Autonomous Vehicle Literature Review

Abstract

The purpose of this literature review is to explore contemporary work around the primary and secondary policy impacts of autonomous vehicles in cities. The question we seek to answer is: How will autonomous vehicles impact the residents of New York City beyond the direct mobility effects?

The works summarized here are focused on the issues of safety, equity, data stewardship, sustainability, work displacement, integration with public transportation and community engagement. Although this project is centered on the introduction of autonomous vehicles to New York City, the literature review considers the topic of AVs more broadly.

Policy Principles

Several local governments and organizations have developed notable autonomous vehicle-oriented policy principles. A collaborative of California state agencies offers non-specific Key Principles that align with those presented in this report, especially multi-modality and sustainability (California Multi-Agency Workgroup on AV Deployment for Healthy and Sustainable Communities). Building on that work, the University of California at Berkeley's "Autonomous Vehicles Strategic Framework: Draft Vision and Guiding Principles," which seeks to "maximize the potential public benefits" of AV deployment in the state. The City of Pittsburgh outlined "Pittsburgh's Shared + Autonomous Mobility Principles," centered on "People, Planet, Place and Performance."

Each of these principles documents aims to prioritize shared common goals, including safety, equity, and sustainability, and are woven into the discussions in this project. They each exist in locations already testing and using autonomous vehicles, and will be observed as first-movers as they test these principles against real-world circumstances.

Vehicle and Street Safety

Autonomous vehicles show promise to reduce crashes due to human error or impaired driving. These safety benefits, if AVs prove to be safer in large numbers, could increase the appeal of walking and cycling, especially in neighborhoods that currently see high numbers of crashes (Rojas-Rueda et. al, 2020.

Measuring and Proving Safety

Measuring and proving AV safety, especially in comparison to human drivers, is key to allowing AVs to operate in cities. Rates of crashes, especially fatal crashes, are low enough per mile driven that compiling enough driving to test AVs on the path to proving safety is a challenge. Kalra and Paddock (2016) estimated that AVs would need to drive 275 million miles without a single fatal crash to demonstrate with 95% confidence that they cause fewer deaths than human drivers. Because failures have already occurred, demonstrating with 95% confidence and 80% power that AVs are 20% safer than human drivers at avoiding fatal crashes would require 11 billion miles of driving and require decades of testing. Given the rapid evolution of software, it is unlikely that any build will be tested enough to meet this statistical standard.

Without the ability to prove safety through driving enough to provide statistical significance, other approaches are needed. Waymo has been covering billions of miles in simulation to complement its road testing and trial service provision in Arizona, and simulates recent actual human-driven crashes to test how a Waymo car would have fared ("The Future of Autonomous Vehicles," 2021). This methodology allows for testing of specific crash scenarios, which would not be covered by looking only at disengagements. In a different approach, Tesla is running the autonomous system in the background while the human is driving to compare the system's decisions (which are not controlling the car) with the human driver's decisions (Lundgren, 2020).

McBridge (2016) suggests a driver's test for AVs, but cautions that it would require sufficient variation in tests that companies could not write specific software for the test, as Volkswagen did for diesel emissions. Other methods are available, including accelerated testing, virtual testing and simulations, mathematical modeling and analysis, scenario and behavior testing, and pilot studies (Kalra and Paddock, 2016). Lundgren (2020) cautions that for any testing procedure based on simulation, the results are only as good as the assumptions on which the scenarios are based, and there is not a clear procedure of objectively evaluating the completeness and accuracy of these simulations. However, it is clear that the question of AVs operating more safely than human drivers is more nuanced than a pass/fail test, and regulators must develop standards and procedures for acting under this uncertainty.

The second consideration is what metrics to use to measure safety. The most common milestone for companies testing AVs has been the rate of disengagements (when the human driver must take over from the autonomous system). This measure alone is incomplete, as it fails to account for differences in driving conditions and scenarios (Simpson, 2021). The Transport Research Laboratory proposed 3 criteria to assess proposed safety metrics: whether it has a recognized link with adverse safety events, whether it does not encourage unfavorable driving or behaviors, and whether it is reliable, repeatable, and measurable.

Beyond disengagements, metrics might entail driving infractions, safety envelope violations, the driving style of the vehicle using the vehicle kinematic systems, a measure of incomplete missions that goes beyond disengagements, the ability to recognize and identify hazards and accurately perceive driving risk, and qualitative user feedback.

The third aspect of assessing safety is determining how safe is “safe enough” to support full operation on city streets. Proponents cite the commonly-used figure from NHTSA (2015) that 94 percent of motor vehicle crashes are due to human error, and thus imply that autonomous driving systems would be able to avoid all or most of these. However, others find this statistic misleading (Shetty, et. al. 2021): it includes not just those crashes due to distracted or impaired driving or violating traffic rules, but also causes such as “false assumption of other’s actions,” “decision error,” “recognition error” and “inadequate surveillance.” It is not clear that autonomous vehicles are better than humans at correctly assuming the actions of other road users, for instance. In addition, AVs may be better equipped to handle specific driving situations, such as at night, when 50 percent of traffic deaths occur, according to the National Safety Council. The World Economic Forum’s Safe Driving Initiative recommends that regulators define localized scenarios to be tested during each milestone (Dawkins, 2020).

It may still be possible to measure, with sufficient data or estimation, whether crash and fatality rates are lower for autonomous systems than human drivers. However, this is a shifting baseline. Over the following decades during the AV transition, policies other than vehicle driving autonomy (such as street design) could make human driving safer, suggesting that AVs should be benchmarked against future human-driven vehicles and their safety systems rather than the present (Lundgren, 2020). Alcohol locks, speed governors, and focus improvements could reduce human error due to intoxication, speeding, and distracted driving respectively, making human driving safer and setting a higher standard for AVs to be safer than human drivers. Conversely, new technologies might make driving more dangerous, by enabling new forms of distraction while driving (Boudette, 2021), as well as owner-hacked vehicles for rule-breaking. It does not follow simply from the existence of the technology that human drivers and politicians will welcome its implementation. If human driving (and coexisting with human drivers on the road) was less safe in the future, AVs would be able to claim safety greater than human driving by meeting a lower standard.

Traffic fatalities in the United States increased by 23.4% on a per-mile basis, to 1.37 deaths per 100 million miles traveled (NHTSA, 2021), after a decade in which traffic fatalities per capita were flat for motor vehicle occupants and rising for pedestrians and cyclists. Both the 2019 and 2020 figures are above the 1.09 fatalities per 100 million miles that Lundgren (2020) uses. It is not clear which way to expect traffic injuries and fatalities to trend over the following decades.

A fourth consideration is what level of risk should be allowable for AVs operating in uncertain conditions in densely populated cities. Shetty, et. al., (2021) identified two approaches to ensuring vehicle safety. The first is the Responsibility-Sensitive Safety (RSS) framework, proposed by researchers from Mobileye, one of the companies currently testing in New York City. This approach involves limiting an AV’s maneuvers so that it is safe under all reasonable future outcomes from its partial observations, but it is limited by the information that it can gather and requires significant tradeoffs between safety and throughput. The second approach would be to use vehicle-to-vehicle and vehicle-to-infrastructure connectivity to bridge information gaps. In a dense urban environment like New York City, where important interactions are not just with other vehicles but with a mass of pedestrians and cyclists, a communication-based approach will always leave out a significant portion of road users.

Various trolley problem scenarios are not likely to be relevant to autonomous vehicle policy in the near-term. Lundgren (2020) notes that AVs will not have all the information necessary to make trolley problem judgements in the split second before a crash. An AV would have to identify not only the existence of a person in front, also estimate their likelihood of survival and retrieve personal information about them (age, life status, etc.) in order to make a decision. However, the decision point between prioritizing pedestrians and passengers will likely fall in favor of the vehicle's owner.

Passenger Safety

Per prior research from the NYU Rudin Center for Transportation, shared mobility often presents a safety risk to female passengers. Women (including femme-presenting individuals) are three times as likely to fear for their safety on public transit (Kaufman et al, 2018). Sexual harassment and assault is prevalent on public transit worldwide, leading women to report reduced transit usage (Kash, 2019). Likewise, a shared AV shuttle might present similar issues, as strangers riding together may present dangerous or unsavory activities.

An extension of passenger safety is the issue of travelers with caregivers, who must ensure that these children, elderly parents or other dependents can travel safely. They may require car seats, wheelchair fasteners or space for non-folded strollers in these shared vehicles. Nationally, caregivers are disproportionately women (AARP, 2020), so a lack of options for these travelers prevents them from making use of shared AVs.

Equity

Equitable services are made more possible by identifying community needs and shaping deployment (Steckler et al, 2021).

According to research conducted in San Francisco, experience with AVs is highly correlated with income, with high-income residents eight times as likely to have ridden in an AV than low-income residents (Blomqvist, 2022). A lack of familiarity with AVs is likely to affect community responses to the technology.

AVs present several opportunities to overcome historical racial biases in mobility.

For example, AVs could reduce discrimination in ride hailing and driving. AV riders would not face discrimination from drivers based on their appearance or destination, which is a long-noted problem with taxis (Belcher, 2015). In addition, residents who have faced administrative barriers in gaining a driver's license due to immigrant documentation status could benefit from reliable transportation (Blomqvist, 2022).

Still, autonomous vehicle technology is, like any algorithm, subject to the biases of its creators. The NYC CTO report (Office of the Chief Technology Officer, 2021) put the responsibility on the public authority to ensure that artificial intelligence technology (used by autonomous vehicle technology) is not deployed in a way that creates discriminatory outcomes, either through the software or humans' interaction with it. The report also acknowledged that the increased data collection requirements to measure a disparate racial impact could infringe on privacy and carry data security risks.

Numerous studies have found that AI facial recognition systems have consistently failed to recognize Black people, especially women, at a higher rate than for white people and men (Lohr, 2018) (Brandom, 2018). One study of object-detection models, though not peer-reviewed, found that the models were five percentage points less likely to detect dark-skinned pedestrians than light-skinned pedestrians, suggesting that camera systems in AVs would show a similar disparity (Wilson, Hoffman, & Morgenstern, 2019). As a result, researchers suspect that autonomous vehicles are more likely to hit dark-skinned pedestrians, but because these models are trade secrets, they have not been tested publicly (Samuel, 2019). Ensuring diverse representation creating these algorithms is one potential solution to these biases.

Racial and economic inequality are inexorably intertwined, and autonomous vehicles could serve to exacerbate wealth inequality. Owners of personal AVs could rent out their cars as revenue sources, serving as ride hailing vehicles during that time. Meanwhile, ride prices might be lowered by reduced labor costs, leading AVs to increase mobility options for lower-income residents, enabling direct trips that were previously too expensive. Of course, these residents may be directly impacted by the reduced jobs available for drivers, and electric vehicle chargers may be difficult to access.

Shifting from a model of primarily privately owned vehicles to a primarily shared vehicles offers opportunities for price discrimination, which could have potential new forms discriminatory effects against the poor (Sparrow & Howard, 2020). For example, users might pay more to be the first in line to be picked up, ahead of other users booking at the same time.

These pricing mechanisms present a new slate of ethics complications. For example, systematically pulling vehicles over to allow those containing higher-paying users to pass would be considered the least ethical (Sparrow & Howard, 2020), and would be reminiscent of commoners stepping aside to make way for nobility in feudal societies. Notably, it would reveal the relative wealth of all road users and undercut access to publicly funded services; because the roads are public space, equal access to them must be maintained. A less direct and simple method would be slightly longer waits for those who choose not to pay extra, a version of which has already been implemented by Uber and Lyft, which give riders the option to wait and save (Lyft, 2020) (Griswold, 2018). Ethically, this privileges those able to pay, but also makes ride-hailing available at a lower price than previously for those able to wait, where they pay with time rather than money.

In order to maximize considerations of all potential AV users and non-riders alike, governance should seek the input of historically underrepresented communities in decision-making, as recommended by the American Public Health Association (2021). These groups include BIPOC, women, and LGBTQIA+ individuals, who reflect the identities of their communities. In addition, project budget and scheduling must account for adequate engagement processes to take place. Finally, members of these historically excluded groups and communities in which testing is taking place should be considered for roles in AV companies (Minnesota Department of Transportation
Office of Connected and Automated Vehicles, 2018).

Neighborhood Equity

The adoption of AVs is likely to be quicker in rich countries and richer areas within countries (Rojas-Rueda, et. al, 2020), which could leave behind lower-income neighborhoods. AV use could be further constrained by access to smartphones and to credit card and digital payments, which remains unevenly distributed. Cohn, et. al. (2019) found that AVs could result in mixed outcomes in the Washington DC region, by narrowing the auto travel time gap compared to affluent areas, but also potentially increasing disparities in exposure to collisions, noise, and air pollution. Cohen and Shirazi (2017) noted that in order to achieve the promised accessibility benefits for disadvantaged communities, public agencies must develop strategies to reduce the linguistic, financial, technological, and cultural barriers to AV use.

Neighborhood equity also comes into play when considering the conflict of AV parking: when not in use, AVs can park in “peripheral” parking locations (Bahrami and Roorda, 2021). However, this pattern leads to increased traffic congestion by zero-occupant vehicles and high numbers of parking garages in lower-income neighborhoods, raising issues of air quality, congestion and low economic activity in historically marginalized communities.

Accessibility

Much like human-driven vehicles, autonomous vehicles present challenges for people with physical and cognitive disabilities. The vehicles themselves may be inaccessible for people with mobility impairments. Considerations include: vehicle design, safety and operations testing, public engagement, and universal design for both vehicles and areas of operation (Wolf, 2019). People with disabilities should be included in testing door-to-door travel, not only experiences within the vehicles (Bleach et al, 2020).

Among specific disabilities, several solutions have been proposed by Claypool et al (2017). For visually impaired users, information about the ride through auditory and braille notifications would make the trip more useful. For people with mobility or ambulatory impairments, wheelchair ramps or lifts are necessary, and for deaf drivers, visual notifications to replicate auditory signals are necessary. For passengers with intellectual disabilities, simplified controls and interfaces, as well as tracking by caregivers, are necessary. Finally, the standards of driver licensing should be adjusted for autonomous driving, so that people with disabilities who have historically been precluded from getting licenses might be able to legally operate these vehicles (Minnesota Department of Transportation Office of Connected and Automated Vehicles).

People with disabilities’ participation in the workforce is often limited by a lack of reliable, accessible transportation to work, hindering their access to educational and financial opportunities (Wolf, 2019). It is estimated that widespread deployment of AVs would enable two million Americans with disabilities to secure employment opportunities (Claypool et al, 2017).

Community Engagement

The CTO (2021) emphasizes the importance of public engagement on any system or process that uses computation to aid or replace decisions that impact opportunities, access, liberties, rights, or safety. Since public authorities are accountable to their constituents and operate under stronger standards of fairness in the provision of goods than private businesses do, it is their responsibility to ensure that a system benefits the public, especially when rewarding a private business with a valuable contract or permit. When AI systems are deployed that don't reflect community needs, either real or perceived, they may be defeated by public opposition regardless of their other benefits.

Blomqvist (2022) shared that important components to inclusive, effective community engagement are: education, awareness, stakeholder input, community partnerships, communication from community members, and culturally-relevant materials. Opportunities for feedback and monitoring should be ongoing.

Data Stewardship

AVs collect an enormous amount of data, including images and video of surrounding environments, street conditions, navigation, communications and location recordings. They are estimated to collect at least 1 gigabyte of data every second (Collingwood, 2017). This data must be stored, transmitted, used, and ultimately deleted. While data in the public sphere is not new, the volume and public setting of autonomous vehicle data presents unique challenges and opportunities.

Once a concentration of AVs are traveling throughout cities, the data they collect could provide new tools for transportation authorities to manage traffic, maintain awareness of street conditions, and simplify traffic rerouting and street closures (Thomopolous & Givoni, 2015). The process of introducing congestion pricing would also be simplified (Simoni, et. al, 2019), as would the design of mass transit routes. (Congestion pricing would be especially valuable to avoid cars cruising rather than paying for parking (Millard-Ball, 2019).) Smith & Thesiera (2020) establish that governments should prepare for further data sharing with the proliferation of disruptive transport technologies. Useful data sharing requires privacy control algorithms and partial aggregation of data, in order to entice private providers to risk a competitive advantage by sharing data with the public sector (He & Chow, 2020).

Aggregation can ensure not only privacy, but also data reliability. Data reliability of minority groups might be much lower due to small sample sizes of these groups. Take Census Tract #93 in Manhattan as an example, according to the American Community Survey (ACS), the estimated number of people above 18 is 8,559 with a 7.72% margin of error, while the estimated number of people above 75 is 1,307 with a 28.08% margin of error (Explore census data, n.d.). Such low data reliability can be observed for all kinds of minority groups. Large sampling error can be reduced through aggregating the areal units into fewer, larger units, to improve the overall reliability of statistical analysis (Dark and Bram, 2007). The process of aggregating small basic spatial units into larger zones is referred to as "districting" in the literature (Fleischmann and Paraschis,1988). Different designs of zone aggregation lead to different systematic evaluation results with the same data, which is known as the Modifiable Areal Unit Problem (MAUP). MAUP refers to the sensitivity of statistical results to changes in the areal units of analysis. MAUP leads to two major concerns (Dark and Bram, 2007): the scaling effect and the zoning effect. The scaling effect refers to the phenomenon that changes in the number of areal units for a given region lead to variation in numerical results (Openshaw, 1979). The zoning effect refers to the phenomenon that different ways of grouping a set of smaller areal units into larger areal units leads to variation in numerical results (Openshaw, 1979). In this case, even if the scale is not changing, combinations of areal units affect the statistical results (Dark and Bram, 2007). Hence, finding a zoning system with proper scales and designs is vital for reliable analysis and evaluation, hence vital for transportation management and policy-making.

In the literature, there are a lot of districting problems studied, including the Police Districting Problem (Camacho-Collados et al., 2015; Liberatore et al.,2020), Political districting (Garfinkel and Nemhauser, 1970; Ricca et al., 2013), sales territory design (Shanker et al., 1975; Salazar-Aguilar et al., 2011), and so on. Methods considered include clustering and optimization. Density-based clustering was applied to earthquake zoning focused on recognizing non-convex shapes (Scitovski, 2018). Spatially-constrained clustering was used to design optimal traffic analysis zones to achieve homogeneous intrazonal socio-economic and land-use characteristics (O'Neill, 1991), as well as identifying optimal Freight Traffic Analysis Zones (FTAZs) with homogeneous intrazonal freight-related characteristics (Sahu et al., 2020). Optimization methods were applied to such problems as early as the 1970s. Openshaw, one of the pioneers in the area of districting and MAUP, formulated an optimization problem which maximizes interzonal variance and minimizes intrazonal variance (Openshaw, 1977). Guo and Aultman-Hall (2014) studied zone design for national freight origin–destination data and with optimization with a single objective, minimizing weighted interzonal distance. Martínez et al. (2009) applied optimization with a single objective to the design of Traffic Analysis Zones (TAZs), minimizing the standard deviation of trip densities within zones and the total number of intrazonal trips. Sometimes one objective cannot incorporate all requirements of zoning, so multi-objective optimization has been applied. Datta et al. (2012) optimized the design of census tracts with objectives including minimizing the intrazonal deviation from its maximum degree of compactness, the intrazonal deviation in population, and the intrazonal deviation in area. Common constraints include contiguity, compactness, and convexity of the zones, while nothing regarding data reliability has been studied to the best of our knowledge. In a word, with proper zoning system design, data reliability and privacy can be ensured.

Furthermore, according to (Docherty, 2018), it is important that city governments not give away data to private interests that are competitive and that these interests would otherwise pay a substantial sum for. They recommended adopting licensing rules that require companies using public data for commercial purposes to provide the state access to some aspects of their application and the data it generates. Any third-party data access would also require regulation.

New York City's Office of the Chief Technology Officer (2021) created a Citywide Data Integration Agreement, which specified standards for privacy, data security, and interoperability for sharing between agencies, creating a clear standard that can be used in setting policy for AVs and other uses of data in the city. Its recently adopted permitting requirements require companies to "share data on where cars operate, total miles, how long backup drivers are in the vehicle and any instances when the operator takes over the vehicle." (Deffenbaugh, 2021). While this is more stringent than requirements for potential AV marketplace uses, the city does condition the granting of permits to rideshare companies on sharing aggregated trip data with the city. This data is specifically used for the purpose of improving transportation policy (Office of the Chief Technology Officer, 2021), and AV data offers similar benefits, for AV rideshare as well as in other applications.

Collection of data by AVs creates privacy concerns for both riders and non-riders. While public and private security cameras already exist, the number of automatic cameras on the road would increase with the widespread use of AVs. It is important to define the rights of non-riders whose movements and locations could be recorded using these cameras. Unlike with cell phone data applications, where the tracker is owned by and on the person of the user, location data of other road users would be taken by a system they do not own and have no control over.

It is likely that targeted advertising and selling of user data would be more prevalent as AVs reach the mass market or for shared rides, where producers are inclined to differentiate themselves. Glancy (2012) noted that data from AVs could convey sensitive information about where the user is, what they are doing, and a list of places the user has visited in the past and will visit in the future. For example, the location where the car is parked (e.g. in a low-income neighborhood) could be used to profile the user (e.g. as low-wealth, risky credit, more likely to be a victim of violence, etc.). AV data is another surveillance tool that could be used by law enforcement, which could help apprehend criminals, or to track and harass protestors or unfriendly journalists (Collingwood, 2017). Multiple tradeoffs exist between privacy rights and streamlined AV operations.

New York City's Office of the Chief Technology Officer (2021) released a citywide Artificial Intelligence Strategy, citing the need for ethics, accountability, fairness, privacy and security, and community engagement. Specifically, the report mentioned the need to acknowledge the tradeoffs between privacy, security, fairness, and accuracy. Ensuring fairness and accuracy often requires collecting more data than is strictly necessary, which introduces privacy and data security risks. Proper data procedures including de-identification, confidentiality agreements, and secure multiparty computation are necessary to ensure that data is used to benefit the public.

An additional privacy issue concerns the privacy of autonomy, or the control that people have over their actions and mobility. Physical privacy could be enhanced in AVs if design changes such as fewer windows allow for more activities in the car on public roads that would otherwise be done in the home (Collingwood, 2017). It is not clear whether the privacy of autonomy is substantially helped or harmed, and the outcomes are different for different users. For many adult drivers, AVs would take away their autonomy by providing certain levels of service, determining routes, and otherwise making decisions (Collingwood, 2017). Teenagers would likely no longer learn to drive if AVs become common, depriving them of future control of their own mobility, and the ability to drive could atrophy in current drivers. Mobility, and privacy of activities, could be increased for the disabled, elderly, children, and other non-drivers, who would no longer depend on others for mobility. Choosing to either drive or ride in an autonomous vehicle is an exercise in positive autonomy, for those who have the choice (Glancy, 2012). Autonomous vehicles would seem to increase the changes brought by rideshare, where users hail rides provided by a private company and driven by strangers.

Finally, a major concern around data is cybersecurity. Autonomous vehicles are more vulnerable to hacking, and drivers are less able to intervene when an attack occurs (Taeihagh and Lim, 2019). Regulatory requirements must ensure continuous updating of protective measures.

Sustainability

The adoption of autonomous vehicles (AVs) is likely to significantly impact pollution, congestion, and urban sprawl. Electrification of AV fleets and government regulation will dictate the impact on pollution. A changing ownership model for these vehicles in conjunction with the effectiveness of urban development can alleviate congestion, but could have a long-term positive correlation to sprawl.

Widespread adoption of AVs presents an opportunity for the transportation sector to significantly reduce its greenhouse gas emissions. The transportation sector accounts for 28.5% of greenhouse gas emissions across the United States, 60% of which comes from passenger cars (Jones, Leibowicz, 2019). The state of California has already taken one step to couple AVs and environmental progress, requiring that all new light-duty autonomous vehicles are zero emissions, starting in 2030 (Bonifacic).

If AVs are widely adopted by rideshare networks, it is likely that fewer individuals would own cars, opting for shared vehicles, possibly decreasing congestion in urban areas. However, this trend may actually increase congestion if individual ownership remains the norm in the short-term, or if vehicles are set to cruise when not in use. In any case, increased AV adoption will introduce a new mode of transportation that will ultimately grant people the flexibility to live further away from city centers, potentially perpetuating urban sprawl (Jones and Leibowicz, 2019).

Assuming a shared mobility system is widely adopted, cities have an opportunity to repurpose roads and spaces to promote sustainability. For example, curbs dedicated to parking spaces can be converted into pickup/dropoff zones. City lanes can be reduced and tightened, allowing for the prioritization of bus and bicycle lanes as well as pedestrian paths. Major thoroughfares and highways can incorporate dedicated AV lanes to support and promote shared AV use (Litman). These dedicated lanes would allow for platooning, optimizing travel speed and mitigating congestion and pollution (Litman).

Policies surrounding AV sustainability are mostly proposed in the realm of reducing vehicle miles traveled through regulation, financial incentives, and public transit improvements (Greenwald and Kornhauser, 2019).

Work displacement

The nature of work and working hours could change if traveling in a car no longer requires driver attention, but it is unclear how that change will occur in practice, depending not just on technology but on social relations. Commute time could either serve as a less stressful break from work, or could be used as work time. This work time could either replace in-office time or add to it, either reducing or increasing stress and overwork (Rojas-Rueda, et. al, 2020). AVs could either increase social interactions, through allowing passengers to use travel time for socializing, or decrease it, through replacing in-office social interaction at work.

Increased AV use could eliminate 1.3 million - 2.3 million jobs over the next 30 years (Groshen, et. al. 2018), which will have negative economic and health effects on those workers. In New York City, more than 200,000 professional drivers are licensed by the Taxi and Limousine Commission (NYC TLC, 2022). According to Groshen et al, job losses caused by AVs will disproportionately affect men and individuals with lower education levels. The authors propose an offset of AVs' financial benefits for retraining and mitigating the employment losses of these workers temporarily.

Integration with Public Transportation

Several cities are hosting pilots of autonomous shuttles with 4-8 people traveling through urban areas; there is desire in the private sector to expand these programs further. In a review of pilot programs, Hagenzieker et. al. (2020) found that the public and passengers were generally enthusiastic about the proliferation of AV shuttles, but that the slow speeds of existing service and propensity to stop frequently around obstacles limits their utility and popularity over time. These pilots tend to have first/last mile applications going between transit stations and slightly distant destinations. However, the Covid-19 pandemic led to the stoppage of many pilots due to shifts in travel patterns. A review of one pilot in the La Defense business district of Paris, conducted from 2017 to 2019, found that the shuttles achieved an average speed of only 7 km/h in a crowded, pedestrianized district, but that passengers generally had a positive opinion of the shuttles (Wiesmayer, 2019). A further ongoing test in Paris involves shuttles from the Saint-Quentin train station to a nearby business park, with V2X technology to communicate with traffic lights and a retractable bollard ("Driverless passenger shuttle launched in Paris," 2020). There has been interest in scaling these vehicles up to operate an autonomous on-demand transit system in Trenton, New Jersey, USA, with an RFEI issued in December 2021 (Mumich, 2021).

There is potential in automated bus rapid transit to carry as many passengers as light rail for a lower price (Feller, 2021). Automation would lower labor costs and potentially increase passenger safety without the expensive and extensive infrastructure associated with rail. It could instead navigate on dedicated lanes on existing roads.

While automated buses could theoretically platoon for more corridor capacity and fuel savings, the use cases for bus platooning are narrow (Peirce et. al., 2019) ("*Bus automation: Cost-effective solutions for transit operators*," 2021). Platooning would require space on the ends of the route to line up buses, dedicated right of way, traffic signal priority, and a route with sufficient passenger demand.

WSP found high potential for autonomous operations in bus yards and depots, with benefits including increased yard capacity, fewer necessary overhead chargers, faster operations, and staffing savings ("*Bus automation: Cost-effective solutions for transit operators*," 2021).

Existing regulations around autonomous bus operations are considered to be placeholders, and should be updated for advanced driver assist technology as well as full automation.

Impact on Cities and Driving

Autonomous vehicles could potentially provide considerable access benefits to schools, jobs and community resources to those for whom public transit is far or unusable, and are unable to drive. For instance, elderly people traveling to doctors' appointments would create a large increase in health and equity (Schmitt, 2018). AVs would reduce the stress of driving and traffic, which reportedly causes increased risk of heart attacks (O'Connor, 2004) and increased incidence of domestic violence (Beland and Brent, 2018). AVs could reduce crashes resulting from drunk or impaired driving, as people under the influence will not need to operate a vehicle. However, laws must be clarified regarding operation of AVs under the influence.

Safer AVs could increase the appeal of walking and cycling, especially in neighborhoods that currently see high numbers of crashes (Rojas-Rueda, et. al, 2020), by making walking environments less hazardous. They could reduce the cost of taxis and public transit by increasing the efficiency of shared vehicles, allowing fewer vehicles to provide the same number of passenger-trips (Metz, 2018). Both of these developments would aid in achieving cities' goals around climate and safety. AVs might facilitate congestion pricing schemes, which would effectively price their cost to congestion and raise revenue for socially beneficial spending on transit or access. Reducing traffic congestion would provide benefits to health, noise, and reduced environmental impacts (Simoni, et. al., 2019). Cost savings related to reduced congestion could balance out the reduction or elimination of two major sources of municipal revenue: parking fees and traffic fines (Schmitt, 2018).

However, reducing drivers' negative experiences could potentially lead to more miles traveled, which produces negative externalities to the city as a whole. Reducing the cost of auto transport could incentivize more car travel, and create conditions where vehicles will travel unoccupied, which would add to urban traffic congestion (Metz, 2018; Townsend, 2020) and could create new opposition to restrictions on urban driving.

The prospect of zero-occupancy vehicles is a dangerous one for congestion. If an autonomous vehicle can run errands for its owner, circle the block while they shop, and return home while they are at work, these zero-occupancy trips consume phenomenal road space. Divorcing the pain of sitting in traffic from the reward of completing the trip externalizes even more of the harm of traffic, and creates an AV "hell" (Chase, 2014). Conversely, a world with shared AVs would be heaven, as walking and cycling become safer, health outcomes improve, parking lots become parks or housing, and emissions are reduced.

Additional Considerations

The impacts of AVs in cities will be broad. Several key factors that fall beyond the scope of this project are summarized below, and should be considered in future research.

- **Public Health**
  Rojas-Rueda, et. al (2020) explored several potential public health impacts from AVs. Major considerations include: social connectivity,

traffic safety, better access to health resources, physical activity, and environmental exposures. Desired outcomes should be baked into urban AV policies.

- **Liability**
  AVs raise the question of assessing liability and responsibility for crashes that cause physical and monetary harm. In crashes involving human-driven cars, courts and insurance agencies assess fault using a responsibility framework, and those deemed "responsible" through intent or negligent driving behavior are punished (Liu, 2017). There are laws clearly defining driving transgressions (speeding, driving under the influence, etc.) and breaking them makes the driver liable for negative consequences. For autonomous vehicles, which would not knowingly perform against their own programmatic rules for safe driving, the transgression is unclear. Giving one autonomous vehicle a speeding ticket does not remind it to be more careful next time. The practical application of the software in the vehicle produced a harmful outcome. That could be due to the programmer of the software, the manufacturer of the vehicle, or the testing body that certified it, all of which are remote to the actual crash event. Liu (2017) suggests a restitution framework, where the victims are compensated, and funded through a form of insurance or other collectivized risk-mitigation scheme.

- **Regulation**
  Many authors emphasized the need for governments to actively regulate "smart mobility," including autonomous vehicles, to balance profitable operation of mobility services with social obligations and objectives (Docherty, 2018) (Pangbourne, et. al., 2018). Smith, et. al. (2020), reporting on Workshop 5 of the International Conference on Competition and Ownership in Land Passenger Transport, listed several principles for regulating disruptive transport technologies: establish the baseline understanding of the societal role of transport that might be disrupted; set the ambition of how technology should change transportation systems; open up for dialogue with government, citizens,

and industry actors; regulate with a light but firm touch; prepare systems and physical and legal structures for data sharing; and analyze social effects of the changes in the short and long term.

Works Cited

AARP. (2020). *Caregiving in the U.S*. Retrieved April 06, 2021, from https://www.aarp.org/content/dam/aarp/ppi/2020/05/full-report-caregiving-in-the-united-states.doi.10.26419-2Fppi.00103.001.pdf

American Public Health Association. (2021). *Ensuring Equity in Transportation and Land Use Decisions to Promote Health and Well-Being in Metropolitan Areas*. https://www.apha.org/Policies-and-Advocacy/Public-Health-Policy-Statements/Policy-Database/2022/01/10/Ensuring-Equity-in-Transportation

Bahrami, S. and Roorda, M. (2022). *Autonomous vehicle parking policies: A case study of the City of Toronto*. Transportation Research Part A: Policy and Practice, Volume 155, Pages 283-296, ISSN 0965-8564. https://doi.org/10.1016/j.tra.2021.11.003.

Belcher, C. (2021, October 6). *As a black man, it's hard to catch a cab. and my research shows even white people know that*. The Washington Post. https://www.washingtonpost.com/posteverything/wp/2015/07/23/as-a-black-man-its-hard-to-catch-a-cab-research-shows-even-white-people-know-that/.

Bleach, K., Fairchild, N., Rogers, P., and Rosenblum, LP. (2020). *Improving Transportation Systems for People with Vision Loss*. American Foundation for the Blind. https://www.afb.org/sites/default/files/2020-03/Improving-Transportation-Systems-People-Vision-Loss.pdf

Blomqvist, Alexis. *Transforming Transportation: Community Perspectives on E-Mobility: Autonomous Vehicles, Electric Vehicles and Shared Mobility*. EVNoire. Accessed March 2022. https://drive.google.com/file/d/1g4aEkdCx9SNXDtKydqjIPJJoSM5nKeDN/view

Bonifacic, I. (2021). *California makes zero-emission autonomous vehicles mandatory by 2030*. TechCrunch. https://techcrunch.com/2021/09/24/california-makes-zero-emission-autonomous-vehicles-mandatory-by-2030/

Boudette, N. E. (2021, December 8). *Safety Agency says it is looking into Tesla video games that can be played while moving*. The New York Times. https://www.nytimes.com/2021/12/08/business/tesla-video-games-nhtsa.html.

Brandom, R. (2018, July 26). *Amazon's facial recognition matched 28 members of Congress to Criminal Mugshots*. The Verge. https://www.theverge.com/2018/7/26/17615634/amazon-rekognition-aclu-mug-shot-congress-facial-recognition.

Bus automation: Cost-effective solutions for transit operators. WSPglobal. (2021, December 10). https://www.wsp.com/en-US/insights/2021-bus-automation-cost-effective-solutions-for-transit.

California Multi-Agency Workgroup on AV Deployment for Healthy and Sustainable Communities. (2018). *Automated Vehicle Principles for Healthy and Sustainable Communities*.

https://opr.ca.gov/docs/20181115-California_Automated_Vehicle_Principles_for_Healthy_and_Sustainable_Communities.pdf

Camacho-Collados, M., Liberatore, F., & Angulo, J. M. (2015). A multi-criteria police districting problem for the efficient and effective design of patrol sector. European journal of operational research, 246(2), 674-684.

Chase, R. (2014, April 3). *Will a World of Driverless Cars Be Heaven or Hell?* Bloomberg.com. https://www.bloomberg.com/news/articles/2014-04-03/will-a-world-of-driverless-cars-be-heaven-or-hell.

City of Pittsburgh. *Pittsburgh's Shared + Autonomous Mobility Principles*. Page accessed March 2022. https://pittsburghpa.gov/domi/autonomous

Claypool, H., Bin-Nun, A., and Gerlach, J. (2017). *Self-Driving Cars: The Impact on People with Disabilities*. The Ruderman Family Foundation and Securing America's Future Energy. https://rudermanfoundation.org/wp-content/uploads/2017/08/Self-Driving-Cars-The-Impact-on-People-with-Disabilities_FINAL.pdf

Collingwood, L. (2017). Privacy implications and liability issues of Autonomous Vehicles. *Information & Communications Technology Law*, *26*(1), 32–45. https://doi.org/10.1080/13600834.2017.1269871.

Dark, S. J., & Bram, D. (2007). The modifiable areal unit problem (MAUP) in physical geography. Progress in Physical Geography, 31(5), 471-479.

Datta, D., Malczewski, J., & Figueira, J. R. (2012). Spatial aggregation and compactness of census areas with a multiobjective genetic algorithm: a case study in Canada. *Environment and Planning B: Planning and Design*, *39*(2), 376-392.

Dawkins, T. (2020). *Safe Drive Initiative: SafeDI scenario-based AV policy framework – an overview for policy-makers*. World Economic Forum. https://www3.weforum.org/docs/WEF_Safe_DI_AV_policy_framework_2020.pdf

Deffenbaugh, R. (2021, September 8). *City Green-lights self-driving vehicle permit despite industry opposition*. Crain's New York Business. https://www.crainsnewyork.com/technology/new-york-city-require-new-permit-self-driving-vehicles-despite-industry-opposition.

Docherty, I. (2018). New governance challenges in the era of 'smart' mobility. *Governance of the Smart Mobility Transition*, 19–32. https://doi.org/10.1108/978-1-78754-317-120181002.

Driverless passenger shuttle launched in Paris ile-de-france. Smart Cities World. (2021, April 1). https://www.smartcitiesworld.net/news/news/driverless-passenger-shuttle-launched-in-paris-ile-de-france-6262.

Explore census data. (n.d.(a)). Retrieved December 17, 2021, from https://data.census.gov/cedsci/table?g=1400000US36061009300&tid=ACSST5Y2019.S0101

Feller, G. (2021, July 8). *Automated Bus Rapid Transit: The future of urban transit is here*. Metro Magazine. https://www.metro-magazine.com/10146448/automated-bus-rapid-transit-the-future-of-urban-transit-is-here.

Fleischmann, B., & Paraschis, J. N. (1988). Solving a large scale districting problem: a case report. *Computers & Operations Research*, *15*(6), 521-533.

Garfinkel, R. S., & Nemhauser, G. L. (1970). Optimal political districting by implicit enumeration techniques. *Management Science*, *16*(8), B-495.

Greenwald, J. & Kornhauser, A. (2019). It's up to us: Policies to improve climate outcomes from automated vehicles. *Energy Policy*, Volume 127, Pages 445-451. https://doi.org/10.1016/j.enpol.2018.12.017

Griswold, A. (n.d.). *Uber is experimenting with letting riders wait longer in exchange for cheaper fares*. Quartz. https://qz.com/1308173/uber-is-experimenting-with-letting-riders-wait-longer-for-a-cheaper-fare/.

Groshen, E., Helper, S., MacDuffie, JP., & Carson, C. (2019). "Preparing U.S. Workers and Employers for an Autonomous Vehicle Future." Upjohn Institute Technical Report No. 19-036. Kalamazoo, MI: W.E. Upjohn Institute for Employment Research. https://doi.org/10.17848/tr19-036

Guo, F., & Aultman-Hall, L. (2014). A zone design methodology for national freight origin–destination data and transportation modeling. *Transportation Planning and Technology*, *37*(8), 738-756.

Hagenzieker, M., Boersma, R., Nuñez Velasco, P., Ozturker, M., Zubin, I., & Heikoop, D. (2021). *Automated buses in Europe*. TU Delft. http://resolver.tudelft.nl/uuid:96531c63-c961-45f5-98c6-586d19938f21.

He, B. Y., & Chow, J. Y. J. (2020). Optimal Privacy Control for Transport Network Data sharing. *Transportation Research Part C: Emerging Technologies*, *113*, 370–387. https://doi.org/10.1016/j.trc.2019.07.010.

Jenelius, E., & Mattson, L.-G. (2020, May 24). *Resilience of Transport Systems*. https://people.kth.se/~jenelius/JM_2020.pdf.

Jones, E., & Leibowicz, B. (2019). Contributions of shared autonomous vehicles to climate change mitigation. *Transportation Research Part D: Transport and Environment*, Volume 72, Pages 279-298. https://doi.org/10.1016/j.trd.2019.05.005.

Kalra, N., & Paddock, S. M. (2016). Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability? *Transportation Research Part A: Policy and Practice*, *94*, 182–193. https://doi.org/10.1016/j.tra.2016.09.010.

Kaufman, S., Interiano, G., & Peacock, M. (2021). *The Future of Autonomous Vehicles. WRLDCTY*.

Kaufman, S., Polack, C., & Campbell, G. (2018). *The Pink Tax on Transportation*. NYU Wagner Rudin Center for Transportation Policy & Management.

Kash, G. (2019). *Always on the defensive: The effects of transit sexual assault on travel behavior and experience in Colombia and Bolivia*. Journal of Transport & Health, 13, 234-246. https://doi.org/10.1016/j.jth.2019.04.004

Liberatore, F., Camacho-Collados, M., & Vitoriano, B. (2020). Police districting problem: literature review and annotated bibliography. *Optimal Districting and Territory Design*, 9-29.

Litman, T. (2022). Autonomous Vehicle Implementation Predictions: Implications for Transport Planning. Victoria Transport Policy Institute. https://www.vtpi.org/avip.pdf

Liu, H.-Y. (2017). Irresponsibilities, inequalities and injustice for Autonomous Vehicles. *Ethics and Information Technology*, *19*(3), 193–207. https://doi.org/10.1007/s10676-017-9436-2.

Lohr, S. (2018, February 9). *Facial recognition is accurate, if you're a white guy*. The New York Times. https://www.nytimes.com/2018/02/09/technology/facial-recognition-race-artificial-intelligence.html?module=inline.

Lundgren, B. (2020). Safety requirements vs. crashing ethically: What matters most for policies on Autonomous Vehicles. *AI & SOCIETY*, *36*(2), 405–415. https://doi.org/10.1007/s00146-020-00964-6.

Lyft. (2020, May 5). *Wait & save: The most affordable lyft ride for households and individuals*. Lyft Blog. https://www.lyft.com/blog/posts/wait-and-save.

Martínez, L. M., Viegas, J. M., & Silva, E. A. (2009). A traffic analysis zone definition: a new methodology and algorithm. *Transportation*, *36*(5), 581-599.

Mayor’s Office of the Chief Technology Officer (2021) The New York City AI Strategy, NYC CTO, https://www1.nyc.gov/assets/cto/#/project/ai-strategy.

Millard-Ball, A. (2019) The autonomous vehicle parking problem, Transport Policy, Volume 75, 2019, Pages 99-108, ISSN 0967-070X. https://doi.org/10.1016/j.tranpol.2019.01.003.

Minnesota Department of Transportation Office of Connected and Automated Vehicles (2018). Governor’s Advisory Council on Connected and Automated Vehicles: Executive Report.

http://www.dot.state.mn.us/automated/docs/Governor's%20Advisory%20Council%20Connected%20and%20Automated%20Vehicles%20Executive%20R....pdf

Mumich, D. (2021, December 8). *Trenton Moves Project aims to create the first autonomous vehicle-based Urban Transit System in America*. TrentonDaily. https://www.trentondaily.com/murphy-administration-announces-rfei-for-project-to-create-the-first-autonomous-vehicle-based-urban-transit-system-in-america/.

National Safety Council. The Most Dangerous Time to Drive. Retrieved Mar 30, 2022. https://www.nsc.org/road-safety/safety-topics/night-driving

New York City Taxi and Limousine Commission. "About TLC." Retrieved March 31, 2022. https://www1.nyc.gov/site/tlc/about/about-tlc.page

NHTSA (2015) Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey. U.S. Department of Transportation. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115.

NHTSA (2021) Early Estimate of Motor Vehicle Traffic Fatalities in 2020. U.S. Department of Transportation. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813115.

O'Neill, W. A. (1991). Developing optimal transportation analysis zones using GIS. In *Proceedings of the 1991 Geographic Information Systems (GIS) for Transportation SymposiumCo-sponsored by the Federal Highway Administration, the Highway Engineering Exchange Program, Transportation Research Board, and Urban & Regional Information Systems Association.*

Openshaw, S. (1979). A million or so correlation coefficients, three experiments on the modifiable areal unit problem. *Statistical applications in the spatial science*, 127-144.

Pangbourne, K., Stead, D., Mladenović, M., & Milakis, D. (2018). The case of mobility as a service: A critical reflection on challenges for urban transport and mobility governance. *Governance of the Smart Mobility Transition*, 33–48. https://doi.org/10.1108/978-1-78754-317-120181003.

Peirce, S., Cregger, J., Burkman, E., Richardson, H., Machek, E., Mortensen, S., & Mahavier, K. (2019). Assessing the transit agency business case for partial and full automation of bus services. *Transportation Research Record: Journal of* *the Transportation Research Board*, *2673*(5), 109–118. https://doi.org/10.1177/0361198119842113.

Ricca, F., Scozzari, A., & Simeone, B. (2013). Political districting: from classical models to recent approaches. *Annals of Operations Research*, *204*(1), 271-299.

Roberts, F. S. (2021). Chapter 7 Data Science and Resilience. *Resilience in the Digital Age*, 118–138. https://doi.org/10.1007/978-3-030-70370-7_7.

Rojas-Rueda, D., Nieuwenhuijsen, M. J., Khreis, H., & Frumkin, H. (2020). Autonomous Vehicles and Public Health. *Annual Review of Public Health*, *41*(1), 329–345. https://doi.org/10.1146/annurev-publhealth-040119-094035.

Sahu, P. K., Chandra, A., Pani, A., & Majumdar, B. B. (2020). Designing freight traffic analysis zones for metropolitan areas: identification of optimal scale for macro-level freight travel analysis. *Transportation Planning and Technology*, *43*(6), 620-637.

Salazar-Aguilar, M. A., Ríos-Mercado, R. Z., & Cabrera-Ríos, M. (2011). New models for commercial territory design. *Networks and Spatial Economics*, *11*(3), 487-507.

Samuel, S. (2019, March 5). *A new study finds a potential risk with self-driving cars: Failure to detect dark-skinned pedestrians*. Vox. https://www.vox.com/future-perfect/2019/3/5/18251924/self-driving-car-racial-bias-study-autonomous-vehicle-dark-skin.

Schmitt, A. (2018, July 6). *Self-driving cars are coming. Will they serve profit or the public?* In These Times. https://inthesetimes.com/features/self-driving_cars_auto_industry_city_planning.html.

Scitovski, S. (2018). A density-based clustering algorithm for earthquake zoning. *Computers & Geosciences*, *110*, 90-95.

Shanker, R. J., Turner, R. E., & Zoltners, A. A. (1975). Sales territory design: an integrated approach. *Management Science*, *22*(3), 309-320.

Shetty, A., Yu, M., Kurzhanskiy, A., Grembek, O., Tavafoghi, H., & Varaiya, P. (2021). Safety challenges for autonomous vehicles in the absence of connectivity. *Transportation Research Part C: Emerging Technologies*, *128*, 103133. https://doi.org/10.1016/j.trc.2021.103133.

Simoni, M. D., Kockelman, K. M., Gurumurthy, K. M., & Bischoff, J. (2019). Congestion pricing in a world of self-driving vehicles: An analysis of different strategies in alternative future scenarios. *Transportation Research Part C: Emerging Technologies*, *98*, 167–185. https://doi.org/10.1016/j.trc.2018.11.002.

Simpson (2021) TRL identifies Metrics for Autonomous Vehicle Safety Assessment. Highways Today. https://highways.today/2021/10/12/trl-metrics-autonomous-vehicles/.

Smith, G., & Theseira, W. (2020). Workshop 5 report: How much regulation should disruptive transport technologies be subject to? *Research in Transportation Economics*, *83*, 100915. https://doi.org/10.1016/j.retrec.2020.100915.

Sparrow, R., & Howard, M. (2020). Make way for the wealthy? Autonomous Vehicles, markets in mobility, and Social Justice. *Mobilities*, *15*(4), 514–526. https://doi.org/10.1080/17450101.2020.1739832.

Steckler, B., Howell, A., Larco, N., and Kaplowitz, G. (2021). A Framework for Shaping the Deployment of Autonomous Vehicles and Advancing Equity Outcomes. Urbanism Next Center. https://www.urbanismnext.org/resources/a-framework-for-shaping-the-deployment-of-autonomous-vehicles-and-advancing-equity-outcomes

Taeihagh, A., & Lim, HSM. (2019). Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks, Transport Reviews, 39:1, 103-128, DOI: 10.1080/01441647.2018.1494640.

Thomopoulos, N., & Givoni, M. (2015). The autonomous car—a blessing or a curse for the future of Low Carbon Mobility? an exploration of likely vs. desirable outcomes. *European Journal of Futures Research*, *3*(1). https://doi.org/10.1007/s40309-015-0071-z.

Townsend, A. *Ghost Road: Beyond the Driverless Car.* W. W. Norton & Company; 1st edition (June 16, 2020).

University of California at Berkeley, "Autonomous Vehicles Strategic Framework: Draft Vision and Guiding Principles," 2021. https://path.berkeley.edu/sites/default/files/011321_draft_-_avsf_framework_guiding_principles_2.pdf

Vargas, J., Alsweiss, S., Toker, O., Razdan, R., & Santos, J. (2021). An overview of autonomous vehicles sensors and their vulnerability to weather conditions. *Sensors*, *21*(16), 5397. https://doi.org/10.3390/s21165397.

Wiesmayer, P. (2019, August 10). *Self-driving buses: Paris ends experiment after two years*. Innovation Origins. https://innovationorigins.com/en/self-driving-buses-paris-ends-experiment-after-two-years/.

Wilson, Benjamin & Hoffman, Judy & Morgenstern, Jamie. (2019). Predictive Inequity in Object Detection. https://www.researchgate.net/publication/331429615_Predictive_Inequity_in_Object_Detection.

Wolf, M. (2019). *How Autonomous Vehicles Can Affect People With Disabilities*. National Conference of State Legislatures. https://www.ncsl.org/blog/2019/12/10/how-autonomous-vehicles-can-affect-people-with-disabilities.aspx