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Autonomous Vehicles in Healthcare

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ABSTRACT

Autonomous technology is the systems that can control vehicles without constant physical control or a human operator directing the vehicle. Autonomous vehicles (AVs) have great potential in healthcare to enhance efficiency, accessibility, safety, and operational resiliency. A few of the applications include medical supply delivery, patient transportation, mobile clinics serving underserved populations, and contactless operations in sensitive or high-risk areas. The introduction of AVs into healthcare can maximize operational performance in the field and complement the experiences of healthcare personnel and patients. Nevertheless, the influence of AV adoption on the population's health can be either positive or negative, depending on many determinants, including the degree of automation, ownership and usage schemes, and propulsion type (e.g., internal combustion, hybrid, or electric). This report provides a detailed background on the analogous implementation, usage, advantages, difficulties, and prospects of autonomous vehicle technologies in the healthcare industry.

KEYWORDS: *Autonomous vehicles, self-driving vehicles, connected vehicles, healthcare.*

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1. INTRODUCTION

The recent breakthroughs in autonomous vehicle (AV) technologies have revolutionized various industries and changed the very nature of transportation, logistics, and mobility systems. These cars drive with little or no human intervention, which is a pivotal step in the development of smart vehicles. In addition to their traditional transportation uses, AVs also have enormous disruptive potential in other areas of healthcare and logistics.

AV technologies in the healthcare sector are advancing in their ability to improve operational efficiency, enhance safety measures, and increase service availability. Their integration is slowly transforming hospital and clinical settings by enhancing internal logistics, patient mobility, and emergency response. Differences in models of AV use and ownership can lead to significant consequences for public health, thereby affecting access to care, patient safety, and the system resilience of healthcare. Fig. 1 [1] shows the examples of autonomous vehicles, whereas Fig. 2 depicts a typical hospital setting [2].

Autonomous cars represent a paradigm shift, likely transforming the lives and urban organization of the whole city, as well as the country's transportation infrastructure and safety standards. AVs provide healthcare systems with greater opportunities to improve patient care, service delivery, and population health outcomes when implemented. Such innovations have the potential to save lives, lower health care disparities, and empower health care systems around the world.

2. Research Methodology

This research employs a mixed-methods analysis, primarily drawing on a comprehensive review and synthesis of existing literature to assess the possible consequences of autonomous vehicles for healthcare provision. The discussion is based on access, safety, cost-efficiency, logistics performance, and efficacy of emergency response [3].

The literature used in the research is based on secondary data, such as peer-reviewed journal articles, conference paper, reports issued by international organizations such as the World Health

Organization (WHO), the International Civil Aviation Organization (ICAO), the Federal Aviation Administration (FAA), and reports by international organizations, such as the North Atlantic Treaty Organization (NATO). Other resources will include industry reports on upcoming drone and pharmaceutical companies. They were carefully analysed to determine the main uses, opportunities, and challenges, as well as possible directions for implementing AV in healthcare.

3. Objective

The primary objective of this paper is to explore the different categories of self-driving technologies and their impact on the medical field. Specifically, it discusses how autonomous vehicles (AVs) can enhance the efficiency, accessibility, and safety of healthcare. The paper examines various applications of AVs, including medical supply distribution, patient transportation, and mobile clinics that serve underserved populations. It also highlights the potential for AVs to minimize human interaction in sensitive medical and military settings. Finally, the paper outlines the significant advantages, practical applications, challenges, and opportunities associated with implementing AVs in healthcare.

4. Significance Of The Study

This research delves deeply into four key areas regarding autonomous vehicles (AVs). First, it highlights the potential of AVs to improve mobility for underserved and remote communities. Second, it discusses how AVs can help overcome transportation challenges faced by older adults and individuals with disabilities, thereby increasing access to medical services. Third, the paper examines how AVs can save lives during critical medical emergencies by reducing response times. Finally, it underscores the advantages of efficient, safer medical logistics delivery systems, which minimize the risks associated with human error and delays.

5. Literature Review

5.1. Concept of Autonomous Vehicles

One of the most recent developments in artificial intelligence (AI) and intelligent transportation systems is the development of autonomous vehicles (AVs). A self-driving vehicle, also known as an autonomous vehicle, self-driving car, or robot car, can sense its surroundings and move autonomously without human operation. Such vehicles are based on automated control systems that enable them to drive themselves using real-time information about the environment and the planned destination. Figure 3 [3] shows the general structure of an autonomous car, its perception, decision-making, and control layers.

AVs are highly advanced, multidisciplinary systems, combining technologies in electronics, communications, mechatronics, software engineering, artificial intelligence, the global positioning system (GPS), and the industrial Internet of Things (IoT). AVs combine cameras, radar, LiDAR (Light Detection and Ranging), GPS/GNSS, and sophisticated sensors to monitor the road environment, detect and avoid road obstacles, read traffic signs, and avoid accidents. These systems are designed so that artificial intelligence can process sensor data, predict behavior around them, and make real-time driving decisions. Other AI applications, such as voice and speech recognition, gesture trackers, eye trackers, and driver-monitoring systems, also enhance the vehicle's intelligence and safety.

Self-driving and networked cars have become the foundation of a more digital and networked world. They have caught the eyes of a significant number of governments, car manufacturers, service providers, educational institutions, and customers. Developing AV is mainly aimed at producing an autonomous system that can sense the road environment more realistically and respond more consistently to situations than an actual driver, thereby enhancing safety and efficiency. Figure 4 [6] shows the operational scheme of the autonomous vehicles (sensing, perception, planning, and actuation processes).

Autonomous vehicles are generally welcomed as an innovative remedy to significant transportation issues, such as traffic jams, road accidents, and environmental pollution. They will be the key to the next generation of intelligent transportation systems (ITS), providing better road safety, travelling comfort, and added value. Outside civilian use, AVs have been deployed for search and rescue, military supply, logistics, convoy, and dangerous-environment missions, demonstrating their ability to save lives [4][5].

5.2. Levels of Autonomy

Autonomous vehicles perform various levels of autonomy. In an effort to provide a standard structure, SAE International (formerly the Society of Automotive Engineers) has developed 6 levels of vehicle automation, with Level 0 as the lowest and Level 5 as the highest. This widely followed categorization, accepted by regulators including the U.S. Department of Transportation (DOT), describes how human driving can be gradually shifted to entirely autonomous systems [7], [8]. Table 1 summarises the level of autonomy under SAE.

Table 1: SAE Levels of Vehicle Autonomy

Level	Automation Name	Description
Level 0	No Automation	All driving tasks are performed by the human driver. The system may issue warnings but does not control the vehicle.
Level 1	Driver Assistance	Provides limited assistance with either steering or speed control. The driver must remain engaged at all times.
Level 2	Partial Automation	The system controls both steering and acceleration/deceleration simultaneously. Continuous driver supervision is required.
Level 3	Conditional Automation	The vehicle performs all driving tasks under specific conditions. The driver must intervene when requested.
Level 4	High Automation	The system drives autonomously within defined environments and conditions, with no human input required in those settings.
Level 5	Full Automation	The vehicle operates autonomously under all conditions without any human involvement.

Figure 5 [9] graphically depicts the six levels of autonomy, which are usually grouped into No Automation, Driver Assistance, Partial Automation, Conditional Automation, High Automation, and Full Automation. Most of the commercially available vehicles are currently at Levels 1 and 2 and are not fully independent but offer a high level of driver assistance. Despite the significant gains of Levels 4 and 5 in safety, efficiency, and accessibility, they are associated with development and construction costs, as well as numerous technical, legal, and regulatory challenges. Full autonomy is a long-term goal that involves further innovation and policy adjustments.

5.3. Autonomous Vehicles in Healthcare

Hospitals are experiencing increasing demand, old facilities, and developing patient needs. Autonomous vehicles (AVs) are bound to change the way healthcare is delivered, the nature of infrastructure, and the way hospitals operate [10]. On the ground and in the air, AVs are being developed today to serve in clinical and hospital environments. They are coded to travel along predefined routes, using sophisticated sensors to identify obstacles, move safely, and carry out automated tasks. Such integration offers the most incredible opportunity to streamline logistics, patient transportation, and internal processes.

AVs can transform the idea of urban mobility and healthcare. They can provide convenient transport for people with limited mobility, assist with non-emergency medical transport, and offer mobile medical services to isolated and underserved populations. AVs that are medically equipped can also move quickly and navigate complex settings, offering full access to care where traditional transport might be restricted.

Some of the mainstream organisations that have been at the forefront of developing AVs in the medical field include Waymo, Tesla, Uber, Cruise Automation by General Motors, and conventional vehicle companies like Ford, Toyota, and BMW, among others [10]. AVs improve operational efficiency, reduce human error, and enhance patient outcomes by automating patient and supply transport. Nonetheless, practical application in health care needs to be carefully determined, taking into account technical, social, security, and regulatory issues, to be integrated safely, efficiently, and equitably within the prevailing healthcare frameworks.

5.4. Applications of Autonomous Vehicles in Healthcare

The integration of autonomous vehicles (AVs) into healthcare has expanded rapidly, encompassing a broad range of applications. These applications include autonomous delivery robots, smart carts for internal logistics, self-navigating patient transport vehicles, mobile clinics for remote populations, and non-emergency medical transport (NEMT). Collectively, these applications enhance care delivery, improve operational efficiency, reduce costs, and expand access to healthcare services [11]–[13].

Efficient Delivery of Medical Supplies. AVs enable the continuous, reliable delivery of people, medication, specimens, and medical equipment in healthcare facilities. Self-driving technology eliminates the need for human drivers, reduces the risk of human error, and speeds up delivery. For example, CVS Pharmacy introduced a pilot project in Houston in which a fleet of Nuro autonomous vehicles drove through the city to deliver prescriptions and other goods to customers free of charge. The CVS + Nuro collaboration illustrates how AVs could facilitate last-mile delivery in medical logistics. One can observe an autonomous delivery vehicle by CVS as shown in Figure 6 [14].

Drone-Based Medical Logistics. One of the fastest-developing uses of AV technology in healthcare logistics is drones. In urban and rural areas, autonomous drones may deliver medicine, medical equipment, and biomaterials without human control, acting entirely in automatic flight; however, during landing. Drones can be optimally planned using optimization algorithms to navigate emergency medical service networks effectively, delivering essential, potentially life-saving medical equipment such as defibrillators, vaccines, and blood products in time. The GPS coordinates help drones determine latitude, longitude, and altitude precisely and quickly, making them effective for deployment in emergencies.

Emergency Response. AVs can revolutionize emergency care by serving as first responders who provide the necessary medical equipment and AI-controlled triage services. They can shorten response time, provide initial diagnostics during transport to hospitals, and facilitate emergency department work by automating the offloading of patients and their access to care. Although traditional ambulance operators are allowed to bypass traffic in emergencies, autonomous ambulances need sophisticated AI to navigate through city traffic jams. In Figure 7, we present a typical ambulance [2].

Non-Emergency Medical Transport (NEMT). AV technology can support NEMT by reducing dependence on drivers and allowing staff to focus on patient care. Rather than replacing human drivers entirely, autonomous vehicles can complement the workforce by bridging gaps where drivers are unavailable. For individuals with limited mobility, AVs provide reliable access to medical facilities, helping reduce barriers to care. Figure 8 illustrates a person using a wheelchair in a go MARTI self-driving van [15]. These vehicles can significantly enhance transportation equity while maintaining patient safety.

Urban Transportation and Healthcare Access. Self-driving cars also have implications for urban health dynamics. AVs change the health of the population by transforming the nature of urban mobility by enhancing access to health care, lowering the time spent on travel, and decreasing air pollution associated with traffic. The AV technology implemented in urban transportation policies can facilitate exercise by promoting social connection, access to green areas, and health services, and can advance the general health of the population.

Autonomous Mobile Clinics. Among the most radical uses of AVs is the creation of mobile autonomous clinics. These technologies bring hospital services to communities, especially the underserved and remote communities, and can frequently run AI-driven diagnostic tools. Mobile clinics can receive and store patient information, including vital signs such as pulse, blood pressure, and oxygen saturation, in electronic health records (EHRs). Telemedicine systems enable doctors to conduct remote consultations effectively, with integrated systems. Autonomous mobile clinics can help advance universal health coverage (UHC) by increasing their accessibility and affordability. Moreover, in emergencies such as an outbreak of an infectious disease or an earthquake, these mobile stations can serve as urgent-response health facilities, delivering services in areas considered at risk or difficult to access.

To conclude, there are a variety of AV applications in healthcare, including internal logistics and NEMT, emergency response, and mobile clinics, which demonstrate their ability to enhance efficiency, safety, and equity. With ongoing technological growth, AVs are most likely to be adopted in next-generation healthcare delivery models, transforming the processes of company operations and patient experiences [11]-[15].

6. Discussion of Benefits and Challenges

Autonomous technology describes systems that take control of a vehicle without physical control or constant human attention. The development of autonomous vehicles (AVs) has the potential not only to positively impact the country's population in terms of health and healthcare delivery practices but also to pose threats across various aspects, such as modes of implementation, energy sources, coexistence with other transportation modes, and usage conditions [16]. The most promising areas in healthcare are logistics, patient transport, and emergency response, but obstacles such as safety, trust, regulation, and equity remain.

6.1. Benefits of Autonomous Vehicles

AVs represent a transformative intervention in transport systems, with far-reaching implications for public health. Beyond improving traffic safety, AVs could enhance healthcare delivery and sustainability, particularly when deployed as fully electric vehicles, integrated with public transportation, or utilized in ridesharing formats [16]– [18]. The following key benefits have been observed:

Automation in Healthcare Operations. The AV functionality revolves around automation. AV technology can be used in medical logistics to automatically sort goods, efficiently transport supplies, and deliver medical tests and drugs in a timely manner. This minimizes human error, enhances operational efficiency, and addresses logistical challenges posed by large quantities of medical materials. As automation continues, healthcare facilities may embrace AV technologies to streamline internal processes, whether for delivering medications to internal patients or to external patients.

Traffic Safety. One of the most substantial advantages of the AV introduction is safety. In 2017, 94 percent of fatal motor vehicle accidents were caused by driver factors, such as impaired driving, driving distractions, speeding, and unlawful maneuvers. Road accidents in the world cause the death of about 1.3 million people every year. A fully automated car can significantly reduce crashes caused by human factors by eliminating human error, saving thousands of lives annually [16]. Safer transport can help safeguard patients during ambulance or NEMT transport in a healthcare setting.

Sustainability and Green Infrastructure. Parking infrastructure is limited by autonomous cars. Hospitals may use unused parking spaces to create green spaces that promote environmental sustainability, improve patient recovery, and advance community welfare. Figure 9 depicts an example of a hospital campus with green spaces created by the reduced need to drive to the hospital to park [18]. The eradication of parking pain will enable AVs to self-park and release patients, reducing the need to search for parking areas under stress and optimizing drop-off and pick-up areas, thereby enhancing accessibility and hospital layout.

Enhanced Work Conditions. Fully autonomous vehicles can free the driver of active driving responsibilities, allowing commuting time to be spent on work, rest, or telemedicine. It could enhance overall well-being, reduce commuting stress, and facilitate a healthier work-life balance. In the long term, AVs can reduce stress and exhaustion among transport employees and drivers in NEMT services.

6.2. Challenges of Autonomous Vehicles

Although these are the positive aspects, there are several major challenges to the adoption of AV in healthcare and urban mobility, including technical and regulatory challenges, as well as social and environmental factors.

Decision-Making and Liability. The ownership of critical driving decisions, including rerouting to the hospital in emergencies, is yet to be decided. Legal frameworks should address liability, particularly in situations that are life-threatening. The introduction of AVs also correlates with rising healthcare expenditures worldwide. Unequal access to health services remains a problem for the onward achievement of universal health coverage, and the Deployment of AVs has to take into account equitable accessibility for all groups of people [16].

Security and Trust. AV systems are vulnerable to attacks, and in health care, security is paramount. AVs should protect against physical and electronic attacks, including the unauthorized disclosure of sensitive patient information. Trust is strongly associated with system reliability, transparency, and technical competence. AVs are more likely to be accepted by their users when systems not only perform similarly but also ensure data privacy and operational safety, even in unforeseen circumstances. The inability to establish trust may undermine acceptance and diminish the benefits of autonomous healthcare systems.

Air Pollution and Environmental Impacts. Although AVs will help alleviate road congestion, their use to minimize it will be affected by energy sources. This means that 95 percent of the world's population lives in conditions that exceed the WHO-recommended air quality standards. City air pollutants also cause mortality and morbidity because of motorised transport. The AVs that use internal combustion engines may continue to worsen these problems, while electric AVs offer a chance to mitigate emissions and air pollution in cities.

Road Traffic Noise. Noise in urban transportation is linked to sleeping disturbance, irritation, cardiovascular disease, and high blood pressure. Self-driving cars with classic engines may further contribute to noise pollution, a danger to the population's health. Minimizing noise, such as electrification and enhanced traffic control, will play a crucial role in realizing the full benefits of AV.

Regulatory and Legal Frameworks. The biggest obstacle to AV adoption is regulatory uncertainty. The five U.S. states and the District of Columbia that have passed legislation allowing autonomous vehicles on highways are flourishing in this field. The regulatory structures should be revised to address safety levels, liability, ethics, and their integration with current transport systems. In the absence of clear policies, mass AV adoption may be postponed, and the potential positive impact on people may be limited.

Social and Equity Considerations. The key factors that affect the uptake of AV are trust, cultural acceptance, and equity. Perceptions of safety, technical competence, and reliability determine the public's perception of the positive development of autonomous technology. Furthermore, AV implementation should take social inequalities into account, ensuring vulnerable groups have access, particularly in rural or underserved areas. Lack of attention to these aspects can intensify existing disparities in healthcare services.

Integration with Urban Transportation. AVs can transform urban mobility, access to medical care, and travel. By combining AVs with the transportation system, ridesharing, and active mobility, public health benefits will increase. Nevertheless, poor planning or integration failures may cause traffic inefficiencies, increased congestion, or unfair service allocation, thereby undermining the potential health benefits.

To sum up, self-driving cars can provide significant advantages for healthcare and population health, such as improved safety, greater operational efficiency, greater availability, sustainability, and a better work environment. At the same time, they are also very challenging, including security, trust, environmental impacts, regulatory complexity, and equity. It is essential to balance these advantages and challenges to ensure a safe and beneficial integration of AVs into healthcare systems. The transformational potential of autonomous vehicles will be realized through the implementation of strategic policies, technological innovation, and stakeholder engagement to reduce risks that may arise [16]-[18].

7. Results

The paper illustrates that self-driving cars (AVs) have significant potential to enhance the delivery of healthcare services. The major advantages are increased medical logistical efficiency, reduced human error, and increased healthcare access for patients, especially those with limited mobility. AVs can facilitate the timely delivery of medical supplies, specimens, and medicines as an intervention, thereby improving emergency response time and system resilience in the context of the public health crisis [19].

Human-error-related accidents can also be minimized through the integration of autonomous driving systems, which would increase patient and healthcare personnel safety [20]. AVs can be helpful for elderly and mobility-impaired patients by providing a reliable, independent mode of transportation, enhancing access to necessary healthcare services, and promoting continuity of care [21]. AVs can also enable the delivery of medical supplies in emergencies without direct contact, thereby reducing the risk of infection for healthcare professionals and maintaining service delivery [22].

Moreover, AVs are beneficial for operational efficiency, as they reduce labor and transportation costs, enabling healthcare providers to devote more resources directly to patient care. These results show a promising future; however, issues of data security, patient privacy, and regulatory compliance remain. The results indicate that AV may be used in the healthcare industry to reduce errors and improve logistical capabilities, thereby optimizing patient outcomes and facilitating safer, more convenient, and cost-effective healthcare provision.

8. Policy Implications and Future Directions

8.1. Policy Implications

Autonomous vehicles (AVs) may have significant potential in healthcare, but they also carry important policy implications. The major concerns are data protection, cybersecurity, business ethics, certification principles, and societal approval [23]. Semiautomatic medical vehicles track vulnerable patients and their performance data, and make real-time decisions in severe conditions, which underscores the importance of high-quality governance frameworks. These policymakers have to ensure that AV systems comply with data protection laws and patient privacy requirements and operate transparently to build trust among system users. Ethical frameworks could also be fundamental to decision-making during emergencies, especially when AVs must safeguard patients first or allocate limited resources. Indeed, aviation certification procedures and operational guidelines ought to be introduced to test the performance of AV in terms of safety, reliability, and competence in health care.

8.2. Future Directions

AVs in healthcare can offer a revolutionary way to reshape and alter hospital infrastructure, urban planning, and population health. The reduced use of human drivers and the implementation of electric AVs may reduce the number of road accidents and environmental impacts. An alternative ridesharing format that incorporates public transportation, cycling, and walking infrastructure may further improve urban health outcomes [24]. Healing gardens, outdoor therapies, and pedestrian-friendly paths can be incorporated into the future hospital design, enabled by a reduction in the footprint of the vehicle infrastructure.

The combination of smart IoT, wearable, and health-monitoring devices will enable intelligent, data-driven healthcare networks. AVs can also be equipped with medical emergency detection ability, including heart attack detection during transportation in the near future, which may save lives. This future vision, in particular, must be collaboratively developed by architects, health professionals, urban planners, and technology developers to ensure that the systems are safe, available, and sustainable. Figure 10 demonstrates the estimated timeline for the release of driverless cars [25].

Conclusion

This paper notes that autonomous vehicles have tremendous potential to transform healthcare provision, making it safer, more accessible, reliable, and efficient. AVs have the potential to improve healthcare services, especially in underserved and rural areas, and to support emergency management during an epidemic. In addition to healthcare, AVs can revolutionize city life, alter travel patterns, and reduce morbidity and mortality from traffic accidents. AVs can be used as a tool to improve healthy, sustainable cities by being rolled out as electric, shared, and active-transport options.

Nevertheless, AVs based on adoption also pose potential health hazards, including air pollution, noise, and sedentary behavior, which need to be addressed through proper regulation and planning. Policy makers, medical practitioners, and industry players should collectively establish ethical codes, legal systems, and operational standards to ensure safe, fair, and efficient deployment. Carefully balanced and combined, AVs will be one of the pillars of healthcare systems of the future, enhancing patient outcomes, promoting sustainability, and boosting the reliability of the medical services. To continue investigations and monitor the developments of AVs in the healthcare sector, refer to [26,27] and journals such as:

- Artificial Intelligence Review
- Applied Artificial Intelligence
- Artificial Intelligence and Law
- AI Magazine
- Vehicular Communications

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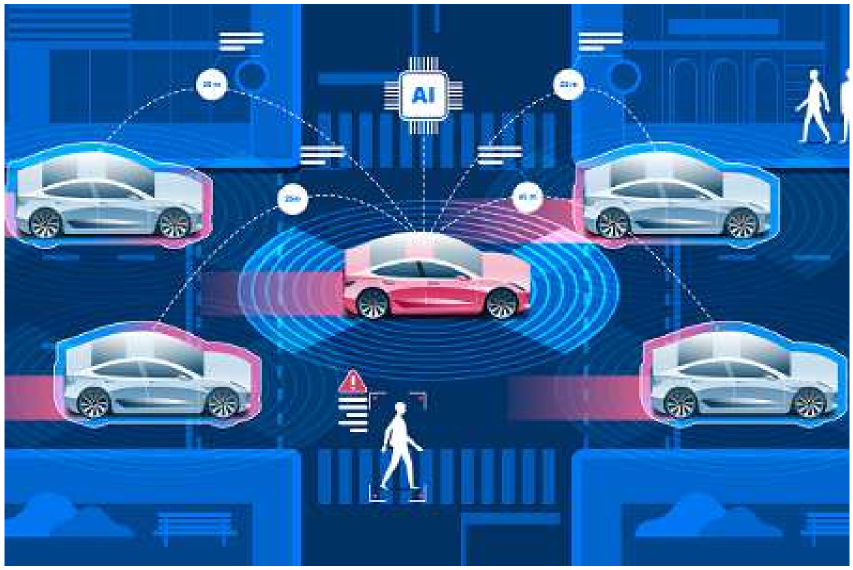

Figure 1 Examples of autonomous vehicles [1].

Figure 2 A typical hospital environment [2].

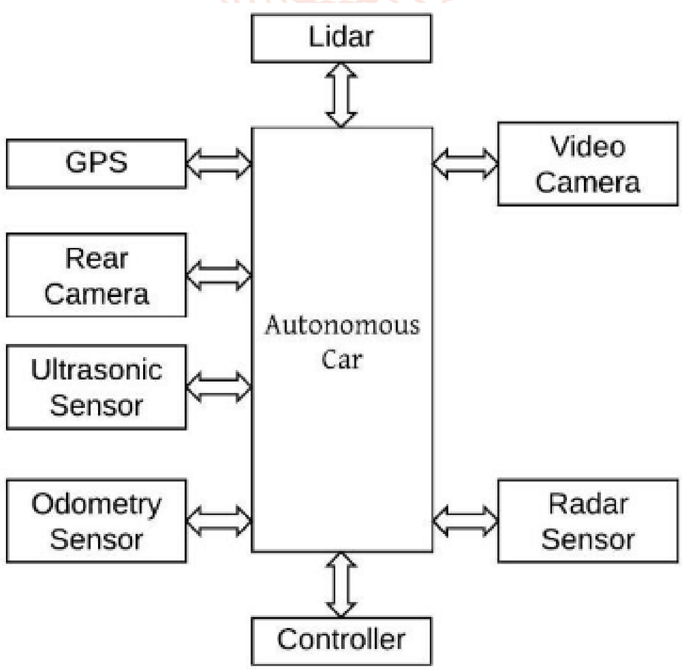

Figure 3 Architecture of Autonomous Car [3].

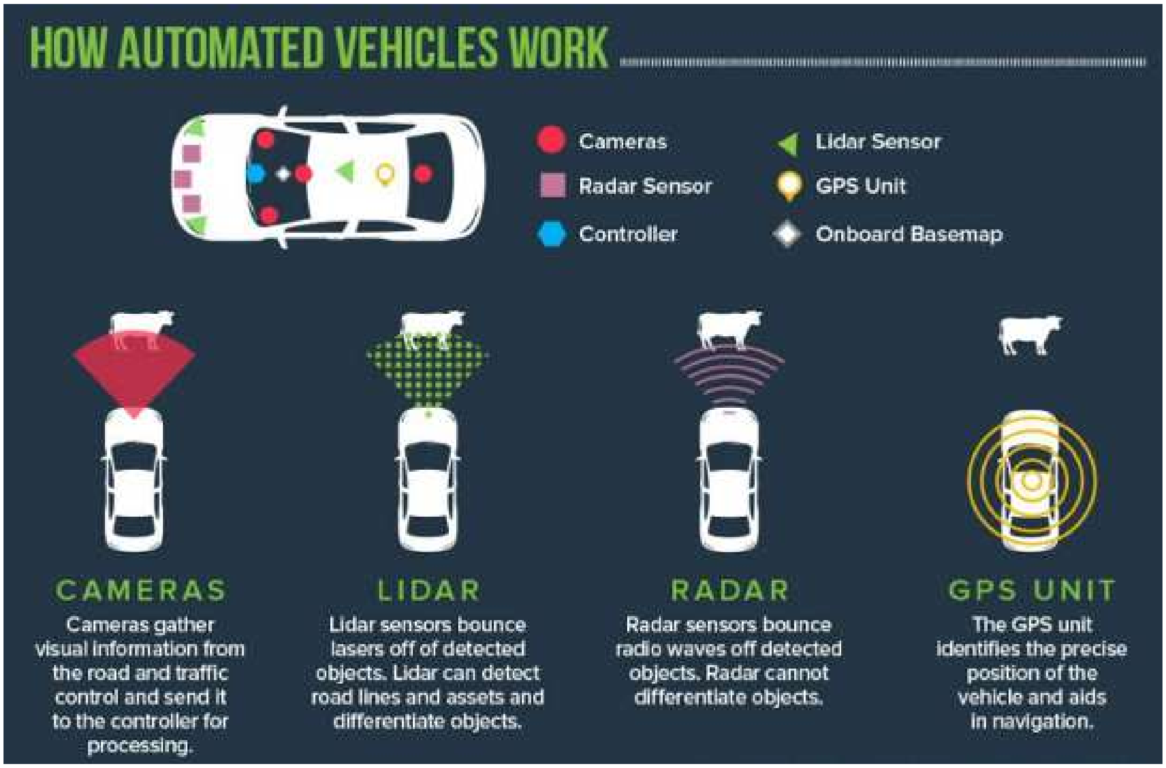

Figure 4 How autonomous vehicles work [6].

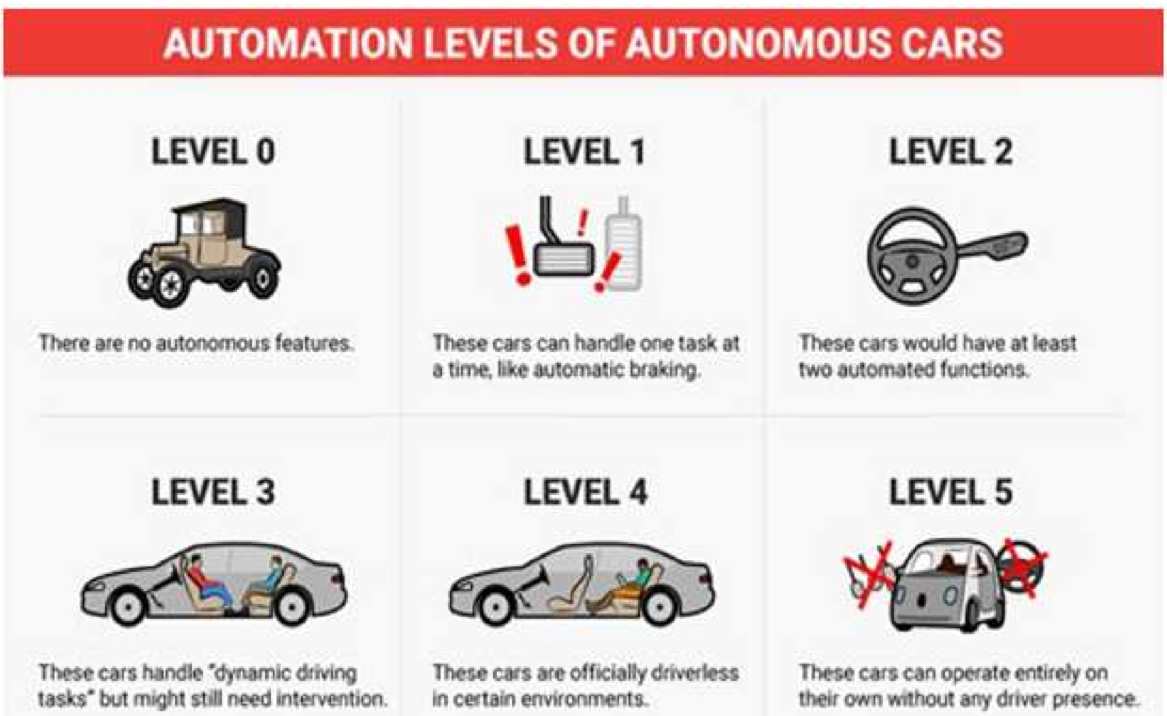

Figure 5 The six levels of autonomy [9].

Figure 6 A CVS delivery vehicle [14].

Figure 7 A typical ambulance [2].

Figure 8 A person using wheelchair to take a ride in a goMARTI self-driving van [15].

Figure 9 Green spaces [18].

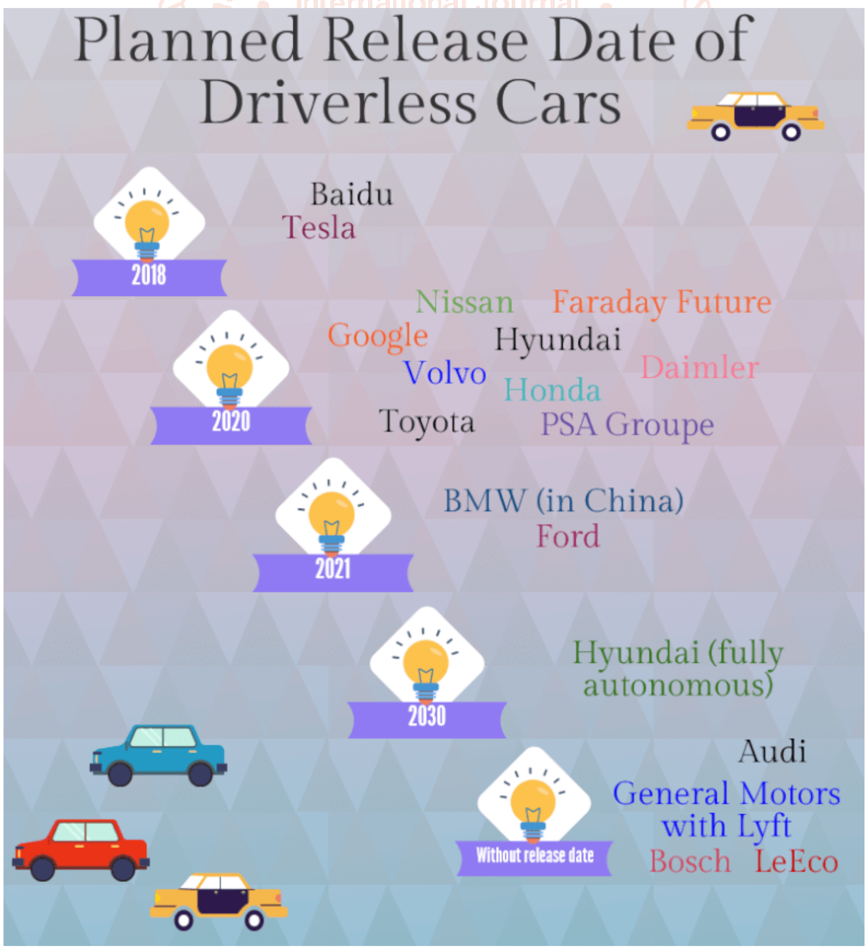

Figure 10 Planned release date of driverless cars [20].