An Evaluation of the Safety and Ethics of Autonomous Vehicles

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This report evaluates whether autonomous vehicles can reach the safety and ethical requirements necessary to integrate into society, and it recommends possible measures vehicle manufacturers should take to improve the outlook of autonomous vehicles. The report examines the ethics behind the autonomous car's decision process and the safety statistics and technologies of self-driving.

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EXECUTIVE SUMMARY

This evaluation report explores whether autonomous cars can meet the safety and ethical requirements necessary to integrate into society. The purpose of this paper is to improve the outlook of autonomous vehicles by providing valuable insight on how to design safe and ethical driverless cars. This will be accomplished by determining whether self-driving cars can achieve the necessary safety and ethical standards to integrate into society. Engineers working on driverless technologies will be interested in the findings of this paper as the recommendations will address the ethical and safety concerns of autonomous vehicles.

A critical subject that needs to be addressed for autonomous vehicles is their safety. Before autonomous vehicles can be made available for widespread use, it is necessary that they are at least as safe as human drivers. Through analyzing statistics on the accidents of autonomous cars, it is clear that through continuous road testing and implementing technologies such as radar, driverless cars can be as safe as human drivers.

Another issue surrounding autonomous cars is the ethical dilemma of putting the safety of passengers in the hands of computers. Through extensive research, it is clear that in order for a self-driving vehicle to make ethical decisions, engineers have to build the artificial intelligence of the autonomous vehicle like a human brain. The most efficient way to accomplish this is to use a brain–cerebellum–organ coordination artificial intelligence model. This framework is able to make ethical and thought out decisions as it imitates human behaviour.

In addition to safety and ethics, another worry is that current autonomous technology is too primitive compared to the desired full autonomy. Through assessing the reliability of autonomous technology, it is apparent current technologies are quickly approaching the capabilities of full autonomy. If engineers continue to allow autonomous cars to gain more driving experience, the reality of safe and reliable autonomy is imminent.

In conclusion, autonomous cars can meet the safety and ethical requirements necessary to integrate into society if engineers continuously improve autonomous technology. This includes implementing radar systems, continuous road testing and utilizing a brain–cerebellum–organ coordination artificial intelligence model.

To summarize, this report dispels the concerns that fully autonomous vehicle do not meet the safety and ethical standards. Through continuous improvements in autonomous technology such as implementing … …. autonomous vehicles will be hitting the road in the very near future.

1.0 INTRODUCTION

With car companies promising full autonomy in the near future, self-driving cars are becoming a reality. If this technology is designed as advertised, it will provide many benefits over human drivers. Autonomous vehicles would lower accidents, reduce traffic and allow the once driver to be more productive during their commute. But before the public trusts their lives to the hands of an artificial intelligence, the safety and ethical concerns of autonomous vehicles must be assessed to determine the true value of driverless technology.

The goal of this report is to improve the outlook of autonomous vehicles through providing valuable insight on how to design autonomous cars to be safer and more ethical. This will be executed by evaluating whether autonomous cars can meet the safety and ethical requirements necessary to integrate into society. The findings within this report will be of interest to engineers who are developing driverless technologies as the recommendations in this report will resolve the ethical and safety concerns of autonomous vehicles.

The report is divided into three main sections. The first section will provide background information on what autonomous cars are and how they work. The second section will discuss the evaluation method and discuss the findings on if autonomous vehicles can meet the safety and ethical requirements. The final part of the report will present recommendations and conclusions on how to improve the safety and ethics of autonomous cars.

2.0 BACKGROUND INFORMATION

This section discusses what autonomous vehicles are and how they work. It goes in-depth into the levels of autonomy and how far the technology has come along. Additionally, this section discusses the technologies that allow autonomous vehicles to capture data, understand their environment and make crucial decisions.

2.1 What are Autonomous Vehicles

As reported by Antonialli et al. (2019), autonomous vehicles "are cars with motion and action capabilities that do not require any sort of conductor (driver) or teleoperation control (remote control)" (para. 8). There are 6 levels of autonomy, which can be seen in Table 1 with each level increasing the amount of driving automation.

Table 1. Levels of Automation. *Source:* (Automated Vehicles for Safety, n.d.)

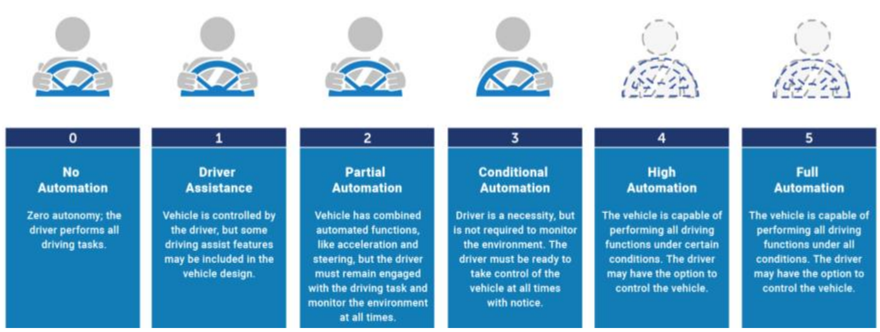

Table 1 displays the six different levels of autonomy, from level zero; fully manual to level five; fully autonomous. Levels one and two have very basic forms of automation and the driver must still be in control. The leap from level two to three is significant as the driver does not need to be in control since the car can now detect obstacles and monitor the environment. Levels four and five are the highest forms of autonomy as the vehicle is able to take over all driving functions under any condition.

Large automakers are seeing the potential of autonomous vehicles and they are soon to be a reality as Ford, GM, Google and Uber are already testing their fully autonomous vehicles. According to Antonialli et al. (2019), Google's autonomous vehicles have already passed the 5 million kilometer mark from their testing, and automakers such as Tesla and Mercedes are already offering level three autonomy (para. 12).

2.2 How Autonomous Vehicles Work

Autonomous driving technology is a complicated system made up of several sub-systems. According to Liu et al. (2018), this system uses a plethora of advanced technologies such as its own operating system, high definition mapping, intricate algorithms, data storage and machine learning models (p.1). However, all of these technologies can be broken down into three major components seen in **Figure 2** (Liu et al., 2018, p.1).

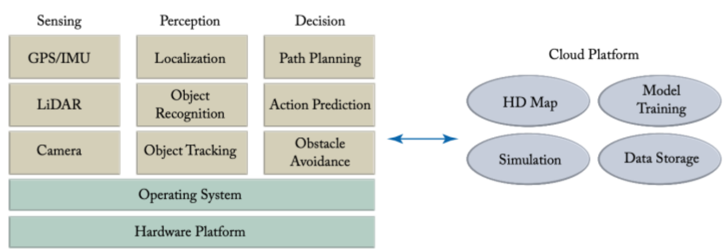

Figure 1. The Three Major Components of Autonomous Driving. *Source:* (Liu et al., 2018, p.2)

Figure 1 displays the three main components of self-driving and the technologies associated with them. Figure 1 displays how the sensing, perception and decision stages are all based on an operating system built on a hardware platform. Moreover, the figure also shows the roles of each stage. The role of the sensing stage is to collect data using various sensors such as GPS, IMU, LiDAR and cameras. This data is then processed in the perception stage for localization, object recognition and object tracking. The map created from the perception stage is then used in the decision stage to determine the best path the car should take to avoid obstacles.

Typically, a self-driving car has several major sensors onboard and each type of sensor has its own advantages and drawbacks. Engineers design autonomous cars to have a combination of different sensors to increase reliability and safety. The sensing technology used in autonomous cars can include a combination of the following:

- **GPS/IMU:** By reporting both inertial updates and global location estimates at a high rate, the GPS/IMU system aids the autonomous vehicle's localization (Liu et al., 2018, p.2). Localization allows the autonomous car to know its location in space. Although GPS is a precise localization sensor, it updates at a slow rate whereas the IMU can produce updates in real-time (Liu et al., 2018, p.2). The use of both GPS and IMU can provide accurate and real-time vehicle location updates (Liu et al., 2018, p.2).

- **LiDAR:** LIDAR is used for mapping, localization, and obstacle avoidance (Liu et al., 2018, p.2). It works by bouncing a laser beam off different surfaces and measuring the time it takes for the reflection to return. (Liu et al., 2018, p.3). This allows LIDAR to measure how far certain obstacles are, which is used to create high definition maps, locate moving vehicles and detect obstacles (Liu et al., 2018, p.3).

- **Cameras:** Cameras are commonly employed for lane detection, traffic signal detection and pedestrian identification (Liu et al., 2018, p.3). Engineers often place eight or more 1080p cameras around the car to detect, recognize and track objects around the vehicle to improve autonomous vehicle safety (Liu et al., 2018, p.3).

- **Radar and Sonar:** In obstacle avoidance, radar and sonar systems are typically deployed as the last line of defense as it can only detect close obstacles (Liu et al., 2018, p.3). The distance and speed of the nearest object in front of the vehicle's route are collected by radar and sonar (Liu et al., 2018, p.3). When the radar detects an object is approaching and that there is a risk of collision, the autonomous car immediately applies the brakes to avoid the hazard (Liu et al., 2018, p.3).

The data collected from the sensors is then uploaded to the perception stage where the vehicle is able to understand its environment (Liu et al., 2018, p.3). The onboard computer processes the images and data that was collected from the GPS, IMU, LiDAR and cameras to perform object detection and tracking (Liu et al., 2018, p.3). To achieve this, the computer has Deep Learning technology, an object recognition software that can extract the features of the object such as the type, size and location (Liu et al., 2018, p.3). The computer then tracks and predicts the trajectory of the object through using machine learning, a software that can recognize patterns similar to a human (Baloglu et al., 2021, para. 2).

The final stage is the vehicle’s decision which is responsible to determine the safest and most efficient path for the vehicle to take (Liu et al., 2018, p.7). Using the map created in the perception stage, the artificial intelligence calculates all possible paths and decides the best course of action to take (Liu et al., 2018, p.7).

3.0 EVALUATION METHOD

Autonomous vehicles are going to become a major form of transportation, but before the public trusts their lives to the hands of artificial intelligence, the safety and ethical concerns of autonomous vehicles must be addressed to see if they can harmlessly integrate into society. To achieve this, the abilities of autonomous vehicles must be compared to a list of criteria to determine the value self-driving cars add to society. This criteria consists of comparing the safety of autonomous cars to traditional cars, analyzing if the decision making of autonomous cars can be ethical and evaluating how close current autonomous technologies are to full autonomy. A combination of these perspectives can determine if autonomous vehicles can meet the safety and ethical requirements necessary to integrate into society.

A critical subject that needs to be addressed for autonomous vehicles is their safety. According to Bhat and Nair (2019), "before AVs can be made available for widespread use, it is necessary to demonstrate to the general public as well as regulators that the autonomous driving technology in AVs is mature enough to be at least as safe as human drivers" (p. 2). Through analyzing past incidents with autonomous cars and comparing the accident statistics between autonomous and conventional vehicles, the safety of autonomous vehicles can be gauged. This can then be compared to the safety of current traditional vehicles to see if the safety of autonomy meets consumer standards.

Furthermore, analyzing the ethics of the decision making process of an autonomous car's artificial intelligence is essential to determine the value of self-driving vehicles. This is since according to Hussain and Zeadally (2019), consumers would be more accepting towards self-driving vehicles if they had similar values to a human (p. 33). Evaluating how similarly the decision making process of autonomous cars can be made to a human's can provide insight on how accepting consumers will be towards autonomous cars.

Lastly**,** assessing how close current autonomous technologies are to full autonomy can provide valuable information on the rate of advancement of current technologies. Once the rate of technological improvement is established, the value of autonomous cars can be determined as it can provide an understanding of the possibility of full autonomy. This is key to identifying the next steps for autonomous vehicles to take in order to be accepted into society.

4.0 DESCRIPTION OF THE TECHNOLOGY

As written by Bhat and Nair (2019), "the advent of autonomous vehicles (AVs) (sometimes referred to as driverless cars) with no need for human assistance is expected to bring forth a multitude of benefits to the transportation system" (p.1).

4.1 Improved Safety

The largest potential benefit of driverless cars is the improved safety it offers. As reported by Hussain and Zeadally (2019), "every year road accidents claim 1.3 million lives and 50 million serious injuries around the globe … and 94% of accidents are caused by human errors" (p. 7). These human errors are a result of various factors including intoxication, carelessness, distraction and aggressiveness.

The implementation of AVs has the potential to reduce the number of accidents drastically as driverless cars are not susceptible to human errors. As stated by Huang et al. (2020), just the employment of "partially autonomous technology such as forward collision and lane departure warning systems, side view assist, and adaptive headlights will potentially prevent or mitigate crashes, and the reduction in injuries and fatalities can be up to 33%" (para. 3). However, this is just speculation and the data collected from rigorous testing needs to be analyzed to determine the safety impact autonomous vehicles will have on roads.

4.2 Increased Convenience and Productivity

Yet another benefit of self-driving cars is the increased convenience and productivity its users will experience. Bhat and Nair (2019) explained that autonomous vehicles have "no need for human assistance" (p.1). This allows AVs to provide accessible and convenient transportation to demographics who are unable to drive such as children, the elderly and those with disabilities. Another convenience issue AVs can tackle is parking. Parking in metropolitan cities is a major nuisance as in denser populations parking is expensive and hard to find. With the integration of AVs, vehicles would simply be able to drop off its occupants and park themselves, eliminating this entire issue.

Furthermore, the lack of a need for human assistance in driverless cars allows the once driver to be more productive. The time the driver once wasted on long commutes would no longer be an issue as passengers of autonomous cars would be able to work or use the car's entertainment system during the ride.

4.3 Increased Traffic Efficiency

According to Hussain and Zeadally (2019), due to the autonomous vehicle's ability to communicate with other AVs, traffic conditions would improve dramatically (p.8). The amount of headway kept between autonomous vehicles would decrease as AVs would know each other's location and movements (Hussain and Zeadally, 2019, p.8). This will increase the amount of space on roads and thus improve traffic congestion. In addition, Hussain and Zeadally (2019) reported, "autonomous cars will also improve fuel efficiency by selecting the best routes, which will also decrease air pollution " (p.8). If the world decides to adopt autonomous vehicles, traffic congestion and air pollution will improve.

5.0 DISCUSSION OF FINDINGS

This section discusses the research findings of the safety and ethics of autonomous vehicles. This includes comparing the safety of autonomous vehicles to conventional vehicles, evaluating how the decision making process of autonomous cars can be made more ethical and evaluating how close current AV technology is to full autonomy.

5.1 Safety of Autonomous Vehicles Versus the Safety of Conventional Vehicles

In order to determine if autonomous vehicles can meet the safety and ethical requirements necessary to integrate into society, the level of safety self-driving offers needs to be established.

To gain an understanding of the safety of self-driving cars, examining past incidents with AVs is essential. Huang et al. (2021) reported, “in 2016, a Tesla vehicle Model S crashed into a truck that was turning left when it was passing through a crossroad” (p.2). Banks et al. (2018) revealed, “that the vehicle was being operated in Autopilot mode”, an enhanced level 2 autonomous system (p.1). The cause of the crash was a result of the vehicle failing to recognize the truck. Banks et al. (2018) stated, the “camera technology failed to detect the trailer against a brightly lit sky” (p.4). This suggests that the onboard cameras on the vehicle failed, which is an error a human driver would not make. However, if the vehicle was equipped with backup sensors such as radar and LiDAR, the crash could have been avoided.

Another point of comparison to be made about the safety of autonomous vehicles versus conventional vehicles is the rate of accidents. Eurich et al. (2017) reported, “accident frequencies computed for all manufacturers showed that conventional vehicles drive one order of magnitude more miles compared to AVs before encountering an accident, with a mean mileage before a crash for conventional vehicles of about 500,000 miles, compared to 42,017 miles for AVs” (p.9). In other words, the accident rate of autonomous vehicles is about 10 times higher than that of conventional vehicles. The accident rate of autonomous vehicles may be unnaturally higher than that of traditional vehicles for the following reasons:

- According to Eurich et al. (2017), 60% of autonomous vehicle accidents are low impact, accidents drivers of traditional cars would allow to go unreported (p.9). This would inflate the ratio of autonomous accidents to conventional accidents.
- Eurich et al. (2017) reported, that other drivers on the road may be “tempted to test out the AV performance at the expense of safety with a more aggressive type of behavior” (p.7). This would result in an increase in unnatural accidents in autonomous vehicles.
- According to Eurich et al. (2017), autonomous vehicles are continuously learning and testing new cars with limited miles which positions these new cars at a higher risk of accident (p.8). This would not accurately reflect the number of accidents that would occur when fully autonomous vehicles come to market.

Despite the high accident rate of autonomous vehicles, Fumkin et al. (2020) estimated that if “90% of the automobiles in the United States became autonomous, an estimated 25,000 lives could be saved each year, with annual economic savings estimated at more than $200 billion in the United States” (para. 9). This implies that even though autonomous vehicles currently get into more accidents than human drivers, it still offers a level of safety unmatched by human drivers.

5.2 Analyzing how Decision Making of Autonomous Vehicles can be Ethical

One of the major ethical concerns about autonomous vehicles is how it makes decisions; especially when the consequence of the choice results in life or death. For example, when the autonomous car is in a situation where it has to choose between saving its passenger or a pedestrian crossing the road, how does it make its decision?

Hussain and Zeadally (2019) reported, autonomous vehicles should have an accident algorithm fast enough that occasions where the AV has to make a decision of who to save should be rare (p.33). However, in the rare event where the vehicle has to make this decision, it has to be ethical and thought out. Hussain and Zeadally (2019) stated, "autonomous cars should adapt a combination of multiple ethical theories based on different parameters such as, but not limited to, maximizing utility, deontological ethics, morality, and so on to be able to make morally and ethically correct decisions while responding to an unforeseen but expected crash" (p.33). These characteristics are specific to the human conscience. This implies that the best way to implement morals into the artificial intelligence of autonomous vehicles is to design them to think like a human.

Huang et al. (2021) explained, the optimum technique of creating artificial intelligence to think like a human brain is to utilize a brain–cerebellum–organ coordination model (p.5). This model is created through allowing artificial intelligence to perceive, evaluate, learn and think about its environment (Huang et al., 2021, p.5). As shown in **Figure 2**, the brain–cerebellum–organ coordination model senses its environment, stores data in its memory and performs its decision making through thinking.

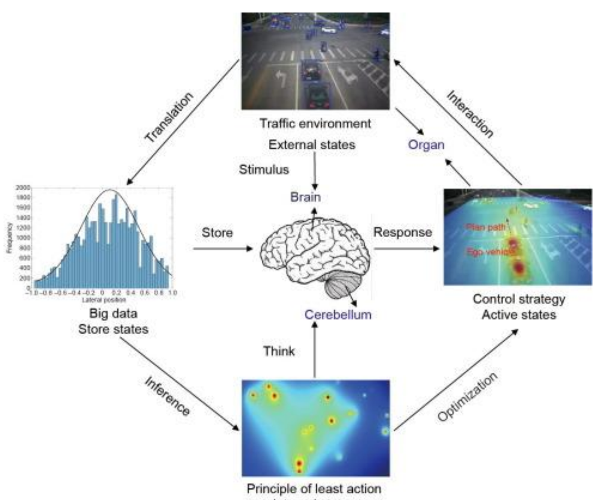

Figure 2. The Brain–Cerebellum–Organ Coordination Model.
Source: (Huang et al., 2021, p.6)

Figure 2 displays how the sensors, data, thinking process and output of the brain–cerebellum–organ coordination model interact with each other. External states activate the brain where traffic information is stored and then the cerebellum calls the internal state to start thinking.

Through programming basic morals and exposing artificial intelligence that utilizes this framework to road testing, the vehicle will gain ethical principles to follow (Huang et al., 2021, p.6). Through road testing, artificial intelligence can learn and imitate human behaviour and ethics through observing its environment. The vehicle would then be able to make ethical and thought out decisions.

5.3 Evaluating How Close Current Autonomous Technologies are to Full Autonomy

Evaluating how close current autonomous technologies are to full autonomy can provide information on the rate of safety and ethical improvement. A way to evaluate the advancement of autonomous vehicles is to examine the number of disengagements, in other words, the number of times a human had to take control of the car.

According to Eurich et al. (2018), in 2015 Google reported a total 341 of disengagements which occurred over 424 331 miles of testing (p.4). In the next year, this number improved to 124 disengagements despite an increase in testing to 635 868 miles (Eurich et al., 2018, p.4). The number of disengagements improved by a factor of 4 and will continue to improve as artificial intelligence gains more road experience and enhances its driving dynamics. A car with level 5 autonomy should have 0 disengagements as seen in **Table 1**, and if autonomous cars continue to improve at such a high rate, full autonomy could arrive in the near future.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Autonomous cars can meet the safety and ethical requirements necessary to integrate into society.

Even though autonomous vehicles have an accident rate higher than traditional cars and have incidents of disengagements, they can still be as safe and ethical as conventional vehicles if engineers design them to the following recommendations:

- Implement radar and sonar sensors discussed in **Section 2.2**. These sensors would have prevented many autonomous accidents such as the 2016 Tesla crash discussed in **Section 5.1** as it would have provided a last line of defence to detect the obstacle.
- Continue to allow artificial intelligence to learn driving behaviors through continuous testing on roads. This will allow autonomous technology to continue to improve at a rate of a factor of 4 and will result in safer and more reliable self-driving sooner.
- Design the artificial intelligence utilizing the brain–cerebellum–organ coordination model discussed in Section **5.2**. This will allow autonomous vehicles to make thought out ethical decisions as it imitates human behavior.

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