# Navigating the Road to Autonomous Vehicles: Balancing Technological Advancements, Ethical Dilemmas, and Societal Impact

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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## Introduction

Autonomy proves to be a defining theme of the 21st century, with its influence extending into the realm of transportation through the development of autonomous vehicles (AVs). The introduction to AVs has completely reshaped how we envision mobility, safety, and environmental sustainability, bringing forth unprecedented ethical dilemmas. Autonomous vehicles may be the solution to minimize many of society’s travel issues such as traffic congestion on the roads, safety risks, and the negative environmental impacts of human operated vehicles. Despite the potential benefits to the implementation of autonomous vehicles, the underlying ethical issues have significantly hindered progress towards a full scale adaptation of AVs in our current society. The idea of autonomous vehicles dates back to the 1960s, but the first autonomous vehicle was developed in 1980 by Mercedes-Benz partnering with Bundeswehr University in Munich (Othman, 2022). Since then, progress was steadily increasing until the autonomous industry experienced exponential growth within the last two decades. Beginning with Google’s 2009 launch of a self-driving car project, followed by Apple’s 2014 launch of “Project Titan” (Otthman, 2022), both projects operated with the goal of developing fully autonomous vehicles by the early 2020s. Unfortunately, the two projects failed to meet their goals due to an overwhelming number of obstacles, such as the technology itself, laws and regulations, public acceptance, and ethical issues.

In the United States, vehicle crashes are the leading cause of death for people ages 1-54, claiming 1.35 million lives a year worldwide (CDC,2023). Studies show that about 94% of these crashes are a result of human error and that full-scale implementation of autonomous vehicles could reduce this statistic by 90% (Fleetwood, 2017). In order for society to adopt a full implementation to reach this statistic, it is essential to develop driving simulators and other testing technologies that ensure the safety and reliability of these AVs. According to the June 2023 Report to Congress regarding autonomous vehicles, the process of passing even just a small feature of the system involves several stages. These stages include: test scenarios, metrics, simulation, test track, on-road, framework testing, and preventative maintenance (Report to congress, 2023). The report indicates that most of the primary and critical testing is done in the simulation and test track phases, therefore highlighting the urgent need of high-level adaptive AV simulators to further the progression of the new technology. The technical project based off of this research paper aims to develop an autonomous vehicle simulator that is able to communicate with other vehicles on the road. In this research paper, my approach supports the vision of transforming transportation systems into safer, more efficient, and environmentally sustainable networks through the full-scale implementation of autonomous vehicles.

**Literature Review/Background**

The National Highway Transportation Administration recognizes 6 tiers of automation from level 0, indicating no automation to level 5 signifying full autonomation. Figure 1 defines these levels in terms of autonomous vehicle technology and provides examples and features included within each level (Roth, 2020). The majority of cars on our current road system fall into the category of partial automation, but car manufacturers are putting increasingly more autonomous features in vehicle designs just to stay competitive (Fleetwood, 2017). Most literature regarding autonomous vehicle technology highlights a significant focus on the transition from level 2 to level 3 automation,

| Level of Automation | Defining AV Technology | Examples |
|---|---|---|
| 0- No Automation | The driver performs most tasks | Features like cruise control and crash assistance are still a part of the vehicle system |
| 1- Driver Assistance | Steering or braking assistance, but not both | Advanced cruise control that will brake when possible collision detected |
| 2- Partial Automation | Steering and braking assistance | Maintaining driving position while on the highway |
| 3- Conditional Automation | Complete automation of a simple driving task, Automated Driving System-L3 | AV likely able to drive from a simple point A to B |
| 4- High Automation | Full automation in pre-planned driving scenarios, Automated Driving System-L4 | AV can accomplish all driving tasks, including parking |
| 5- Full Automation | Automated Driving System-L5 | A driver is no longer needed |

**Figure 1***: Levels of Automation*

where control can shift from human drivers to conditional automation. This transition represents a critical threshold, introducing legal, ethical, and technical challenges essential to creating a road system compatible for both human drivers and AVs. Navigating this period will likely be the most challenging and dangerous phase of implementation, but once surpassed, AVs hold the promise of significantly enhancing road safety, efficiency, and sustainability.

## Methodology

Using a series of reports regarding studies on autonomous driving, this paper will attempt to synthesize current findings to highlight the key challenges and benefits of adopting a full scale implementation of autonomous vehicles. The quantitative data collected from the technical project based on this research paper will provide a means to test the safety and reliability of autonomous vehicles before they are introduced to the public road systems. Focusing on the qualitative approach, this research paper will provide a comparative analysis of the impacts of autonomous vehicles and human drivers, as well as weighing the benefits and setbacks of implementing AVs into society.

## Discussion

Technology and autonomy undoubtedly hold the potential to transform our society and change the way we live, work, and interact with our environment on a daily basis. Due to the fact that this time period that we are currently witnessing is so significant, researchers refer to it as the "Fourth Industrial Revolution" (Bezai, 2021). This revolution is characterized mainly by the combination of the physical and digital worlds, which we have seen in widespread emergence of artificial intelligence starting in 2022. The vast capabilities of AI are rapidly turning the focus of societal advancement onto autonomous vehicles and actively weighing the risks and opportunities AVs bring.

Much like any significant change to a system, the idea of altering transportation has completely steered many away from potentially owning a driverless car. A study from the Pew Research Center showed that the majority of the adults from their study believe that the widespread adaptation of AVs would be a negative effect rather than positive (Rainie, 2022). Figure 2 shows the results from this study depicted in a pie chart with 44 percent of adults falling into the “bad idea” category and 29 percent falling into the “not sure” category.

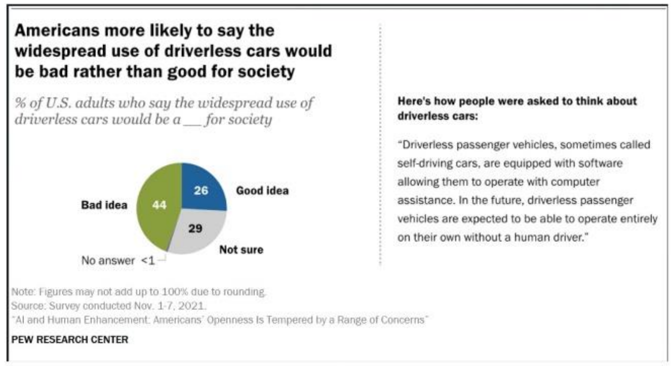


**Figure 2:** *Pew Research Center poll statistics*

These results were expected and somewhat justified given the negative effects that the initial implementation of autonomous vehicles would have. The most impactful drawbacks of AVs are mostly temporary and only have a significant effect directly after implementation. These drawbacks include job shifts, initial cost of infrastructure changes and new legislation, increased digital risk like hacking and system failures, and ethical dilemmas in programming. If AV’s are ever fully implemented, the first significant change will be the shift in transportation jobs affecting more than 4 million people. In the United States, 2.9 percent of workers are employed in driving occupations. With the introduction of autonomous vehicles, this percentage will be out of work and new higher-level job opportunities will arise in the realm of technology (Klaver, 2020). Although this transformation of work will initially create a disruption to the economy, investing in training programs to ensure workers are equipped with the necessary skills to take on these new roles would mitigate the overall problem (Hoffman, 2022).

Another hesitation that most people mention when speaking against the implementation of AVs is the initial cost of buying an AV and infrastructure changes on the road systems. A complete turnover from human operated vehicles to driverless cars does not happen instantaneously. The process will take at least a few years, leading to a period of time in which both AVs and human drivers travel on the same roads. This transition era has the potential to become the most dangerous aspect of integrating autonomous vehicles into the road systems due to the mix of infrastructure required for human drivers and autonomous vehicles to operate cooperatively (*Figure 3*). In order to operate safely, AVs need highly visible road curves, speed limits, and other signage as well as a predictable environment around them (Othman, 2021). Human drivers are anything but predictable as they often do not abide by the rules of the road, which is a crucial aspect in the safe execution of AV technology. The conversion period, which may last for several years, can only be navigated through new legislation and changes in the way the road system operates to ensure that both human drivers and AVs travel cooperatively and without harm. Similar to other systems heavily reliant on technology, autonomous vehicles are vulnerable to hacking and system malfunctions creating a realm of unprecedented aspects of transportation.

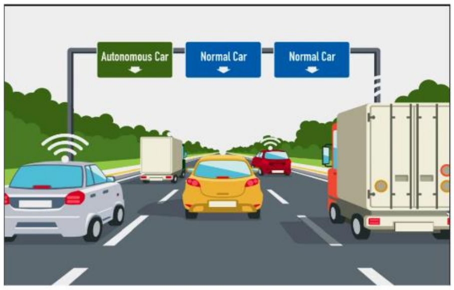

**Figure 3:** *Example road system during the transition period from human drivers to AVs (Stewart, 2017)*

Despite the initial challenges and societal apprehensions surrounding the implementation of AVs, the long-term benefits significantly outweigh the temporary setbacks. Through extensive research, autonomous vehicles have proven to be substantially safer, more efficient, and better for the environment. The paramount concern of safety is addressed by AV's ability to reduce human error, which is the cause of 93 percent of traffic accidents (Nikowitz, 2015). Figure 4 shows the breakdown of total vehicle crashes per year in the United States, quantifying the percentage of crashes that resulted from the following human errors: alcohol-related, speeding, distracted, failure to stay in lane, failure to yield, wet roads, erratic vehicle operation, inexperience, drug-related, snow/ice on roads, fatigue, and other driving errors. From this list, AVs will eliminate all human driving errors and substantially reduce crashes related to hazardous roads by introducing new technology to counteract difficult weather conditions. The technology behind AVs include advanced sensors, machine learning algorithms and comprehensive data analysis, which enable them to navigate the road system with a level of precision that far surpasses human capability. Given that transportation injuries are the fifth leading cause of death around the world (Bimbraw, 2015), this technology holds the potential to save millions of lives every year and make transportation considerably safer. Due to the sharp decline in vehicle accidents after AVs are fully implemented, there will be a substantial economic advantage, as the cost of traffic-related economic losses in the United States annually exceeds $300 billion (Nikowitz, 2015). Not only do AVs lower the amount of money spent on vehicle repairs and crash recovery because of the infinitely safer road system, they also reduce ownership costs due to their increased efficiency.

| | |
|---|---|
| Total crashes per year in U.S. | 5.5 million |
| %human cause as primary factor | 93% |
| Economic costs of U.S. crashes | $300 billion<br>€272 billion |
| % of U.S. gross domestic product (GDP) | 2% |
| Total fatal &injurious crashes per year in U.S. | 2.22 million |
| Fatal crashes per year in U.S. | 32,367 |
| % of fatal crashes involving alcohol | 31% |
| % involving speeding | 30% |
| % involving distracted driver | 21% |
| % involving failure to keep in proper lane | 14% |
| % involving failure to yield right-of-way | 11% |
| % involving wet road surface | 11% |
| % involving erratic vehicle operation | 9% |
| % involving inexperience overseen | 8% |
| % involving drugs | 7% |
| % involving ice, snow, debris or other slippery surface | 3.7% |
| % involving fatigued or sleeping driver | 2.5% |
| % involving other prohibited driver errors | 21% |

**Figure 4:** *U.S. crash motor vehicle scope and selected human and environmental factor involvement (Nikowitz, 2015)*

Efficiency is another significant benefit, as autonomous vehicles promise to optimize travel time, increase accessibility, reduce traffic congestion and minimize land use. Through advanced navigation systems, AVs can navigate roads more smoothly, reducing unnecessary stops and starts which leads to less traffic, more mileage, and better travel time. In a study done in 2020, a traffic simulation collected platform data from a one direction two lane expressway with a mixture of connected autonomous vehicles and human drivers (Li, 2020). As shown in figure 5, the average travel time decreases as the number of autonomous vehicles increases. After full implementation of AVs, the average travel time is at an absolute minimum with much fewer vehicles per hour on the roads. In addition to optimizing travel time and decreasing traffic congestion, autonomous vehicles introduce an aspect of accessibility that significantly enhances transportation options for various segments of the population. This includes older people, individuals with disabilities, and those who are unable to drive for other reasons, offering them a level of independence and mobility that was previously unattainable. For these groups of people, having the ability to use or even own transportation opens up many doors and opportunities, helping bridge the gap in accessibility by ensuring that these people have access to work, healthcare, and other aspects of life that require travel. In addition, a significant benefit of autonomous vehicles that is frequently overlooked is the ability to reduce parking spaces to preserve land area in cities.  It was estimated that about 31 percent of urban district areas are dedicated to parking space (Shoup, 2011), this number could be significantly reduced with implementation of driverless cars because they do not have to park in the city- they can drive without a human to a less densely populated place to park for the day. With fewer parking lots in cities, urban spaces could be repurposed, potentially enhancing city life and the economy. In contrast to this fact, AVs will cover more distance to get to these rural spots, outputting more emissions into the environment. However, as far as the energy and emissions factors go, the statistical benefits largely outweigh the setbacks.

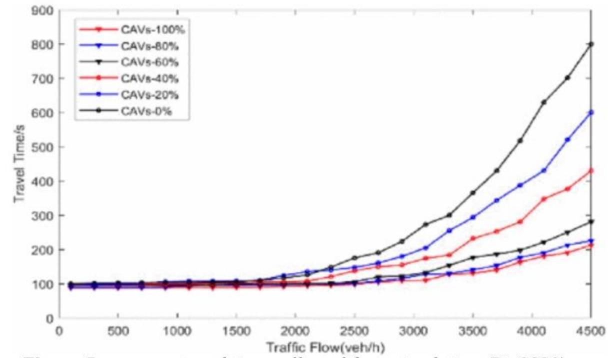

**Figure 5:** *average travel time collected from simulation (Li, 2020)*

With the growing importance of sustainable solutions to combat climate change, the environmental impact of autonomous vehicles is not to be overlooked. Figure 6 depicts a graphic of how the unrelated advantages of autonomous vehicles lead to the 3 main effects on the environment: reduced emissions, minimized noise/light pollution, land/water/biodiversity effects (Silva, 2022). AVs are designed to be highly fuel efficient, optimize driving patterns, and reduce the number of vehicles on the road and therefore have the potential to dramatically lower the carbon footprint of transportation. The U.S. Environmental Protection Agency's 2016 data shown in figure 7, illustrates nearly a 50 percent reduction in fuel consumption since 1975, primarily credited to the introduction of the "eco-driving" component in autonomous vehicles (Bagloee, 2016). Stemming from the same cause, the ability of AVs to reduce traffic can substantially decrease the amount of noise and light pollution emitted by vehicles.

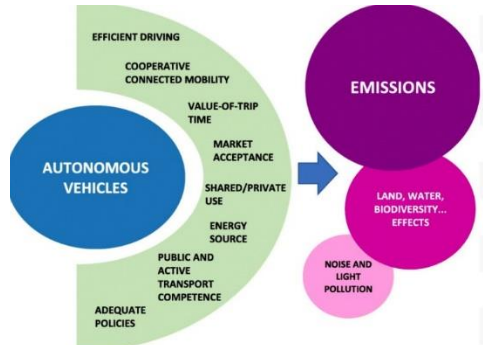


**Figure 6:** *Graphical abstract of the impacts of AVs on the environment (Silva, 2022)*

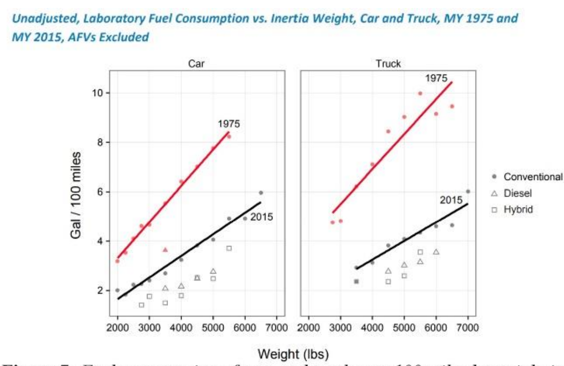


**Figure 7:** *Fuel consumption of cars and trucks per 100 miles by weight in the years 1975 and 2015. Data from the United States Environmental Protection Agency reported in* [https://www.fueleconomy.gov/feg/pdfs/420r16010.pdf](https://www.fueleconomy.gov/feg/pdfs/420r16010.pdf)

In a future world of 100 percent driverless cars, noise pollution would diminish by 24 percent and light pollution would also decrease as AVs can drive safely under low-light conditions (Silva, 2022). The last effect that AVs have on the environment are a mixed bag of both benefits and drawbacks. As discussed earlier in this paper, the increase in urban land space due to the fewer parking lots will greatly benefit cities and city accessibility. Although there has not been much research done on the effects of AVs on water and biodiversity, experts expect that autonomous vehicles will have both positive and negative impacts. The reduction in surface runoff due to fewer roads and parking lots, could lead to less pollution in bodies of water, benefitting the aquatic ecosystems that depend on water quality. On the other hand, the shift towards autonomous vehicles could cause an "urban sprawl" which would encourage increased travel distances, potentially threatening natural habitats and biodiversity (Silva, 2022). By recognizing and addressing the negative impacts, there is opportunity to redesign transportation networks to leverage the benefits and mitigate the potential setbacks to ensure that AVs are truly a force for positive change.

## Conclusion

The full-scale implementation of autonomous vehicles presents significant opportunities, but several challenges as discussed in this paper. Most of the challenges occur in the initial stages of AV implementation, but as technology progresses and society adapts, many of these challenges are expected to diminish, leaving only the benefits and manageable risks. Researchers predict that the technology will experience a gradual increase between 2020 and 2035, as more and more people will begin to have access to it (Bunghez, 2015). In the past four years, this statement has proven to be true with the launch of Tesla Autopilot, self-parking cars, and advanced cruise control. As a society, we have already entered the transition period to complete the integration of driverless cars but navigating this next decade of changeover will require a unified effort from engineers, policymakers, and communities to adapt and establish this new way of travel. Through extensive research, autonomous vehicles have proved to be considerably safer, increasingly more efficient, and significantly more beneficial for the environment than manually operated vehicles. Despite the preliminary effects of job shifting, infrastructure changes, new legislation and programming risks, once overcome, the long-term positive impacts that AVs have on society greatly outweigh the initial challenges. That being said, the manufacturing of autonomous vehicles is dependent on qualitative data and testing of AVs through simulators and test-track phases, highlighting the importance of autonomous driving simulators (discussed in depth in technical report). Further research on this topic could entail a detailed analysis of the redesign of cities and road systems to accommodate autonomous vehicles, capitalizing on the benefits whilst alleviating the setbacks. This research could explore the potential for creating more community spaces in cities, reducing urban sprawl, and enhancing public transportation through the integration of AVs. Overall, the successful integration of autonomous vehicles offers the potential of a new world of transportation contingent upon effectively balancing technological advancements, ethical dilemmas, and the impacts on society.

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