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A Comprehensive Review on Limitations of Autonomous Driving and Its Impact on Accidents and Collisions

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ABSTRACT The emergence of autonomous driving represents a pivotal milestone in the evolution of the transportation system, integrating seamlessly into the daily lives of individuals due to its array of advantages over conventional vehicles. However, self-driving cars pose numerous challenges contributing to accidents and injuries annually. This paper aims to comprehensively examine the limitations inherent in autonomous driving and their consequential impact on accidents and collisions. Using data from the DMV, NMVCCS, and NHTSA, the paper reveals the key factors behind self-driving car accidents. It delves into prevalent limitations faced by self-driving cars, encompassing issues like adverse weather conditions, susceptibility to hacking, data security concerns, technological efficacy, testing and validation intricacies, information handling, and connectivity glitches. By meticulously analyzing reported accidents involving self-driving cars during the period spanning 2019 to 2022, the research evaluates statistical data pertaining to fatalities and injuries across diverse accident classifications. Additionally, the paper delves into the ethical and regulatory dimensions associated with autonomous driving, accentuating the legal complexities that arise from accidents involving self-driving vehicles. This review assists researchers and professionals by identifying current autonomous driving limitations and offering insights for safer adoption. Addressing these limitations through research can transform transportation systems for the better.

INDEX TERMS Autonomous vehicle, sensor technology, accident analysis, vehicle safety, regulatory aspects, and ethical considerations.

I. INTRODUCTION

In recent years, self-driving technology has become one of the most researched topics in the automotive industry. With its potential to revolutionize transportation, the technology has been met with both excitement and skepticism. They offer many benefits, such as reducing human error and increasing traffic efficiency [1]. Autonomous vehicles (AV) can also help people with hearing and vision impairments and the elderly become more independent by providing them with a means of transportation without having to drive themselves [2], [3], [4].

In the early days of self-driving technology, people were quick to embrace it due to its usability, comfort, and efficiency over conventional vehicles. Self-driving cars promised to make our lives easier, reduce accidents caused by human error, and decrease traffic congestion [1]. As a result, early adopters eagerly invested in the technology, and many companies began developing self-driving cars. However, with every innovation comes risk, and there are many risks associated with autonomous vehicles also. As time passed, people began to notice various limitations and challenges in self-driving cars, which started to raise doubts on their vehicle's autonomous driving capabilities. Since there are two sides to a coin, it is good to be aware of the disadvantages of autonomous vehicles too. One of the main limitations of self-driving technology is its inability to operate effectively in all weather and road conditions [5], [6]. For instance, self-driving cars may have difficulty navigating through heavy rain or snow, which can affect the car's sensors and cameras, leading to accidents. Moreover, self-driving cars may have a harder time detecting road hazards such as potholes and construction sites, which can cause the car to malfunction or even crash. The current technology needs to improve to recognize objects in a chaotic city environment. Data protection and privacy are also concerns with self-driving technology [7], [8], [9]. A concerning issue with self-driving cars is their susceptibility to cyber-attacks [10], [11]. Since they rely on computer systems and software to operate, they can be vulnerable to hacking and other security breaches. Hackers could potentially take control of self-driving cars, putting passengers' lives at risk [12], [13]. Due to these various limitations and security issues, people's trust in self-driving cars has decreased significantly. While self-driving technology promises to revolutionize transportation, it is essential to address these challenges and improve the technology's safety and reliability before it becomes widely adopted. In conclusion, the early adoption of self-driving-based cars was fueled by their usability, comfort, and efficiency over conventional vehicles. However, as people notice various limitations and challenges in self-driving cars, their trustworthiness in autonomous driving capabilities has been reduced. To ensure the widespread acceptance of self-driving technology, it is crucial to address these challenges and improve the technology's safety and reliability.

Autonomous vehicles will have to learn how to choose the least harmful option among multiple bad ones, just like humans often do when they face only undesirable choices. The deployment of autonomous vehicles is a daunting task due to the cost associated with these vehicles and their implementation. It may take governments sufficient time to arrange the infrastructure for autonomous vehicles to perform optimally [14], [15], [16]. For autonomous vehicles to be accepted socially and legally, there has to be a reliable safety net for humans to rely on [17], [18]. The most worrying of these limitations, nevertheless, is the danger of accidents resulting from autonomous vehicles. Accidents could result in death or severe injuries, or they could be narrowly avoided; regardless, we need to examine the causes of these unfortunate events. Autonomous vehicles operate on automation, letting humans relax and enjoy the ride while the car takes care of the driving. However, this can be risky and even deadly when the car fails to drive properly. There have been several cases when automation has turned out to be a curse rather than a blessing. As we go through this paper, we will analyze the causes behind such unfortunate incidents. We need to consider how to solve the problem of unreliable autonomous driving. In this paper, we aim to figure out the limitations of autonomous driving to facilitate future research in the right direction. We will go through statistics and various incidents of unfortunate accidents to get an overview of the current scenario. Also, We will focus on the major types of accidents and causes of these accidents. In conventional cars, most accidents are caused by speeding, driving under the influence, driving while distracted, tiredness, driving aggressively, and violating traffic laws. The NMVCCS database lists five categories of driver-related factors that contribute to crashes. These are the human mistakes involved in crashes caused by autonomous vehicles [19]. In many cases, the driver is not always responsible. Problems in sensing and perceiving can lead to hazards being overlooked. In many accidents, pedestrians are more responsible [20]. Thus, it indicates that there are many complications and challenges in the development of autonomous driving.

After looking at the limitations of autonomous driving, we need to understand the statistics on the number of deaths and injuries caused by it, which illustrate the significance and reality of self-driving cars' capabilities. National Highway Traffic Safety Administration (NHTSA) performed various analyzes on such cases and presented reports from time to time. Be it Tesla, Google's self-driving car, or Waymo's autonomous vehicle, there have been instances of car crashes. In February 2016, a self-driving car from Google was involved in a collision [21]. Similarly, in another incident, Uber's autonomous vehicles had 37 accidents [22]. According to the crash rate calculation procedure of the US Department of Transportation, federal highway administration [23], autonomous vehicles have a crash rate of 9.1 over a million miles traveled; in contrast, conventional vehicles have a crash rate of 4.1. We understand that there is a lot of room for improvement as we focus on enhancing technological efficiency to prevent accidents. The purpose of this paper is to review the literature on the causes and consequences of on-road accidents and deaths due to the limitations of autonomous driving. We examine the factors responsible for the occurrence and severity of such accidents, such as technical failures, human errors, environmental conditions, and ethical dilemmas. We identify the main challenges and gaps in the existing research and practice and propose some directions for future work. In the past, there have been few studies that have discussed these issues. They have been summarized in Table 1. In Table 1, for each of these works, we mention how our survey overcomes the limitations faced by those works. The main contributions of this review are as follows:

- We present an overview of the existing status of autonomous driving technology and explore its various limitations, which are key factors responsible for accidents involving autonomous vehicles.
- We review ethics and regulatory considerations for self-driving cars.
- We discuss the present challenges in AV and provide future research directions.

II. STRUCTURE OF SURVEY

This paper is structured as follows: Section I introduces the concept of autonomous driving and its challenges. This section discusses how the current limitations of self-driving cars affect road safety and cause accidents and collisions. Section II outlines the scope and organization of this paper,

TABLE 1. **Related Surveys on Limitations and Challenges of Autonomous Driving**

Sr. No	Year	Author	Contribution of the survey	Limitations of the survey	How this survey overcomes these limitations
1.	2010	Campbell, Mark, *et al.* [25]	Overview of the Difficulties and Opportunities of Autonomous Driving in Urban Environments	Only based on the experiences of the 2007 DARPA Urban Challenge. It was limited to urban environments.	Covers more diverse environments and not limited to urban environment.
2.	2015	Cunningham, Mitchell, and Michael A. Regan. [26]	Survey of Human Factors Issues and Research in Autonomous Vehicles	Focused on awareness of the transition from manually driven to self-driving vehicles.	Considers various non-human factors in addition to a more detailed study on the psychology of drivers and pedestrians to autonomous driving.
4.	2017	Barabas, Istvan, *et al.* [27]	Overview of Current Challenges in Autonomous Driving	Limited and only focuses on the levels of driving automation, without covering any challenges in depth.	Provides an in-depth exploration of the challenges that autonomous driving is currently facing.
5.	2018	Favarò, Francesca, *et al.* [28]	Review of Trends, Triggers, and Regulatory Limitations of Autonomous Vehicles' Disengagements	Limited to California only.	Gives a broader aspect covering worldwide, national-wise ethical and regulatory considerations.
6.	2019	Ro, Yuna, and Youngwook Ha [29]	An Overview of Consumer Expectations for Autonomous Cars	Only considers the expectations of Korean consumers for autonomous cars.	Takes into account both the expectations and the trustworthiness of consumers for autonomous cars, using data from different countries.
7.	2023	This Survey	An Overview on Limitations of autonomous Driving and its Impact on Accidents and Collisions	A detailed mathematical analysis of accident avoidance mechanisms is beyond the scope of this paper.	-

which covers various aspects of autonomous driving research. Section III provides a brief background on the development and evolution of autonomous driving technology as well as covers the reviews of the existing autonomous driving cars in the market, including their manufacturers, models, features and level of autonomy. Section IV analyzes the drawbacks and shortcomings of the current autonomous vehicles, such as their inability to operate in adverse weather conditions, their inability to handle unexpected situations, and their dependence on external infrastructure. Section V examines the cases of accidents and collisions caused by the flaws and failures of self-driving cars. Also, it provides the statistics of fatalities and injuries resulting from autonomous driving incidents. Section VI discusses the ethical issues and dilemmas as well as Regulatory and Litigation Considerations for self-driving cars. involved in autonomous driving technology. Section VII identifies the current challenges and open problems that need to be solved to improve the safety and reliability of autonomous driving technology. This section also suggests some future research directions that could overcome the limitations of autonomous driving technology. Section VIII concludes the paper with a summary of our main findings and contributions to the field of autonomous driving technology. Fig. 1 illustrates the overview of the paper's structure, showing the different sections and how they are connected.

III. BACKGROUND

Self-driving cars were initially met with excitement and enthusiasm as people saw them as a revolutionary step in transportation technology. These vehicles were designed to be efficient, comfortable, and safe. The promise of sitting back and relaxing while the car navigated through traffic was a dream come true for many. However, as time passed, people began to notice various limitations and challenges in self-driving cars. One of the primary concerns was the reliability of the technology. Although the autonomous driving capabilities of self-driving cars were impressive, there were instances where the technology failed, leading to accidents and even fatalities. Another significant limitation of self-driving cars is the lack of human interaction [29], [30], [31], [32]. People missed the ability to drive and control their vehicles, and the lack of control made them feel uncomfortable and vulnerable. Additionally, many drivers felt that self-driving cars lacked the emotional intelligence and intuition of human drivers, which made them less capable of handling complex situations on the road. Furthermore, security concerns also played a significant role in reducing people's trustworthiness in self-driving cars. With cybercrime on the rise, many people are worried about hackers accessing their vehicle systems and taking control of their cars [12], [13], [33], [34]. The potential for accidents caused by a hacker was a real concern, and it made people hesitant to embrace this new technology. Fig. 2 illustrates human concerns and doubts regarding the trustworthiness of self-driving cars due to various present limitations. Yet self-driving cars have the power to transform transportation, and it is crucial to address these concerns to regain people's trust and ensure the safety and reliability of autonomous driving technology [35]. As mentioned above, Table 1 summarizes some of the major survey and review papers that have addressed the limitations and challenges of autonomous driving in recent years. Currently, self-driving cars use either Lidar or Camera technology or both [36], [37]. Depending on the technology, the cars have different self-driving features. Both camera and Lidar technology are robust and offer unique benefits [38]. While image sensors and camera technologies are more sophisticated and frequently

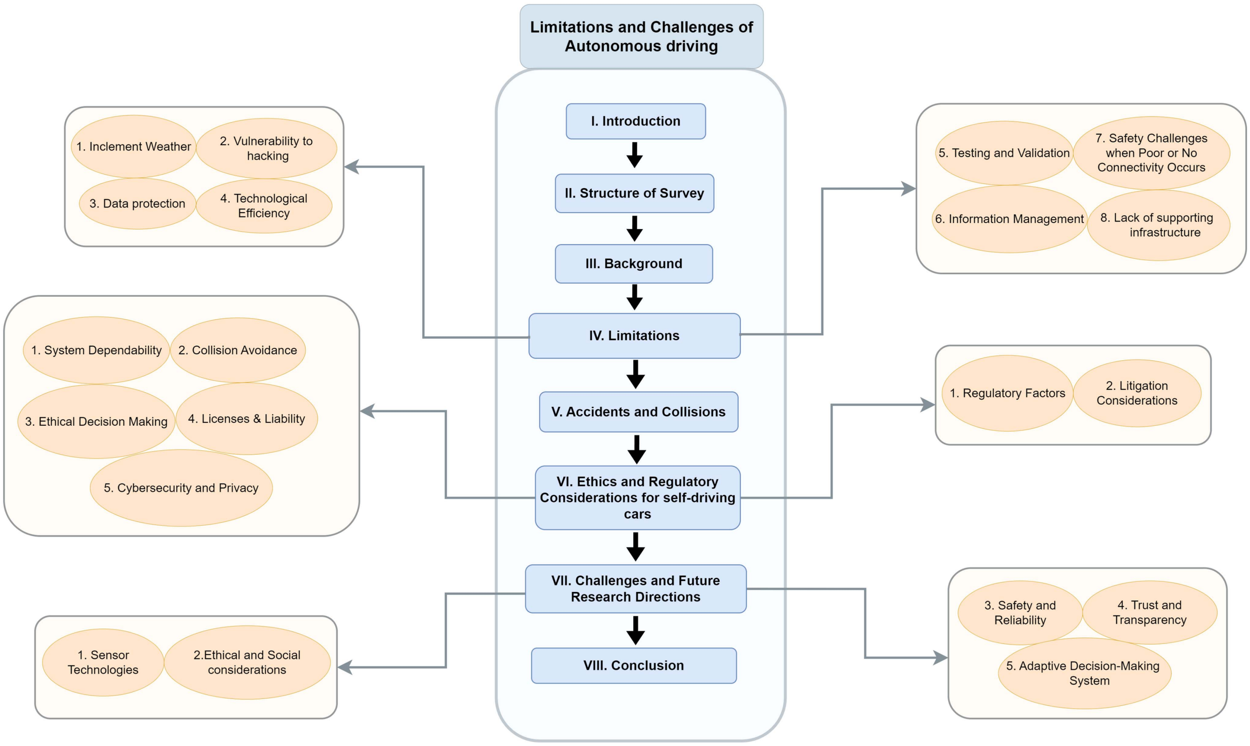

FIGURE 1. **Structure of our Survey.**

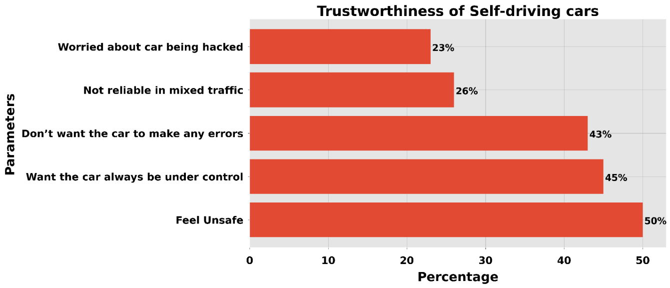

FIGURE 2. **Trustworthiness of Self-driving cars [52], [53].**

used, Lidar can map entire streetscapes with millimeter accuracy [39], [40]. Lidar struggles with visual identification, a task that cameras are far better at handling. Lidar needs more data processing in the system to build images and recognize things. Although more reliable as a visioning technology, cameras lack Lidar's range detection capability. A further benefit of cameras is their lower cost compared to Lidar systems, which lowers the cost of self-driving cars overall and for end users. Since video cameras are already on the market, they are also easier to implement.

Over the past few years, there has been tremendous research and development dedicated to developing autonomous driving technologies. According to Statista [41], there were approximately 31.4 million autonomous vehicles worldwide in 2019 out of the 1.4 billion overall car market. By 2024, this number is expected to rise to approximately 54.2 million. In this section, we will review some of the self-driving cars that are currently on the market. From luxury vehicles to more affordable models, there are several autonomous driving cars present in the market. Several companies and manufacturers are working on building autonomous driving cars. These companies include Tesla, Waymo, General Motors, Mercedes-Benz, Ford, BMW, Volkswagen, and Nissan. The following list includes some of the most well-known autonomous vehicles:

1) *Tesla Model S [42], [43], [44], [45]:* This luxury sedan features level two automation, which contains cruise control that is adaptive, warning on lane departure, and self-parking facilities.
2) *Audi A8 [46]:* The Audi A8 is a luxury sedan with level three automation, which offers a high level of driver-assist technology, but not full autonomy. It has a system called Traffic Jam Pilot that can control steering, braking, and acceleration on divided highways. However, the Audi 8 cannot drive itself in any situation and requires human oversight and input.
3) *Nissan Leaf [47], [48]:* This affordable electric vehicle features level two automation, which involves adaptive cruise control and lane departure warning facilities.
4) *BMW 7 Series [49], [50]:* This luxury sedan features level two automation, which integrates adaptive cruise control and self-parking facilities.
5) *Waymo One [51]:* This is a self-driving ride-hailing service that uses fully autonomous vehicles to transport passengers in selected areas of Arizona.

TABLE 2. Present Autonomous Driving Cars in the Market

Manufacturer	Model	Manufacturer	Model
Tesla	Tesla Model S, X, 3, Y [43–46]	Waymo	Waymo One [52]
Audi	Audi A8 [47]	General Motors	Super Cruise [79]
Mercedes-Benz	Mercedes-Benz EQS, S-Class [80]	Ford	Ford F-150, Mustang Mach-E [81]
BMW	BMW X7 [82]	Volkswagen	Volkswagen ID.4 [83]
Nissan	Nissan Ariya, Rogue, Leaf [48, 49]	Toyota	Lexus LS, Toyota Mirai [84]

Table 2 lists some of the most well-known current self-driving cars in the market, along with their manufacturers and car models. Autonomous driving cars still face many challenges that hinder their widespread adoption, despite their remarkable advances in recent years. All the self-driving cars currently on the market are SAE Level two autonomous. Despite various drawbacks and challenges in present cars, we're still waiting for SAE Level three and higher-level autonomous vehicles, which will be further explored and analyzed in upcoming sections.

IV. LIMITATIONS

While autonomous driving has many potential benefits such as improving safety, convenience, and mobility, it also faces many challenges and limitations that may hinder its development and adoption. Some of these limitations can be overcome through better technology while others are inevitable. For example, environmental effects, susceptibility to hacking, data privacy concerns, and technology efficiency are some of the major limitations of autonomous driving. This section will explore some of these limitations and discuss possible solutions and recommendations.

A. INCLEMENT WEATHER

Perception is the initial stage in the computation process that enables a self-driving car to function safely. However, severe weather conditions can impair the autonomous driving perception system and prevent it from detecting and recognizing on-road objects and sign boards. This can cause self-driving cars to make wrong decisions or fail to make decisions in such situations [5], [6], [54], [55], [56]. In other words, bad weather can hinder autonomous driving capabilities. Severe weather conditions include natural phenomena affecting visibility, such as sleet, fog, rain, snow, and blizzards. Fog, sleet, snow, and rain all reduce the vision and perception of self-driving cars [57], [58]. Limited visibility can make it harder for drivers to read road signs and follow standard driving guidelines.

Adverse weather conditions present significant challenges for autonomous driving cars, affecting their performance in areas such as sensor degradation, map accuracy, localization errors, and decision-making. The research article [59] explores the impact of various weather conditions on sensor performance. An analysis conducted by Zhang, Yuxiao, et al. [59] reveals that the risk of accidents increases by 70% in rainy conditions compared to normal environmental conditions. Moreover, national statistics from the United States indicate that each year, more than 30,000 vehicle crashes occur on snowy or icy roads or during snowfall or sleet. Further evidence supporting the influence of adverse weather conditions on road safety is provided by the U.S. Department of Transportation [60]. Their records indicate that an average of 5,891,000 vehicle crashes occur annually, with approximately 1,235,000 of these incidents attributed to adverse weather conditions, such as snow, rain, fog, and severe wind [60]. Wet pavement and rainy conditions are identified as the most common causes of weather-related accidents, accounting for 76% and 46% of crashes, respectively [60].

Moreover, bad weather makes driving more dangerous. In places that experience extreme snowfall, lane markings often disappear due to the heavy snowing. Likewise, a heavy downpour can cause low visibility. These limitations result from sensors that struggle to distinguish lane lines, road signs, and nearby objects in heavy rain. To reduce our dependence on the weather, we require better sensors that can manage difficult situations. Manufacturers need to make the perception model more adaptable so that it can function in all weather conditions or not be affected by its perception system due to weather. To achieve this, they must train the AI models with diverse weather condition footage and improve object detection and recognition models that can operate in all weather conditions. Additionally, most automated vehicles currently combine radar images with a laser-based system called light detection and ranging, also known as Lidar. Such a sensor takes detailed 3D images of the area around autonomous vehicles. The technology is quite effective and produces high-quality images on clear days. However, its major drawback is that it cannot see in foggy situations when navigating through rain and snow or travelling through dusty areas. Another area for improvement with Lidar is that they are expensive, which increases self-driving car costs and makes them less affordable to customers. Radar for imaging captures only a partial picture of the road surrounding a vehicle [54].

B. VULNERABILITY TO HACKING

A nightmare scenario for many people is losing control of their self-driving vehicle to a remote hacker. Autonomous vehicles depend on technology to operate and are vulnerable to potential cyberattacks. Hackers target the safety-critical functions of artificial intelligence systems. In some cases, hackers painted the road and tricked an AV into crashing into a navigation or stop sign [61]. Some standard hacking methods for self-driving cars are remote access and direct tampering. Remote access can be done through the Internet or Bluetooth [62]. Direct tampering involves interfering with the sensors, installing a specialized device, or compromising the supply chain to alter the vehicle's construction, such as adding a backdoor [63], [64], [65], [66]. In 2019, white hat hackers Richard Zhu and Amat Cama [67] were successful in hacking a Tesla Model 3. They took over the vehicle quickly and safely in a controlled environment. Several other incidents have reinforced the argument that self-driving cars are vulnerable to hacking. For example, in 2010, a disgruntled former employee accessed a corporate computer in Austin, Texas, and disabled more than 100 vehicles while making their horns blare uncontrollably. Security experts also found flaws in General Motors' OnStar system in 2010 that could allow hackers to take over the vehicle completely. In June 2016, the BBC [67] reported a problem with the Mitsubishi Outlander hybrid car. According to them, security bugs have been discovered by researchers in its onboard Wi-Fi. These bugs can allow hackers to turn off the alarm on the car. This very loophole could provide thieves to break into a vehicle and indulge in automobile theft. In 2014, Kaspersky Labs published a report [68] analyzing BMW's ConnectedDrive system. The report claims that connected cars can potentially expose drivers to threats in the world of automation. Hackers could figure out and steal the passwords of connected car owners. This would reveal the vehicle's location and enable the doors to be unlocked remotely. New risks that never existed before pose a threat to privacy, which is essential for today's motorists.

According to a report [69], the vehicle industry has seen a significant rise in cyberattacks on vehicles. The report reveals 900 reported cyberattacks on cars in the past decade. The frequency of attacks has increased by 225% from 2018 to 2021, with 85% of attacks carried out remotely. Around 40% of attacks targeted back-end servers, and 54.1% of attacks in 2021 were attributed to "Black Hat" actors. The top three attack categories were data/privacy breaches (38%), car theft/break-ins (27%), and control systems manipulation (20%). Keyless entry and key fob attacks accounted for 50% of vehicle thefts. These findings underscore the urgent need for robust cybersecurity measures in the automotive industry to protect against cyber threats and ensure the safety and privacy of drivers and passengers [70], [71].

C. DATA PROTECTION

Connected and autonomous vehicles produce and share a large amount of data with other vehicles and other transportation system components [72], [73], [74]. One autonomous-driving car generates a substantial amount of data. An autonomous car is estimated to generate over 300 TB (terabytes) of data per year [75]. The vast amount of data generated by autonomous vehicles underscores the need for robust data storage and processing capabilities to handle the immense data flow and support the advanced algorithms and systems used in autonomous driving technologies. Therefore, data protection law is especially important in connected and autonomous mobility. However, only some data produced is essential for enabling connected and autonomous driving. For instance, data that drivers or users share for convenience or enjoyment is not essential. Data for Car-to-X services, predictive monitoring and analysis, and eCall systems are gathered along with automobile functioning values such as exhaust, average speed, fault memory, and number of failures, and technical data such as sensor data [76]. A lot of this data will fall under the category of personal information, which means that connected and autonomous vehicles will have to comply with the General Data Protection Regulation (GDPR) [77] and, in the future, with regulations like the ePrivacy Regulation (which is still awaiting approval).

D. TECHNOLOGICAL EFFICIENCY

Although technology has made significant progress, the widespread use of level five autonomous vehicles requires both their capability to report to all situations and the reliability of their software. The car's artificial intelligence algorithms for navigation and environment recognition still struggle to work appropriately in crowded urban areas. [84]. These algorithms rely on various sensors, such as cameras, radars, and Lidars, to perceive the surrounding environment and make decisions. However, each sensor has its limitations and challenges. Cameras can suffer from poor lighting and obstructions, radars can have low resolution and interference challenges, and Lidars can be costly and rare. As mentioned earlier, Lidar can help us cope with bad weather better than cameras or radars because it uses laser beams to measure distances and create 3D maps of the environment [85]. However, Lidar systems are rarely used in mass production because of their high cost and limited availability. Therefore, finding a way to decrease the cost and increase the supply of Lidar systems is crucial for advancing the development and deployment of level five autonomous vehicles.

E. TESTING AND VALIDATION

The traditional automobile industry is well aware that autonomous vehicles face different challenges when they operate in an open environment with millions of other vehicles than when they work in controlled settings with a few vehicles and experience safety drivers. The technology behind AVs has demonstrated its readiness for wide-scale use after several successful demonstrations and hundreds of thousands of miles of driving. However, how much testing alone can guarantee adequate safety is uncertain. Engineers are working on the testing platform, but how much more and how to measure the safety level of the resulting vehicles are also unclear. AVs should only be considered safe if they can comply with ISO 26262 or another relevant and reputable software safety standard [86]. Testing and validation are major limitations for AVs due to various reasons [87]. One reason is the impossibility of exhaustive testing, which makes it hard to verify the safety of AVs on real roads. The testing environment must accurately reflect real-world conditions and account for the possibility of rare but catastrophic failures due to software bugs or malfunctions. Another reason is the uncertainty and randomness involved in stochastic and non-deterministic algorithms, which also affect the testing process. A third reason is the difficulty of validating machine learning systems, which are based on inductive reasoning. To test thoroughly, it would be necessary to validate the assumption that rare and unpredictable data (“black swans”) would occur at random and independent rates and to use appropriately sized data sets for testing. This could be done with enough resources, but since new black swans will always emerge, it would also be necessary to estimate the probability of system failures for a large number of operating scenarios and input values to ensure a reasonably low risk of disasters.

F. INFORMATION MANAGEMENT

Self-driving cars rely on various technologies, but the most prominent is the Internet of Things (IoT), which enables data transfer over a network without human interaction. To operate efficiently, an autonomous vehicle needs effective information management for service delivery. This requires the interconnections of vehicles, also known as the Internet of Vehicles (IoV), which follows the IoT paradigms and makes intelligent judgments [88], [89]. However, one of the main challenges is the need for more sensors and software in an AV, which connects to the IoV and addresses different aspects of autonomous driving. Although the IoV facilitates the interconnection of AVs, it still has many issues that need to be resolved to facilitate safety in autonomous transportation. One of the critical issues is latency. To ensure road safety, information has to be shared among vehicles at a high data rate. The current technologies used by AVs are DSRC (Dedicated Short Range Communications Service) and 4G-cellular LTE [54]. However, these have limitations in time-sensitive situations, so the 5 G cellular network is a potential solution [90], [91], [92]. To meet the demands of advanced services, 5 G Vehicular Cloud Computing (VCC) [93] systems use various network access technologies [93]. This technology is essential for Industry 4.0. However, an alternative internet network called tactile internet (TI) [94], [95] has emerged as a high-speed and low-power LTE system that also offers wide coverage, secure and reliable end-to-end communication, and ultra-low latency of less than a millisecond. This advanced technology poses a new challenge for researchers, such as the deployment of TI in AV [94], [96]. This is still an open question that requires further investigation. Another issue is the heterogeneity of communication technologies [97], [98]. Wireless technology is the backbone of autonomous vehicles’ communication. A comparison between DSRC and 4G-LTE shows that 4G-LTE is suitable for non-safety applications such as file download, transmission of traffic data, and internet access. At the same time, DSRC is preferred for safety applications such as collision avoidance. The choice between DSRC or 5 G would compromise the vehicle’s ability to save lives [99], [100]. This problem affects the system’s interoperability, which is crucial for AV and needs to be solved. Data generation and Big Data management are other concerns. According to the Analysis of the author [101], cameras generate 20-40 MB of data per second, RADAR and SONAR generate 10-100 KB per second, GPS generates 50 KB per second, and Lidar generates 70-100 MB per second. Some of the research papers explored the difficulties that Big Data presents for IoV [102], [103]. The V2V link’s performance is affected by interference from tall buildings, overhead bridges, and changing traffic conditions. The communication between the fixed and mobile elements of the network topology, that is, the infrastructure and vehicles respectively is often disrupted due to the fast moving cars and the restricted coverage of wireless technology. The spectrum allocated for DSRC becomes insufficient when media-rich applications of AVs are used in high densities. High network bandwidth is required to handle all the data produced by sensors and other devices. AVs use maps that are different from those obtained by GPS functions on mobile devices to find the best route and avoid blocked or congested roads. These maps are more accurate in terms of lane width, curb height, and distance from pedestrians. They require large memory and powerful processing for storage. Several attempts have been directed towards obtaining such accurate maps using odometry and 3D Lidar sensors. However, the industry faces challenges due to the dynamic environment and road conditions. This problem can be solved by collecting data from onboard and on-road sources based on IoV data, that is, by using Big data to the rescue. Onboard data monitors vehicle status. On-road data refers to events that happen on the road and can be obtained from onboard or other IoT devices.

G. SAFETY CHALLENGES WHEN POOR OR NO CONNECTIVITY OCCURS

Even if autonomous vehicles can perceive and sense their surroundings flawlessly, they still face safety challenges and cannot avoid all collisions without connectivity [104]. AVs require communication with the infrastructure (I2V) or other vehicles (V2V) to ensure absolute safety. However, three main challenges hinder AVs from achieving this goal: occlusions [105], traffic rule violations, and behavior prediction uncertainty [104]. These challenges create information gaps that increase the risk of collisions. AVs have to estimate the position and behavior of other vehicles and pedestrians in their surroundings, but this may not be sufficient. An alternative approach to ensuring safety is the Responsibility Sensitive Safety (RSS) framework [106], [107], which imposes strict constraints on the actions of AVs [104]. However, this approach may compromise traffic efficiency and throughput. The author of [104] listed out some of these limitations could be overcome by using I2V and V2V communication. For instance, I2V communication could help AVs detect each other in time when occlusions or traffic violations occur at intersections [108], [109], [110], [111]. Likewise, V2V communication could enable AVs to coordinate their lane changes and avoid potential hazards [112], [113]. However, connectivity also has its drawbacks, such as high costs and technical challenges.

H. LACK OF SUPPORTING INFRASTRUCTURE

AVs need supporting infrastructure to work properly and sustainably. However, many accidents involving Tesla and Uber vehicles have happened because of a lack of contextual cues. Therefore, it is important to examine the challenges for AVs in rural and urban areas [24], [114], [115], [116], [117]. Connected and autonomous vehicles must deal with the fact that they will face difficulties in rural areas. A study [115] investigated the positioning capability of autonomous vehicles in the U.K. and found that rural locations had the highest rates of traffic deaths, poor public transportation, and low levels of digital access. Compared to urban areas, which still need some background support for AVs, rural areas seem like a far-off goal. Some key factors that affect the suitability of AVs are network connectivity, signage, and road infrastructure quality and consistency. Another study [118] indicates that AV adoption in rural areas could be impeded by transportation infrastructure.

Transport infrastructure needs to change, but it is a slow and tedious process. However, it is essential for AVs to become common and dominant on the roads. Rural communities must accept that they may need more funding to create an infrastructure suitable for AVs. This is especially true for unincorporated counties with low population densities. Moreover, rural areas need assistance to comply with new federal road regulations due to the widespread use of driverless vehicles. According to a Congressional Research Service Report [87], current AVs depend on pavement markings and signs to navigate traffic and lanes, requiring both major and minor roads to be compatible with conventional vehicles. This will require consistency in applying traffic control devices and voluntary state cooperation with the Federal Highway Administration (FHWA). Dirt and gravel roads, which are common in rural areas with insufficient funding for road repaving, could also pose problems for AVs. They lack clear pavement markings and make it harder for cameras to detect potholes or the edges of the road. After examining the current infrastructure challenges in rural areas, it is only fair also to consider the difficulties in urban and suburban areas. Another study [119] shows that platooning AVs could boost the road infrastructure capacity by 50%, which shows that the current road infrastructure has a lot of room for improvement to support AVs. Studies show that designs of bridges and the standards associated with them need to be revised to handle the changed loading patterns and increased loads caused by the platoons of autonomous goods vehicles [120], [121]. An autonomous fleet will likely move faster and with shorter gaps than connected vehicles, regardless of the type of vehicle. This could result in higher traffic flow and heavier loads on the pavement of the roads. The impact on the loading structure would be more significant on highways with a much higher proportion of heavy vehicles. Roadside features such as gas stations, parking lots, and transfer points need innovative designs to support AV-enabled mobility systems. A serious problem is the lack of guidelines for enabling this infrastructure, such as the number of sensing devices needed to provide a smooth and accurate information process, especially in complicated situations like on highways having multiple lanes or when several users are a part of the system.

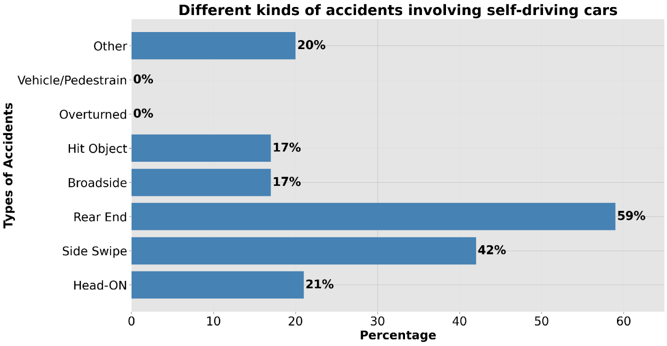

FIGURE 3. Different kinds of accidents involving self-driving cars [122], [123].

V. ACCIDENTS AND COLLISIONS

The California Department of Motor Vehicles (DMV) manages the Autonomous Vehicles Program [122], [123], which grants permits to manufacturers who test and deploy self-driving cars on public roads in California. According to the DMV [122], [123], manufacturers who test self-driving cars must report any crashes that cause damage to property or people within ten days. The DMV has received 581 reports of such crashes as of April 14, 2023. The reports contain various information such as the car model and year, the date, time, and location of the crash, the vehicle's status and mode, the parties involved in the crash, the extent of damage and injury, and the environmental conditions. A crash can involve different types of accidents, depending on the area affected by the car crash or the movement of the car. These include accidents such as head-on, side-swipe, rear-end, broadside collisions, hitting an object, overturning, vehicle/pedestrian, and others. Fig. 3 shows the various types of accidents that involve self-driving cars as per the DMV reports [122], [123]. We can examine those types of accidents in more detail as follows:

1) *Head-on:* Two vehicles crashing into each other frontally is a head-on collision. These collisions can happen when two cars are moving in opposite directions and hit each other directly. The force of these collisions is very great because the two cars crash head-on. These collisions are also very perilous and can result in many deaths on the roads, even if the car bonnets may fold to mitigate some of the impacts. A car can also experience a head-on collision when it rams into a telephone pole or a road barrier frontally.
2) *Side-swipe:* When two cars moving in the same direction hit each other, with the left side of one striking the right of the other, it is called a side-swipe collision. These collisions often occur because one of the two cars leaves its lane when unsafe. Therefore, side-swipe collisions are signs of faulty lane-changing mechanisms in autonomous vehicles.
3) *Rear End:* A rear-end collision is when a driver hits the car in front of them from the back. This often happens when cars are stopped or moving slowly because of a sign, a light, or traffic. Sometimes rear-end collisions

can happen on fast roads like highways. Usually, only two cars are involved in a rear-end collision. But sometimes they can cause other cars to crash into each other too [124].

4) *Broadside collisions:* A broadside collision occurs when one car's front end slams into another car's side at high speed. This type of crash is very serious because there is little space or protection between the person in the hit car and the impact point. Unlike a head-on collision or a rear-end collision that causes the person to move back and forth, a broadside collision makes the person swing from side to side.
5) *Hit Object:* When a vehicle crashes into something that is either moving or not, it is called a collision. The thing that the vehicle hits could be anything from a signpost to a telephone pole to a road divider. Both the vehicle and the thing can get damaged by the collision. How much damage they get depends on how big, heavy, and strong they are. For self-driving cars, this means that their technology for seeing and avoiding things is not working well.
6) *Overturned:* An overturned vehicle has flipped over because of a collision. This usually happens when the vehicle is out of control. Two types of accidents can make a vehicle overturn: untripped and tripped rollovers. According to the National Highway Safety Administration (NHTSA), most rollovers (95%) are tripped [125], which means they are caused by hitting something outside. This can happen when a vehicle slides off the road and sideways and then hits something or digs into the ground. It can also happen when a vehicle crashes into another one. Untripped rollovers are less common. They happen when the forces of gravity, the spinning force, and the tire forces pull in different directions. Untripped rollovers are more likely at high speeds and in heavy vehicles like trucks and vans.
7) *Vehicle/Pedestrian:*- When an AV collides with another vehicle or a person, the other party may be moving or stationary. Detecting pedestrians is hard for AVs today, especially when they are on bikes, or the road is crowded. But AVs are not always at fault for these crashes; sometimes pedestrians cause them by being careless or breaking traffic rules.

Autonomous driving cars are more efficient, intelligent, and competent than conventional cars. They use self-driving capabilities to navigate the road. However, they are not risk-free. There have been many cases of accidents involving autonomous driving cars. Accidents and collisions can occur due to various factors, including technical failures, environmental conditions, and human errors. According to a 2016 National Highway Traffic Safety Agency (NHTSA) study, human error causes between 94% and 96% of all automobile accidents [126]. However, how much closer are we to preventing accidents if we eliminate the "human error" factor? Are self-driving cars immune to accidents? Can we avoid "human mistakes" when dealing with self-driving cars? While autonomous driving technology has the scope to limit accidents caused by human error, such as distracted driving, it can also introduce new risks. For example, some autonomous vehicle accidents have been attributed to technical malfunctions, such as faulty sensors or software glitches. Other accidents have been caused by external factors such as poor weather conditions, road construction, or unexpected obstacles. It is important to note that accidents involving autonomous vehicles are relatively rare compared to the number of accidents attributed to human drivers. However, each incident is closely scrutinized and can significantly impact public perception and the future development of autonomous driving technology. To address the potential risks associated with autonomous driving, manufacturers are working to improve the reliability and safety of their systems through rigorous testing and development. Additionally, regulatory agencies are developing standards and guidelines to ensure the secure deployment of AVs on public roads.

According to the report of IDTechEx [127], some accidents happen due to the mistake of the human driver in the next car. The next car collides with the autonomous car. They found that 81 incidents where a human driver collided with an autonomously driven vehicle were typical crashes, with most of these collisions being rear-end crashes in stopped or moving traffic. The National Motor Vehicle Crash Causation Survey (NMVCCS) database [128], [129], [130] reveals the main driver-related factors that contribute to crashes. These include: (1) impaired perception, (2) misjudgment of other vehicles' behavior, (3) poor decision-making and violation of traffic rules, (4) incapacitation, and (5) improper and incompetent vehicle control. According to Teoh and Kidd [131], autonomous vehicles tested by Google (now Waymo) had significantly fewer crashes per mile than human-driven vehicles. However, when they did crash, it was usually because of other human drivers who sideswiped or rear-ended them [132]. Therefore, AVs need to be designed to minimize the impact of human errors. Drivers are not the only ones who can cause accidents. Pedestrians can also be responsible for collisions with vehicles. This is especially true in countries where walking and bicycling are common modes of transportation. Some of the factors that contribute to pedestrian-vehicle crashes are: poor judgment, distraction, recklessness, disobeying traffic signals, alcohol impairment and rushing [20].

According to the Society of Automotive Engineers (SAE), there are five driving automation system levels. Currently, level two vehicles are in abundance. Level two AVs can steer, accelerate, and brake independently, but drivers need to pay attention and intervene in emergencies [133]. However, even with advanced technology, there is always a possibility of error that may result in crashes. To enhance the safety of autonomous vehicles, we need to look at the data on crashes and collisions involving them and identify the factors that contributed to them. For example, the latest safety report issued by Tesla claims that human drivers are more prone to making errors than its autopilot. But the data from the National Highway Traffic Safety Administration (NHTSA) does not clearly show whether driver error or technology failure was the main cause of the accidents. Therefore, we need to analyze the data carefully. Some organizations, such as Waymo and Argo AI, communicate with their AVs and detect crashes automatically. Although AVs are still in the testing phase and the number of traffic incidents studied is small, several authors have already examined AV-related traffic accidents [27], [134], [135], [136].

One of the first studies on AV-related traffic accidents analyzed the data from California between September 2014 and November 2015 [134]. The authors of this study investigated 12 traffic collisions involving AVs. Subsequent studies examined specific time periods in California: up to March 2017 [136], and up to July 2017 [27]. According to the California Department of Motor Vehicles, there were 129 vehicle accidents involving AVs until December 2018. Out of these, 62% were rear-end collisions and 21% were sideswipe collisions [137]. Although there is a lack of recent data on this topic, it is worth noting that there were 88 AV accidents involving human drivers in California in 2014 alone. Moreover, of the 62 accidents that occurred while the vehicle was in fully autonomous mode, only one was caused by an AV.

In 2022, vehicles with automated driving systems caused eleven deaths in four months in the United States [138]. There is a worrying growth of incidents involving self-driving technology. In the case of the eleven accidents, all of them involved Tesla vehicles. Remarkably, ten of these accidents were solely detected by the company's software and data-storage chip. However, for these ten accidents, it remains uncertain whether the causes were attributable to the vehicle's performance or the actions of the driver. The eleventh accident occurred on a California freeway in August 2019 and involved a Tesla Model 3 and a Ford pickup car. Several other incidents have also revealed the dangers of self-driving car crashes. For example, in 2021, a Tesla crashed into a Mercedes SUV and a parked police car without slowing down, despite having the Autopilot system on [139]. The driver did not intervene either. In 2019, a pedestrian in Florida was killed by a self-driving Tesla Model S [140]. The database revealed that the car had advanced driver assistance systems activated at the time. The driver of a Tesla died from the impact when the autopilot failed to detect a white tractor-trailer in a fatal accident in the highway in 2016 [141]. In 2016, a collision with a bus marked the first crash of Google's self-driving car, the Lexus SUV, which was minor and injury-free [142]. Two years later, Google's Waymo van was involved in another crash, but it was not in self-driving mode [143].

Pedestrians are as much a part of accidents as the driver or the AV. It is therefore imperative to analyze the accidents involving pedestrians and objects that are outside the AV. The first pedestrian fatality caused by a self-driving car happened on March 18, 2018, when Elaine Herzberg was hit by an Uber test car in Tempe, Arizona [144]. The car, a Volvo XC 90, was driven by Rafaela Vasquez, a 44-year-old e-taxi driver. She was watching The Voice on Hulu on her phone and did not brake until after the car, which was going at 38 miles per hour, struck Herzberg. This was the first time in history that an autonomous vehicle killed a pedestrian. Uber had been testing its self-driving cars on the streets for three months before the incident and had reported 37 collisions [133], [145]. Let us now look at the very recent accidents that made the headlines. Waymo is constantly developing and improving its self-driving technology. Out of the 6.1 million autonomous miles, they have driven, over 65,000 miles were without a human driver, mainly in Phoenix and Arizona. In the 20 months from 2019 to September 2020, Waymo's AVs were involved in 18 accidents and 29 cases of disengagement, where human intervention was needed to avoid a crash. The accidents involved pedestrians, cyclists, and objects [146]. The New York Times reports that Tesla Autopilot and other driver-assist systems are linked to hundreds of crashes [147]. Between July 1st, 2021, and May 15th, 2022, driver assistance and partially self-driving technologies were linked to 392 accidents by NHTSA. Teslas using the Full Self-Driving beta or Autopilot made up 273 or about 70% of these accidents.

Tesla has been a prominent flag-bearer of AVs. With increasing deployment, there are have also been an increased number of accidents. In the past six years, Tesla's autopilot system has been involved in accidents that killed three Tesla drivers. In 2018, a Tesla Model X SUV accelerated and hit a barricade, killing the driver who was engrossed in a video game while the car was in semiautonomous Autopilot mode. Tesla has faced criticism for not having adequate technology to monitor driver alertness [148]. Subaru models [149] were involved in 10 incidents, compared to 90 incidents involving Honda vehicles. Ford, Chevrolet, volkswagen, and Toyota were among the other brands with five or fewer accidents. Out of the 98 collisions with injury reports, there were 11 major injuries. Five of the Tesla accidents resulted in fatalities. Autonomous vehicles have been involved in 130 crashes, including 108 collisions with other vehicles and 11 with "vulnerable" road users [150] such as pedestrians and cyclists. Tesla's Autopilot is once again under scrutiny after a fatal crash. According to KHOU, the Wall Street Journal, and Reuters [151], in 2019 two men died when a Model S hit a tree north of Houston with no driver present in the car. Tesla Autopilot has also been linked to other crashes. For example, on May 12, a Model S crashed in Newport Beach's Mariners Mile neighborhood, killing all three passengers of the EV. The Orange County Register [152] reported that the car hit a curb and construction equipment. In 2018, a Tesla S in Autopilot mode struck a fire engine in Utah [153]. In December 2017, a self-driving Chevy Bolt with the Cruise autonomous driving system hit a motorcycle rider in California. The self-driving car injured the rider when it suddenly changed lanes while on autopilot. The rider collided with the car and fell to the ground. The driver of the autonomous vehicle did not have their hands on the wheel at the time of the crash.

Tesla's competitor Waymo was involved in two traffic collisions in February 2022. In the first one, on February 24th, Waymo was hit by a big truck while trying to yield to an oncoming vehicle on a narrow road [123]. In the second

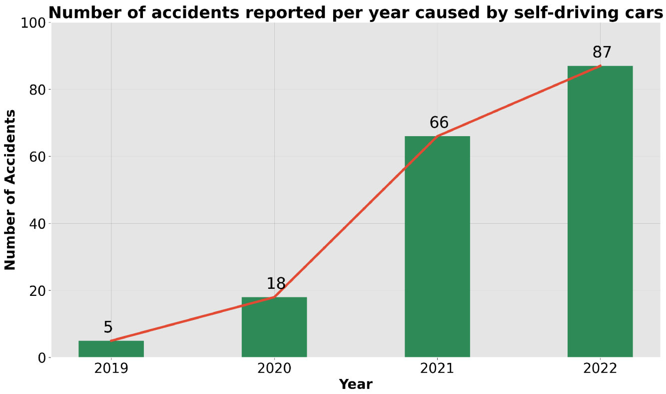

FIGURE 4. Number of accidents reported per year caused by self-driving cars [122], [123].

one, on February 25th, Waymo collided with another vehicle while making a left turn at a road intersection without traffic signals [123]. Google Streetview confirms the absence of traffic signals at the intersection. In another incident, on February 15th, Waymo hit some cardboard debris on the road and damaged its front bumper [122]. Zoox also faced some challenges in February 2022. On February 7th, Zoox was struck by a vehicle while turning right at an intersection [122]. On February 8th and 11th, Zoox reported rear-end collisions with other vehicles [122]. The Mercedes-Benz L3 test vehicle was also rear-ended by another vehicle on February 11th, after it slowed down to avoid a truck that had entered its lane [122]. In his book 'How Safe Is Safe Enough?', he discussed various ethical and practical issues related to AVs. Based on the DMV collision report [122], [123], Fig. 4 presents valuable insights into the number of accidents reported per year related to self-driving cars during the period from 2019 to 2022. The data indicates the following trends,

1) In 2019, there were a total of 5 reported accidents, constituting approximately 2% of the total self-driving car accidents recorded from 2019 to 2022.
2) The year 2020 witnessed a notable increase, with 18 accidents reported, accounting for roughly 10% of the total self-driving car accidents during this period.
3) In 2021, the number of accidents further escalated to 66, representing a significant 37.5% of the total self-driving car accidents recorded in the same time frame.
4) The year 2022 recorded the highest number of accidents, with a total of 87 reported incidents, which accounted for approximately 49% of the total self-driving car accidents spanning from 2019 to 2022. The year 2022 had the highest number of accidents due to the growth of self-driving cars with existing faults and limitations in the vehicle.

In response to accidents and collisions involving autonomous driving, researchers have proposed a range of methods to enhance safety [18]. One prominent approach involves the integration of advanced sensor technologies, such as Lidar, radar, and cameras, to provide comprehensive and real-time environmental perception [154]. These sensors enable vehicles to detect and respond to dynamic surroundings more accurately, minimizing the risk of collisions. Additionally, the use of high-definition mapping and localization systems assists in precise navigation, contributing to safer decision-making by the autonomous vehicle [155]. To improve safety, researchers have also focused on enhancing the robustness of the underlying algorithms and models. This includes developing more sophisticated perception and object recognition algorithms that can accurately identify pedestrians, cyclists, and other vehicles in complex scenarios. Furthermore, advancements in machine learning techniques, like reinforcement learning [156] and neural architecture search, are being explored to optimize decision-making processes and adapt to unforeseen circumstances [157]. Furthermore, several research endeavours delve into specific aspects such as Blind Spot Monitoring [158], [159], Night Vision Capability [160], and dedicated Autonomous Collision Avoidance systems [161]. These initiatives aim to enhance the safety of autonomous driving vehicles by addressing critical factors like reducing collisions and accidents and augmenting the overall decision-making process, ultimately contributing to a safer and more reliable autonomous driving experience.

VI. ETHICS AND REGULATORY CONSIDERATIONS FOR SELF-DRIVING CARS

The ethical concerns surrounding self-driving cars are crucial and intricate, involving various moral dilemmas and social consequences. These ethical considerations involve the analysis and assessment of the ethical values and standards that influence the creation, advancement, and implementation of self-driving cars. Ethical considerations of autonomous vehicles involve system dependability, collision avoidance, ethical decision-making, licenses, liability, cybersecurity, and privacy. The significance of ethical considerations regarding self-driving cars lies in their impact on the future security, confidence, adoption, and durability of autonomous vehicles. Fig. 5 represents the ethical considerations of self-driving cars. Following are the five major ethical considerations of self-driving cars,

A. SYSTEM DEPENDABILITY

Many people argue that an AI-driven vehicle can avoid human errors such as fatigue, distraction, or speeding that can lead to accidents. However, the ethical issues of self-driving cars are not about the safety or reliability of the technology itself. Sensor technology already exists to make self-driving vehicles safe. The challenge is to train and fine-tune the driving algorithms properly. The main ethical dilemma is how to program the algorithms to make the best decisions in high-risk situations.

B. COLLISION AVOIDANCE

When faced with an accident, human drivers often react impulsively and emotionally. They do not have the opportunity to reason or plan and do what they feel is right at the moment.

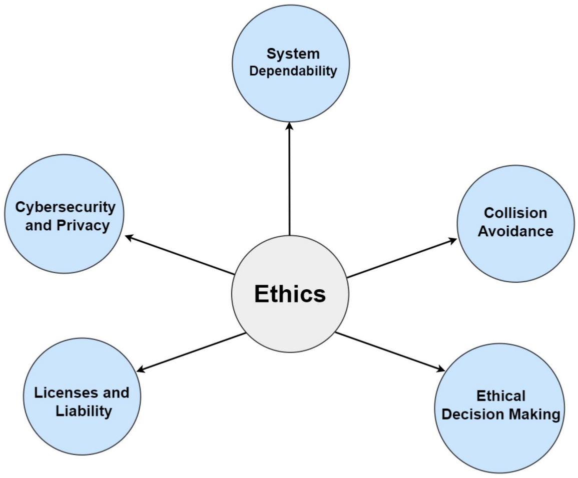

FIGURE 5. Ethical Considerations of Self-Driving Cars.

This can sometimes cause more damage than benefit. However, humans regard this as an unavoidable risk of driving. Self-driving cars are different. They do not have impulses or emotions but have algorithms that guide their actions. These algorithms are designed and trained to avoid dangerous situations as much as possible but cannot prevent all accidents, especially when they share the road with human drivers. This raises a complex ethical question: How should an autonomous vehicle behave in an accident? More specifically, how should it behave in a situation where someone will get hurt no matter what? For example, suppose a self-driving car has to choose between hitting one of two pedestrians or crashing into a wall and injuring its passengers. How does the algorithm decide? Does it protect the passengers first, the pedestrians, or other drivers?

C. ETHICAL DECISION MAKING

Autonomous vehicle manufacturers and developers face a profound dilemma, how should they program their cars to act in a crash situation? Should the government regulate the ethical choices of self-driving cars, or should the driver have the final say? In 2016, a study called "Morality Machine [162]" tried to address this question by creating an online game that asked people from different countries to choose who they would want their autonomous car to save in a collision scenario. The study found that people's preferences varied depending on physical characteristics, but the specific factors differed across regions. For instance, people in Western countries favored saving an older person over a younger one. Some patterns, like preferring females over males, were primarily consistent across cultures. The main implication of this study is that moral values are not universal. Different cultures have different biases about who deserves to be saved in a car accident. However, these biases are not a fair basis for preparing autonomous vehicles. A possible solution is to teach algorithms to maximize the number of lives saved, regardless of physical attributes. The algorithms of self-driving cars should at least be developed in a way to prioritize human life over property or animals, as Germany already decrees.

D. LICENSES & LIABILITY

As the technology of fully self-driving cars advances, many people wonder if driver licenses will become obsolete. This also raises the issue of responsibility and liability on the road. For example, could a child ride to school in an autonomous vehicle without a licensed driver? Who would pay for the damages if an accident happened? Typically, the driver of the car would be accountable. However, one of the biggest myths about AI is that it can make its own decisions, which is different (yet). The AI that drives the car is just software following its instructions—it cannot be blamed for its actions. So who should be held responsible? The car maker? The software engineers? These are ethical questions that need government regulation. Local laws may still require a licensed driver to be present and ready to intervene if necessary. Likewise, liability of the accident will likely depend on the root cause of the crash. If a technical problem or limitation is found to be the cause, then the manufacturer may be liable.

E. CYBERSECURITY AND PRIVACY

The safety of AI in charge of human lives is another crucial issue. Computers controlling something as potentially hazardous as a car may cause more trouble than they prevent. For example, the car could be vulnerable to hacking attacks that could be fatal. This is not a fictional scenario. Hackers have already succeeded in hacking and taking over vehicles remotely, even those not self-driving. With autonomous vehicles, this threat is amplified since the car would have to connect to the internet for software updates and GPS. A hacker could take over someone's car while driving, steal it without their awareness, or unlock their doors from a distance. From an ethical perspective, is this situation safer than the risks of human errors on the road? Considering the increasing cybercrime rates, some may say self-driving cars are too risky to become widespread. Self-driving cars are closer than ever before to going mainstream. Serial ethical concerns are surfacing with the growing deployment of AVs. Questions such as who is responsible in case of an accident, how should the car be programmed to react in unavoidable accidents, how should the car be programmed to react in situations where harm to pedestrians or passengers is unavoidable, how should the car be programmed to react in situations where it must choose between harming pedestrians or passengers, and how should the car be programmed to react in situations where it must choose between harming different groups of pedestrians are all important questions that will shape the fate of self-driving vehicles. There should be some ethics for self-driving cars, which is a set of principles and guidelines that advise on the design and outcomes of self-driving cars while driving and other road operations. Out of six Levels of Vehicle Autonomy, level zero (No Automation), level one (Driver Assistance), level two (Partial Automation), and level three (conditional automation) are considered driver dependent or in which driver's attention is required. Whereas levels four (high automation) and level five (full automation) are considered completely autonomous or driver independent. The main question arises when, In case of an accident caused by a fully autonomous or self-driving car, which is level four and level five cars, who is responsible? The company or body that got approval for the self-driving features used by the vehicle should be legally liable for accidents caused by self-driving vehicles, not the person in the driver's seat. However, this is an evolving area of law and policy that will decide who is responsible when an automated car causes harm to people or property. Some parties that could be responsible for your injuries and accident include other drivers, self-driving car manufacturers, auto part manufacturers, government entities, and drivers of the self-driving car.

Similarly, when anyone drives advanced driver-assistance systems (ADAS) cars (SAE Level zero to Level three) and makes accidents, is the driver considered responsible for it? Many of the most promising ADAS technologies are created to recognize and respond to possible danger more rapidly than a human driver. Depending on the manufacturer, customer should understand that ADAS technique have distinct abilities. It is up to drivers to comprehend the proper utilize of these technique. While some are so productive that drivers may think the car is driving itself, trusting too much on assistive safety aspect can be a deadly fault. ADAS technique are meant to assist drivers minimize their driving risk, not to take over the task of driving. At present, the driver of an automobile is accountable for the action of the car. In most instance, the owner of the car is indirectly accountable for the driver's carelessness. Yet, According to California's product liability laws, if an accident occurs because the ADAS was improperly designed or installed incorrectly during the manufacturing process, the automaker that produced the vehicle could be held responsible for it. However, in an ADAS system, the driver is still engaged in the act of driving and is ultimately responsible for the vehicle's safe operation.

F. REGULATORY FACTORS

Different standards for ADAS technologies have emerged as they are being implemented, especially between the U.S. and the E.U. ADAS technology is expanding globally, even though the requirements and guidlines for its installation vary from place to place. Moreover, it is unclear how these variation in requirements for ADAS affect entire safety. When comparing regulatory variance, one must consider the various approaches to regulation. In the E.U., all vehicles sold must undergo pre-market approval. A set of industrial standards determined by the regulatory authority is what a vehicle needs to meet to get type approval. In contrast, regulations in the U.S. market are based on mandatory self-certification. That is, manufacturers have flexibility in how they deploy the technologies. So far, the U.S. government's direction on these issues has been mostly flexible and technology-neutral, evolving as technology does [163].

There are no federal safety standards for ADAS technology. This gives manufacturers and developers freedom to create new ADAS technology for lower levels of automation, but poses challenges for higher levels of automation that may not fit current standards. The regulators have not been able to keep up with the innovation in this area. Therefore, the regulations for ADAS in the U.S. may differ by the state until federal legislation is passed [164]. The federal government has issued guidance documents to assert its authority and establish the certification of automated vehicles. However, some stakeholders may want more guidance and oversight from the federal government. The safety benefits of some technologies are not fully proven and are still developing.

G. LITIGATION CONSIDERATIONS

Since there are no federal standards for ADAS technology, litigators face both difficulties and possibilities. Litigants cannot use Federal Motor Vehicle Safety Standards (FMVSS) compliance or non-compliance as evidence of defect or non-defect, because FMVSS does not apply to ADAS technology. This also means that some state laws that presume products are not defective if they comply with FMVSS may not cover claims involving ADAS technology. Similarly, state-law tort claims based on the absence or failure of ADAS technology may not face federal preemption defenses from manufacturers. Since ADAS technology is mostly optional and driven by the industry, plaintiffs who claim that a vehicle is defective without ADAS technology can potentially make defects, negligence, and punitive damages arguments based on not following the best practices. On the other hand, manufacturers who use ADAS technology that meets the industry standards should have the advantage of best practices defenses. ADAS technology also creates new questions about causation. For technologies like blind spot warning (BSW) or forward collision warning (FCW) that only warn drivers of possible dangers or crashes but do not control the vehicle, a claim that a crash was caused by the lack or failure of the technology would have to prove that the driver would have acted differently if the technology was working. Moreover, claims of defect with ADAS technology must prove that the ADAS would have worked in the specific crash situation.

VII. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

Self-driving cars encounter some of the following significant challenges:

- Developing algorithms for autonomous driving involves addressing the differences in driving rules between countries, particularly in terms of Left-hand traffic (LHT) and Right-hand traffic (RHT) standards. LHT countries, such as the United Kingdom and Japan, keep traffic on the left side of the road with the steering wheel on the right (RHD) and clockwise roundabouts. On the other hand, RHT countries like the United States and Germany keep traffic on the right side, have the steering wheel on the left (LHD), and use counterclockwise roundabouts. Examples of LHT countries include Australia, India, and Malaysia, while RHT countries include Canada, China, and France. Adapting algorithms to accommodate these variations is essential for the successful implementation of autonomous driving across different countries. Out of 240 countries and territories in the world, 165 use RHT and 75 use LHT. This makes it challenging to design and implement a global algorithm for autonomous driving. Algorithms for tasks such as path planning, estimation, and overtaking have to account for such variation in lane driving. It also makes it hard to establish common guidelines or rules based on a specific side/lane.

- The safety of autonomous driving systems confronts significant hurdles posed by the opacity of deep learning models [165], [166], compounded by factors such as stochastic behaviour, limited interpretability [167], and intricate debugging. The complexity of neural networks makes it challenging to decipher decision-making processes, leading to uncertainty in predicting errors. Inherent randomness introduces unpredictability, undermining the system's consistency, while debugging complexity raises concerns about identifying and rectifying issues promptly. These challenges collectively underscore the need for improved transparency and reliability in deep learning-based autonomous driving to ensure their safe and effective deployment.
- Weather conditions vary across the world, such as snow, sun, rain, dust, etc. These affect the perception and decision-making abilities of self-driving cars in different scenarios. This poses a challenge for creating self-driving cars that can operate and be accepted universally. Additionally, to resolve this issue, the model should be trained on an enormous diverse dataset that consists of sufficient samples from such weather conditions. However, there are not enough realistic datasets for this purpose. If we use synthetic data to train models, they may not perform well in real scenarios. Therefore, one of the challenges in developing self-driving cars is the availability of diverse weather condition datasets for training models.
- Some self-driving cars use detailed pre-made maps along with sensors that detect obstacles on the road in real-time. Google's self-driving cars work in this way, using maps that show features such as crosswalk length, traffic light height, and turn curves. However, creating such maps is complex and time-consuming. Moreover, such static maps are not very useful as they do not reflect real-time changes in the surroundings, which can lead to accidents. Therefore, a challenge for some self-driving cars is to create efficient maps and integrate them with the car's sensors to make them more realistic.
- Currently, there are no standard guidelines or regulations for the self-driving car industry. This creates uncertainty and difficulty for the development of self-driving cars, as there are no clear principles, standards or laws to follow. Moreover, different countries have different rules and regulations, which add to the ambiguity in various stages of research. Therefore, the lack of a standard guideline or council for self-driving cars is a challenge for the development and research of the autonomous driving industry.

Self-driving cars still face many challenges, but they can be overcome with more research and innovation. Various countries have conducted research and registered patents related to this technology [168]. The United States of America has seen the most applications and patents for driverless car-related technology, with a total of 135,828 [168]. China follows with 132,844 patents, then Japan with 57,065 patents. South Korea has 38,097 patents, while Germany has 38,512 patents. Canada has 14,585 patents, Australia has 14,026 patents, Russia has 12,121 patents, France has 9,488 patents, and Spain has 7,145 patents. Fig. 6 illustrating Country-wise self-driving car-related patents of all time.

Self-driving car patents are enormously wide-ranging. In 2017, there was substantial growth in new driverless car patents across a range of countries. The United States of America submitted 49% more patents than in 2016, with China (28%), Japan (34%), South Korea (68%), and Germany (56%) all massively increasing their new filings too. Most US patents concentrate on the comfort and entertainment of passengers in their driverless cars. In contrast, German patents concentrate on improving the safety of all passengers on board autonomous vehicles. Similarly, South Korean patents tend to focus on enhancing the interiors of autonomous vehicles.

Autonomous driving has made tremendous progress, but there is still room for improvement that can only be achieved through research.

1) *Improving the performance and reliability of sensor technologies:* Sensors are essential for autonomous vehicles to map the environment and help the vehicle's control system make decisions about steering and braking. These sensors need to be accurate in detecting subjects, depth, speeds, and other factors in any situation. However, factors such as bad weather, heavy traffic, and confusing road signs can affect the camera's detection ability. The study [169] emphasized the role of sensors in allowing autonomous vehicles to sense and navigate the environment. Future research could investigate how to enhance the performance and reliability of these sensors, such as by creating new sensor technologies or by improving existing ones.
2) *Integrating ethical and social considerations into autonomous driving systems:* Autonomous driving creates ethical and social dilemmas, such as how it affects employment and how the benefits and risks of the technology are shared. Moreover, various studies [169], [170], [171], [172] exhibit that users' trust in autonomous driving systems relies on factors such as the system's ability to make ethical decisions. Future research could investigate how to integrate ethical elements into these systems, for example, by establishing rules that promote safety and fairness or by engaging the public in the dialogue about the technology. Another option is to design algorithms that protect the well-being of everyone on

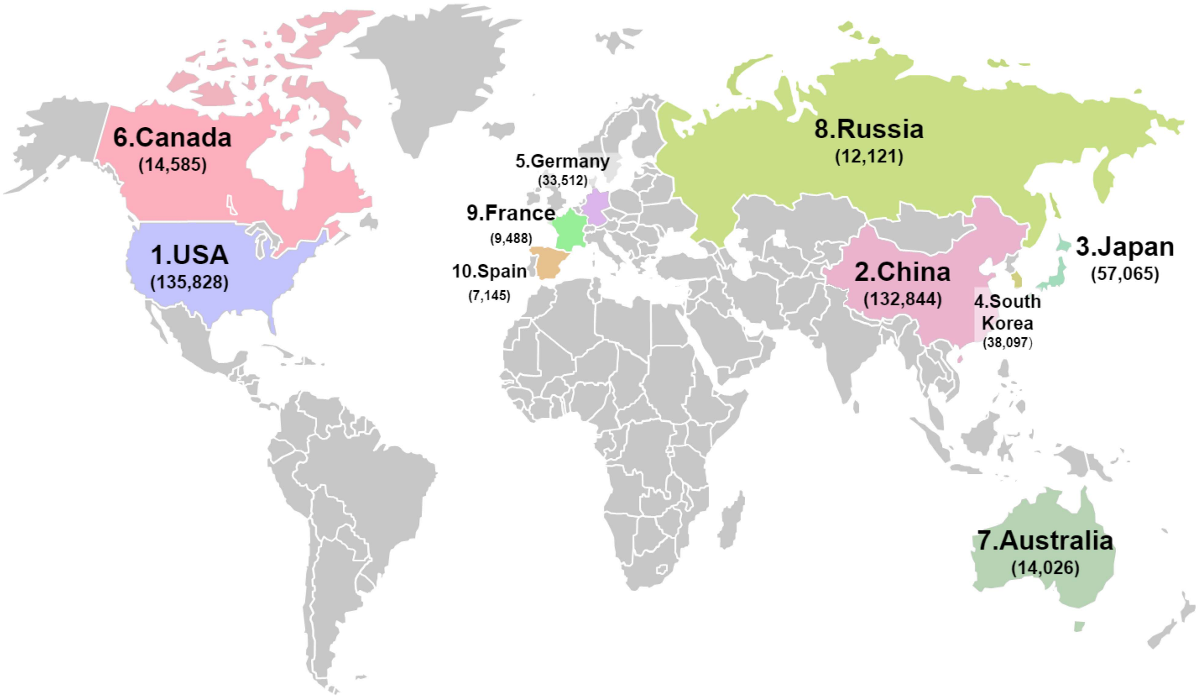

FIGURE 6. **Country-wise self-driving car-related patents of all time [168].**

the road or to allow users to modify the system's ethical settings.

3) *Improving the safety and reliability of autonomous driving systems:* Autonomous driving systems must be safe and reliable, especially because they can cause disastrous consequences if they fail. Disastrous consequences in autonomous driving are situations where the system's malfunction or error leads to serious harm or damage to the people or things on the road [173]. For instance, a disaster could happen if the system does not see an obstacle, misunderstands a traffic sign, or loses control of the car. These failures could result in injuries, deaths, or legal problems. Therefore, it is essential to avoid or anticipate such failures and enhance the safety and reliability of autonomous driving systems [174], [175]. Future research could investigate how to improve these aspects of the systems, such as by creating more resilient fault detection and recovery methods or by increasing the system's ability to handle unexpected events.

4) *Enhancing Trust and Transparency in Autonomous Driving:* Factors such as how transparent and predictable the system is can affect how much people trust autonomous driving systems. The study [169] suggested a way to calculate trust in autonomous driving systems based on factors such as how reliable and benevolent the system seems. Trusting autonomous driving systems too much or too little can have negative consequences. However, other factors may also play a role in how people trust these systems, such as their previous experience with autonomous driving or their cultural background [176], [177]. Future research could look into how to make these systems more transparent, such as by giving more information about how the system makes decisions or by letting users interact with the system in easier ways, as well as better ways to calculate trust that consider different factors, and ways to prevent and reduce trust-related problems, such as by using warning systems or training programs that help users keep a reasonable level of doubt and alertness.

5) *Developing more flexible and adaptive decision-making systems:* Autonomous driving systems need to adjust to various driving scenarios and cope with changing environmental conditions. To process sensor data and enhance their capabilities in object identification, depth, motion estimation, and decision-making, most self-driving cars rely on machine learning (ML) and computer vision. This allows them to combine and improve different sensor outputs for a holistic view. However, the trustworthiness of machine learning algorithms is not well established and accepted. The best practices for training, testing, and validating machine learning models are still lacking a common agreement across the industry. Future research could look into how to develop more effective sensors and more adaptable and resilient adaptive decision-making systems by using more accurate and robust artificial intelligence techniques.

VIII. CONCLUSION

In conclusion, autonomous vehicles are expected to dominate the streets in the near future and have a positive impact on social and economic infrastructure. However, they also face several limitations and challenges. This review paper has examined the state of autonomous driving technology comprehensively, analyzed data from various sources, and discussed the limitations of the self-driving technology regarding inclement weather, hacking vulnerability, data protection, technological efficiency, testing and validation, information management, and lack of supporting infrastructure. It has also reviewed the accident cases involving self-driving cars from 2019 to 2022, based on DMV reports, and analyzed the statistics of deaths and injuries caused by these accidents. Moreover, it has addressed the ethical issues surrounding autonomous driving, such as system dependability, collision avoidance, ethical decision making, licenses liability, and cybersecurity and privacy. Furthermore, it has explored the regulatory and litigation considerations for self-driving cars, which cover regulatory factors and litigation considerations. Overall, this review paper provides a comprehensive study of the challenges, solutions, outcome, and future research directions in the field of autonomous vehicles and their accidents. We hope that this survey will help researchers and professionals who are working on improving autonomous driving cars and that it will serve as a useful guide in identifying the current limitations and challenges of this technology and suggesting ways to reduce the risk of accidents and injuries caused by autonomous driving cars.

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