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(Review Article)

Advancements and challenges in achieving fully autonomous self-driving vehicles

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Abstract

This article presents a review and analysis of the prospects of achieving full-length autonomous driving, a concept that has long been a dream of humans. Although the automotive industry has made significant progress in many areas, creating fully automated vehicles (level 5) has remained a challenge. This paper examines some companies that are already racing to achieve this feat, such as Tesla, Google's Waymo, and Uber, and the challenges they face, such as ensuring safety and reliability while also dealing with complex and expensive technology. The article highlights the issues that must be addressed when discussing fully automated vehicles, such as legal and regulatory frameworks, public acceptance, and cybersecurity. The current generation of autonomous vehicles has not yet passed road tests, which raises questions about the feasibility of creating and being able to use fully automated vehicles in the near future. Despite the challenges, the article suggests that the high level of technological development implies that fully autonomous vehicles will become a reality someday. The author concludes that while we may not see fully autonomous driving cars on our roads soon, the progress being made in the field is promising, and we may expect to see these vehicles become a common sight on our roads in the future.

Keywords: Autonomous Driving; Technology Development; Safety; Reliability; Feasibility.

1. Introduction

1.1. Developments in Fully Autonomous (Level 5) of Self-Driving

Humans have been dreaming about having machines that can perform tasks independent of human control. Many developments have been made in many fields, but this has not yet been achieved in the automotive industry as fully automated (level 5) vehicles have been theorized but not created yet [1]. The high level of technological development implies that fully autonomous vehicles will become a reality one day. Many issues must be addressed when discussing fully automated vehicles, including safety and reliability. The current generation of autonomous vehicles has not passed road tests and uses complex and expensive technology, which leads to questions about the feasibility of creating and being able to use fully automated vehicles in a few years coming.

1.2. Current Developments in Autonomous Cars

The highest level of vehicle autonomy is level 5, where vehicles are completely autonomous and self-driving. The vehicles will drive independently of human control, handle many types of road conditions and weathers, and travel outside geo-fenced locations. A level 5 vehicle has been defined as one that will have high safety and emergency capabilities. Level 5 vehicles will fully autonomously transfer people and goods between two locations safely without human control. No company has commercially produced a level 5 vehicle, but many organizations, including Zoox, Waymo, and Tesla. More companies have developed an interest in developing autonomous cars.

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The critical issue with developing level 5 cars for public use is that no country has adequate infrastructure to support them. The technology used in the vehicles needs external infrastructure to support its sensory and control system so that the vehicles can work on public roads. The infrastructural requirement implies that countries need a decade or over to upgrade their infrastructure to support autonomous vehicles. Original equipment manufacturers (OEMs) should focus on the transformation to the software-defined vehicle and increase the communication capacities between vehicles and outside vehicles to ensure the technological supports will be available when the regulators create a regulatory environment.

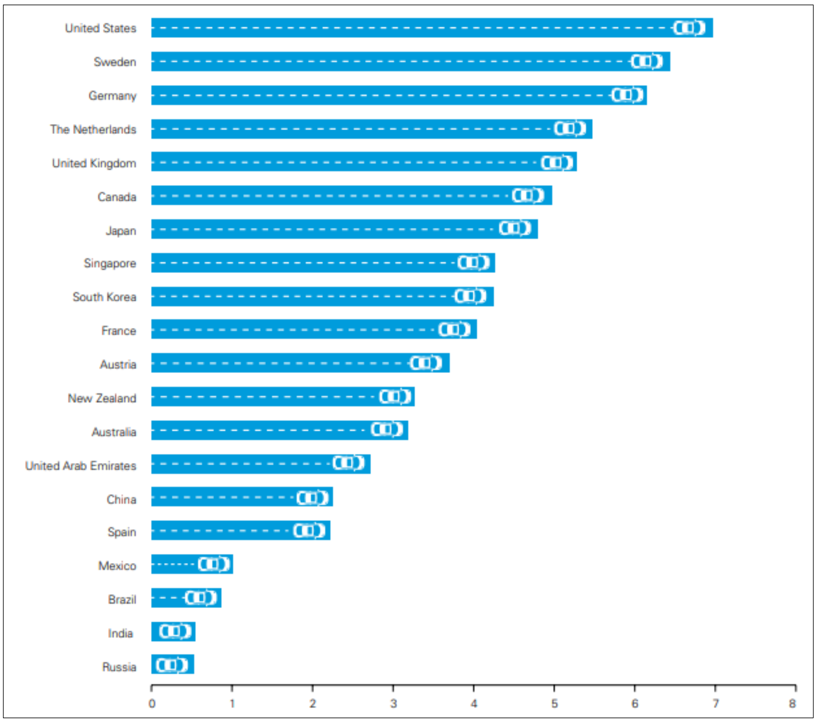

Figure 1 Technology and Innovation Pillar Scores by Country (KPMG International, 2018) [2].

The scores in the above figure have been calculated using nine variables: five from previous research, one derived from the data provided by Uber, and two created purposively by KMPG International for the index. The United States, Sweden, Germany, the Netherlands, and the United Kingdom scored the highest in this pillar, while Mexico, Brazil, India, and Russia scored the lowest. These countries have created and are initiating higher developments in the creation of autonomous vehicles.

Engineers, regulators, consumers, and other stakeholders are interested in knowing the developments that are being made in the autonomous vehicle development industry. While some optimists believe that level 5 vehicles will be commercially available in the next five years, most agree that it could only hit the roads at least a decade from now. This limitation is because it requires a not yet invented disruptive technology, and there will be a need for many infrastructure developments before they can be used commercially.

2. Review Scope: Study Analysis and Safety Assessment

The most recent autonomous vehicles are level 4, which can assist the driver whenever a system fails, or something goes wrong. Level 4 vehicles require minimal human interference, even if they allow humans to override manually. The vehicles can self-drive, but the lack of infrastructure and legislation has limited their use to small areas, normally the urban environment where speed limits are limited to 30mph, called geofencing. The regulation makes most level 4 vehicles to be used for ridesharing, including Waymo, NAVVYA, and Magna.

Level 5 vehicles only exist theoretically and are perceived as not requiring any human intervention while driving. The vehicles will not have any acceleration/braking pedals or steering wheels. They will not be subject to geofencing and will do everything human drivers can. Many companies are said to be testing level 5 cars, but none has presented its level 5 model to the public yet. Many people find the idea of a level 5 car interesting and exciting, but it seems they will not happen any time soon. For instance, the has only permitted mainstream production up to level 2. The US has declined to approve level 3 and 4 autonomous cars because of security and user safety concerns. Reports show that the technology used to make the cars has not been fully audited to allow the creation of a legal framework for using those cars. Also, the country is not yet ready to install infrastructure that supports the two levels and installing the technology would be very expensive and inconvenient to the public.

Overall rank	Country	Total score	Policy and legislation		Technology & innovation		Infrastructure		Consumer acceptance	
			Rank	Score	Rank	Score	Rank	Score	Rank	Score
1	The Netherlands	27.73	3	7.89	4	5.46	1	7.89	2	6.49
2	Singapore	26.08	1	8.49	8	4.26	2	6.72	1	6.63
3	United States	24.75	10	6.38	1	6.97	7	5.84	4	5.56
4	Sweden	24.73	8	6.83	2	6.44	6	6.04	6	5.41
5	United Kingdom	23.99	4	7.55	5	5.28	10	5.31	3	5.84
6	Germany	22.74	5	7.33	3	6.15	12	5.17	12	4.09
7	Canada	22.61	7	7.12	6	4.97	11	5.22	7	5.30
8	United Arab Emirates	20.89	6	7.26	14	2.71	5	6.12	8	4.79
9	New Zealand	20.75	2	7.92	12	3.26	16	4.14	5	5.43
10	South Korea	20.71	14	5.78	9	4.24	4	6.32	11	4.38
11	Japan	20.28	12	5.93	7	4.79	3	6.55	16	3.01
12	Austria	20.00	9	6.73	11	3.69	8	5.66	13	3.91
13	France	19.44	13	5.92	10	4.03	13	4.94	10	4.55
14	Australia	19.40	11	6.01	13	3.18	9	5.43	9	4.78
15	Spain	14.58	15	4.95	16	2.21	14	4.69	17	2.72
16	China	13.94	16	4.38	15	2.25	15	4.18	15	3.13
17	Brazil	7.17	20	0.93	18	0.86	19	1.89	14	3.49
18	Russia	7.09	17	2.58	20	0.52	20	1.64	18	2.35
19	Mexico	6.51	19	1.16	17	1.01	17	2.34	19	2.00
20	India	6.14	18	1.41	19	0.54	18	2.28	20	1.91

Figure 2 Autonomous Vehicles Readiness Index (KPMG International, 2018) [2].

The total score has been combined by assessing the policies and legislation, the level of technology and innovativeness, the level of infrastructural readiness, and the acceptance of the vehicles by consumers. The top 15 countries are developed, while the bottom five are developing. Only 16 countries have a score of more than ten, indicating that most countries are not ready for autonomous vehicles.

Safety is a critical aspect of road transport, and all vehicles must comply with certain safety requirements before they can be used on public roads. The makers of automated cars must intricately balance usefulness and safety. Automated vehicles heavily rely on algorithms for observation and control, which is critical for road safety. The algorithms must analyze a massive amount of data from any instruments, analyze it, and make critical decisions regarding the next steps they should take. Driving automation system systems collect massive data from lidars, cameras, radars, and ultrasonic sensors. The vehicles use cameras to read the surrounding environment and detect many things, including pedestrians, roads, and traffic signs. Radar is used to detect the position of surrounding vehicles on the road. Lidar uses light from the surrounding environment to detect the edges and curves of the road, measure the distance from other vehicles, and since the road marking. Ultrasonic sensors are located on the wheels and help detect other vehicles and curbs when parked. The algorithm combines this data to create a full-dimensional image of the surrounding objects and features to enhance vehicle safety. The algorithms also create enriched maps that can determine the exact positioning of the vehicle, which represents orientation and position.

Control is another critical aspect of the safety of autonomous vehicles. After an autonomous car establishes its position and surroundings, the algorithm will decide the next best action. The decisions are determined based on many factors, including coded rules, algorithms for avoiding obstacles, object recognition algorithms, and predictive algorithms. The algorithms work to instruct the actuators of the vehicle to control steering, braking, and acceleration. The driving automation system decides the next steps based on the observed situation. This process must be dynamic because the observations made by the system also change dynamically [3-6].

The major issues derailing the development of level 5 vehicles are technological and safety-related barriers. As most diver-assistance capabilities, including automatic emergency braking, have lowered rear-end vehicle collisions by half, the difference between full vehicle autonomy and advanced driver assistance (ADS) is huge. One of the main reasons is that the vehicle needs to collect and analyze massive data amounts in a fraction of a second, which could consume more power than current vehicles generate. The current vehicle architecture would require 100-150 electronic control (ECU) units combined with specific hardware that relies on monolithic software. As level 5 vehicles require new capabilities or features, an extra ECU and all the hardware that support it include wiring, development, testing, and costs. Level 5 vehicles need a major shift in the underlying vehicle architecture.

2.1. Autonomous Vehicle Industry Collaborations

Many automotive industry stakeholders, including software makers, telecommunications providers, technology giants, car manufacturers, higher learning institutions, and insurance companies, are increasingly collaborating to develop and commercialize automated vehicles, share risks, and prepare consumers. Some notable partnerships are General Motors and Lyft; the company also started conducting R&D with other car makers, including Mobileye, Volkswagen and Honda. Ford Motor collaborated with Amazon, Google, and AT&T to create SmartDeviceLink open-source software. Toyota Motor also partnered with Microsoft to advance its idea of an autonomous vehicle. Tesla also partnered with Panasonic and Lotus cars, and its R&D department collaborates with Panasonic to create batteries with higher efficiency. These partnerships are not new in all industries but are more significant in rapidly evolving markets with technological convergence [7-10]. The collaboration results because many conventional carmakers specialize in designing, testing, manufacturing, assembling, selling, and servicing vehicles and lack enough expertise to develop information technology products. Technology companies have many years of expertise and experience in matters like software development, data science, Global Position System (GPS) mapping systems, and telematics, which are critical in the development and operation of automated vehicles. The partnerships ensure that these technology companies bring their experience and expertise to the automotive industry to assist in improving current automotive and developing level 5 automotive [11].

2.2. Connectivity Requirements for Autonomous Driving

Autonomous driving is a manifestation of human ingenuity in technical engineering. Many companies, including Audi, Apple, Lyft, Uber, Waymo, Tesla, Renault, and Ford, have heavily invested in the development of level-5 vehicles, and while they have not achieved this, they have figured out all the technical requirements for such vehicles and developing technologies to achieve them. Connectivity is an important matter for autonomous vehicles, so the dream cannot be achieved by achieving a high level of connectivity. Manufacturers must master connectivity so that they can provide vehicle-to-everything (V2X) capabilities that are required for level 5 vehicles. The following are some of the connectivity requirements that could be needed for a level 5 autonomous vehicle as shown in figure 3.

The level 5 autonomous vehicle architectures must be real-time and redundant. A stable, secure, high-speed connection is critical for all autonomous vehicles. There would be high demand for more reliable network-reliant structures, which need real-time, redundant architectures. These architectures would aim to arrange high-performing bundles located in functional domains that must be linked through a central gateway using an advanced framework. All group sensors and actuators must be arranged hierarchically. As shown in the above diagram, driver assistants, safety, vehicle motion, infotainment, and body electronics have many functional level elements that form the data backbone. The data backbone forms the central gateway, facilitating cloud/backend communication, mobile communication, satellite communications, and V2V/V2X.

The car manufacturers must consistently increase bandwidths for distributed network structures and point-to-data pies structures to address the increasing data demands. In operation, level 5 autonomous vehicles are expected to send approximately 25 gigabytes (GB) of data to the cloud hourly. The usage level means the vehicles could require 5G internet connections or better. 5G upload speed can transfer up to 20 Gigabits per second (Gbps). The internet was designed to address the ever-increasing need for the internet.

The applications in level 5 autonomous vehicles require high-speed external connectivity. Vehicle-to-everything (V2X) communications must consistently collect, analyze, and interpret data about the environment surrounding the vehicles. The information is needed to determine the actions of the vehicles, like acceleration and braking, without human driver intervention. V2X communication relies on radio-based communication and sensor technology. The sensors help the vehicle to interact with the environment, while the radio system facilitates information transfer between vehicles and traffic infrastructure like tolls, lights, and signs.

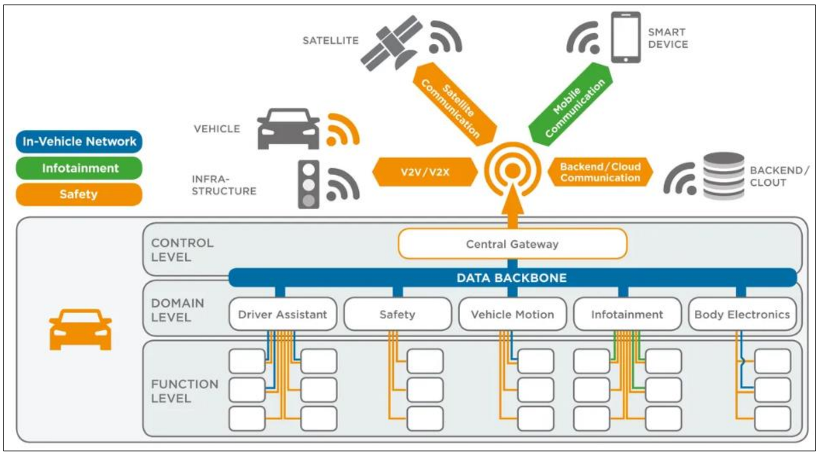

Figure 3 Autonomous Vehicle Functional Domains for Inter-vehicle Connections with High speeds (IEEE Spectrum, 2023) [11].

Level 5 autonomous vehicles could need 100 percent reliability in addition to data sensing and real-time capabilities, and this means that connection is not supposed to fail due to poor road conditions or extended use. The solution uses robust automotive-focused connectivity systems manufactured by experienced and highly competent suppliers. The preferred suppliers for original equipment manufacturers (OEMs) must be experienced in electromagnetic connections.

The performance and safety of level 5 vehicles depending on the speed, reliability, and safety of their data collection, analysis, and interpretation. The vehicles must have state-of-art data and physical safety protocols. Automotive manufacturers are currently studying whether using optical-fiber connectivity could prevent electromagnetic interference. They have found that these materials are unaffected by signal, crosstalk distortions, or electromagnetic emissions. Suppliers are also creating in-vehicle networks as required by the global automotive Ethernet standards that can transfer encrypted data instead of using legacy and proprietary networks with high data vulnerability and decryption. Level 5 autonomous vehicles will use these standards to protect them from hacking and unauthorized remote control.

Level 5 autonomous vehicles need many types of equipment, so they will be bulky and ugly if their components are not miniaturized. To keep the vehicles well-functioning, make vehicles aesthetically appealing, and reduce damage to equipment, the V2X systems must be fitted under the hood of vehicles; this could only happen if the automotive manufacturers develop automotive grade miniaturized and highly functional connectivity systems. The current technological developments have proved effective in miniaturizing actuators and sensors. Automotive Ethernet cables enable level 5 vehicle manufacturers to deliver data and power over one pair of wires, unshielded or shielded. TE Connectivity and bother companies specialize in establishing the creepage and clearance margins required to meet this goal. Manufacturers will be required to determine and meet moisture and pollution tolerance systems. Level 5 vehicle in-vehicle networks would have to create the leanest and cleanest cable connection and assemblies that will be installed in denser configurations. Many companies, including TE Connections, help to make these trade-offs and create better solutions that increase the connectivity and power efficiency of autonomous vehicle systems using less cabling and material connectors.

2.3. Safety of Level 5 Vehicles

Experts believe that vehicle safety is enhanced with automation. Higher levels of automation called automated driving systems, reduce the involvement of human mistakes that often cause accidents. These systems have not been actualized, but it is expected that they will provide immense benefit in road safety when fully developed. The current levels of vehicle automation are called active safety systems and provide lower automation levels that detect impending dangers and take measures to avoid or eliminate them. These technologies, when fully advanced, will increase protection for pedestrians, drivers, passengers, cyclists and other road users. However, some aspects of driving require human involvement.

Level 5 cars will depend on computer vision systems to navigate the roads and environment, but they can be fooled in ways humans cannot. For example, vehicles use cameras to read speed signs, and there are instances when the speed limit signs might be removed, knocked, or altered markings. Under these circumstances, the fully automated vehicle cannot use judgment like humans to know what to do because it has not been programmed for that. Studies show that minor changes to the number of speed signs could cause machine learning to misread it. In one instance, some people tricked the Tesla autopilot into changing lanes when they used fake stickers to create a fake lane. These two examples show how easy tricks that cannot trick humans can trick machines. Many worries concern how machine intelligence in automated vehicles perceives the world. For example, some Tesla owners driving in the real world have noticed that their vehicles treat tree shadows as trees. While these examples are not for level 4 automated vehicles, they show some critical issues that must be addressed before level 5 vehicles can pass the safety test to be accepted on public roads.

Many people are involved in determining the parameters for determining the safety of self-driving vehicles, including regulators, engineers, researchers, and manufacturers. In most countries, including the US, a comprehensive framework for evaluating safety has not been established, and many debates are going on. Regulators are still establishing the data they can expect and the best ways to analyze it to evaluate the safety of self-driving vehicles. The US regulatory framework is complex as the federal government should handle some driving behaviors embedded in the vehicles while the interaction with other drivers and driving behavior is the responsibility of the state governments. This ambiguity creates confusion and complicates the matter even more. Preliminary analysis has shown that the current self-automation of vehicles improves their safety, but they are prone to errors. The critical matter is defining safety and determining ways to improve it. Many people have expressed concern about fully dedicating their safety on the road to artificial intelligence systems.

The general agreement is that self-driving vehicles should be safer than non-automated, partially automated vehicles, but their safety level is hard to answer. Self-driving vehicles are associated with many technical issues, but moral questions linger too. No clear parameter has been established for qualifying a self-driving car as safe enough to be allowed on the road. Even when there are defined parameters, a standard for measuring whether they have been met is yet to be established; this means that it is difficult to assess the safety levels of level 5 cars because that of level 4 cars has not been fully established. Current studies show that road safety is maximized when self-driving technology complements human driving. There are many safety issues that humans can handle better than machines, while there are safety issues that machines can handle better than humans.

3. Conclusion and Future Scope

The automotive industry has been making significant progress toward the development of fully autonomous vehicles. However, despite many collaborations and advancements in technology, level 5 autonomous vehicles have not yet been created. Currently, level 2 automation is commercially available, and level 4 automation is only feasible in geofenced locations. Limitations in technology and regulations between countries are significant obstacles to the development of level 5 vehicles. Developed nations have made more progress in vehicle automation, making them more likely to introduce level 5 cars first. However, even if a fully developed level 5 car were available, it may be unusable on most roads due to regulations and infrastructure limitations.

While automation has improved the safety of vehicles, it has mostly been used to assist human drivers, and therefore the safety of level 5 cars remains uncertain. Furthermore, the complexity and expense of the technology required for fully autonomous vehicles raise questions about the feasibility of creating and using them in the near future. Nevertheless, the rapid technological advancements being made in the automotive industry could lead to the invention of level 5 vehicles within the next decade.

The future scope of autonomous driving technology is vast and can impact the automotive industry, transportation sector, and society as a whole. The successful development of level 5 autonomous vehicles could reduce accidents caused by human error, increase road safety, and improve transportation efficiency. Furthermore, it could transform the transportation industry by reducing the need for personal car ownership and traditional taxi services, as fully autonomous vehicles can be programmed to pick up and drop off passengers.

The advancements in autonomous driving technology have also opened up opportunities for new business models, such as ride-sharing and last-mile delivery services, that can reduce traffic congestion and carbon emissions. The introduction of fully autonomous vehicles can also lead to the development of smart cities, where traffic can be managed more efficiently, leading to reduced travel times, reduced carbon emissions, and improved air quality.

However, the successful deployment of fully autonomous vehicles requires collaboration between the automotive industry, regulators, and policymakers to establish a common framework for the development and deployment of level 5 vehicles. Additionally, infrastructure such as road networks, charging stations, and communication systems must be developed to support fully autonomous vehicles.

In conclusion, while the development of level 5 autonomous vehicles remains a significant challenge, rapid advancements in technology and collaborations between companies are increasing the likelihood of its realization. The successful deployment of fully autonomous vehicles can have a significant impact on society, the transportation industry, and the environment. However, significant efforts must be made to overcome the technological, regulatory, and infrastructure barriers to ensure the safe and efficient deployment of level 5 autonomous vehicles.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflicts of interest.

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