Autonomous Vehicle Good Citizenry Standard

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16. Abstract

To establish a framework for considering these wraparound AV impacts in New York City, the NYU Rudin Center for Transportation Policy and Management led a multi-stakeholder initiative in conjunction with NYU’s C2SMART, USDOT University Transportation Center. The team hosted three workshops in December 2021 addressing issues and opportunities in seven topic areas: Local Governance, Community Outreach, Integration with Public Transit, Equity, Accessibility, Safety and Data Privacy. Participants represented the public and private sectors, advocacy and civic organizations, and academia.

In addition, the research team conducted a quantitative study of equitable deployment of new mobility in New York City. The study finds that the ideal data aggregation level depends on the reliability of the public data collected for that community, and recommends a new tool to help design the appropriate data structure for data sharing.

Based on this foundational research and stakeholder input, seven mobility policy principles are presented as a preliminary framework for approaching the wraparound policies concerning the introduction of autonomous vehicles to New York City: safety, serve all NYers equitably, engage NY's diverse communities, coexist with public transportation, intelligent interactions with the city, New York City’s ongoing sustainability efforts, and publlic-private partnerships.

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AVs in NYC: A Policy Framework

July 2022

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Autonomous Vehicle Good Citizenry Standard: A Policy Framework Executive Summary

While the reality of autonomous vehicles in New York City remains several years away, this timeline grants us the opportunity to set up a transportation model for equitable, safe and accessible mobility.

Although AVs are regulated for safety and efficacy within the transportation realm, they are rarely evaluated from a policy perspective. Autonomy's impacts will be far-reaching, prompting significant social concerns like potential job displacement, equitable neighborhood access, and data privacy.

To establish a framework for considering these wraparound AV impacts in New York City, the NYU Rudin Center for Transportation Policy and Management led a multi-stakeholder initiative in conjunction with NYU's C2SMART, USDOT University Transportation Center. The team hosted three workshops in December 2021 addressing issues and opportunities in seven topic areas: Local Governance, Community Outreach, Integration with Public Transit, Equity, Accessibility, Safety and Data Privacy. Participants represented the public and private sectors, advocacy and civic organizations, and academia.

In addition, the research team conducted a quantitative study of equitable deployment of new mobility in New York City. The study finds that the ideal data aggregation level depends on the reliability of the public data collected for that community, and recommends a new tool to help design the appropriate data structure for data sharing.

Based on this foundational research and stakeholder input, seven mobility policy principles are presented as a preliminary framework for approaching the wraparound policies concerning the introduction of autonomous vehicles to New York City:

1. **Safety**, and public trust in that safety, is paramount to the introduction of autonomous vehicles on city streets.
2. **Serve all New Yorkers equitably**, raising the voices of our diverse populations in developing, testing and using AVs to make them accessible to all.

3. **Engage New York's diverse communities**, hearing out community goals and concerns while also promoting innovation and equity.
4. Shared-ride autonomous vehicles must **coexist with public transportation**, which continues to serve as the lifeblood of New York City.
5. New technologies introduced by AVs should foster increasingly **intelligent interactions with the city**.
6. Adoption of AVs must **augment New York City's ongoing sustainability efforts**, including vehicle electrification, minimized vehicle miles traveled, and sharing rides.
7. **Public-private partnerships** are key to setting and achieving safety, equity and sustainability goals.

These policy principles are intended to establish cross-sector strategic partnerships to advance both public innovation and social tenets. By centering the city's goals of equity, safety, and sustainability, this initiative aims to ensure that AVs sufficiently support and move New Yorkers.

Introduction

Progress in the development of autonomous vehicles has reached a point of public expectation of these burgeoning technologies. Although the technology is not quite ready for New York City's busy street environment, AVs are a generational transformation. The forthcoming reality of their introduction prompts the need to evaluate how the technology will impact New York's residents and streetscape and how the City can best position itself.

Assuming AVs offer an upgraded level of street safety, they present significant opportunities for New Yorkers. Most importantly, the optimized transportation of people and goods would help street traffic move more efficiently, expanding access to job opportunities and increasing transportation accessibility across the city.

Conversely, if allowed to proliferate unfettered, AV's may pull New York City backwards in reaching its goals: increasing traffic congestion and vehicular miles traveled by presenting a travel option that draws riders away from public transportation, further alienating historically marginalized communities and directly contradicting local equity and sustainability goals.

Although AVs are primarily regulated for safety and efficacy within the transportation realm, they are rarely addressed outside of the industry, limiting the comprehensiveness of planning for their introduction. However, AV impacts will be far-reaching, prompting significant social issues like potential job displacement, equitable neighborhood access, and data stewardship. Assessing these often-sidelined issues will require input from multiple stakeholders, as regulations and solutions can be folded into the burgeoning technologies.

Although these concerns affect all United States cities, as the largest and most densely populated city in the country, New York presents a special challenge to autonomous vehicle developers. The local transportation model flips the U.S. trends: New Yorkers are primarily pedestrians, ride transit at far higher rates than any other city, and only two-thirds own cars. These factors complicate the street environment on which AVs are typically trained, and exacerbate already pressing questions about the role and function of cars in New York's future. In addition, as a preeminent city for technology startups and an ambitious workforce, New York presents profound opportunities for collaboration with AV companies. Because of New York City's particular circumstances, any partnership goals and policy regulations will require customization.

To establish a framework for policymakers' considerations of wraparound AV impacts in New York City, the NYU Rudin Center for Transportation Policy and Management has led a multi-stakeholder initiative in conjunction with NYU's C2SMART, USDOT University Transportation Center.

The Rudin Center & C2SMART hosted three workshops in December 2021 addressing issues and opportunities in seven topic areas: NYC Governance, Community Outreach, Integration with Public Transit, Equity, Accessibility, Safety and Data Privacy. Participants represented the public and private sectors, advocacy and civic organizations, and academia. The outcomes of these discussions are reflected in the text below.

To augment the qualitative outcomes, the research team at NYU's C2SMART Center conducted a quantitative study of equitable deployment of new mobility in New York City. One of the key challenges in bringing different mobility providers together in a city is the need for a common data interchange that can adequately measure the impacts of performance on everyone. The study found that the data structure chosen for sharing data is crucial for ensuring adequate measurement of equity. For example, requiring mobility providers to share highly aggregated data would not be useful for measuring spatial variations in a community, but highly disaggregated data sharing may also result in undersampled public data for such underserved population segments as seniors, low-income households, or people with disabilities. The study finds an ideal data aggregation level depends on the reliability of the public data collected for that community and recommends a new tool to help design the appropriate data structure for data sharing.

Based on this foundational research and stakeholder input, seven mobility policy principles are presented as a preliminary framework for approaching the wraparound policies concerning the introduction of autonomous vehicles to New York City:

1. Safety is paramount to the introduction of autonomous vehicles on city streets.
2. Serve all New Yorkers equitably, raising the voices of our diverse populations in developing, testing and using AVs to make them accessible to all.

3. Engage New York’s diverse communities, hearing out community goals and concerns while also promoting innovation and equity.
4. Shared-ride autonomous vehicles must coexist with public transportation, which continues to serve as the lifeblood of New York City.
5. New technologies introduced by AVs should foster increasingly intelligent interactions between vehicles and the city.
6. Adoption of AVs must augment New York City’s ongoing sustainability efforts, including vehicle electrification, minimized vehicle miles traveled, and sharing rides.
7. Public-private partnerships are key to setting and achieving safety, equity and sustainability goals.

These policy principles are intended to establish cross-sector strategic partnerships to advance both public innovation and social tenets. By centering the city’s goals of equity, safety, and sustainability, this initiative aims to ensure that AVs sufficiently support and move New Yorkers.

Assumptions

In order to explore the policy areas surrounding autonomous vehicle adoption, the research team has made several assumptions to level set the research and conversations:

1. Autonomous Vehicle safety will reach an acceptable level for operation in New York City: At some point, AVs will be deemed “safe enough” to operate in the city, regardless of whether that is 80, 100 or 200 percent the safety rating of human drivers. This discussion informs the timeframe when AVs reach that policy goalpost, wherever it may fall.
2. This discussion covers AV’s that do not require human intervention: The project assumes the operation of autonomous vehicles that are entirely self-functioning. While the timeline to this end may remain in question, this assumption removes the need for discussion around vehicle control, focusing instead on the urbanist policies.
3. Most AV trips will service e-hail or shared rides: Because New York City is already working to reduce vehicular traffic, it is assumed in this discussion that the majority of AVs permitted to operate will be of the e-hail or shared-shuttle model. That is, they will not add significantly to vehicular traffic or car ownership, and will complement public transportation. This assumption helps to serve New York’s goals of reducing congestion and improving sustainability; references in the discussion below to AV companies are particularly focused on those that will replace existing e-hail vehicles, deliver goods, or provide shared services.
4. AVs will be electrically-powered: To comport with New York City’s sustainability goals, it is assumed that autonomous vehicles permitted to operate in the city will be powered by electricity and not gas. This assumption helps to set the standard for discussing AV impacts to sustainability goals.

Policy Principles

These proposed principles aim to provide key considerations for the responsible deployment of autonomous vehicles in New York City.

1. **Safety is paramount to the introduction of autonomous vehicles on city streets.**
    - On-street safety: New York's unique street environment necessitates that AVs will interact with other modes more than in any other U.S. city: Many vulnerable road users – including pedestrians, cyclists, and micromobility riders – compete for road space with vehicles, presenting conflicts that will persist with AVs as well.
    - Accelerating New York's existing stated goals on Vision Zero, bike infrastructure, pedestrianization, and transit prioritization will improve the performance and safety of AVs.
    - New Yorkers deserve to move around on city streets without threats of physical danger. Vehicle speeds, movements and stops should be regulated to accommodate New York's pedestrian-first environment.
        - New York City's explosive growth of micromobility usage, including bikes, scooters, e-bikes and mopeds, should be built into autonomous vehicles' intelligence.
        - Policies concerning AVs should include considerations of how small-form, sidewalk delivery robots might fit into New York City's streetscapes.
    - On-board security: Shared vehicles must implement measures to ensure riders are safe from potential safety threats from other riders, including harassment, assault and theft - persistent threats for women, especially, based on prior research from the NYU Rudin Center for Transportation.[1] In-vehicle monitoring, as well as emergency response procedures, must be in place.
        - Making child safety car seats (or anchors) available can vastly improve the safety of traveling families.
    - Enforcement of traffic incidents, such as collisions, must be clarified among first responders, traffic enforcers and passengers about traffic rules and liabilities.

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[1] https://wagner.nyu.edu/impact/research/publications/pink-tax-transportation-womens-challenges-mobility

2. **Serve all New Yorkers equitably, raising the voices of our diverse populations in developing, testing and using AVs to make them accessible to all.** New York is exceedingly and increasingly racially diverse. Nearly half of New Yorkers speak a language other than English at home, ten percent of New Yorkers have a disability, and 17 percent live in poverty.[2,3] Due to the extent of New Yorkers' diversity, the introduction of any new mode of transportation must include a plan for equitably serving needs across race, income, gender identity, language spoken and physical ability. Local government and the private sector must take steps to deploy autonomous vehicles equitably, specifically considering:
    - Neighborhood equity: Long commutes detract from residents' economic mobility, limiting access to work and school opportunities. Neighborhoods lacking sufficient transit services should be prioritized, and policymakers should consider setting service requirements for historically underserved neighborhoods, as well as off-hour travel to accommodate shift workers.
        - Demographic data that describes the mobility needs of minority groups is unreliable (large margin of error) due to low sample sizes compared with majority groups.[4]
    - Vehicle accessibility: A new mobility mode cannot be deployed without accessibility for people with physical and cognitive disabilities.
        - Policymakers must set goals and requirements to ensure that an adequate percentage of shared rides are usable by users of wheelchairs and other mobility devices.
        - Passengers must be able to interact with vehicles through multiple formats (visual and audio), and accessible through all phone formats for low vision users (including requesting remote help).
        - Potential AV users with disabilities should be engaged early in vehicle planning and testing to ensure accessibility.
    - Low-income and unbanked users: Ride pricing will be key to making trips more accessible to New Yorkers with lower incomes, as will payment in peer-to-peer payment apps.[5]
    - Driving as a profession: Approximately 185,000 New Yorkers drive professionally, and more than 90 percent of those drivers are

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[2] 2020 census https://www.census.gov/quickfacts/fact/table/newyorkcitynewyork/DIS010220#DIS010220

[3] NYC MOPD (2021) https://www1.nyc.gov/assets/mopd/downloads/pdf/AccessibleNYC2021.pdf

[4] ACS: https://data.census.gov/cedsci/all?g=1400000US36061009300

[5] Peer-to-peer payment apps include Venmo, Zelle and Paypal.

foreign-born.[6] Driving a New York City taxi or for-hire vehicle has long served as a path to economic opportunity for immigrants and minorities. Although AVs will eventually preclude the need for professional drivers, the transition to this point will require extensive partnership with drivers. Job retraining can mitigate job losses, and AV taxis can be classified as a separate medallion class so as not to detract from existing taxi offerings.

  - Equitable street safety: Streets that present safety hazards for pedestrians and cyclists are overrepresented in some low-income communities of color. Often bordering highways and major arterial roads, speeding cars through these neighborhoods particularly endanger Black and Brown pedestrians.[7] Any AV deployments in these neighborhoods must be preceded by street design improvements to reduce traffic speeds and avoid compounding already hazardous conditions.

3. **Engage New York's diverse communities**, hearing out community goals and concerns while also promoting innovation and equity. Community engagement calls for ongoing public participation at all stages, including policymaking, testing and deployment. It should be informative and collaborative, eliciting and incorporating diverse stakeholder inputs, while building trust with new mobility companies.
    - Both AV companies and the NYC government should help officials and the general public understand AV operations, terminology and goals.
        - Materials should be presented to leaders and diverse community groups in multiple languages and both digital and paper formats.
    - By defining clear expectations for public engagement and making AV companies adhere to them as a precondition for operating licenses, NYC policymakers will create clarity for the private sector and understanding for the public sector.
        - Public engagement should inform standards for meaningful AV testing for both companies and communities.
    - Communities should be empowered, through their local elected officials, to engage in the process of voicing their mobility pain points, concerns about vehicles, and participate in pilots, through both digital and analog channels.

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[6] NYC TLC Factbook https://www1.nyc.gov/assets/tlc/downloads/pdf/2020-tlc-factbook.pdf

[7] https://howsmydrivingny.nyc/cameras/ based on NYC Open Data

   - NYC policymakers should require that AV companies hire a fixed percentage of employees from throughout the city, at all company levels, to ensure community needs and diverse interests are represented.

4. Shared-ride autonomous vehicles must **coexist with public transportation**, which continues to serve as the lifeblood of New York City. New mobility modes, including AVs, can offer an additional option in an efficient, sustainable and affordable mobility menu.
   - Public transit remains the most efficient mode to move New York City's 8.5 million residents. Attracting choice riders away from subways and buses could substantially harm public transit, where funding depends on ridership and reducing services could be especially harmful to already underserved populations. New York policymakers should set a clear expectation that AVs will complement, rather than compete with, transit services.
     - Planned congestion pricing funds must be reinvested into public transit to ensure it is competitive and accessible to all users.
   - Developing first- and last-mile microtransit could use AVs for safe, reliable transportation between transit stations and final destinations.
     - Replacing or complementing low-ridership bus routes, or subway routes with service outages, with dynamic microtransit could lower transit agency costs while improving service delivery.
   - Knowledge-based partnerships should explore how AV and Advanced Driver Assistance System technologies can be shared with bus and taxi services to assist with vehicle-to-vehicle communications, improving street flow and safety.
5. New technologies introduced by AVs should foster increasingly **intelligent interactions** between vehicles and the city.
   - Trip data, anonymized and aggregated, must flow both ways between fleet operators and the city government to promote efficient mobility offerings and measure safety and equity.
     - NYC policymakers should standardize and share infrastructure-related data, such as road closures and construction work.
     - Private AV companies can submit ground-level data that would be useful for operations and planning purposes, such as problematic intersections.

   - Data exchanges across modes[8] can help to organize microtransit solutions based on real-time conditions, such as train delays or street closures.
- Autonomous vehicle operation requires the constant intake and processing of data from wayside infrastructure, camera imagery and sensors. AV companies must act as strong stewards of public data, while NYC policymakers should define and set data privacy and protection standards that must be met by private AV companies looking to operate in the city.
   - Protection of user data will require standards for cybersecurity, user access, aggregation, removing personally identifiable information, and archiving. Metrics for best practices are yet to be defined.
   - AV cameras collect both rider and non-rider geotagged images. Legal procedures must be in place for data collection, control and potential third-party access by authorities and advertisers.
   - These standards should protect all New Yorkers, regardless of immigrant, legal or other status.
- AV intelligence, such as on-board data and wayside sensors, can be harnessed to help manage the curb, which should be organized to make room for e-commerce loading zones and dynamically-priced parking, and to ensure safe pickup and dropoff of passengers.

6. Adoption of AVs must **augment New York City's ongoing sustainability efforts,** including vehicle electrification, minimized vehicle miles traveled, and sharing rides.
   - New light-duty autonomous vehicles deployed in New York City should be zero emissions-required, comporting with the city's goals of reducing greenhouse gas emissions 80% by 2050.[9]
   - The addition of robotaxi services should not increase the total vehicle miles traveled in New York City, but instead should focus on complementing public transportation and supplanting less efficient vehicles.
   - New York's focus on reducing road space dedicated to cars and instead to more dynamic uses, including streets open to pedestrians, increased bike lanes, commercial loading zones, and containerized trash, should not be thwarted by the introduction of this new mode. These new

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[8] https://www.transportation.gov/av/data

[9] https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/Carbon-Neutral-NYC.pdf

    dedications of space are essential to efficient movements and sustainability efforts like stormwater absorption.

7. **Public-private partnerships** are key to setting and achieving safety, equity and sustainability goals.
    - NYC policymakers, with the input of private companies, must develop a roadmap to incubate innovative ideas and be prepared for new modes and technologies going forward.
    - Opportunities abound in developing public-private microtransit solutions in areas currently underserved by static transit.
        - For example, microtransit shuttles can bring workers between residential clusters and job anchor locations, such as airports and hospitals, reducing travel time for large numbers of essential workers.
        - In areas with low bus ridership, microtransit services could provide more direct, on-demand services in smaller-form vehicles.
    - Existing NYC workforce development and training programs can be leveraged for the next generation of workers.
        - Partnering with NYC's high school coding courses can be mutually beneficial to enhancing students' education and developing projects for companies.
        - Partnerships with universities, libraries and the tech industry will lead to large job pools.
    - Partnerships may be modeled after the New York City Housing Authority's policy, which requires a fixed percentage of all contract awards to be designated to training, hiring or advancing residents. Similarly, AV companies seeking to operate locally can be required to tap into the local workforce.

Neighborhood Equity Modeling

Introduction

In addition to service data from the mobility providers, demographic data is necessary to conduct evaluations of equity in service. However, demographic data is not fully reliable, because it is highly dependent on sampling. As a result, demographic data of minority groups is more likely to be unreliable compared with majority groups. For example, the margin of error of the population above 18 years old in census tract 93 in Manhattan is 7.72%, while the margin of error is 35.95% for the disabled population in the same census tract. Unreliable data of minority groups makes it harder to incorporate equity in service evaluation and decision making.

With the existing demographic data already collected by local agencies, large sampling errors can be reduced through aggregating the areal units into fewer, larger units to improve the overall reliability of statistical analysis.[10] For example, if data based on census tracts are aggregated into Neighborhood Tabulation Areas (NTAs), the sample size in each NTA would be larger than each census tract, which leads to smaller sampling errors and more reliable analysis for minority groups at that spatial aggregation level. However, it results in data that is lower resolution for spatial analysis. Such a process of aggregating small basic spatial units into larger zones is referred to as "districting" in the literature[11].

The scale and design of the aggregated zones affect the statistical results, which is known as the Modifiable Areal Unit Problem (MAUP), which refers to the sensitivity of statistical results to changes in the areal units of analysis. Therefore, finding a zoning system with proper scale and design is vital for reliable and equitable analysis and evaluation.

To summarize, in order to plan for equity in transportation decision-making, zoning systems must be designed for sharing data between AV mobility providers and local

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

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

agencies such that underserved communities are reliably represented. A zone-design (districting) algorithm is needed. The algorithm should be able to identify an optimal zoning system given one or more demographic dimensions (e.g. age, income, disability), which are based on a system of basic spatial units. The optimal zoning system should meet some criteria, such as the scale of the zones and the largest tolerable sampling error of the given data dimensions, which should be lower than the original data based on the basic spatial units.

Method

For the specific districting problem considering sampling error, the team implemented an algorithm that outputs an aggregated zoning system given a set of basic spatial units, adapted from the max-p-regions algorithm proposed by Duque et al. (2012). The algorithm generates as many districts as possible that minimize heterogeneity within districts while making sure that the sampling error of all districts are sufficiently low. The problem is first formulated as an integer programming optimization problem, which minimizes the total heterogeneity within the districts. The constraints ensure that the generated districts are contiguous, and the sampling error of the generated districts are within a threshold. The problem is NP-hard, which means it cannot be solved to optimality within polynomial time. Hence, we implemented a heuristic to solve it. First, districts are grown from random basic zones, minimizing total heterogeneity and margin of error within the districts. Then a *Tabu Search* is applied to make improvements on the grown districts, further improving the total heterogeneity.

NYC Equity Zoning

The method is applied to design a zoning system for New York City (NYC) to allow AV mobility providers to share data at a zone aggregation level that ensures reliable demographic data, using margin of errors from demographic data collected from the American Community Survey (ACS).[12] Underserved groups of interest include the population above 67 years old (elderly), the population under the poverty level (the threshold is $36,262 for a household of 2 adults and 2 children in 2019 for NYC[13]), the

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[12] https://data.census.gov/cedsci/

[13] New York City Government Poverty Measure 2019: https://www1.nyc.gov/assets/opportunity/pdf/21_poverty_measure_report.pdf

population with a commute time above one hour, and the population with one or more disabilities. While only the former three groups are considered in districting, populations with one or more disabilities are highly correlated with the others. The basic zone unit is the census tract. We use the proposed heuristic algorithm to aggregate census tracts, designing a zoning system for NYC which improves the data reliability of the above data dimensions of minority groups. The results are shown in Figure 1 and Table 1. The 2,168 census tracts in NYC are aggregated into 574 districts. The result of one example zone in lower Manhattan is shown in Figure 2 and Table 2, which shows significant improvement in data reliability. The algorithm is paused after 1,200 iterations of Tabu Search since it becomes significantly harder to find an improvement after around 1,100 iterations as shown in Figure 3. Hence, the solution after 1,200 is considered satisfactory. Data reliability of the four minority groups are significantly improved, as shown in Table 1.

Figure 1. District design for NYC to improve reliability of seniors, low-income, and long commute residents over census tracts.

Table 1. Average margin of error percentage of census tracts and equitable zones from districting

	Average margin of error (%)		
Zone aggregation level	Population above 67 years old	Population below poverty level	Population with a commute time >1 hour
Census tracts	15.22%	50.07%	18.23%
Equitable districts	8.02%	12.33%	9.88%

Table 2. Margin of error improvement of an example zone

Margin of error (%)	Population above 67 years old	Population below poverty level	Population with a commute time >1 hour
Aggregated zone	6.19%	19.43%	7.08%
Census tract 1	7.40%	40.24%	12.67%
Census tract 2	13.02%	36.19%	11.34%
Census tract 3	11.48%	27.03%	11.94%

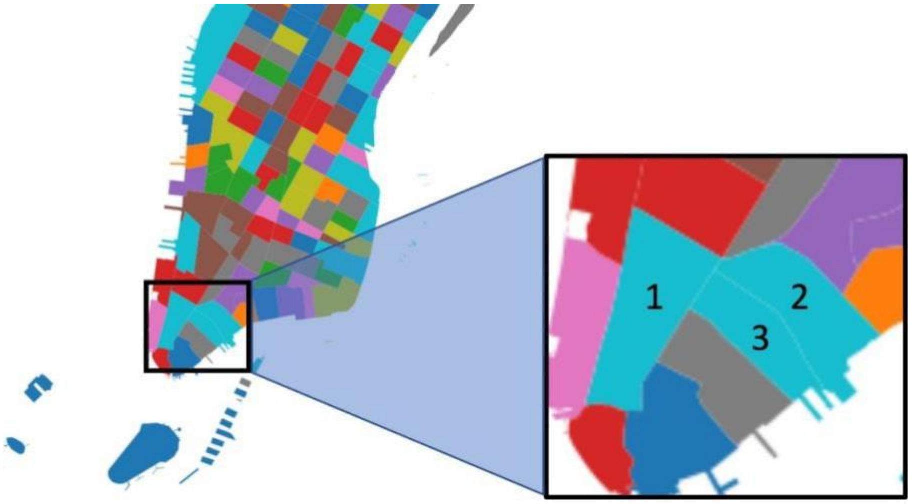
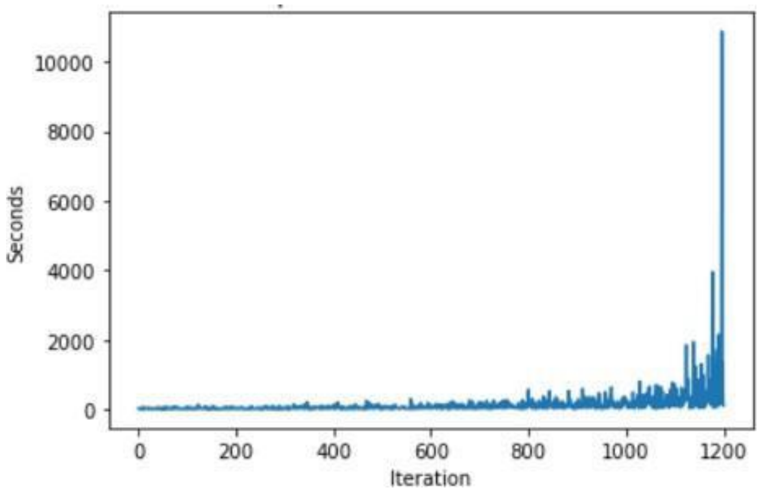
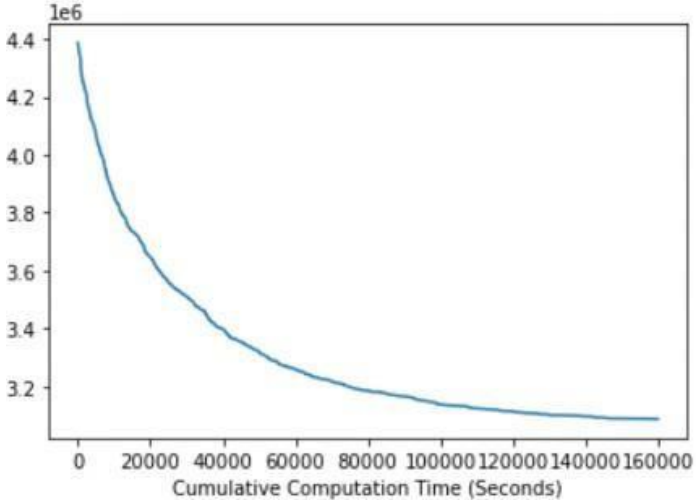


Figure 2. Margin of error improvement of an example zone



(a) Computation time of each iteration



(b) Heterogeneity changes with cumulative computation time

Figure 3. Relationship between computation time and total heterogeneity

Discussion

As AV mobility providers consider NYC a potential market, the zone design shown in Figure 1 offers an aggregation level that can potentially reduce the average margin of error of demographic data by 48% for seniors, 75% for low income residents, and 46% for residents with hour-long commute times. NYC policymakers measuring service using this zone structure will allow them to better measure the impacts on these groups with significantly more accuracy. For example, if Waymo shares passenger pickups and drop-offs at the proposed aggregation level, that data can be linked to population-level commute data that informs on impacts to low-income travelers while remaining spatially relevant. In turn, this means that NYC would be able to better assess the equity of Waymo's service offerings. Sharing data aggregated at zone levels can also alleviate the privacy concerns of the AV mobility providers. The districting algorithm can be used to provide different levels of aggregation for negotiation between the regulatory agencies and the AV mobility providers.

This zone design method can also provide an opportunity to share data through new digital infrastructures. First, data-sharing digital infrastructure enabled with the districting function could help users, mobility providers, and regulatory agencies to create a more equitable and privacy-aware data-sharing pattern by producing different zoning systems given different sampling error tolerance and scale threshold. Furthermore, the districting function could empower the digital infrastructure in a broader sense. Data-sharing could extend beyond the AV mobility providers and regulatory agencies to different mobility providers as well as the general public. Data can be aggregated to different extents with different zone designs to meet the requirements under different circumstances. The mobility providers could work together with different parties to find levels of aggregation at which they are willing to share data with each other and the general public, to create an accessible clearinghouse of mobility data.

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.

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AV Stakeholder Workshops Synthesis

A summary of comments from stakeholders during the NYU Rudin Center's AV Stakeholder Workshops hosted in December, 2021

Governance

Where might local government address needs around data stewardship, equitable deployments and partnership in experiential learning?

Challenges

Sound local governance can only be achieved through jurisdictional clarity, engagement between the private industry and public officials, and standards-setting.

Jurisdiction: Because city, state, and federal governments each set their own rules for testing of AVs, jurisdictional issues present challenges.

- A lack of broad federal rules on the technology side creates a patchwork of standards locally.
    - Further, might different standards apply to distinct neighborhoods or categories of neighborhoods across NYC?
- It is unclear where the regulatory jurisdiction and role starts as advanced driver assistance systems develop into higher levels of autonomy.

Regulation: The city's regulatory role and capacity are unclear, as are the city's requirements and resources in providing infrastructure and technology.

- Locally-focused standards and licensing will be necessary throughout the AV deployment process.
    - Funding and administration of pilot projects is not yet identified.
    - The licensed vehicle industry, including taxis and for-hire vehicles, must play a part. (AV technologies are not currently permitted to test on TLC vehicles.)

Liability: Governance includes liability concerns between operator, developer, and government agencies, especially in vehicle-to-infrastructure connections.

Aversion: The public sector remains scarred by past experiences with emerging mobility companies' ethos of asking forgiveness rather than permission, which has created distrust.

Opportunities

New York's population size and density means it can serve as a leader and positive example for other cities in setting standards around safety, accessibility, equity, and engagement.

Setting Goals: NYC's can issue policy requirements for AVs that comport with citywide goals of safety, equity, sustainability and efficiency. Public-private partnerships can help to achieve these goals, including:

    - Avoid net addition of vehicle miles traveled or pulling people away from transit
    - Ensure availability and funding of accessible rides
    - Contribute to net jobs created and reskilling of workers
    - Data sharing requirements
    - Servicing first- and last-mile needs

Jurisdiction: AV regulation presents an opportunity for alignment between state and local governments.

- New York City controls the curb, a necessary area to control to improve safety and reduce congestion.

Standards and Licensing: A licensing model can ensure high standards and control the growth of AVs.

- NYC should proactively define its policy goals and measure how AV companies might impact these goals. Where they are not in alignment, earlier collaboration is favorable.
- Local government should act as both an enabler and safety regulator.

Learning from Experience: A review of what worked and what did not work in past implementations can offer guidance to regulating AVs:

- Draw from other cities’ successes in AV community engagement and safety testing.
- Locally, other modes include the taxi medallion system, rideshare and bike share.
    - The taxi medallion system ensured high standards and created value and financing opportunities
    - In bike share, standards were used as a condition of giving out licenses.
- Consider franchising out public roadways to specific AV operators, similar to UK rail, NYC subway construction, and internet service in South Korea. The public sector could manage engagement and franchise out operations.

Safety

What are the safety challenges specific to New York City's density, built environment and personality?

This project is designed on the assumption that AVs will, at some point, be deemed safe enough to operate in New York City, whether that time is one or twenty years away. As such, these workshop discussions were centered around the wraparound policy issues for the actual introduction of AVs. However, safety is certainly paramount and not limited to the street environment, so it is considered here in broad strokes.

New York City's street environment is unique, chaotic, multimodal and lively, presenting a range of challenges and opportunities to the introduction of AVs. In addition, the concept of safety includes that of passengers inside shared vehicles as well as the future of traffic enforcement.

Challenges

AVs will face significant challenges adapting to New York City's chaotic street environment and mixing of pedestrians, cyclists, e-bikes, scooters, double-parked vehicles, and construction equipment.

New York's unique street environment necessitates that AVs will interact with other modes more than in any other U.S. city:

- Many vulnerable road users, including pedestrians, cyclists, and micromobility users, compete for road space with vehicles, presenting conflicts that will persist with AVs as well.
    - A lack of substantial protected lanes for bikes, e-bikes, and small motorized vehicles exacerbates this issue.
- Other street activities, including construction, double-parking and vehicles blocking bus/bike lanes add to the street environment's unpredictability, which presents further complications to AV intelligence.
- AV intelligence is limited by what can be learned from private testing before bringing the technology to public roads.
- A lack of designated pickup/dropoff zones at curbs makes it unclear where passenger activities might occur most safely.

Passenger safety: Because automated rideshare vehicles will likely lack an ‘operator’ or some other kind of monitor inside the vehicle, passengers are subject to non-mobility threats.

- Female and femme-presenting public transit passengers have long reported sexual harassment and assault on subways and buses; sharing AVs would present similar dangers.
    - Monitoring of safety, through CCTV or otherwise, would likely be insufficient to protect passengers.
- Additional unintended uses, including drugs, violence and sexual activities, present hazardous situations to passengers.
- If child safety car seats (or anchors for families bringing their own seats) are not made available, children and their caregivers may be precluded from using these services.

Enforcement: Police enforcement of traffic laws has long been a source of conflict among residents and public officials, often deemed “too much” or “not enough.” Automation of vehicles presents further challenges:

- There is currently a lack of clarity among first responders, traffic enforcers and passengers about traffic rules and liabilities.
- Traffic laws in New York City have historically been guidelines, rather than fully enforced; AVs would present records of activity and rule-following, as well as a difficult transition period when manual and automated vehicles are sharing the road.
- Existing traffic control devices, from painted lanes to speed and red light cameras, require review, and may need to be updated for AVs.

Opportunities

Accelerating New York’s existing stated goals on Vision Zero, bike infrastructure, pedestrianization, parking reform, and curb management will improve the performance and safety of AVs.

Street safety: Measures should be taken to organize New York’s unique street environment, and AV companies should strive to partner with local government efforts to help improve vehicle functionality.

- Accelerate new and existing efforts around limiting on-street parking, building dynamic curb uses, maintaining exclusive bus and bike lanes, and pedestrianizing more street spaces.
- Expand barrier-protected bike lanes, and consider usage of micromobility lanes by small form, low-speed AVs, such as sidewalk delivery robots.
- Organize curb access to make room for e-commerce loading zones and dynamically-priced parking, and to ensure safe pickup and dropoff of passengers.
    - In addition, curbs must be maintained in terms of structure, snow clearance and trash pickup.
- Sharing real-time data with AV providers, and maintaining adequate signage, about street construction and closures will assist in the flow and predictability of traffic.
- The city will need federal cooperation to ensure that AVs follow local traffic laws in order to realize many of the promised safety benefits.

Passenger safety: Develop tools within vehicles to mitigate passenger safety concerns.

- In rideshare vehicles, on-board ‘operators’ may remain present to ensure safe behavior by passengers. For private companies, passengers may be removed from the rideshare platform for dangerous behavior.
- Protocols must be established for alerting police or other emergency responders quickly and easily from the vehicle.
- Fold-away specialized child safety car seats should be made available to caregivers.

Enforcement: Agreements and standards are necessary for how riders will get help from within the vehicle and how law enforcement should interact with AV riders.

- A standard method to connect with enforcement or customer service response should be developed and shared across companies.

Equity

How can we promote the engagement and voices of diverse populations in developing, testing and using AVs?

Conversations about equity can be hampered by a lack of specificity about the populations affected. In this work, equity is considered in terms of: access and impacts across neighborhoods, obstacles for lower-income New Yorkers, economic opportunities, and funding streams.

Challenges

Challenges abound in introducing new technologies in urban environments, particularly related to where and with whom testing and access are available.

Neighborhood equity: New York City neighborhoods can be sharply divided along race and income lines, and the impacts of AV testing and use will vary significantly across them.

- Technology solutions are often deployed first in Manhattan (which is dense, wealthier, and already well-served by transit), leaving other boroughs behind.
- Conversely, Black and Brown neighborhoods experience higher rates of pedestrian fatalities, and may be opposed to the safety risks of testing new mobility solutions on their streets.
- Detracting choice riders from transit is harmful to equitable mobility, as transit services will be cut.
- Bolstering the built environment in areas where AVs are being tested and deployed will lead to unevenly distributed street improvements.

Financial challenges: The introduction of AVs in New York may perpetuate existing challenges and introduce new complexities.

- As with human-driven rideshare, AV rideshare presents obstacles for those without credit cards or smartphones.
- Funding equity-oriented programs around AVs does not align with investing in more universal programs, such as making public transit accessible.
- How are we using funding programs to achieve local equity goals for AVs when AVs cross the silos that federal and local funding are typically limited to?

Driving as a profession: With approximately 150,000 licensed taxi, for-hire-vehicle and other professional drivers, fully automated AVs present the potential for major shifts in traditional driving jobs, an equity challenge for the predominantly lower and middle-class and immigrant drivers.

- The taxi and FHV industry will be disincentivized from testing and adopting AVs when their own jobs may be put at risk.

Opportunities

NYC should use existing equity metrics to set goals for providing equitable services to all New Yorkers, regardless of race, income, disability status and gender identity. The city may also look at other cities' experiences in measuring equity impacts of AVs.

Neighborhood equity: Engaging diverse neighborhood stakeholders will help to represent needs of different communities and environments.

- NYC can set requirements for adequately implementing AV rides in areas underserved by transit.
  - Long commutes detract from residents' economic mobility; neighborhoods without sufficient rapid transit should be prioritized in equity requirements.
- Data transparency by rideshare providers continues to be key to measuring performance and outcomes of equity measures.
- Ensure that diverse populations are represented in testing and deployment.
- Recognize that everyone is a pedestrian.

Financial challenges: Ride pricing will be key to making trips more accessible to New Yorkers with lower incomes, as will payment in digital currencies.

- Harnessing congestion pricing funds for reinvestment in public transit will help to ensure that subways and buses are competitive and accessible.

Driving as a profession: Although AVs will eventually preclude the need for professional drivers, the transition to this point will require extensive partnership with drivers.

- Despite the planned full-automation of AV rideshare, regulations for in-car attendants or single drivers in the lead of platoons can mitigate job losses.
- Opportunities exist for workforce development in AV transition: technicians and mechanics will be repurposed to serving fleets of AVs; local workers can be hired and trained.

- AV taxis can be classified as a separate medallion class so as not to detract from existing taxi offerings.

Partnership: AV companies should hire from throughout the city, at all company levels, to ensure diverse interests are represented and new technologies are rooted in community needs.

- Existing NYC workforce development and training programs can be leveraged for the next generation of workers.
- Partnering with NYC's high school coding courses can be mutually beneficial.
- Partnerships with universities, libraries and the tech industry will lead to large job pools.
- Consider NYCHA's model, which requires a fixed percentage of all contract awards to be designated to training, hiring or advancing residents.

Accessibility

How might AVs enhance the mobility of persons with physical, sensory and cognitive disabilities?

Challenges

Autonomous vehicles reinforce a car-based mobility system, which presents several accessibility challenges.

Street accessibility: New York's street environments pose challenges to people with physical, sensory and cognitive disabilities.

- Streetscape challenges include a lack of mid-block curb ramps for vehicle boarding, and accessing pickup and dropoff among parked vehicles and bus/bike lanes.

Vehicle accessibility challenges include:

  - Authentication of ride for both passenger and vehicle can be inaccessible for passengers with visual impairments.
  - Wheelchair securement, entrance and exit from vehicles
  - Lack of required accessible announcements inside rideshare vehicles, including audio induction loops for the hearing impaired and visual display of audio announcements
  - Locating vehicles for visually impaired passengers
  - Accessibility of rideshare apps, including in-vehicle touchscreens, is key.
  - Many riders with disabilities will require aide companions and/or service animals, and will need to reserve in-vehicle space.

Engagement: Involvement of disability advocates, especially those with cognitive disabilities, has historically come too late in the process.

- Riders with disabilities should be included in policy discussions and vehicle testing.

Funding: Accessibility funding for subways has been subpar, and it is unclear whether AV accessibility will be funded. If AVs detract funding from subways, they will pose greater harm to accessibility.

Opportunities

Street accessibility: Bolstering NYC's street safety measures will immensely benefit all users, including people with disabilities.

- Safe street design with protected lanes, regulated curb space, and loading zones on every block will help issues of AV access, and AV companies offering rideshare might be expected to subsidize these improvements.

In-vehicle accessibility: Ensure every type of communication is equally distributed (visual and audio), and accessible through all phone formats for low vision users (including requesting remote help).

Engagement: Companies must involve disability advocates earlier to test all features of hailing, accessing, and using the vehicle.

Testing: There is room for experimentation and public funding of pilots for paratransit, both in closed-campus locations and offering access to grocery stores and other necessities.

- Testers should be subsidized for their expertise.

Funding: If public funding is made available for AV testing and deployment, it should be required to fulfill accessibility requirements.

Community Engagement

How can we hear out community goals and concerns while also promoting innovation and equity?

Challenges

Community engagement often falls short of regular participation and impact from the start.

Education: Key to AV understanding and development, education is the first step in community engagement.

- Education about AVs should be offered to public officials at all levels, from City Hall to community board members.
- Private sector participants often feel that education falls to them, with no standard for acceptable engagement and a lack of understanding on the part of the companies, public, and governments.

Responsibility: It is unclear whether private companies, government or community and advocacy groups, or some combination, are primarily responsible for public engagement.

- Engagement is often led by the private sector and individual AV companies, with no standard for integration with a community.
- Engagement with specific groups, particularly people with disabilities and historically underserved communities, usually comes too late in the process.
- Standard engagement processes are not yet determined, leaving goalposts unclear.

Opportunities

Defining clear expectations for public engagement and making AV companies adhere to them as a precondition for operating licenses will create clarity for the private sector and understanding for the public sector. These expectations should include local representatives and elected officials and include material in local languages, and on multiple digital and analog channels.

Education: Both AV companies and the NYC government should help officials and the general public understand AV operations, terminology and goals.

- Materials should be made available to leaders, presented in multiple languages and digital and paper formats, and be delivered to diverse community groups.

Partnerships: Public and private sectors should collaborate to set and work towards public engagement goals.

- Set standards for meaningful AV testing for both companies and communities.
- Community engagement should be informative and collaborative, eliciting and incorporating diverse stakeholder inputs.
- Partner with interested communities on local testing initiatives.

Relationship to Public Transit

How might AVs and transit coexist in an efficient and sustainable mobility menu for New Yorkers?

Challenges

Widespread popularity of AVs could detract from several of New York City's major goals.

Transit Ridership: Public transit remains the most efficient mode to move New York City's 8.5 million residents. Attracting choice riders away from subways and buses could substantially harm public transit.

- Because transit funding relies on ridership numbers, vastly reducing the population on-board could lead to service cuts and fare increases, potentially launching a transit death spiral.
- New congestion caused by additional vehicles in street traffic will slow down bus service significantly, further incentivizing riders away from transit.

Serving all riders: Because public transit is designed to serve residents from all neighborhoods, incomes and abilities, detracting from its services could be especially harmful to already underserved populations.

Sustainability: Although AVs may be electric, public transit remains more environmentally sustainable. Keeping riders on transit is more closely aligned with New York City's climate emissions goals.

Opportunities

NYC should develop a clear expectation that AVs will complement, rather than replace, transit services.

Microtransit: Opportunities abound in developing dynamic microtransit solutions in areas currently underserved by static transit as public-private partnerships.

- Developing first- and last-mile microtransit could use AVs for safe, reliable transportation between transit stations and final destinations.

- Replacing or complementing low-ridership bus routes, or subway routes with service outages, with dynamic microtransit could lower transit agency costs while improving service delivery.

Data-sharing: Sharing data between transit providers and AV rideshare companies can help to organize microtransit solutions based on real-time conditions, such as train delays or street closures.

Congestion Pricing: Planned congestion pricing funds must be reinvested into public transit to ensure it is competitive and accessible to all users.

Technology: Public-private partnerships might explore how AV and Advanced Driver Assistance System technologies can be shared with bus and taxi services to assist with vehicle-to-vehicle communications, improving street flow and safety.

Data Stewardship

Autonomous vehicle operation requires the constant intake and processing of data from wayside infrastructure, camera imagery and sensors. How might AV companies operate as strategic data partners with New York City and strong stewards of public data?

Challenges

Private companies and the New York City government both collect data with different priorities, presenting a challenge to balancing operations and privacy.

Data sharing: The disconnect between the types, formats, geographies and timeframes of data collected by the public and private sectors presents a challenge to future data-centric efficiencies.

- NYC collects travel data through infrequent travel surveys and sporadic mounted counting technologies, as well as non-standardized for-hire-vehicle trip data. However, private companies collect data in real time, producing information that is difficult to share with government in a useful fashion.
- Private sector mobility data, especially from rideshare providers, is not representative of the entire city, merely their customer base, which cannot be used for the basis of planning or policy.

- Data aggregation presents a privacy solution, but may also be a barrier to direct data sharing if not clearly aligned.
- Cybersecurity presents a major concern, both in terms of personal data hacking and the interference in fleet vehicles' operations.

Collection and protection of data: AVs collect immense volumes of data for both riders and bystanders, but regulations are not yet in place or consistent across jurisdictions for the use, retention, sharing and removal of data.

- AV cameras collect both rider and non-rider geotagged images. Legal procedures must be in place for data collection, control and potentially sharing with authorities and advertisers.
- Protection of user data will require standards for cybersecurity, user access, aggregation, removing personally identifiable information, and archiving. Metrics for best practices are yet to be defined.

Opportunities

New York City has an opportunity to define public policy goals pertaining to data and set requirements as the price of entry into the local market. This work will require cultivating public-private partnerships, dedicating personnel and building robust infrastructure.

Data sharing: NYC and private companies can exchange useful data in a mutually beneficial partnership.

- NYC can standardize and share infrastructure-related data, such as road closures and construction work.
- Private AV companies can submit ground-level data that would be useful for operations and planning purposes, such as problematic intersections.
- Maps are growing as a neutral intermediary between companies and cities, and could serve as a centralized, standardized data repository.

Data privacy: NYC should define and set data privacy and protection standards that must be met by private AV companies looking to operate in the city. These standards should protect all New Yorkers regardless of immigrant, legal or other status.

Workshop Participants

(affiliations listed as of December 2021)

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8. Emily Gallo, Director of Infrastructure and Mobility Equity, HNTB (Breakout session moderator)
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Conclusion

This work is intended to seed a more equitable and sustainable future of mobility in New York City. We aim to inform policy makers so they can better understand the larger policy issues inherent in autonomous vehicles' learning and behavior. Autonomous Vehicles offer an opportunity for New York to build on its ambitious goals of equity, sustainability and tech-forward services. Getting this right–and doing so in a thoughtful, proactive manner–will pay off for generations of New Yorkers to come.

The timeline of autonomous vehicle readiness is uncertain, and New Yorkers' technologies and travel needs will continue to shift in the coming years. However, now is the time to consider the social impacts of autonomy and build in awareness and protections for our historically underrepresented and underserved communities. Regardless of street design and technological development, future mobility must meet the needs of all New Yorkers, regardless of race, income or abilities.

This project is intended to establish a policy framework for the introduction of autonomous vehicles, but should be expanded as AVs become more of a certainty. Most notably, greater community representation is necessary, particularly in a variety of languages and technological awarenesses.

If these policies are not implemented, New York faces a new era of segmented travel, offering different classes of service above and below ground. These different transportation modes will result in discrepancies among residents' access to school and work opportunities, needs for childcare, and ability to live in optimal locations.

To lay the foundation for AV implementation in New York City, we must engage public officials, private companies and the general public to increase awareness and shape how the city will welcome and sculpt this new technology to meet our diverse needs.

Most importantly, all policies concerning autonomy must remain living documents, making room for changing travel, social and environmental needs.

Appendix: Methodology

The Policy Principles presented in this report are the result of several phases of research and stakeholder engagement:

1. Convened a series of three virtual workshops to analyze the larger policy issues surrounding autonomous vehicles' opportunities and challenges in New York City. The workshops were attended by representatives from the public and private sectors, advocacy and academia, and were centered around major topic areas:
    a. December 10th, 2021: NYC Governance and Integration with Public Transportation
    b. December 16th, 2021: Equity and Accessibility
    c. December 17th, 2021: Safety and Data

Each 90-minute workshop began with a presentation on the subject matter, followed by moderated discussions in breakout rooms about specific challenges and opportunities.

2. Conducted a literature review focused on recent publications about AV impacts to safety, equity, sustainability, responsible use of data, potential job displacement and other relevant topics.
3. Districting using optimization methods considering data equity, as noted in the Neighborhood Equity Modeling section of this report.