The Imminent Challenges of Autonomous Vehicles and How to Ethically Address Them

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***Abstract*—As society heads into the 2020s it will be poised to deal with a plethora of issues provoked by technological innovation. Chief amongst these technologies is self-driving autonomous vehicles (AV). The advent of AV is due to innovation in key technological areas within the last decade: computational power in various sensor suites, data processing and management, artificial intelligence, and increased connectivity through IoT technologies. Each of these technologies themselves requires extensive review and analysis; each is important in shaping the near future. However, their intersection within AV is testament to the elevated importance that society must place on trying to bssetter understand AV and be better prepared to tackle the issues this technology will bring as it is incorporated into society. Critical discussions are to be had if governments hope to create suitable public policy and if AV companies hope to steer their technology in trajectories that are beneficial to society.**

It is also becoming increasingly understood that these discussions must be held today. The AV industry has enjoyed a period of development and refinement within the last decade as major self-driving companies have developed their AV within closed-door laboratories. Some companies such as Waymo and Lyft have slowly rolled out quite advanced AV in limited conditions, while others such as Tesla have begun wide-scale implementation of AV with less advanced capabilities. Regardless it is evident that society is in a transition period as AV are moved from the laboratory into our public roads. The alarming rate at which these technologies are being adopted and advanced is highlighted by Elon Musks prediction that by the middle of 2020, a driver operating a Tesla vehicle with autonomous capabilities will not need to pay attention in highway driving [1]. Longtime car manufacturers such as Daimler expects large-scale commercial production of fully-autonomous driving by 2025. And Hyundai expects fully autonomous urban driving (a much harder problem to solve than highway driving) by 2030 [2]. Therefore, just as the improvement and employment of technologies related to AV is being accelerated, so must be the discussions regarding its effects on society and the public policy that will be implemented to curtail these effects.

I. Introduction

The purpose of this paper is to serve as a resource to facilitate those discussions that explore AV and their implementation in our society, both in the present and in the future. This paper will be broken down into 3 distinct parts. The first part of this paper will offer an introduction to autonomous vehicles and self-driving technology. This begins with an overview of the history of autonomous vehicles and the development of major technological components that together have allowed autonomous vehicles to become a reality. This part will explore the state of the art, current goals and timelines. Then follows an overview of major actors in the field of autonomous vehicles: tech-companies, automobile-manufacturers, policy organizations, etc. This includes a comparison between actors within the United States and abroad. The second part of this paper focuses on the societal implications and ethical dilemmas that autonomous vehicles will bring forth. This explores the adoption of autonomous vehicles into the drivers everyday life. This includes topics such as the assessment of safety, vehicle-driver relationships, and changes in lifestyle and culture. Furthermore, a discussion regarding the drivers community is developed. This explores how autonomous vehicles will change the infrastructure of our cities and how automation will transform the job market. The third part of this paper offers recommendations and guidelines to regulate and govern AV. This part expands upon ideas in the second part and explores how inequalities in society can arise from the changes that AV will bring. It explores questions such as how society can guarantee equal access to these technologies, how to protect communities from infrastructure changes, and how to ensure job security for victims of automation. This part analyzes current policy developed by government institutions and think tanks. Further, new recommendations and guidelines are shaped considering the issues discussed above. The purpose of this paper is to serve as a resources that is extensive in breadth, not in depth. The goal is to give the reader the adequate tools to understand the current state of AV and where society is headed. Further, a multifaceted approach to exploring the dilemmas AV will bring forth is necessary if one is to develop public policy that is effective, comprehensive, and inclusive.

II. Introduction to Autonomous Vehicles and Self-Driving Technology

In Control Systems problems the goal is to design a controller for a system. The system which is being controlled is referred to as the *plant* and an output of the system can be a state of that plant. The goal of the controller is provide an actuating signal to the input of the plant, based on an input to the controller with the ultimate goal of driving the plant to a desired state. In the formulation of a feedback control system, one or more states of the plant are fed to the controller to calculate the error between the current state of the plant and the desired state.

A. Definitions and Levels of Automation

The field of autonomous vehicles is extensive and complex; therefore, it is crucial to adequately define key terms, ideas, and technologies. This is particularly true as AV become mainstream and widely used - it is to no persons benefit to have a misinformed understanding of a technology that has numerous safety concerns. The purpose of this section is to aid this understanding.

The State of California Department of Motor Vehicles defines autonomous technology as technology that has the capability to drive a vehicle without the active physical control or monitoring by a human operator [3]. While this may seem self-evident and encompasses its purpose, autonomous technology has many layers that are contingent on the specific technological components that are used in the deployment of an AV, the degree of driver-engagement, and the AVs capability to performs in under certain conditions and environments. In 2018. the Society of Automotive Engineers released SAEJ3016: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, a regulatory framework that AV technology actors can use to guide their design, development, and testing of AV [4]. This document classifies AV technology into 7 distinct levels ranging from 0 - 6. The following provides a summary of each level of autonomous driving:

- **SAE Level 0: No Driving Automation**
  - Vehicle control is dependent entirely on the human driver. This level of autonomy is found in conventional automobiles. This level limits features providing warnings such as lane departure warnings and momentary assistance such as emergency braking.
- **SAE Level 1: Driver Assistance**
  - A vehicle provides driver assistance in either lateral or longitudinal control. Lateral control refers to vehicle steering; longitudinal control refers to vehicle acceleration and braking. This level supports features such as lane centering or adaptive cruise control. Both features cannot be employed at the same time.
- **SAE Level 2: Partial Driving Automation**
  - A vehicle provides driver assistance in both lateral and longitudinal control. At this level, features such as lane centering and adaptive cruise control can be used simultaneously.

SAE Levels 0 - 2 require a human to be driving the vehicle as these features are employed and to be constantly supervising these features. A driver must be able to control of any of these features as needed.

SAE Levels 3 - 4 vary in driver engagement.

- **SAE Level 3: Conditional Driving Automation**
  - A vehicle engages in autonomous driving and can take complete control steering, acceleration and braking under certain conditions. This mode has environmental detection capabilities; therefore, driver monitoring is not required but the driver must be able to override autonomous control in the event that the autonomous system is unable to continue.
- **SAE Level 4: High Driving Automation**
  - A vehicle has complete autonomous control of all driving features in nearly all conditions and does not require any driver intervention at any moment. While it is not required, driver override is still an option at this level. Furthermore, at this level the vehicle has the ability to autonomously navigate a predefine route within a confined geographical area.
- **SAE Level 5: Full Driving Automation**
  - A vehicle has complete autonomous control of all driving features in all conditions and neither requires nor allows driver intervention. At this level a vehicle with no steering wheel can navigate a passenger along any public roadway from any start/endpoint and under any condition of road, traffic, or weather.

This framework is widely regarded by AV manufacturers, researchers, and legal entities as the golden standard for defining AV technology and implementation. It has been adopted by major AV technology actors such as the U.S. Department of Transportation (DoT) who incorporated these levels into its Federal Automated Vehicles Policy [5]. This framework also provides a roadmap that AV manufacturers can use to develop their company goals and timelines. The next section will give a brief review of these timelines beginning with the history of the autonomous vehicles industry.

B. Brief History

The concept of the autonomous vehicles can be dated back centuries before the invention of the first automobile. In the 1500s Le0nardo DaVinci envisioned a cart that could move and steer through string tension rather than being conventionally pushed or pulled [6]. Nearly 500 years after DaVinci, and nearly 100 years after the first automobile, in the 1990s university research centers were at the forefront of innovation and worked to define the AV of today. Carnegie Mellon researcher Dean Pomerleau published his thesis detailing the use of neural networks that took raw images as input and output steering commands [7] . Today, this approach has been refined is considered state of the art. Another researcher Todd Jochem and his team trekked 2,797 miles from Pittsburgh, Pennsylvania to San Diego, California in an autonomous minivan that they could only control in speed and braking [8]. And across the Atlantic, similar efforts were underway in Germany as Ernst Dickmanns, a professor at the Bundeswehr University logged thousands of kilometers in autonomous driving using computer vision techniques [9]. The culmination of university research efforts led to the 2004 DARPA Grand Challenge, a contest with a prize of $1 million for the team that could complete an obstacle course through the Mojave Desert with an AV [10]. Several teams from universities to independent technologists competed, but not one team completed the challenge. However, in 2005 DARPA doubled the prize money and 5 teams completed the obstacle course, with first place going to a team from Stanford University. In 2007 DARPA introduced the Grand Urban Challenge which featured an obstacle course with urban conditions. The DARPA Grand Challenges are widely regarded as the catalyst of innovation as it incentivized development. They are also considered a major turning point as major companies began to invest in AV technology.

C. Major Players

In 2009 Google secretly began developing its own AV. Unsurprisingly, this project was at the leadership of Sebastian Thrun, the former leader of the Stanford University team that won the first DARPA Grand Challenge. In short time, Google developed autonomous driving pods that had no steering wheel, gas pedal, or break pedal. After major corporate restructuring into Alphabet Inc., their autonomous driving division became Waymo, now a subsidiary of Alphabet. Waymo has since shifted focus from manufacturing an AV, to partnering with companies such as Chrysler and Honda to build their cars, while Waymo works on improving AV technology [11]. In Phoenix, Arizona and Silicon Valley Waymo is employing their AV as a taxi-service that has had over 10,000 rides [12].

Shortly after Google big car manufacturers began to enter the market. In 2015 Tesla released an over the air update that enabled the AutoPilot feature which enabled lane-following, lane-changing, and autonomous parking on its publicly available Model S. Since then, Tesla has made major strides in making AV available to the public and has plans to launch the Tesla Network, a taxi service like that of Waymos [12]. Major car manufacturer General Motors has risen above the rest, buying Cruise, an AV technology company in 2016, and in 2018 being classified as the top leader in a study classifying all of the major companies investing in AV technology [13] . GM has now deployed a fleet of AV taxis that rival Googles technology and are commonly seen operating in the streets of San Francisco. Hoping to not be left behind, other car manufacturers such as Honda, Chrysler, Mercedes and Ford began opening AV divisions and heavily investing money into their own technology. In 2019, Audi released their A8 model with Level 3 capabilities such as Traffic jam navigation. Other notable companies with AV departments include Uber and Lyft, who hope to leverage their current ride-sharing platforms to get ahead in AV ride sharing.

D. State of the Art

To have a complete understanding of AV, it is important to understand the technological components that drive them. This section seeks to give a review of key technologies. This includes different sensor suites, robotics concepts, and approaches.

- **Cameras**
  - Cameras are one of the most frequently used sensors used in an AV. Cameras offer an information rich visual representation of an AVs environment. Using Computer Vision techniques, an AV can use a camera not only to navigate but to identity objects such as pedestrians, traffic lights, and other vehicles, allowing it to make decisions in a dynamic and uncertain environment. One major limiting factor of camera technology is that it requires good visibility conditions things such as rain, fog, snow can hinder a camera system. Furthermore, Computer Vision algorithms require a tremendous amount of processing power, parallel to the human brain which processes our own visual input. However, advances in artificial intelligence and data acquisition and storage have led to major strides in camera technology for AV. Teslas own system heavily relies on cameras rather than other sensors like LIDAR because it has a major advantage in the amount of data they have acquired from Tesla drivers, thus improved their algorithms immensely [14].
- **LIDAR**
  - LIDAR is an acronym for LIght Detection And Ranging. This technology shoots laser pulses of light into the environment which then collide with an obstacle and reflect back. By measuring the time of flight, an AV can have a highly-detailed understanding of its environment. While LIDAR is very powerful, it is also much more expensive as compared to cameras and other technologies. For this reason companies like Tesla do not use LIDAR, relying instead on improving their camera technology through the mass amount of data they have collected. Meanwhile, other companies such as Waymo have chosen to invest heavily on LIDAR making it an integral part of their AV system. This decision hinges on LIDAR technology becoming less expensive every year, as well as using LIDAR to aid its entire system not the main component [15].
- **Radar**
  - Radar is often used to complement cameras when they are not operating in ideal visual conditions such as darkness, rain, snow, and fog. Radar works the same way that LIDAR works, but instead uses radio waves that do not offer as highly detailed information as LIDAR, and at lower range [16]. Despite this, radar can be an extremely useful and less expensive alternative that is found in many companies sensor suites such as both Waymo and Tesla.
- **Global Positioning System (GPS)**
  - In an AV, a GPS will communication with a Global Navigation Satellite System (GNSS) to obtain real-time information about is longitude, latitude, and speed [17]. Essentially, an AV uses GPS to understand its location in an environment. This can be especially useful as an AV navigates from one endpoint to another. Its also aids other sensors as it tries to localize itself within a local environment.
- **Sensor Fusion**

– Each sensor in AV offers rich information about its environment, however not one sensor can allow an AV to navigate our complex and dynamic world. For this reason, AV rely on sensor fusion to combine data from multiple sources. This relies heavily on probabilistic techniques such as Kalman Filtering [18]. This helps solve robotics problems such as mapping, which is creating a 2D/3D representation of a robots environment using sensor information, and localization, which is using a sensors information to understand where in the environment the robot itself is. These robotics concepts are heavily explored and developed in other applications besides AV, such as autonomous multicopters, autonomous boats, and agricultural robotics to name a few.

E. Standards and Regulatory Bodies

The United States Federal Government understands that AV will become an integral part of society in the very near future and through the Department of Transportation (DoT) creates federal standards and regulations that prioritize safety while ensuring that they do not hinder innovation and foster economic growth. Within the DoT, several agencies are tasked with specific sector of the automotive industry. Descriptions and roles of these agencies are fully expanded on in the DoT policy statement on automation Preparing For the Future of Transportation: Automated Vehicles 3.0 [19].

The National Highway Traffic Safety Administration (NHTSA) has authority over the safety standards of AV and AV technology found within all transportation vehicles such as usage of steering wheel, brakes and other control features. The Federal Highway Safety Administration (FHSA) has authority over traffic control devices installed on any road open to public travel such as signs, signals, and markings. It is taking steps to update its current policy in order to integrate how AV technologies interpret traffic control devices. The Federal Transit Administration (FTA) has authority over public transportation and acts a safety oversight regulatory body that ensures transit agencies are establishing appropriate safety objectives, developing plans to mitigate risks and promoting safety through training and communication. . The Federal Motor Carrier Safety Administration (FMCSA) regulates commercial motor vehicles operating in interstate commerce. Due to the uncertainty in the workforce created by automation in commercial trucks, the FMSCA is working with the Department of Labor (DoL) to assess the impacts of this technology and create policy that ensures workforce stability. Another examples of inter-agency collaborations includes the Accessible Transportation Technologies Research Initiative (ATTRI) which, between the DoT, DoL, and the Department of Health and Human Services (HHS), seeks to create policy that enables access to AV technologies for people with disabilities.

In Europe many countries have setup government departments and enacted legislation that seeks to also solve many of the problems AV technologies bring. The United Kingdom has the Centre for Connected and Autonomous Vehicles (CAV) which invests and works closely with industry, academia and regulators to develop both technology and legislation [20]. Through its Federal Ministry of Transport and Digital Infrastructure Germany has pushed major ethics regulations that define things like the prioritization of human life, and how an AV collects and uses private driver information. Germany is using its large automobile industry (BMW, Daimler, Volkswagen) to deploy these ethics regulations and become a leader [21]. The European Commission also supports introducing standards and legislation at the European level regarding AV technology. Theyve focused on initiatives related to overlapping technologies that cross borders such as 5G, cybersecurity, privacy and free flow of data [22].

III. Societal Implications and Ethical Dilemmas

A. Vehicle Driver Relationship

Society today generally tends to welcome new technologies and adopt them quickly. This is especially true for technologies that can change small patterns in a persons everyday life, but it is not exclusive to such technologies with low-impact. The proliferation of cellphones is a perfect example of such technology, as it is inarguable that it has redefined many sectors of society from communications to commerce and was adopted rapidly due to its substantial advantages. AV technology is another example of technology with tremendous advantages and an unprecedented level of impact. However, there is much speculation surrounding the publics adoption of this technology in their everyday lives.

A study that assessed the publics perception of AV showed that there is a lesser degree of acceptance for AV with higher levels of autonomy such as SAE Level 4 and Level 5 [23]. Factors such as anxiety, safety, and even performance are more negatively perceived as the level of autonomy increases. Furthermore, for lower levels of autonomy there is an expectation of higher level of driver engagement. This is indicative of there being a general understanding that technology of high autonomy is still experimental it not being completely developed leads the general public be overly-cautious of its implementation. It is crucial for AV technology developers to understand these trends so that they are able to address them within their technology. However, there are cases where the opposite perception is exhibited. Recently a viral video depicted a Tesla driver sleeping while using the vehicles Autopilot feature, driving autonomously within a highway lane at an estimated 60 MPH [24]. Tesla addressed this by pointing out that it has system that requires the driver to be engaged (hands on the steering wheel), however there are several ways to trick the Autopilot in its assessment of driver engagement. This is an example of how it is important that a person understands the level of autonomy of the car it is operating in. In this scenario, the Tesla operates at Level 3, however the driver was operating as if it was Level 4 or Level 5; if the vehicle encountered a challenging situation, catastrophic consequences would have surely followed.

Surveys also show that the perceived level of acceptance varies more specifically between the specific AV technologies used and not just the level of autonomy they belong to [25]. Features such as Lane Departure Warnings and Navigation

Assistance are perceived to have high overall value to drivers. These features are reported to increase feelings of safety, confidence and relaxation, while significantly reducing stress. Furthermore, these are features that are frequently used when compared to other features such as Night-Vision Enhancements or voice-Activated control. Other features are rated to have lower overall value such as Intelligent Speed Adaption, which users report to have very little experience with, Blind-Spot Warnings that are reported to be distracting. It appears that the overall value of each feature is tied to the impact on safety that it has. For example, highly valued systems such as Lane Departure Warnings can potentially reduce crashes up to 30%. In contrast, users of Blind-Spot Warnings are concerned with the problem of over-confidence, reporting that using this feature leads them to less frequently check their blind spot physically and less frequently use their turning lights.

B. Infrastructure

Just as it is important to contemplate the publics adoption of AV, it is important to analyze how cities will adopt AV in their infrastructure. This discussion begins by examining the way in which people will use AV in the future whether they are privately owned AV, public AV, or ride-shared AV. While this discussion could easily be explored in the above section by focusing on the driver-vehicle relationship, it is better place in this section as those relationships will have direct impact on what cities will have to consider as they prepare for AV. As explored in the previous section, AV technology generally tends to decrease the stress and anxiety one experiences as they use an automobiles (this is predicated on the technology being well developed and understood). With this, a space is opened for drivers to engage in activities that they otherwise could not. Currently, people who use automobiles report that their main activity is focusing on the road and route, with 80% of drivers making space for other activities that can be done simultaneously such as listening to music or enjoying the landscape [26]. In turn, only 7% of drivers reported working. This pattern is not exclusive to privately owned vehicles, as 77% and 69% of public transit users report to never work on short and long distance journeys, respectively.

Another aspect that rebounds on the concept of vehicle-driver relationships, is how pedestrians will perceive AV and how cities will need to react to this. This builds off on the previously explored topic of overconfidence in AV technology, as pedestrians may tend to engage in dangerous behaviors near AV that increase the risk of an accident [28]. This behavior can be induced by the pedestrian believing that an AV will properly react to this dangerous behavior as it is programmed for safety. In urban settings this could be seen as increased jaywalking and in more suburban areas this can be seen as parents being more careless and allowing children to play in dangerous roads. Regardless of the environment, cities will need to heavily consider the safety of not only the car, but the people outside of the car.

The use of AV will also lead cities to consider how they invest in public roads. Currently only 41% of US roads meet the requirements for a good ride, influenced by things such as potholes and poorly marked roads [29]. This will be incredibly detrimental to autonomous vehicles that require a high precision understanding of the world. Furthermore, sporadic disturbances in vehicle conditions lead to dangerous scenarios than an AV may not be able to handle. If cities wish to maintain the original goal of AV to increase passenger safety then they must make substantial investments in improving road infrastructure.

Cities will also need to make well use of their space to accommodate fleets of AV of all categories. Primarily, parking spaces are already a major issue in cities worldwide. AV will lead cities to rethink how parking spaces are placed in their cities, and how many of them they need. For example, a privately owned autonomous that can drop off a person at their specified location, can now find parking in a location that is much further from where their owner was dropped off. With this, you will no longer need parking spaces placed in every corner of the city. Furthermore, as ride-sharing increases, estimates show that parking demand itself will decrease by up to 90% [30]. Cities will need to evaluate the best uses for all this new space.

Cities should be deeply concerned with the environmental impact that AV will bring forth. While experts are optimistic that autonomous vehicles can solve traffic problems in certain situations, it is clear that AV may increase traffic congestion overall. This is due to the increased use of vehicles as a whole. People who typically did not use vehicles as a means of transportation will then be more likely to use them as they become cheaper and more accessible through ride-sharing. Furthermore, the pool of people than will use autonomous vehicles will be widened to non-traditional users of AV such as younger kids and people with disabilities. Another issue is the increased use of AV even when there is no driver present, an issue that is known as deadhandling. Deadhandling can happen for example when an AV travels to pick up a driver or if is circling in traffic awaiting a driver. This issue will further increase emissions released into the environment and will be present for both privately owned AV and those used in public transit.

C. Jobs

Technological innovation has brought fear and anxiety for centuries, in regard to how it can rapidly change a workforce. This fear and anxiety is not exclusive to worker replacement, but is also rooted in uncertainty related to safety, reliability, and longevity. In recent decades, these reservations have been at an all time high due to increased automation. Shortly after 2000, manufacturing jobs in particular underwent a negative trend up to the recession. In this period, over 5 million jobs were lost, with 80% of these jobs being due to automation [31]. The impact of these trends is still being felt today. Furthermore, the advent of AV has increased anxieties as jobs that relate to AV make up a significant portion of the workforce.

A study in 2015 found that up to 15.5 million jobs could be affected by the introduction of AV [32]. This figure includes 3.8 million positions where driving is the primary action encompassing jobs in the transportation and warehousing industry such as a truck drivers. Positions where vehicles are used to deliver services or travel for work accounted for a larger share of 11.7 million jobs primarily in the construction, government, and healthcare industry. Such jobs range from first responders to construction workers. In each type, it is predicted that positions that face relatively repetitive tasks are at increased to be replaced with automations. Focusing, on the first type, analysis shows that workers engage in related activities other than driving that impact performance of the job. This leads to an optimistic viewpoint that these type of workers can still participate in their jobs in parallel with an AV. However, this viewpoint is understood as a slippery-slope, as the technology of AV will continue improving over time and the role of a worker will decrease. As for the second type of positions, its workers are found to have a diversified set of work activities, knowledge, and skills. The optimistic solution for these workers is for them adapt to AV and be retrained for other related jobs. This is clearly contingent on the fact that workers in this category are more likely to be younger and have a higher level of education.

Many point to the positive impacts that AV can have on the workforce by pointing to the plethora of new jobs that they will bring. However, it is important to note what kinds of jobs these are currently the top autonomous driving jobs available are for engineers, technicians, software developers and designers that build autonomous vehicles [33]. These kinds of jobs are not the type that can be easily taken by the people who belong to the jobs that are being displaced as they do not have the extensive education needed to undertake them. Therefore, while this may increase jobs, it does not address how to manage worker displacement.

According to a study in which key stakeholders in AV technology were interviewed, it is of high importance that proactive planning and appropriate strategies are deployed in a timely manner so that those who face job displacement can adequately prepare [**?**]. A survey of truck drivers found that many were not concerned at all that autonomous trucks would take over their jobs [31]. However, many companies are actively developing their AV technology, with Tesla debuting its autonomous freight truck Semi in 2017. UPS, a company that uses trucks for services such as shipping has partnered with autonomous truck startup TuSimple to handle shipments in Arizona [35]. This leads for one to question just how aware truck drivers about the impending changes are that are soon to come in the next few years. Truck drivers are a vital part of our economy, delivering the products that we consume and use very single day. While autonomous trucks will still be able to transport these products, it is important to contemplate how the economy will react if 3.5 million trucker jobs are eliminated. This will affect approximately 5.2 million other jobs that directly interact with them (diners, motels, truck stops, etc.) and create a loss of $17.5 billion dollars [31]. While in the minority, some truck drivers seem to be aware of the incoming challenges as a group of them protested against AV in Jefferson City, MO [36]. One protestor is quoted stating: We are facing annihilation autonomous trucks are right on top of us right now.

IV. Recommendations and Guidelines to Regulate and Govern AV

A. *Addressing Vehicle Driver Relationships*

It is incredibly important to gauge public perception before fully developing any technology, especially AV. In this way, refinements can be actively made not just in how AV are technically developed, but in the manner that it is made available to the public. Furthermore, this allows developers to assess what kinds of supplementary resources need to be made available so that the public can better understand the capabilities of their technology. The goal in understanding the relationship that drivers have with AV should be centered on increasing the overall safety of the system, as this is clearly the primary concern for the majority of the public. This will in turn lead to an increase in positive perception of AV and increased adoption into the publics everyday lives.

Foremost in this endeavor should be investing in educating the public in regard to AV technology. Much of the public is only offered snippets of information from news headlines of AV and are not aware of the complex development (expanded on in Part I of this paper) and the intricacies of deploying them in public settings (expanded on in Part II). Therefore, companies that are actively developing and deploying AV should heavily invest in programs that will shed light on their capabilities. These programs can include social media campaigns and workshops where people can learn more about these capabilities. Furthermore, companies should be transparent with the timelines of their development so that the public can gain an understanding of where the technology is headed. It is important to take initiative in these endeavors now that AV technology is not daily aspect of the publics life. Doing so early allows the public time to digest the implications of AV and prepare for it; doing so early, allows a smoother transition from a society that has only know manual driving to one where roads are shared with AV. Currently, Tesla has countless showrooms where potential customers can try their vehicles on the road before buying them [37]. This outlet provides an opportunity for customers to try the autonomous features and learn more about them. Furthermore, Tesla annually holds an event called Tesla Autonomy Day where presenters delve into the AV technology the company is developing and future plans [38]. An increase across companies of these types of strategies will greatly improve public education of AV and thus contribute to a more positive perception. It is important to note that as AV technology is implemented as a public commodity into public transit, governments should also have a stake in educating the public on AV technology. Additionally, with its legislative ability, a government could go further and require that a person passes a test to be able to use an AV. This is much like how a person has a license today to operate a regular vehicle. This policy could also be expanded to include privately owned vehicles.

Even with the best driver education, there are still scenarios where a drivers behavior will influence safety. As such was the case discussed in Part II where a Tesla driver was using Autopilot , a blatant violation of Teslas rules and an example of overconfidence in the system. Teslas requirement of hands on the wheel did not do enough to ensure safety. For these reasons, companies have begun to employ more advanced driver monitoring systems such as Cadillacs multi-camera monitoring [24]. This type of system uses Computer Vision to monitor the driver and ensure that they are meeting their requirements in operating an AV of a certain level, for example ensuring that they are not asleep and that their eyes are on the road, or verifying that their hands are in fact on the wheel and the person is not tricking the system. Ultimately, these systems should be a requirement in AV of all levels, from private AV to public AV. Elon Musk has recently stated that within a year, human intervention will lead to a decrease in overall safety [39]. While this is a bold prediction, it does call for society to redefine what it means to be a passenger what is and is not allowed inside of a vehicle. Ultimately, increasing safety is of the most importance and if camera-based driver monitoring systems do this, then they should certainly be employed.

B. Addressing Infrastructure Needs

The very first infrastructure issues that will need to be addressed are those regarding the inside of an AV and how a person uses it. As detailed in Part II, AV technology will open a space for people to replace the activity of driving. AV developers should be incentivized to take advantage of this and provide mediums for passengers to engage in activities that they otherwise would not have the ability to while operating a regular vehicle. These activities will vary from user to user and developers will need to be able to adapt to these needs. In Part II it was explored how drivers tend to not work, both in their privately owned vehicles and in public transit. Understanding this can lead to AV manufacturers to produce designs that stimulate productivity such as desks, charging stations, and other features that will essentially turn a car into a mobile office. In the case of public transit, cities will need to address how the problem of crowdedness and lack of privacy influence productivity currently, and how to best implement mobile offices in this setting. And perhaps due to those problems, people in certain areas (i.e. white collar working class people) will tend to privately owned vehicles and cities in those areas will not need to deploy as many public transit options with mobile office settings. AV developers will also need to consider the increased pool of passengers that will include people who traditionally could not use vehicles because of a physical disability (blindness, partial-body paralysis, etc.) or mental disability (driving fear or anxiety). Developers will need to accommodate the needs of these passengers with specialized features. Furthermore, AV with these features should be widely available and affordable.

Without a doubt, the next infrastructure issues that cities will need to tackle are related to the AVs environment namely the condition of roads and other traffic infrastructure that if left in its current state, will be detrimental to AV performance and safety. Foremost, developers will need to ensure that their AV can perform within these environments. While this may seem inherent to the goal of AV to be able to autonomously drive under any condition it is important to consider that at different stages in development, AV will operate at different levels of autonomy and in some scenarios will meet unfavorable conditions that it is not equipped to handle. It is important that developers validate what current infrastructure will allow their AV to operate safely and only allow their AV to operate within those capabilities. Obviously, cities will also need to invest in rebuilding their infrastructure so that AV can perform better and be safer. When doing this, it is best if cities coordinate with AV developers so that they can rebuild with the most optimal infrastructure for AV. Developers should also take advantage of this and develop infrastructure technology that will aid AV themselves such as special signage and traffic lights that allow AV to make better decisions, and technology that communicates between traffic infrastructure and AV itself. Lastly, when choosing what areas of infrastructure to upgrade, cities should have systems that ensure that underprivileged communities are not left out.

The second part of this paper outlined potential problems that have the capacity to impact the environment. These problems are primarily due to increased traffic congestion as a result to increased accessibility to transportation. To tackle this issue, cities should incentivize the use of ride-sharing services as a way to decrease the number of vehicles on the road. Cities should make sure that these services are very low-cost so as to not discourage their use. This can happen through cities working with AV developers, and through developers improving their technology to where it reduces costs.

Furthermore, cities should heavily integrate AV into public infrastructure. Currently a major reason for the public not using public infrastructure is due to the fact that it cannot take you directly to your desired destination. This problem is reduced with AV that increase the range of transportation. Part II raises the issue of deadhandling, the problem of AV driving autonomously in roads when there is no one in them. This is a problem that can be tied to the use of parking spaces; i.e. if a parking space is deemed more expensive for an AV to use than to drive around aimlessly, then it would prefer to do deadhandle. However, while it keeps the costs down for that particular person, that extra time spent driving increases traffic congestion and emissions. To curtail this issue cities will need to ensure that parking costs are low. As mentioned before, parking spaces will be fewer with the increased use of ridesharing services. Therefore, cities will need to strategically place the remaining parking spaces in places that are convenient for AV to access. The decrease of parking spaces will also open an opportunity for cities to repurpose the land being previously used for parking spaces. Cities should choose to use this land in a way that will benefit the public. For example, they should aim to build many greenspaces such as parks that will both benefit the public and help the environment. These spaces can also be used to incentivize ridesharing and public AV by repurposing it with infrastructure.

C. Addressing Job Protection

One of the biggest problems that needs to be addressed regarding autonomous vehicles is their impact on the job market and workforce. Part II detailed the economic consequences of mass worker displacement, the diversity of the workforce that is likely to be replaced, and various areas of the economy this will further effect. When approaching solutions to these problems, it is important to place the needs of workers first and employ specific policy that aids specific workers needs in this transition period.

The most important aspect of this transition period is that it should be a slow and long period. First, it should be a requirement for companies that plan to use AV in the future to disclose this information to their workers so that they are aware of the impending changes and can make appropriate plans and adjustments. This should be done well in advance of actual implantation. Furthermore, the companies should invest in resources for their workers once they find themselves unemployed and are in the process of finding new employment. To allow for this transition period, companies should roll out the technology incrementally, allowing for stages where human operation is needed. Slowly after each stage, less and less of a person will be needed to operate these machines until they are completely autonomous.

As mentioned in Part II, AV technology brings the opportunity to create many new jobs in the market that can help alleviate the impact of the jobs it will displace. This will mainly be manifested in highly skilled sectors such as engineering and computer science but also lesser skilled sectors such as manufacturing. Both the private sector and governments should employ policies that prioritize projects that will create many new jobs. However, companies should not only rely new workers entering the workforce through these higher skilled jobs but should try their best to retrain the people whose jobs are being displaced. This is difficult when one takes into account the disparity in education and technical ability that was discussed in Part II ; this varies between certain jobs for example between truck drivers and EMT workers. For workers with higher levels of education it is possible to retrain so that they are able to help in more technical roles. These roles would not be engineering roles that redefine AV technology, but technician roles that are able to diagnose potential problems and service AV. As for people who do not have a high level of education or skillset, it is possible to invest in their education so that they too can participate in these roles. However, as detailed before, these people should play a role in operating AV technology as it is rolled out in stages.

There is opportunity for cities to incentivize job growth by heavily investing into the use of AV in their public infrastructure. This will be primarily be manifested in the new workers that will be needed to service these AV. Take for example the mobile offices discussed in Part II workers will be needed to regularly maintain these spaces and keep them clean for all passengers. Furthermore, new facilities to support more public infrastructure will be added and regular workers to service these will be needed. Cities should incentivize the use of AV in services where human operators are inherent. An example of this is special AV for people with disabilities that are mentioned in Part II.

V. Conclusions

Like all new technologies, AV will bring many challenges. Some of these challenges remain unknown, but others are predictable. The purpose of this paper was to outline those challenges and find possible solutions to tackle them. The first part focused heavily on the technology itself, as it is important that before people make important policy decisions, they have a clear understanding of how the technology works, what the current state of the art is, and who the leaders in industry and government are. This should be standard followed by any party involved in making policy for AV. In Part II the challenges AV will bring were identified. While there are endless problems that could be explored, the three topics of vehicle-driver relationships, infrastructure, and jobs were chosen as these areas have the most direct and widescale impact on the public. The public should be the number one priority for both AV manufacturers and the governments that write legislation for them. And it is imperative that this legislation is ethical.

Ethics is defined as choosing what is right and good through the application of morals. Today 1.25 million people die in road crashes each year and 20 to 50 million others are injured or disabled to the car crashes [40]. This statistic provides a clear incentive to develop AV technology and provides a framework for the morality surrounding this technology. It should be one rooted in a desire to help the public and decisions should be made to maximize public benefit. This moral framework was applied in Part III of this paper as solutions were sought for the challenging problems AV will cause. With AV passengers, companies and governments should be transparent and as informational as possible so that the public can make the best decisions for themselves. For infrastructure, strategies should be deployed that incentivize low cost ride sharing and public transit that many especially the underprivileged can benefit from; furthermore, it should be friendly to the environment that all of the public shares. And when it comes to job displacement, the publics needs should be the leading priority in all stages of the transition period from being transparent with workers before AV technology is implemented to retraining workers in jobs that involve AV.

AV technology has the potential to be very unpredictable and it will without a doubt fundamentally change every aspect of every persons life at some point in the future. The challenges that will come will be difficult, however if the parties who have the ability to create this technology and create legislation follow the framework in this paper of prioritizing public interest, one can be hopeful for the future to come.

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