Title
Public mobility on demand services: Use cases and equity impacts in the U.S. before and during the Covid-19 pandemic

Author
Lucken, Emma

Publication Date
2022

Peer reviewed|Thesis/dissertation

Public mobility on demand services:
Use cases and equity impacts in the U.S.
before and during the Covid-19 pandemic

By

Emma Lucken

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Engineering – Civil and Environmental Engineering

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Joan Walker, Co-Chair
Professor Susan Shaheen, Co-Chair
Professor Mark Hansen
Professor Karen Trapenberg Frick

Fall 2022

Public mobility on demand services:
Use cases and equity impacts in the U.S.
before and during the Covid-19 pandemic

By
Emma Lucken

Abstract

Public mobility on demand services:
Use cases and equity impacts in the U.S.
before and during the Covid-19 pandemic

By

Emma Lucken

Doctor of Philosophy in Civil and Environmental Engineering

Emphasis in Transportation Engineering

University of California, Berkeley

Professor Joan Walker, Co-Chair

Professor Susan Shaheen, Co-Chair

With the rise of app-based, on-demand transportation network companies (TNCs) like Uber and Lyft, public transportation agencies began piloting their own on-demand services to test whether the technology could attract new riders or improve service for existing riders. These pilots multiplied in the Covid-19 pandemic, when fixed-route ridership plummeted, as a way to serve remaining transit-dependent riders and essential workers with fewer vehicles. Questions about these publicly funded mobility on demand (MOD)[1] and microtransit services focus on their environmental, efficiency, and transportation equity[2] impacts: do they reduce vehicle miles traveled (VMT) by attracting drivers away from personal vehicles and TNCs, or increase it by inducing trips and shifting trips from non-motorized / higher-occupancy fixed-route modes? Can they serve the same number of passengers per hour as low-ridership bus routes, at lower cost?

[1] In this dissertation, I define public microtransit as app-based, on-demand services in motor vehicles operated by a public transportation agency. I use mobility on demand (MOD) as a more generic term to encompass app-based, on-demand motor vehicle services that may not be subsidized or operated by a public entity.
[2] I use the transportation equity definition from Bills and Walker (2017): “fair or just distribution of transportation costs and benefits, among current (and future) members of society,” with a focus on vertical equity (“the distribution of transportation impacts among sub-populations that differ in ability and need”).

Do they disproportionately benefit low-income, transit-dependent populations or well-resourced groups that could afford Uber/Lyft?

This abstract describes research objectives and overarching methodology, identifies methodological and empirical contributions, highlights key results from these contributions, and concludes with policy implications and a summary.

Research Objectives: To evaluate the environmental and transportation equity impacts of publicly subsidized on-demand services, I sought to understand: 1) what types of public MOD services currently exist, including benefits and challenges of each type from an environmental, transportation equity, and operational lens; 2) who uses and benefits from public MOD services, how this shifted in the Covid-19 pandemic, and what modes public MOD riders used before; and 3) how public MOD riders perceive public MOD relative to drive alone, TNCs, and fixed-route transit, what service and demographic characteristics impact their likelihood of using each mode, and how this changed in the Covid-19 pandemic.

Methodology: To accomplish these objectives, I completed the following: 1) developed a conceptual framework for understanding variation in the design of public MOD services (Chapter 3); 2) surveyed public microtransit riders and non-riders at 14 public transportation agencies across the U.S. and analyzed the results for demographic variation in frequency of public microtransit use before and during the Covid-19 pandemic, as well as induced trips, replaced modes, and satisfaction with the service (Chapter 4); and 3) designed a stated preference experiment to include in the survey to test the impact of public microtransit service characteristics and Covid-19 conditions on mode choice; estimated a mode choice model from the stated preference results, including a flexible variance/covariance matrix with individual variation in shared error terms between modes; and used the mode choice model to forecast mode shares for a range of demographic groups and service designs (Chapter 5). After examining publicly subsidized MOD services more generally for the typology, I focused on van-based public microtransit services for the stated preference survey and the mode-choice model due to the increasing popularity of that service type.

Methodological Contributions: The dissertation included three main methodological contributions:

1) Typology of partnerships between public transportation agencies and MOD companies (Chapter 3): As of 2019, there was no agreed-upon conceptual framework for understanding the myriad of pilot projects between public transportation agencies and companies offering on-demand, app-based transportation, in particular one that included van-based microtransit services as well as companies offering ride-matching and routing algorithms for public agencies to deploy on public vehicles. I addressed this gap by conducting expert interviews and a comprehensive review of existing partnerships to develop a typology of partnerships, including the benefits and disadvantages of each, trends in the implementation of each type, and potential environmental and transportation equity implications. My typology development was informed by 34 structured interviews with experts at four MOD companies, 21 public transit agencies, two transportation authorities, and three cities (from October 2017 through April 2018).

2) Mode choice preferences among public microtransit riders / non-riders (Chapter 5): I developed one of the first mode choice models to incorporate public microtransit using stated-preference data, and the first to use an enriched sample of experienced public microtransit passengers. I designed and administered a stated preference survey to 1519 public microtransit riders and 320 non-riders at 14 public transportation agencies across the U.S. from April through December 2021. I used the results to estimate a mode choice model that includes public microtransit, drive alone, fixed-route bus, ride-alone Uber/Lyft, pooled Uber/Lyft, and two first-mile/last-mile (FMLM) modes: public microtransit to fixed-route bus and Uber/Lyft to fixed-route bus. Using the mode choice model, I forecasted how public microtransit mode share varies with changes in service variables like cost, frequency of delay, and walk, wait, and in-vehicle times. I also forecasted changes in mode shares for systems without public microtransit, with FMLM microtransit, and with door-to-door microtransit that replaces fixed-route bus service.

3) Flexible variance/covariance matrix from shared error components (Chapter 5): In developing the mode choice model, I applied an innovative method to estimate a flexible and individual-specific covariance matrix of the error terms that is specific to the public microtransit context. Because the covariance matrix determines substitution between public microtransit and the other modes when applying the model to forecast impacts or estimate replaced modes from public microtransit services, it is important to estimate parameters to allow for flexible substitution between modes. For example, the correlation between public microtransit and fixed-route bus and the correlation between public microtransit and TNCs may both be non-zero, may not equal each other, and may also vary across individuals. The commonly used logit and nested logit models cannot capture these effects. Cross-nested logit can capture both correlation values (and more), but these values cannot vary by individual or capture correlation across responses from a single individual. While probit is fully flexible and can capture the full covariance matrix as well as correlation across responses, it is computationally burdensome and the estimated parameters are not readily interpretable as correlation between the modes. Therefore, I employed shared error components (mixed logit) to identify a flexible covariance matrix that was supported by the data, allowed clear interpretation of correlation between modes, and captured correlation across responses from the same individual. This method also enabled me to test individual variation in perceived correlation based on individual characteristics such as experience with public microtransit and access to a personal vehicle by interacting the error components with these characteristics.

Empirical Contributions: The dissertation offered two main empirical contributions:

1) Comprehensive database of partnerships between public transportation agencies and MOD companies (Chapter 3): I compiled a database of projects in the U.S. through April 2019 in which public agencies and private companies collaborated to provide MOD services that meet the FTA definition of public transportation: "regular, continuing shared-ride surface transportation services that are open to the general public or open to a segment of the general public defined by age, disability, or low income" (FTA 2016). The database included 62 partnerships with information on participating public and private entities, start/end dates, fares, eligibility restrictions, and any publicly available evaluation metrics from the project. The UC

Berkeley Transportation Sustainability Research Center adopted the database, which contributed to a key research element in a major research project for Ford Motor Company.

2) Multi-agency survey of public microtransit riders (Chapters 4 and 5): Due to privacy concerns, microtransit software companies do not collect demographic data about those who register to receive rides through their apps, leaving public transportation agencies without a direct way to measure equity impacts of the public microtransit services. My stated preference survey, described above, also collected demographic data and mode use patterns (from 1519 public microtransit riders across 14 U.S. public transportation agencies from April through December 2021). I identified demographic differences in frequency of public microtransit use, induced trips, replaced modes, perceptions of the service, change in use during the Covid-19 pandemic, and anticipated change in use after the pandemic (Chapter 4). Demographic dimensions included income, age, race, gender, ability, vehicle access, and two categories of particular salience for app-based, on-demand modes: smartphone ownership and banked/unbanked status.

<u>Typology Results (Chapter 3):</u> I identified four main types of partnerships: 1) first-mile/last-mile (FMLM), 2) low-density, 3) off-peak, and 4) paratransit. I also identified two additional dimensions by which to characterize these partnerships to understand environmental and equity impacts: 1) asset contribution and 2) vehicle type. For asset contribution, public partners either: a) contract with the private partner to provide the entire service or b) provide the vehicles and drivers and contract with the private partner for the algorithm and app. I found that the public agencies have more control over the service design and trip data when they operate the service with their own vehicles and drivers, which impacts their ability to measure and address any disparities in service or competition with fixed-route service. Vehicle type included van, taxi, or drivers' personal vehicles, and affects potential occupancy and VMT impacts of the service. I found that initial pilot projects were dominated by agency-subsidized TNC services, likely due to ease of implementation, but that agency-operated services using publicly owned vans were becoming more common. Most early partnerships offered "low-density" door-to-door service in a specified zone during the same hours as fixed-route transit, while the next most frequent use case was FMLM, in which subsidized trips had to start or end at a public transit stop.

<u>Demographic Survey Results (Chapter 4):</u> I found that underserved groups report higher rates of induced trips and are more likely to switch to public microtransit from non-motorized/higher-occupancy modes, while more privileged groups are more likely to switch from lower-occupancy modes like drive alone and Uber/Lyft. More privileged groups are also more likely to use public microtransit as a FMLM connection to fixed-route bus/rail and for work commutes, and less privileged groups are more likely to use it for errands, healthcare appointments, and social/recreational trips. Though low-income groups, riders without access to a personal vehicle, and women report greater satisfaction and quality of life improvements from public microtransit than nonmarginalized groups, riders without smartphones and/or bank accounts report lower satisfaction and no statistically significant quality of life improvements. Riders from less privileged groups also perceive more frequent delays past the public microtransit vehicles' estimated time of arrival (ETA). Regarding Covid-19 impacts, low-income riders, those without vehicle access, and essential workers maintained public microtransit use during the pandemic but decreased their use of fixed-route bus/rail, while other groups decreased their use of fixed-route bus/rail by even more and also decreased their use of public microtransit.

Mode Choice and Shared Error Results (Chapter 5): The forecasts suggested that the combined mode share of fixed-route bus and microtransit is lowest in systems that replace fixed-route bus service with public microtransit and highest in systems with supplemental, door-to-door public microtransit, while the reverse is true for personal vehicle mode share. The model results also showed that respondents without smartphones were more likely than other users to use fixed-route bus, while forecasts found that smartphone ownership and access to a personal vehicle have a larger impact than income on mode splits. Regarding Covid-19 impacts, riders perceive fixed-route bus service more negatively than public microtransit as local in-patient rates increase, while trip cost has less of an impact on mode choice during the Covid-19 pandemic. Regarding the shared error components, perceived correlation between modes varies with vehicle access and familiarity with the public microtransit service. Respondents who sometimes or never have access to a personal vehicle view door-to-door public microtransit as most correlated with drive alone, while vehicle owners perceive less correlation between the two modes. Experienced microtransit riders, meanwhile, view public microtransit as more correlated with Uber/Lyft than with fixed-route bus, while those who have never used public microtransit perceive it as much more correlated with fixed-route bus than Uber/Lyft.

Policy Implications: I identified several policy implications based on my results:

- Public transit agencies should exercise caution when replacing fixed-route service with public microtransit, as forecasting suggests steep declines in overall public transit ridership in this scenario (Chapter 5).
- Replacing traditional paratransit and dial-a-ride services with app-based public microtransit offers equity benefits through improved experiences for transit-dependent populations, provided the agency ensures continued call-in and cash options for passengers without smartphones and/or bank accounts (Chapters 3, 4).
- More work needs to be done to improve public microtransit service for riders without smartphones or bank accounts. These groups do not report the same benefits from public microtransit services and are the only underserved groups to anticipate reducing their use of public microtransit by as much or more than fixed-route transit after the Covid-19 pandemic. Investing in improved fixed-route service may be a more effective way of serving these riders (Chapters 4, 5).
- For new public microtransit services that do not replace fixed-route bus or a pre-existing paratransit or dial-a-ride service, environmental and equity goals may conflict. Public transportation agencies may need to choose between: 1) advancing environmental goals by targeting higher-income riders switching from lower-occupancy modes like drive alone or 2) improving transportation equity by targeting lower-income riders, who are more likely to switch from non-motorized or higher-occupancy modes (Chapter 4).

Summary: This dissertation analyzed the environmental and transportation equity impacts of public MOD and microtransit services through: a comprehensive review and typology of such services in the U.S., demographic analysis of the largest multi-agency survey of public microtransit passengers so far, and a mode choice model with shared error components to understand heterogeneity in preferences among riders and non-riders before and during the Covid-19 pandemic. I found that the environmental and equity goals of public microtransit services may conflict, as riders from underserved groups report higher rates of induced trips and switch disproportionately away from non-motorized / higher-occupancy modes. While public microtransit appears to address barriers that riders with disabilities faced from TNCs, results indicate continued disparities for riders without smartphones and/or bank accounts. Future research could identify displaced riders when fixed-route bus services are replaced with public microtransit services, perhaps through a longitudinal survey, to more fully capture equity impacts. Next steps also include using the mode choice model I estimated with agent-based simulation to compare local environmental and equity impacts of investing in public microtransit versus improved fixed-route bus service.

For the transit riders

& the survey takers

•

Lupe and Zubair

Mom and Dad

Sigri, Barqat, and Telmo

Talhah

Table of Contents

Acknowledgements

I have been immensely fortunate to have Professor Joan Walker and Professor Susan Shaheen as my advisors. Undisputed experts and leaders in their fields, their mentorship has molded my development as a researcher and as a person. None of this would have been possible without them. Thank you also to Professor Karen Trapenberg Frick for her early guidance and continued support as I shaped my dissertation topic and research plan. I am grateful to Professor Paul Waddell for all I learned in his lab and to him and Professor Mark Hansen for their feedback over the course of this research, as well. Dr. Joshua Hassol, Steve Barrett, and Meredith Klekotka provided invaluable assistance in supporting my graduate fellowship applications and my career in general. I am inspired that the transportation field is populated by such intelligent, dedicated, and kind-hearted individuals.

I am deeply indebted to my fellow students for their feedback, support, and comradery. Jessica Lazarus, in particular, provided integral assistance that enhanced my research and results. Alex Pan, Ivan Tereshchenko, and Stephen Wong also shaped my graduate experience, as did Gordon Bauer, Amine Bouzaghrane, Juan David Caicedo, Jayne Chang, Lu Dai, Wesley Darling, Dagin Faulkner, Teddy Forscher, Max Gardner, Jeremy Halpern, Mustapha Harb, Anu Kuncheria, Mengying Ju, Qianhuo Luo, Aqshems Nichols, Hassan Obeid, Bassel Sadek, Jason Soria, Ziad Yassine, and Mengqiao Yu.

Thank you to my contacts at the public transportation agencies and microtransit companies who provided interviews, feedback on the survey, help with survey distribution, and service and trip data. I am grateful to each survey respondent for devoting time to answer the questions and trusting me with the analysis.

To my family- thank you to Grandma and Grandpa Koob for being our California home and to Grandma Lucken for doting on us in Minnesota. Thank you to Adam, Karl, Aran, and Junaid for being loving brothers and uncles.

I remember Gregory Koob and Philip Kreycik, who should both still be with us continuing their significant improvements to the world; Luca Pedicelli, who brought light to our lives in his short time here and continues to do so; and Carmen Silva, who blessed us with her grace, love, and generosity as family matriarch.

Finally, I simply could not have simultaneously written this dissertation and grown my family (…during a global pandemic) without the help of my parents, Sarah Lucken and Michael Koob, and parents-in-law, Lupe Llanga and Zubair Masood. You are second and third sets of parents for the kids and unimpeachable proof of the power of multigenerational child-rearing. Mom and Dad, thank you for starting me on the path and for the boundless support, counsel, and encouragement you have given me along the way. Sigri, Barqat, and Telmo, you are the most beautiful, joyful, hilarious, and delicious children and I feel so lucky you're mine. Talhah, the journey continues—thank you for traveling it with me.

Chapter 1. Introduction

Fixed-route public transportation ridership began declining after 2014, fell precipitously in the Covid-19 pandemic, and has yet to recover (FTA 2022). This development is concerning on two fronts: environment and transportation equity. Environmentally, the transportation sector is one of the largest contributors to greenhouse gas (GHG) emissions in the United States (U.S.), and fixed-route bus and rail have offered the most efficient way to meet transportation needs, with lowest vehicle-miles-traveled (VMT) and GHG emissions per trip of any non-electric motorized mode (FTA 2010). Even with rapid advances in electrification, VMT matters; to meet Paris Climate Agreement goals of reducing U.S. GHG emissions 50% below 2005 levels by 2030, all new vehicles would need to be electric and total passenger VMT must decrease by 20% per capita below 2019 levels (Subin et al. 2021). From a transportation equity[3] perspective, a large swath of the population is transit-dependent because they either cannot afford their own vehicle, or because they cannot drive due to age, ability, or other restrictions on their driving. Reductions in fixed-route ridership lead to less fare revenue, followed by reductions in service and further loss of riders, in a well-documented "downward spiral," which undercuts the environmental and equity benefits of public transportation (NACTO 2016).

Beginning about half a decade before the decline in fixed-route public transit ridership, the proliferation of smartphones and development of ride-matching and routing algorithms led to the rise of private transportation network companies (TNCs) like Uber and Lyft, which offered heavily subsidized ride-alone and pooled on-demand trips that contributed to fixed-route transit's downward spiral (Monahan & Lamb 2022, Diao et al. 2021, Erhardt et al. 2021, Martin et al. 2021). In 2015, public transportation agencies began responding to the new technology by piloting their own on-demand, app-based services. These agencies contracted with private companies either to operate the service (e.g., subsidizing Uber/Lyft rides) or to provide ride-matching and routing algorithms and apps the public transportation agencies could use on public vehicles (Chapter 3). The term mobility on demand (MOD) encompasses both forms of contracting and describes the broad idea of consumers having on-demand access to both passenger and goods movement through an integrated multi-modal network, though in this dissertation I am referring specifically to passenger movement on motor vehicles. The version of public microtransit that I focus on in my dissertation includes only the latter version of contracting, involving app-based, on-demand services in motor vehicles (generally wheelchair accessible vans (WAVs) or minibuses) operated by a public transportation agency. I refer to public microtransit throughout most of this introduction due to increasing popularity and benefits of this form of public MOD, including more agency control over service design and trip data, potential for greater occupancy, and more equitable service for individuals with mobility impairments.

[3] I use the transportation equity definition from Bills and Walker (2017): "fair or just distribution of transportation costs and benefits, among current (and future) members of society," with a focus on vertical equity ("the distribution of transportation impacts among sub-populations that differ in ability and needs").

While public microtransit services had the potential to lower wait times and in-vehicle times for transit-dependent passengers, they could also pose barriers to access for those without smartphones or bank accounts. Moreover, while they could lower VMT by attracting riders from personal vehicles, they could also increase VMT by generating induced demand or drawing travelers from non-motorized modes like walking or biking or from higher-occupancy modes like fixed-route bus or rail. If public microtransit reached the same number of riders from the same demographic groups as fixed-route transit and provided them with lower wait times and in-vehicle times at about the same cost, many public transportation agencies would likely decide that the environmental impacts are inconsequential; it is difficult to argue that transit-dependent groups should not receive better service that enables them to make more trips just because it increases VMT, especially when people with personal vehicles contribute far more to the transportation sectors' GHG emissions (FTA 2010).

These commonly cited concerns about increased VMT and inequitable access for riders without smartphones and/or bank accounts, however, may miss broader equity impacts of public microtransit services. In particular, existing analysis indicates public microtransit vehicles serve fewer passengers per hour than even the emptiest fixed-route buses. Top-performing public microtransit services provide at most seven passenger trips per hour per vehicle, and many serve around half that (Via 2022, Xing et al. 2022, Brown et al. 2021, Montgomery County 2020, RTD 2019, Urgo 2018). In contrast, agencies' worst-performing fixed-route buses generally provide a minimum of 10 passenger trips per hour per vehicle (FTA 2021, RTD 2019, Walker 2019a). No research thus far suggests public microtransit costs proportionately less per vehicle to achieve an equal or lower cost per passenger than the lowest-ridership buses. Rather, the lower maintenance and gas costs of public microtransit vans may be negligible compared to the hourly costs of paying for one operator per vehicle, which are equivalent for a microtransit van or fixed-route bus—and even the lower gas and maintenance costs for smaller MOD vehicles may initially be offset by the cost of the app and algorithm (Niles & Pogodzinski 2021, Urgo 2018). Hence, for about the same per-vehicle costs, public MOD services provide fewer passenger trips per hour per vehicle. As Jarrett Walker in particular has argued, this not only raises questions about how public MOD services would reverse the ridership decline in public transportation, but also about the redistribution of resources to provide improved, on-demand services to fewer people (Walker 2019a, 2019b, 2018a, 2018b).

To the extent that public MOD services offer lower wait and in-vehicle times compared to fixed-route bus, surveys that reach public MOD passengers will likely indicate positive perceptions of the service, as they have in many cases, including in this dissertation (Chapters 4-5, Schank & Huang 2022). However, the other key demographic to reach is the group behind the displaced passengers per hour. When low-ridership fixed-route bus routes are replaced with public microtransit, who are the four to seven passengers per hour per vehicle who can no longer make their trips? Alternatively, when a new public microtransit service is created without replacing fixed-route bus service, who are the additional passengers who could have been served if the funding had instead gone to increase frequency on a bus route? If the public microtransit service primarily reaches low-income or otherwise underserved people outside the range of the fixed-route service, serving fewer people may not constitute upward redistribution of resources, especially if the replaced fixed-route bus route (in the former case) or the bus route that could have had increased frequency (the latter case) disproportionately serve more advantaged groups than those using the new public microtransit service. While this could be the case in some areas, the only study that has directly compared the demographics of public microtransit ridership to those of local fixed-route ridership found the opposite. A survey of passengers of LA Metro's public microtransit service that provided first-mile/last-mile (FMLM) service to fixed-route stations found that riders were whiter, higher income, and much more likely to have smartphones and bank accounts compared to the county population and even more so compared to the agency's fixed-route riders (Brown et al. 2021). Similarly, an analysis of SacRT public microtransit, one of the largest of these services in the U.S., compared rider demographics to the census characteristics of each service area and found that fewer public microtransit passengers were 65 or older and, in seven out of nine service areas, a greater proportion were white and had Bachelor's degrees (Xing et al. 2022). Moreover, the authors of the LA Metro study described public microtransit as potentially duplicative with TNCs, and, to avoid subsidizing groups that could access TNCs anyway, recommended targeting public microtransit to four populations: people with low incomes, without smartphones, without checking accounts, or with mobility impairments that require WAVs (Brown et al. 2021). They suggested late-night service as a use case well-suited to disproportionately reaching these populations.

For both transportation equity and efficiency reasons, then, current research suggests public microtransit may not be an alternative to fixed-route bus but rather to demand response and paratransit services, which already target locations, times, and populations that generate fewer passengers per service hour. The same equity and efficiency reasons also caution public transportation agencies against dedicating funding to expand public microtransit service beyond existing demand response areas, regardless of rider satisfaction, as those funds may increase ridership and benefit underserved populations more effectively if dedicated to improving fixed-route bus service (Walker 2018a). Walker describes this as a patronage/coverage tradeoff; each public transportation agency must decide how to divide funding between maximizing ridership and providing access to low ridership areas/times/populations (Walker 2008). To the extent that public microtransit shifts decisions about this tradeoff, it would be how to spend the funds freed by providing pre-existing "coverage" service at a lower cost, whether by dedicating it entirely to increasing ridership with fixed-route service, entirely to expanding coverage service, or to some combination.

Limiting public microtransit applications to replacing demand response and paratransit services does not mean consigning this innovation to obscurity, however; more public transit systems in the U.S. operate demand response services than any other type of transit (1760 systems, compared to 1240 that operate fixed-route bus) (Dickens 2021). These replacements offer improved customer experience opportunities for two of the four groups mentioned above: those with low-incomes and those with mobility impairments that require WAVs. Research in this dissertation and elsewhere identifies people without smartphones and/or bank accounts, however, as facing barriers to public microtransit use that have not yet been adequately addressed (Chapters 3-5, Brown et al. 2021). Moreover, if increased popularity of the improved demand response service with the general public reduces service quality for these four core groups, agencies may need to restrict or prioritize service on the basis of low-income and/or ADA status, as Kansas City has recently done with its Freedom On-Demand service (RideKC 2022). Some research has focused on developing equity-centric ride-matching and routing algorithms that could help with this prioritization process (Bardaka et al. 2020).

The role for public microtransit could change with automation, when agencies may not need to pay an operator. Indeed, eliminating operator costs was the only scenario in which one study could show public microtransit as approaching the cost-effectiveness of low-performance fixed-route bus (Niles & Pogodzinski 2021). This study assumed continued costs for fixed-route bus operators, however; if buses also lost operators, the saved costs on any given low-performance fixed-route bus route could potentially be reinvested in the route by adding frequency that could increase demand and ridership, rendering it again more cost-effective than replacing it with automated microtransit, which would still have the same efficiency ceiling on passengers per hour. Nonetheless, one automated future could involve declines in private vehicle ownership and a rise in shared automated fleets that offer FMLM service to high-frequency fixed-route corridors (Lazarus et al. 2021). Providing public microtransit services now could potentially help public transportation agencies prepare for managing such fleets. Of course, this vision also assumes enough funding dedicated to public transportation for agencies to purchase and manage sufficient automated buses and on-demand vans, even if labor costs decrease; this would require a shift from current constraints on public transportation funding (Whitmore et al. 2022). Moreover, the equity impacts of eliminating operator jobs would need to be navigated carefully (Rodriguez et al. 2020, Yankelevich et al. 2018).

While this dissertation does not assess aspects of public MOD such as passengers per hour per vehicle, cost per passenger, demographics of displaced passengers, or potential impacts of automation, these issues provide important context for the research described here and offer avenues for additional work. This dissertation, instead, seeks to understand transportation equity and environmental impacts of public MOD services based on the early years of public transportation agencies beginning to experiment with these services, including use cases, service design, and demographics and preferences of public microtransit passengers:

Chapter 2 provides background on the use of MOD services by U.S. public transportation agencies, the state of the literature regarding the impacts of such services, and research gaps.

Chapter 3 addresses the first research objective of the dissertation: to understand what types of public MOD services currently exist, including benefits and challenges of each type from an environmental, transportation equity, and operational lens. The chapter includes a comprehensive review of 62 public MOD services in the U.S. as of 2019, develops a typology of use cases and service models, and discusses the benefits and challenges of each use case. The conceptual framework for understanding variation in the design of public MOD services constitutes one contribution to the literature, while the comprehensive database of public MOD services constitutes another.

Chapter 4 addresses the second research objective: to understand who uses and benefits from public MOD services, how this shifted in the Covid-19 pandemic, and what modes public MOD riders used before. The chapter presents a 2021 survey of 1519 public microtransit riders and 320 non-riders across 14 U.S. public transportation agencies; descriptive statistics analyzing how microtransit use, levels of service, perceptions of the service, and Covid-19 impacts differ by demographic group; and equity and policy implications of the findings. Contributions to the literature include one of the first multi-agency demographic analyses of public microtransit riders and their use and perceptions of the nascent mode.

Chapter 5 addresses the final research objective: to understand how public MOD riders perceive public MOD relative to drive alone, TNCs, and fixed-route transit, what service and demographic characteristics impact their likelihood of using each mode, and how this changed in the Covid-19 pandemic. The chapter presents one of the first mode choice models to incorporate public microtransit from stated preference data, and the first to draw from an enriched sample of experienced public microtransit riders. Another contribution to the literature is a flexible variance/covariance matrix from shared error components that enables estimation and interpretation of individual variation in perceived correlation between public microtransit and other modes like drive alone, Uber/Lyft, and fixed-route bus. The mode choice model, which I estimated from the 2021 survey introduced in Chapter 4, illuminates changes in mode preferences during the Covid-19 pandemic and under a range of service models, such as restricting public microtransit use to FMLM trips or replacing fixed-route bus service with door-to-door microtransit.

The Conclusion summarizes major findings, policy recommendations, and directions for future work.

References

Bardaka, E., Hajibabai, L., & Singh, M.P. (2020). Reimagining Ride Sharing: Efficient, Equitable, Sustainable Public Microtransit. *Institute of Electrical and Electronics Engineers* 24:5. https://doi.org/10.1109/MIC.2020.3018038

Bills, T., & Walker, J. (2017). Looking beyond the mean for equity analysis: Examining distributional impacts of transportation improvements. *Transport Policy* 54, 61-69. https://doi.org/10.1016/j.tranpol.2016.08.003

Brown, A., Manville, M., & Weber, A. (2021). Can mobility on demand bridge the first-last mile transit gap? Equity implications of Los Angeles' pilot program. *Transportation Research Interdisciplinary Perspectives* 10. https://doi.org/10.1016/j.trip.2021.100396

Diao, M., Kong, H., & Zhao, J. (2021). Impacts of transportation network companies on urban mobility. *Nature Sustainability* 4, 494-500. https://doi.org/10.1038/s41893-020-00678-z

Dickens, M. (2021). 2021 Public Transportation Fact Book. *American Public Transportation Association*. Accessed Nov. 22, 2022. https://www.apta.com/wp-content/uploads/APTA-2021-Fact-Book.pdf

Erhardt, G.D., Mucci, R.A., Cooper, D., Sana, B., Chen, M., & Castiglione, J. (2021) Do transportation network companies increase or decrease transit ridership? Empirical evidence from San Francisco. *Transportation* 49, 313-342. https://doi.org/10.1007/s11116-021-10178-4

Federal Transit Administration (2022). 2021 National Transit Summaries and Trends. *U.S. Department of Transportation.* Accessed Nov. 22, 2022. https://www.transit.dot.gov/ntd/data-product/2021-national-transit-summaries-and-trends-ntst

Federal Transit Administration (2021). 2020 National Transit Summaries and Trends. *U.S. Department of Transportation.* Accessed Nov. 22, 2022. https://www.transit.dot.gov/ntd/data-product/2020-national-transit-summaries-and-trends-ntst

Federal Transit Administration (2010). Public Transportation's Role in Responding to Climate Change. *U.S. Department of Transportation*. Accessed Nov. 22, 2022. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/PublicTransportationsRoleInRespondingToClimateChange2010.pdf

Lazarus, J., Bauer, G., Greenblatt, J., Shaheen, S.A. (2021). Bridging the Income and Digital Divide with Shared Automated Electric Vehicles. *UC Berkeley and Emerging Futures Report for the California Strategic Growth Council*. doi:10.7922/G2707ZQ4

Martin, E., Shaheen, S., Stocker, A. (2021). Impacts of Transportation Network Companies on Vehicle Miles Traveled, Greenhouse Gas Emissions, and Travel Behavior Analysis from the Washington D.C., Los Angeles, and San Francisco Markets. *UC Berkeley Transportation Sustainability Research Center*. https://doi.org/10.7922/G2BC3WV9

Monahan, T., & Lamb, C.G. (2022). Transit's downward spiral: Assessing the social-justice implications of ride-hailing platforms and COVID-19 for public transportation in the US. *Cities* 120. https://doi.org/10.1016/j.cities.2021.103438

Montgomery County Department of Transportation, Metropolitan Washington Council of Governments, KFH Group (2020). Ride On Flex Microtransit Performance Assessment.

National Association of City Transportation Officials (2016). Transit Street Design Guide. *IslandPress*. https://nacto.org/publication/transit-street-design-guide/introduction/why/reliability-matters/

Niles, J.S., Pogodzinski, J.M. (2021). Steps to Supplement Park-and-Ride Transit Access with Ride-and-Ride Shuttles. *Mineta Transportation Institute*. Accessed Nov. 22, 2022. https://transweb.sjsu.edu/research/1950-Park-and-Ride-Transit-Access

RideKC (2022). Freedom On-Demand Changes. Accessed Nov. 22, 2022. https://ridekc.org/bulletins/freedom-on-demand-changes

Rodriquez, G., Bailey-Campbell, P., Bittner, J., Shriber, J., Constantine, S., & Coyner, K. (2020). Impacts of Automated Vehicles and Shared Mobility on Transit and Partnership Opportunities. *National Cooperative Highway Research Program Project 20-113F*. https://onlinepubs.trb.org/onlinepubs/AVSMForum/products/7-NCHRP_Transit_Final_10-28-20v2.pdf

Schank, J. & Huang, E. (2022). Microtransit: A Good Idea Just Got Even Better. *Mineta Transportation Institute*. Accessed Nov. 21, 2022. https://transweb.sjsu.edu/research/2249-Demand-Responsive-Transportation-Shared-Mobility

Subin, Z., Teplin, C., & Corvidae, J. (2021). Policy Brief: US Sector-Level Strategies and Targets to Limit Warming to 1.5C. *Rocky Mountain Institute*. https://rmi.org/insight/scaling-us-climate-ambitions/

Urgo, J. (2018). Flex v. Fixed: An Experiment in On-Demand Transit. *Transit Center*. https://transitcenter.org/adding-flexible-routes-improve-fixed-route-network/

Via (2022). Jersey City's on-demand, affordable public transit service Via surpasses 1 million rides. Accessed Nov. 21, 2022. https://ridewithvia.com/news/jersey-citys-on-demand-affordable-public-transit-service-via-surpasses-1-million-rides

Walker, J. (2019a). The Problem with On-Demand "Transit." *Shelterforce*. Accessed Nov. 21, 2022. https://shelterforce.org/2019/12/16/the-problem-with-on-demand-transit/

Walker, J. (2019b). What is "Microtransit" For? *Human Transit*. Accessed Nov. 21, 2022. https://humantransit.org/2019/08/what-is-microtransit-for.html

Walker, J. (2018a). Is Microtransit a Sensible Transit Investment? *Human Transit.* Access Nov. 21, 2022. https://humantransit.org/2018/02/is-microtransit-a-sensible-transit-investment.html

Walker, J. (2018b). Microtransit: What I Think We Know. *Human Transit*. Accessed Nov. 21, 2022. https://humantransit.org/2018/02/microtransit-what-i-think-we-know.html

Walker, J. (2008). Purpose-driven public transport: creating a clear conversation about public transport goals. *Journal of Transport Geography* 16, 436-442. https://doi.org/10.1016/j.jtrangeo.2008.06.005

Whitmore, Hendrickson, Matthews, & Samaras, C. (2022). Improving Access and Equity via Shared Automated Mobility in U.S. Public Transportation Systems. *Mobility 21: A USDOT National University Transportation Center*. https://rosap.ntl.bts.gov/view/dot/64434

Xing, Y., Pike, S., Pourrahmani, E., Handy, S., & Wang, Y. (2022). Exploring the Consumer Market of Microtransit Services in the Sacramento Area, California. *National Center for Sustainable Transportation*.

Yankelevich, A., Rikard, R.V., Kadylak, T., Hall, M.J., Mack, E.A., Verboncoeur, J.P., & Cotton, S.R. (2018). Preparing the Workforce for Automated Vehicles. *The American Center for Mobility*.

Chapter 2. Background and Literature Review:

Incorporating Mobility on Demand (MOD) and Mobility as a Service (MaaS) automotive services into public transportation

Emma Lucken

Susan A. Shaheen

This chapter, with slight modifications, was published in the Handbook of Public Transport Research (2021) and can be accessed here:
https://www.elgaronline.com/view/edcoll/9781788978651/9781788978651.00028.xml

The objective of this chapter is to provide background on the use of MOD services by U.S. public transportation agencies, the state of the literature regarding the impacts of such services, and research gaps. I conducted the initial literature review, wrote the original manuscript, and revised and edited based on feedback from Professor Shaheen and anonymous reviewers.

ABSTRACT

In the past decade, public transportation services worldwide have faced increasing competition from mobility on demand (MOD) options such as those provided by transportation network companies (TNCs, e.g. Lyft, Uber). Many public transit agencies have responded by piloting MOD public-private partnerships (MOD PPPs) that aim to provide more efficient and attractive service in times and places with insufficient demand to support fixed-route options. Most existing research on MOD PPPs agree on four core service models: 1) first-mile/last-mile, 2) low-density, 3) off-peak, and 4) paratransit. While qualitative analyses have documented strategies for addressing implementation challenges related to equitable access, data sharing, liability, and labor union concerns, further research is needed to determine quantitative impacts from existing MOD PPPs on agency costs, accessibility, vehicle miles traveled, and transportation equity. In particular, a main research gap involves estimating induced demand for MOD PPP services, potentially by expanding upon current agent-based simulation and stated-preference survey methods.

2.1. Introduction

As smartphone-enabled mobility services have gained prominence around the world, public transportation agencies have started experimenting with strategies to incorporate elements of these innovative mobility options to make public transit service more attractive and efficient. In the United States (U.S.), the emerging transportation services have been conceptualized as Mobility on Demand (MOD), in which consumers have on-demand access to both passenger and goods movement through an integrated multi-modal network (Shaheen et al., 2017a). In Europe, the prevalent terminology is Mobility as a Service (MaaS), which involves the provision of an array of aggregated passenger mobility services as bundled subscription options (Shaheen and Cohen, 2019). Both MOD and MaaS involve the concept of providing a single user interface for trip planning and booking, real-time information, and fare payment.

While MOD and MaaS services offer the possibility of more convenient travel and a reduction in private-vehicle ownership, they also raise several concerns about their potential societal impacts.

These include drawing riders away from public transportation, thereby increasing congestion and vehicle miles/kilometers traveled (VMT/VKT), and creating barriers to equitable service for transit-dependent disabled, older adult, and low-income populations. Implementing MOD and MaaS services in ways that promote the public good will require public transportation agencies to address these environmental and equity challenges.

This chapter focuses primarily on MOD services, particularly microtransit and transportation network companies (TNCs, also known as ridesourcing and ridesharing), and their integration with public transportation service in the U.S. For an overview on MaaS services and research, Kamargianni et al. (2016), Jittrapirom et al. (2017), Durand et al. (2018), and Wong et al. (2018) are valuable resources. In the next section, we discuss existing research on the impacts from MOD companies on public transit ridership. Section 3 provides a detailed analysis of partnerships between MOD companies and public transportation agencies (MOD PPPs) in the U.S., including proposed typologies for such partnerships and research on associated benefits, challenges, and recommendations. Section 4 presents the state of the research on modelling the impacts on the transportation system from integrating MOD services with public transportation. We conclude with a section on new research frontiers. The following definitions for terms used throughout the chapter are from the U.S. Federal Highway Administration (FHWA) 2017 report, "Mobility on Demand: Operational Concept Report:"

- **Mobility on Demand (MOD):** Transportation concept where consumers can access mobility, goods, and services on-demand by dispatching or using shared mobility, courier services, unmanned aerial vehicles, and public transportation solutions. Passenger modes facilitated through MOD providers can include: shared modes, public transportation, and other emerging transportation solutions (e.g., aerial taxis). Goods delivery through MOD can include app-based and aerial delivery services (e.g., drones).

- **Mobility as a Service (MaaS):** MaaS emphasizes mobility aggregation, smartphone and app-based subscription access, and multimodal integration (infrastructure, information, and fare integration). MaaS tends to emphasize the integration and convergence of passenger mobility services, mobile devices, real-time information, and payment mechanisms.

- **Public Transportation:** Any transport system available to the public with set fares.

- **Shared Mobility:** Transportation strategy that enables users to have short-term access to a transportation mode (e.g., vehicle, bicycle, or other low-speed travel mode) on an as-needed basis. Shared mobility can include: roundtrip services (vehicle, bicycle, or other low-speed mode is returned to its origin); one-way station-based services (vehicle, bicycle, or low-speed mode is returned to a different designated station location); and one-way free-floating services (vehicle, bicycle, or low-speed mode can be returned anywhere within a geographic area).

- **Microtransit:** A privately owned and operated shared transportation system that can have fixed routes and schedules, as well as flexible routes and on-demand scheduling. The vehicles generally include vans and mini-buses.

- **TNCs:** TNCs (also known as ridehailing and ridesourcing, e.g. Lyft, Uber) provide prearranged and on-demand transportation services for compensation, which connect drivers of personal vehicles with passengers. Smartphone mobile applications are used for booking, ratings (for both drivers and passengers), and electronic payment. TNCs also include “ridesplitting” (or pooling), in which customers can choose to split a ride and fare in a TNC vehicle (where available).

2.2. MOD company impacts on public transportation ridership

An examination of the integration of MOD services with public transportation prompts the question of MOD companies’ current impacts on public transit ridership. After reaching a peak in 2014, total public transit ridership in the U.S. declined 7.2% by 2019 (American Public Transportation Association, 2014, 2019). The literature is mixed as to whether MOD companies have contributed to this decline. Empirical studies in this area focus on ride-alone TNCs, with no conclusive studies on the impacts on public transit ridership from TNC pooled services (e.g., Lyft Shared rides or UberPool) or microtransit vans.

Some studies found a relatively modest effect from TNCs on public transportation ridership. An American Public Transportation Association (APTA) survey of 4,500 people who used shared modes (including public transit, bikesharing, carsharing, and TNCs) in Austin, Boston, Chicago, Los Angeles, San Francisco, Seattle and Washington, D.C. found that TNC use is higher on weekends than weekdays and peaks between 8pm and 4am, when public transit is less available, indicating TNCs may complement public transit by providing service during off-peak times (Murphy and Feigon, 2016). Among respondents who listed TNCs as their preferred mode: 34% would drive alone or with a friend if TNCs were not an option, 24% would choose carsharing, 8% would take a taxi, and 14% would take a public bus or train. Less than 1% said they would not have made the trip. While these numbers suggest that very frequent TNC users primarily transfer away from car-based modes rather than from public transit, the results are not representative of less frequent TNC users. These results do indicate a disproportional shift away from public transit; in most U.S. cities, public transit has less than a 14% mode share, while the combination of drive alone, carpool, and carshare has greater than a 58% mode share. Moreover, the authors ask what mode respondents most often use TNCs to replace, rather than asking the mode they replaced with their most recent trip. This could result in lower replacement rates for less commonly replaced modes. Finally, aggregating across cities hides land-use and built environment effects that differ by city. Hampshire et al. (2017) surveyed 1,840 former Lyft and/or Uber users in Austin, TX to learn what modes they chose after the two companies suspended service in the city in May 2016. They found that 42% of respondents switched to another TNC, 41% to a personal vehicle, and 3% to public transit. Leaving out the switch to other TNCs, which does not convey additional information about TNC impacts on public transit ridership, the switch away from public transit is disproportionately high: 3.6% of Austin residents commuted to work by public transit in 2016 (about the same percentage as those that switched to public transit from Uber and Lyft), but 73.5% commuted by driving alone (almost twice as many as switched to personal vehicle) (American Community Survey, 2016).

Other research has found a stronger negative impact on public transit ridership. Rayle et al. (2016) surveyed 380 TNC users in San Francisco in 2014 and found that, if TNCs were not available, 39% would have taken a taxi, 7% would have driven alone or with a friend, 24% would have taken a public bus, and 9% would have taken public rail. They also found that 8% would not have taken the trip at all, reflecting a greater induced travel effect than the APTA study described above. Five percent used their TNC trip as a first-mile/last-mile strategy to get to or from public transit, while 40% of respondents who owned a car reported driving less as a result of TNCs. Study limitations include surveying respondents at three heavily-used TNC locations during the evening, thus capturing mainly social trips but not commute, school, errand, or airport trips. Another survey of 311 Lyft and Uber riders in the Denver area found that 40% used public transit less as a result of TNCs, 5% used public transit more, 32% drove less, and 2% drove more (Henao, 2017). A survey of 4,094 urban and suburban residents of Boston, Chicago, Los Angeles, New York, the San Francisco Bay Area, Seattle, and Washington, D.C., 21% of whom use TNCs, found that TNC users decrease their bus use by 6% and light rail use by 3%, while increasing heavy rail use by 3% (Clewlow and Mishra, 2017). This suggests that, on average, TNCs compete with bus and light rail but complement heavy rail, perhaps by offering more convenient first-mile/last-mile service to heavy rail stations. Nine percent of TNC users reported getting rid of a vehicle due to TNCs. Results also showed that 22% of TNC trips were induced trips, 21% would have been made by private vehicle, 18% would have been by carpool, 1% by taxi, and 15% by public transit. Limitations of this study include aggregating across cities, which could obscure city-specific trends, as well as asking respondents what mode they generally use TNCs to replace, rather than the mode they replaced with their most recent TNC trip. This approach may yield artificially low replacement rates for less commonly replaced modes, including public transit and taxis.

Outside of survey-based research, several studies have examined how public transit ridership changes in relation to various measures that approximate TNC use. Results from the strongest of these analyses suggest that TNCs negatively impact public transit ridership. One study used a difference-in-differences analysis of all 196 U.S. Metropolitan Statistical Areas (MSAs) that have both Uber and public transit to examine the impact of Uber entry in the MSA on public transit ridership (Hall et al., 2018). This study also analyzed the impact of Uber penetration, as measured by the number of Google searches for "Uber," which correlates with the number of Uber drivers per capita. The authors found that, after the arrival of Uber, public transit ridership in MSAs of below median population (280,000 people) decreased by 5.9%, while ridership in MSAs of above median population increased by 0.8%. A standard deviation increase in Uber penetration, meanwhile, correlated with a 0.5% decrease in public transit ridership among agencies in smaller MSAs and a 1.8% increase in ridership among agencies in larger MSAs. A drawback of this work is the use of two imperfect measures of Uber use; Uber entry does not account for changing impact over time, while Google searches are an inexact approximation of ridership. A more recent publication improves on these measures by using year since TNC entry as its independent variable, thereby combining an exact measure (date of entry) with a ridership approximation that accounts for changes over time (this measure assumes ridership increases linearly by year). In this study, a longitudinal analysis of the determinants of public transit ridership in 22 large U.S. cities from 2002 to 2018 found that heavy rail ridership decreased 1.29% for each year after TNCs began operating in the service area, while bus ridership decreased 1.70% per year (Graehler Jr et al., 2019). The authors note that impacts may differ in smaller and medium cities. Results from both studies would benefit greatly from data on TNC ridership by city. In NYC, where TNC ridership data are available, a separate analysis indicated that as TNC ridership increased by 7 million, 17 million, and 29 million in 2014, 2015, and 2016, respectively, bus ridership decreased by 10, 17, and 12 million and subway ridership increased by 43 million and 11 million before decreasing by 7 million in 2016 (Schaller, 2017). This represents a reversal of over a decade of transit-led growth in the city. The author attributes the change to TNCs but did not provide causal evidence to support this conclusion.

2.3. Public transportation agency partnerships with MOD companies

As of April 2019, 47 public agencies in the U.S., including public transportation agencies, public transportation authorities, and cities, have partnered with private companies to provide 62 MOD services that meet the U.S. Federal Transit Administration (FTA) definition of public transportation: "regular, continuing shared-ride surface transportation services that are open to the general public or open to a segment of the general public defined by age, disability, or low income" (FTA, 2016a). Some of these MOD public-private partnerships (MOD PPPs) have received support from the MOD Sandbox Program, which the FTA started in 2016 to provide $8 million in funding to public transportation agencies that integrate MOD services, including partnerships with TNCs and microtransit (FTA, 2016b; Lucken, Trapenberg Frick, Shaheen (2019)). The federal program aims to generate best practices for how to develop such partnerships; measure MOD impacts on the transportation system; and determine government requirements, regulations, and policies that help or hinder the integration of MOD services with public transit.

Outside the U.S., the European Union (EU) MaaS4EU, EU MaaS Alliance, and Australia Future Transport Digital Accelerator are all government-supported initiatives that promote research into implementing MaaS in ways that meet societal goals. Among other locations, MaaS services that incorporate public and private modes have been piloted in Gothenburg, Sweden (2013 to 2014); Hannover, Germany (2014); Turku, Finland (2015); Italy (2015); Germany (2016); Helsinki, Finland (2016), Birmingham, UK (2017), Amsterdam/Nijmegen (2017), Singapore (2017 to 2018), and Antwerp, Belgium (2018) (Jittrapirom et al., 2017; Wong et al., 2018).

In the following subsections, we present typologies for the 62 U.S. MOD PPPs as well as qualitative benefits, challenges, and recommendations for these partnerships as identified in the literature. Sections 4 and 5 discuss quantitative research into the impacts of incorporating MOD services with public transportation.

2.3.1. Overview of MOD PPPs in the U.S.

Several reports have proposed typologies for U.S. partnerships between public agencies and MOD companies, including Lucken, Trapenberg Frick, and Shaheen (2019), Curtis et al. (2019), the U.S. Government Accountability Office (GAO) (2018), Schwieterman et al. (2018), and Blodgett et al. (2017). Table 2.1 indicates the differences among the proposed typologies. The three potential types of MOD companies considered in the publications as MOD PPP participants include TNCs, van-based microtransit services, and companies that provide ride-matching and routing software for public agencies to operate their own MOD services. The four main categories of service provided by MOD PPPs include first-mile/last-mile (FMLM) connections to fixed-route public transit, gap-filling services in low-density areas, off-peak services during times when fixed-route service is not available, and paratransit for disabled and older adult populations.

In addition to categorizing MOD PPPs by the service provided, Blodgett et al. (2017) include payment structure as a dimension in their typology, with four categories: 1) city pays all, 2) city pays a fixed fraction, 3) customer pays a fixed amount, and 4) tailored to customer. In Lucken, Trapenberg Frick, and Shaheen (2019), the authors introduced two additional analysis dimensions: 1) the assets each partner contributes to enable service and 2) the vehicle type used to provide the service. The two asset contribution models include: 1) Agency-Operated MOD, in which the public partner uses its own vehicles and drivers and the private partner provides the ride-matching and routing algorithm, and 2) Agency-Subsidized Private MOD, in which the private partner provides the vehicles and drivers as well as the MOD algorithm. The three vehicle types include: vans, taxis, and TNC drivers' personal vehicles. While the type of service provided impacts the risk that a MOD PPP will compete with fixed-route transit, the asset contribution model impacts each partner's control over service operations and data, and the vehicle type affects operational costs and potential impacts on congestion, VMT, and emissions.

Table 2.1. Publications Proposing Typologies of MOD PPPs

Publication	MOD Companies Considered			Service Models Considered				
	TNCs	Van-based	Software	First-Mile/ Last-Mile	Low-Density	Off-Peak	Paratransit	Other(s)
Lucken, Trapenberg Frick, Shaheen (2019)	X	X	X	X	X	X	X	None. Considers alleviation of parking demand as a possible impact of MOD PPPs. Considers the other categories below as strategies to support the four core service models to the right.
Curtis et al. (2019)	X			X	X	X	X	Guaranteed Rides Home
U.S. GAO (2018)	X	X	X	X	X		X	Trip Planning & Fare Integration, Marketing
Schwieterman et al. (2018)	X			X		X	X	Trip Planning & Fare Integration, Data Sharing, Alleviation of Parking Demand
Blodgett et al. (2017)	X			X	X	X	X	None.

2.3.2. Benefits

A growing number of qualitative analyses suggest that incorporating MOD services offers a range of potential benefits to public transit agencies. The primary benefit to public transportation agencies is the ability to offer on-demand versions of the services identified in the previous section, sometimes at a lower cost than fixed-route or traditional paratransit service. For instance, Shaheen and Chan (2016) assert that TNCs can complement public transit by providing a FMLM strategy during off-peak times or in less-served areas, while microtransit could also provide FMLM service and reduce overcrowding on high-ridership bus routes. Lazarus et al. (2018) recommend that public transportation agencies could reduce costs and improve transit access by replacing low-ridership bus routes and offering FMLM strategies with subsidized TNC trips. The authors identify partnership opportunities as those times when and areas where public transit service is inefficient and TNC driver pools are available. They also advise public transportation agencies to take advantage of such partnerships to concentrate fixed-route service along high-volume corridors. Shaheen and Cohen (2018a) recommend the use of MOD PPPs to right-size transit vehicles, reduce operating costs, and optimize passenger experience to compete with private-vehicle ownership, particularly with the onset of vehicle automation. Schaller (2018) identifies paratransit service, FMLM connections, and dispersed travel markets as the main opportunities for public benefit from MOD services. Kuhr et al. (2017) state that partnerships between public transportation agencies and TNCs allow the public sector to innovate while sharing risk.

2.3.3. Challenges and Recommendations

Our literature analysis yielded four main categories of challenges and recommendations for MOD PPPs: 1) equity, 2) data sharing, 3) regulations and liability, and 4) labor-management relationships. We discuss recommendations from the literature in the context of these categories. Figure 2.1 below provides an overview of the recommendations within each category.

Several reports offer high-level analysis of challenges and recommendations for partnerships between public transit agencies and MOD companies. These include the TransitCenter's September 2016 report, *Private Mobility, Public Interest: How public agencies can work with emerging mobility providers* (Tsay et al., 2016). The authors conducted over 100 interviews with public- and private-sector representatives, including those involved in early partnerships between public transit agencies and MOD companies, over the course of 2015 and 2016. They provide extensive analysis of these early partnerships and offer many detailed recommendations under four overarching guidelines: 1) partner to reinforce public transit's strengths, 2) leverage agency-controlled assets, 3) plan for a streamlined user experience, and 4) be open to new ways of providing useful transit. Another resource is the Federal Highway Administration (FHWA) April 2016 report, *Shared Mobility: Current Practices and Guiding Principles*, which examines many shared modes but includes recommendations specific to TNCs as they relate to equity, data sharing, multimodal integration, insurance requirements, and leveraging public agency resources (Shaheen et al., 2016). The American Planning Association (APA) July 2016 report, *Planning for Shared Mobility*, offers further analysis of the way public agencies can use public rights-of-way, incentive zoning, and transportation demand management to influence MOD companies for the public good, with case studies from eight cities (Cohen and Shaheen, 2016). Finally, the National Research Council (NRC) and Transportation Research Board (TRB) 2015 report, *Between Public and Private Mobility: Examining the Rise of Technology-Enabled Transportation Services*, provides an in-depth look at the equity, insurance, and labor issues surrounding TNCs and microtransit, as well as recommendations for public agencies on how to address them (Taylor et al., 2015).

2.3.3a. Overarching Requirements and Recommendations

To use federal funds for Agency-Subsidized Private MOD, public transportation agencies in the U.S. must ensure the service meets the definition of public transportation—"regular, continuing shared-ride surface transportation services that are open to the general public"—or is an alternative to public transportation, as in job access and reverse commute programs (FTA, 2016c).

Two overarching strategies often recommended include: 1) leveraging agency-controlled assets in negotiations with MOD companies and 2) sharing lessons learned with other agencies. Leveraging financial resources, curb access for passenger loading zones, and off-street parking for waiting zones could help public transit agencies secure desired data or other requests, such as the procurement of wheelchair-accessible vehicles (WAVs), in their partnerships with MOD companies (Shaheen et al., 2016; Tsay et al., 2016). Exchanging lessons learned with other public transit agencies involved in similar partnerships can suggest additional best practices and facilitate the learning process in preparing, implementing, and adjusting or expanding pilot projects.

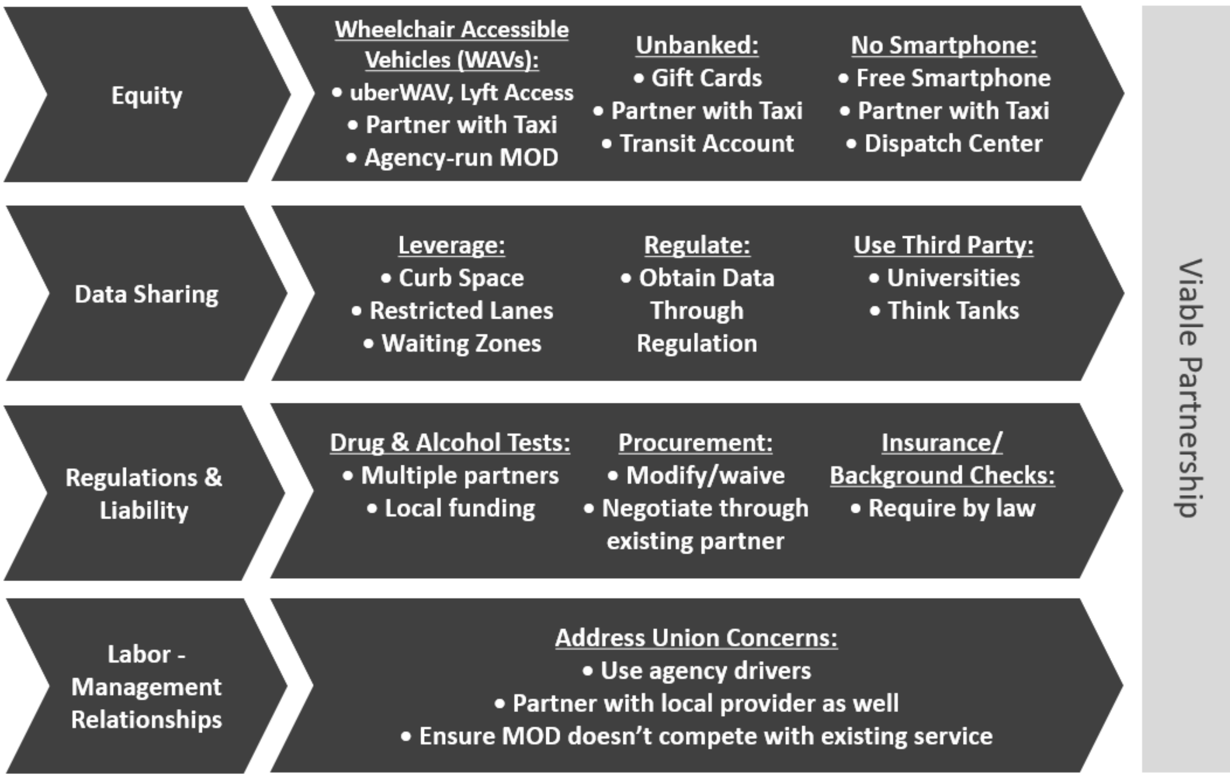


Figure 2.1. Challenges and Strategies for MOD PPPs

2.3.3b. Equity in MOD PPPs

Equity is a primary area of study and concern relating to MOD companies in general and also to MOD PPPs. Partnering with MOD companies presents many equity-related challenges, including limited WAV availability, lack of driver training to assist disabled passengers to the vehicle, the potential for race-based discrimination by MOD company drivers, barriers for people without bank accounts or smartphones, and lack of driver availability in rural areas.

However, such partnerships also offer significant opportunities to improve service for low-income, disabled, older adult, and rural populations. Indeed, these opportunities are one of the main motivations for public transportation agencies to partner with MOD companies. By partnering with MOD companies to replace or supplement service that the public agency struggles to provide efficiently, such as paratransit or low-ridership bus routes in less dense areas, agencies can save money while simultaneously improving transportation quality for the populations that previously relied on the inefficient service.

Public agencies in the U.S. that receive federal funding must ensure their services do not discriminate by race, color, or national origin, as dictated by Title VI Statute of the Civil Rights Act of 1964. All transportation services must also abide by the Americans with Disabilities Act (ADA) of 1990, which requires equitable service for those with physical or mental disabilities. Public transportation agencies need any service they provide through MOD company partnerships to abide by Title VI and ADA regulations as well (FTA, 2016d). The USDOT has specifically required that public transportation agencies in MOD PPPs provide alternative methods of payment and reservations for individuals without bank accounts or smartphones; offer WAV access; and ensure the same level of service for all users with regard to fares, response times, and areas and times of service (Foxx, 2016; FTA, 2016d; Shaheen and Cohen 2018). To evaluate the equity of potential or existing MOD PPPs, public transportation agencies can use the FHWA STEPS (Spatial – Temporal – Economic – Physiological – Social) framework to analyze the service along spatial, temporal, economic, physiological, and social dimensions (Shaheen et al., 2017b).

A few notable resources offer substantial analysis of the barriers and opportunities MOD service poses for equitable transportation quality and access. The New York University Ruden Center for Transportation Policy and Management's 2016 report, (Kaufman et al., 2016), analyzes the potential for MOD technology to enhance paratransit, identifying the need for collaboration between MOD companies and paratransit agencies. The Citizens Budget Commission of New York published a report analyzing the obstacles to and potential benefits from public transit agencies partnering with MOD companies to provide paratransit service (*Access-A-Ride*, 2016). An APTA report, *Shared Mobility and the Transformation of Public Transit*, includes a chapter on the same topic. The Brookings Institution also performed an economic analysis suggesting substantial cost savings to public transit agencies from offering paratransit service through partnerships with MOD companies (Kane et al., 2016). Finally, the Institute for Transportation and Development Policy (ITDP) report, *Connecting Low-Income People to Opportunity with Shared Mobility*, provides a comprehensive review of the challenges low-income communities face in accessing shared mobility, including MOD services, as well as the challenges shared mobility providers face in serving such communities (Kodransky and Lewenstein, 2014). The report offers recommendations for addressing these challenges, including launching pilot projects based on research on low-income community transportation needs, and concludes that programs to help low-income individuals benefit from shared mobility should address at least three barriers to be successful.

Table 2.2 offers an in-depth examination of equity-related challenges and recommendations, while Table 2.3 presents existing literature on operational challenges and recommendations.

Table 2.2. Equity-Related Challenges and Recommendations for MOD PPPs

Vulnerable Population	Challenges	Recommendations
Individuals with Disabilities (NCMM, 2018; Foxx, 2016; Blake et al., 2016; Danielsen, 2016; Taylor et al., 2015)	• **Low WAV availability** in MOD company fleets • Higher fares and wait times • MOD companies may decrease the number of WAVs in a city, if they drive taxi companies out of business • MOD company **drivers often lack training** in assisting disabled passengers	• In-app options to request WAVs (e.g., uberWAV, Lyft Access Mode) or request drivers with specialized training (e.g., uberASSIST) • Contract with third-party WAV providers like taxi companies • Use an agency's existing WAVs • Require MOD company to meet a specified number of WAVs before entering into MOD PPP
Minorities (Ge et al., 2016)	• MOD company drivers may cancel trips more often for passengers with pictures and/or names associated with racial minorities	• Remove the rider's picture and/or name from MOD apps ○ Drivers could still cancel after seeing the passenger in person, leading to even longer wait times for these passengers
Seniors (NCMM, 2018; Shirgaokar, 2018; SUMC, 2016)	• Barriers by age may include **need for assistance to the vehicle** or **lack of access to/comfort with smartphones**	• Train drivers to assist passengers to board vehicles, offer training on how to use the app, and/or provide alternatives to smartphones
Low-Income Individuals (Smith, 2016)	• MOD services often have high fares	• Offer subsidized rides to low-income individuals
Unbanked/ Underbanked Individuals (Kodransky and Lewenstein, 2014)	• MOD services often **require payment by credit card** ○ 20% of U.S. households do not have access to a credit card (FDIC, 2016)	• Purchase Uber and Lyft **gift cards** with cash • **Partner with a local credit union or bank** that can provide accounts and debit or credit cards for unbanked individuals
Individuals without Smartphones	• MOD services often **require smartphones to request rides** ○ Less than half of low-income Californians own smartphones (Chang, 2015)	• Through centralized call centers (e.g., Uber Central, Lyft Concierge), organizations can order rides for their constituents
Rural Populations (Rodier and Podolsky, 2017; Shaheen et al., 2017b; Shaheen et al., 2016)	• Lower driver availability • Unreliable mobile phone service	• Subsidize service in rural areas • Use community gathering places, such as faith-based buildings, as MOD hubs

Table 2.3. Operational Challenges and Recommendations for MOD PPPs

<table>
<tr><th colspan="2">Challenge</th><th>Description</th><th>Recommendations</th></tr>
<tr><td colspan="2">Data Sharing (GAO-18-539, 2018; Tsay et al., 2016; Corey et al., 2017; Uber, 2016; Shaheen et al., 2016)</td><td>• MOD companies avoid sharing data due to proprietary concerns and the need to protect customer information.
• Public transportation agencies entering into MOD PPPs need access to data on the rides they are subsidizing to analyze the partnership’s success and further improve service.</td><td>• Clearly define the desired data, how to use the data to answer specific questions, and how to ensure data security and privacy
• Obtain data through regulation rather than voluntary agreements
• Leverage agency-controlled assets in negotiations for data access
• Seek data analysis through a third party, such as an academic institution
• Set industry-wide standards for “data formats, data sharing protocols, and privacy protections”
• Develop a nationwide, neutral MOD company data platform</td></tr>
<tr><td rowspan="4">Regulations and Liability</td><td>Drug and Alcohol Testing (FTA, 2016e)</td><td>• Public agencies that receive funds under the FTA’s Urbanized Area, Capital Investment Grant, and Rural Area programs must ensure drug and alcohol testing of the partner company’s drivers.</td><td>• Consider partnering with more than one MOD company and/or taxi company and allow the passenger to choose which service to use, as this exempts the partnership from FTA drug and alcohol testing requirements</td></tr>
<tr><td>Insurance Coverage and Background Checks</td><td>• Public agencies may have concerns around liability with regard to insurance coverage or driver background checks by their MOD company partner.</td><td>• Work with state and local governments to set regulations and requirements regarding insurance and background checks by MOD companies (Shaheen et al., 2016; Schaller, 2016)</td></tr>
<tr><td>Procurement Requirements (Tsay et al., 2016)</td><td>• Public agencies may need to modify or waive their existing procurement requirements to enable MOD PPPs.</td><td>• Negotiate the partnership through a company with which the public agency already has a contract, such as trip-planning providers like TransLoc (recently acquired by Ford)</td></tr>
<tr><td>Instability of MOD companies and prices</td><td>• Public agencies assume risk by subsidizing trips in the volatile MOD market (Tsay et al., 2016).</td><td>• Minimize risk by conducting short pilots
• Protect against surge pricing by capping trip subsidies</td></tr>
<tr><td colspan="2">Labor-Management Relationships</td><td>• Existing contracts and relationships with unionized labor can financially, legally, and politically restrict agencies from entering into MOD PPPs (Tsay et al., 2016).</td><td>• Procure software to provide Agency-Operated MOD service
• Partner with a local transportation provider alongside a MOD company
• Ensure the new service will complement, not replace, existing services</td></tr>
</table>

2.4. Existing methods for estimating demand for vehicular MOD services

To quantify the impacts of MOD PPPs on a variety of public goals, including VMT reduction, an increase in accessibility, and improved equity, a method is required for measuring the replaced modes and induced demand from existing MOD PPP services. Beyond measuring existing impacts, estimating the demand for new MOD services is a necessary step for: 1) identifying the potential impacts on VMT, accessibility, and equity from MOD PPP implementation on a broader scale and 2) identifying the best locations, densities, and land-use mixes in which to implement MOD PPPs to most advance these societal goals. Regarding the second objective, estimating how demand for MOD services varies throughout a public transportation agency's service area is also essential for selecting MOD PPP locations that entail a manageable level of public subsidy, thereby improving the chances the service will remain financially sustainable long-term.

Thus far, the two main approaches to achieving the objectives described above have been agent-based simulation and stated preference surveys. Agent-based simulation has been a popular approach to exploring the impacts of MOD services on travel times and VMT. These studies vary in their focus on MOD or automated MOD (AMOD) services, including shared automated vehicles (SAVs), and on single-passenger or shared MOD services. Table 2.4 presents a synopsis of this research, which has focused on optimizing the design of MOD and AMOD services, simulating the integration of MOD and AMOD services with fixed-route transit, and incorporating synthetic mode choice models into MOD and AMOD simulation. Drakoulis et al. (2018) and Inturri et al. (2018) also simulated shared-ride MOD services, while Tsao et al. (2019), Winter et al. (2018), and Archetti et al. (2018) simulated shared-ride AMOD services. Other simulation-based research on shared-ride, intermodal MOD includes Stiglic et al. (2018). Single-passenger, intermodal AMOD simulations include Salazar et al. (2018) and Bischoff et al. (2017), while Martinez and Viegas (2017) simulated a shared-ride, intermodal AMOD system in Lisbon, Portugal. The Intermodal Transport Forum's 2015 report, *Urban Mobility System Upgrade*, provides an overview of early SAV simulations and includes an additional simulation comparing VMT impact in scenarios with shared-ride or single-passenger SAV fleets and with or without high-capacity public transportation. The research described in this paragraph has all assumed exogenous demand or used synthetic mode choice models rather than estimating a mode choice model from real-world data. The results thus lack support from observed mode choice behavior and also cannot provide estimates for induced demand, a crucial element in predicting the use of MOD services.

Table 2.4. Literature on agent-based simulation of MOD and AMOD services

Subject	Journal Article(s)	Main Empirical or Methodological Contribution
Optimizing MOD service design	Alonso-Mora et al., 2017	Showed efficiency gains from 4-passenger and 10-passenger MOD services compared to existing taxi demand in Manhattan, New York
	Fiedler et al., 2017	Found increased congestion and VMT from single-passenger MOD service
	Djavadian and Chow, 2017a, 2017b	Simulated two-sided market equilibrium from dynamic adjustment by MOD operator in Oakville, Ontario
	Martinez et al., 2015	Tested passenger-vehicle matching scheme for a shared-taxi system in Lisbon, Portugal
	Santi et al., 2014	Showed efficiency gains from a two-passenger shared MOD service
	Ma et al., 2013	Proposed dispatching strategy for a MOD fleet
Optimizing AMOD service design	Fagnant & Kockelman, 2018, 2014	Simulated SAV fleet size and VMT impacts for single-passenger (2014) and shared (2018)
	Leich & Bischoff, 2018	Found higher operating costs and slight travel time savings from replacing buses with SAVs
	Dia & Javanshour, 2017	Optimized SAV fleet size in Melbourne, Australia
	Zhang et al. 2017, 2015	Calculated SAV impact on parking needs
	Fagnant et al., 2016	Found SAVs can meet current demand in Austin, Texas with one-tenth the current number of privately owned vehicles
Integrating MOD and AMOD services with fixed-route transit	Ma, 2017	Proposed dispatching system for efficient MOD service integration with fixed-route transit in and around Luxembourg City
	Vakayil et al., 2017	Simulated AMOD service with fixed-route transit in Washington, DC
	Shen et al., 2017	Simulated SAVs as a FMLM service in Singapore, identified bus routes to keep
	Moorthy et al., 2017	Simulated SAV fleet as FMLM service in Ann Arbor, Michigan
Integrating synthetic endogenous demand models in MOD and AMOD simulation	Basu et al., 2018	• Added AMOD to mode choice model with nests of private modes (drive alone, carpool, motorcycle), fixed-route transit (bus, rail), and on-demand (taxi) • Set the AMOD utility equation and parameters equal to those of taxi, with adjusted fares and travel times
	Hao & Yamamoto, 2017	Estimated model for SAV use and the sharing of privately owned vehicles in Meito Ward, Nagoya, Japan
	Hörl et al., 2016	Simulated single-passenger SAV system in which demand varies based on traffic
	Atasoy et al., 2015	Included mode choice model with options of taxi, shared taxi, and mini bus

Source: Adapted and expanded from Liu et al. (2019)

A few studies have begun estimating models for MOD demand based on stated preference choice experiments. Frei et al. (2016) conducted a stated preference survey with 183 respondents who completed 1,997 choice experiments comparing drive alone, indirect shared MOD service, and fixed-route transit, although the sample is biased toward current public transit riders due to survey collection within a university community and through a public transportation agency website. They estimated a mode choice model that included: income, age, gender, trip and parking costs, in-vehicle time as well as walk and wait time, number of transfers, trip distance, distance to the nearest public transit stop, the weather and season, and a variety of opinions and preferences. Lazarus et al. (2021) drew on a stated preference survey with 2,398 respondents from Sacramento, San Francisco, Los Angeles, and San Diego, California. The survey resulted in 10,912 choice experiments comparing single-passenger, shared door-to-door, and shared indirect TNC services, thereby estimating travellers' choice between TNC modes but not the choice of TNCs over other modes. The mode choice model they estimated included explanatory variables similar to those in Frei et al. (2016) as well as frequency of TNC use, trip purpose, and three categories of promotional offers. Aside from mode choice models, a few studies have used stated preference choice experiments to estimate models for related aspects of MOD service. Alemi et al. (2019) used a survey of 1,975 California millennials and members of Generation X to estimate a model for the use frequency of Uber and Lyft, although the use of coarse frequency categories may have masked the impacts of geographic region and sociodemographic characteristics on frequency of use. Bansal et al. (2016) and Krueger et al. (2016) estimated how demographic, social, and service characteristics impact willingness to pay for shared and single-passenger SAV services. Matyas and Kamargianni (2019a, 2019b) estimated models for the choice of MaaS subscription bundles and find that respondents do not prefer bundles with shared modes but would be more willing to try shared modes after subscribing to bundles that include these services.

One study has combined stated preference choice experiments and agent-based simulation, enabling realistic demand estimates, supply-side optimization, and the identification of a supply-demand equilibrium. Liu et al. (2019) conducted a stated-preference survey of 1,507 New York City residents, who each answered one choice experiment comparing single-passenger Uber, UberPool, and the respondents' current mode: drive-alone car, carpool, or fixed-route transit. Explanatory variables included walk and wait time, in-vehicle travel time, trip cost, parking cost, and whether the vehicle was electric and/or automated. With NYC taxi trip data providing a set level of demand, the authors estimated mode share between fixed-route transit and three MOD modes, using the utility equation for single-passenger Uber to estimate demand for a single-passenger MOD mode and the utility equation for UberPool to estimate demand for 4-passenger and 10-passenger MOD modes. Agent-based simulation provided travel and wait times based on the fleet sizes and demand for each MOD mode. They assumed all three MOD modes are operated by a profit-maximizing service provider, and used Bayesian optimization to determine this provider's five decision variables: the fleet size for each MOD mode and the discount factors for the two shared-ride MOD modes. Through an iterative process, the authors identify a supply-demand equilibrium with mode share, fleet sizes, and fares for each mode. This research does not consider induced demand or competition with traditional drive modes.

2.5. New Research Frontiers

Understanding of MOD PPPs could benefit from further research in several areas, including: 1) quantitative analysis of existing partnerships on how agency cost, VMT, accessibility, and equity impacts vary by service design; 2) estimation of induced demand from MOD PPP services; 3) the appropriate service environment (e.g., density, land use) for each MOD PPP service model and vehicle size, as well as the policy levers that encourage the best match of service environment and MOD PPP design; and 4) evaluation of how MOD PPP impacts may change with the transition to automated vehicles.

Section 2.3 and Section 2.4 highlight a clear research gap: the use of data from existing MOD PPPs to provide guidance for public transportation agencies on how to best integrate MOD services with fixed-route transit to meet societal goals at a sustainable level of public subsidy. As described at the start of Section 2.4, determining replaced modes and induced demand from existing partnerships is a crucial step to enable accurate estimates of ridership and thus VMT impacts and required subsidies. None of the research reviewed in Section 2.4 includes a method to estimate induced demand. As indicated by the research on general TNC impacts in Section 2.2, one way to estimate replaced modes and induced demand is to ask passengers of MOD PPP services what mode they would have used for their last trip on the service or if they would not have made the trip, if the service was not available. More work like Liu et al. (2019) and Lazarus et al. (2021) is needed to estimate mode choice models that include single-passenger and shared MOD modes, fixed-route transit, traditional drive modes, and non-motorized modes and draw on revealed or stated preference data from people familiar with MOD modes, such as residents in MOD PPP service areas. The surveys to estimate induced demand and mode choice must include demographic data to enable analysis of equity impacts, including relative travel time and wait time changes by income, race, age, ability, and geographic location.

Another area of needed research involves determining the most appropriate service environment for each type of partnership between public transportation agencies and MOD companies: FMLM, Low-Density, Off-Peak, and Paratransit services, with vehicle sizes of 4-passenger, 10-passenger, or larger. After drawing on data from existing MOD PPPs to estimate induced demand and mode choice models that include demographic variables, researchers can expand on the work by Liu et al. (2019) and use agent-based simulation and supply-side optimization to determine the optimal service type and vehicle size by density and land use. In this context, the supply-side optimization would focus not on maximizing profit but rather on maximizing societal goals, including VMT reduction, equity, and accessibility, subject to a maximum acceptable public subsidy.

Future research is also needed to identify policy levers that encourage the ideal distributions of MOD PPP services and vehicle sizes. This could involve testing outcomes under status-quo policies as well as combinations of: 1) subsidies to support socially desirable MOD uses like service in unprofitable low-income and rural areas, 2) fees to penalize undesirable uses like single-occupancy trips in high-traffic areas and times, and 3) dedicated infrastructure policies like assigning curb and road space to favor desirable modes and restrict MOD modes from competing with public transit along high-volume corridors.

Finally, the research outlined in this section can inform work on estimating transportation equity, accessibility, VMT, and cost impacts as MOD modes transition to automated services.

2.6. Conclusion

Survey-based and econometric analysis suggest negative impacts from TNCs on public transit ridership. In light of this competition, public transportation agencies are experimenting with the provision of smartphone-enabled, on-demand service by partnering with MOD companies, including TNCs, van-based microtransit, and ride-matching and routing software companies. The four main service models provided include FMLM, low-density, off-peak, and paratransit service. These partnerships aim to fill gaps or replace existing service in scenarios in which demand is too low or dispersed to support fixed-route service. Agencies implementing MOD PPPs face challenges such as ensuring equitable access, reaching data sharing agreements with the private partner to enable in-house evaluation of the service, navigating regulations like driver background checks and drug tests, and addressing concerns from public transit labor unions about contracting with outside providers.

Most quantitative analyses on the impacts of shared-ride MOD services have involved agent-based simulation. These studies have primarily optimized MOD service design to minimize costs, evaluated travel time and VMT impacts, and assumed exogenous demand or synthetic mode choice models. A few research groups have used stated preference surveys to estimate mode choice models that include drive alone, ride-alone MOD, shared-ride MOD, and fixed-route public transit. A single study has used such a model in combination with agent-based simulation to identify a supply-demand equilibrium with mode share, fleet sizes, and fares for each mode. While this work has begun to address methods for designing intermodal MOD and fixed-route services, further research is needed on the impacts of existing and planned MOD PPPs.

In particular, none of the research described in this chapter has used trip data or surveys from existing MOD PPPs to evaluate how travel time and cost impacts vary by demographic group—a crucial step to ensuring benefits of the new service model are distributed equitably and meet the needs of transit-dependent populations. Moreover, none of the research includes a method to estimate induced demand, which is necessary to accurately analyze VMT impacts from existing MOD PPPs and to project ridership and agency costs for new partnerships. Additional research is also needed to identify the appropriate service environment for each type of MOD PPP, policy levers to encourage the socially optimal design of intermodal MOD services, and guidance for managing the transition to automated vehicles. While MOD PPPs offer the potential to improve travel times and reduce operational costs, public transit agencies and researchers must carefully monitor impacts to ensure these partnerships not only attract new ridership but also support fixed-route public transit service, lower overall VMT, and meet the needs of vulnerable populations.

2.7. References

Access-A-Ride, 2016. Citizens Budget Commission of New York [WWW Document]. URL https://cbcny.org/research/access-ride.

Alemi, F., Circella, G., Mokhtarian, P., Handy, S., 2019. What drives the use of ridehailing in California? Ordered probit models of the usage frequency of Uber and Lyft. Transp. Res. Part C Emerg. Technol. 102, 233–248. https://doi.org/10.1016/j.trc.2018.12.016

Alonso-Mora, J., Samaranayake, S., Wallar, A., Frazzoli, E., Rus, D., 2017. On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment. Proc. Natl. Acad. Sci. 114, 462–467. https://doi.org/10.1073/pnas.1611675114

American Community Survey, 2016 [WWW Document]. Means of Transportation to Work in Austin City, TX in 2016. URL https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_16_1YR_B08301&prodType=table.

American Public Transportation Association, 2019 [WWW Document]. Transit Ridership Report: Second Quarter 2019. URL https://www.apta.com/wp-content/uploads/2019-Q2-Ridership-APTA.pdf.

American Public Transportation Association, 2014. Transit Ridership Report: Second Quarter 2014 [WWW Document]. URL https://www.apta.com/wp-content/uploads/Resources/resources/statistics/Documents/Ridership/2014-q2-ridership-APTA.pdf.

Archetti, C., Speranza, M.G., Weyland, D., 2018. A simulation study of an on-demand transportation system. Int. Trans. Oper. Res. 25, 1137–1161. https://doi.org/10.1111/itor.12476

Atasoy, B., Ikeda, T., Ben-Akiva, M., 2015. Optimizing a Flexible Mobility on Demand System. Transp. Res. Rec. J. Transp. Res. Board 2536, 76–85. https://doi.org/10.3141/2536-10

Bansal, P., Kockelman, K.M., Singh, A., 2016. Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. Transp. Res. Part C Emerg. Technol. 67, 1–14. https://doi.org/10.1016/j.trc.2016.01.019

Basu, R., Araldo, A., Akkinepally, A.P., Nahmias Biran, B.H., Basak, K., Seshadri, R., Deshmukh, N., Kumar, N., Azevedo, C.L., Ben-Akiva, M., 2018. Automated Mobility-on-Demand vs. Mass Transit: A Multi-Modal Activity-Driven Agent-Based Simulation Approach. Transp. Res. Rec. 2672, 608–618. https://doi.org/10.1177/0361198118758630

Bischoff, J., Kaddoura, I., Maciejewski, M., Nagel, K., 2017. Re-defining the role of public transport in a world of Shared Autonomous Vehicles. Presented at the Symposium of the European Association for Research in Transportation (hEART), Israel Institute of Technology.

Blake, C., Franklin, S., McFadden-Resper, S., Muhammad, K., Abdul-Mateen, S., Dash, A., 2016. Annual Report on Accessible Vehicle for Hire Service [WWW Document]. URL https://dfhv.dc.gov/sites/default/files/dc/sites/dc%20taxi/page_content/attachments/DFHV%20Accessibility%20Advisory%20Committee%202016%20Annual%20Report%20120216%20FINAL%20Update.pdf (accessed 12.1.17).

Blodgett, M., Khani, A., Negoescu, D., Benjaafar, S., 2017 [WWW Document]. Public/Private Partnerships in Transit: Case Studies and Analysis (Report). Minnesota Council on Transportation Access. URL http://conservancy.umn.edu/handle/11299/192846.

Chang, T., 2015. Crossing the Digital and Income Divide [WWW Document]. Presented at the Crossing the Digital and Income Divide: Making Mobility Innovations Accessible to All, San Francisco, CA, February 18. URL http://innovativemobility.org/?project=crossing-the-digital-and-income-divide-making-mobility-innovations-accessible-to-all-workshop-summary.

Clewlow, R.R., Mishra, G.S., 2017. Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States [WWW Document]. URL https://trid.trb.org/view.aspx?id=1485471.

Cohen, A., Shaheen, S., 2016. Planning for Shared Mobility (PAS 583) [WWW Document]. American Planning Association. URL https://www.planning.org/publications/report/9107556/.
Corey, E., Hastings, A., Krawczyk, T., de la Pena, B., Thompson, M., Hobson, M., Kubly, S., 2017. New Mobility Playbook. Seattle Department of Transportation.
Curtis, T., Merritt, M., Chen, C., Perlmutter, D., Berez, D., Ellis, B., 2019. Partnerships Between Transit Agencies and Transportation Network Companies. The National Academies of Sciences.
Danielsen, C., 2016. Groundbreaking Settlement to End Discrimination Against Blind Uber Riders Who Use Guide Dogs [WWW Document]. Natl. Fed. Blind. URL https://nfb.org/groundbreaking-settlement-end-discrimination-against-blind-uber-riders-who-use-guide-dogs (accessed 12.1.17).
Dia, H., Javanshour, F., 2017. Autonomous Shared Mobility-On-Demand: Melbourne Pilot Simulation Study. Transp. Res. Procedia, 19th EURO Working Group on Transportation Meeting, EWGT2016, 5-7 September 2016, Istanbul, Turkey 22, 285–296. https://doi.org/10.1016/j.trpro.2017.03.035
Djavadian, S., Chow, J.Y.J., 2017a. Agent-based day-to-day adjustment process to evaluate dynamic flexible transport service policies. Transp. B Transp. Dyn. 5, 281–306. https://doi.org/10.1080/21680566.2016.1190674
Djavadian, S., Chow, J.Y.J., 2017b. An agent-based day-to-day adjustment process for modeling "Mobility as a Service" with a two-sided flexible transport market. Transp. Res. Part B Methodol. 104, 36–57. https://doi.org/10.1016/j.trb.2017.06.015
Drakoulis, R., Bellotti, F., Bakas, I., Berta, R., Paranthaman, P.K., Dange, G.R., Lytrivis, P., Pagle, K., De Gloria, A., Amditis, A., 2018. A Gamified Flexible Transportation Service for On-Demand Public Transport. IEEE Trans. Intell. Transp. Syst. 19, 921–933. https://doi.org/10.1109/TITS.2018.2791643
Durand, A., Harms, L., Hoogendoorn-Lanser, S., Zijlstra, T., 2018. Mobility-as-a-Service and changes in travel preferences and travel behaviour: a literature review. https://doi.org/10.13140/RG.2.2.32813.33760
Fagnant, D.J., Kockelman, K.M., 2018. Dynamic ride-sharing and fleet sizing for a system of shared autonomous vehicles in Austin, Texas. Transportation 45, 143–158. https://doi.org/10.1007/s11116-016-9729-z
Fagnant, D.J., Kockelman, K.M., 2014. The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. Transp. Res. Part C Emerg. Technol. 40, 1–13. https://doi.org/10.1016/j.trc.2013.12.001
Fagnant, D.J., Kockelman, K.M., Bansal, P., 2016. Operations of Shared Autonomous Vehicle Fleet for Austin, Texas, Market. Transp. Res. Rec. 2563, 98–106. https://doi.org/10.3141/2536-12
FDIC, 2016. FDIC National Survey of Unbanked and Underbanked Households. Federal Deposit Insurance Corporation.
Fiedler, D., Cáp, M., Certický, M., 2017. Impact of mobility-on-demand on traffic congestion: Simulation-based study. 2017 IEEE 20th Int. Conf. Intell. Transp. Syst. ITSC 1–6. https://doi.org/10.1109/ITSC.2017.8317830
Foxx, A., 2016. DOT Dear Colleague Letter (Equity, Access for Shared Mobility Initiatives) [WWW Document]. FTA. URL https://www.transit.dot.gov/regulations-and-

guidance/policy-letters/dot-dear-colleague-letter-equity-access-shared-mobility (accessed 12.1.17).
Frei, C., Hyland, M., Mahmassani, H.S., 2016. Assessing the Potential for Demand Adaptive Transit via a Stated Preference Choice Survey. Presented at the Transportation Research Board 95th Annual MeetingTransportation Research Board.
FTA, 2016a. Shared Mobility Definitions [WWW Document]. Fed. Transit Adm. URL https://www.transit.dot.gov/regulations-and-guidance/shared-mobility-definitions (accessed 5.7.19).
FTA, 2016b. Mobility on Demand (MOD) Sandbox Program [WWW Document]. FTA. URL https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program.html (accessed 11.25.17).
FTA, 2016c. Shared Mobility Frequently Asked Questions [WWW Document]. Fed. Transit Adm. URL https://www.transit.dot.gov/regulations-and-guidance/shared-mobility-frequently-asked-questions (accessed 12.2.17).
FTA, 2016d. Shared Mobility FAQs: Americans with Disabilities Act (ADA) [WWW Document]. Fed. Transit Adm. URL https://www.transit.dot.gov/regulations-and-guidance/shared-mobility-faqs-americans-disabilities-act-ada (accessed 12.2.17).
FTA, 2016e. Shared Mobility FAQs: Controlled Substance and Alcohol Testing Requirements [WWW Document]. Fed. Transit Adm. URL https://www.transit.dot.gov/regulations-and-guidance/shared-mobility-faqs-controlled-substance-and-alcohol-testing-requirements (accessed 12.2.17).
GAO-18-539, 2018. Public Transit Partnerships: Additional Information Needed to Clarify Data Reporting and Share Best Practices. U Gov. Account. Off.
Ge, Y., Knittel, C.R., MacKenzie, D., Zoepf, S., 2016. Racial and Gender Discrimination in Transportation Network Companies (Working Paper No. 22776). National Bureau of Economic Research. https://doi.org/10.3386/w22776
Graehler Jr, M., Mucci, R.A., Erhardt, G.D., 2019. Understanding the Recent Transit Ridership Decline in Major US Cities: Service Cuts or Emerging Modes? Presented at the Transportation Research Board 98th Annual MeetingTransportation Research Board.
Hall, J.D., Palsson, C., Price, J., 2018. Is Uber a substitute or complement for public transit? J. Urban Econ. 108, 36–50. https://doi.org/10.1016/j.jue.2018.09.003
Hampshire, R., Simek, C., Fabusuyi, T., Di, X., Chen, X., 2017. Measuring the Impact of an Unanticipated Suspension of Ride-Sourcing in Austin, Texas (SSRN Scholarly Paper No. ID 2977969). Social Science Research Network, Rochester, NY.
Hao, M., Yamamoto, T., 2017. Analysis on supply and demand of shared autonomous vehicles considering household vehicle ownership and shared use, in: 2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC). Presented at the 2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC), pp. 185–190. https://doi.org/10.1109/ITSC.2017.8317920
Henao, A., 2017. Impacts of Ridesourcing - Lyft and Uber - on Transportation Including VMT, Mode Replacement, Parking, and Travel Behavior (Ph.D.). University of Colorado at Denver, United States -- Colorado.
Hörl, S., Erath, A., Axhausen, K.W., 2016. Simulation of autonomous taxis in a multi-modal traffic scenario with dynamic demand (Working Paper). IVT, ETH Zurich. https://doi.org/10.3929/ethz-b-000118794

Inturri, G., Giuffrida, N., Ignaccolo, M., Le Pira, M., Pluchino, A., Rapisarda, A., 2018. Testing Demand Responsive Shared Transport Services via Agent-Based Simulations, in: Daniele, P., Scrimali, L. (Eds.), New Trends in Emerging Complex Real Life Problems: ODS, Taormina, Italy, September 10–13, 2018, AIRO Springer Series. Springer International Publishing, Cham, pp. 313–320. https://doi.org/10.1007/978-3-030-00473-6_34

Jittrapirom, P., Caiati, V., Feneri, A.-M., Ebrahimigharehbaghi, S., González, M.J.A., Narayan, J., 2017. Mobility as a Service: A Critical Review of Definitions, Assessments of Schemes, and Key Challenges. Urban Plan. 2, 13–25. https://doi.org/10.17645/up.v2i2.931

Kamargianni, M., Li, W., Matyas, M., Schäfer, A., 2016. A Critical Review of New Mobility Services for Urban Transport. Transp. Res. Procedia, Transport Research Arena TRA2016 14, 3294–3303. https://doi.org/10.1016/j.trpro.2016.05.277

Kane, J., Tomer, A., Puentes, R., 2016. How Lyft and Uber can improve transit agency budgets. The Brookings Institution.

Kaufman, S., Smith, A., O'Connell, J., Marulli, D., 2016. Intelligent Paratransit. New York University Rudin Center for Transportation Policy and Management.

Kodransky, M., Lewenstein, G., 2014. Connecting Low-Income People to Opportunity with Shared Mobility. Institute for Transportation and Development Policy.

Krueger, R., Rashidi, T.H., Rose, J.M., 2016. Preferences for shared autonomous vehicles. Transp. Res. Part C Emerg. Technol. 69, 343–355. https://doi.org/10.1016/j.trc.2016.06.015

Kuhr, J., Bhat, C.R., Duthie, J., Ruiz, N., 2017. Ridesharing & Public-Private Partnerships: Current Issues, A Proposed Framework and Benefits. Presented at the Transportation Research Board 96th Annual MeetingTransportation Research Board.

Lazarus, J.R., Caicedo, J.D., Bayen, A.M., & Shaheen, S.A. (2021). To Pool or Not to Pool? Understanding opportunities, challenges, and equity considerations to expanding the market for pooling. Transportation Research Part A: Policy and Practice 148, 199–222. https://doi.org/10.1016/j.tra.2020.10.007

Lazarus, J.R., Shaheen, S.A., Young, S.E., Fagnant, D., Voege, T., Baumgardner, W., Fishelson, J., Lott, J.S., 2018. Shared Automated Mobility and Public Transport, in: Road Vehicle Automation 4, Lecture Notes in Mobility. Springer, Cham, pp. 141–161. https://doi.org/10.1007/978-3-319-60934-8_13

Leich, G., Bischoff, J., 2018. Should autonomous shared taxis replace buses? A simulation study. https://doi.org/http://dx.doi.org/10.14279/depositonce-8478

Liu, Y., Bansal, P., Daziano, R., Samaranayake, S., 2019. A framework to integrate mode choice in the design of mobility-on-demand systems. Transp. Res. Part C Emerg. Technol. 105, 648–665. https://doi.org/10.1016/j.trc.2018.09.022

Lucken, E., Trapenberg Frick, K., Shaheen, S., 2019. "Three Ps in a MOD:" Role for Mobility on Demand (MOD) Public-Private Partnerships in Public Transit Provision. Research in Transportation Business & Management, 32. https://doi.org/10.1016/j.rtbm.2020.100433

Ma, S., Zheng, Y., Wolfson, O., 2013. T-share: A large-scale dynamic taxi ridesharing service. Presented at the Proceedings - International Conference on Data Engineering, pp. 410–421. https://doi.org/10.1109/ICDE.2013.6544843

Ma, T.-Y., 2017. On-demand dynamic Bi-/multi-modal ride-sharing using optimal passenger-vehicle assignments. 2017 IEEE Int. Conf. Environ. Electr. Eng. 2017 IEEE Ind.

Commer. Power Syst. Eur. EEEIC ICPS Eur. 1–5. https://doi.org/10.1109/eeeic.2017.7977646
Martínez, L., 2015. Urban Mobility System Upgrade (Text). International Transport Forum.
Martinez, L.M., Correia, G.H.A., Viegas, J.M., 2015. An agent-based simulation model to assess the impacts of introducing a shared-taxi system: an application to Lisbon (Portugal). J. Adv. Transp. 49, 475–495. https://doi.org/10.1002/atr.1283
Martinez, L.M., Viegas, J.M., 2017. Assessing the impacts of deploying a shared self-driving urban mobility system: An agent-based model applied to the city of Lisbon, Portugal. Int. J. Transp. Sci. Technol., Connected and Automated Vehicles: Effects on Traffic, Mobility and Urban Design 6, 13–27. https://doi.org/10.1016/j.ijtst.2017.05.005
Matyas, M., Kamargianni, M., 2019a. Survey design for exploring demand for Mobility as a Service plans. Transportation 46, 1525–1558. https://doi.org/10.1007/s11116-018-9938-8
Matyas, M., Kamargianni, M., 2019b. The potential of mobility as a service bundles as a mobility management tool. Transportation 46, 1951–1968. https://doi.org/10.1007/s11116-018-9913-4
Moorthy, A., Kleine, R.D.D., Keoleian, G.A., Good, J., Lewis, G., 2017. Shared Autonomous Vehicles as a Sustainable Solution to the Last Mile Problem: A Case Study of Ann Arbor-Detroit Area. https://doi.org/10.4271/2017-01-1276
Murphy, C., Feigon, S., 2016. Shared Mobility and the Transformation of Public Transit. American Public Transportation Association.
NCMM, 2018. Considerations for TNC Partnerships: Seniors and Individuals with Disabilities.
Rayle, L., Dai, D., Chan, N., Cervero, R., Shaheen, S., 2016. Just a better taxi? A survey-based comparison of taxis, transit, and ridesourcing services in San Francisco. Transp. Policy 45, 168–178. https://doi.org/10.1016/j.tranpol.2015.10.004
Rodier, C., Podolsky, L., 2017. Opportunities for Shared-Use Mobility Services in Rural Disadvantaged Communities in California's San Joaquin Valley: Existing Conditions and Conceptual Program Development. National Center for Sustainable Transportation.
Salazar, M., Rossi, F., Schiffer, M., Onder, C.H., Pavone, M., 2018. On the Interaction between Autonomous Mobility-on-Demand and Public Transportation Systems, in: 2018 21st International Conference on Intelligent Transportation Systems (ITSC). Presented at the 2018 21st International Conference on Intelligent Transportation Systems (ITSC), pp. 2262–2269. https://doi.org/10.1109/ITSC.2018.8569381
Santi, P., Resta, G., Szell, M., Sobolevsky, S., Strogatz, S., Ratti, C., 2014. Quantifying the benefits of vehicle pooling with shareability networks. Proc. Natl. Acad. Sci. U. S. A. 111. https://doi.org/10.1073/pnas.1403657111
Schaller, B., 2018. The New Automobility: Lyft, Uber and the Future of American Cities.
Schaller, B., 2017. Unsustainable? The Growth of App-Based Ride Services and Traffic, Travel and the Future of New York City.
Schaller, B., 2016. Unfinished Business: A Blueprint for Uber, Lyft and Taxi Regulation. Schaller Consulting.
Schwieterman, J.P., Livingston, M., Van Der Slot, S., 2018. Partners in Transit: A Review of Partnerships Between Transportation Network Companies and Public Agencies in the United States.
Shaheen, S., Chan, N., 2016. Mobility and the Sharing Economy: Potential to Facilitate the First- and Last-Mile Public Transit Connections. Built Environ. 42, 573–588. https://doi.org/10.2148/benv.42.4.573

Shaheen, S., Cohen, A., 2019. Mobility on Demand (MOD) and Mobility as a Service (MaaS) How Are They Similar and Different? [WWW Document]. Medium. URL https://medium.com/move-forward-blog/mobility-on-demand-mod-and-mobility-as-a-service-maas-how-are-they-similar-and-different-a853c853b0b8 (accessed 10.26.19).
Shaheen, S., Cohen, A., 2018a. Is It Time for a Public Transit Renaissance?: Navigating Travel Behavior, Technology, and Business Model Shifts in a Brave New World. J. Public Transp. 21. https://doi.org/https://doi.org/10.5038/2375-0901.21.1.8
Shaheen, S., Cohen, A., 2018b. Equity and Shared Mobility. ITS Berkeley Policy Briefs 2018. https://doi.org/10.7922/G2MC8X6K
Shaheen, S., Cohen, A., Yelchuru, B., Sarkhili, S., 2017a. Mobility on Demand Operational Concept Report (No. FHWA-JPO-18-611). Federal Highway Administration.
Shaheen, S., Bell, C., Cohen, A., Yelchuru, B., 2017b. Travel Behavior: Shared Mobility and Transportation Equity. Federal Highway Administration.
Shaheen, S., Cohen, A., Zohdy, I., 2016. Shared Mobility: Current Practices and Guiding Principles. Federal Highway Administration.
Shen, Y., Zhang, H., Zhao, J., 2017. Embedding Autonomous Vehicle Sharing in Public Transit System: An Example of Last-Mile Problem. Presented at the Transportation Research Board 96th Annual MeetingTransportation Research Board.
Shirgaokar, M., 2018. Expanding Seniors' Mobility through Phone Apps: Potential Responses from the Private and Public Sectors. J. Plan. Educ. Res. 0739456X18769133. https://doi.org/10.1177/0739456X18769133
Smith, A., 2016. Shared, Collaborative and On Demand: The New Digital Economy. Pew Res. Cent. Internet Sci. Tech. URL http://www.pewinternet.org/2016/05/19/the-new-digital-economy/ (accessed 11.25.17).
Stiglic, M., Agatz, N., Savelsbergh, M., Gradisar, M., 2018. Enhancing urban mobility: Integrating ride-sharing and public transit. Comput. Oper. Res. 90, 12–21. https://doi.org/10.1016/j.cor.2017.08.016
SUMC, 2016. 7 Services Expanding Mobility for Aging Americans. Shar. Use Mobil. Cent. URL http://sharedusemobilitycenter.org/news/7-new-services-expanding-mobility-for-aging-americans/ (accessed 12.1.17).
Taylor, B., Chin, R., Crotty, M., Dill, J., Hoel, L., Manville, M., 2015. Between Public and Private Mobility: Examining the Rise of Technology-Enabled Transportation Services. National Resource Council, Transportation Research Board. https://doi.org/10.17226/21875
Tsao, M., Milojević, D., Ruch, C., Salazar, M., Frazzoli, E., Pavone, M., 2019. Model Predictive Control of Ride-sharing Autonomous Mobility-on-Demand Systems. 2019 Int. Conf. Robot. Autom. ICRA 6665–6671. https://doi.org/10.1109/ICRA.2019.8794194
Tsay, S., Accuardi, Z., Schaller, B., Hovenkotter, K., 2016. Private Mobility, Public Interest. TransitCenter.
Uber, 2016. Transparency Report. Uber.
Vakayil, A., Gruel, W., Samaranayake, S., 2017. Integrating Shared-Vehicle Mobility-on-Demand Systems with Public Transit. Presented at the Transportation Research Board 96th Annual MeetingTransportation Research Board.
Winter, K., Cats, O., Correia, G., van Arem, B., 2018. Performance analysis and fleet requirements of automated demand-responsive transport systems as an urban public

transport service. Int. J. Transp. Sci. Technol. 7, 151–167. https://doi.org/10.1016/j.ijtst.2018.04.004
Wong, Y.Z., Hensher, D.A., Mulley, C., 2018. Emerging transport technologies and the modal efficiency framework: A case for mobility as a service (MaaS) (Working Paper).
Zhang, W., Guhathakurta, S., 2017. Parking Spaces in the Age of Shared Autonomous Vehicles: How Much Parking Will We Need and Where? Transp. Res. Rec. 2651, 80–91. https://doi.org/10.3141/2651-09
Zhang, W., Guhathakurta, S., Fang, J., Zhang, G., 2015. Exploring the impact of shared autonomous vehicles on urban parking demand: An agent-based simulation approach. Sustain. Cities Soc. 19, 34–45. https://doi.org/10.1016/j.scs.2015.07.006

Chapter 3. "Three Ps in a MOD:" Role for Mobility on Demand (MOD) Public-Private Partnerships in Public Transit Provision

Emma Lucken

Karen Trapenberg Frick, Ph.D.

Susan A. Shaheen, Ph.D.

This chapter, with slight modifications, was published in Research in Transportation Business and Management (2019) and can be accessed here: https://www.sciencedirect.com/science/article/pii/S2210539519300987

The chapter addresses the first research objective of the dissertation: to understand what types of public MOD services currently exist, including benefits and challenges of each type from an environmental, transportation equity, and operational lens.

As lead author, I worked with Professor Trapenberg Frick and Professor Shaheen to conceptualize the paper and refine the typology. I performed the rest of the methodology (identified public MOD services, created the database of services, contacted interviewees, and conducted the interviews), wrote the original draft, and revised and edited based on reviews of the other authors and anonymous reviewers.

ABSTRACT

The growing number of public transportation agencies partnering with Mobility on Demand (MOD) or Mobility as a Service (MaaS) companies raises the question of what role MOD companies can, should, and currently play in the provision of public transport. In this article, we develop a typology reflecting 62 MOD public-private partnerships (MOD PPPs) in the United States and present lessons learned. We conducted 34 interviews with representatives from four MOD companies and 27 public agencies. The interviews spanned October 2017 to April 2018. The resulting MOD PPP typology consists of four service models: 1) First-Mile/Last-Mile (FMLM), 2) Low Density, 3) Off-Peak, and 4) Paratransit. The typology also includes two MOD asset contribution models: 1) Agency-Operated MOD and 2) Agency-Subsidized Private MOD. Lessons learned for limiting competition with fixed-route public transit include: a) if agencies have sufficient resources, they can generally maintain greater data access and control over the service with Agency-Operated MOD than Agency-Subsidized Private MOD; b) public agencies can supplement the Agency-Operated MOD model with Agency-Subsidized Private MOD during peak demand; c) public agencies sometimes encourage FMLM transfers to fixed-route public transit by creating service zones that divide trip generators and attractors and assigning one or two designated transfer stops to each zone; and d) one approach to protecting fixed-route public transit is to restrict Low-Density MOD services to trips that start and end outside a geofenced fixed-route service area.

Keywords: Mobility as a Service, Mobility on Demand, Public-private partnership, Public transportation, First-mile/last-mile, Typology

3.1. Introduction

In a time of declining public transit ridership in the United States (U.S.), public transportation agencies have started partnering with Mobility on Demand (MOD) or Mobility as a Service (MaaS) companies in an effort to improve the efficiency and quality of public transit service. We use the MOD terminology throughout this paper, as it was adopted by the U.S. Department of Transportation in 2016 to describe this emerging concept. MOD, according to the U.S. DOT definition, is a concept that encompasses both passenger and goods movement as commodities that consumers can access on demand through an integrated multi-modal network (Shaheen et al. 2017). MaaS, in contrast, is a European concept that focuses on aggregating passenger mobility services and ultimately providing them as bundled subscription options (Shaheen and Cohen 2019). Both MOD and MaaS aim to incorporate trip planning and booking, real-time information, and fare payment into a single user interface. Some operational aspects involved in MOD and MaaS preceded the development of companies like Uber and Lyft, including technological elements (e.g., integrated planning and booking systems like Cleric, a company started in the United Kingdom in 1985) and their application (e.g., Scotland's Transport to Employment service that centrally coordinated passengers' trips beginning in 2006).

The MOD companies we examine in this article include transportation network companies (TNCs, also known as ridesourcing and ridehailing) like Uber and Lyft that connect passengers with drivers who provide service in their personal vehicles, microtransit companies like Via that offer shared-ride services with flexible routing and/or scheduling, and software companies like TransLoc and DemandTrans that provide the algorithms for public transportation agencies to operate their own on-demand service. These innovative partnerships, which we call MOD public-private partnerships (MOD PPPs), seek to accomplish a variety of goals including: a) improving transportation quality for transit-dependent elderly, disabled, and low-income populations; b) serving new public transit riders; and c) enabling public transportation agencies to redistribute resources to more efficiently serve low-ridership bus routes and paratransit while increasing frequency along higher-density corridors.

For context, public transportation in the U.S. is administered at the level of the metropolitan region, county, or city. The federal government provides roughly half of the public transit capital funding and some operating funds. States often contribute both transit capital and operating funds to regional public transit districts, and many county and city governments employ local taxes to provide operational funding for regional transit agencies (TRB 2001). Unlike Western Europe, where contracting with private bus operators is common on a route-by-route basis or for whole networks even in major metropolitan areas, contracting with private transit providers in the U.S. occurs mainly in smaller and less urban transit systems or for services like paratransit (TRB 2001).

The previous chapter provides an extensive overview of existing literature on MOD PPPs. The literature review highlighted three critical gaps in the academic literature: 1) a conceptual framework for MOD PPPs, especially one that includes microtransit services and "agency-operated" partnerships in which the private partner provides only the ride-matching and routing algorithm, 2) trends in the number of public transportation agencies employing each MOD PPP model, and 3) comparative benefits, disadvantages, and recommendations for public transportation agencies regarding the implementation of each type of partnership. While some articles have discussed challenges and recommendations from a case study examination (e.g., Westervelt et al. 2017, 2018), we broadened our review to a comprehensive examination of existing MOD PPPs.

3.1.1. Overview

The questions we sought to answer with our analysis are:

a) **Typology:** What types of MOD PPPs exist and how do they relate to one another?
b) **Benefits and Disadvantages:** Based on publicly available documentation on MOD PPPs and feedback from public and private partners, what are the benefits and drawbacks of each type of MOD PPP for public transportation agencies?
c) **Trends:** At what rates are public transportation agencies implementing each type of MOD PPP and how do the identified benefits and disadvantages help interpret these trends?
d) **Implications:** In light of the identified benefits and disadvantages, how do representative public and private partners recommend that public transportation agencies decide between MOD PPP models and optimize implementation of the chosen model for the agency and its passengers?

The next section includes a discussion of our methodological approach for analyzing existing MOD PPPs and identifying the answers to each question listed above. We then present three sections of findings corresponding to the first three questions. We conclude by examining key implications of the findings for public transportation agencies considering MOD PPPs.

3.2. Methodological Approach

To develop a conceptual framework for MOD PPPs, we first compiled a database of MOD PPPs in the U.S. by reviewing online newspaper articles and public transit agency and MOD company websites. Inclusion criteria for MOD PPPs involved public agencies and private companies collaborating to provide MOD services that meet the FTA definition of public transportation: "regular, continuing shared-ride surface transportation services that are open to the general public or open to a segment of the general public defined by age, disability, or low income" (FTA 2016b). These include MOD company partnerships with public transportation agencies, transportation authorities, and cities. For simplicity, we refer to public transportation agencies throughout the text, except in Table 3.6, where we explicitly include only public transportation agencies in the table and describe transportation authority and city partnerships in the footnotes. Due to the rapid growth in the number of partnerships, some MOD PPPs may have been omitted from our analysis. The database we developed informed our first draft of a MOD PPP typology, which we refined through expert interviews.

Between October 2017 and April 2018, we conducted 34 interviews with representatives from four MOD companies, 21 public transit agencies, two transportation authorities, one regional planning agency, and three cities. We chose organizations to interview based on their involvement in MOD PPPs that were the “first of their kind” or that experienced notable success or challenges with a unique partnership feature. The partnerships examined through the interviews span each category of the typology and represent a range of geographies, densities, use cases, and target populations. We identified individual interviewees based on their familiarity and involvement with the development and implementation of the partnerships. Table 3.1 below summarizes interviewees’ roles by organization type. Interview questions included: a) how the organization decided to create the partnership; b) how it identified partners; c) how the MOD service fills gaps in the public transit network; d) the benefits and disadvantages from the partnership for the organization and how these are quantified; and e) how the partners share data, lessons learned, and next steps. Interviews were documented with written notes, and we sought written clarification from the interviewees after the interviews, as necessary.

Table 3.1. Expert Interviews

Type and Number of Organizations	Number of Interviewees	Function in Organization
4 MOD Companies	5	• **Vice President** • **Managers:** Transportation Partnerships, Transportation Policy, Accessibility Policy, Business Development
21 Public Transportation Agencies, defined as agencies required to report to the National Transit Database	27	• **Innovation:** Director, Program Manager • **Planning:** Director, Vice President, Manager, Principal Planner, Transportation Planner • **Operations:** Deputy Chief Officer, Director • **Demand Response:** Vice President, Manager, Supervisor • **Contract Services:** Director, Administrator • **Marketing:** Chief Officer, Director, Strategic Manager • **Information Technology:** Senior Director
2 Transportation Authorities	2	• **Planning:** Manager • **Operations:** Program Services Manager
1 Regional Planning Agency	4	• **Planning:** Deputy Director, Senior Regional Planner • **Operations:** Senior Program Specialist
3 Cities	3	• **Innovation:** Senior Officer • **Transportation:** Engineering Manager, Assistant Planner

We processed the interviews to refine the typology by tagging defining characteristics of the partnerships, identifying themes in how these characteristics varied across the partnerships, cross-checking the themes against all identified partnerships to ensure they helped describe variation throughout, and organizing the themes into a typology with descriptions of each level and category.

To analyze trends, we classified each identified MOD PPP according to the typology and graphed the occurrence of each model by start and end date. The initial classification enabled us to isolate interactions between the asset contribution models and the service models, while the graphs enable a comparative analysis of changes in the frequency of each model over time.

To inform the remaining findings and implications sections of the paper, we tagged benefits, disadvantages, and recommendations mentioned in the interviews and sorted them by MOD PPP model. We then applied the benefits and disadvantages as a lens through which to analyze potential explanations for the observed trends.

3.3. Findings: Typology of MOD PPPs

Based on our analysis, we classified MOD PPPs along three key dimensions: asset contribution (assets contributed by each partner to enable service), service provision (service provided to the public through the partnership), and vehicle type (the vehicles used to provide the service). We defined two asset contribution models: Agency-Operated MOD, in which the private partner provides only the ride-matching and routing algorithm, and Agency-Subsidized Private MOD, in which the private partner also provides the vehicles and/or the drivers. We identified four service models: 1) First-Mile/Last-Mile (FMLM), 2) Low-Density, 3) Off-Peak, and 4) Paratransit. Finally, we observed three vehicle types: vans, taxis, and personal vehicles owned by TNC drivers. Each dimension offers a lens through which to analyze how to meet service goals while minimizing competition with fixed-route public transit. The asset contribution model impacts the public agency's level of data access and control over the service and, in turn, its ability to monitor whether the MOD PPP competes with fixed-route transit or meets equity and environmental goals. Not surprisingly, the service model affects the risk that a MOD PPP will compete with fixed-route transit. Vehicle size affects potential vehicle occupancy and impacts on congestion, VMT, and emissions. Figure 3.1 maps the locations of 62 MOD PPPs by U.S. public transit agencies, transportation authorities, and cities. The map distinguishes MOD PPPs by asset contribution model and service model. Figure 3.2 depicts the observed relationship between asset contribution model, service model, and vehicle type among MOD PPPs in the U.S.

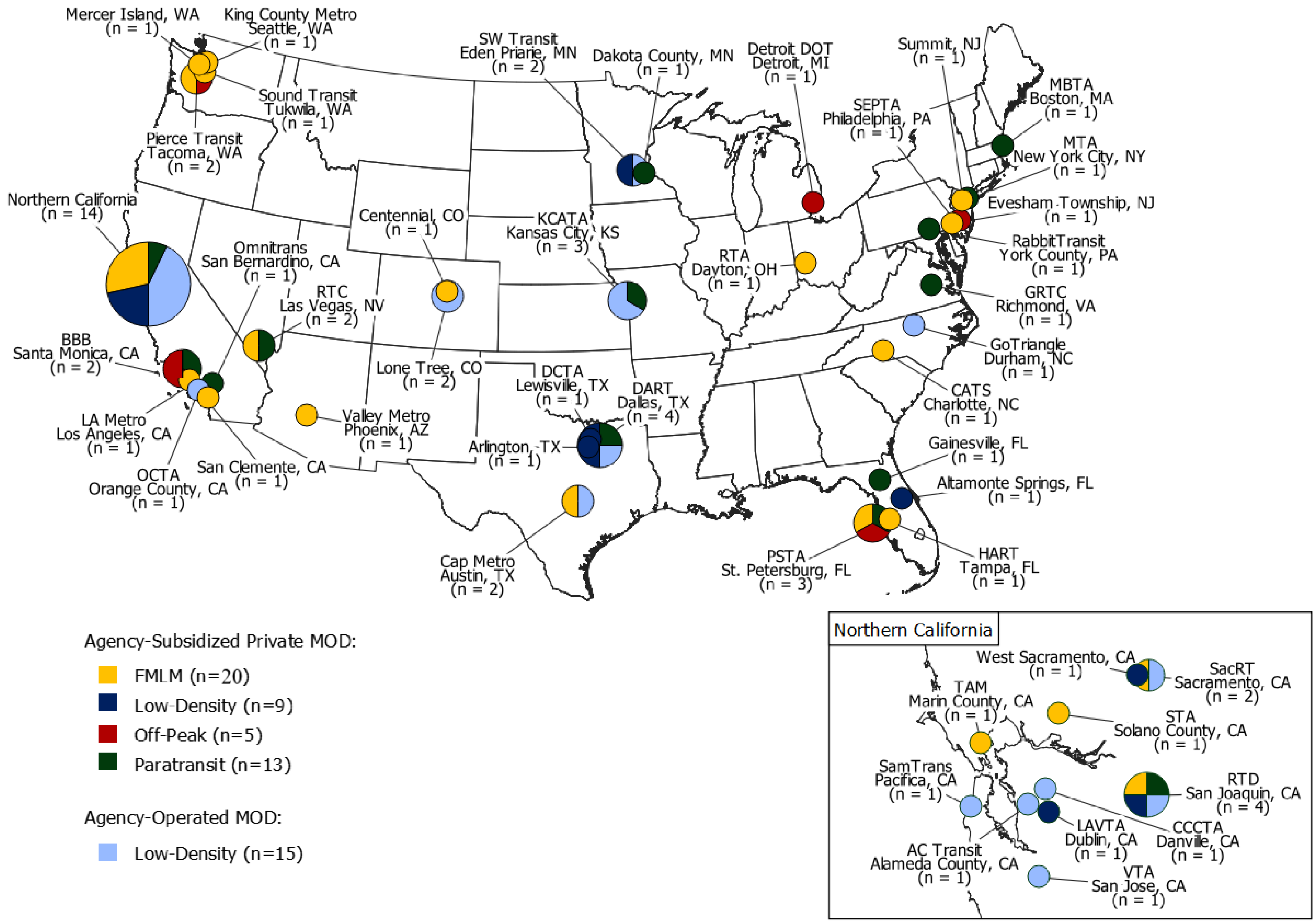


Figure 3.1. Map of MOD PPPs in the U.S.

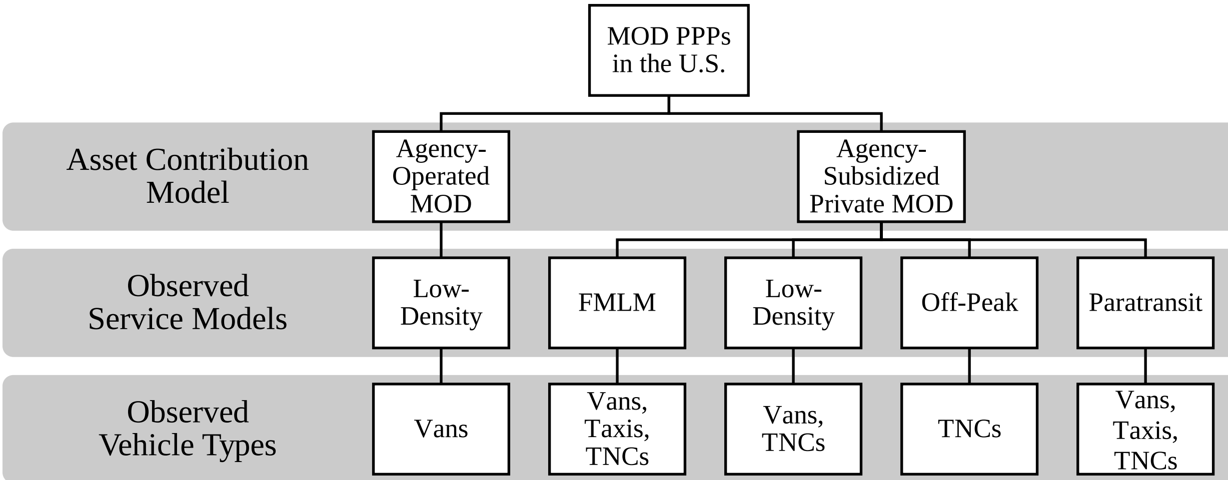


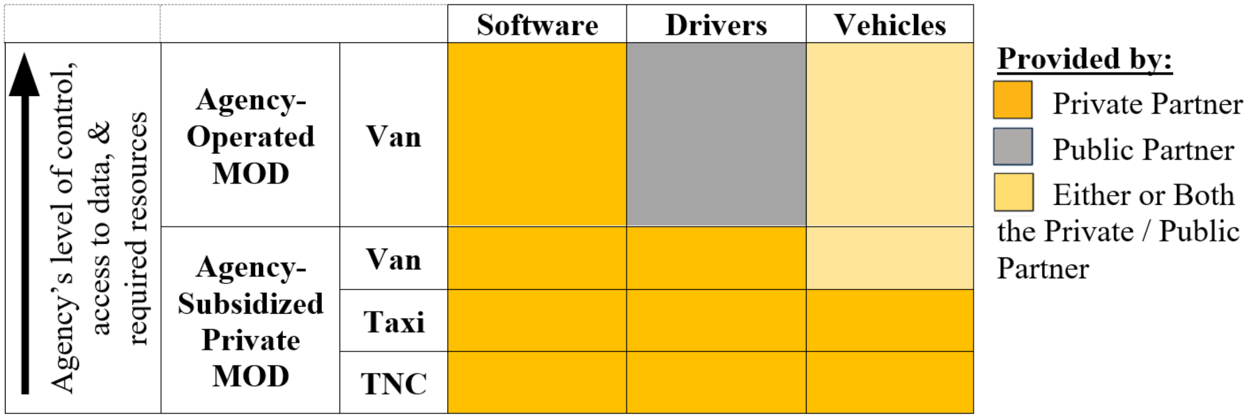
Figure 3.2. MOD PPP Typology

3.3.1. Asset Contribution Models

The MOD asset contribution models vary by which partner provides necessary assets for the MOD service: on-demand ride-matching and routing software, drivers, and vehicles. In each model, the public partner pays the private partner and the private partner designs the on-demand ride-matching and routing software. In Agency-Operated MOD, the public partner uses this software to offer services with its own employed or contracted drivers. With Agency-Subsidized Private MOD, the private partner is responsible for employing or contracting with the drivers. While all observed Agency-Operated MOD partnerships use microtransit vans to provide service, Agency-Subsidized Private MOD may use microtransit vans, taxis, or personal vehicles owned by TNC drivers. For Agency-Subsidized TNCs or MOD Taxis, the private partner owns the vehicles or arranges for drivers to use their personal vehicles. Generally, the public partner owns the vans used for Agency-Operated MOD and the private partner owns them for Agency-Subsidized Private Microtransit, though either partner or both partners can contribute these vehicles.

Table 3.2 illustrates these contributions. The arrow indicates that the public agency's control over the service and access to trip data is lowest under the Agency-Subsidized TNC model, increases under Agency-Subsidized MOD Taxi and Microtransit models, and is greatest under Agency-Operated MOD. This hierarchy reflects differences between the type of data that the private sector partners typically provide public agencies. Uber and Lyft often give the public partner aggregated measures such as: average trip fare and trip length, a heat map of trip volume by geographic area, and the percent of trips under designated estimated times of arrival (ETAs). The microtransit company Via generally offers trip-level data down to the nearest intersection of pick-ups/drop-offs. Companies that provide only the ride-matching and routing software for Agency-Operated MOD supply the public partners with all trip-level data.

Table 3.2. Asset Contribution Models by Public and Private Contributions



3.3.2. Service Models

The service models are distinguished by socio-demographic, geo-spatial, and temporal restrictions on trip provision. Table 3.3 presents how these restrictions differ by service model. The highlighted cells in the table indicate which restriction defines each model. For instance, FMLM partnerships are defined by their geo-spatial restrictions because they only subsidize trips that start and end at a public transit stop or station, thereby supporting public transit transfers. Low-Density and Paratransit partnerships do not require transfers to transit and instead serve trips from their origin to destination (point-to-point service), while Off-Peak partnerships can either: a) employ point-to-point service or b) set FMLM restrictions, if the agency operates reduced fixed-route service in off-peak hours. Low-Density partnerships restrict subsidized service to trips taken within specified zones, generally located in areas with densities too low to support frequent fixed-route bus service. Similarly, Off-Peak partnerships only subsidize trips taken during times in which demand is too low to support frequent fixed-route bus service. Off-Peak partnerships differ from FMLM or Low-Density partnerships because they specifically fill gaps caused by scaling back fixed-route service during off-peak hours, whereas FMLM and Low-Density partnerships provide service during standard fixed-route service hours or only during peak hours. Finally, Paratransit partnerships only subsidize trips made by individuals with disabilities or above a designated age.

While the first three service models do not restrict subsidies to those within a specified demographic, they can incorporate demographic restrictions to meet agency goals. For example, a FMLM partnership could restrict service to those with a transit station parking pass, thereby reducing parking demand at stations by only subsidizing those who would otherwise drive and park. An Off-Peak partnership could restrict service to low-income night-shift workers, thereby targeting subsidies to help individuals secure and keep otherwise-hard-to-access jobs.

Any of the four service models can either fill gaps by providing service where no comparable service existed previously or replace a previously existing, less efficient service. FMLM, Low-Density, and Off-Peak partnerships can replace low-ridership fixed bus routes. Low-Density partnerships can also replace general public dial-a-ride services, and Paratransit partnerships can replace and/or supplement prior paratransit services.

Table 3.3. Service Models by Restrictions on Passengers' Eligibility for Subsidized Trips

	Socio-Demographic *(e.g., Income, Ability, Age, Frequency of Transit Use)* **Only serve trips made by:**	**Geo-Spatial** **Only serve trips that:**	**Temporal** **Only serve trips made during:**
First-Mile/ Last-Mile	Anyone, But Could Restrict Eligibility *(e.g., only serve commuters or those who own transit station parking passes)*	Start/End at Fixed-Route Public Transit Stop or Station	Public Transit Service Hours (or Peak Hours)
Low-Density (Geo-Spatial Gap-Filling or Replacement)	Anyone, But Could Restrict Eligibility	Are Outside Fixed-Route Service Area *(e.g., within buffer zone of replaced bus route)*	Public Transit Service Hours
Off-Peak (Temporal Gap-Filling or Replacement)	Anyone, But Could Restrict Eligibility *(e.g., only serve low-income night-shift workers)*	Are Within Public Transit Service Area	Off-Peak Hours *(e.g., night, possibly midday)*
Paratransit	Persons with Disabilities; Senior Citizens	Are Within Public Transit Service Area	Public Transit Service Hours

As an example of two different partnership models in the same city, Dallas Area Rapid Transit (DART) started GoLink, an Agency-Operated MOD partnership with DemandTrans, in June 2017 and a separate Agency-Subsidized Private MOD partnership with Uber in March 2019. GoLink provides Low-Density point-to-point service in 13 zones for $1.50 per trip on weekdays from 5am to 9pm. DART encourages FMLM trips by offering free GoLink service with any DART pass. In the same zones and times, passengers can use the GoPass app to access $3 UberPOOL rides anywhere within a given zone (Low-Density, point-to-point service). As with GoLink, DART encourages FMLM trips by offering $1 UberPOOL trips to or from eligible DART stations. DART presents the UberPOOL option as a faster but more expensive option for passengers than GoLink (DART 2019).

3.4. Findings: Benefits and Disadvantages of Each MOD PPP Model

In this section, we consolidate the benefits and disadvantages of each asset contribution model and service model, as identified in the expert interviews and a review of publicly available documentation of existing MOD PPPs. Each public transportation agency acronym used here and in following sections is identified by location in Figure 3.2, above.

Table 3.4 explores each asset contribution model and its potential benefits and disadvantages. In general, greater control and access to data under the Agency-Operated MOD model enables public agencies to better understand the MOD service and promote the public good, such as increasing equity and public transit ridership. Two reasons deter some public agencies from selecting Agency-Operated MOD as an asset contribution model, including: 1) the financial and physical resources required by the agency to operate the service are greatest under the Agency-Operated MOD model and 2) demand is insufficient to justify the large microtransit vans typically used in Agency-Operated MOD.

In Table 3.5, we provide an overview of the four MOD service models and their potential benefits and disadvantages. From the perspective of minimizing competition with fixed-route services, the Paratransit and Off-Peak models offer advantages because paratransit is a separate service, while Off-Peak partnerships, by definition, typically operate outside fixed-route service hours. Protecting fixed-route services under the FMLM and Low-Density models requires additional precautions, as discussed in the implications section.

Table 3.4. Description, Benefits, and Disadvantages of Each Asset Contribution Model

Name and Description	Potential Benefits	Potential Disadvantages
Agency-Operated MOD: Private MOD company provides only on-demand ride-matching and routing software, while the agency uses its own drivers or drivers from its existing contract.	• Public agency has complete control over the service and retains access to all data (e.g., AC Transit, King County Transit) • Employing agency drivers can earn union support (e.g., KCATA) • Microtransit vans enable greater vehicle occupancy, potentially reducing VMT more than taxis or TNCs	• Requires more resources • Can be difficult to aggregate enough riders to offset costs (e.g., VTA) • Microtransit service may pull riders from more sustainable modes such as: bus, rail, bicycle, or walking
Agency-Subsidized Private MOD: • **Agency-Subsidized Private Microtransit:** Private partner hires their own drivers or contracts with a third party for driver services only. • **Agency-Subsidized Private MOD Taxis:** Private partner contracts with taxi companies for their vehicles and drivers. • **Agency-Subsidized TNCs:** Private partner contracts with independent drivers who use their personal vehicles.	• Public transportation agency does not need to own vehicles or hire drivers for the MOD service	• Subsidizing a service that employs private MOD company drivers sometimes leads to union resistance (e.g., DART) • Public partner may have limited access to trip data (e.g., PSTA) • Subsidizing trips on smaller vehicles could increase VMT

Table 3.5. Description, Benefits, and Disadvantages of MOD Service Models

Name and Description	Potential Benefits	Potential Disadvantages
First-Mile/Last-Mile Public partner subsidizes MOD trips to or from public transit stops or stations. MOD company geofences the designated transit stops or stations to ensure the discount only applies to eligible trips.	• Protects transit by only subsidizing rides to/from public transit stations (e.g., PSTA) • Can modify discount to reduce parking demand at transit stations (e.g., Summit, NJ) • May increase proportion of FMLM rides that are shared • Restricting discount to peak hours attracts commuters who require reliable FMLM service (e.g., RTD) • When geared toward commuters, employers may help cover service cost (e.g., STA)	• Can compete with other non-SOV FMLM options, such as riding the bus, biking, or walking • Transfers and multiple payments may deter potential passengers → Address this by allowing riders to plan and pay for trips on one platform (e.g., DART)
Low-Density Public partner subsidizes MOD trips anywhere within a designated zone. These partnerships target low-density areas that cannot support fixed route bus service.	• Better service than infrequent, low-ridership bus routes, at a lower cost than a dial-a-ride service (e.g., RTD, SW Transit) • Zone structure can make it easier for riders to understand which trips are eligible for a discount (e.g., LAVTA)	• Directly substitutes for public transit use → Mitigate this by only serving trips that start or end outside range of existing fixed-route service (e.g., RTD)
Off-Peak Public partner discounts MOD trips during off-peak hours.	• Direct, on-demand trips at a lower cost to agency than low-ridership late-night transit service • Discourage drunk driving (e.g., Evesham Township, NJ) • Better serve night-shift workers (e.g., PSTA)	• Public transportation agencies often do not provide services at night, so the off-peak subsidies could represent an additional cost
Paratransit Public or private partner uses MOD technology to supplement or replace the public transportation agency's existing paratransit service.	• Provides on-demand paratransit trips rather than requiring riders to schedule trips a day or more in advance • Lower per-trip costs for public agency and passengers (e.g., MBTA)	• MOD companies may need time to add wheelchair accessible vehicles to fleet (e.g., MBTA) • MOD company drivers may have less training in assisting paratransit riders (e.g., RabbitTransit)

3.5. Findings: Partnership Trends

After categorizing the models, we analyzed existing MOD PPPs according to the typology to identify trends in the partnership models used. In the few cases where partnerships lacked service time restrictions, thereby providing Off-Peak service in addition to FMLM or Low-Density service (e.g., Dublin, CA), we classified them as FMLM or Low-Density, respectively, because the decision to provide all-day service was for convenience rather than to explicitly fill off-peak gaps. The expert interviews provide possible explanations for the observed trends, while the trends provide context for how each MOD PPP model's benefits and disadvantages might impact the start and end of partnerships. Table 3.6 shows the number of public transit agency MOD PPPs in the U.S. that employ the various models, with city and transportation authority MOD PPPs listed as footnotes. The pilots are organized by the year operations began.

Table 3.6. Number of Public Transit Agency MOD PPPs in the U.S.

	Agency-Operated MOD	**Agency-Subsidized Private MOD**			
		Microtransit Vans	**Taxi**	**TNC (Personal Vehicles)**	**Total:**
FMLM		**2**	**1**	**11**[a]	14
2016			Tampa*	St. Petersburg (FL), Philadelphia*, Sacramento*	
2017				Dayton, San Joaquin (CA), Phoenix*	
2018		Seattle		Charlotte, Tacoma, Austin, Las Vegas	
2019		Seattle		Los Angeles	
Low-Density	**13**[b]	**0**[c]		**6**[d]	19
2015	Eden Prairie (MN)				
2016	San Jose*, Kansas City*, Alameda County (CA)			Dallas*, Lewisville (TX)	
2017	Austin*, Dallas			Dublin (CA), San Joaquin (CA)	
2018	Sacramento, Durham, Contra Costa (CA)*, San Joaquin (CA), Orange County			Eden Prairie (MN)*	
2019	Kansas City, Pacifica (CA)			Dallas	
Off-Peak				**4**[e]	4
2016				St. Petersburg (FL)	
2017				*Santa Monica*	
2018				Tacoma, *Detroit*	
Paratransit		**1**	**2**	**8**[f]	11
2016				Boston	
2017		San Joaquin (CA)	NYC, Kansas City	York County (PA), Richmond (VA), Dallas	
2018				Las Vegas, San Bernardino (CA),	

				Santa Monica, St. Petersburg (FL)	
Total:	13	3	3	29	**48**

Note: The italicized Off-Peak partnerships employ FMLM restrictions, as opposed to point-to-point service. Please note that this table excludes PPPs with transportation authorities and cities, focusing on public transportation agencies only.
* MOD PPP has ended.
[a] Also includes four MOD partnerships with cities and two with transportation authorities: 1) Centennial, CO (2016*); 2) Summit, NJ (2016); 3) San Clemente, CA (2016); 4) Mercer Island, WA (2018*); 5) Solano Transportation Authority, CA (2017); and 6) Transportation Authority of Marin, CA (2017).
[b] Includes Lone Tree, CO (2017* and 2019).
[c] Includes: 1) Arlington, TX (2017) and 2) West Sacramento, CA (2018).
[d] Also includes: 1) Altamonte Springs, Lake Mary, Longwood, Maitland, and Sanford in Florida (2016*) and 2) Monrovia, CA (2018).
[e] Also includes Evesham Township, NJ (2015).
[f] Also includes: 1) Gainesville, FL (2015) and 2) Dakota County, MN (2019).

Figures 3.3 and 3.4 below show the frequency distribution of all new and ongoing MOD PPPs from 2015 to 2019 according to asset contribution model and service model, respectively. Trends are discussed through 2018, as the 2019 partnerships were counted through April, so there is not a full year of data to convey the continuation of trends. The results highlight seven key trends:

1) Agency-Operated MOD partnerships only provide Low-Density service. Public agencies implementing Agency-Operated MOD may have less need to restrict service to FMLM trips, as they have more data access and control over the service to ensure the MOD service does not compete with existing fixed-route services. However, some public agencies with Agency-Operated MOD services have considered restricting service to FMLM trips to reduce competition with fixed-route services. At off-peak, demand may be too low to support the microtransit vans used for Agency-Operated MOD. Finally, all Agency-Operated MOD services employ wheelchair accessible vehicles, thereby serving paratransit passengers as well as the general public.

2) Agency-Subsidized Private TNCs are the most common asset contribution model, followed by Agency-Operated MOD. TNCs are more ubiquitous than MOD software, MOD microtransit, or MOD taxi companies. Not surprisingly, subsidizing TNC rides requires less planning and resources than directly operating a MOD service. This model is especially attractive for smaller agencies that already contract for driver services, as the agency can shift some of the contracted services to TNCs. Meanwhile, Agency-Operated MOD has been the typical choice for agencies that want access to all trip-related data and have the resources to provide vehicles and drivers for a MOD service.

3) Between 2015 and 2018, Agency-Operated MOD and Agency-Subsidized Private Microtransit appear to be increasing, while the number of new partnerships in the other two categories have remained fairly constant. The expert interviews suggest that this trend is due to concerns about the difficulty of securing data from TNCs, the potential for greater vehicle occupancy and VMT reduction from the use of microtransit vans, and the sense that these models compete less with fixed-route services. MOD companies that operate microtransit vans and offer

MOD software for public agency use are also gaining experience in adapting their services to fit public agency needs, increasing partnership opportunities.

4) MOD Asset Contribution Model Terminations: Eight of 38 Agency-Subsidized Private TNC partnerships, 5 of 13 Agency-Operated MOD partnerships, and 1 of 3 Agency-Subsidized Private Taxi partnerships have been terminated. The agency-subsidized MOD taxi service ended due to excessive costs. Agency-Operated MOD services ended due to:

- Overly-restricted service areas that led to insufficient ridership (2 pilots),
- Unadaptable ride-matching and routing algorithm (2 pilots), and
- Concerns about competition with fixed-route services (1 pilot).

The latter two pilots were replaced, respectively, with 1) another Agency-Operated MOD service with an improved routing algorithm and 2) an Agency-Subsidized TNC pilot for FMLM service.

Reasons for terminating the Agency-Subsidized TNC pilots included:

- Concerns about competition with fixed-route services (1 FMLM pilot and 2 Low-Density pilots);
- Overall difficulty working with TNCs, including cost, labor union concerns, lack of data access, and difficulty of providing an equitable paratransit alternative (2 FMLM pilots and 1 Low-Density pilot);
- Decision to evaluate other options before potentially scaling up the service (2 Low-Density pilots).

Two agencies replaced Agency-Subsidized TNC pilots with Agency-Operated MOD services. One of these subsequently re-introduced an Agency-Subsidized TNC service in the same zones as its Agency-Operated MOD service but restricted the discount to ridesplitting trips only.

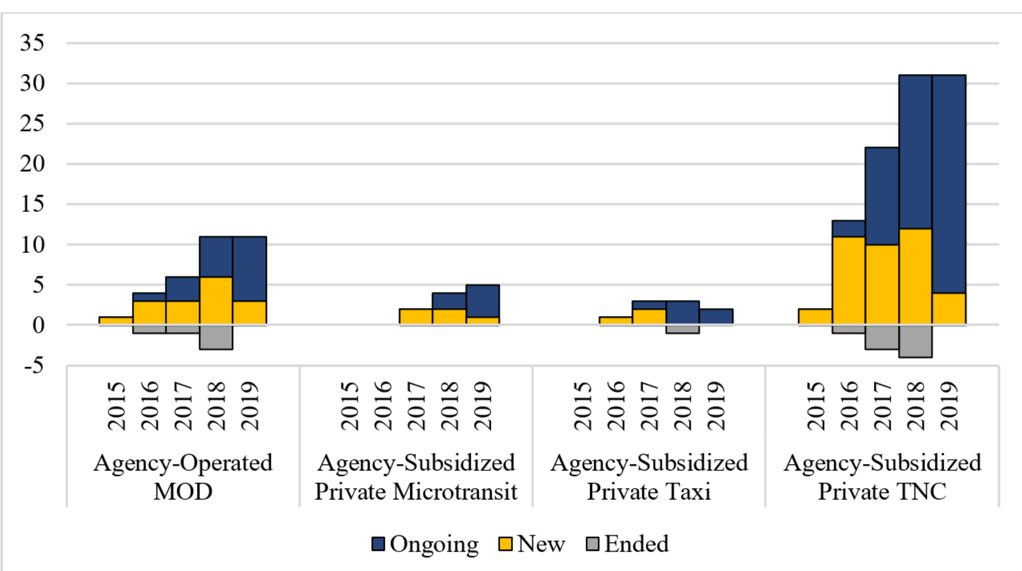


Figure 3.3. Number of new and ongoing asset contribution models from 2015 to April 2019.

5) The most common service model is Low-Density, closely followed by FMLM. Low-Density is also the easiest model to implement, as it involves a general zone-based structure for subsidized ride eligibility, while FMLM is a popular choice because it increases the chance that riders will use the subsidized service to access public transit.

6) The number of new MOD PPPs for FMLM and Off-Peak service has been relatively steady since 2016, while new MOD PPPs for Paratransit service peaked in 2017, and new MOD PPPs for Low-Density service seem to be increasing.

7) MOD Service Model Terminations: Categorizing the terminated pilots by service model shows that 6 of 21 FMLM pilots and 8 of 25 Low-Density pilots have ended, compared to none of the Off-Peak or Paratransit pilots. The relative longevity of MOD Paratransit pilots is likely due in part to the greater cost savings and service improvements these partnerships typically provide (e.g., MBTA).

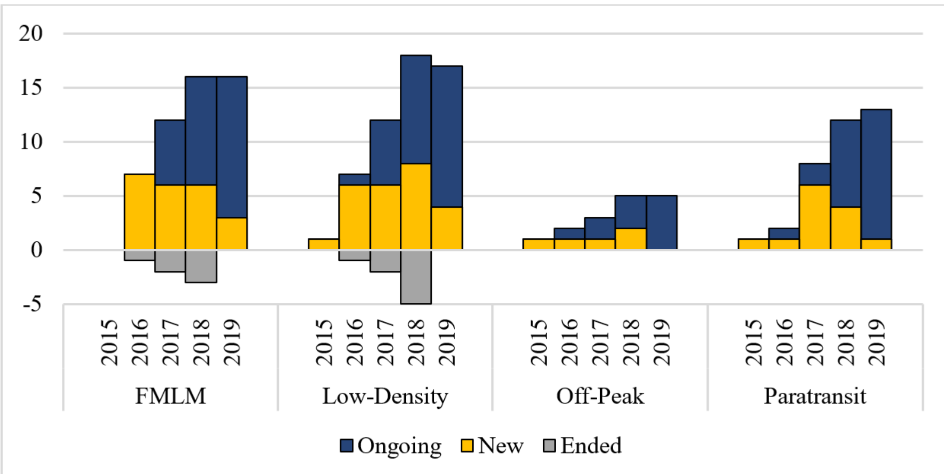


Figure 3.4. Number of new and ongoing service models from 2015 to 2019.

3.6. Implications

Partnerships with MOD companies present public transit agencies with opportunities to improve the efficiency and quality of service, particularly for elderly, disabled, low-income, and rural populations. At the same time, such partnerships can compete with existing public transit service when not implemented carefully. We analyzed 62 existing MOD PPPs in the U.S. and conducted 34 interviews with public and private partners. This work informed the identification of a typology of MOD PPPs, benefits and disadvantages of each partnership model, and comparative trends in the occurrence of each model.

Our analysis suggests several considerations for choosing service models and asset contribution models for a MOD PPP. Key recommendations focus on protecting fixed-route public transit and meeting equity and environmental goals. The recommendations are neither universal nor backed by empirical support, but are instead based on evidence from the interviews and review of publicly available documentation on existing MOD PPPs. Agencies that have adopted or considered the strategies are cited.

When choosing a service model, agencies should consider that, while Off-Peak and Paratransit MOD PPPs do not compete with fixed-route services, FMLM and Low-Density models may require strategies to support rather than undermine existing public transportation. Although the FMLM model encourages transfers to fixed-route services by requiring trips to start/end at public transit stops, some agencies take additional measures to reduce the likelihood of passengers using the MOD service to access locations near the public transit stop rather than transferring. These strategies include: a) setting required start/end stops on high-performance routes in places without major trip attractors (e.g., PSTA) and b) creating catchment zones that divide trip generators and attractors and assigning one or two designated transfer stops to each zone (e.g., HART, PSTA). One way to protect fixed-route services under the Low-Density model is to restrict service to areas outside the geofenced fixed-route service area (e.g., RTD). Less aggressive measures include: a) using microtransit vans to allow greater vehicle occupancy (e.g., 15 partnerships); b) subsidizing only ridesplitting or pooled trips (e.g., DART, LAVTA); and c) offering higher subsidies for shared rides (e.g., MBTA), large groups (e.g., SacRT), and transfers to/from fixed-route services (e.g., DART, GoTriangle). Offering higher subsidies for disadvantaged populations also helps meet equity goals (e.g., DART, KCATA, LA Metro, RTD, SacRT). For both FMLM and Low-Density partnerships, our interviewees identified the ideal use cases as locations dense enough to support shared rides but with disparate origins and destinations that are difficult to serve with fixed-route public transit.

Regarding the selection of asset contribution models, our analysis suggests that, if agencies have sufficient resources, the Agency-Operated model generally allows greater data access and control over the service than Agency-Subsidized Private MOD. In some cases, the public agency has sufficient resources for Agency-Operated MOD but too few microtransit vans to meet peak demand. A few public agencies have started to address this problem by employing a mix of asset contribution models to meet peak demand, while preserving as much data access and control over the MOD service as possible (e.g., SW Transit). These agencies employ Agency-Operated MOD to provide a majority of the service and supplement with Agency-Subsidized Private MOD for “overflow” service in peak periods. The challenge raised by this strategy is that private MOD operators typically also have long wait times in peak periods. In other cases, agency resources and/or demand for the service are simply insufficient to enable Agency-Operated MOD. The expert interviews suggest that better data sharing strategies, including laws that protect an individual’s location data from public information requests, could help public agencies to ensure Agency-Subsidized Private MOD supports equity and environmental goals. Other strategies to increase the public agency’s data access under Agency-Subsidized Private MOD include: a) centrally dispatching trips (e.g., RabbitTransit) and b) enabling passengers to pay for the MOD service using funds from their public transit accounts (e.g., DART). These approaches allow the public agency to track when and where trips occur and, in the second strategy, whether passengers transfer to fixed-route public transit service.

Other takeaways from the expert interviews relate to identifying gaps or inefficiencies in public transit service, determining goals and data needs, contracting with MOD companies, and marketing. Potential opportunities for MOD PPPs to fill gaps in public transit service include: low-ridership bus routes; dial-a-ride/paratransit services with high costs per passenger; dispersed employment centers; public transit stations with high parking demand; late-night transportation for workers; non-emergency medical transportation; and temporary needs, such as events or construction. With respect to goals and data needs, MOD performance metrics are most similar to those for dial-a-ride service (e.g., average wait time between request and pick-up). In terms of cost per passenger and passengers per hour, most MOD PPPs perform better than traditional dial-a-ride or paratransit services but worse than fixed-route services (e.g., OCTA, SW Transit). Agencies can also facilitate user surveys by requiring potential passengers to register with the agency before receiving a discount code (e.g., DART). When developing a contract with selected partner(s), agencies should consider ensuring the contract allows adjusting service easily, such as expanding service areas or restricting subsidy eligibility (e.g., VTA). Several agencies also noted the importance of considering ease of marketability when designing service, including how eligible trips are defined (e.g., LAVTA) and selecting service zones with well-known boundaries (e.g., GoTriangle).

The trends analysis combined with the identified benefits and disadvantages suggests that, as MOD PPPs become more sophisticated, the common asset contribution models will likely continue to shift toward Agency-Operated MOD and Agency-Subsidized Private Microtransit because these models enable higher vehicle occupancy and potentially lower VMT. Among service models, FMLM will likely become more common as MOD companies become better able to restrict subsidized trips to those that start and end at public transit stops. Paratransit MOD PPPs will also likely become more popular due to the large potential cost savings, decrease in wait times, and lack of competition with fixed-route services. Low-density MOD PPPs will likely continue to replace general public dial-a-ride service for the same reasons.

Opportunities for future research include empirically analyzing the benefits, disadvantages, and recommendations that we identified qualitatively. Future efforts could also involve matching each service model to an ideal density range, as well as further analyzing MOD PPPs' equity and VMT impacts. Examining induced demand for MOD PPP service is crucial to this work, as providing service with shorter wait times and more direct trips will draw new riders, potentially increasing VMT and agency costs. Agent-based and activity-based modeling could suggest the most appropriate policy combinations for MOD PPPs to achieve a range of societal goals, including equitable travel/wait times and costs for low-income, minority, and rural populations. Similar techniques could highlight a phased policy approach for public transportation agencies to prepare for the next generation of MOD PPPs as automated vehicle (AV) technology and shared AV fleets are deployed.

3.7. Funding

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. DGE 1752814 and by the Federal Highway Administration under Grant No. DTFH693JJ31845030. This research also received support from the Department of City and Regional Planning at UC Berkeley and the Transportation Sustainability Research Center at UC Berkeley. Any opinions, findings, and conclusions or

recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the organizations named here.

3.8. Acknowledgments

This research was made possible through the generosity of the interviewed experts with their time and knowledge. We would also like to thank Nicholas Atchison for fact-checking details about the MOD PPPs and Jessica Lazarus for her help with the map of partnerships. We are grateful to the U.S. Federal Highway Administration Dwight D. Eisenhower Transportation Fellowship Program, the National Science Foundation Graduate Research Fellowships Program, the Department of City and Regional Planning at UC Berkeley, and the Transportation Sustainability Research Center for their financial support and the freedom to pursue this research topic.

3.9. References

APTA. 2014. "Transit Ridership Report: Second Quarter 2014." American Public Transportation Association. August 27, 2014. https://www.apta.com/resources/statistics/Documents/Ridership/2014-q2-ridership-APTA.pdf.

———. 2018. "Transit Ridership Report: Second Quarter 2018." American Public Transportation Association. August 24, 2018. https://www.apta.com/resources/statistics/Documents/Ridership/2018-q2-ridership-APTA.pdf.

Blodgett, Moira, Alireza Khani, Diana Negoescu, and Saif Benjaafar. 2017. "Public/Private Partnerships in Transit: Case Studies and Analysis." Report. Minnesota Council on Transportation Access. http://conservancy.umn.edu/handle/11299/192846.

Clewlow, Regina R., and Gouri Shankar Mishra. 2017. "Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States," October. https://trid.trb.org/view.aspx?id=1485471.

Curtis, Terra, Meg Merritt, Carmen Chen, David Perlmutter, Dan Berez, and Buffy Ellis. 2019. "Partnerships Between Transit Agencies and Transportation Network Companies." The National Academies of Sciences. https://www.nap.edu/download/25425.

Dallas Area Rapid Transit. 2019. "GoLink." 2019. https://www.dart.org/riding/golink.asp.

FTA. 2016a. "Mobility on Demand (MOD) Sandbox Program." Text. FTA. April 20, 2016. https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program.html.

———. 2016b. "Shared Mobility Definitions." Text. Federal Transit Administration. December 7, 2016. https://www.transit.dot.gov/regulations-and-guidance/shared-mobility-definitions.

Hampshire, Robert, Chris Simek, Tayo Fabusuyi, Xuan Di, and Xi Chen. 2017. "Measuring the Impact of an Unanticipated Suspension of Ride-Sourcing in Austin, Texas." SSRN Scholarly Paper ID 2977969. Rochester, NY: Social Science Research Network. https://papers.ssrn.com/abstract=2977969.

Henao, Alejandro. 2017. "Impacts of Ridesourcing - Lyft and Uber - on Transportation Including VMT, Mode Replacement, Parking, and Travel Behavior." Ph.D., United States --

Colorado: University of Colorado at Denver. https://search.proquest.com/docview/1899208739/abstract/EA20C52AE86438APQ/1.

Kuhr, James, Chandra R. Bhat, Jennifer Duthie, and Natalia Ruiz. 2017. "Ridesharing & Public-Private Partnerships: Current Issues, A Proposed Framework and Benefits." In . https://trid.trb.org/view/1438928.

Lazarus, Jessica, Susan Shaheen, Stanley E. Young, Daniel Fagnant, Tom Voege, Will Baumgardner, James Fishelson, and J. Sam Lott. 2018. "Shared Automated Mobility and Public Transport." In *Road Vehicle Automation 4*, 141–61. Lecture Notes in Mobility. Springer, Cham. https://doi.org/10.1007/978-3-319-60934-8_13.

Murphy, Colin, and Sharon Feigon. 2016. "Shared Mobility and the Transformation of Public Transit." American Public Transportation Association. http://www.apta.com/resources/hottopics/Pages/Shared-Use-Mobility.aspx.

Office, U. S. Government Accountability. 2018. "Public Transit Partnerships: Additional Information Needed to Clarify Data Reporting and Share Best Practices," no. GAO-18-539 (July). https://www.gao.gov/products/GAO-18-539.

Rayle, Lisa, Danielle Dai, Nelson Chan, Robert Cervero, and Susan Shaheen. 2016. "Just a Better Taxi? A Survey-Based Comparison of Taxis, Transit, and Ridesourcing Services in San Francisco." *Transport Policy* 45 (Supplement C): 168–78. https://doi.org/10.1016/j.tranpol.2015.10.004.

Schaller, Bruce. 2018. "The New Automobility: Lyft, Uber and the Future of American Cities," July. https://trid.trb.org/view/1527868.

Schwieterman, Joseph P., Mallory Livingston, and Stijn Van Der Slot. 2018. "Partners in Transit: A Review of Partnerships Between Transportation Network Companies and Public Agencies in the United States," August. https://trid.trb.org/view/1582297.

Shaheen, Susan, and Nelson Chan. 2016. "Mobility and the Sharing Economy: Potential to Facilitate the First- and Last-Mile Public Transit Connections." *Built Environment* 42 (4): 573–88. https://doi.org/10.2148/benv.42.4.573.

Shaheen, Susan, and Adam Cohen. 2019. "Mobility on Demand (MOD) and Mobility as a Service (MaaS) How Are They Similar and Different?" Medium. May 23, 2019. https://medium.com/move-forward-blog/mobility-on-demand-mod-and-mobility-as-a-service-maas-how-are-they-similar-and-different-a853c853b0b8.

Shaheen, Susan, Adam Cohen, Balaji Yelchuru, and Sara Sarkhili. 2017. "Mobility on Demand Operational Concept Report." FHWA-JPO-18-611. Federal Highway Administration. https://rosap.ntl.bts.gov/view/dot/34258.

TRB. 2001. *Making Transit Work: Insight from Western Europe, Canada, and the United States -- Special Report 257*. https://doi.org/10.17226/10110.

Tsay, Shin-pei, Zak Accuardi, Bruce Schaller, and Kirk Hovenkotter. 2016. "Private Mobility, Public Interest." TransitCenter. http://transitcenter.org/publications/private-mobility-public-interest/.

Westervelt, Marla, Emma Huang, Joshua Schank, Nolan Borgman, Tamar Fuhrer, Colin Peppard, and Rani Narula-Woods. 2018. "UpRouted: Exploring Microtransit in the United States," January. https://trid.trb.org/view/1497526.

Westervelt, Marla, Joshua Schank, and Emma Huang. 2017. "Partnerships with Technology-Enabled Mobility Companies." *Transportation Research Record: Journal of the Transportation Research Board* 2649 (January): 106–12. https://doi.org/10.3141/2649-12.

Chapter 4. Demographic trends in public microtransit use and perceptions: Equity and environmental implications before and during the Covid-19 pandemic

Emma Lucken

Susan A. Shaheen

Joan L. Walker

This chapter addresses the second research objective of the dissertation: to understand who uses and benefits from public microtransit services, how this shifted in the Covid-19 pandemic, and what modes public microtransit riders used before.

As lead author, I surveyed public microtransit riders and non-riders at 14 public transportation agencies across the U.S. and analyzed the results for demographic variation in frequency of public microtransit use, induced trips, replaced modes, and satisfaction with the service. I wrote the original draft and revised it based on feedback from Professor Shaheen and Professor Walker.

ABSTRACT

On-demand, app-based transportation options are now familiar throughout the United States (U.S.), and public transportation agencies are nearing six years of piloting these modes using their own vehicles in an array of use cases. However, analysis of the demographics and preferences of public microtransit riders is still in its infancy, limited to case studies that focus on one to three agencies each. Identifying demographic trends that hold across multiple agencies in a variety of geographic contexts and system designs will suggest broadly applicable equity-related challenges and recommendations as agencies around the country continue designing or refining their own public microtransit services. In this chapter, we present results from our survey of 1519 public microtransit riders and 320 non-riders from 14 public transportation agencies across the U.S, analyzing how frequency of microtransit use, replaced modes, first-mile/last-mile (FMLM) connections, trip purpose, perceptions of the service, and change in use during the Covid-19 pandemic vary by demographic group, including income, age, race, gender, ability, access to a personal vehicle, smartphone ownership, and banked/unbanked status. Main findings include: 1) underserved groups report more induced trips (up to 26% for riders with disabilities that prevent driving, compared to 15% for riders without such disabilities), are more likely to switch from non-motorized/higher-occupancy fixed-route modes, are less likely to use the service for commutes or FMLM connections, and perceive more frequent delays past the estimated time of arrival (up to 40% of unbanked riders report delays on most or all trips, compared to 20% of riders with bank accounts); 2) although lower-income riders, those without access to a personal vehicle, and women reported the greatest satisfaction and quality of life improvements from public microtransit service, riders without smartphones and/or bank accounts report no statistically significant improvements in their quality of life; and 3) lower-income riders, those without access to a personal vehicle, and essential workers decreased their use of

fixed-route public transit during the pandemic but maintained their use of public microtransit. Our results suggest that public transportation agencies face tradeoffs between: a) improving transportation equity by offering public microtransit services that improve quality of life and increase vehicle miles traveled (VMT) among underserved groups, and b) reducing VMT by attracting more privileged groups away from their personal vehicles or ride-alone Uber/Lyft. The findings also highlight key areas for improvement in advancing transportation equity, primarily expanding access for those without smartphones or bank accounts and ensuring equitable wait times for underserved groups.

Keywords: public microtransit; transportation equity; induced demand; VMT implication; multi-agency passenger survey

4.1. Introduction

Prior to the Covid-19 pandemic, public transportation agencies faced increasing competition from app-based, on-demand transportation network companies (TNCs) like Uber and Lyft (Martin et al., 2021). Previous work has identified that, in response, public transportation agencies began piloting mobility on demand (MOD) services to fill first-mile/last-mile (FMLM) gaps, replace low-ridership bus routes, introduce new service in low-density areas or off-peak times, and improve paratransit service (Blodgett et al., 2017). While many early MOD services offered by public agencies actually involved outsourcing operations to TNCs, an analysis of 62 public MOD services in the U.S. indicated that public agencies are increasingly turning to van-based microtransit services to increase vehicle occupancy, limit VMT, and better control transportation equity impacts and potential competition with fixed-route services (Lucken, Trapenberg Frick, & Shaheen, 2019). In this chapter, we use the transportation equity definition from Bills and Walker (2017): “fair or just distribution of transportation costs and benefits, among current (and future) members of society,” with a focus on vertical equity (“the distribution of transportation impacts among sub-populations that differ in ability and needs”). We also mention transportation-disadvantaged populations, or those who are less able to access personal vehicles or private TNCs, including: people with low incomes, without smartphones, without bank/checking accounts, or with disabilities that prevent driving (Brown et al. 2021).

As Covid-19 conditions have continued to shift through widespread vaccine availability and the spread of more contagious variants, public transportation agencies have considered whether van-based microtransit services offer a way to retain existing riders, win back pre-pandemic riders, and attract new riders away from personal vehicles and ride-alone TNC options while reducing VMT and supporting fixed-route transit services (Schank and Huang, 2022). Although numerous studies have qualitatively examined partnerships between public transportation agencies and MOD companies to develop typologies and examine potential transportation equity impacts and policy options, quantitative analysis of the environmental and equity impacts of publicly funded, on-demand microtransit services is more recent, especially in the U.S. The microtransit pilots included in the Federal Transit Administration MOD Sandbox program represent one source of quantitative analysis (FTA, 2021). For one of these pilots, a FMLM microtransit service in Dallas, TX, survey data and trip data indicated that about 24% of microtransit trips replaced ride-alone modes, microtransit increased the area accessible by public transit from 44% to 82%, and the average subsidy per rider in the service area decreased from $33.71 on fixed-route bus to $16.37 on microtransit (Martin et al., 2021).

Apart from the MOD Sandbox, a survey of 130 Utah Transportation Authority (UTA) riders showed that among adults, those under 25 and those with households of four or more people were most willing to try microtransit while those between the ages of 25 and 44 were least willing to try microtransit (Macfarlane et al, 2021). Another study used eigendecomposition and k-clique percolation methods to analyze how the spatio-temporal patterns of UTA microtransit trips changed during the pandemic, finding that the use of microtransit as a FMLM connection declined from 58% to 29% of all microtransit trips (Zhou et al., 2021). Moreover, these FMLM trips retained the same hourly distribution associated with commutes, suggesting transit dependency for the remaining FMLM riders. Xing et. al. (2022) estimated a binary logit model on likelihood to use the public microtransit service in Sacramento, California, based on their survey of 997 people in the city, 79.5% of whom had used the service. They found that families with young children are more likely to use microtransit and those who like fixed-route transit are less likely to use it. Outside the U.S., Haglund et al. (2019) performed a detailed analysis of trip data from Kutsuplus, a public microtransit service in Helsinki, and found that users were mostly between 30-65 years old, while those 18-29 years old used the service for morning peak hour trips and those over 65 used it mostly within the downtown area. They found that the service had similar trip times as personal vehicles for short trips but may also replace 20-25% of riders' walking or bicycle trips.

Several studies focus on the pandemic's impact on willingness to use shared modes similar to public microtransit. These include an unpublished analysis of a survey of 700 U.S. residents in June 2020, which found that those with left-leaning political views and those living in areas in which stay-at-home orders were instituted earlier were less willing to use TNCs during the pandemic, while those who reported pro-environmentalism were more willing to use TNCs (Said, pending). This work also found that respondents perceived taking TNCs as a higher Covid-19 risk than riding public transit, while TNCs were in turn perceived as more risky than private modes. A separate, peer-reviewed analysis of interviews with 66 Madrid residents who used carsharing during the pandemic found that respondents valued carsharing as a way to travel without others in the vehicle, which does not apply to public microtransit, and also that their concerns about carsharing centered on sanitizing surfaces (del Mar Alonso-Almeida, 2022). An application of the Bayesian structural time series model to 20 years of Chicago daily transit ridership data showed that ridership declined 72.4%; areas with more white, high-income, and college-educated individuals experienced greater declines; and areas with more COVID-19 cases and deaths had smaller declines (Hu & Chen, 2021). Similarly, a study of Seattle paratransit trips in the pandemic found that riders with lower incomes and less access to personal vehicles had less of a reduction in paratransit trips compared to other riders (Wang et al., 2022).

A research gap—both pre-pandemic and during the pandemic—is multi-agency analysis of how public microtransit services across the U.S. have changed how their riders travel, including induced trips, replaced modes, FMLM connections, and differences in these measures among demographic groups. This paper addresses that gap through a survey of riders and non-riders of 14 public microtransit services, analyzing how frequency of public microtransit use, impact on other modes, reasons for using the service, perceptions of the service, and Covid-19 impacts differ by income, age, race, and access to a personal vehicle. We also focus on differences in responses among public microtransit riders without a smartphone, without bank accounts or credit cards (unbanked), and/or with disabilities that prevent driving, as previous research has identified these groups as facing particular challenges in using other largely app-based and on-demand modes such as Uber/Lyft (Chapters 2 and 3). An assessment of how replaced modes, levels of service, and satisfaction with the service differ by demographic group can help to inform understanding of the environmental and equity impacts of public microtransit services, as well as suggest strategies for public transportation agencies to support particular demographics (e.g., transit-dependent riders, paratransit riders, and unbanked individuals) when designing public microtransit services.

4.2. Methodology

In January 2021, we contacted three van-based microtransit companies to identify which of their U.S. public transportation agency partners may be interested in participating in the study and also represented a range of geographic locations, pilot area sizes, population and job densities, ridership levels, and service designs. Fourteen public agencies decided to participate, including three with corner-to-corner service (i.e., indirect trip pickup/drop off, as opposed to curb-to-curb), three that used their microtransit service to replace bus routes, three that have light rail or heavy rail connections available in the microtransit service area, and one that primarily served a commercial district and required FMLM connections to a commuter bus route. We distributed the survey to public microtransit riders through one or both of the following methods, depending on agencies' preferences: 1) the company partner or the agency itself emailed or texted the survey description and link to the list of registered riders, and 2) the agency advertised the survey link on its websites and social media and/or with paper flyers onboard the microtransit vehicles and in the service area. Non-riders who traveled in the service area were also targeted with the online advertising and paper flyers. The survey was available in both English and Spanish in a desktop or mobile format. Surveys were collected from April through December 2021. We encouraged participation with a drawing incentive.

The survey included questions on what modes respondents used in the last two years, how frequently they used those modes before and during the Covid-19 pandemic (prior to vaccine availability), how they would have made their most recent public microtransit trip, whether and by how much they increased/decreased their use of other modes as a result of the public microtransit service, and how frequently they used public microtransit to connect with fixed-route bus and/or rail (where available). We also asked respondents for their perceptions of the public microtransit service, their reasons for using it over other modes, and their experience of delay while using the service. For all survey questions in this paper except the section focused on Covid-19 impacts, we asked about pre-pandemic use. Respondents who only started using public microtransit during the pandemic were excluded from this analysis (except where noted).

After cleaning the data by removing duplicate responses, we identified demographic categories of interest. For age, we used 60 years as a cutoff for one category, as many public transportation agencies use this threshold to define eligibility for paratransit service (CATA; Rice Lake County, IL; Paying for Senior Care 2020). Riders aged 21 and under formed another category due to sharing characteristics such as likelihood to still be in school (there were insufficient responses from riders aged 16 and under (N=11) or 18 and under (N=32) to analyze these age groups separately). We chose income thresholds of $15k and $50k based on the sample size and similar responses among those with household incomes under, between, and over these values. We also examined access to a personal vehicle (always, sometimes, or never) as a measure of transit dependency. For race, we did not receive sufficient responses from Native Hawaiian and Pacific Islander (N=22), Middle Eastern and North African respondents (N=19), or Sub-Saharan African respondents (N=8) to provide adequate analysis of trends in these groups. We also combined East Asian (N=35) and Southeast Asian (N=40) respondents to provide a sufficient group size for analysis, after confirming that these groups showed similar trends. We received 13 responses from individuals with a gender other than female or male, which was also insufficient to identify trends. We identified four groups representing frequency of public microtransit use: those who had never used the service (N=320), those who used it less than once per week (low-frequency, N=486), those who used it 1-6 times per week (mid-frequency, N=579), and those who used it daily or more (high-frequency, N=146).

To compare demographics of survey respondents to those of the public microtransit service areas, we used QGIS to create shapefiles of the 14 public microtransit service areas based on maps provided on the transit agency websites. We intersected these shapefiles with census tract shapefiles and used American Community Survey 2021 census tract estimates to calculate population, race, income, age, gender, and commute mode share for the service areas, weighting border census tracts by the proportion of the census tract inside the service area (U.S. Census Bureau 2022). We also compared results with U.S. demographics. We used Pew Research Center 2021 data to compare smartphone ownership by household income and age in the U.S. with that in our survey sample (Pew Research Center 2021). As shown in Table 4.2 in Appendix A, the service areas are more white than the U.S. (82.5% vs. 74.5%), but our survey sample is much less white than both (55.1%). Similarly, the service areas are higher income than the U.S. (27.9% vs. 36.5% with household incomes under $50k, 20.4% vs. 17.7% over $150k) and our survey sample is much lower income than both (60.9% under $50k, 2.9% over $150k). Only 3.8% of households in the service areas own no vehicles, compared to 8.3% of households in the U.S. and 31.7% in our survey sample. Conversely, a greater proportion of our survey sample owns a smartphone compared to the U.S. population (94% vs. 85%), a trend that holds true across income groups and age categories except for respondents 18 to 29 years old, who have lower rates of smartphone ownership than their age category in the U.S. population (88% vs. 96%). A greater proportion of our sample is between 20 and 54 years old compared to the service areas or the U.S. (76.7% vs. 46.3% and 45.8%, respectively), a smaller proportion is age 55 or over (19.5% vs. 25.5% and 29%), and a much smaller proportion is under age 20 (0.3% vs. 28.3% and 25.2%). The microtransit service areas have a lower pre-pandemic public transport mode share for commutes (1.5%) than the U.S. population (5.0%). While the survey looked at overall mode share rather than commute mode share, the numbers nonetheless suggest the survey sample is heavily skewed toward public transportation users (as expected from an enriched sample of public microtransit riders): we calculated a pre-pandemic public transport mode share of 25.6% among respondents who have never used public microtransit and 39.5% among respondents who have tried public microtransit at least once. For additional insight into the demographics of survey respondents, Figure 4.12 in Appendix B shows cross-tabulations between select individual characteristics.

For each survey question, we performed t-tests on differences in the average response for each group. We present the results with significance levels of $p<0.10$, $p<0.05$, and $p<0.01$, with some insignificant results left in for comparison. We note any instances in which results are left out for insufficient sample size rather than for insignificant differences (not all respondents answered each question, which sometimes left insufficient responses from those without smartphones or bank accounts).

To compare means for questions with frequency values, such as how much respondents decreased or increased their use of other modes as a result of the public microtransit service, we assigned a value to each frequency category to create a "trips per month" metric (less than once per month = 0.5; about once per month = 1.0; 1-3 trips per week = 8.0; 4-6 trips per week = 12.0; Daily = 30; More than daily = 45). We performed a sensitivity analysis on these value assignments to see if changing the values, especially the "more than daily" and "less than once per month" values, affected the results, and the directionality of the significant differences between groups remained the same. To calculate mode shares, we summed the frequency values across modes for each respondent and divided each mode by the total. This approach, with minor modifications, is described in more detail in Martin et al. (2021).

4.3. Results

The results section presents demographic differences in three areas: 1) how respondents use the public microtransit service and how the service has impacted their use of other modes, 2) perceptions of public microtransit service, and 3) Covid-19 impacts on respondents' use and perceptions of public microtransit service.

4.3.1. Use of the Public Microtransit Service

In this section, we discuss: a) demographics of public microtransit passengers, b) replaced modes for most recent public microtransit trip, c) net change in use of other modes, d) frequency of FMLM connections to fixed-route bus and rail, e) trip purpose, and f) reasons for replaced modes.

4.3.1a. Demographics of public microtransit passengers

Finding 1: As expected from the literature, public microtransit passengers are disproportionately lower-income, lack full access to a personal vehicle, and use fixed-route transit modes and Uber/Lyft at a greater rate than respondents who had never used public microtransit.

As shown in Figure 4.1, the survey results indicated that frequent microtransit riders are more likely to belong to a number of less privileged demographic groups. They are more likely to have household incomes under $50k and less likely to have access to a personal vehicle. Compared to those who have never used public microtransit, microtransit riders are more likely to be Black or South Asian. Among those who have used public microtransit, riders with disabilities that prevent them from driving are more likely to use microtransit at least weekly (51.8% vs. 43.0%), while women are more likely than men to use it 1-6 times per week (38.6% vs. 32.3%, at a level of significance of $p<0.05$; not presented in the figure).

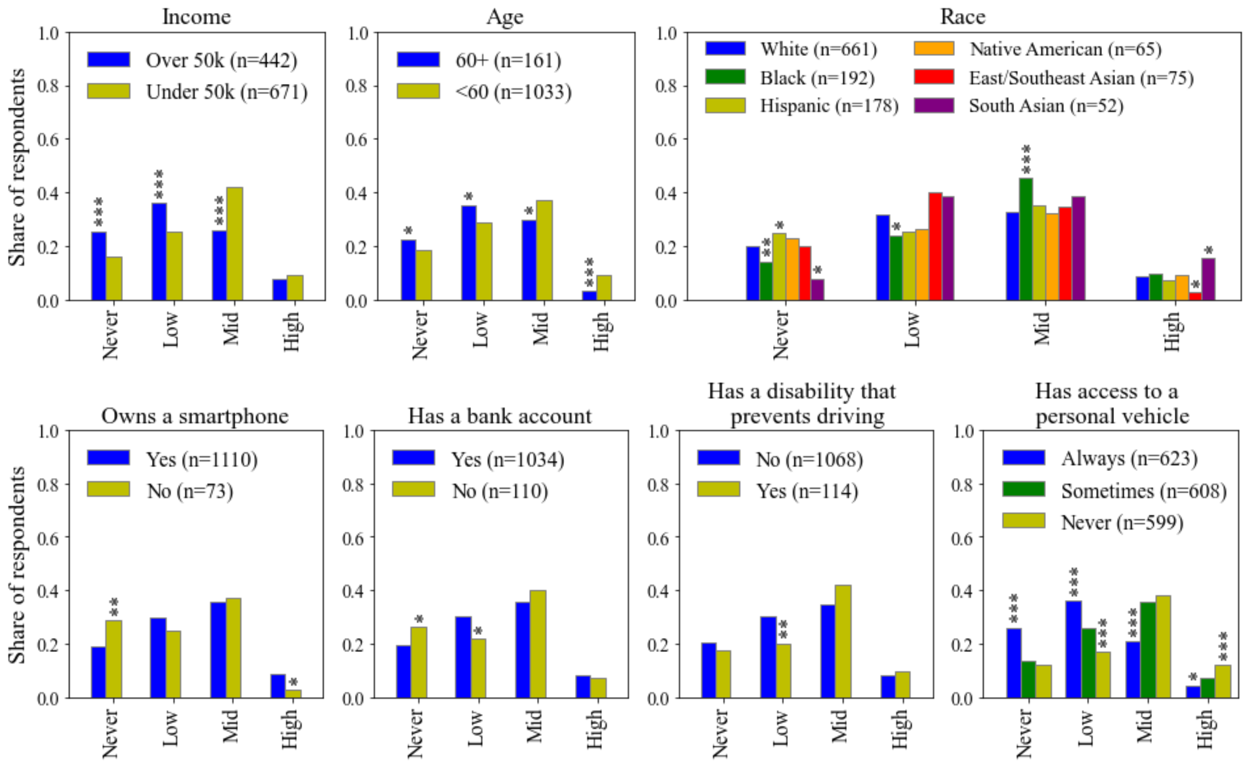


Figure 4.1. Frequency of public microtransit use by demographic group: Never (n=320, 17.4%); Low (less than once per week, n=486, 26.4%); Mid (1-6 times per week, n=579, 31.5%); High (daily or more, n=146, 7.9%). $p < 0.01$ *(***);* $p < 0.05$ *(**); $p<0.10$ (*). For race, calculated significant difference from white. For vehicle access, calculated significant difference from "sometimes."*

Although respondents over age 60 used public microtransit less frequently than younger respondents, they reported fewer trips overall so there was no statistically significant difference in microtransit mode share by age. All other demographic differences in frequency of public microtransit use were echoed by differences in microtransit mode share.

Table 4.1 shows that among non-microtransit trips, respondents who used public microtransit at least once per week had lower shares of drive-alone trips and higher shares of fixed-route bus and ride-alone Uber/Lyft trips than respondents who used the service less than once per week. Respondents who never used public microtransit, meanwhile, had higher shares of fixed-route rail and bike trips. There was no statistically significant difference in the share of non-microtransit trips made by carpool, walk, or paratransit, or by the following low-use modes not shown in the table: bikesharing (average mode share of 1.4%), taxi (1.4%), personal motorcycle/electric scooter (0.9%), pooled Uber/Lyft (0.7%), or carsharing (0.3%).

Table 4.1. Pre-pandemic mode share of non-microtransit trips by frequency of public microtransit use. [a]

	Never (N=320)	Less than once per week (N=486)	1-6 times per week (N=579)	Daily or more (N=146)
Drive alone	28.1	30.8	***<u>14.7</u>****	***<u>13.1</u>****
Carpool	19.2	20.4	20.6	18.2
Fixed-route bus	12.9	16.1	***<u>21.1</u>****	***<u>26.3</u>***†
Walk	12.3	13.2	14.2	14.4
Fixed-route rail	10.6	***<u>5.5</u>***	**8.0**	**6.6**
Ride-alone Uber/Lyft	2.9	4.3	***<u>8.1</u>****	***<u>8.4</u>****
Personal bike	6.7	***3.7***	***3.9***	**3.2**
Paratransit	2.4	2.9	3.7	4.2

[a] Significantly different from "Never": p<0.10 in bold, p<0.05 in bold and italics, p<0.01 in bold, italics, and underlined.
* Significantly different from "Less than once per week" at a level of p<0.01.
† Significantly different from "1-6 times per week" at a level of p<0.10.

4.3.1b. Replaced modes and induced trips

Replaced modes and induced trips have important implications for the environmental impacts of public microtransit. Any induced trips indicate increased VMT, while public microtransit trips that replace trips on nonmotorized or higher occupancy modes such as walk, fixed-route bus, or fixed-route rail also suggest an increase in VMT. Meanwhile, public microtransit trips that replace trips on modes with lower maximum occupancy, such as drive alone or ride-alone Uber/Lyft, indicate a potential reduction in VMT. The deadheading and rerouting to pick up public microtransit passengers, however, means that public microtransit does not necessarily have lower VMT than drive alone or ride-alone Uber/Lyft. Some replaced modes, like carpool, for example, also have a less clear VMT impact, as the impact depends on whether the carpool trip would have taken place regardless of whether the person of interest (the public microtransit rider) was in the vehicle, as may be the case in commute or recreational trips, or if it would not have taken place—for instance, if the trip occurred to chauffeur the person of interest, as may happen with family members or friends who cannot drive due to age or disability. In the former case, the microtransit trip that replaces a carpool trip may increase VMT, while in the latter, it may have a neutral or negative impact. The occupancy level of the carpool would also affect the VMT impact, as public microtransit uses larger vehicles than most carpools and thus has the potential for greater occupancy. Paratransit trips, meanwhile, may use similar size vehicles and may have comparable occupancy as public microtransit. In this case, the VMT impact of public microtransit may depend on whether its app-based routing and scheduling yields more efficient ordering of passenger requests than in traditional call-based paratransit.

Beyond VMT impacts, however, replaced modes and induced trips also have transportation equity implications. Induced trips, especially among transit-dependent groups, may indicate that public microtransit is meeting an unmet demand. Replacing trips on non-motorized or higher-occupancy modes, though increasing VMT, may also improve travel times for transit-dependent groups, thereby increasing transportation equity.

Based on how survey respondents would have made their most recent public microtransit trip if the service did not exist, the largest share of public microtransit trips is induced (17.0%), meaning it would not have been made at all. Of the remaining trips, two of the highest replaced modes indicate a potential VMT reduction from public microtransit (drive alone at 16.1% and ride-alone Uber/Lyft at 14.1%), while other replaced modes indicate that the availability of public microtransit led to an increase in VMT (fixed-route bus at 15.5% and walk at 9.2%). The 14.6% of trips that would have been made by carpool are more ambiguous in their VMT impact. Replaced modes representing less than 3% of trips are not shown, including bike (2.5%), taxi (1.4%), pooled Uber/Lyft (0.7%), bikesharing/ shared electric scooters (0.6%), carsharing (0.2%), and personal motorcycle/electric scooter (0.2%). Figure 4.2 shows share of induced trips by demographic group, as well as the replaced modes with statistically significant differences in each demographic category. The modes are arranged in approximate VMT impact, from an increase in VMT on the left to a potential reduction in VMT on the right.

Finding 2: Induced trips are more common among transportation-disadvantaged groups. In general, greater shares of transportation-disadvantaged respondents also report switching away from non-motorized/higher-occupancy modes like walking and fixed-route bus, while a greater share of more privileged groups report switching away from lower-occupancy modes like drive alone and ride-alone Uber/Lyft.

Figure 4.2 indicates that induced trips are higher for riders with lower household incomes, less than 22 years of age, disabilities that prevent driving, no bank account, and/or no access to a personal vehicle, suggesting that the public microtransit service filled a greater unmet demand for travel among these groups. In many cases, these groups were also more likely to switch from higher-occupancy modes like fixed-route bus and less likely to switch from lower-occupancy modes like drive alone or ride-alone Uber/Lyft. More respondents without access to a personal vehicle report switching from fixed-route bus, rail, or walking, and fewer report switching from drive alone compared to those with access to a vehicle. They are also more likely to switch from ride-alone Uber/Lyft and less likely to switch from carpool, but their overall share of nonmotorized/higher-occupancy replaced modes is greater than the equivalent for riders with personal vehicle access, and vice versa for lower-occupancy replaced modes.

Similarly, lower-income respondents are more likely to switch from fixed-route bus and less likely to switch from drive alone or carpool. Those without a bank account are less likely to switch from ride-alone Uber/Lyft or carpool, and women are less likely than men to switch from drive alone and more likely to switch from rail or ride-alone Uber/Lyft.

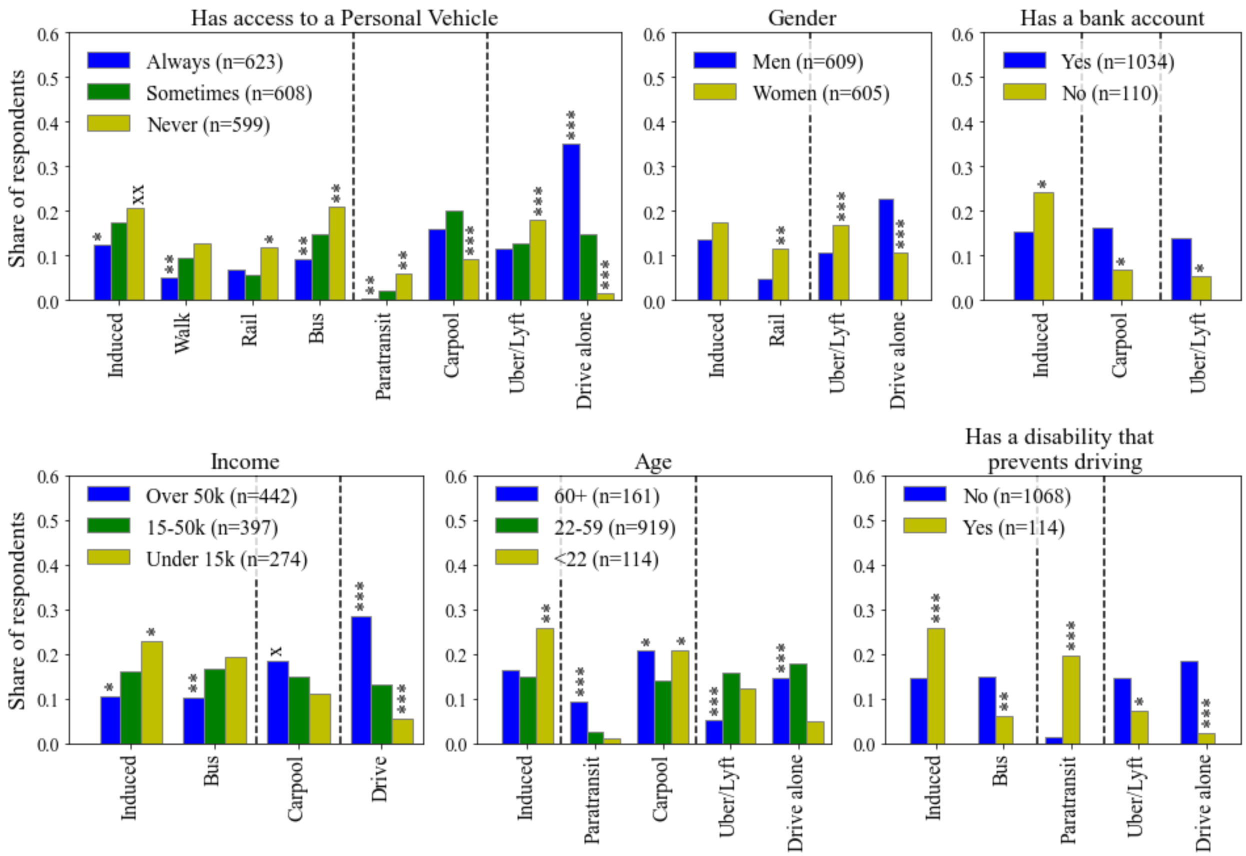


Figure 4.2. How respondents would have made their most recent public microtransit trip, by demographic group. Induced, non-motorized, and higher occupancy modes are on the left, lower-occupancy modes are on the right, and modes with uncertain VMT comparison are in the middle. Significant differences shown: p *< 0.01 (***);* p *< 0.05 (**); p<0.10 (*).*

[a] For plots with three categories, statistically significant differences use the middle category as the base. For these plots, (x) indicates significant difference from rest of categories (rather than middle category). For race, calculated significant difference from white.

[b] Rail replacement values shown for three microtransit services with rail in the service area.

With age, the most privileged group is in the middle, from 22 to 59 years, and this group is among the ages most likely to switch from drive alone (along with those age 60 and above) and from ride-alone Uber/Lyft (along with those age 21 and under). This is also the age group least likely to switch from carpooling. Those age 60 and above are by far the most likely age to switch from paratransit. Respondents with disabilities that prevent driving are also more likely to switch from paratransit and less likely to switch from drive alone, ride-alone Uber/Lyft, or fixed-route bus.

These results suggest public microtransit riders from transportation-disadvantaged groups may be contributing more to the VMT impact of public microtransit services than riders from more privileged groups. However, assuming public microtransit trips are faster than the non-motorized or higher-occupancy modes they replace, the results also indicate public microtransit services may be contributing to transportation equity by improving options for transit-dependent groups.

4.3.1c. Net change in use of other modes

To assess another measure of the impact of public microtransit service on other modes, we asked respondents whether they increased, decreased, or did not change their use of each mode as a result of the public microtransit service, and by how much. Almost 40% of public microtransit riders (39.1%) reported not changing their use of any other modes as a result of the service. For the remaining riders, who reported increasing or decreasing their use of at least one mode by anywhere from once per month to more than four trips per week, we assigned a “per-month” value to each frequency category as described in the methodology section. We then calculated the average net increase or decrease in each mode within each demographic group, allowing a comparison of relative magnitudes of impacts across modes. Figure 4.3. shows how this measure differs by demographic group.

Finding 3: Similar to the previous section, more privileged groups report a greater decrease in lower-occupancy modes like drive alone, while underserved groups report a greater decrease in higher-occupancy modes like walk, rail, and bus.

Overall, respondents report most decreasing carpool, ride-alone Uber/Lyft, and drive alone as a result of public microtransit (-2.02, -1.48, and -1.35 trips/month), followed by fixed-route bus and walk (-1.25 and -0.92 trips/month). The proportion of respondents that report decreasing their frequency of driving alone as a result of public microtransit is greater among men, higher-income groups, and those with greater access to personal vehicles. Respondents over age 60, those with disabilities that prevent driving, and those with less vehicle access reported greater net decreases in paratransit. The latter group, along with lower-income individuals, also reported greater decreases in walk trips, while lower-income riders reported greater decreases in fixed-route rail, as well. Women reported greater decreases in carpool.

Respondents who always have access to a personal vehicle and those over age 40 reported positive but statistically insignificant increases in fixed-route rail. As discussed in the next section, these groups are also among those that connect disproportionately to rail over fixed-route bus, which could offset any replaced rail trips.

Unbanked individuals do not significantly change their use of Uber/Lyft, potentially because they did not use this mode even before the introduction of the public microtransit service. They are also the only group to report a positive, albeit not statistically significant, increase in their frequency of driving alone. One explanation could be that app-based public microtransit service is less accessible to unbanked individuals than traditional paratransit or fixed-route bus services it replaces, leading some to turn to driving alone as a substitute.

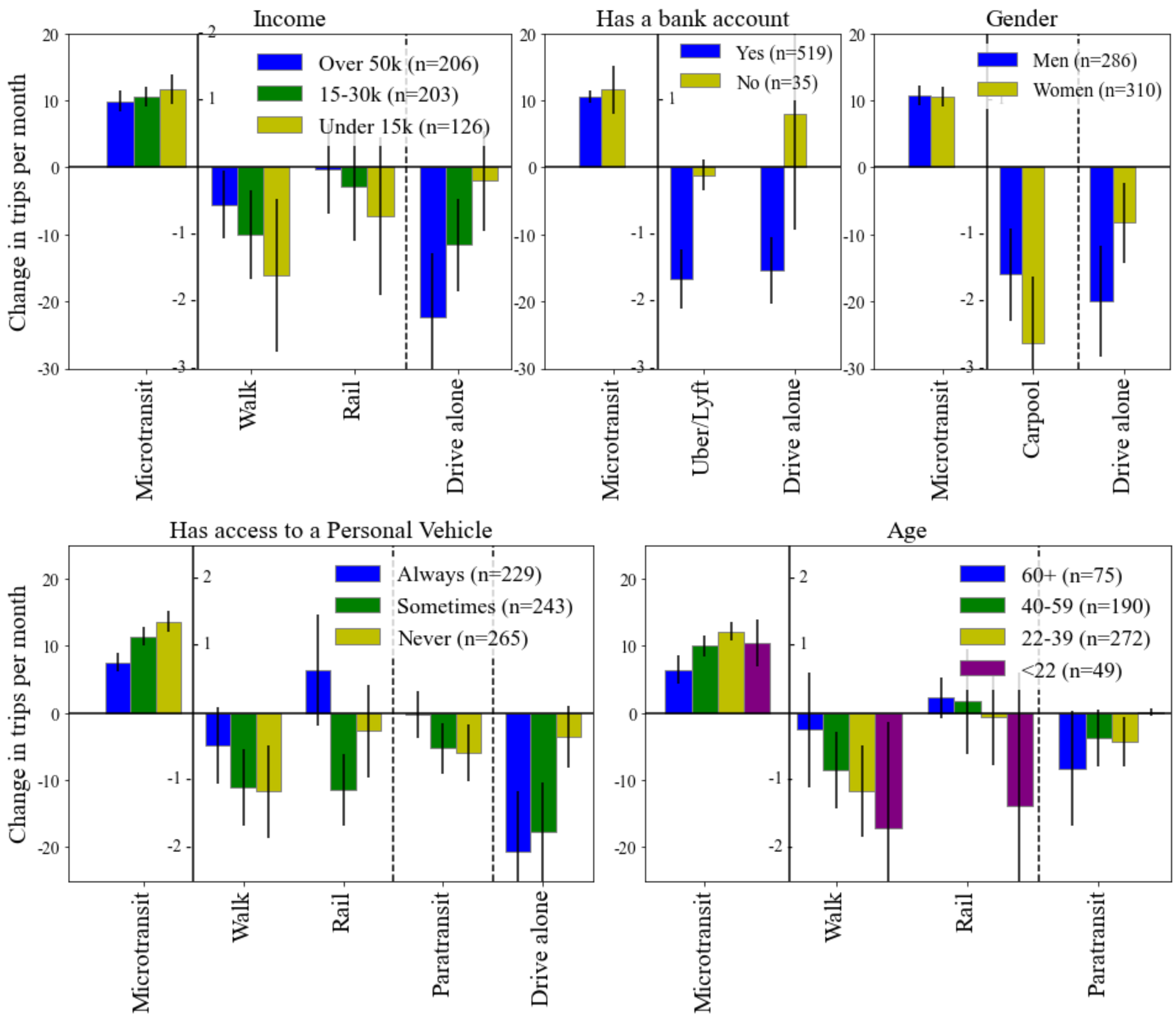


Figure 4.3. Public microtransit trips per month and net change in trips per month on modes with demographic differences.

4.3.1d. First-mile/Last-mile trips

Like replaced modes and induced trips, the proportion of public microtransit trips used for FMLM access to fixed-route public transit has environmental implications, as these trips may support rather than replace high-occupancy bus and rail services. In Figure 4.4, we present FMLM rates for public microtransit services in systems without rail connections available in the service area ("Overall, no rail") and with rail connections in the service area ("Overall with rail"), as well as the share of fixed-route bus and fixed-route rail connections for the latter services.

Finding 4: Groups with more privilege used public microtransit for FMLM connections to fixed-route transit at a greater rate than transportation-disadvantaged groups, especially to rail.

Systems with rail connections available in the service area have higher FMLM rates than systems without rail. In services with rail available, the overall rate of FMLM connections to rail is higher than to bus. In both types of systems, lower-income individuals, those without smartphones, and those without full access to a personal vehicle had lower FMLM rates. For systems with rail, unbanked individuals as well as Black, Hispanic, and Native American riders had lower FMLM rates across both bus and rail, while only rail FMLM rates were lower for women, lower-income riders, those with disabilities that prevent driving, and those with less access to a personal vehicle.

FMLM connections could indicate longer-distance trips to destinations outside the microtransit service area and could potentially reflect more frequent work commutes among more privileged groups, as discussed in the next subsection.

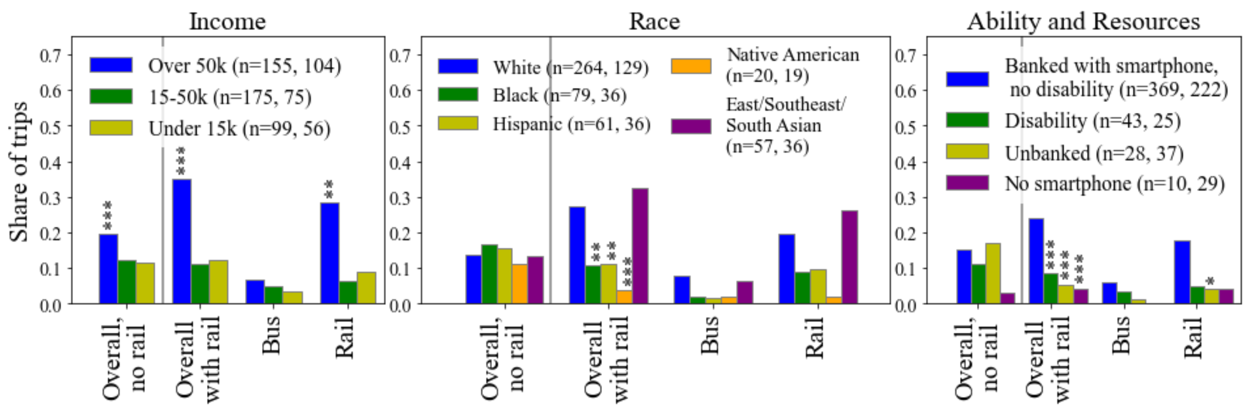


Figure 4.4. Frequency of FMLM connections by demographic group for public microtransit services without (left) and with rail connections in the service area (N= 'without', 'with'). Race plot shows statistically significant differences from white.

4.3.1e. Trip Purpose

Variation in the purpose of public microtransit trips by demographic group could suggest locations or times for public transportation agencies to prioritize public microtransit to better serve transportation-disadvantaged populations and/or to attract more privileged groups away from low-occupancy modes like driving and Uber/Lyft.

The most common purpose for public microtransit trips is the work commute (29.4%), followed by errands (19.2%), social/recreational trips (19.0%), work meetings (11.3%), healthcare appointments (10.7%), and school commutes (10.5%). More frequent public microtransit riders disproportionately use the mode for work and school commutes, while less frequent riders disproportionately use it for healthcare appointments, errands, and social/recreational trips.

Finding 5: In general, transportation-disadvantaged groups are less likely than more privileged groups to use public microtransit for work commutes and more likely to use it for errands, healthcare appointments, and/or social/recreational trips.

Figure 4.5 shows that lower-income groups, unbanked individuals, people without smartphones, and those with less access to a personal vehicle or disabilities that prevent driving are all less likely to use public microtransit for work commutes and more likely to use it for healthcare appointments. Riders without access to a personal vehicle, those with disabilities that prevent driving, and those with lower incomes are also more likely to use public microtransit to run errands, while the latter two groups are also more likely to use it for social trips. Riders under age 22 are less likely to use public microtransit for work and more likely to use it for school, while those age 60 or above are more likely to use it for errands and healthcare appointments.

These findings suggest that concentrating public microtransit service areas around employment centers may disproportionately benefit more privileged groups, while service near shopping centers and healthcare clinics may disproportionately benefit transportation-disadvantaged groups.

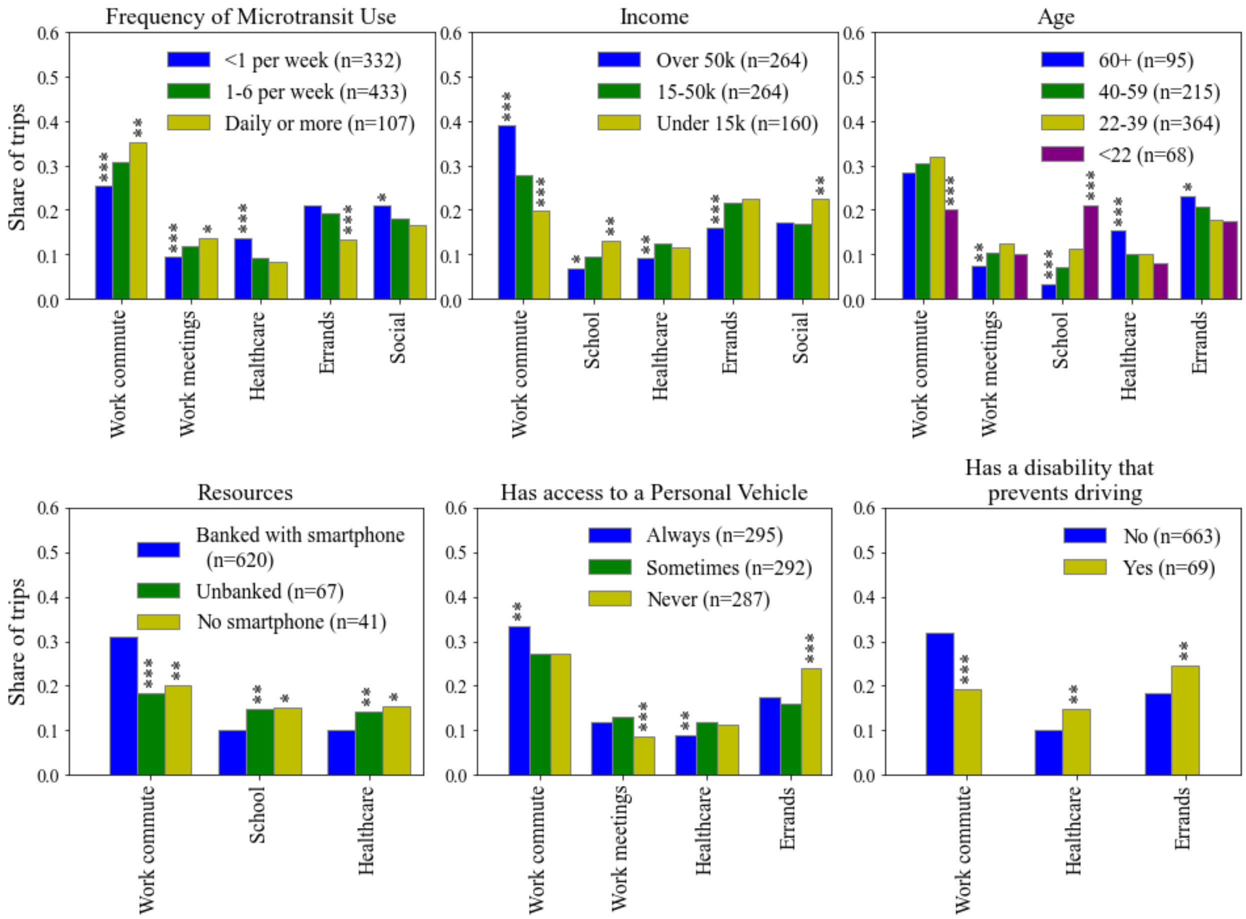


Figure 4.5. Trip purpose by demographic group.

4.3.1f. Reasons for replaced modes

The reasons respondents provide for choosing public microtransit over other modes may suggest strategies for public transportation agencies to attract riders away from driving alone or using ride-alone Uber/Lyft, to keep riders on fixed-route buses, and to improve service for transit-dependent populations. The only respondents who received these questions were those who reported decreasing their use of drive alone, Uber/Lyft, and/or fixed-route bus as a result of public microtransit. They could select more than one reason per mode.

Cost played the largest role in respondents' decision to use public microtransit over driving and Uber/Lyft (58.4% and 89.3%), followed by a desire to support public transportation (43.4% and 40.2%). Avoiding parking was the next most common reason for choosing public microtransit over driving (31.7%), while over a quarter of those who reported replacing Uber/Lyft trips perceived public microtransit as more reliable (29.0%). These findings suggest public transportation agencies could attract public microtransit riders from lower-occupancy modes by emphasizing the low costs and the ability to avoid looking for parking.

Finding 6: Riders with higher incomes and vehicle access were disproportionately more likely to cite environmental concerns and support for public transportation as a reason for using public microtransit over driving and Uber/Lyft. Transportation-disadvantaged groups disproportionately cited safety, ease of transporting packages and family members, and fewer passengers as reasons for selecting public microtransit over fixed-route bus.

Concern for supporting public transportation varied with income and vehicle ownership. Among riders who reported decreasing their use of personal vehicles and/or Uber/Lyft as a result of the public microtransit service, the proportion saying they did so in part to support public transportation and the environment increased with income and access to a personal vehicle. Respondents who use public microtransit at least daily, meanwhile, were less likely to report concern for the environment as a reason for selecting public microtransit over personal vehicle than those who use it less frequently (19.4% vs. 35.3%, $p<0.05$).

For lower-income riders and those without access to a personal vehicle, ease of transporting purchases was as great of a concern as environmental reasons in selecting public microtransit over Uber/Lyft (around 30.0% vs. 27.5% for riders with household incomes under 50k and 27.8% vs. 26.8% for riders without vehicle access). Riders with household incomes under $15k were also more likely than higher income riders to cite ease of transporting family members as a reason to use public microtransit over Uber/Lyft.

The demographic differences were even more pronounced in respondents' reasons for selecting public microtransit over fixed-route bus. As a whole, over half of respondents reported faster trips as a reason they used public microtransit over fixed-route transit (51.4%), followed by access to more destinations (38.9%). About a third cited fewer stops, greater reliability, better service hours, and cost (35.1%, 32.4%, 32.4%, and 29.7%); about a quarter cited ability to transport purchases (26.5%); a fifth cited safety (18.9%); and a tenth cited comfort as well as ease of transporting family members (10.3% and 11.9%). Respondents without access to a personal vehicle particularly valued public microtransit for providing access to more destinations than fixed-route bus and for being an easier way to transport purchases. Women and those with household incomes under 15k were more likely than other groups to cite safety as a reason for selecting public microtransit over bus, and a higher proportion of women also cited fewer passengers and ease of transporting purchases and family members. There were insufficient responses to these questions to compare answers for riders without smartphones or bank accounts.

Transportation-disadvantaged riders' greater focus on transporting purchases and family members echoes their disproportionate use of public microtransit for errands, school, and social/recreational trips. The disproportionate concern for safety among women and low-income respondents, meanwhile, as well as the focus on accessing more locations among respondents without access to a personal vehicle, suggest that public microtransit is impacting riders' quality of life. These impacts are discussed further in the next section.

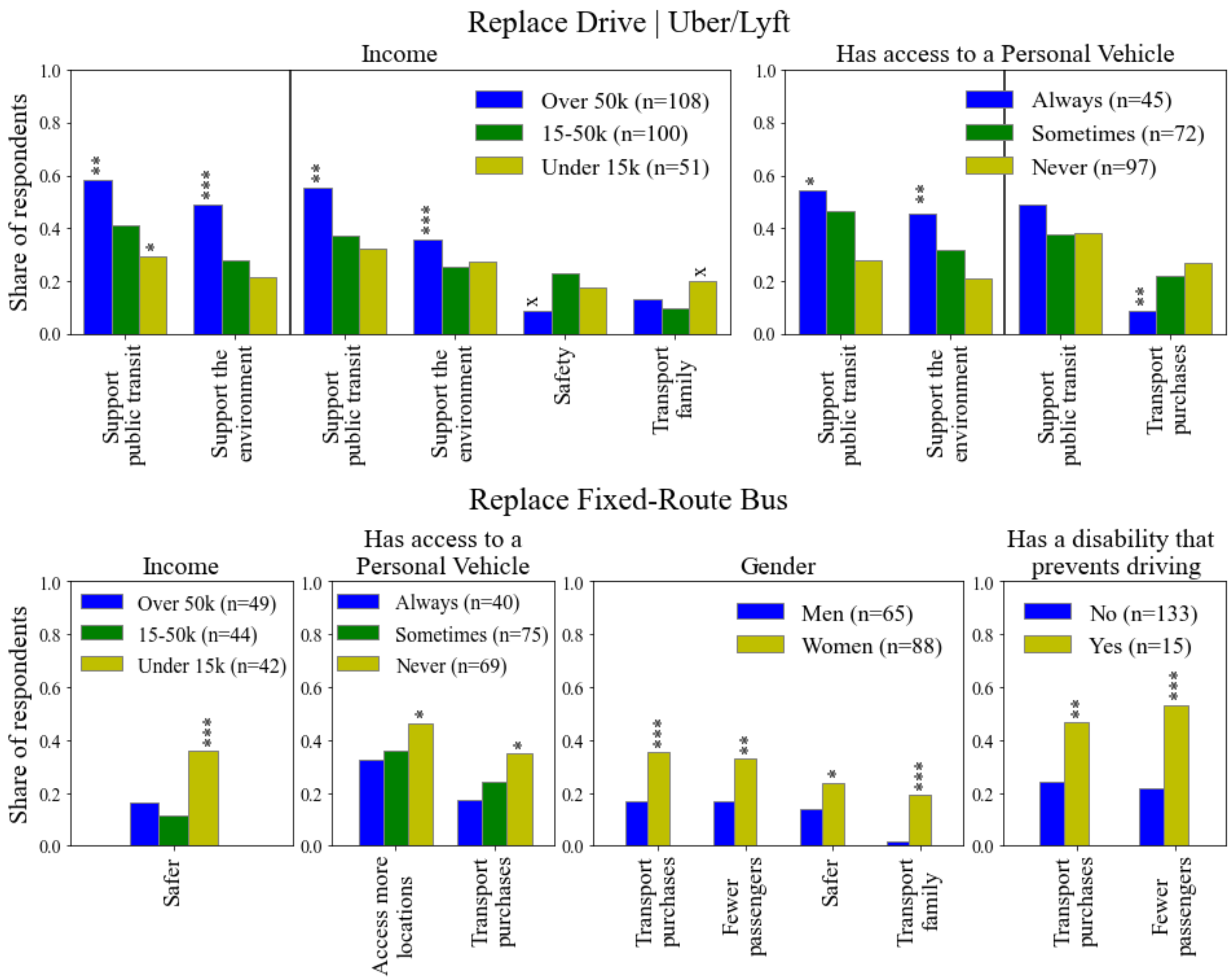


Figure 4.6. Demographic differences in reasons to use public microtransit in place of: drive alone (top row, left side), Uber/Lyft (top row, right side), and fixed-route bus (bottom row).

4.3.2. Perceptions of the Public Microtransit Service

Demographic differences in respondents' perceptions of public microtransit could indicate successes or challenges in serving particular groups. This section includes two categories of perceptions: a) respondents' stated satisfaction and quality of life impacts from the service, and b) their experience of delay past the estimated time of arrival (ETA).

4.3.2a. Satisfaction and Quality of Life Impacts

In this section, we assigned numerical values to the Likert scale responses of very satisfied/greatly improved quality of life (2) to very dissatisfied/greatly decreased quality of life (-2) and used the average values to compare satisfaction and quality of life impacts across measures and demographic groups.

As shown in Figure 4.7, public microtransit passengers as a whole are most satisfied with their overall experience, followed by their experience with the app and their feeling of safety. They are least satisfied with the wait time, reliability and hours of service. Similarly, riders reported the greatest quality of life improvements from the microtransit service overall, followed by impacts on their independence, access to employment, and access to medical care. They reported negative quality of life impacts from the effects on transportation costs and minimal impact on their access to childcare (Figure 4.8).

Finding 7. Satisfaction and quality of life improvements are highest for daily public microtransit riders, lower-income groups, those without access to personal vehicles, and women.

More frequent public microtransit riders report greater satisfaction with all aspects of the service, which fits with their decision to continue using the service. They also report greater quality of life impacts on every measure except transportation expenses, which is also expected.

Women and respondents without access to a personal vehicle report greater quality of life impacts on everything except access to childcare and costs, suggesting positive equity impacts from the service. Those who always have access to a personal vehicle, however, are more satisfied with the FMLM connections available, in alignment with their more frequent use of these options (0.74 vs. 0.61, $p<0.05$). Respondents with the lowest incomes report greater quality of life improvements than higher-income respondents on everything except independence and expenses.

By age, riders under 40 report greater improvements in their access to education, those under 60 report greater improvements in their access to employment, and those age 60 or over report greater improvements in their access to medical care. Riders in the 60 and over age group also report by far the greatest improvements in their level of independence, indicating a positive impact for these riders.

Finding 8. Riders without smartphones and/or bank accounts are significantly less satisfied with most aspects of public microtransit service. They also report much lower to no improvements to their quality of life.

The transportation equity benefits from public microtransit are not universal. Riders without smartphones are significantly less satisfied with all aspects of the service, and their dissatisfaction with wait times, on average, is the only metric among any demographic group without a statistically significant positive response. Riders without bank accounts are also significantly less satisfied with all aspects except hours, reliability, and wait time. These two groups also report no statistically significant quality of life impacts except the negative impact on transportation expenses. This finding suggests that public microtransit services have not successfully addressed the barriers to access for these riders.

Other findings also indicate inequitable distribution of benefits from public microtransit. Riders with disabilities that prevent them from driving are less satisfied with the walk times (0.48 vs. 0.73, $p<0.05$) and hours of service (0.26 vs. 0.52, $p<0.05$). Riders 21 years old or younger are less satisfied with the places they can go using the service (0.38 vs. 0.68, $p<0.01$) and its reliability (0.27 vs. 0.47, $p<0.10$).

As shown in Figure 4.8, Hispanic, Native, and East/Southeast Asian respondents report smaller improvements in their quality of life overall and in their levels of independence, and the latter two groups also report smaller improvements in their access to employment. East/Southeast Asian respondents report no impact on their access to healthy food or education, and South Asian riders report more negative impacts on their transportation expenses. Minority groups report better impacts than white respondents in only two instances: South Asian riders report greater improvements in their access to education, and Black and Hispanic riders report less negative impacts on their transportation costs.

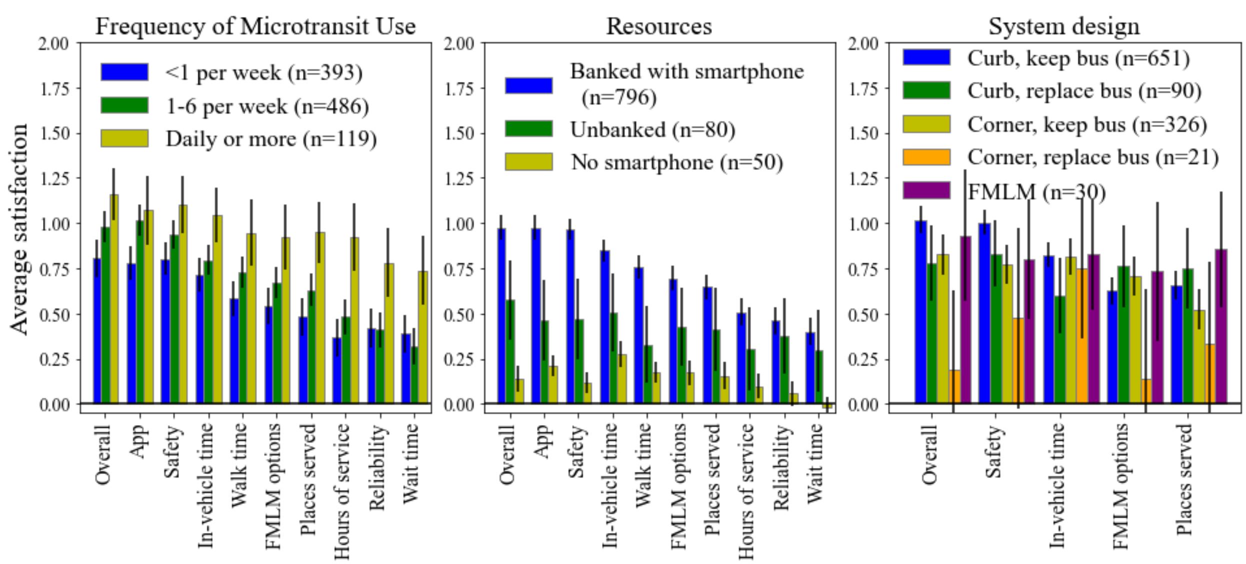


Figure 4.7. Average satisfaction on ten measures of service, by frequency of public microtransit use, banked/unbanked status, and smartphone ownership. (2=Extremely satisfied, 1 = Satisfied, 0 = Neither satisfied nor dissatisfied, -1 = Dissatisfied, -2 = Extremely dissatisfied).

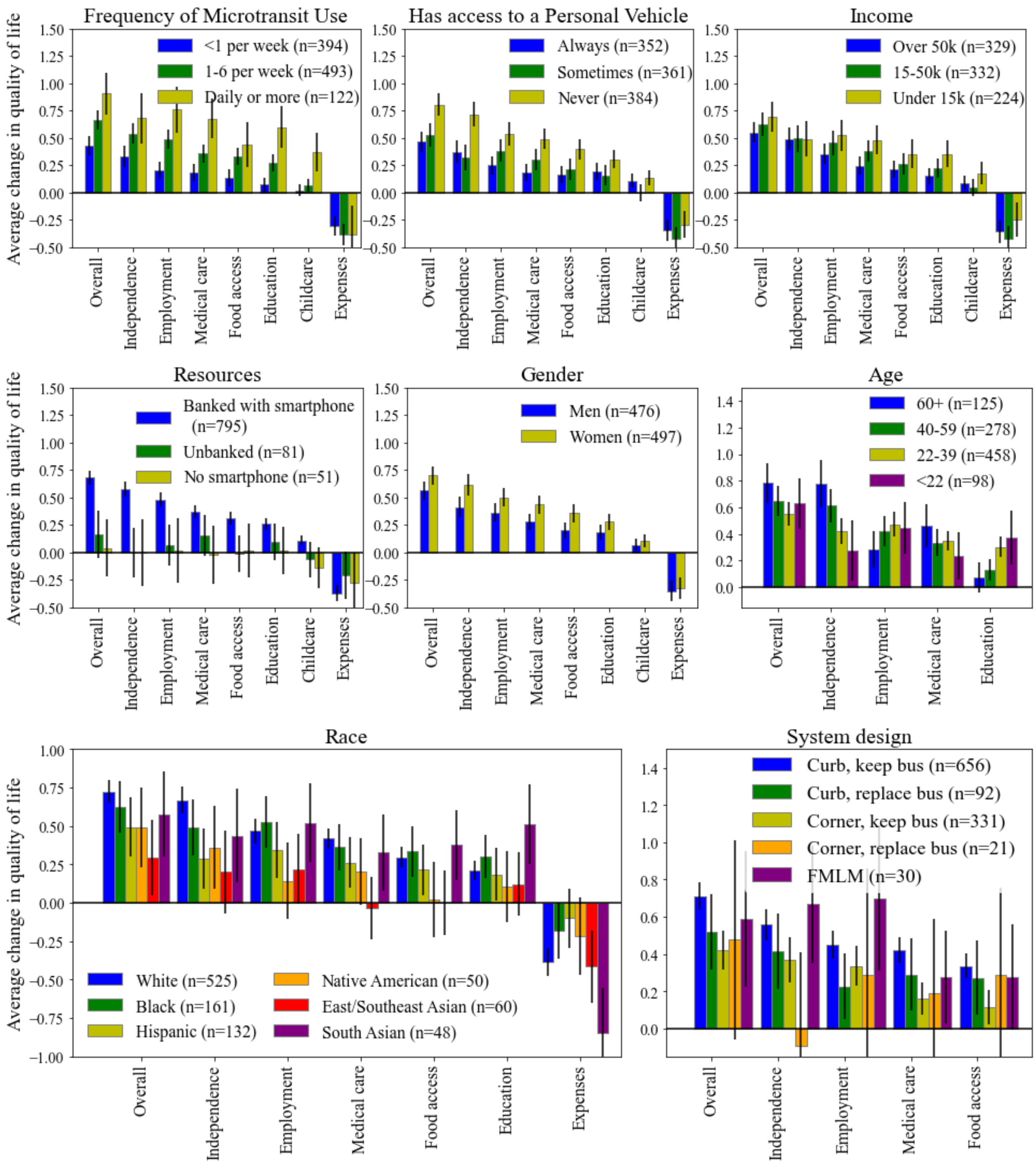


Figure 4.8. Quality of life impacts from public microtransit by demographic group and service design. (2= Greatly improved, 1 = Improved, 0 = Did not change, -1 = Decreased, -2 = Greatly decreased).

Finding 9. Riders at agencies that provided curb-to-curb microtransit service and maintained fixed-route bus service reported the greatest satisfaction and quality of life impacts.

Because the satisfaction and quality of life questions included responses from riders who started using the service during the pandemic, there were sufficient sample sizes to compare impacts by service design. Variations in three service design variables yielded five types of services: **1.** The most common type of service included agencies that did not replace bus routes and provided curb-to-curb service (n=656 respondents, seven agencies). **2.** The second most responses came from services that did not replace bus routes and provided corner-to-corner service (n=331, two agencies). **3 & 4.** Among agencies that used public microtransit to replace fixed-route bus routes, two provided curb-to-curb service (n=92 respondents) and one provided corner-to-corner service (n=21 respondents). **5.** A single agency required public microtransit trips to start or end at a bus stop and focused on providing FMLM service to low-wage jobs in a commercial area (n=29 respondents). The last service also charged $0.25 fares even before the pandemic, lower than the typical range of $2-$4 fares.

Among the first and second types of services (that did not replace bus routes or require FMLM trips), respondents at the agencies with corner-to-corner service reported smaller quality of life improvements compared to those with curb-to-curb service (0.43 vs. 0.69, $p<0.01$), and smaller improvements to their independence (0.37 vs 0.56, $p<0.01$). Those with corner-to-corner service also reported lower satisfaction with the service overall (0.83 vs. 1.0, $p<0.01$), their feeling of safety (0.83 vs. 1.0, $p<0.01$), and the places the service goes (0.52 vs. 0.66, $p<0.10$). However, they are more satisfied with the wait times (0.43 vs. 0.33, $p<0.10$), which could indicate that the corner-to-corner services are succeeding in offering lower wait times—one of the main objectives in selecting this service model.

Compared to riders at agencies with curb-to-curb service that did not remove bus service, respondents at the two agencies that replaced bus service with curb-to-curb service (n=87) were less satisfied with the service overall (0.77 vs. 1.0, $p<0.05$), the in-vehicle time (0.60 vs. 0.83, $p<0.05$), and with safety while waiting for the vehicle (0.83 vs. 1.0, $p<0.10$). These riders also reported smaller improvements in their access to employment (0.22 vs. 0.45, $p<0.10$).

The 21 respondents associated with the only agency that both replaced bus routes and used corner-to-corner service reported neutral to negative impacts on their level of independence ($p<0.01$ compared to agencies with curb-to-curb service and $p<0.10$ compared to the two other agencies with corner-to-corner service). These respondents were also less satisfied with the service overall ($p<0.01$ compared to agencies that maintained fixed-route bus routes and $p<0.10$ compared to agencies that replaced bus routes with curb-to-curb service), with their feeling of safety ($p<0.01$ compared to agencies that both maintained bus routes and offered curb-to-curb service), and with the FMLM options ($p<0.05$ compared to all other agencies).

Respondents at the service with FMLM service in a commercial area, with $0.25 fares, reported the greatest improvements in their access to employment (0.70 vs. 0.38, $p<0.10$) and transportation costs (0.11 vs. -0.37, $p<0.05$, n=29 vs. 1035). They reported the lowest satisfaction with the app (0.57 vs. 0.93, $p<0.05$), which could reflect the predominance of walk-on trips at this service, where public microtransit vehicles waited at the commuter bus stops for timed transfers.

4.3.2b. Delay past Estimated Time of Arrival (ETA)

We asked respondents about how frequently they experience delays in pickup times past their public microtransit vehicle's ETA, as well as the average length of delay, the longest delay they had experienced, and how much advance notice they would need to reduce the inconvenience of delay. We also asked how much advance notice they would need to meet the public microtransit vehicle at an earlier arrival time if the vehicle happened to be running ahead of schedule.

Finding 10. Based on survey responses, public microtransit delay is inequitably distributed, with transportation-disadvantaged groups experiencing more frequent and longer delays on average.

Lower income riders report experiencing more frequent delays past the ETA, as shown in Figure 4.10. Respondents with household incomes under $50k reported longer average delays (12.0 min. vs. 9.5 min., $p<0.05$) and longer maximum delays (24.7 min. vs. 21.5 min, $p<0.10$) than riders with household incomes over $50k. Other groups experiencing more frequent delays past ETA include public microtransit riders who are younger, have disabilities that prevent driving, and lack vehicle access, smartphones, and/or bank accounts. Riders without vehicle access report longer average delays than riders who have access to a personal vehicle sometimes or always (13.5 min. vs. 10.0 min., $p<0.01$). They also report longer maximum delays (30.6 min., 20.6 min., and 17.9 min., respectively, $p<0.01$ for 'never' compared to 'sometimes' and $p<0.10$ for 'sometimes' compared to 'always'). Those without smartphones report longer average delays (15.5 min. vs. 11.3 min., $p<0.10$). However, these riders and those without bank accounts report shorter maximum delays (16.2 min. and 16.6 min., respectively, compared to 24.5 min. for people with smartphones and bank accounts, $p<0.05$ and $p<0.01$).

Twelve and a half percent (12.5%) of riders said no amount of advance notice would reduce the inconvenience of delay, 23.0% requested over 30 minutes of advance notice, and the remainder requested an average of 13.2 minutes advance notice to reduce the inconvenience of delay. Those without smartphones requested the most advance notice (17.0 min. vs. 13.0 min., $p<0.01$), although this is the precise group that is most difficult to reach with information about delays. More riders age 60 and above said no amount of advance notice would reduce the inconvenience of delay (19.6% vs. 11.5%, $p<0.05$), as did riders without access to personal vehicles (15.3% vs. 11.1%, $p<0.05$).

For public microtransit vehicles arriving before the ETA, 9.6% of riders said no amount of advance notice would enable them to be ready for the new, earlier arrival time, 15.8% requested over 30 minutes of advance notice, and the remainder said an average of 12.4 minutes of advance notice would enable them to be ready for the new, earlier arrival time. Low frequency riders requested more advance notice of early arrivals (13.3 min. vs. 11.7 min., $p<0.01$). Riders with disabilities that prevent them from driving also requested more advance notice of early arrivals (14.0 min. vs. 12.1 min., $p<0.10$) and a greater share of these riders requested over 30 minutes of advance notice (22.6% vs. 15.2%, $p<0.10$). A greater share of unbanked riders requested over 30 minutes of notice (27.8% vs. 14.5%, $p<0.01$). Riders without access to personal vehicles, meanwhile, required less advance notice of early arrivals (11.1 min. vs. 13.1 min., $p<0.01$) and fewer of these riders requested over 30 minutes of advance notice (11.9% vs. 17.8%, $p<0.01$).

The main challenge with these requests for advance notice is that they are barely less than most agencies' target wait times of 15 minutes. To provide the level of advance notice requested, agencies would need to notify riders of delay or early arrivals within a minute or so of the initial request. However, knowing the average levels of advance notice requested by riders could still be useful in cases where initial wait times are projected to be longer than 15 minutes.

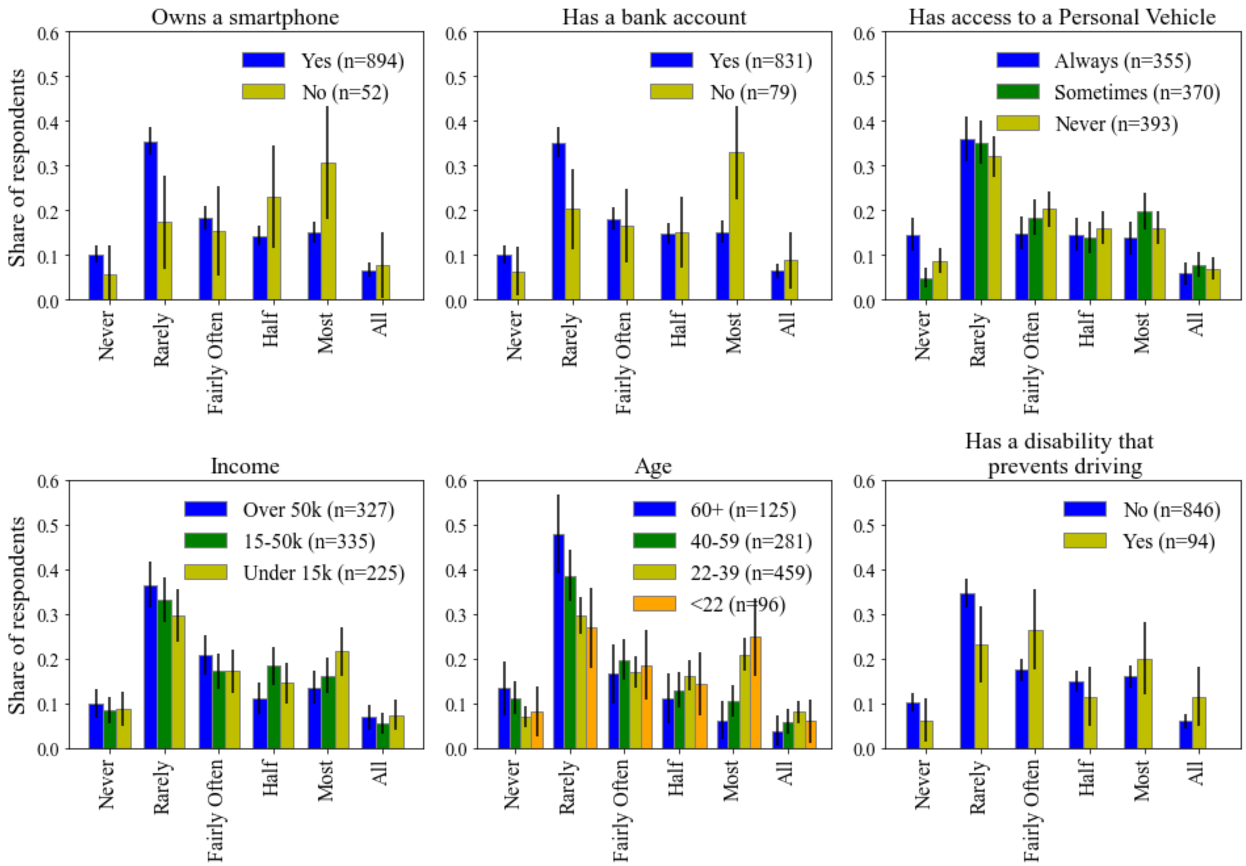


Figure 4.9. Frequency of delay past ETA by demographic group.

4.3.3. Covid-19 Impacts

In this section, we examine: a) respondents' relative perception of risk on each mode, and b) how respondents' mode use changed during the pandemic and how they anticipate it changing post-pandemic.

4.3.3a. Perception of risk by mode

To better understand the role for public microtransit as an alternative to fixed-route bus during a pandemic, we asked respondents how they perceived the risk of contracting Covid-19, from low risk (1) to high risk (5), on these modes and four others.

Finding 11: Regardless of demographic group, respondents perceived public microtransit as posing less risk for contracting Covid-19 than ride-alone Uber/Lyft, fixed-route bus, or carpool.

Respondents perceived carpool and fixed-route bus as most risky (3.29 and 3.28, the only modes not significantly different from each other), followed by Uber/Lyft (2.96), public microtransit (2.67), walk (1.80) and drive alone (1.58). While the order of risk by mode did not vary by whether the respondents had used public microtransit, non-riders perceived carpool, bus, and public microtransit as riskier than those who had tried public microtransit ($p<0.05$, $p<0.10$, and $p<0.01$, respectively). Public microtransit riders over age 60 viewed carpool as more risky than younger riders (3.50 vs. 3.26, $p<0.05$) but public microtransit as less risky (2.51 vs. 2.70, $p<0.05$). Those age 21 or under, meanwhile, viewed fixed-route bus as less risky than older riders ($p<0.05$). Riders with incomes under 15k perceived all shared modes as less risky ($p<0.01$ for carpool and Uber/Lyft, $p<0.05$ for public microtransit, and $p<0.10$ for fixed-route bus), as did those without access to a personal vehicle ($p<0.01$ for public microtransit and Uber/Lyft and $p<0.05$ for fixed-route bus and carpool). Riders without smartphones, unbanked riders, and those with disabilities that prevent driving perceived carpool and fixed-route bus as less risky. Black riders perceived Uber/Lyft, carpool, and public microtransit as more risky than white riders ($p<0.01$, $p<0.05$, and $p<0.10$, respectively), while women perceived all shared modes as more risky than men did ($p<0.01$ for fixed-route bus and Uber/Lyft, $p<0.05$ for public microtransit, and $p<0.10$ for carpool).

One potential explanation for most transportation-disadvantaged groups viewing shared modes as less risky could be that they had to continue using those modes during the pandemic and were desensitized to the risk. We examine demographic differences in mode shift during the pandemic in the next subsection.

4.3.3b. Change in pandemic and post-pandemic mode use

For each mode respondents reported using in the past two years, we asked them how frequently they used it during the pandemic and how frequently they anticipated using it after the pandemic. Respondents were given the option to select “Same as before the pandemic” for each question, so any change in use was consciously indicated. The question on pre-pandemic use was also provided on the same screen, so respondents could easily reference their responses across these three questions. To analyze change across time periods, we assigned each frequency category a single value, as described in the methodology section, and subtracted the pre-pandemic values to yield a “change in trips per month” metric. We used the average of this metric to compare shifts across modes, time periods, and demographic groups. Figures 4.10 and 4.11 show results for the 11 agencies that started their public microtransit pilots before the pandemic, excluding respondents who reported never using public microtransit before or during the pandemic.

Overall, respondents who had ever used public microtransit reported most decreasing their use of fixed-route bus and rail during the pandemic (-3.3 and -2.9 trips/month), followed by their use of public microtransit (-2.0 trips/month), carpool (-0.6 trips/month), and ride-alone Uber/Lyft (-0.5 trips/month). These decreases were all significantly different from zero at the level of $p<0.01$, except for carpool at the level of $p<0.05$. These respondents did not report statistically significant shifts in their frequency of drive alone trips either during the pandemic or post-pandemic. Of the most frequently used shared modes, respondents only anticipated returning to pre-pandemic levels of use for public microtransit (no statistically significant changes compared to pre-pandemic use). They anticipated returning to fixed-route bus and rail but at decreased frequencies compared to pre-pandemic (-1.6 and -1.2 trips/month, $p<0.01$). Finally, they anticipated maintaining pandemic-era frequencies of use for ride-alone Uber/Lyft and carpool (-0.5 trips/month, no significant change from pandemic frequencies but significantly different from zero at the level of $p<0.01$ and $p<0.05$, respectively).

Finding 12: Lower-income riders, those without access to a personal vehicle, and essential workers maintained their public microtransit use during the pandemic but decreased their use of fixed-route transit. Higher-income riders and those with greater vehicle access decreased their use of both public microtransit and fixed-route rail and bus by more than transportation-disadvantaged groups.

Finding 13: Riders without access to a personal vehicle anticipate using public microtransit more post-pandemic than they did before the pandemic; this is the only group that anticipates increasing their use of any shared mode post-pandemic. Most income groups and levels of vehicle access anticipate maintaining lower frequencies of fixed-route transit and Uber/Lyft use post-pandemic.

Riders with household incomes over $50k and who always have access to personal vehicles were the only income and vehicle access groups to significantly decrease their use of every shared mode during the Covid-19 pandemic. Riders with household incomes under $50k did not significantly change their use of public microtransit during the pandemic and do not anticipate changing it post-pandemic. In contrast, these riders anticipated slightly decreasing their use of carpool and ride-alone Uber/Lyft post-pandemic, after not significantly changing their use of these modes during the pandemic (aside from riders with incomes over $15k, who did report statistically significant decreases in their use of ride-alone Uber/Lyft during the pandemic). Although lower-income riders reported reducing their use of fixed-route bus and rail less than higher-income riders during the pandemic, there were no significant differences between income groups in the anticipated post-pandemic use of these modes. Riders with incomes under $15k anticipated increasing their frequency of driving alone after the pandemic ($p<0.10$ with a one-sided t-test, insignificant with a two-sided t-test).

Riders who never have access to a personal vehicle did not report statistically significant changes in their use of public microtransit, carpool, or ride-alone Uber/Lyft during the pandemic, but anticipated using public microtransit more frequently post-pandemic than they did before the pandemic (0.9 more trips/month, $p<0.10$) and using carpool and ride-alone Uber/Lyft less frequently (0.6 and 0.4 fewer trips/month, $p<0.10$). Unlike other respondents, these riders also anticipate returning to pre-pandemic frequencies of rail use.

Critically, essential workers also maintained their public microtransit use during the pandemic while decreasing their fixed-route transit use, suggesting that they perhaps perceived public microtransit as a safer alternative for their continued commuting, as discussed in the previous section. These riders also maintained their use of ride-alone Uber/Lyft during the pandemic but anticipate decreasing their use after the pandemic (-0.3 trips/month, $p<0.10$).

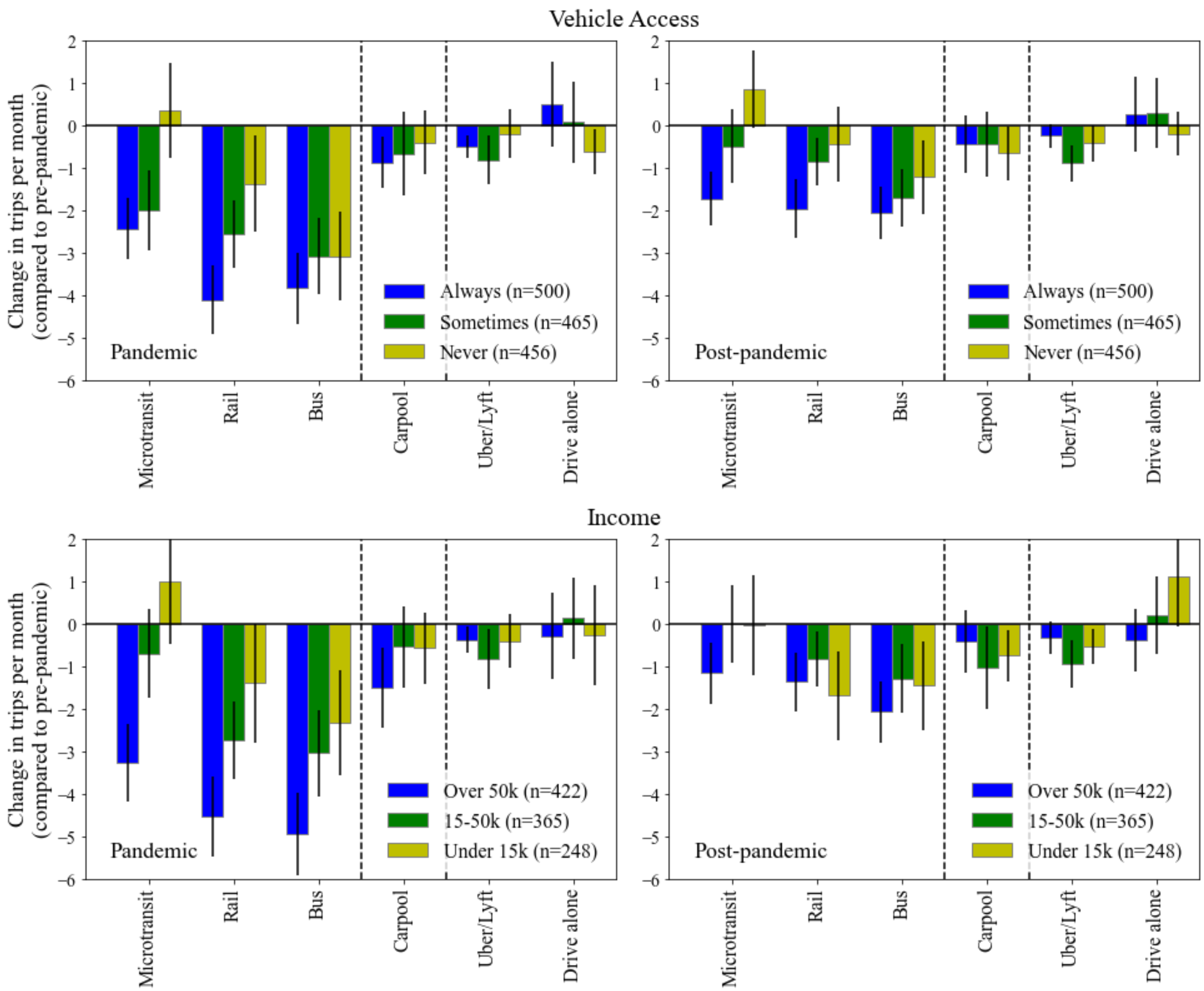


Figure 4.10. Change in mode use during the Covid-19 pandemic and anticipated change in mode use post-pandemic (compared to pre-pandemic use), by vehicle access and income.

Finding 14: Unlike any other group, riders without smartphones decreased their public microtransit use by more than their fixed-route public transit use during the pandemic. These riders and unbanked riders also anticipate using public microtransit less post-pandemic than pre-pandemic (Figure 4.11).

Riders without smartphones significantly decreased their use of public microtransit during the pandemic (-1.8 trips/month, p<0.05) but did not significantly decrease their use of fixed-route bus or rail. These riders anticipate maintaining lower microtransit frequencies post-pandemic (p<0.05), while unbanked riders also anticipate decreasing their use of public microtransit post-pandemic (-2.7 trips/month, p<0.01).

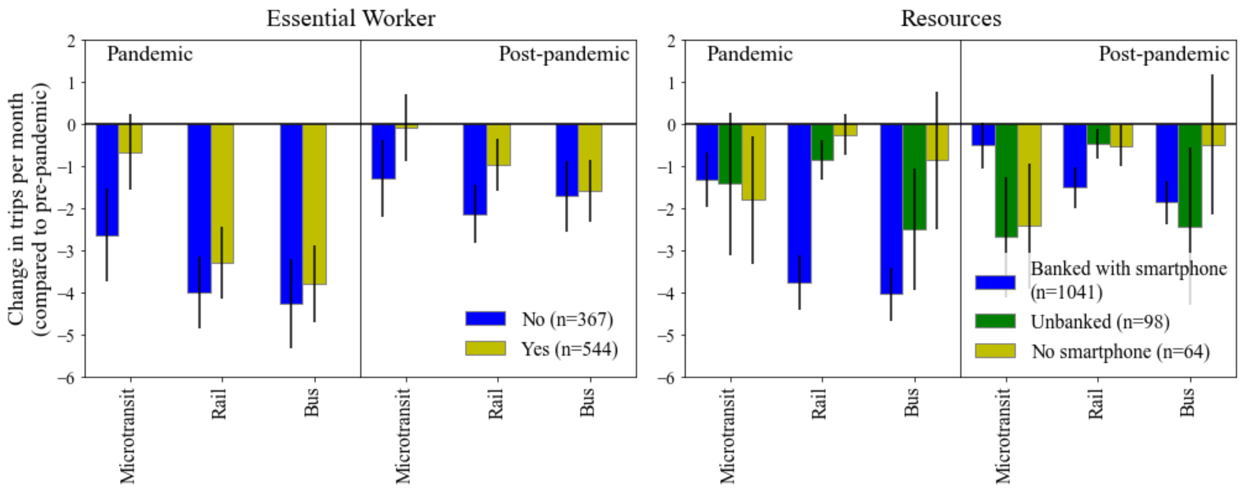


Figure 4.11. Change in use of highest-occupancy modes during the Covid-19 pandemic and anticipated change in mode use post-pandemic (compared to pre-pandemic use), by resources and essential worker status.

A few other demographic differences in mode shift during the pandemic also indicate equity concerns. Women decreased their ride-alone Uber/Lyft use by more than men (-0.77 vs. -0.22 trips/month, $p<0.10$) but decreased their fixed-route bus use by less than men (-3.2 vs. -4.5 trips/month, $p<0.05$). This could reflect that essential workers were more likely to be women (51.3% vs. 43.3%, $p<0.05$). Essential workers were also more likely to be Hispanic (17.2% vs. 9.9%, $p<0.01$) and have incomes under 15k (22.5% vs. 18.4%, $p<0.10$). Among respondents who used public microtransit at least once per week before the pandemic, only 33.6% (n=193) were able to reduce their use to less than once per week. The remainder (n=381) were not only more likely to be lower income, essential workers, and have less access to personal vehicles, as already discussed, but were also more likely to be Black (16.5% vs. 10.4%, $p<0.05$) and more likely to report reductions in income during the pandemic (39.3% vs. 32.6%, $p<0.10$). The riders who used public microtransit at least once per week pre-pandemic and decreased their use to less than once per week during the pandemic switched to driving alone, reporting an average increase of 2.1 drive trips/month during the pandemic ($p<0.01$). They anticipate continuing to drive alone more and use public microtransit less post-pandemic than they did pre-pandemic (1.7 trips/month and -6.1 trips/month, respectively, both different from zero at a level of $p<0.01$).

On the other end of the spectrum, some infrequent or non-riders anticipated using public microtransit at least once per week after the pandemic even though they had used it less than weekly or never before and during the pandemic. These responses were excluded from the post-pandemic analysis above, but may offer insights into the type of rider willing to try public microtransit. 5.9% of public microtransit riders had only ever used it less than once a week but anticipated using public microtransit more than once per week after the pandemic (n=65). Compared to infrequent riders who anticipated continuing to use public microtransit less than once per week after the pandemic (n=350), these aspiring frequent riders were less likely to always have access to a personal vehicle and more likely to have access sometimes ($p<0.01$ for each) and more likely to have experienced income reductions (, $p<0.05$) and employment changes during the pandemic (44.8% vs. 34.6%, p<0.10).

Almost half of respondents who reported never using public microtransit (n=185) said they anticipated using it after the pandemic (for an average of 7.1 trips/month). Compared to the non-riders who said they would continue not to use public microtransit after the pandemic (n=190), these anticipatory riders were more likely not to have smartphones (14.1% vs. 2.5%, $p<0.01$) or bank accounts (13.7% vs. 8.8%, $p<0.05$), more likely to have incomes from 15-50k (36.7% vs. 23.0%, $p<0.05$), and less likely to always have access to a personal vehicle (37.0% vs. 50.0%, $p<0.05$). This group also anticipated statistically significant post-pandemic decreases in their use of drive alone, fixed-route bus, and fixed-route rail (-1.5, -1.4, and -1.3 trips/month, respectively, $p<0.01$ for all), so they could conceivably switch to public microtransit from these modes. In contrast, non-riders who did not anticipate trying public microtransit did not report statistically significant changes in these modes.

4.4. Implications

This paper holds a number of environmental and equity implications for public transportation agencies operating or considering public microtransit services. First, the service may have a negative environmental impact, as many riders say their trips were induced or switched from nonmotorized/higher-occupancy modes such as fixed-route bus, which would have served the trip with lower VMT. The riders who said they switched from lower-occupancy modes such as drive alone and ride-alone Uber/Lyft tended to belong to more advantaged demographic groups, so efforts to improve the environmental impact of public microtransit by attracting passengers from their personal vehicles or Uber/Lyft may come at the cost of improving service for transportation-disadvantaged groups. The demographic differences in trip purpose supported this idea—tailoring service to work commutes and FMLM connections to fixed-route rail may disproportionately benefit higher-income riders who own personal vehicles, while locating service areas around shopping centers, grocery stores, and healthcare facilities may better serve transit-dependent and lower-income riders.

While the responses around induced trips and replaced modes suggest public microtransit may have a negative environmental impact, many findings indicate the services may improve transportation quality for some riders from transportation-disadvantaged groups. Riders tend to be lower-income and transit-dependent, and the greater proportion of induced trips among these groups suggest public microtransit is filling a previously unmet demand. Their greater levels of replaced walking and fixed-route public transit trips could indicate improved travel times for transit-dependent passengers, as well. Indeed, these riders report greater satisfaction and quality of life impacts from the service, and disproportionately cite safety and ease of transporting purchases and family members as reasons for selecting public microtransit over fixed-route bus. Moreover, during the Covid-19 pandemic, all respondents perceived public microtransit as a safer alternative to fixed-route bus, ride-alone Uber/Lyft, and carpool. The results indicate they took advantage of this alternative, with more essential workers and low-income and transit-dependent riders maintaining their pre-pandemic frequencies of public microtransit use while decreasing their use of fixed-route bus. Riders without a personal vehicle like the service enough that they anticipate using it more frequently after the pandemic.

At the same time, the results also highlight key transportation equity challenges for public microtransit services, particularly around riders without bank accounts or smartphones. These riders reported less satisfaction and no significant quality of life improvements from public microtransit. During the pandemic, riders without smartphones were the only group to decrease their public microtransit use by more than fixed-route bus and rail, while both they and unbanked riders anticipated returning to public microtransit at lower rates than other riders after the pandemic. While most agencies offer a call-in dispatcher and cash options, our results suggest public transportation agencies need to do more to reduce barriers to access for these groups. Notably, among respondents who had never used microtransit, those without smartphones or bank accounts indicated disproportionate interest in using public microtransit post-pandemic, suggesting the potential to reach these riders if the barriers can be addressed.

The other main equity-related concern was in the responses around public microtransit delay. Riders without smartphones and/or bank accounts were again the ones to report the most frequent delays past ETA, though low-income riders, riders without personal vehicles, and riders with disabilities that prevent driving also reported more frequent delays. This finding suggests public transportation agencies should assess delayed trips to ensure this burden does not fall disproportionately on transportation-disadvantaged groups. Areas for future research include assessing public microtransit trip data to identify demographic differences in delay, wait, and in-vehicle times. This analysis would require four to five time points to accurately measure wait times and delay: 1) time of request and 2) requested pick-up time (these are different for trips scheduled in advance), 3) initial ETA, 4) actual pick-up time, and 5) drop-off time. Differences in #2 and #4 allow a measure of wait time, while differences in #3 and #4 allow a measure of delay. This work could allow additional insight into the distribution of wait time and travel time savings by demographic group.

Analyzing public microtransit trip data across agencies could also yield a stronger understanding of how travel time and transportation equity impacts differ by service design variables such as providing corner-to-corner or curb-to-curb service or requiring trips to start/end at a transit stop. For instance, we found that riders at agencies with corner-to-corner service felt more satisfied with wait times; cross-agency trip data could indicate whether corner-to-corner services have shorter wait times on average than curb-to-curb services. We also found that riders at public microtransit services that replaced bus routes or used corner-to-corner service were less satisfied with the service overall than those that maintained bus routes and offered curb-to-curb service. The FMLM service in a commercial area, meanwhile, yielded the biggest rider-reported improvements in access to employment. Future work could control for other differences between services, such as density, land use, and service area demographics to isolate the impacts of the design variables.

Finally, a mode choice model that incorporates stated-preference data from public microtransit riders could identify additional factors underlying mode choice preferences of public microtransit passengers, how these differ from non-riders, and how these changed during the Covid-19 pandemic. We discuss the development of one such model in the next chapter.

4.5. Appendix A

This appendix contains select demographics for survey respondents who had never used public microtransit, survey respondents who had used public microtransit at least once, the population in the 14 public microtransit service areas targeted with the survey, and the U.S. population as a whole. Race, household income, age, gender, and vehicle ownership for the U.S. are taken from ACS 2021 one-year estimates, while the same measures for the service areas are calculated using QGIS and ACS 2021 one-year estimates at the census tract level (U.S. Census Bureau 2022). Pre-pandemic commute mode shares use ACS 2019 five-year estimates (U.S. Census Bureau 2020). Smartphone ownership by household income and age for the U.S. population are taken from the Pew Research Center (2021). Survey sample percentages are calculated for those who responded to the question, with the percentage that did not answer provided separately.

Table 4.2. Demographics of survey sample compared to population in service areas and U.S.

	United States	14 Public Microtransit Service Areas	Survey Sample: Never used public microtransit	Survey Sample: Used public microtransit at least once
Number of people	329,725,481	1,195,073	320	1519
Race alone or in combination with one or more other races				
White	74.5%	82.5%	56.8%	54.7%
Black	14.3%	4.7%	11.5%	17.1%
Native American	1.9%	1.7%	6.4%	5.2%
Asian	6.9%	6.4%	7.7%	11.2%
Native Hawaiian & Pacific Islander	0.4%	0.7%	2.6%	1.7%
Hispanic: Any race	18.4%	19.3%	18.8%	13.9%
No response or prefer not to answer (PNA)	-	-	26.9%	36.4%
Household Income				
Under $10,000	6.0%	3.1%	8.1%	14.7%
$10,000 - $14,999	3.9%	2.3%	13.1%	10.8%
$15,000 - $24,999	7.5%	5.5%	10.0%	12.6%
$25,000 - $34,999	7.8%	6.6%	11.3%	13.1%
$35,000 - $49,999	11.3%	10.4%	6.3%	12.0%
$50,000 - $74,999	16.8%	17.5%	20.8%	16.0%
$75,000 - $99,999	12.8%	14.4%	13.6%	9.8%
$100,000 - $149,999	16.3%	19.8%	12.7%	8.5%
$150,000 and above	17.7%	20.4%	4.1%	2.6%
No response or PNA	-	-	30.9%	41.3%
Age (years)				
Under 15	18.6%	21.3%	0.0%	0.4%
15 to 19	6.6%	7.0%	2.2%	3.6%
20 to 24	6.5%	6.2%	17.0%	15.2%
25 to 34	13.8%	14.3%	27.1%	26.6%

35 to 44	12.9%	14.0%	16.6%	20.4%
45 to 54	12.6%	11.8%	17.0%	14.2%
55 to 59	6.7%	6.1%	4.4%	6.5%
60 to 64	6.3%	5.5%	3.9%	5.3%
65 to 74	9.6%	8.6%	9.6%	5.6%
75 to 84	4.5%	3.6%	2.2%	2.0%
85 and above	1.9%	1.7%	0.0%	0.1%
No response or PNA	-	-	28.4%	36.5%
Gender				
Female	50.5%	50.1%	45.1%	50.7%
Male	49.5%	49.9%	53.2%	48.4%
Other	0.0%	0.0%	1.7%	0.9%
No response or PNA	-	-	25.9%	34.8%
Vehicle Ownership				
No vehicles	8.3%	3.8%	20.5%	34.4%
1 vehicle	32.5%	28.7%	32.0%	35.4%
2 vehicles	37.1%	41.8%	31.1%	19.5%
3 or more vehicles	22.1%	25.6%	16.4%	10.7%
No response or PNA	-	-	23.8%	32.3%
Smartphone Ownership by Household Income *For survey sample columns, cutoff is $25,000 rather than $30,000				
All incomes	85%	-	91.0%	94.5%
Less than $30,000*	76%	-	83.3%	90.8%
$30,000 - $49,999*	83%	-	82.4%	93.3%
$50,000 - $74,999	85%	-	97.8%	98.6%
$75,000 or more	96%	-	98.5%	98.3%
No response or PNA	-	-	26.9%	37.5%
Smartphone Ownership by Age (years)				
Ages 18-29	96%	-	79.7%	90.3%
30-49	95%	-	100.0%	98.1%
50-64	83%	-	100.0%	96.4%
65 and above	61%	-	96.2%	94.2%
Pre-Pandemic Mode Share				
	Commute		Overall	
Drive alone	76.3%	80.2%	28.4%	16.6%
Carpool	9.0%	9.3%	18.1%	15.1%
Public transport	5.0%	1.5%	25.6%	39.5%
Walk	2.7%	1.4%	13.0%	13.4%
Other	1.8%	1.6%	14.9%	15.4%
Work from home	5.2%	6.0%	-	-

4.6. Appendix B

This appendix shows cross-tabulations for select individual characteristics, including not owning a smartphone, not having a bank account, having a disability that precludes driving, never having access to a personal vehicle, always having access to a personal vehicle, being 60 years of age or above, and having a household income below $15k.

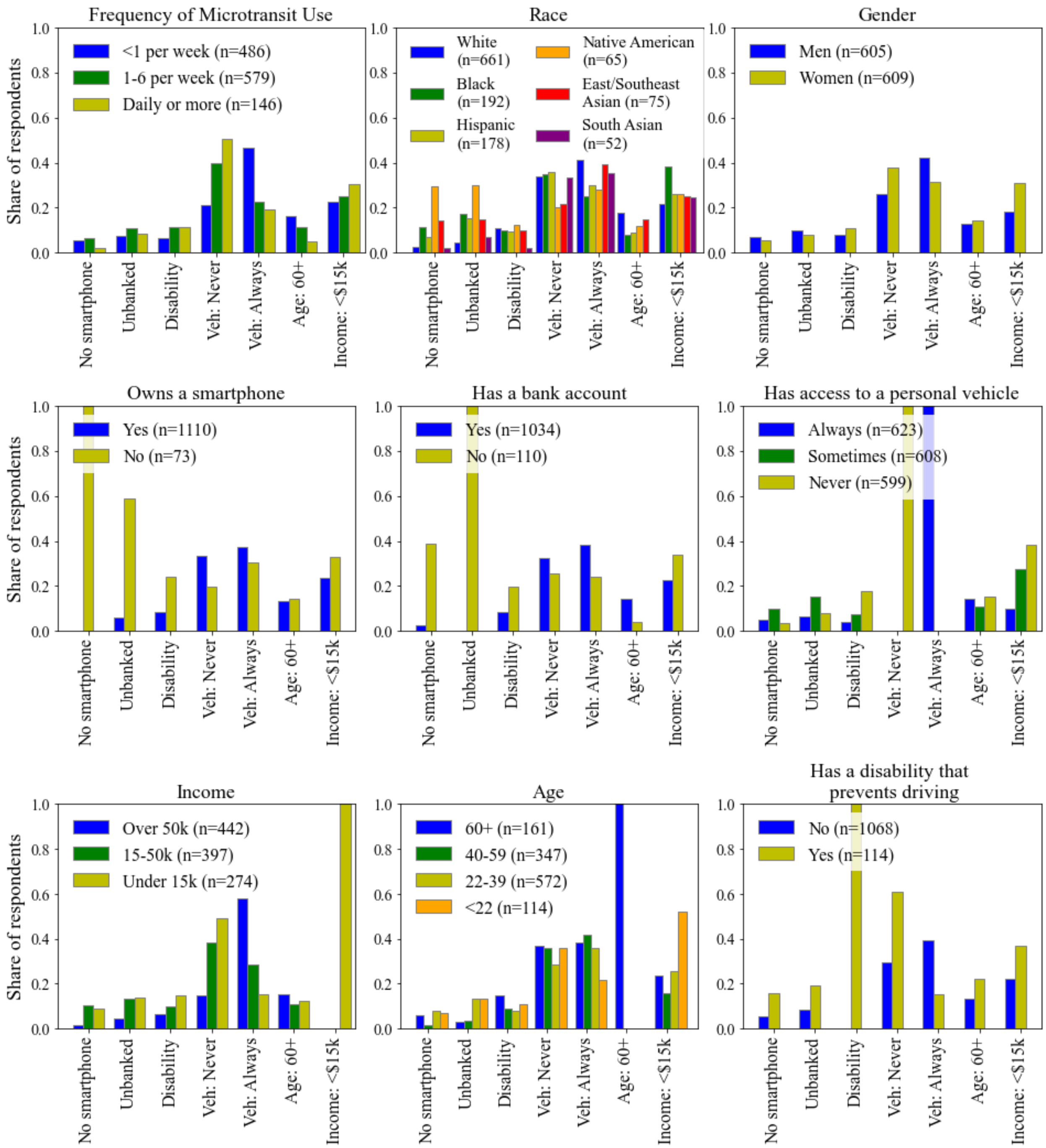


Figure 4.12. Cross-tabulations for select individual characteristics.

4.7. Acknowledgements

The authors would like to acknowledge the Transportation Sustainability Research Center for its generous support for the costs associated with producing and distributing paper surveys, as well as the Northwestern University Transportation Center on Telemobility for its financial support for this research and text message survey distribution. We would also like to thank three microtransit companies for sharing anonymous microtransit trip data, identifying interested public transportation agencies, and distributing the survey to microtransit riders. Thanks also goes to the contacts at each participating public transit agency for coordinating survey distribution. We would also like to recognize the National Science Foundation Graduate Research Fellowship Program and the U.S. Federal Highway Association Dwight D. Eisenhower Fellowship Program for enabling us to pursue this research.

4.8. References

Bills, T., & Walker, J. (2017). Looking beyond the mean for equity analysis: Examining distributional impacts of transportation improvements. *Transport Policy* 54, 61-69. https://doi.org/10.1016/j.tranpol.2016.08.003

Blodgett, M., Khani, A., Negoescu, D. & Benjaafar, S. (2017). Public/Private Partnerships in transit: Case studies and analysis (Report). Minnesota Council on Transportation Access. Accessed at http://conservancy.umn.edu/handle/11299/192846.

Brown, A., Manville, M., & Weber, A. (2021). Can mobility on demand bridge the first-last mile transit gap? Equity implications of Los Angeles' pilot program. *Transportation Research Interdisciplinary Perspectives* 10. https://doi.org/10.1016/j.trip.2021.100396

Cape Ann Transportation Authority. Dial-a-Ride & ADA Service. https://canntran.com/dial-a-ride/. Accessed Nov. 15, 2022.

Federal Transit Administration (2021). *Mobility on Demand (MOD) Sandbox Program*. https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program. Last updated June 29, 2021. Accessed July 28, 2021.

Haglund, N., Mladenović, M.N., Kujala, R., Weckström, C., & Saramäki, J. (2019). Where did Kutsuplus drive us? Ex post evaluation of on-demand micro-transit pilot in the Helsinki capital region. *Research in Transportation Business & Management* 32, 100390, ISSN 2210-5395. https://doi.org/10.1016/j.rtbm.2019.100390

Johnson, D. (2020). Microtransit Gives City Agencies a Lift During the Pandemic. *Wired*. https://www.wired.com/story/microtransit-gives-city-agencies-a-lift-during-the-pandemic/. Accessed July 28, 2021.

Lake County, IL. Ride Lake County. https://www.lakecountyil.gov/563/Ride-Lake-County. Accessed Nov. 15, 2022.

Lucken, E., Shaheen, S. (2021). Incorporating Mobility-on-Demand (MOD) and Mobility-as-a-Service (MaaS) automotive services into public transportation. *Handbook of Public Transport Research*. DOI: https://doi.org/10.4337/9781788978668.00028, pp. 410-433.

Lucken, E., Trapenberg Frick, K., & Shaheen, S.A. (2019). "Three Ps in a MOD:" Role for mobility on demand (MOD) public-private partnerships in public transit provision.

Research in Transportation Business & Management. The future of public transport 32, 100433. https://doi.org/10.1016/j.rtbm.2020.100433

Macfarlane, G.S., Hunter, C., Martinez, A., & Smith, E. (2021). Rider Perceptions of an On-Demand Microtransit Service in Salt Lake County, Utah. *Smart Cities* 4, 717-727. https://doi.org/10.3390/smartcities4020036

Martin, E., Shaheen, S., Stocker, A. (2021). Impacts of Transportation Network Companies on Vehicle Miles Traveled, Greenhouse Gas Emissions, and Travel Behavior Analysis from the Washington D.C., Los Angeles, and San Francisco Markets. *UC Berkeley Transportation Sustainability Research Center*. https://doi.org/10.7922/G2BC3WV9

Martin, E., Stocker, A., Cohen, A., & Shaheen, S.A. (2021). Mobility on Demand (MOD) Sandbox Demonstration: Dallas Area Rapid Transit (DART) First and Last Mile Solution Evaluation Report. Federal Transit Administration Report No. 0195.

Paying for Senior Care (2020). Affordable Transportation Options for the Elderly. https://www.payingforseniorcare.com/aging-in-place-technology/transportation-elderly

Pew Research Center (2021). Mobile Fact Sheet. https://www.pewresearch.org/internet/fact-sheet/mobile/

Schank, J. & Huang, E. (2022). Microtransit: A good idea just got better. *Mineta Transportation Institute.* https://transweb.sjsu.edu/research/2249

U.S. Census Bureau (2020). 2019 American Community Survey 5-Year Estimates. https://data.census.gov/table?q=DP03&tid=ACSDP5Y2019.DP03

U.S. Census Bureau (2022). 2021 American Community Survey 1-Year Estimates. https://data.census.gov/table?q=DP03; https://data.census.gov/table?q=DP04; https://data.census.gov/table?q=DP05

Xing, Y., Pike, S., Pourrahmani, E., Handy, S., & Wang, Y. (2022). Exploring the Consumer Market of Microtransit Services in the Sacramento Area, California. *UC Davis: National Center for Sustainable Transportation*. http://dx.doi.org/10.7922/G2HX1B0S

Zhou, Y., Liu, X.C., & Grubesic, T. (2021). Unravel the impact of COVID-19 on the spatio-temporal mobility patterns of microtransit. *Journal of Transport Geography* 97. https://doi.org/10.1016/j.jtrangeo.2021.103226

Chapter 5. Modeling use and impacts of public microtransit in the United States before and during the Covid-19 pandemic

Emma Lucken

Jessica R. Lazarus

Susan A. Shaheen

Joan L. Walker

This chapter addresses the third and final research objective of the dissertation: to understand how public microtransit riders perceive public microtransit relative to drive alone, TNCs, and fixed-route transit, what service and demographic characteristics impact their likelihood of using each mode, and how this changed in the Covid-19 pandemic.

As lead author, I adapted a stated preference experiment from Lazarus et al. (2021) to test the impact of public microtransit service characteristics and Covid-19 conditions on mode choice; coordinated survey distribution with three microtransit companies and 14 public transportation agencies; estimated a mode choice model from the stated preference results, including a flexible variance/covariance matrix with individual variation in shared error terms between modes; and used the mode choice model to forecast mode shares for a range of demographic groups and service designs. I wrote the original draft and revised it based on feedback from the other authors.

ABSTRACT

Before and during the Covid-19 pandemic, public transportation agencies in the United States (U.S.) have begun turning to on-demand, van-based microtransit to lower operating costs in areas with low levels of ridership. To identify service design improvements for public microtransit, agencies need to understand the factors underlying riders' choice to use public microtransit relative to other modes, as well as how these factors have shifted in the Covid-19 pandemic. From April to December 2021, we surveyed 1519 microtransit riders and 320 non-riders across 14 public transit agencies to capture their stated preferences in a total of 5109 pre-pandemic trip scenarios and 4636 pandemic trip scenarios. We estimated a mixed logit model, the first mode choice model to incorporate public microtransit based on stated preference data from experienced public microtransit passengers. The choice model also includes ride-alone Uber/Lyft, pooled Uber/Lyft, personal vehicle, fixed-route bus, and first-mile/last-mile public microtransit and Uber/Lyft as fixed-route transit connections. Major findings include: 1) forecasts suggest personal vehicle mode share is highest in systems that replace fixed-route bus service with public microtransit and lowest in systems with supplemental, door-to-door public microtransit, while the reverse is true for the combined mode share of fixed-route bus and microtransit; 2) smartphone ownership and access to a personal vehicle have a larger impact than income on forecasted mode splits; 3) experienced microtransit riders view public microtransit as

more correlated with Uber/Lyft than with fixed-route bus; 4) riders perceive fixed-route bus service more negatively than public microtransit as percent of in-patient beds in their county filled with Covid-19 patients increases; and 5) trip cost has less of an impact on mode choice during the Covid-19 pandemic.

Keywords: Mobility-on-Demand; Microtransit; Mode Choice Model

5.1. Introduction

Even before the COVID-19 pandemic, the growing number of public transportation agencies partnering with Mobility on Demand (MOD)/Mobility as a Service (MaaS) companies raised the question of what role MOD/MaaS companies can and should play in the provision of public transport (Lucken & Shaheen, 2021). We use the term MOD in this paper, as this terminology is consistent with the U.S. Department of Transportation's terminology and early initiatives in this space (Shaheen & Cohen, 2020). There is notable overlap between the MOD and MaaS concepts (Shaheen, Cohen, & Farrar, 2020; Shaheen & Cohen, 2021). The partnership trend behind public MOD services has only accelerated since the pandemic began, as public transit agencies attempt to stem revenue losses from plummeting ridership and serve their remaining riders in a more cost-effective way (Johnson, 2020).

In the previous chapter, we presented the demographics and replaced modes of public microtransit riders based on direct survey questions about their travel behavior. Stated preference experiments offer another approach to identifying the mode shift and transportation equity impacts of public microtransit services. Stated preference surveys support the estimation of mode choice models that quantify the impacts of service design elements on the decision to use a given mode, how travelers perceive that mode relative to other options, how these impacts and perceptions differ by demographic group, and how ridership and mode share may change in new contexts, such as a different service design or COVID-19 infection level. One pre-pandemic study used a stated preference survey in four California metropolitan regions to develop a mode choice model for three TNC modes: ride-alone, door-to-door pooled ride, and indirect pooled ride (in which riders walk to or from a more efficient pick-up or drop-off location). The model showed that women and low-income riders were more willing to choose pooled options and that riders preferred ride-alone TNC for trips to or from home (Lazarus et al., 2021). Another stated-preference survey on the impact of Covid-19 on Spanish public transport and shared mobility users' willingness to pay found that health measures like vehicle disinfection increased riders' likelihood to choose shared modes but only if fares remained at pre-pandemic levels (Awad-Núñez et al., 2021).

In the last year, a few studies have emerged that incorporate app-based public MOD options into mode choice models. A Connected Cities with Smart Transportation report from August 2021 used a new method to simulate FMLM and direct microtransit trips based on existing trip data from five cities (Chow et al., 2021). The simulated microtransit trips were then combined with public trip data on other modes to estimate a choice model that includes car, bike, fixed-route bus, walk, and microtransit. After testing the model on four of the original cities, the authors forecasted microtransit ridership in two other groups of cities with the same predicted total

VMT. This enabled projection of which cities may be well-suited for microtransit services, but the lack of data on individual riders' demographics and preferences meant the work could not identify factors that motivate individual riders' choice of mode. One still-unpublished study used a stated-preference survey of public transit and car commuters in Israel to examine willingness to use new microtransit services based on fare, number of other passengers, and reservation, walk, wait, and in-vehicle time (Soria et al., 2022). The work found that car commuters were more sensitive to COVID risk and travel time increases than public transit commuters when deciding whether to try microtransit, although car commuters who viewed sharing more favorably were more willing to try the new mode. One disadvantage of this study is that few respondents had used public microtransit before, so had less experience to inform which mode they would choose in the survey scenarios.

No work thus far has used stated preferences from an enriched sample of experienced public microtransit riders to estimate a mode choice model or used discrete choice analysis to examine how preferences between personal vehicle, TNCs, public microtransit, and fixed-route bus have shifted during the Covid-19 pandemic. This paper aims to fill these gaps, using a stated preference survey of U.S. public microtransit riders and non-riders between April and December 2021 to identify: 1) who is using public microtransit; how they perceive public microtransit relative to personal vehicle, ride-alone and pooled TNC, and fixed-route bus; and how their mode choice preferences differ from people who are not using it, and 2) how the preferences underlying mode choice between this set of private and shared modes changed during the Covid-19 pandemic.

5.2. Methodology

We identified public transportation agencies with microtransit services across a range of U.S. locations, ridership demographics, and use cases by first requesting recommendations from TransLoc, Via Transportation, and Spare Labs, three private microtransit companies that partner with such agencies. After connecting with interested agencies, the company or agency distributed the surveys from April to December 2021 through email, text, posting the link on the service website, and/or paper flyers onboard the microtransit vehicles. Respondents could select English or Spanish versions of the survey. We encouraged participation by offering a drawing incentive.

Survey respondents were presented with three trip scenarios set in a pre-pandemic context and three trip scenarios set during the pandemic. They were first introduced to the seven possible modes: their personal vehicle, their local publicly funded microtransit service, ride-alone Uber/Lyft, pooled Uber/Lyft, their local public fixed-route bus service, and two modes in which either the local microtransit service or Uber/Lyft were used as first-mile/last-mile access to the local fixed-route transit service. Respondents who reported never hearing about the local microtransit service before were presented with a photo of one of the vehicles alongside a description of the service, including how to use it as well as its hours and fare. To simplify the decision and help respondents pay attention to all attributes of each mode when making their decision, only three of the seven possible modes were presented in each scenario. The local microtransit service was included as an option in each scenario, and the local microtransit service as first-mile/last-mile access to local fixed-route transit was included in at least one pre-pandemic and one pandemic scenario. The remaining modes were randomly chosen, although personal vehicle only appeared as an option to respondents who reported having access to a personal vehicle always or sometimes. Figure 5.1 shows an example of one pandemic scenario.

Scenario 4

In this scenario, the COVID-19 pandemic is in a state of: **community spread**.

There is a vaccine available and it has been distributed to **1 in 2 people**. You and your close family and friends **HAVE NOT** been offered the vaccine.

Imagine you are making a trip **from home** to **a store** with **plenty of time to spare.** You have the following options to make this trip.

	SW Prime	Ride Alone Uber/Lyft	Shared Ride Uber/Lyft
ESTIMATED COST and TRAVEL TIMES:			
Total cost	$10	$19	$17.3
Total time	33 min.	17 min.	25 min.
Walk time	7 min.	0 min.	2 min.
Wait time	6 min.	2 min.	6 min.
In-vehicle time	20 min.	15 min.	17 min.
RELIABILITY: How often the vehicle arrives late at pick-up.			
15 minutes late	8 in 10 times	3 in 10 times	1 in 10 times
30 minutes late	1 in 10 times	0 in 10 times	2 in 10 times
OTHER FACTORS:			
# Other riders	5	0	1
# Transfers	0	0	0

Under these COVID-19 and vaccination conditions, which would you choose for a trip from home to a store with plenty of time to spare?

Figure 5.1. One of three scenarios set during the Covid-19 pandemic. For pre-pandemic scenarios, the first two paragraphs were replaced with the statement, "Think back to before the Covid-19 pandemic."

The trips in each scenario had five potential origins and destinations: home, work (or school), a healthcare appointment, a store, or a recreational activity. Trips to work/school always began at home, and these trips were only presented to respondents who reported physically commuting to work or school at least once per week before the Covid-19 pandemic (for the three pre-pandemic scenarios) or currently (for the pandemic scenarios). The respondents were told they had no, some, or plenty of time to spare for their trip. For the three pandemic scenarios, respondents were also told whether the Covid-19 pandemic was in a state of accelerated spread (hospitals full or almost full), community spread (requires widespread testing and contact tracing but NOT shelter-in-place advisories), or containment (mostly business-as-usual, monitor with targeted testing and contact tracing). They were also told what fraction of the population had been vaccinated and whether the respondent and/or their close family and friends had been offered the vaccine (the survey stated they had been "offered" the vaccine as opposed to "received" the vaccine in an attempt to avoid dropout from vaccine-averse respondents). Respondents were told the scenarios assume the vaccine provides nearly complete protection from severe illness or death from Covid-19 and that all travel choices follow recommended Covid-19 safety guidelines, including required masks, plastic partitions between drivers and passengers, six feet between passengers, and frequent cleaning.

In addition to these attributes of the overall trip, respondents were shown the total cost, total time, walk time, wait time, and in-vehicle time on each mode, as well as the number of other passengers, number of transfers, and frequency with which the mode arrives at pick-up 15 minutes and 30 minutes late (units of x in 10 times). Wait time and frequency of delay were always zero for personal vehicle, number of other passengers was always zero for ride-alone Uber/Lyft and personal vehicle, and number of transfers was only non-zero for the fixed-route bus and two first-mile/last-mile modes. The levels chosen for each attribute differed by mode to reflect the full range of travel times, fares, and occupancy observed in the field, based on microtransit trip data shared by two companies as well as Uber/Lyft and fixed-route bus estimates for trips in the microtransit service areas of participating transit agencies. The levels for each mode in each scenario were randomly chosen from the range of potential values. However, the levels for in-vehicle time, cost, and transfers were loosely connected across modes so all modes in a given scenario reflected the context of a short, medium, or long trip.

The survey also included questions on the respondents' travel behavior, including modes used and frequency of use before and during the Covid-19 pandemic, demographic questions, and whether the respondent had been or planned to get vaccinated.

The survey responses were cleaned to eliminate respondents from outside the geographic regions of the public transit agency identified in their survey, duplicate responses, and responses in which a stated preference question was answered in less than three seconds. The three-second cut-off was chosen after analysis of the distribution of response times for these questions, as it marked a drop in the distribution. This could suggest that most people clicking through the questions without looking at even the names of the modes did so in less than three seconds.

We estimated a mixed logit choice model to identify how microtransit service characteristics and demographics impacted the preferences underlying mode choice, as well as how these preferences differed before and during the Covid-19 pandemic. The mixed logit structure enabled us to include shared error components in the model to account for correlation in preferences between modes. In contrast, multinomial logit models assume a restricted diagonal variance-covariance matrix, which ignores statistically significant correlations between modes and can distort marginal rates of substitution between modes when forecasting impacts or estimating replaced modes. We used the estimates from the shared error components to calculate the correlation matrix between modes to examine which modes survey respondents perceived as most correlated with public microtransit.

Finally, we used the estimated model to forecast changes in mode shares for different demographic groups, including by income, smartphone ownership, and personal vehicle access.

We also forecasted mode shares under different service models, including systems without public microtransit, with unrestricted microtransit, with only FMLM microtransit, and with door-to-door microtransit that has replaced public bus service. For the forecast scenario, we set trip characteristics based on a 20-minute drive in a personal vehicle under pre-pandemic conditions in which public microtransit takes longer than driving alone but less time than fixed-route bus. We drew average microtransit and fixed-route costs and wait times from the public transportation agencies represented in the survey, used Uber price estimator in the service locations to set TNC costs, and employed a combination of sources to calculate drive alone costs (IRS 2021, Levinson 2014, Uber 2022). Table 5.1 includes the travel time and cost values used in the base case forecast scenario. Demographic variables in the base case were set at the average values for survey respondents (age 40, household income of 50k, always have access to a personal vehicle, own a smartphone, used public microtransit more than twice). Dummy variables related to trip purpose, time sensitivity, and service design characteristics were set to zero. We adjusted the model constants in the base case to reflect the pre-pandemic mode shares of survey respondents (who are skewed toward microtransit and fixed-route transit riders). For a comparison to the general population, we also adjusted the model constants to reflect U.S. commute mode shares from the 2019 American Community Survey (ACS) five-year estimates. In this second set of constants, we set microtransit mode shares as equal to TNC mode shares. For all forecasting, we left pooled TNC and FMLM TNC out of the model for simplicity.

Table 5.1. Travel time, cost, and delay frequency values by mode in base case forecast scenario.

Variable	Personal Vehicle	Ride-Alone Uber/Lyft	Public Microtransit	Fixed-Route Bus	FMLM Public Microtransit to Fixed-Route Bus
In-vehicle time (min.)	20	20	23	30	26
Wait time (min.)	0	6	9	9	9
Walk time (min.)	1	0	0	5	0
Trip Cost ($)	4	11	2.5	1.5	2.5
Frequency of 15-30 min. delay (x in 10 times)	0	1	3	3	3

5.3. Results

5.3.1. Demographics

The survey was taken by 1839 people across 14 agencies and 12 states. The respondents answered a total of 5109 pre-pandemic scenarios and 4636 pandemic scenarios. 1221 respondents (66.4%) had used their local microtransit service at least three times, 298 (16.2%) had used it once or twice, and 320 (17.4%) had never used it. The sample purposely skews toward public microtransit riders, as these respondents have experience with the new mode and can better envision the choice offered in stated-preference scenarios between public microtransit and competing modes. No other stated-preference surveys have targeted these riders to this extent, and our study aims to learn from the experiences and preferences of this more transitoriented population. Due to the enriched sample of respondents more likely to use public microtransit and public transit in general, results will skew toward the best-case scenario for public microtransit. We divided the riders into people who used it once or twice (“inexperienced riders”) and those who used it three times or more (“experienced riders”) because this was the divide that yielded the greatest significance in the model in affecting mode choice and perceived correlation between modes. Using it at least three times could indicate a certain level of accepting the mode, whereas those who used it once or twice may have been willing to try public microtransit but decided against continuing to use it.

Of the people who had used microtransit at least three times, 27% reported always having access to a personal vehicle, 33% reported sometimes having access to a personal vehicle, and 39% reported never having access to a personal vehicle, compared to 47%, 34%, and 19%, respectively, among people who had tried microtransit twice or less. As another measure of vehicle access, 38% of experienced riders reported owning no vehicles, compared to 20% of inexperienced and non-riders, 3.8% of the general population in the 14 microtransit service areas, and 8.3% of people in the U.S. Fifty-five percent of overall respondents identified as white; 16% as Black; 15% as Hispanic; 5% as Native American; 4% as South Asian; 3% each as East Asian and Southeast Asian; 2% each as Native Hawaiian / Pacific Islander and Middle Eastern / North African; 1% as Sub-Saharan African; and 9% as more than one race or ethnicity (35% did not identify their race or ethnicity). These percentages were similar for people who had used microtransit at least three times and those who used it less. The survey sample was less white than the general population in the service areas (83%) or the U.S. (75%).

Respondents who had used microtransit at least three times were slightly more middle-aged than those who had used it twice or less, with 13% of both groups above age 60, 44% vs. 35% from age 35 to 59, and 43% vs. 52% from age 15 to 34 (37% and 31%, respectively, did not report their age). The survey sample as a whole was more middle-aged than the service area population and U.S. population, as well; 19% of the service area population and 22% of the U.S. population were over age 60, 32% of each were ages 35 to 59, and 28% and 27%, respectively, were ages 15 to 34. Experienced microtransit riders also tended to have lower household incomes than inexperienced microtransit users, with 65% vs. 53% making less than 50k and 9% vs. 16% making over 100k (43% and 32%, respectively, did not report household income). The sample was lower income than the general population in the service area, which was itself slightly higher income than the U.S. population: 28% of the service area population and 37% of the U.S. population had household incomes under 50k, while 40% and 34%, respectively, had household incomes over 100k.

The same percentage of respondents used wheelchairs (2%) regardless of microtransit use, while more experienced microtransit users were more likely than inexperienced microtransit users or nonriders to have disabilities that prevented them from driving (10% vs. 8%), lack a driver’s license (30% vs. 22%), have a bank account (93% vs. 85%), and own a smartphone (97% vs. 89%, compared to 85% of the U.S. population). More extensive analysis of respondents’ demographics can be found in Chapter 4 and Table 4.2.

5.3.2. Mixed Logit Model

Table 5.2 shows the mixed logit model drawn from the full dataset of 3042 pre-pandemic scenarios and 2803 pandemic scenarios. The table includes parameter values, p-values, and check marks to indicate presence in the seven modes' utility equations. We organize the table rows as follows: first we provide alternative-specific constants, then travel time and cost variables, including frequency of 15-30 minute delays. The next section includes trip origin and destination, reflecting trip purposes such shopping and healthcare, as well as time sensitivity of the trip (i.e., whether the respondent was told they have no time to spare). The section on demographic variables includes prior public microtransit use, access to a personal vehicle, smartphone ownership, age, and household income. The following two sections include variables that were not defined in the stated preference scenario but were found to impact respondents' preferences, including local Covid-19 conditions and the design of the local public microtransit service. The final section shows the covariance parameters between modes, including variation by access to a personal vehicle and how many times the respondent had used public microtransit.

Table 5.2. Mixed logit model comparing mode choice before/during Covid-19 pandemic:

Variables	Parameters	P>|z|	MT	RA TNC	P TNC	PV	B	MT-B	TNC-B
Alternative Specific Constants									
Microtransit (MT)	0	(fixed)	√						
Ride Alone TNC (RA TNC)	***-0.655***	0.004		√					
Pooled TNC (P TNC)	***-0.994***	0.000			√				
Personal Vehicle (PV)	***-0.597***	0.001				√			
Fixed-Route Bus (B)	**0.439**	0.021					√		
Microtransit to Fixed-Route Bus (MT-B)	0.256	0.204						√	
TNC to Fixed-Route Bus (TNC-B)	***-0.780***	0.000							√
Travel Time and Cost									
In-vehicle time (min)	***-0.016***	0.000	√	√	√	√	√	√	√
Wait time (min)	***-0.018***	0.000	√	√	√		√	√	√
Walk time (min)	**-0.012**	0.042	√	√	√	√	√	√	√
Trip Cost ($): Before Covid	***-0.034***	0.000	√	√	√	√	√	√	√
Trip Cost ($): During Covid	***-0.018***	0.000	√	√	√	√	√	√	√
Freq. of 15-30 minute delay (x in 10 times)	***-0.030***	0.000	√	√	√		√	√	√
Trip Origin, Destination, and Time Sensitivity									
Store — **Origin**	**-0.440**	0.010	√	√	√				
	-0.750	0.000					√	√	√
Healthcare appointment — **Destination**	***-0.373***	0.005	√		√			√	√
	-0.683	0.000					√		
Respondent told they have no time to spare	***-1.070***	0.000	√				√	√	√
Demographic Variables									
Used public microtransit more than two times	***0.798***	0.000	√						
	0.437	0.001						√	
Always has access to a personal vehicle	***0.684***	0.000				√			

Vehicle access unreported	0.640	0.343				√			
Does not own a smartphone	**0.545**	0.031					√	√	√
Smartphone ownership unreported	-0.160	0.243					√	√	√
Age – In years – Before pandemic	***-0.022***	0.000			√		√	√	√
Age – In years – During pandemic	***-0.026***	0.000			√		√	√	√
Age – In years – No difference before vs. during pandemic	***-0.014***	0.002		√					
Age – Unreported	***-0.857***	0.000	√	√	√		√	√	√
Household Income ($)	***-0.003***	0.009	√				√	√	√
Household Income unreported	0.017	0.898	√				√	√	√
State of Covid-19 Pandemic									
Average percent of the county's inpatient beds filled with Covid-19 patients over the past 7 days	***-0.095***	0.000					√	√	√
	-0.064	0.000	√						
	-0.047	0.012		√	√				
Local Service Design Characteristics									
FMLM restriction	***1.060***	0.000					√	√	
Corner-to-corner service	***0.355***	0.005						√	
	-0.237	0.031	√						
Replaced fixed-route bus service with curb-to-curb	0.325	0.055	√						
Service uses taxi vehicles	***-0.812***	0.000					√	√	
Covariance Parameters (Error Components)									
Ride-alone & Shared TNC	***1.020***	0.000		√	√				
Microtransit & Personal Vehicle – Sometimes/Never has access to a personal vehicle	***1.040***	0.000		√		√			
Microtransit & Personal Vehicle – Always has access to a personal vehicle	***0.686***	0.000		√		√			
Unshared modes	***0.906***	0.000		√		√			
Three bus modes	***0.897***	0.000					√	√	√
Two microtransit modes	***0.827***	0.000	√					√	
Microtransit & fixed-route bus – Never tried MT	***1.010***	0.000	√				√		
Microtransit & fixed-route bus – Rode 1-2 times	***0.722***	0.001	√				√		
Microtransit & fixed-route bus – Rode 3+ times	***0.615***	0.000	√				√		
Microtransit & TNC modes – Rode 1+ times	***0.677***	0.000	√	√	√				
Microtransit & TNC modes – Never tried MT	0.489	0.074	√	√	√				

[a] $p < 0.01$ is bold and italicized; $p < 0.05$ is bold. Some non-significant results are left in for comparison.
[b] Log-likelihood at zero: -10705.98. Log-likelihood at convergence: -8224.77. Number of Observations: 9745 scenarios (1839 respondents).

Finding 1: Among the service characteristics that public transit agencies can adjust to increase microtransit ridership, reducing wait time has a bigger impact than reducing in-vehicle or walk time.

Table 5.3 shows the amount public transportation agencies would need to change five service characteristics to increase the combined mode share of door-to-door and FMLM microtransit by 0.5%. This assumes a base mode share of 19.6%, drawing from pre-pandemic mode shares among survey respondents who used public microtransit more than twice. To increase mode share among this group to 20.1%, public transportation agencies would need to reduce fares by $1.02, delay by 11.1%, wait times by 2.17 minutes, in-vehicle times by 2.5 minutes, and walk times by 3.85 minutes. Based on forecasting results, the impacts of service improvements generally increase slightly with age and decrease with income, meaning that the oldest group and lowest-income group would most increase their microtransit use in response to improvements in microtransit service characteristics.

While in-vehicle, wait, and walk time are as onerous before and during the Covid-19 pandemic, the negative impact of trip cost on mode selection is almost half as great during the pandemic than before. The result suggests that considerations of a mode's risk of Covid-19 exposure reduce the importance of cost in mode selection. Based on the parameters for trip cost and in-vehicle time, respondents' value of time increases from $28/hour pre-pandemic to $53/hour during the pandemic, reflecting the increased risk of in-vehicle time.

Table 5.3. Change in microtransit service characteristic needed to achieve a 0.5% increase in combined mode share of door-to-door and FMLM microtransit. [a]

	Cost	Frequency of Delay	Wait Time	In-Vehicle Time	Walk Time
0.5% increase in microtransit mode share	-$1.02	-11.1%	-2.17 min.	-2.50 min.	-3.85 min.

[a] Based on starting mode share of 19.6%, drawn from pre-pandemic mode shares among survey respondents who used public microtransit more than twice. Forecast is for a representative trip that takes 20 min. by personal vehicle and a representative rider who has used microtransit more than twice, has a household income of $50k, and is 40 years old (complete values provided in methodology section).

Finding 2: Unlike other shared modes, public microtransit use does not decrease with age.

With every additional year of age, respondents were more likely to choose personal vehicle or public microtransit than ride-alone Uber. As age increased, respondents were even less likely to choose pooled Uber/Lyft, fixed-route bus, or either FMLM mode. This aversion to shared modes (other than microtransit) strengthened in the pandemic scenarios, presumably due to the increased health risks of sharing a vehicle. One reason older individuals seemed as likely to choose microtransit as personal vehicle, all else equal, may be that the microtransit services are in part marketed as a more convenient alternative to paratransit.

Finding 3: Smartphone ownership and access to a personal vehicle have a larger impact than income on forecasted mode splits (as shown in Table 5.3).

The model coefficients indicate that respondents without smartphones are less likely to use public microtransit, TNC, or personal vehicle than fixed-route bus. Higher-income respondents are more likely to use personal vehicle or TNC than other modes, and respondents who always have access to a personal vehicle are more likely to use that mode.

Table 5.4 shows how differences in the model coefficients translate to differences in mode splits between demographic groups.

Within the subset of respondents who own a smartphone and always have access to a personal vehicle, income has a slight impact on mode shares, with a 5.0 range in personal vehicle mode share down to a 0.6 range in FMLM microtransit mode share between the lowest and highest income groups (though TNC and personal vehicle use increases with income and use of shared modes decreases with income). Within the lowest income group, however, smartphone ownership and access to a personal vehicle have a large impact on mode shares, with personal vehicle mode share dropping by 16.3, fixed-route mode share increasing by 11.0, and combined microtransit increasing by 7.4 for low-income groups with smartphones but without full access to a personal vehicle. For low-income groups who also do not own smartphones, the mode shares of personal vehicle, TNC, and door-to-door microtransit decrease while public fixed-route mode share almost doubles. Interestingly, demand for FMLM public microtransit is also highest for low-income groups without smartphones or personal vehicles, perhaps reflecting a preference for fixed-route transit but a desire for better fixed-route connections.

Table 5.4. Forecasted difference from base mode shares (shown in parentheses).[a]

<table>
<tr><th></th><th colspan="3">Low- Income
(0-10k)</th><th>Mid-Income
(50k)</th><th>High-
Income
(100-150k)</th></tr>
<tr><td>Owns a smartphone</td><td></td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Always has access to
a personal vehicle</td><td></td><td></td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Combined Public Transit</td><td>23.2</td><td>22.8</td><td>2.1</td><td>0 (49.7)</td><td>-3.8</td></tr>
<tr><td>Combined Microtransit</td><td>3.2</td><td>10.6</td><td>0.9</td><td>0 (19.6)</td><td>-1.5</td></tr>
<tr><td>Door-to-door Microtransit</td><td>-1.0</td><td>8.1</td><td>0.7</td><td>0 (13.8)</td><td>-1.1</td></tr>
<tr><td>FMLM Microtransit</td><td>4.2</td><td>2.5</td><td>0.2</td><td>0 (5.8)</td><td>-0.4</td></tr>
<tr><td>Public Fixed-Route</td><td>20.0</td><td>12.2</td><td>1.2</td><td>0 (30.1)</td><td>-2.3</td></tr>
<tr><td>TNC</td><td>0.3</td><td>2.1</td><td>-0.3</td><td>0 (6.9)</td><td>0.5</td></tr>
<tr><td>Personal Vehicle</td><td>-22.8</td><td>-18.1</td><td>-1.8</td><td>0 (43.5)</td><td>3.2</td></tr>
</table>

[a] Base mode shares calculated based on pre-pandemic mode shares of survey respondents, for a representative trip that takes 20 min. by personal vehicle (values provided in methodology section).

Finding 4: For trips from stores and to healthcare appointments, respondents preferred public microtransit over fixed-route bus.

Based on the estimated coefficients, respondents were least likely to use the three fixed-route bus modes and most likely to use personal vehicle on trips from a store, suggesting they perceived transporting purchases as easiest in a personal vehicle, more difficult on public microtransit or TNC, and most difficult by bus. For trips to healthcare appointments, respondents were least likely to use fixed-route bus and most likely to use ride-alone TNC or personal vehicle, suggesting they perceived ride-alone modes as most reliable and bus as least reliable for time-sensitive trips. When told they had no time to spare for the trip, respondents were less likely to use public microtransit or the three modes involving fixed-route bus.

Finding 5: As more Covid-19 patients fill inpatient beds in the county where the microtransit service is located, respondents have the greatest aversion to the three modes involving fixed-route bus, then public microtransit, and the least aversion to ride-alone and pooled TNC, compared to using their personal vehicle.

We tested the impact of telling respondents in the stated-preference scenarios the hypothetical level of Covid-19 spread and vaccination rate in their community, as well as whether they or their families had hypothetically been offered the vaccine. However, these factors did not impact their mode choice as much as actual Covid-19 conditions in the county of their local microtransit service on the day they took the survey (something we did not tell them in the survey but rather looked up afterward). The measure of Covid-19 severity that yielded the most significant results in the model was the percent of local inpatient beds filled with confirmed Covid-19 patients (averaged over the previous 7 days). This indicates that the real-world Covid-19 conditions in respondents' time and place affected their survey responses, and reflects their changing preferences for/against shared modes under these conditions.

Finding 6: The design of the public microtransit service may impact riders' underlying preferences for public microtransit modes.

While we defined the mode choices within the stated preference scenarios by the factors described in the methodology section, we found that respondents' preferences for the public microtransit modes varied by location even after controlling for the stated mode characteristics, demographic differences between respondents, and local Covid-19 conditions. In particular, services that shared certain design characteristics indicated similar impacts on likelihood to select public microtransit alone or as a FMLM mode. Respondents at the three agencies with corner-to-corner service, for example, were less likely to select public microtransit, which could reflect the inconvenience of needing to walk to the pickup/drop-off locations. These respondents were also more likely to select FMLM microtransit, perhaps indicating that the subset of people willing to use corner-to-corner service is also more willing to transfer to fixed-route service. At the two agencies that replaced fixed-route bus service with door-to-door microtransit, the results showed a weakly significant increase in likelihood of choosing public microtransit, potentially suggesting that respondents were happier with the new service than with the replaced bus routes, or that these agencies dedicated more resources to operating and/or marketing the public microtransit service, or even just that these respondents recognized that this was the only transit option available. Interestingly, these respondents were not less likely to select fixed-route bus, however. Two other agencies had unique aspects of their public microtransit services that may have been reflected in the model: one required trips to start or end at the commuter bus line; respondents at this agency were more likely than other respondents to select FMLM microtransit or fixed-route bus. The other fulfilled public microtransit requests with local taxi companies rather than agency vans. Respondents here were less likely to select FMLM microtransit or fixed-route bus, perhaps because the taxis were perceived more as a substitute than a complement to fixed-route bus, or perhaps reflecting stronger aversion to fixed-route bus service in this location.

These results are preliminary and suggest avenues for future research that controls for other differences between services, such as density and land use, to isolate impacts of the service design variables.

Finding 7: Respondents who have never used public microtransit perceived little correlation between microtransit and TNCs, whereas experienced microtransit riders view public microtransit as more correlated with TNCs than with bus (as shown in Table 5.5).

The shared error components play an important role in determining substitution between modes when the model is used in forecasting; if the public microtransit modes are removed from the model, for example, the probabilities previously assigned to those modes will shift more to modes highly correlated with public microtransit than to less correlated modes. In our model, we identified demographic variation in the shared error terms—perceived correlation between public microtransit and driving alone decreases with access to a personal vehicle, while greater familiarity with public microtransit decreases perceived correlation between public microtransit and fixed-route bus and increases perceived correlation between public microtransit and Uber/Lyft. Respondents who sometimes or never have access to a personal vehicle perceive public microtransit as more correlated to drive alone than any other mode, suggesting they view public microtransit as the closest substitute for owning their own vehicle. Of these respondents, those who have never tried public microtransit view it as next most correlated with fixed-route bus, followed by FMLM microtransit, pooled Uber/Lyft, and ride-alone Uber/Lyft, while those who have tried public microtransit at least three times perceive it as more correlated with the Uber/Lyft modes than with bus. Among respondents who always have access to a personal vehicle, meanwhile, those who have never used public microtransit perceive it as most correlated with fixed-route bus, then FMLM microtransit, then drive alone, pooled Uber/Lyft, and finally ride-alone Uber/Lyft. For vehicle owners who have tried public microtransit at three times, that order stays the same except that fixed-route bus moves from most perceived correlation to least perceived correlation.

Table 5.5a-d. Perceived correlation between modes by frequency of public microtransit use and access to a personal vehicle. Green indicates greatest correlation and red indicates least correlation.

A. *Used public microtransit 3+ times, incomplete/no access to personal vehicle:*

	Microtransit	Ride-Alone Uber/Lyft	Pooled Uber/Lyft	Drive Alone	Bus	Microtransit to Bus	Uber/Lyft to Bus
Microtransit	1	0.109	0.123	0.274	0.107	0.184	-
Ride-Alone Uber/Lyft		1	0.431	0.218	-	-	0.288
Pooled Uber/Lyft			1	-	-	-	0.323
Drive Alone				1	-	-	-
Bus					1	0.270	0.255
Microtransit to Bus						1	-
Uber/Lyft to Bus							1

B. *Used public microtransit 3+ times, complete access to personal vehicle:*

	Microtransit	Ride-Alone Uber/Lyft	Pooled Uber/Lyft	Drive Alone	Bus	Microtransit to Bus	Uber/Lyft to Bus
Microtransit	1	0.118	0.132	0.141	0.116	0.199	-
Ride-Alone Uber/Lyft		1	0.431	0.239	-	-	0.288
Pooled Uber/Lyft			1	-	-	-	0.323
Drive Alone				1	-	-	-

Bus					1	0.270	0.255
Microtransit to Bus						1	-
Uber/Lyft to Bus							1

C. Never used public microtransit, incomplete/no access to personal vehicle:

	Microtransit	Ride-Alone Uber/Lyft	Pooled Uber/Lyft	Drive Alone	Bus	Microtransit to Bus	Uber/Lyft to Bus
Microtransit	1	0.056	0.063	0.262	0.250	0.176	-
Ride-Alone Uber/Lyft		1	0.394	0.224	-	-	0.296
Pooled Uber/Lyft			1	-	-	-	0.334
Drive Alone				1	-	-	-
Bus					1	0.244	0.230
Microtransit to Bus						1	-
Uber/Lyft to Bus							1

D. Never used public microtransit, complete access to personal vehicle:

	Microtransit	Ride-Alone Uber/Lyft	Pooled Uber/Lyft	Drive Alone	Bus	Microtransit to Bus	Uber/Lyft to Bus
Microtransit	1	0.060	0.068	0.134	0.267	0.188	-
Ride-Alone Uber/Lyft		1	0.394	0.246	-	-	0.296
Pooled Uber/Lyft			1	-	-	-	0.334
Drive Alone				1	-	-	-
Bus					1	0.244	0.230
Microtransit to Bus						1	-
Uber/Lyft to Bus							1

Finding 8: Forecasts suggest personal vehicle mode share is lowest in scenarios with door-to-door microtransit that supplements existing fixed-route transit and highest in scenarios that replace fixed-route transit with microtransit. The reverse is true for total public transit mode share (fixed-route transit plus microtransit).

For the representative 20-minute trip defined in the methodology section, we forecasted changes in mode shares based on public transit service models with: 1) no microtransit service; 2) door-to-door microtransit service without FMLM restrictions; 3) microtransit service with FMLM restrictions, in which microtransit trips must start or end at a public transit stop; and 4) microtransit service that has replaced fixed-route bus service. To demonstrate individual variation in mode shares in these scenarios, we forecasted shares for individuals with and without access to a personal vehicle. Results are shown in Table 5.6.

Assuming no change in total trips (no induced demand) for individuals who always have access to a personal vehicle, forecasting the introduction of microtransit service with no FMLM restrictions suggests that about half of public microtransit trips shift from personal vehicle, about 42% from fixed-route public transit, and about 8% from TNC. Forecasted services that require public microtransit trips to start or end at public transit stops have less than half as many public microtransit trips, but higher fixed-route mode share than systems with unrestricted microtransit and more public transit trips overall than systems without public microtransit. When forecasting mode share for systems that replace fixed-route bus service with public microtransit, overall public transit mode share drops from 38.4% to 23.4% even among those more inclined to use public transit, and from 6.2% to 1.9% in the general population (the parenthetical mode shares based on 2019 ACS five-year U.S. estimates). About a third of bus mode share switches to personal vehicle and 5.7% switches to TNC.

Among those who never have access to a personal vehicle, the same trends hold true but with different magnitudes. In this group, replacing fixed-route bus with public microtransit also minimizes overall public transit mode share but by less, with 17.2% of fixed-route bus trips switching to TNCs.

Table 5.6a-b. Mode shares by service model for those with and without access to a personal vehicle. Base case in bold; forecast is based on pre-pandemic mode shares of survey respondents and a representative trip that takes 20 min. by personal vehicle (variable values provided in methodology section). Units in percentages, with mode shares adjusted from 2019 ACS five-year U.S. commute mode share estimates in parentheses.

A. Complete access to personal vehicle:

Mode	No Microtransit	With Unrestricted Microtransit	FMLM Microtransit Only	Replace Bus with Microtransit
Combined Public Transit	38.4 *(6.2)*	**49.7 *(8.3)***	41.8 *(7.0)*	23.4 *(1.9)*
Combined Microtransit		**19.6 *(2.5)***	7.0 *(1.0)*	23.4 *(1.9)*
Door-to-door Microtransit		**13.8 *(1.5)***		23.4 *(1.9)*
FMLM Microtransit		**5.8 *(1.0)***	7.0 *(1.0)*	
Public Fixed-Route	38.4 *(6.2)*	**30.1 *(5.8)***	34.8 *(6.0)*	
Personal Vehicle	53.1 *(92.3)*	**43.5 *(90.1)***	50.1 *(91.4)*	66.1 *(96.5)*
TNC	8.4 *(1.5)*	**6.9 *(1.5)***	8.0 *(1.5)*	10.6 *(1.6)*

B. No access to personal vehicle:

Mode	No Microtransit	With Unrestricted Microtransit	FMLM Microtransit Only	Replace Bus with Microtransit
Combined Public Transit	77.2 *(65.8)*	85.4 *(74.9)*	79.8 *(69.9)*	63.9 *(46.4)*
Combined Microtransit		36.0 *(29.2)*	13.8 *(13.2)*	63.9 *(46.4)*
Door-to-door Microtransit		26.4 *(18.7)*		63.9 *(46.4)*
FMLM Microtransit		9.6 *(10.5)*	13.8 *(13.2)*	
Public Fixed-Route	77.2 *(65.8)*	49.4 *(45.7)*	66.0 *(56.7)*	
Personal Vehicle				
TNC	22.8 *(34.2)*	14.6 *(25.1)*	20.2 *(30.1)*	36.1 *(53.6)*

5.4. Discussion

Our discussion of implications is sorted into three themes, with some overlap: 1) preferences underlying use of public, van-based microtransit; 2) how mode choice preferences changed during the COVID-19 pandemic; and 3) transportation equity impacts.

As the first mode choice model to incorporate public, van-based microtransit based on survey responses from an enriched sample of experienced public microtransit riders, the results allow novel insights into how respondents' preferences for public, van-based microtransit compare to their preferences for the other modes tested. As agencies decide whether to introduce microtransit service and whether to implement a door-to-door or FMLM service design, the model suggests circumstances in which respondents may most value microtransit as an option and how door-to-door microtransit might perform relative to a microtransit service that operates as a FMLM option to/from fixed-route bus. In particular, public transit agencies must consider their objective for introducing public microtransit service, from minimizing personal vehicle mode share, to maximizing the mode share of public microtransit and/or fixed-route transit, to minimized public costs while still serving a transit-dependent population. The forecasting results from this paper suggest that unrestricted microtransit service best accomplishes the goal of minimizing personal vehicle mode share, but at the cost of minimizing fixed-route transit mode share as well (setting aside systems that remove fixed-route service altogether). Restricting public microtransit service to FMLM trips protects fixed-route bus to an extent, though how much depends on how much of the FMLM microtransit mode share is assigned to fixed-route bus and how much to microtransit; fixed-route bus breaks about even if the FMLM microtransit mode share is split down the middle. Another takeaway is that public transit agencies should exercise caution when replacing fixed-route service with public microtransit, as our results suggest steep declines in overall public transit ridership and that many trips previously taken on public transit switch to personal vehicle rather than the new microtransit service.

As agencies consider how to use limited resources to improve microtransit service, the results suggest that reducing fares and frequency of pick-up delays most impacts people's propensity to use public microtransit and may attract riders away from Uber/Lyft and personal vehicle. Based on trip data from one agency that included magnitude of delay, about 30% of trips had delays greater than 10 minutes. Based on the model, reducing that number to 20% could have as large of an impact on increasing ridership as reducing wait times by about two minutes. Conversely, the agency could list their anticipated pick-up times as much as two minutes later (increasing wait times) and maintain the same level of ridership if it enabled them to reduce delays from 30% to 20%.

The model also indicates public transit agencies could make microtransit more attractive by replacing wait time with higher walk times at a ratio of up to 4:5. The lower burden of walk time suggests public transit agencies can assign microtransit pick-up and drop-off locations that reduce wait time and in-vehicle time and may be slightly farther from riders' origins and destinations. This strategy, which also applies to fixed-route bus, would need to include alternatives for people who have difficulty walking to a farther microtransit or bus stop.

Regarding the COVID-19 pandemic, the model suggests that riders transition to personal vehicle and away from modes with more passengers (TNCs, even more so public microtransit, and to the greatest extent fixed-route bus) and that they will transition back to these modes as case counts decline. Respondents' stronger aversion to fixed-route bus over public microtransit supports public transit agencies' decisions to shift from fixed-route service to microtransit service when case counts were high in their local communities. As the pandemic eases, public transportation agencies should expect sensitivity to fare to increase again, meaning fare reductions will more effectively encourage fixed-route bus or public microtransit ridership now than during the height of the pandemic.

The models also yielded several transportation equity implications. The most striking finding is that users without smartphones are much less likely to use public microtransit or TNCs, suggesting that public microtransit does not sufficiently accommodate riders without smartphones. While most public transit agencies allow riders to book rides by phone call, the discrepancy could indicate the need for additional strategies and outreach. The results also indicate that public microtransit users are more likely to be transit dependent, with lower incomes and less access to personal vehicles. Older individuals are also more likely to use public microtransit than other shared modes, all else equal, while those with higher household incomes are more likely to use personal vehicle or ride-alone TNC. These findings reinforce the importance of ensuring microtransit fares, app functionality, and service areas meet the needs of transit-dependent and older populations.

One limitation of our forecasting results is that they reflect mode shares for generic cases and demographic groups. More than mode share, VMT better reflects the environmental cost of not only personal vehicles but also TNCs, fixed-route buses, and public microtransit. To support more detailed decision-making regarding choice of microtransit service model, future work could use simulated origin-destination pairs to analyze forecasted VMT on each mode and use a simulated population that matches vehicle ownership rates and other demographic characteristics to those in this survey, larger national surveys, or surveys tailored to the location of interest. For instance, public transportation agencies can incorporate our mode choice model into their full activity-based travel demand model framework for a more complete understanding of impacts including induced demand and other behavioral shifts related to introducing public microtransit in their service area.

Next steps include forecasting mode share shifts from changes in Covid-19 conditions and comparing results to survey respondents' reported changes in frequency of trips made on each mode during the pandemic and their anticipated use post-pandemic. Applying the model to microtransit trip data from the participating transit agencies before and during the pandemic could also improve understanding of the VMT and equity impacts of these services. The results will provide additional guidance to public transportation agencies on how to tailor public microtransit services to reduce single-occupancy vehicle use and support fixed-route transit services in a socially equitable way as we continue to transition out of the Covid-19 pandemic.

5.5. Acknowledgements

The authors would like to acknowledge the Transportation Sustainability Research Center for its generous support for the costs associated with producing and distributing paper surveys, as well as the Northwestern University Transportation Center on Telemobility for its financial support for this research and text message survey distribution. We would also like to thank three microtransit companies for sharing anonymous microtransit trip data, identifying interested public transportation agencies, and distributing the survey to microtransit riders. Thanks also goes to the contacts at each participating public transit agency for coordinating survey distribution. We would also like to recognize the National Science Foundation Graduate Research Fellowship Program and the U.S. Federal Highway Association Dwight D. Eisenhower Fellowship Program for enabling us to pursue this research.

5.6. References

Awad-Núñez, S., Julio, R., Gomez, J., Moya-Gómez, B., & González, J.S. (2021). Post-COVID-19 travel behaviour patterns: impact on the willingness to pay of users of public transport and shared mobility services. *Spain. Eur. Transp. Res. Rev*. 13, 20. https://doi.org/10.1186/s12544-021-00476-4

Blodgett, M., Khani, A., Negoescu, D. & Benjaafar, S. (2017). Public/Private Partnerships in transit: Case studies and analysis (Report). Minnesota Council on Transportation Access. Accessed at http://conservancy.umn.edu/handle/11299/192846.

Chow, J.Y.J., Zimmerman, R., Rath, S., Liu, B., & Yoon, G. (2021). Urban Microtransit Cross-Sectional Study for Service Portfolio Design. USDOT Award No. 69A3551747124.

del Mar Alonso-Almeida, M. (2022). To Use or Not Use Car Sharing Mobility in the Ongoing COVID-19 Pandemic? Identifying Sharing Mobility Behaviour in Times of Crisis. *Int. J. Environ. Res. Public Health* 19, 3127. https://doi.org/10.3390/ijerph19053127

Federal Transit Administration (2021). *Mobility on Demand (MOD) Sandbox Program*. https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program. Last updated June 29, 2021. Accessed July 28, 2021.

Haglund, N., Mladenović, M.N., Kujala, R., Weckström, C., & Saramäki, J. (2019). Where did Kutsuplus drive us? Ex post evaluation of on-demand micro-transit pilot in the Helsinki capital region. *Research in Transportation Business & Management* 32, 100390, ISSN 2210-5395. https://doi.org/10.1016/j.rtbm.2019.100390

Hu, S. & Chen, P. (2021). Who left riding transit? Examining socioeconomic disparities in the impact of COVID-19 on ridership. *Transportation Research Part D: Transport and Environment* 90. https://doi.org/10.1016/j.trd.2020.102654

Internal Revenue Service (IRS) (2021). IRS issues standard mileage rates for 2022. https://www.irs.gov/newsroom/irs-issues-standard-mileage-rates-for-2022

Johnson, D. (2020). Microtransit Gives City Agencies a Lift During the Pandemic. *Wired*. https://www.wired.com/story/microtransit-gives-city-agencies-a-lift-during-the-pandemic/. Accessed July 28, 2021.

Lazarus, J.R., Caicedo, J.D., Bayen, A.M., & Shaheen, S.A. (2021). To Pool or Not to Pool? Understanding opportunities, challenges, and equity considerations to expanding the market for pooling. Transportation Research Part A: Policy and Practice 148, 199–222. https://doi.org/10.1016/j.tra.2020.10.007

Levinson, D. (2014). How much does driving your car cost, per minute? *Transportist*. https://transportist.org/2014/08/09/how-much-does-driving-your-car-cost-per-minute/

Lucken, E., Shaheen, S. (2021). Incorporating Mobility-on-Demand (MOD) and Mobility-as-a-Service (MaaS) automotive services into public transportation. *Handbook of Public Transport Research*. DOI: https://doi.org/10.4337/9781788978668.00028, pp. 410-433.

Lucken, E., Trapenberg Frick, K., & Shaheen, S.A. (2019). “Three Ps in a MOD:” Role for mobility on demand (MOD) public-private partnerships in public transit provision. *Research in Transportation Business & Management*. The future of public transport 32, 100433. https://doi.org/10.1016/j.rtbm.2020.100433

Macfarlane, G.S., Hunter, C., Martinez, A., & Smith, E. (2021). Rider Perceptions of an On-Demand Microtransit Service in Salt Lake County, Utah. *Smart Cities* 4, 717-727. https://doi.org/10.3390/smartcities4020036

Martin, E., Stocker, A., Cohen, A., & Shaheen, S.A. (2021). Mobility on Demand (MOD) Sandbox Demonstration: Dallas Area Rapid Transit (DART) First and Last Mile Solution Evaluation Report. Federal Transit Administration Report No. 0195.

Said, M., Soria, J., & Stathopoulos, A., (pending). Shifting Mobility Behaviors in Unprecedented Times: Intentions to Use On-Demand Ride Services During the COVID-19 Pandemic. https://doi.org/10.48550/arXiv.2108.02324

Shaheen, S. & Cohen, A. (2020). Mobility on Demand in the United States: From Operational Concepts and Definitions to Early Pilot Projects and Future Automation. *Analytics for the Sharing Economy: Mathematics, Engineering and Business Perspectives*. DOI: 10.1007/978-3-030-35032-1_14, pp. 227-254. https://escholarship.org/uc/item/14f893rv#main

Shaheen, S. & Cohen, A. (2021). Shared Mobility: An Overview of Definitions, Current Practices, and Its Relationship to Mobility on Demand and Mobility as a Service. In *International Encyclopedia of Transportation* (Roger Vickerman, ed.), UK: Elsevier Ltd. Vol. 5, pp. 155-159. https://doi.org/10.1016/B978-0-08-102671-7.10420-8

Shaheen, S., Cohen, A., & Farrar, E. (2020). Chapter Six: Mobility on Demand: Evolving and Growing Shared Mobility in Suburbs of Northern Virginia. *Implications of Mobility as a Service (MaaS) in Urban and Rural Environments: Emerging Research and Opportunities*. DOI: 10.4018/978-1-7998-1614-0.ch006, pp. 125-155. https://escholarship.org/uc/item/8d28s4f3

Soria, J., Etzioni, S., Shiftan, Y., Stathopoulos, A., & Ben-Elia, E. (2022). Microtransit adoption in the wake of the COVID-19 pandemic: evidence from a choice experiment with transit and car commuters. https://doi.org/10.48550/arXiv.2204.01974

Uber (2022). Uber price estimator. https://www.uber.com/global/en/price-estimate/

U.S. Census Bureau (2020). 2019 American Community Survey 5-Year Estimates. https://data.census.gov/table?q=DP03&tid=ACSDP5Y2019.DP03

Wang, Y., Shen, Q., Ashour, L.A., & Dannenberg, A.L. (2022). Ensuring equitable transportation for the disadvantaged: Paratransit usage by persons with disabilities during the COVID-19 pandemic. *Transportation Research Part A: Policy and Practice* 159, 84-95. https://doi.org/10.1016/j.tra.2022.03.013

Xing, Y., Pike, S., Pourrahmani, E., Handy, S., & Wang, Y. (2022). Exploring the Consumer Market of Microtransit Services in the Sacramento Area, California. *UC Davis: National Center for Sustainable Transportation*. http://dx.doi.org/10.7922/G2HX1B0S

Zhou, Y., Liu, X.C., & Grubesic, T. (2021). Unravel the impact of COVID-19 on the spatio-temporal mobility patterns of microtransit. *Journal of Transport Geography* 97. https://doi.org/10.1016/j.jtrangeo.2021.103226

Chapter 6. Conclusion and Future Research Directions

In this dissertation, I sought to analyze the environmental and transportation equity impacts of public MOD services. First, I conducted a literature review of relevant research (Chapter 2). Next, I built a comprehensive database of publicly subsidized MOD services in the U.S. as of April 2019, conducted 34 interviews with representatives from 26 public entities and four private MOD companies, and developed a typology of public MOD services based on the database and interviews (Chapter 3). I then designed and distributed a stated preference survey to 1519 public microtransit riders and 320 non-riders at 14 U.S. public transportation agencies and analyzed demographic trends in their responses to identify equity impacts (Chapter 4). Finally, I estimated the first mode choice model to incorporate public microtransit based on stated preference data from an enriched sample of public microtransit riders, identified demographic variation in shared error terms to enable flexible substitution patterns between modes, and forecasted mode splits for different demographic groups and service designs (Chapter 5). This work yielded a number of empirical contributions and policy implications in the area of public microtransit, methodological contributions regarding the error structure of mixed logit models, and suggestions for future research.

In Chapter 3, I found that publicly operated, van-based MOD services offer public entities more control than publicly subsidized TNC trips over the service design and trip data, greater potential occupancy, and more equitable service for people with mobility impairments that require WAVs. The expert interviews and comprehensive review of services also supported the idea that public microtransit competes least with fixed-route transit when it replaces traditional paratransit and demand response services.

In Chapter 4, the analysis of demographic variation in public microtransit survey responses yielded two key findings: 1) transportation-disadvantaged groups have higher rates of induced trips and switch to public microtransit disproportionately from nonmotorized/higher-occupancy modes, while nonmarginalized groups switch disproportionately from lower-occupancy modes like drive alone and ride-alone TNC; and 2) riders without smartphones and/or bank accounts benefit less from public microtransit than other transportation-disadvantaged groups. The latter finding stems not only from riders without smartphones and/or bank accounts reporting lower satisfaction with public microtransit and no statistically significant quality of life impacts, but also from their reported mode shift during the Covid-19 pandemic. Riders without smartphones were the only group to shift away from public microtransit more than fixed-route bus/rail and, unlike other transportation-disadvantaged groups, both riders without smartphones and those without bank accounts anticipate using public microtransit less post-pandemic than before the pandemic. Barriers facing riders without smartphones were reflected in the estimation of the mode choice model and forecasts in Chapter 5, as well. Respondents without smartphones were more likely to use fixed-route bus than public microtransit, Uber/Lyft, or drive alone, and smartphone ownership was found to have a greater impact than income on mode share. These results suggest improvements in transportation quality from replacing demand response and paratransit services with public microtransit may not extend to those without smartphones and/or bank accounts. This problem extends to the larger context of a potential shift to mobility as a service (MaaS) and automation, as well; we need additional research on how to ensure unbanked individuals and those without smartphones are not left behind with these technological advancements in our transportation system. SMS messages and kiosks may offer one strategy for those without smartphones, while transit fare cards that can be filled with cash and used seamlessly across modes could help the unbanked (Shaheen et al. 2017, NASEM 2019). Potentially, the shift to MaaS and automation could make smartphones so essential that public entities develop programs to provide free smartphones to low-income groups (Steiner et al. 2021). If phone payment offers the same cash refill options and seamless multimodal use as the transit fare cards, such phone provision programs could solve the access barriers of both groups (Pike et al. 2022).

One limitation from Chapter 4 centers on the control population used in equity analysis; comparing demographic differences between public microtransit riders, local non-riders, and the general population in the service area does not capture the full equity impacts of public microtransit services. Rather, more research should compare the demographics of public microtransit riders with the demographics of local fixed-route bus ridership, as the LA Metro analysis described in the introduction did (Brown et al. 2021). Future research should also aim to identify displaced riders when public microtransit service replaces fixed-route bus, demand response, or paratransit service. A longitudinal survey of riders using the pre-existing services before replacement could track demographics of any who do not end up accessing the public microtransit service, the barriers to access, and the modes they switch to instead. The longitudinal survey would be supplemented with a survey of new riders who use the public microtransit service but did not use the replaced service. Comparing the demographics of these new riders, the riders that do not switch to the public microtransit service, and those that both used the replaced service and switched to the public microtransit service would give a more complete understanding of the equity impacts of replacing fixed-route bus, demand response, and paratransit services with public microtransit. To the extent that public microtransit services are found to disproportionately benefit nonmarginalized groups, more research should examine options for restricting public microtransit use to transportation-disadvantaged populations, especially the four groups described in the introduction who cannot access TNCs: people with low incomes, with mobility impairments that require the use of WAVs, without smartphones, and/or without bank accounts.

In Chapter 5, forecasts from the mode choice model suggested that replacing fixed-route bus with public microtransit minimized public transit ridership, which would be expected based on the discussion in the introduction about public microtransit's lower passengers per hour per vehicle and higher cost per passenger. Analysis of public microtransit services that replace fixed-route bus, demand response, and paratransit should involve a direct comparison of passengers per hour per vehicle and cost per passenger between public microtransit and the replaced services to better understand the ridership and cost-effectiveness impacts of such replacements. Comparing these metrics across public microtransit services could also indicate how the mode's cost-effectiveness differs by density, land use, fixed-route transit availability, and design factors such as corner-to-corner vs. curb-to-curb and door-to-door vs. FMLM. The other main contribution from Chapter 5 involved the introduction of individual variation in the shared error components to capture correlation across an individual's responses, enable interpretation of perceived correlation between modes and how this perception differs by individual characteristics, and allow flexible substitution between modes for improved forecasting. I found that respondents without full access to a personal vehicle perceived public microtransit as most correlated with driving alone, while greater familiarity with public microtransit increased its perceived correlation with TNC and decreased its perceived correlation with fixed-route bus. These findings support interpretation of public microtransit as a substitute to driving alone for riders without personal vehicles, suggest that free trials and other initiatives to increase familiarity with public microtransit may increase adoption of the mode, and highlight shared error components as an underexamined source of behavioral insight in mixed logit models.

The primary limitation of Chapter 5 is the use of generic trip conditions and demographic groups. Incorporating the mode choice model from Chapter 5 into a metropolitan area's activity-based travel demand model could allow additional understanding of potential equity, VMT, and cost impacts from various levels of fixed-route bus and public microtransit provision. Equity impacts can be assessed by comparing distributions of change in logsum measures by demographic group (Bills & Walker 2017, Dixit & Sivakumar 2020). This research could also apply supply-side Bayesian optimization to determine optimal fleet sizes and vehicle types to achieve societal goals, such as maximizing overall improvements in logsum accessibility measures, minimizing the gap between demographic groups with the lowest and highest aggregate logsum values, and minimizing VMT, subject to a maximum acceptable public subsidy (Liu et al. 2019, Martens et al. 2012). This work can be extended to evaluate any changes in optimal distribution of resources to fixed-route bus and public microtransit in the context of automation, as well (Lazarus et al. 2021, Whitmore et al. 2022). Using an integrated land use and activity-based travel demand model would also enable investigating the land use impacts of investing in public microtransit over fixed-route bus before and after automation.

Overall, this dissertation suggests that public MOD services offer transportation quality improvements for transit-dependent demand response and paratransit passengers, provided public transportation agencies identify solutions to barriers for those without smartphones and/or bank accounts and also ensure demand from nonmarginalized riders does not erode service quality for these groups. While rider enthusiasm has prompted widespread experimentation with expanding public microtransit beyond traditional demand response service areas, this research supports additional analysis of the possibility that investing in improved fixed-route bus service may more effectively increase ridership and benefit a greater number of transportation-disadvantaged individuals.

References:

Bills, T., & Walker, J. (2017). Looking beyond the mean for equity analysis: Examining distributional impacts of transportation improvements. *Transport Policy* 54, 61-69. https://doi.org/10.1016/j.tranpol.2016.08.003

Brown, A., Manville, M., & Weber, A. (2021). Can mobility on demand bridge the first-last mile transit gap? Equity implications of Los Angeles' pilot program. *Transportation Research Interdisciplinary Perspectives* 10. https://doi.org/10.1016/j.trip.2021.100396

Dixit, M., & Sivakumar, A. (2020). Capturing the impact of individual characteristics on transport accessibility and equity analysis. *Transportation Research Part D: Transport and Environment* 87. https://doi.org/10.1016/j.trd.2020.102473

Lazarus, J., Bauer, G., Greenblatt, J., Shaheen, S.A. (2021). Bridging the Income and Digital Divide with Shared Automated Electric Vehicles. *UC Berkeley and Emerging Futures Report for the California Strategic Growth Council*. doi:10.7922/G2707ZQ4

Liu, Y., Bansal, P., Daziano, R., Samaranayake, S. (2019). A framework to integrate mode choice in the design of mobility-on-demand systems. Transp. Res. Part C Emerg. Technol. 105, 648–665. https://doi.org/10.1016/j.trc.2018.09.022

Martens, K., Golub, A., & Robinson, G. (2012). A justice-theoretic approach to the distribution of transportation benefits: Implications for transportation planning practice in the United States. *Transportation Research Part A* 46, 684-695. https://doi.org/10.1016/j.tra.2012.01.004

National Academies of Sciences, Engineering, and Medicine (NASEM). (2019). Partnerships Between Transit Agencies and Transportation Network Companies. *Washington, DC: The National Academies Press*. https://doi.org/10.17226/25576

Pike, S., D'Agostino, M., & Flynn, K. (2022). Un- and Underbanked Transit Passengers and the California Integrated Travel Project. *National Center for Sustainable Transportation*. https://doi.org/10.7922/G2F47MFN

Shaheen, S.A., Bell, C., Cohen, A., & Yelchuru, B. (2017). Travel Behavior: Shared Mobility and Transportation Equity. *U.S. DOT Federal Highway Administration*. https://rosap.ntl.bts.gov/view/dot/63186

Steiner, R.L., Srinivasan, S., Mohebbi, M., Yan, X., Patni, S., Krinos, L., Suarez, J., Rummler, J. (2021). Evaluation of East Gainesville's Microtransit Mobility Project. *Florida Department of Transportation*. https://rosap.ntl.bts.gov/view/dot/62598

Whitmore, Hendrickson, Matthews, & Samaras, C. (2022). Improving Access and Equity via Shared Automated Mobility in U.S. Public Transportation Systems. *Mobility 21: A USDOT National University Transportation Center*. https://rosap.ntl.bts.gov/view/dot/64434

Xing, Y., Pike, S., Pourrahmani, E., Handy, S., & Wang, Y. (2022). Exploring the Consumer Market of Microtransit Services in the Sacramento Area, California. *National Center for Sustainable Transportation*.