The Development of an Autonomous Golf Cart to be Used at the University of Virginia

(Technical Topic)

Pedestrian and Passenger Safety Implications Regarding Autonomous Vehicles

(STS Topic)

A Thesis Prospectus in STS 4500

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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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Motor Vehicle Accidents and What Autonomous Vehicles Bring to the Table

Motor vehicle accidents are the 13th leading cause of fatalities in the United States, accounting for over 32,000 deaths and 2 million non-fatal injuries annually (National Highway Traffic Safety Administration, 2015a; Sauber-Schatz et al., 2016). These accidents are not only life-threatening, but, according to the National Highway Traffic Safety Administration (2015b), cause damages that total more than $277 billion per year, a figure that amounts to nearly $900 per person in the United States. Furthermore, with the addition of harm from loss of life, pain, and decreased quality of life due to injuries, that cost increases to over $870 billion a year (ibid). A proposed solution to this social and economic hardship is the advancement and implementation of autonomous vehicles (Umland, 2018).

An autonomous vehicle is an automobile capable of sensing its surroundings and moving safely without human input. The objective is for these vehicles to be both safer and more energy-efficient than the conventional human-driven vehicle. Unfortunately, as with nearly all new technologies, autonomous vehicles have their disadvantages. Society-wide implementation of driverless vehicles is considered a near-impossible feat in it of itself, and coping with the associated societal and economic costs that arise from such a rapid shift in the automobile industry is no easy task as well (Umland, 2018). To top it all off, autonomous vehicles pose a new threat to pedestrian and passenger safety. As such, one goal for this paper is to analyze these new safety implications and discuss possible remedies for an issue that will undoubtedly continue to be prevalent in the future.

The Society of Automotive Engineers discretizes autonomy into 6 levels, with Level 0 corresponding to no automation and Level 5 full automation, see Figure 1. At the moment, the companies at the forefront of autonomous vehicle technology, Tesla and Google, have not fully reached Level 5 autonomy. Google is closest, with their Waymo vehicles operating in the Phoenix metropolitan area at Level 4 autonomy (Hughes, 2017). This project will create a working prototype of an autonomous golf cart that can travel around Grounds at the University of Virginia. Further, this paper aims to examine the technical requirements to develop a system of autonomous features needed to convert an ordinary golf cart into a driverless golf cart. By delving deeper into this aspect of this project, I can gain insights into the specific features that would support widespread implementation of autopilot technology. Motor vehicle accidents are indubitably an avoidable tragedy in society, so further research and analysis on autonomous vehicles and their safety implications must be conducted in order to outline the most cost-effective and reliable system design.

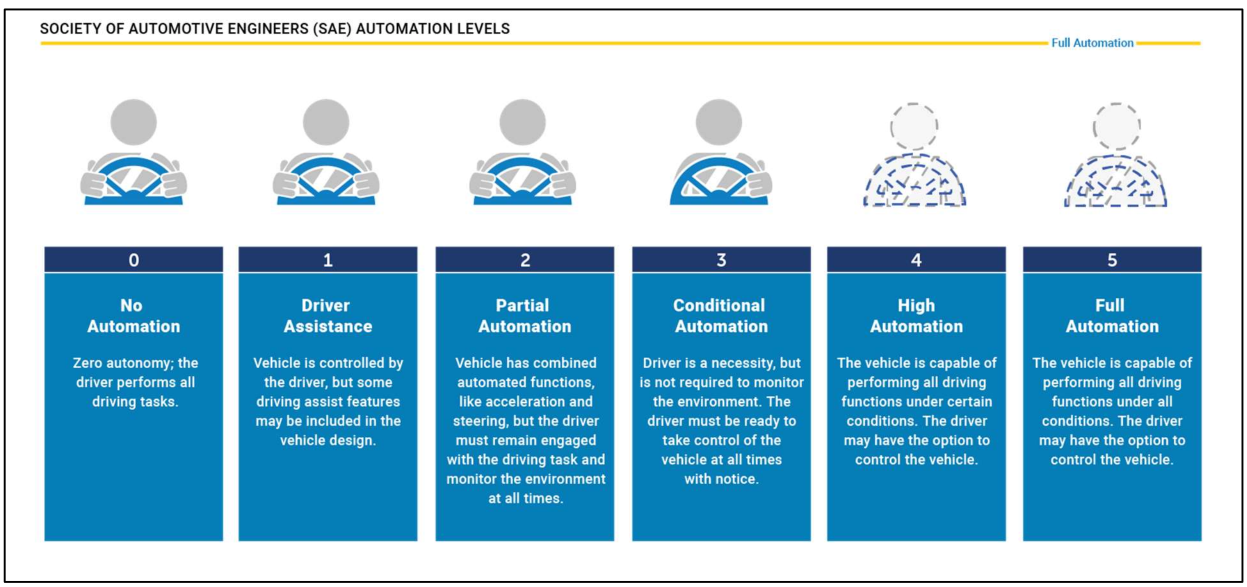

Figure 1. The Six Levels of Autonomy, According to the Society of Automotive Engineers (Image source: Automated Vehicles for Safety, 2020).

The Design and Integration of Autonomous Features on a Golf Cart

With the generous help and funding of Club Car, an industry-leading manufacturer of golf cars, commercial utility vehicles, and personal-use transportation vehicles, my team is working towards developing a level 5 autonomous golf cart that can operate along Engineer's Way, see Figure 2. Further, the vehicle will need to pick up and drop off passengers (About Us, 2020). My team faces multiple challenges, including partially reverse-engineering and taking apart work done by capstone design teams of previous years. Our current objective is to fully complete two autonomous golf carts that can run simultaneously in the same environment. By the end of the fall semester, in late November of 2020, we plan to present a blueprint of the autopilot system, complete with a network of sensors and actuators, to our technical advisor. Starting in February, we will dig deeper into the software aspect of the project, with a special emphasis on object detection and tracking, localization and mapping, and depth perception.

Figure 2. Engineer's Way at the School of Engineering and Applied Sciences at UVa (Image source: Lalonde, 2015).

Currently, Tesla, a market leader in autonomous vehicle technology, utilizes a variety of sensors, mostly cameras, and a sophisticated software network to produce a moderately reliable driverless environment. Such technologies include rearward looking side cameras, wide forward cameras, main forward cameras, narrow forward cameras, rear view cameras, ultrasonics, forward looking side cameras, and radar (Autopilot, 2020). Similar to Tesla, my team also plans to integrate a wide array of sensors and cameras into our autonomous vehicle design. Figure 3 depicts a base framework from which we plan to branch out. As evident from Figure 3, detection instruments are not the only features we need to consider. Other important aspects include processors such as Arduino circuit boards that will aid in the communication between the central computing unit and the actuators, such as the motors that will control the steering and braking of the golf cart.

In terms of hardware, the specifics for many of the components are yet to be determined, but there are some essential items that are required. First, we will be using the Club Car Onward 4 Passenger golf cart. The acceleration can be controlled with the on-board electric motor, but two additional motors will be required, one for steering and one for braking. My team plans on utilizing a linear actuator, which creates motion in a straight line, in contrast to the circular motion of a conventional electric motor, for the braking mechanism. Proper implementation of the braking system is critical for pedestrian safety because, according to a publication by Autoliv, a Swedish automobile parts manufacturer, reduction of impact speed from 50 km/h to 30 km/h decreases fatality risk ten-fold (Rosén et al., 2009). Although the golf carts are not capable of such speeds, the principle of speed reduction before impact is consistent even for less severe injuries. For steering, we will be using the motors already mounted on the steering column by a previous capstone design team. In addition to these actuators, the golf cart will host a central computing unit that runs on the Ubuntu operating system. The computing unit will not only be able to input data from the various sensors and cameras around the vehicle and a touchscreen monitor we plan to install towards the front of the vehicle, but also output signals to the actuators to control the physical movement of the golf cart. My team is looking to incorporate some cameras, such as the Intel RealSense Tracking Camera T265, and LiDAR sensors to allow the golf cart to essentially "see" the world around it and make calculated decisions about its movement patterns. While the sensors and cameras often have USB interfaces that allow for simple connections to the central computing unit, the motors will likely require the use of an Arduino circuit board, a microcontroller, which is essentially a tiny computer used for specific, embedded applications.

Most of the software will be based in the Robot Operating System (ROS) within a Linux operating system. For this case, my team is using ROS Melodic Morenia, the twelfth ROS distribution release, and Ubuntu Bionic Beaver, a version of the Ubuntu Linux distribution released in 2018 (Marguedas, 2018). Within ROS, there are many packages that can aid in object detection and tracking, localization and mapping, and depth perception. For example, the 'find_object_2d' package is a ROS integration of the Find-Object application, a simple Qt interface to try OpenCV implementations of SIFT, SURF, FAST, and BRIEF image matching algorithms (IntRoLab, 2015). When used in conjunction with an Intel RealSense Tracking Camera, this package allows the user to detect and track an object of interest, see Figure 4 (MathieuLabbe, 2016). Another package we hope to use perpetually is 'gmapping', a ROS package that contains a wrapper for OpenSlam's Gmapping. The gmapping package introduces laser-based Simultaneous Localization and Mapping (SLAM) into the ROS environment (GvdHoorn, 2019). SLAM is a commonly used method of allowing robots to map areas while also moving concurrently. This helps the robot not only move around in a certain area without running into walls or other objects, but also detect and move towards objects of interest (Martin, 2019).

By the end of the spring semester, in May of 2021, my team will have a safely working level 5 prototype, even if all of the ancillary functions are not fully operational. Our primary goal, above all else, is safety, so our mission is to compromise nothing in terms of both passenger and pedestrian protection.

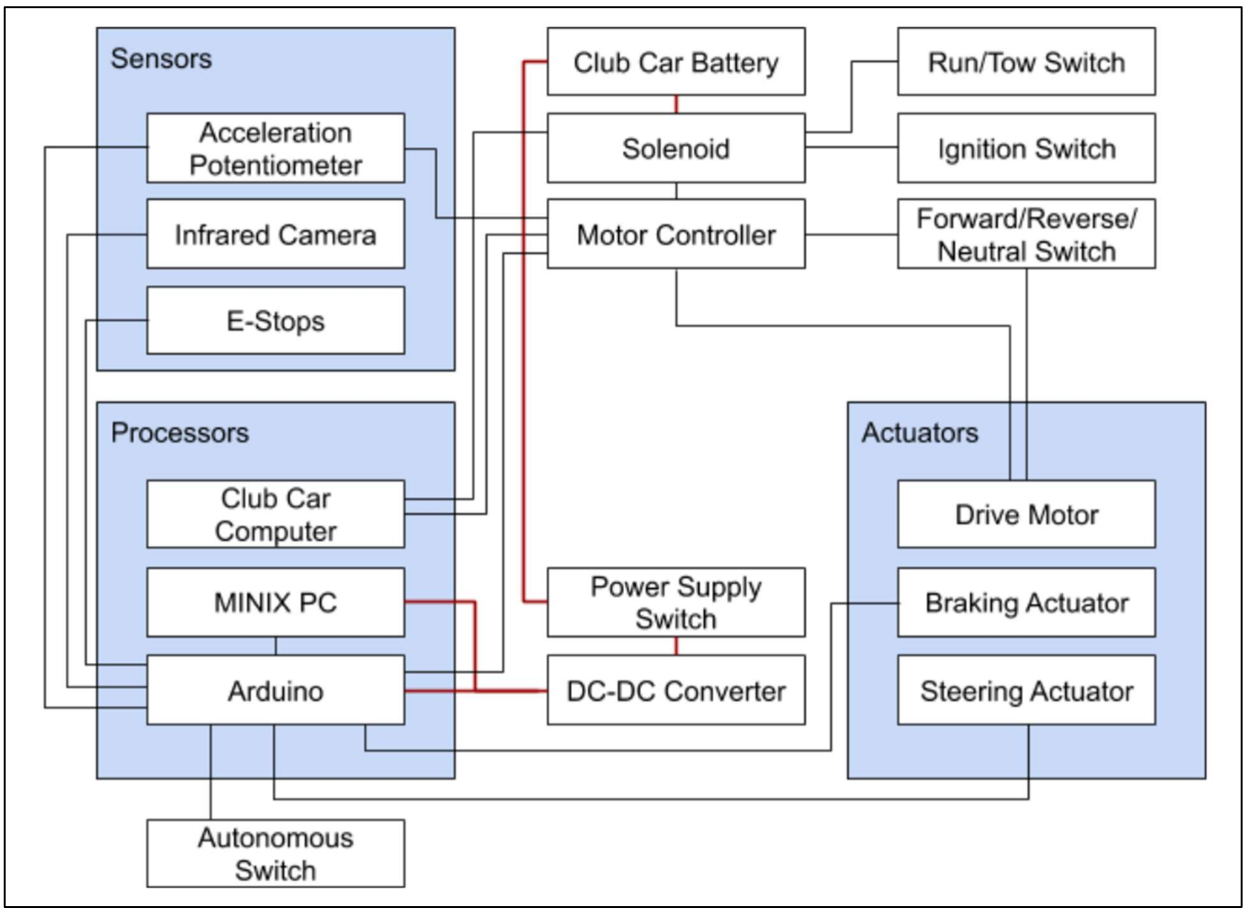

Figure 3. Proposed Hardware System Diagram of Autonomous Golf Cart (incomplete and subject to change) (Image source: Shin, 2020).

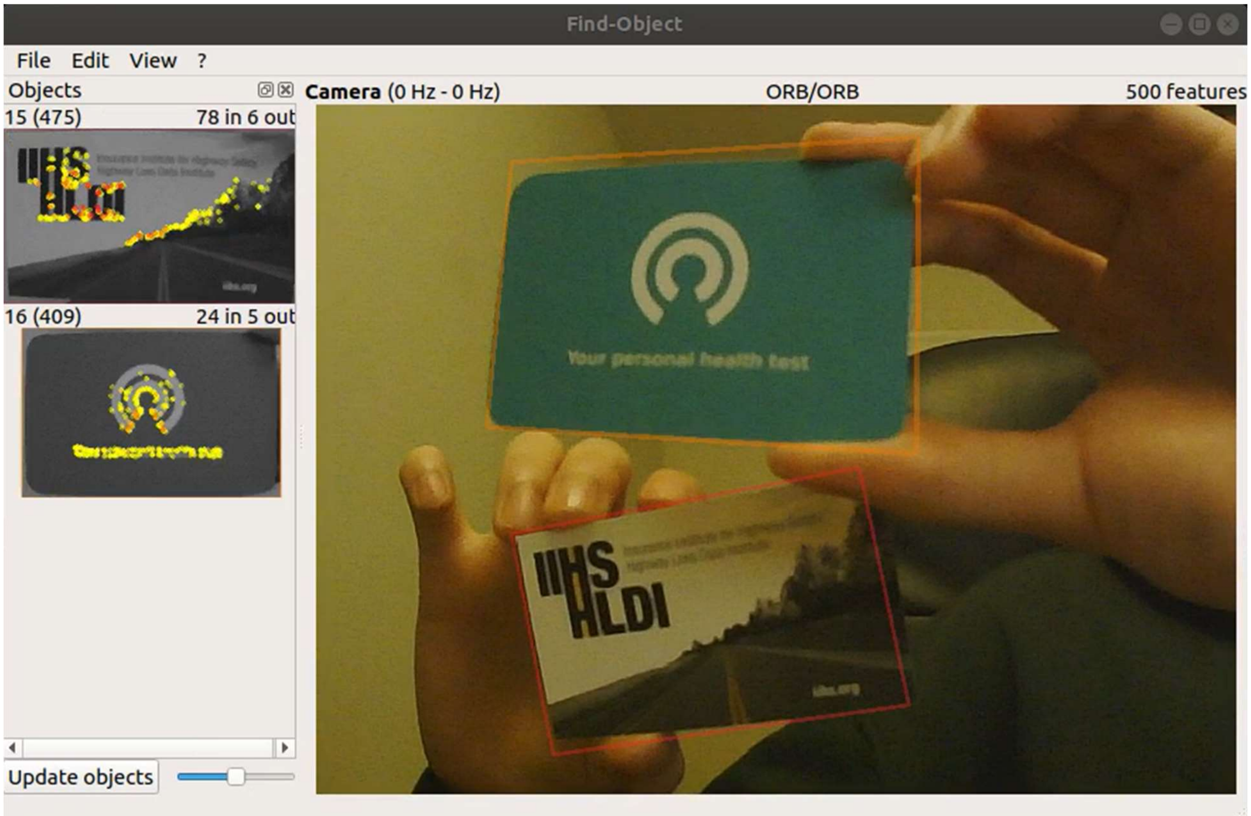

Figure 4. Screen capture of 'find-object-2d' ROS package in use. Two cards are being detected by the software (Image source: Shin, 2020).

Newfound Safety Implications of Autonomous Vehicles

At first glance, it may seem as though this capstone project is purely technical in nature. After all, it is a mechanical engineering project that culminates in the development of a physical product. One could argue, perhaps, that safety features are inherently technical. There is indeed prior literature that highlights the technical nature of automotive safety, such as a publication by a group of researchers at the University of North Carolina, Chapel Hill, on an analysis of the Fatality Analysis Reporting System that concluded that while the use of multiple, leading edge pedestrian detection sensors in autonomous vehicles could significantly reduce pedestrian fatalities, the clear reality is that with more affordable sensors, pedestrian fatality mitigation is unlikely (Combs et al., 2019). Nonetheless, there is no doubt that human and social elements are fundamentally incorporated into the project. For instance, Moody, Bailey, and Zhao (2020) considered the public perception of autonomous vehicle safety. They found more positive autonomous vehicle safety perception among the most risk-taking road users, young males, and in developing countries. These populations overlap with demographic groups and geographic areas facing the largest road safety concerns (ibid).

One of the crucial reasons that autonomous vehicles have not had such a major impact as some anticipated is the concern over safety. One life lost during real-world testing is already one too many, especially considering the fact that human lives are at stake. This has led to numerous controversies over passengers and pedestrians who have lost their lives due to the beta testing of autonomous vehicle technology (Chokshi, 2020). One such company is Tesla, who appear to be on the forefront of autopilot technology (Autopilot, 2020). There is a moral debate over whether or not it is ethical to continue allowing consumers to use this incomplete technology. A paradox was found in a recent survey conducted in Pittsburgh, Pennsylvania by Bike PGH, an organization promoting safety and accessibility for bikers and pedestrians, and researchers from the University of Alabama and Texas A&M. Results indicated that people with direct experience interacting with autonomous vehicles have significantly higher expectations of the safety benefits of autonomous vehicles than respondents with no experience interacting with autonomous vehicles (Penmetsa et al., 2019).

While there is no clear-cut answer to this problem, at least not at the moment, Thomas Hughes' (1987) concept of technological momentum can aid in analyzing this deeply complex issue. Hughes proposes that large technological systems capable of altering society as a whole, such as autonomous vehicles, in my opinion, undergo a series of stages: invention, development, innovation, transfer, growth, competition, and consolidation. Invention is the inception, defined as the creation of something novel, whether conservative or radical, with a conservative one adding to a pre-existing technology and a radical one bringing about something entirely original. Development is the second stage, defined as the transition from an initial invention to one that functions under economic, political, and social characteristics. Transfer can be defined as an adaption of said characteristics to another era or environment. Such movement is often dictated by shifting markets or geographical and social factors. Growth is the stage wherein expansion occurs. More specifically, it concerns what steps are taken to solve problems such as reverse salients, which Hughes defines as components of a system that are either out of phase or no longer considered contemporary, or increase efficiency through logistical changes. Competition involves a sparring between two or more technologies. Each attempt to claim a permanent stake in the future by arguing they have fixed reverse salients. Finally, consolidation occurs when stakeholders of the large technological organizations hold much of the market share, specifically to a degree whereby they begin to drown out the voices of smaller contributors.

Hughes' overarching example throughout his presentation of technological momentum is the U.S. electricity grid. I believe this technology is deeply analogous to autonomous vehicles because of the similarities exhibited in their potentials to alter society at large. Just as the electricity utility system had predecessors in power generation through natural and propane gas, so too do autonomous vehicles in transportation through conventional automobiles. Just as Edison's electricity grid had the potential to enable the productivity of the American people throughout the dark, so too does autopilot technology further advance vehicle safety to a near flawless degree.

I reckon that driverless technology is currently on the cusp of the innovation stage. Through innovation techniques, such as the integration of finite element model simulations and traffic simulations, many future deaths can be avoided, while also elevating the software and thus autonomous vehicle technology as a whole. Obviously, real-world data provides the best form of statistics needed to accurately predict real-world situations. Even so, it would be brazen of society to continue on a path towards neglecting human lives for the sake of developing a product. Moreover, Hughes also argues that innovation is the stepping stone for a technology to become a radical invention, rather than a conservative one, which follows this line of reasoning because autonomous vehicle technology does have the capacity to become a revolutionary invention.

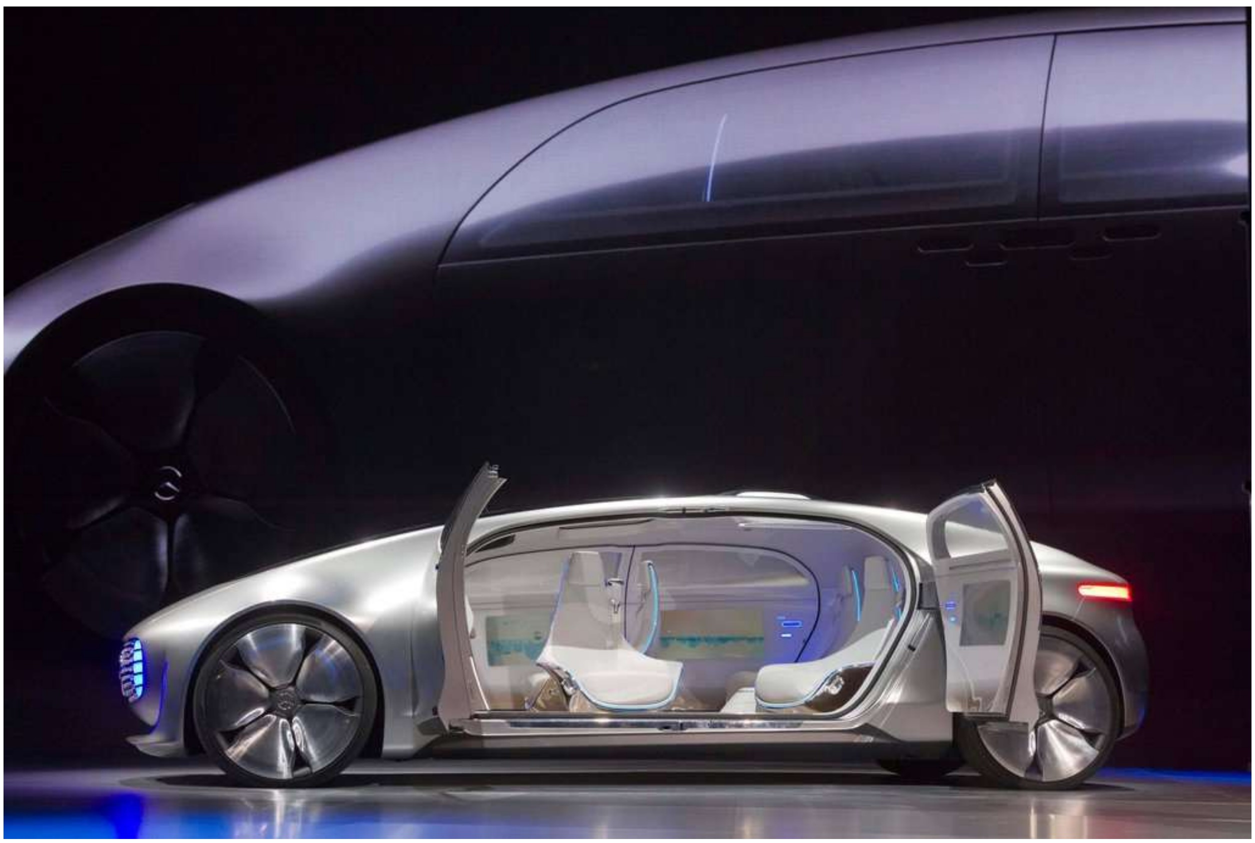

Figure 5. Mercedes-Benz F 015 Luxury in Motion Concept Car. Mercedes describes the seats as "four rotating lounge chairs that allow a face-to-face seat configuration" (Image credit: Steve Marcus/Reuters; Image source: Motavalli, 2015).

Research Question and Methods

What changes does autonomous vehicle technology bring to passenger and pedestrian safety? The answer is vital to the adoption of autonomous vehicles because personal safety is a fundamental human right. While there is no doubt that a small minority of trailblazers will be willing to put everything on the line to perform trials on this new technology, in order for mass adoption to occur, the public must either feel that it is safe or it is essential to everyday life. However, with the vast majority of people already comfortable with conventional automobiles and unlikely to immediately make the switch, autonomous vehicles must feature an extraordinary innovation, such as a near-impeccable safety record.

This research topic will be analyzed using a descriptive approach. More specifically, I will consider case studies and case comparisons. My primary form of evidence collection will be through surveys, interviews, and participant observation. I plan on not only conducting surveys and interviews of my own, but also watching online public meetings to gather a sense of the public perception towards autonomous vehicle safety. The survey will be in a Google Forms format, sent to students at the University of Virginia, and include questions aimed to gauge public perception of autonomous vehicles and their perceived safety benefits and drawbacks. An example question would ask how safe, on a scale of 1 to 5, the survey participant felt about riding a vehicle with a seat design such as the one shown in Figure 5. I will then compare the results of my survey to conclusions from prior literature. Due to the survey population, I may have to account for some biases, such as above-average education and income levels, in making conclusions. Interviews will be conducted of renowned scholars in the vehicle safety field, such as Dr. Jason Kerrigan, the Director of the Center for Applied Biomechanics and the University of Virginia. Moreover, I hope to watch public meetings hosted by the National Highway Traffic Safety Administration. Many such events are posted directly to their website.

My second form of evidence will include think tank reports such as a Congressional testimony delivered by Nidhi Kalra, a senior information scientist at the RAND Corporation, on the challenges and approaches to realizing autonomous vehicle safety and mobility benefits, as well as prior literature, such as a publication by researchers at Mississippi State University on a study of sixteen participants placed in a virtual reality experiment with autonomous vehicles and asked to cross a road when they felt it was safe to do so (Challenges, 2017; Hudson et al., 2019).

Lastly, and most importantly, I plan on comparing the results of my research to the final design of my technical project to determine the viability of public thought. In essence, qualitative research will be conducted to establish how well public observation of autonomous vehicle safety relates to both previous qualitative research and a technically practical and financially feasible design.

Conclusion and Future Work

The very first automobiles ever created were absolutely marvelous feats of engineering. The idea to harness the power of a petroleum or diesel engine and transmit it to rotate the wheels of a carriage revolutionized personal transportation forever. This trailblazing technology was not without its flaws, however. Due to the disregard and thus absence of safety features in early models, widespread use of motor vehicles resulted in heavy casualties, involving both pedestrian and passengers. In recent times, there have been vast advancements in passenger safety, such as the introductions of the seat belt and air bag. Unfortunately, pedestrian safety has not received such attention. With the advent of a society-wide autonomous vehicle system, it is likely that passenger injury risk decreases, as artificial intelligence will be able to make accurate, split-second decisions to minimize bodily harm. Therefore, it is imperative that more attention go towards improving aspects of pedestrian safety. As aforementioned, one of the major goals of this capstone project is to create a safely operational prototype, bar none. From this research paper, I hope to gain a better insight into the implications of passenger and pedestrian safety from autonomous vehicles and find some technical or even societal solutions to the problems at hand. Lastly, as a prospective graduate student, I hope to continue research of this kind even after my undergraduate career.

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