonable steps to avert that harm, such as activating an emergency stop function. Such cases would be rare and would require proof that the occupant possessed both the capacity and the opportunity to intervene effectively. In general, extending criminal liability to occupants of fully autonomous vehicles would undermine the very purpose of automation and could deter the adoption of safety-enhancing technology.

4.2. Manufacturer Responsibility Across the Lifecycle

Manufacturers encompassing developers, producers, and entities responsible for post-sale updates play a continuous role throughout the autonomous vehicle's lifecycle, from design and production to operation and maintenance. A comprehensive framework for manufacturer responsibility must therefore distinguish between the production phase and the application phase, imposing distinct duties and potential criminal consequences in each.

During the production phase, the primary obligation is to ensure that autonomous vehicles comply with applicable safety standards before they are placed on the market. If a defect in design or manufacture is causally linked to an accident, and the defect results from the manufacturer's failure to meet mandatory safety requirements, criminal liability may arise under existing offences such as "producing or selling products not meeting safety standards" under relevant legal provisions. However, the effective application of such provisions requires clear, up-to-date safety standards tailored to autonomous vehicle technology [15]. Current standards are often lagging behind technological developments, and the inherent complexity and opacity of algorithms make it difficult to define static criteria that remain valid over time. In setting these standards, regulators should prioritize the protection of public safety while accommodating the need for innovation. Standards should be periodically reviewed and updated to reflect technological advances and accident data. Where a manufacturer knowingly or recklessly disregards applicable standards and places a dangerously defective vehicle on the market, and that defect causes serious harm, criminal prosecution may be justified.

The application phase imposes ongoing duties on manufacturers to manage the safety of autonomous vehicles throughout their operational lives. Because these vehicles rely on software that can be updated remotely, and because driving conditions evolve, manufacturers are in the best position to monitor vehicle performance and address emerging risks. Accordingly, manufacturers should bear a duty of safety management that includes at least two core obligations: continuous monitoring of vehicle fleets to detect anomalies or patterns indicative of safety defects, and the capacity for remote intervention to prevent or mitigate imminent harm. The monitoring obligation requires manufacturers to collect and analyze operational data, subject to appropriate privacy safeguards, and to take corrective action, such as issuing over-the-air updates or recalling vehicles when a safety-related defect is identified. The remote intervention obligation enables manufacturers to override or guide vehicle behavior in emergency situations, for example by commanding a vehicle to pull over safely if a system failure is detected. Failure to fulfill these duties, where such failure is causally connected to an accident and the circumstances are serious, should attract criminal liability. Seriousness might be assessed by reference to factors such as the duration of the failure, the number of vehicles affected, the manufacturer's awareness of the risk, and the gravity of the resulting harm.

It is important to emphasize that criminal liability for manufacturers should not be imposed lightly. The mere occurrence of an accident involving an autonomous vehicle does not imply manufacturer fault [16–18]. Prosecution should be reserved for cases where the manufacturer's conduct falls significantly below the standard of care reasonably expected of a responsible actor in this field, and where the conduct manifests

a sufficient degree of culpability whether intention, recklessness, or gross negligence. Lesser failures may be adequately addressed through civil remedies, regulatory sanctions, or administrative penalties. Moreover, because manufacturers are often large organizations, questions of corporate criminal liability and individual responsibility within the corporate structure will need careful consideration. The law should provide clear criteria for attributing liability to the corporate entity and, where appropriate, to senior managers or decision makers whose personal culpability contributed to the offence.

In summary, the proposed framework allocates criminal responsibility by distinguishing between driver and manufacturer roles and by calibrating duties to the level of automation and the phase of the product lifecycle. For drivers, responsibility diminishes as automation increases, ceasing altogether at Levels 4 and 5 except in exceptional circumstances. For manufacturers, responsibility extends across the lifecycle, with production phase duties centered on compliance with safety standards and application phase duties focused on ongoing safety management. This differentiated approach respects the principle of personal culpability while adapting criminal law to the realities of autonomous vehicle technology [16].

5. Conclusion

Autonomous vehicles cannot be recognized as subjects of criminal responsibility. Despite their advanced capabilities, AVs remain instruments of human design, lacking the legal personality and moral agency essential for criminal liability. Responsibility must therefore be allocated among human actors, principally drivers and manufacturers, according to a framework calibrated to automation levels and lifecycle phases.

Driver responsibility should diminish as automation increases. At L0-L3, where the driver retains involvement in the driving task, a duty of care applies, and negligence may attract criminal liability. At L4-L5, the occupant is a passenger and owes no driving-related duty, except in the narrowest circumstances where actual knowledge of imminent risk and capacity to avert harm exist. Manufacturer responsibility requires a lifecycle approach. During production, compliance with safety standards is paramount; knowing or reckless disregard causing serious harm may found criminal liability under existing product safety offenses. During application, manufacturers bear ongoing duties of safety management, continuous monitoring, and remote intervention, and failure to fulfill these duties with serious consequences should likewise be capable of attracting criminal sanction, reserved for cases of intention, recklessness, or gross negligence.

As AV technology advances toward full deployment, legislatures must engage proactively with these questions, developing rules that protect public safety without stifling innovation. The framework proposed here, distinguishing driver responsibility by automation level and manufacturer responsibility by lifecycle phase, offers a coherent foundation for such engagement, ensuring accountability while enabling the continued development of transformative transportation technologies.

References

1. C. J. Kahane, "Lives saved by vehicle safety technologies and associated Federal Motor Vehicle Safety Standards, 1960 to 2012–Passenger cars and LTVs–With reviews of 26 FMVSS and the effectiveness of their associated safety technologies in reducing fatalities, injuries, and crashes," Report No. DOT HS, vol. 812, p. 069, 2015.
2. R. Mohammed, "Artificial intelligence-driven robotics for autonomous vehicle navigation and safety," *NEXG AI Review of America*, vol. 3, no. 1, pp. 21-47, 2022.
3. A. Chougule, V. Chamola, A. Sam, F. R. Yu, and B. Sikdar, "A comprehensive review on limitations of autonomous driving and its impact on accidents and collisions," *IEEE Open Journal of Vehicular Technology*, vol. 5, pp. 142-161, 2023.
4. D. N. Reddy, A. Sowmiya, V. S. Pandi, R. Sateesh, and N. Hindumathy, "Autonomous vehicles: Steering the future of transportation with self-driving technology and advanced AI systems," in *2024 5th IEEE Global Conference for Advancement in Technology (GCAT)*, pp. 1-6, Oct. 2024.
5. R. Trypuz, P. Kulicki, and M. Sopek, "Ontology of autonomous driving based on the SAE J3016 standard," *Semantic Web*, vol. 15, no. 5, pp. 1837-1862, 2024.
6. Z. Chai, T. Nie, and J. Becker, *Autonomous driving changes the future*, vol. 166, Berlin/Heidelberg, Germany: Springer, 2021.

7. Y. H. Alnema, M. Almaged, and M. N. Noaman, "Driverless Model Cars: a Review and Analysis of Autonomous Vehicle Literature on Technology and Application," *International Review of Automatic Control*, vol. 13, no. 2, p. 84, 2020.
8. P. Salvini, L. Kunze, and M. Jirotka, "On self-driving cars and its (broken?) promises. A case study analysis of the German Act on Autonomous Driving," *Technology in Society*, vol. 78, p. 102628, 2024.
9. L. Jones, "Driverless when and cars: where?[automotive autonomous vehicles]," *Engineering & Technology*, vol. 12, no. 2, pp. 36-40, 2017.
10. W. M. Alvarez, F. M. Moreno, O. Sipele, N. Smirnov, and C. Olaverri-Monreal, "Autonomous driving: Framework for pedestrian intention estimation in a real world scenario," in *2020 IEEE Intelligent Vehicles Symposium (IV)*, pp. 39-44, Oct. 2020.
11. J. Pérez, V. Milanés, T. De Pedro, and L. Vlacic, "Autonomous driving manoeuvres in urban road traffic environment: a study on roundabouts," *IFAC Proceedings Volumes*, vol. 44, no. 1, pp. 13795-13800, 2011.
12. M. M. Rana and K. Hossain, "Connected and autonomous vehicles and infrastructures: A literature review," *International Journal of Pavement Research and Technology*, vol. 16, no. 2, pp. 264-284, 2023.
13. Y. Wiseman, "Autonomous vehicles," in *Research Anthology on Cross-Disciplinary Designs and Applications of Automation*, IGI Global Scientific Publishing, pp. 878-889, 2022.
14. T. Chen, Z. Li, Y. He, Z. Xu, Z. Yan, and H. Li, "From perception to control: an autonomous driving system for a formula student driverless car," *arXiv preprint arXiv:1909.00119*, 2019.
15. A. Nikitas, E. T. Njoya, and S. Dani, "Examining the myths of connected and autonomous vehicles: analysing the pathway to a driverless mobility paradigm," *International Journal of Automotive Technology and Management*, vol. 19, no. 1-2, pp. 10-30, 2019.
16. A. Broggi et al., "Proud—public road urban driverless-car test," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 6, pp. 3508-3519, 2015.
17. A. Hjalmarsson-Jordanius, M. Edvardsson, M. Romell, J. Isacson, C. J. Aldén, and N. Sundin, "Autonomous transport: transforming logistics through driverless intelligent transportation," *Transportation Research Record*, vol. 2672, no. 7, pp. 24-33, 2018.
18. C. Hodges, S. An, H. Rahmani, and M. Bennamoun, "Deep learning for driverless vehicles," in *Handbook of Deep Learning Applications*, Cham: Springer International Publishing, pp. 83-99, 2019.