Autonomous Driving Simulator Design and Analysis

(Technical Paper)

Navigating the road to Autonomous Vehicles: Balancing Technological Advancements, Ethical Dilemmas, and Societal Impacts

(STS Paper)

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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

Autonomous driving is one of the world's most recent technological advancements and holds the potential to revolutionize the future of transportation. The concept has been developing since the early 1960s but has made the most significant progress within the last 2 decades. Beginning with Google's 2009 launch of a self-driving car project, followed by Apple's 2014 launch of "Project Titan"(Othman, 2022), both projects operate 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. Aside from these challenges, the adaptation of AVs presents clear benefits, such as minimizing energy and emissions, improving mobility and traffic patterns, and facilitating widespread accessibility to transportation.

To further advance the integration of autonomous vehicles in the real world, 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 a small feature of the system involves several stages. These stages include test scenarios, metrics, simulation, test track, on-road, framework testing, and preventive 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, thus highlighting the urgent need for high-level adaptive AV simulators to further the progression of the new technology. The technical project outlined in this prospectus aims to develop an autonomous vehicle simulator that is able to communicate with other vehicles on the road. This initiative is driven by the pursuit of gaining deeper insight into unforeseen situations that might arise as AVs are integrated into real-world road scenarios, ultimately bringing us a step closer to full implementation of

AVs. The STS topic will focus on the ethics behind AV programing and whether this complete implementation will be beneficial or even possible for our society in the near future.

Technical Topic

Autonomous vehicles, like any developing technology with the potential to influence human safety, must undergo rigorous safety assessments and performance evaluations before they can be implemented on roads filled with human drivers. In order to not jeopardize human lives during these testing trials while also obtaining the most accurate data possible, an autonomous driving simulator that is able to communicate with other "cars" in the virtual world can significantly speed up the development process as well as improving safety and technological features within the design. In the VICTOR laboratory, our capstone team is attempting to improve the existing manually operated simulator by incorporating an open-source autonomous driving simulator known as CARLA. CARLA stands for CAR Learning to Act and is a "simulation platform (that) supports flexible specification of sensor suits, environmental conditions, full control of all static and dynamic actors, maps generation and much more." (Team, 2023). CARLA simulation is recognized by the National Highway Transportation Administration as between levels 4-high automation and 5-complete automation. The levels range from 0-5 increasing in order of autonomy, leaving most cars on our current road systems to be around level 2-partial automation (Fleetwood, 2017). The simulator will incorporate CARLA as a mechanism for obtaining simulation data and directing vehicle controls. Figure 1, a schematic diagram of the autonomous driving simulator (ADS) located in the VICTOR laboratory, depicts

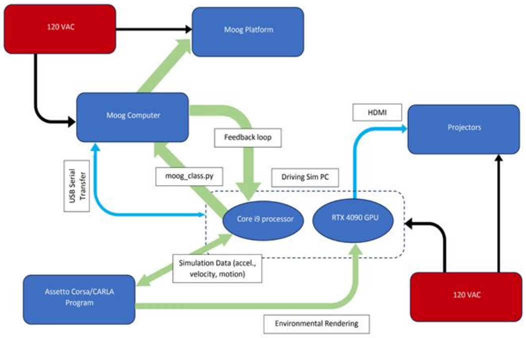


Figure 1: Schematic diagram of the Autonomous Driving Simulator in the VICTOR lab. Created by our capstone team.

how it operates as a mechatronic system. In simple terms, the ADS consists of sensors, controllers, and actuators that allow it to run independently of human control. As the diagram shows, the entire operation is powered off 120 VAC, which is allocated to the MOOG platform and computer. The platform consists of parts that both hold up the simulator and move the actual structure around according to input values of the 7 degrees of freedom (DOF): roll, pitch, heave, yam, lateral, and buffer. The computer consists of a Core i9 processor that both receives and returns simulation data to the CARLA program allowing CARLA to send the information to the RTX 4090 GPU graphics card which displays real life driving scenarios on the projectors through an HDMI connection. The current simulator requires input for any DOF value to move the simulator. When moog_class.py (code mentioned in figure 1) is run, the car moves according to the input values obtained through the manual controls of the human operator. Installing CARLA will eliminate the need for the human driver and allow for performance testing of AVs to be done using this simulator. Although CARLA is very well developed, there are still ample opportunities for improvement. Studies have shown that autonomous vehicle cameras and LiDAR sensors are not entirely weather resistant, meaning that in the case of inclement weather the probability of a system error increases significantly (Jeon, 2022). This issue is amplified when implementing a number of features reliant upon these external and internal sensors, such as freeway merging. Freeway merging is one of the biggest challenges regarding fabricating an AV simulator and is a challenge that we hope to overcome with the VICTOR lab simulator this year. In a study conducted in 2017, 300 simulated vehicles were generated with the same initial speed and the subject being the merging vehicle on a ramp. It was found that the subject vehicle could only merge properly into the target lane when satisfying the conditions of time and space between the subject vehicle and the leader in the target lane as well as the follower (Zhou, 2017).

One of the primary goals of the technical research is to implement this merging system into the AV simulator in the VICTOR lab so that the simulator can successfully communicate with vehicles inside the detection range shown in figure 2.

Developing this seemingly simple feature will decrease congestion on freeways by a notable amount in direct proportion to the number of AVs on the road. This data is proven by Zhou's paper and can be seen in figure 3. Overall, the technical design studied in this paper has the end goal of transforming the driving simulator in the VICTOR lab into an autonomous system with the integration of CARLA and enhancing communication with other vehicles to allow for safe and proper freeway merging. After these goals have been achieved, the AV simulator will be used in testing and performance reviews in technological efforts to establish a safer and more accessible world filled with autonomous vehicles.

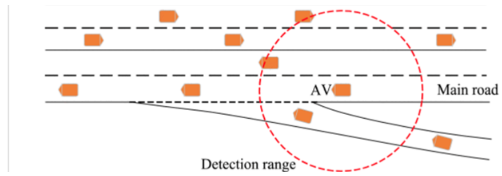


Figure 2: Autonomous car detection range when merging onto a freeway

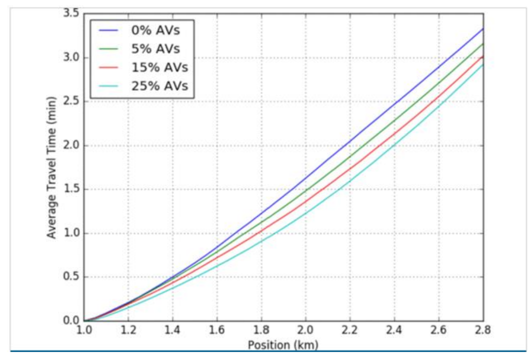
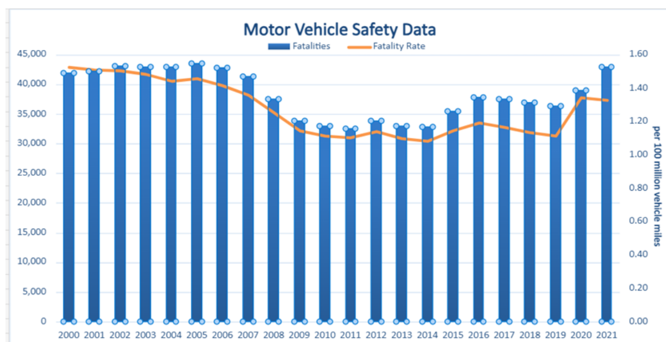


Figure 3: Average travel time in minutes per position in km of all cars on the road system according to the percentage of AVs driving. Graph and data from Zhou 2017.

STS Topic

While an operational AV simulator has the potential to facilitate safe performance testing and expedite the adaptation process, the ethical and safety concerns linked to AVs could hinder their widespread implementation in the real-world. One of the most prominent questions that must be addressed is "Are autonomous vehicles actually safer than human-operated vehicles?" The answer to this question lies in the ethics of the individual being questioned. In 2021, roughly 43,000 fatalities in the United States were attributed to automobile accidents and over 2 million injuries were reported (Bureau of Transportation Statistics, 2021). As shown in figure 4, the fatality count is not only high, but has been on an upward trend since 2014. A study conducted by the National Highway Traffic Safety Administration reported that 93% of these investigated collisions are as a result of human error. (The Relative Frequency, 1999). Although an autonomous vehicle can never be tired, distracted, or inebriated, they do introduce a level of system failures that are not prevalent with human operated vehicles. Overall, AVs are approximately 10% safer than non-automated vehicles and would save hundreds of lives if fully implemented (Kalra, 2016). The lives saved are not necessarily the lives of the people within the autonomous vehicle that is heading toward collision, which brings us to the more subjective ethics of AV programming. This raises the question: are AVs really 10% safer for an AV owner? Human nature is intrinsically self-motivated and often acts for the benefit of oneself; therefore the solution is embedded within software engineering (Mamak & Glanc, 2022). One of the most significant points of contention that has caused many companies to reconsider the pursuit of manufacturing AVs stems from a timeless philosophical debate called the trolley problem, as applied to automated cars. The trolley problem, at its core, proposes a scenario in which an uncontrollable trolley is headed toward hitting five people, but there is an option to divert to another track with only one person on it. The issue seems to have a simple solution: choose the lesser of evils and divert the trolley toward one person. The situation becomes much more complex when assigning a label to each person. For example, what if the single person was someone in close relation to you, such as your parent or child, but the group of five people were doctors? This dilemma presents itself in the software development of autonomous vehicles when preparing for the unavoidable situation of a road collision. AVs must be equipped with a crash optimization algorithm that has sensors to analyze the scenario and make a split-second decision to avoid harm to occupants, but at the potential expense of other vehicles or pedestrians.

While ethics and safety are the utmost concerns and main purpose of using an AV simulator, other factors equally affect adaptation. Some of these factors include, the value of time, accessibility, land use, energy and emission, and job shifting (Bagloee, 2016). Perhaps the most appealing aspect of AVs in society is the idea of being able to disengage from operating the vehicle, allowing for the freedom to do whatever you want during the commute. In addition, relinquishing the need for operation of a vehicle expands transportation accessibility to individuals who are medically restricted from driving, unable to obtain their license, or third world countries that lack proper infrastructure. Another benefit that is frequently overlooked is the preservation of landscape. It was estimated that approximately 31% of urban district areas are dedicated to parking space (Shoup, 2005). This number could be significantly reduced with the 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. On the contrary, AVs will cover greater distance to reach these rural spots, outputting more emissions into the environment. As far as the energy and emissions factors go, the statistical benefits largely outweigh the setbacks. The U.S. Environmental Protection Agency's 2016 data shown in figure 5, illustrates nearly a 50% reduction in fuel consumption since 1975, primarily credited to the introduction of "eco-driving" which is a prominent element integrated into the development of AVs (Bagloee,



While dipping through most of the 2010's, the number of motor vehicle fatalities have unforuntately risen again in recent years.

Figure 4: Motor Vehicle Safety Data. This graph shows the number of fatalities per year from 2000-2021 and the fatality rate modeled from data and statistics gathered from: https://www.bts.gov/content/motor-vehicle-safety-data

2016). Along with fuel efficiency, AVs have the potential to reduce traffic by minimizing human error and quickening reaction times, thereby reducing carbon emissions and drive times. Lastly, a full implementation of driverless vehicles would cause a significant job availability shift from low-level to high-level jobs. Public transportation and truck drivers make up a significant percentage of low-level jobs in the United States, and the adaptation of autonomous vehicles would quickly replace these jobs with higher-level jobs regarding the maintenance and development of car software (Flamig, 2016).

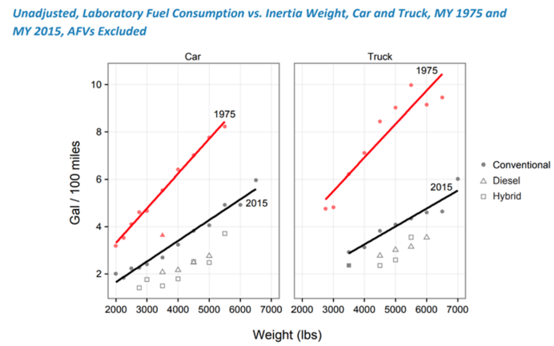


Figure 5: Fuel consumption of cars and trucks per 100 miles by weight in the years 1975 and 2015. Data from the United States Environmental Protection Agency reported in https://www.fueleconomy.gov/feg/pdfs/420r16010.pdf

Research questions and methods

The fundamental question of this analysis is clear: at some point in the near future, will autonomous vehicles be the logical and ethical choice of transportation, leading to widespread adaptation of the technology? Our capstone team intends to experiment with the CARLA simulator on different road scenarios exhibiting potential points of collision or possible unaccounted for system errors. We intend to gather data through research to investigate how the coexistence of both human drivers and autonomous vehicles on the road might look and apply that to situations of controversial ethics. While there will never be one “correct” solution to the issue of ethics in autonomous vehicles, there are statistics that prove that autonomous vehicles may be a more rational and safer choice.

There is no exact number that can quantify precisely how much safer an AV would be than a human driver, some optimists say it is close to 90% but neglect to account for the new risks that an AV may introduce (Litman, 2023). Regardless of how much safer it is, saving a few lives from automobile accidents is better than saving none. In addition to AVs being a good ethical choice, they are also a more logical and cost-effective choice. Litman's article provides research data that shows a cost comparison between human-driving cars and self-operating vehicles. As depicted in Figure 6, the total cost of an AV will eventually equal and surpass the current automobile in terms of inexpensiveness, because they are more fuel efficient, allow for shared rides, can park far away ,and more. Although AVs offer many benefits and implementing them would seemingly improve our way of life, they must first overcome a significant number of challenges.

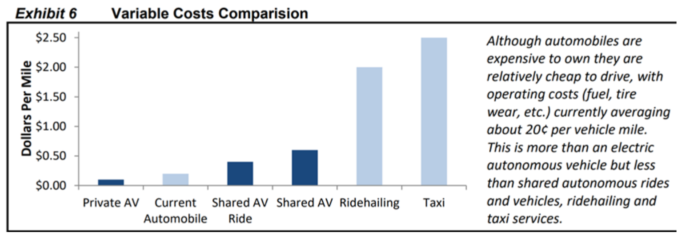


Figure 6: Vehicle costs comparison of AVs vs. current manual automobiles. Data from: Litman, 2023

Conclusion

While both societal and technological advancements still need to be made, the full adaptation of autonomous vehicles is not completely out of reach. With emerging technologies, such as the AV simulator in the VICTOR lab, performance and safety features can be accurately tested in a virtual environment while not harming anyone. Once integrated, the CARLA software and free-way merging communications will bring the VICTOR lab simulator up to regulatory standards to perform these tests. Similarly, while there are inevitable periods of time and unaccounted for situations in which AVs are likely to be somewhat faulty, the overarching consensus is that when programmed correctly and ethically, a full-scale adaptation of AVs would have significantly more benefits than setbacks. In conclusion, the development of an autonomous vehicle simulator and the widespread adoption of AVs hold the promise of creating a safer, more efficient, and environmentally cautious world, ultimately contributing to a better future for all.

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