



Integrating shared mobility services with public transit in areas of low demand



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ABSTRACT

The increasing demand for shared mobility services has led to multiple Public-Private Partnerships (PPP), where public transit agencies and mobility providers work together to increase transit service coverage. However, several partnerships have failed due to budget constraints and lack of ridership. Furthermore, the limited data-sharing agreements restrict the analysis and dissemination of outcomes. This paper analyzes the integration of shared-mobility services into the public transit system using data from pilot programs in Austin, Texas. The use of Transportation Network Companies (TNCs) and microtransit service is evaluated as first-mile-last-mile (FMLM) and door-to-door solutions. The associated TNC, microtransit, and bus transit demand are analyzed using ridership data, and the trip characteristics are discussed and compared. Then, after controlling for confounding variables through matching, a difference-in-differences (DID) model is used to infer the effect of microtransit on bus transit demand. Specifically, by evaluating bus ridership before and after implementing the microtransit program, the DID model estimates the change in bus demand attributed to microtransit. The results suggest that the TNC services, focusing only on FMLM, were not as popular as microtransit services offering FMLM and intrazonal trips. Even though the microtransit trips were longer and, in some cases, the driver response times were higher than for TNC trips. Also, the DID model demonstrates that the microtransit service did not substantially impact the bus transit ridership, suggesting that the trips were mainly used for intrazonal door-to-door trips and not for FMLM trips. A further discussion highlights the need for performance metrics beyond demand and costs to capture the benefits of these partnerships for improving mobility, safety, and customer experience.

1. Introduction

Public transit agencies are evaluating the incorporation of on-demand shared mobility options to increase current transit service coverage. While traditional fixed-routes face challenges to provide efficient and high-quality services in areas with low or sparse demand, alternative on-demand shared modes can supplement fixed-routes and provide flexible service (Mishra et al., 2020). In several cities, public transit authorities have started implementing public-private partnerships (PPP) to provide services in conjunction with transportation network companies (TNCs) and microtransit companies; examples include Boston, San Francisco, and Austin (Blodgett et al., 2017; Feigon et al., 2018).

Compared to TNCs, microtransit requires higher operating costs and significant subsidies. However, the use of TNCs raises accessibility and equity concerns. In particular, TNCs are not subject to regulations by the Americans with Disabilities Act (ADA), and the TNC service can not be used by riders that do not have a smartphone (Lader and Klein, 2018). While incorporating these options seems to provide more public transportation solutions and alleviate transit first-mile-last-mile (FMLM) access and egress concerns, TNCs and microtransit partnership pilot programs have failed due to budget constraints and lack of ridership (Westervelt et al., 2018). Therefore, more research is needed to understand the effective integration of shared mobility with public transit system. This research compares TNCs and microtransit services using information from two pilot programs in Austin, Texas.

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1.1. Background

Ridesourcing or TNCs, such as Uber, Lyft, and Didi, provide pre-arranged or on-demand transportation services for compensation (Shaheen et al., 2016). These services are expanding at a rapid pace and increasing their market share (Yahlia et al., 2021). After its establishment in 2009, Uber completed 140 million annual trips during 2014, and this number increased to a total of 5.22 billion trips worldwide in 2018 (Smith, 2019).

On the other hand, microtransit services are defined as privately owned and operated transit systems (using large vans or minibusses) that can offer fixed and flexible route services (Shaheen et al., 2016); examples include Via, Chariot, and Bridj. While on-demand transit services have existed for decades, emerging microtransit services (enabled by technology similar to the mobile smartphone applications pioneered by TNCs) have gained popularity in recent years (Lucken et al., 2020; Pike and Kazemian, 2020).

The increasing demand for shared mobility options led to the introduction of multiple pilot programs. Public transit agencies partner with mobility providers to integrate these services into the transit system (Westervelt et al., 2018). Lucken et al. (2020) survey of 62 PPP in the U.S. showed that they typically offer four service model types: FMLM (32%), low-density (39%), off-peak (8%), and paratransit (21%). The FMLM model includes trips with start or end at a fixed-route or fixed-stop location. Low-density models serve trips with starts or ends outside a fixed-route service area and can also be used for FMLM trips. Off-peak services are offered to fill the fixed-route temporal gaps, and paratransit trips serve a specific population (e.g., senior citizens). Although several pilot programs have tested these different service models, there are limited analyses of the outcomes, mainly due to the lack of openly-available data. Some partnerships between public transit agencies and private companies restrict the data exchange agreements; this limits the types of analysis that the agencies or external sources can provide (Pike and Kazemian, 2019; Terry and Bachmann, 2020).

1.2. Objective and contributions

This research analyzes the integration of TNCs and microtransit with local fixed-route bus service in areas with low transit demand (while being offered high supply) in Austin, Texas. Data from two pilot programs are used, including PPP offering FMLM and low-density service models in the same geographic location during different periods. The study area corresponds to four zones where land use and road networks make it difficult to provide cost-effective bus service. Previous fixed-route buses in the area were replaced before introducing the pilot programs due to low ridership. These four areas present different socioeconomic attributes, allowing for further comparison of the influence of various characteristics. The PPP analyzed are described as follows:

1. The first pilot program is a partnership with RideAustin, an Austin-based TNC. It lasted approximately six months and consisted of free TNC trips to bus transit users from the designated areas. The service was designed to solve FMLM accessibility, and it was used for trips where either the origin or the destinations occur at a fixed set of stops.
2. The second pilot program, currently operating, consists of a geofenced microtransit service in a partnership with Via called "Pick-Up." In this case, the service has the same cost as a bus ride, but it includes intrazonal door-to-door trips rather than only FMLM trips (i.e., the trips are not restricted to a fixed set of stops).

The analytical framework is divided into two main tasks. The first task includes an analysis of the bus, TNC, and microtransit demand and compares their primary service characteristics in each of the four zones. The second task develops a causal analysis to estimate the effect of

microtransit service on public transit. In particular, the impact of microtransit is evaluated by measuring the change in monthly bus ridership attributed to the implementation of the microtransit program. To this end, a difference-in-differences (DID) study is implemented using bus ridership and microtransit demand information.

The contributions of this work include (i) a comparison of the characteristics of two shared-mobility services offered in the same area during two different periods, (ii) an analysis of the effects of these services on bus demand across four zones with heterogeneous socioeconomic characteristics, and (iii) a causal study implementation to measure the integration of microtransit into the transit system. The main results show that the microtransit service did not result in significant changes in the bus ridership, which suggests that it was mainly used for intrazonal trips and not for FMLM.

1.3. Outline

Subsequent sections of the paper are organized as follows: Section 2 provides a literature review of the principal aspects of TNCs and microtransit and their integration with public transit systems; Section 3 describes the dataset; Section 4 presents the methodology describing the DID method; Section 5 includes the empirical analysis and provides results and discussion; and finally, Section 6 contains conclusions and final remarks.

2. Literature review

Public transit provides an efficient means of travel that can serve captive riders who do not have access to alternative modes. Travelers, however, are unwilling to walk longer than about a quarter-mile (El-Geneidy et al., 2014) to reach their transit stops or their destinations from a stop. This imposes a major hurdle and makes transit an unattractive mode for many origin and destination pairs.

Several studies have looked into transit in the era of TNC and microtransit as an FMLM solution that may improve transit use. There are mixed opinions on whether these services help or erode existing transit services. Shaheen and Chan (2016) studied shared mobility as a potential to overcome the FMLM problem. Their comparison of several shared modes, along with the more recent microtransit option, shows that there is indeed a gap to fill in terms of improving public transit use by solving the FMLM problem. Throughout their study, each shared mode (e.g., shared vehicles, bikes, or scooters) had the potential to improve transit use, but this was not always the case as they may emerge as competing modes. Stiglic et al. (2018) corroborates this from a carpooling perspective, where travelers may share rides to get to and from a rail line. Other authors have used simulation techniques to analyze potential FMLM solutions. Huang et al. (2020) used an agent-based simulation method to analyze the use of shared automated vehicles (SAVs) for FMLM service to rail transit connections in Austin, Texas. The study found that SAV helped to increase the percentage of users shifting from driving alone to transit, but the total travel time served as the most significant determinant in trip makers' mode share. Using a simulation-based approach as well, Gurumurthy et al. (2020) showed that SAVs are not as useful to bus transit on a regional scale. Their results suggest that providing low-cost fares may deter the use of transit and lead to a rise in the SAV mode.

In terms of PPP programs, Blodgett et al. (2017), Westervelt et al. (2018) and Lucken et al. (2020) conducted interviews of several U.S. transit agencies that have PPP's with TNC companies or microtransit services; their studies highlight how quickly such PPP contracts are emerging throughout the country, but the success varies across different programs. In the Dallas area, for example, the Dallas Rapid Area Transit (DART) demonstrated an increase in ridership and after the replacement of less-productive fixed-route services providing microtransit (GoLink) and TNC (Uber) services – without any additional cost – to improve FMLM accessibility (Parks et al., 2020). They highlight that the

major lessons learned include (1) an integrated software development phase, involving planning and implementation staff in the process as early as possible, and (2) the development of an extensive marketing plan (emphasizing one-on-one communication and “feed on the street” strategy), which was necessary to help riders trust the technology and service offered. In contrast, the city of Centennial, Colorado, implemented an FMLM pilot program using TNCs (Lyft) at no cost for the rider, but the program did not see as many users as expected, averaging 11 rides per day during the six-month trial period (Blodgett et al., 2017). The relatively limited ridership may be due to insufficient awareness of the availability of the service (Blodgett et al., 2017), highlighting the importance of an extensive marketing plan. Similarly, the Massachusetts Bay Transportation Authority (MBTA) partnered with Uber and Lyft to provide subsidized on-demand paratransit services in the Massachusetts Bay area. Although the service provides a significant reduction in the ride cost compared to RIDE, the service offered by MBTA (from \$31 per trip using RIDE to \$9 per trip using TNC) the demand for RIDE was higher (63%) than for the on-demand TNC service (37%) (Blodgett et al., 2017). But the overall paratransit demand increased 28%, and the service area and accessibility also increased.

Experiences with PPP using microtransit include the Kansas City Area Transportation Authority (KCATA). Partnering with Bridj, they provided rides in a geofenced area during commuting hours with the same cost as the local bus fare (\$1.50). While KCATA and Bridj expected 200 rides per day, the demand averaged 11 rides per day after the year-long pilot program, with an estimated cost of \$1000 per ride (Westervelt et al., 2018). The main reasons for the low demand include the lack of awareness of the service among potential riders; KCATA recognized that they had not invested enough in marketing within the actual service area, and eventually adjusted their marketing strategy and distributed materials to businesses and residences, marketed to local employers, and conducted geo-targeted digital advertising. Also, users that had signed up for the service complaint that the service area and operating hours were very limited (Westervelt et al., 2018). While there may be areas within Kansas City where a commuter microtransit service is viable, the agency does not yet have sufficient data sets to clearly identify geographies with origin and destination that allow service planners to understand where best to deploy this service (Westervelt et al., 2018). Similarly, Santa Clara County’s Valley Transportation Authority (VTA) offered geofenced microtransit trips in five areas with a need for more transit service but inadequate demand to justify additional fixed routes. The demand for the service was also low, with an average of 16 rides per day during the first three months and 41 rides per day the last three months of the six-month pilot period. Approximately 35% of rides served FMLM trips and 65% door-to-door trips. Although 84% of the users rated the services as “good” or “excellent,” the demand was insufficient to maintain the service.

While both TNC and microtransit have advantages and disadvantages from a qualitative point of view, further analysis is needed to quantify the impact of PPP on transit ridership. The previous review suggests that the program success differs across agencies, but most analyses are based on users surveys and ridership as a performance measure of the program. This paper’s contribution stems from the quantitative analysis of TNC and microtransit programs; specifically, the proposed study investigates the impact of shared mobility partnerships on the fixed-route transit service in Austin, Texas.

3. Data description

This study uses data from several sources. The public transit demand is obtained from the Automatic Passenger Count (APC) information for Austin, publicly available through the Texas Open Data Portal.¹ It

provides public transit vehicle information such as bus boarding and alighting counts, arrival and departure times, vehicle location (latitude and longitude coordinates), among others. This data is combined with stop locations obtained from the General Transit Feed Specification (GTFS) data. The vehicle location from APC was matched with the stop location identification number from GTFS. The processing and cleaning stage included the removal of double counts per stop, counts located more than 50 m away from the corresponding stop, and extreme values of boarding and alighting count.

The information from the TNC trips and the microtransit service was provided by Austin’s public transit agency, Capital Metropolitan Transportation Authority (CapMetro). In June 2018, CapMetro made significant changes in the bus network (CapMetro, 2018). These changes are referred to as CapRemap. After the renovations, CapMetro defined several “Mobility Innovation Zones,” where they implemented alternative mobility options by using various pilot projects. This change implied the removal of some of the fixed-route services and the introduction of a TNC (and eventually a microtransit) service. Fig. 1 shows the location of the four areas analyzed, represented as Traffic Analysis zones (TAZs), and the bus network before and after the bus services changes.

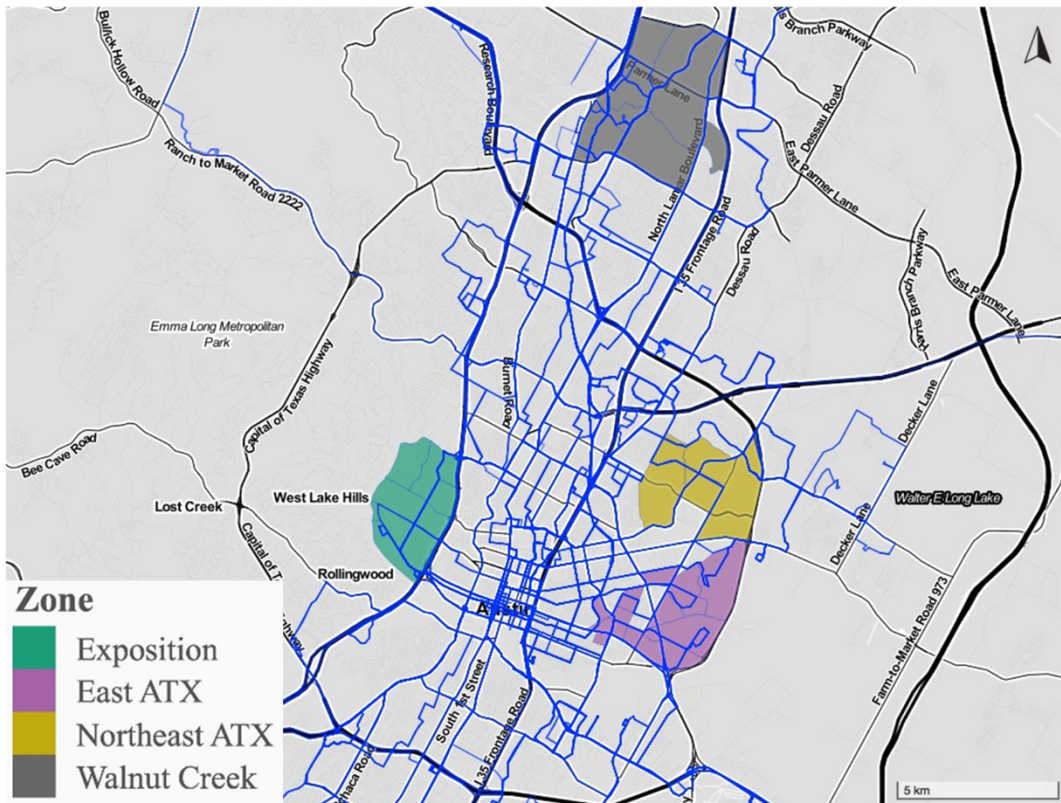
The first pilot program implemented by CapMetro was a partnership with RideAustin, a non-profit TNC based in Austin, Texas. The program started with the Exposition area in June 2018 (right after CapRemap happened) and ended in October 2018. The other zones initiated it in October 2018 and ended in April 2019 approximately. The TNC program consisted of free TNC trips offered to public transit users from the designated areas. The service was implemented exclusively to solve FMLM accessibility, and it involved trips with origins or destinations set to a specific stop. The second pilot program, currently in operation, consists of a geofenced microtransit service in a partnership with Via. In this case, the service has the same cost as a bus ride (\$1.5), but it includes intrazonal door-to-door travel and also allows for FMLM trips. The service started in August 2019 in the same areas where the TNC program was functioning four months before. Refer to Table 1 for a summary of the description of the programs. Both services could be accessed using the mobile application and a service that allows reserving a ride with a call. The marketing campaign included geofenced mail and social media advertisement, radio and television announcements, as well as announcements within the bus rides.

In addition to TNC, microtransit, and public transit trip information, socio-demographic information was obtained, including race and ethnicity, age distribution, and household information to characterize the study area. This information is obtained using TAZ-level data from the Capital Area Metropolitan Planning Organization (CAMPO) website and using the American Community Survey (ACS) 2016. The ACS information is aggregated at Block Groups (BG) level; therefore, an additional spatial process was required to summarize at TAZ-level. The process consisted of intersecting TAZ and BG areas to estimate the proportion of BG per TAZ. The TAZ summary included the average BG values weighted by the BG area and population density. Table 2 provides a summary of description variables for each study area. The four areas show different characteristics. For example, Exposition has the highest average annual household income of \$78k, while for the East Austin zone, the average household income is \$ 31k, a difference of 40%.

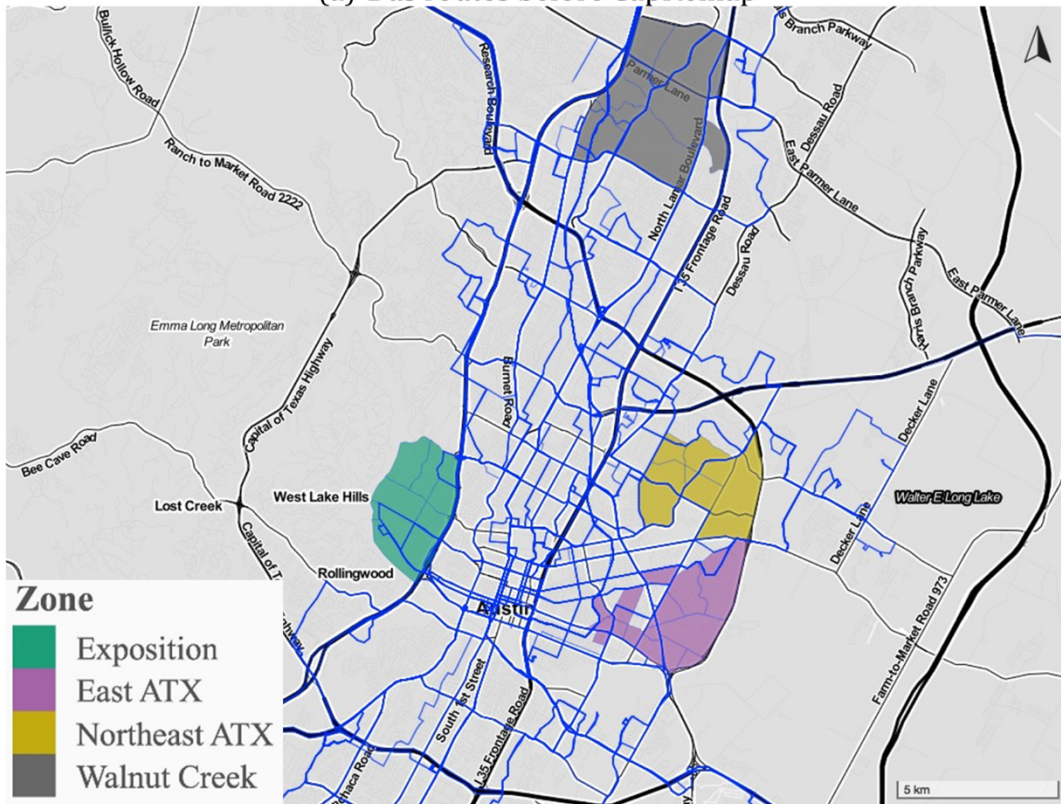
4. Methodology

This study aims to evaluate the impact of incorporating shared mobility services on public transit ridership. For this, a quasi-experimental difference-in-differences (DID) analysis was developed to investigate the causal relationship between mobility services and bus transit. The proposed DID approach calculates the effect of a treatment on an outcome; this effect is determined by comparing the average change of the outcome variable within a treatment group to the

¹ This website can be accessed at <https://data.texas.gov/>



(a) Bus routes before CapRemap



(b) Bus routes after CapRemap

Fig. 1. Description of mobility innovation zone TAZs.

Table 1
Description of the pilot programs.

	TNC	Microtransit
Partnership	RideAustin	Via
Cost	Free	\$1.5
Description	FMLM access to specific stops	FMLM and door-to-door trips
Location	Mobility Innovation zones	Mobility Innovation zones
Geofence	Within zones	Within zones
Duration	6 months	6 months

corresponding change in a control group. In this case, the treatments are the implementation of shared-mobility programs, and the outcome corresponds to the bus transit ridership. The treatment groups are the areas where the service was implemented. The control groups are areas with similar socio-economic, demographic, and mobility characteristics, but where the shared services were not implemented.

The causal analysis requires that the only change in the study area's conditions is due to the treatment application. This restriction comes from the stable unit treatment value assumption (SUTVA). SUTVA requires that a particular unit's response depends only on the assigned treatment, not the treatments of other events or other areas around it. In this case, the TNC service was implemented right after CapRemap when CapMetro made several public transportation network changes. Therefore, it is not possible to isolate the effect of TNC trips from the bus transit demand since it may also capture the impact of the CapRemap changes. The microtransit service, or Pick-Up program, started operating in August 2019, more than a year after CapRemap began, which allows for a more isolated analysis. For this reason, the DID analysis is focused only on microtransit, and TNC services will be analyzed qualitatively in the results section.

To evaluate the effect of the microtransit services on the bus transit demand, first, an intervention date is defined as the date the microtransit started operating, corresponding to August 2019. Then, the pre-intervention period is described from August 2018 to August 2019. Although this period includes months close to the CapRemap date, its effect would not significantly affect the results since there is a large sample (a year). The CapRemap effect would eventually stabilize during this period. Also, although this period includes months in which the TNC service was functioning, the low demand for the service implies that it would not have a significant impact either. The post-intervention period is defined from August 2019 until December 2019. Fig. 2 shows a timeline with the most critical events in the study area and the period definitions.

Table 2
Description of the mobility innovation zones.

Variables	Exposition Mean value	East	Northeast	Walnut Creek
Transit supply [Sept. 2018]				
Stop density (stops/km ²)	4.73	11.04	7.03	6.05
Bus frequency weekday peak hour (bus/hour)	10.37	7.18	11.03	8.49
Bus frequency weekend peak hour (bus/hour)	6.09	5.84	8.86	5.65
Socio-demographic information [2015]				
Population density (residents/km ²)	1247	1346	1730	1754
Employment density (employees/km ²)	778	1122	466	1779
Retail employment density (employees/km ²)	108	188	131	293
Race or ethnicity [2016]				
Proportion of White population	0.85	0.71	0.70	0.65
Proportion of Black/African American pop.	0.02	0.12	0.22	0.12
Proportion of Asian population	0.10	0.13	0.09	0.06
Household information [2015]				
Average household size	2.62	2.61	2.85	1.91
Median household income (\$1000)	78.29	31.45	43.74	45.21
Sample size (number of TAZs)	9	17	10	14

Furthermore, the analysis is extended to include areas surrounding the service zones to account for trips made as FMLM with routes and stops outside the limits of the service area. The following sections further discuss the DID method and explain the methodology used to find the control zones and the buffer-area analysis.

4.1. Difference-in-differences (DID) method

DID is a quasi-experimental research study design often used to study causal relationships in settings where randomized trials are infeasible. This study aims to compare the potential outcome that results from the implementation of the microtransit program (i.e., treatment) with the alternative potential outcome describing the case when the program is not implemented (control). The outcome variable considered is bus transit ridership. Since both potential outcomes can not be observed at the same time and in the same area, the potential outcomes with treatment are factual (can be observed), but the potential outcomes with no treatment are counterfactual (cannot be observed). For this, data from a control group is used to impute untreated outcomes in the treated group. This control group corresponds to areas with similar characteristics but where the Pick-Up (microtransit) service was not provided.

The DID setup uses the Pick-Up service zone as the unit of analysis. This Pick-Up zone is composed of a set of TAZs that represent the treatment group. To define the control group, the treatment group TAZs are matched to reference TAZs not in the Pick-Up service zone. Thus, there are two sets of TAZs composing the treated group and the control group. These two groups $g = 1, 2$ (where group 1 is treatment and group 2 is control) are observed in multiple time periods summarized in monthly bus transit demand from August 2018 until December 2019. These months are assigned to the pre-intervention period and the post-intervention period dummy variable based on the description shown in Fig. 2. In the first period, both groups are exposed to the control conditions. In the second period, the treatment is applied to the treated group but not to the control group. The standard DID estimate equation is described as follows:

$$Y_{gt} = \beta_0 + \beta_1 T_g + \beta_2 P_t + \beta_3 D_{gt} + \epsilon_{gt} \tag{1}$$

$$D_{gt} = T_g * P_t \tag{2}$$

Where, Y is the monthly bus transit demand, g is the group number ($g = 1, 2$) observed in the two time periods t ($t = 1, 2$). The dummy variable T_g identifies the time invariant observations in group g , i.e., its value is 1 for group 1 (treatment) and 0 for group 2 (control). While the dummy variable P_t indicates observations from period t and does not vary across the groups (i.e, its value is 1 for pre-intervention period and

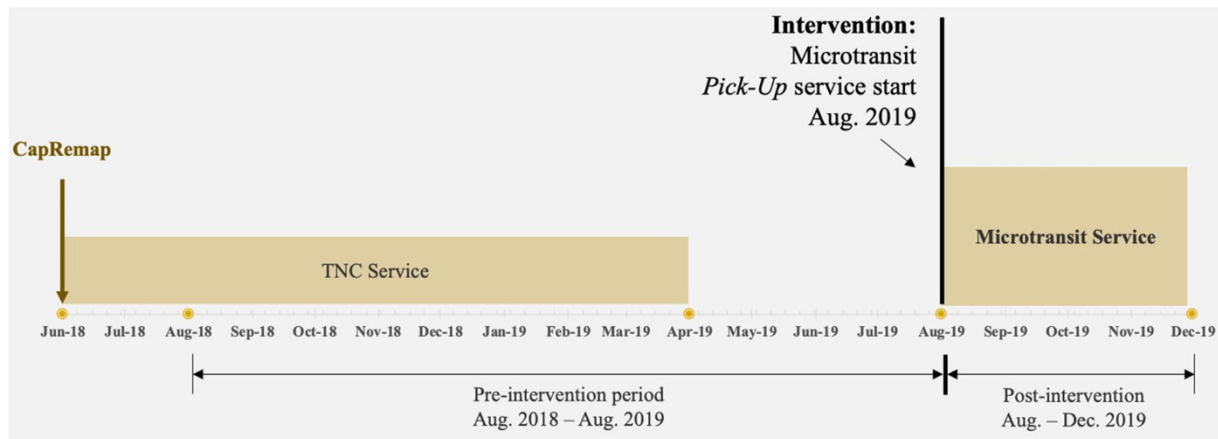


Fig. 2. Timeline and period definition.

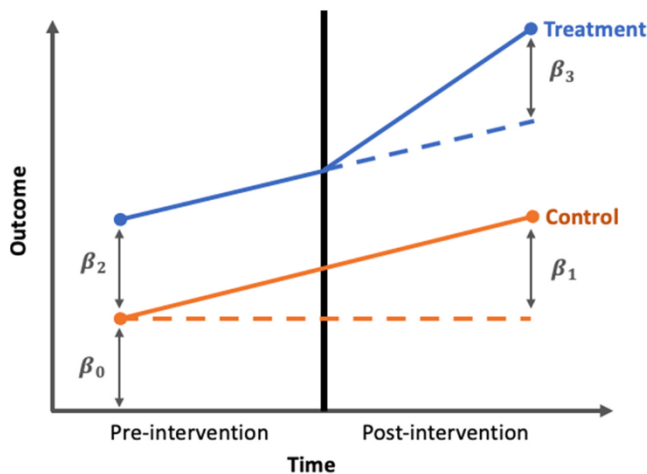


Fig. 3. Difference-in-differences.

0 for post-intervention period). The treatment variable D_{gt} is the product of these two dummy variables. The β_0 coefficient corresponds to the baseline average, β_1 is the time trend in the control group, β_2 is the difference between the two groups before the intervention, and β_3 is the difference in changes over time, also known as the average effect of treatment on the treated (ATT) – the effect of treatment on the treated group in the post-treatment period, as described in Equation 3. Fig. 3

Table 3
Description of the control groups and comparison with the treatment groups.

Variables	Exposition Mean value control group (Mean value treatment group)	East	Northeast	Walnut
Transit supply [2018]				
Stop density (stops/km ²)	5.27 (4.73)	6.95 (11.04)	15.53 (7.03)	4.52 (6.05)
Bus freq. weekday (bus/hour)	9.49 (10.37)	6.72 (7.18)	11.99 (11.03)	9.19 (8.49)
Bus freq. weekend (bus/hour)	8.88 (6.09)	4.88 (5.84)	7.30 (8.86)	6.75 (5.65)
Socio-demographic [2015]				
Population den. (res./km ²)	1563 (1247)	1561 (1346)	2023 (1730)	1545 (1754)
Employment den. (empl./km ²)	679 (778)	1654 (1122)	1879 (466)	1430 (1779)
Retail den. (employees/km ²)	348 (108)	323 (188)	528 (131)	354 (293)
Race or ethnicity [2016]				
Proportion of White population	0.85 (0.85)	0.73 (0.71)	0.70 (0.70)	0.70 (0.65)
Proportion of Black population	0.06 (0.02)	0.09 (0.12)	0.10 (0.22)	0.13 (0.12)
Proportion of Asian population	0.10 (0.10)	0.07 (0.13)	0.05 (0.09)	0.06 (0.06)
Household information [2015]				
Average household size	2.47 (2.62)	2.37 (2.61)	2.64 (2.85)	2.20 (1.91)
Median income (\$1000)	68.71 (78.29)	43.63 (31.45)	38.64 (43.74)	43.40 (45.21)
Sample size (number of TAZs)	9 (9)	17 (17)	10 (10)	14 (14)

shows a graphical representation of the coefficients.

$$ATT \equiv \mathbb{E}[Y^1(2) - Y^0(2)|A = 1] \tag{3}$$

Where, $Y^a(t)$ is the potential outcome given treatment a at time t . Here, $t = 2$ represents the post-treatment period, $a = 1$ represents the treatment, $a = 0$ represents the no treatment, and $A = 1$ refers to the treated group.

The identification of causal effects from the DID model depends on several assumptions. In addition to the SUTVA described previously, the model assumes a “parallel trend” establishing that both the treated and control units would evolve along a parallel path in the absence of treatment. A plot of the outcomes for the treated and control group in the pre-treatment period is used and discussed in the results section as evidence supporting this assumption.

4.2. Matching control groups

The control groups are found using a matching technique. Rather than using the entire sample population to estimate the DID effect, units in the control group are selected based on their “closeness” to units in the treated group. Matching is attractive in DID analysis because it improves the groups’ comparability and possibly their outcome trends.

The matching is done at the TAZ-level by estimating the Mahalanobis distance between pairs of TAZs; the Mahalanobis distance is a metric of closeness used to find how similar two sets of covariates are. The covariates used include population density, retail employment density, median income, the proportion of White population, stop

density, and bus frequency during weekdays and weekends. The distance corresponds to the square root of the squared difference of the set of covariates scaled using its covariance, as denoted in Eq. (4). For each TAZ in the treatment group (Pick-Up service zone), the Mahalanobis distance is computed with every possible TAZ in the control group. Then, the treatment TAZ is matched to the closest control TAZ (minimal Mahalanobis distance). A TAZ in the control group is matched to at most one TAZ in the treatment group. The set of eligible TAZs for the control groups correspond to those located in the CapMetro Austin service area, where the TAZs located within the Pick-Up service zones are excluded.

$$D(X_i, X_j) = \sqrt{(X_i - X_j)^T S^{-1} (X_i - X_j)} \tag{4}$$

In Eq. (4), $D(X_i, X_j)$ is the Mahalanobis distance between TAZ pairs. X_i is the vector of covariates for TAZ i in the treated group (Pick-Up service zone). X_j is the vector of covariates for TAZ j from the set of TAZs in the control group. S is the covariance matrix of X used to scale the variables.

Table 3 shows the description of the control groups found using this method. The values in parenthesis correspond to the treatment group, as shown in Table 2. Although the matching technique is not perfect, the pair of groups share similarities that make the DID analysis possible.

4.3. Buffer areas

Changes that affect the transit demand in the Pick-Up service zones may influence the proximate areas causing a spillover effect. For example, users may take the microtransit service to access bus stops outside the service area. The spillover effect would violate the DID SUTVA assumption since the transit demand changes are not isolated to the Pick-Up service areas but may include the surrounding areas. To limit this effect, the matching and DID process is repeated with a

different unit of analysis; specifically, the modified treatment group consists of the Pick-Up service zones in addition to surrounding buffers. In other words, the treatment group would include an augmented area that adds adjacent TAZs to the Pick-Up service areas. Fig. 4 shows the location of the buffer zones around each service area.

5. Results and discussion

This section presents the results and main findings. First, public transit, TNC, and microtransit demand and trip characteristics are described. The second part presents the DID results used to evaluate the integration of microtransit into the fixed-route services.

5.1. Demand analysis

The historical monthly demand for the bus service in each mobility innovation zone is obtained using information from the passenger counts. This demand is compared with the monthly demand reported for the TNC and microtransit service. Fig. 5 presents the comparison of the estimates.

The information in Fig. 5 shows a marked difference in the demand for TNC FMLM trips and microtransit. On average, there were 37 TNC trips per month and 597 microtransit trips per month, a difference of approximately 1500%. Furthermore, TNC demand seems to decrease with time while the microtransit demand increased. However, it is important to highlight that these two modes functioned on different service model types. TNC trips, focused exclusively on FMLM trips, were not as popular as the microtransit service that allowed for FMLM trips and intrazonal trips. This comparison of demand is particularly useful because it allows differentiating the ridership across zones even though the service model is different. The Exposition area showed the lowest demand for TNC and microtransit, while the Northeast area



Fig. 4. TAZs buffer illustration: the DID analysis is also implemented for augmented service areas that include a surrounding buffer.

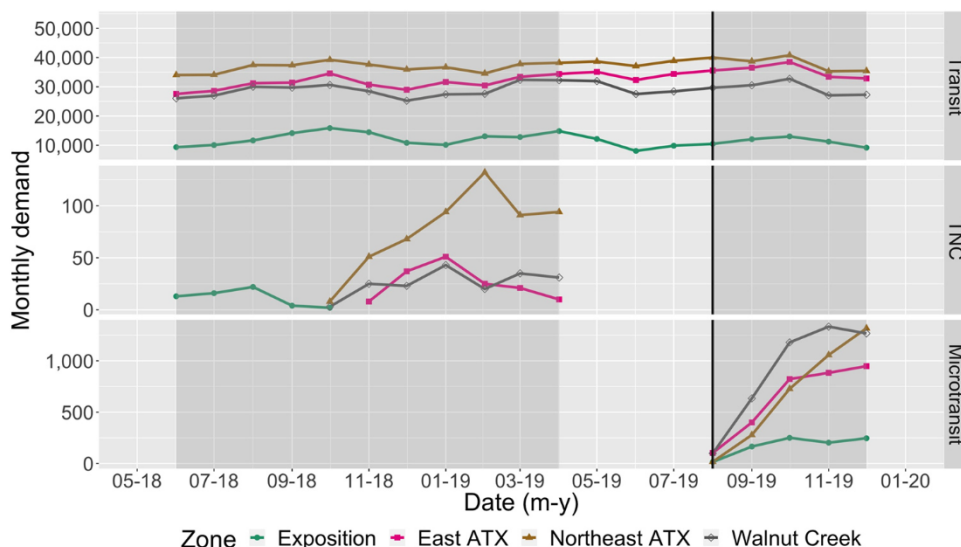


Fig. 5. Monthly demand for bus transit, TNC, and microtransit by zone.

showed the highest TNC demand. Walnut Creek showed the highest microtransit ridership, followed by the Northeast and East zones.

The study areas present different characteristics. The household income ranges between \$31k to \$78k – where the city’s mean is \$55k (2015), and the average household size varies considerably around Austin’s mean of 2.3 (2015). Transit stop density is low in Exposition, at five stops per sq. km, whereas East Austin has more than twice as many stops per sq. km. Population composition by race indicates a prevalence of White population on Exposition (85%) compared to Walnut Creek (65%). The Northeast area presents the highest population density and household size. East Austin and Walnut Creek show the highest employment density, and Walnut Creek’s retail employment density is almost twice the other zones. Research on shared mobility modes showed that areas with high income and a high proportion of Caucasians do not tend to generate high demand for ridesourcing trips (Lavieri et al., 2018) or micromobility services (Zuniga-Garcia et al., 2020a; Zuniga-Garcia and Machemehl, 2020) and users are more prone to travel by car only (Giuliano, 2003; Smart, 2015). This can be related to the low demand for both TNC and microtransit in the Exposition zone, mainly considering the fact that the TNC service in the area could only be used as FMLM to access specific transit stops. In contrast, Walnut Creek shows the highest employment and retail employment density, which can generate more intrazonal trips and, thus, more microtransit demand.

Fig. 6 shows a comparison of the TNC and microtransit trips in terms of trip distance, duration, and driver reach time across the study areas. The plots describe the distribution of the trip’s characteristics summarized in box plots. The TNC trip distance average ranges between 0.6 miles (Exposition) and 1.8 miles (East Austin). In contrast, the microtransit distance of these two zones is greater for Exposition, with an average of 1.0 miles, and lower for East Austin, with 1.1 miles. Northeast and Walnut Creek areas show similar trip distances, both across modes and across sites, with an average of 1.2 miles approximately. On average, the trip duration for microtransit services is higher than for TNC trips.

The driver reaching time is the time it took the driver to pick up the user after the service was requested and is a good indicator of the level of service of the mode (Zuniga-Garcia et al., 2020b; Tec et al., 2019). The average TNC driver reaching time was higher than the microtransit services for East and Northeast Austin zones, with differences of 2.9 and 1.9 min, respectively. However, the Walnut Creek area showed a lower TNC time with a difference of 3.5 min. The information on this variable for the Exposition area was not available. Overall, these results indicated that microtransit services offered a better level of service than

TNCs at East and Northeast Austin. At the same time, TNCs served better at Walnut Creek compared to microtransit service. However, Walnut Creek showed a higher microtransit demand, which indicates that the level of service difference is not influential on user demand.

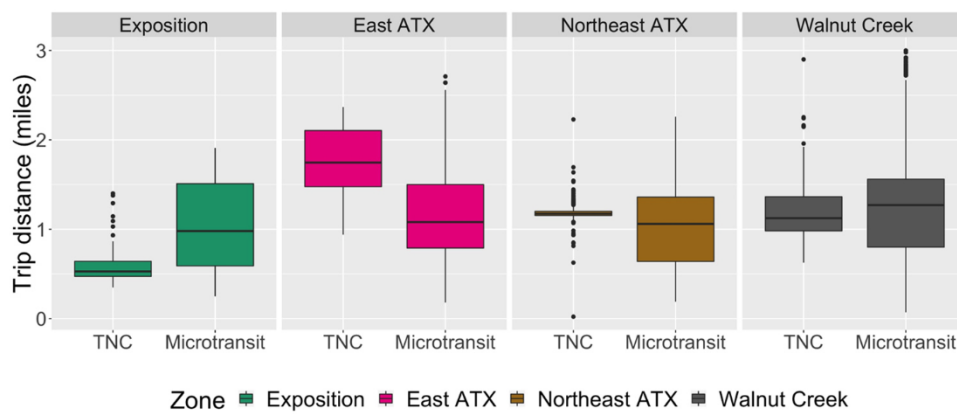
The results described indicate that, among the two shared mobility modes servicing the same area, microtransit trips seem to present the highest user demand. Their trips tend to last longer, and in some cases, the level of service difference did not influence user demand. Likely, the FMLM trips within these areas are not predominant, explaining the difference in demand for TNCs services compared to microtransit.

5.2. Difference-in-differences results

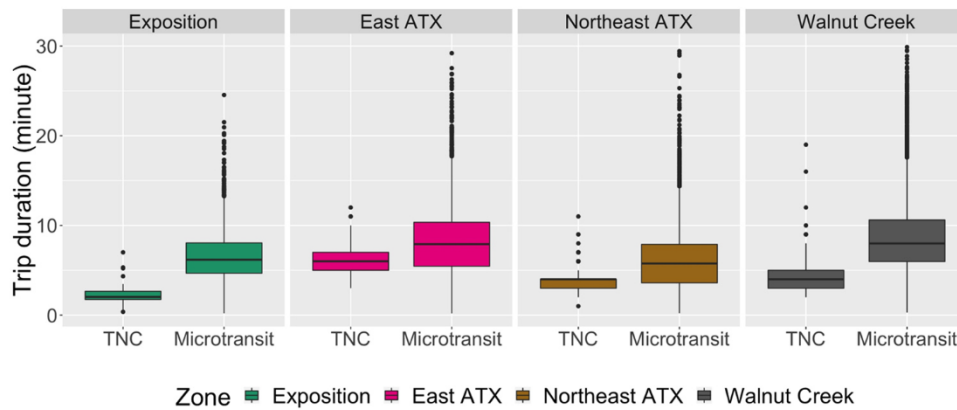
The quasi-experiment consists of a DID analysis of the integration of microtransit into the fixed-route services. A DID model was used to understand the effect of microtransit in altering bus transit demand. The case study of Austin, Texas, revealed that the mobility innovation zones envisioned by the public transit agency proved to be useful for travel within the zones, as seen from the demand for microtransit. However, the results suggest that microtransit had no significant impact on transit use in three of the four mobility zones.

Fig. 7 presents the monthly bus transit demand of the treated groups compared to the control groups. The dashed lines represent the average value for the demand in the pre-intervention and post-intervention periods. The left column presents the zone analysis, while the right column shows the zone analysis when including the buffer areas. Although the control groups were selected based on similarity in resident population characteristics and bus transit service characteristics, a significant difference in transit demand was inherent between the control and treatment zones even before treatment. This finding is expected, but the trend in transit use across time for the control and treatment groups remained parallel from one month to the next, satisfying the parallel trend assumption of the DID model.

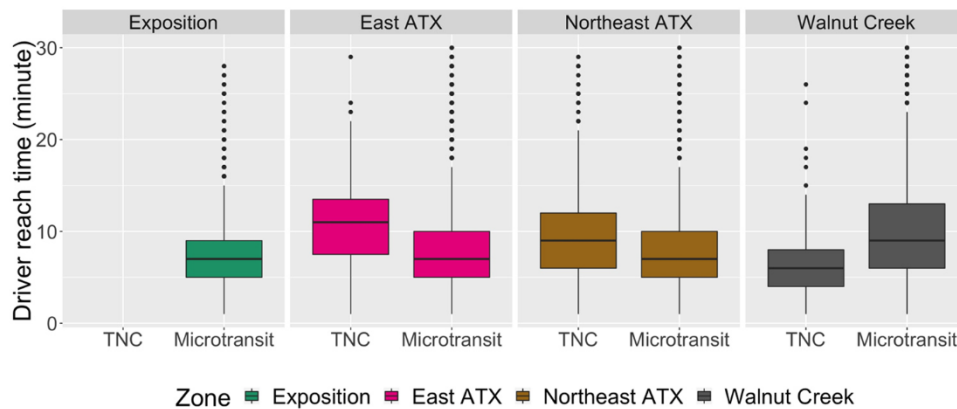
Table 4 shows the estimated coefficients for each of the four zones studied, as well as the estimates of the zones, including the buffered area around the mobility innovation zones. The coefficient β_1 is an indicator of the time trend in the control groups and the treatment group’s expected tendency. The results indicate that the bus transit demand increased over time except for the Exposition zone, where the demand decreased. The mobility innovation zone was envisioned for neighborhoods deemed transit deserts, so this result is intuitive for the three regions (with better transit use in the buffered area). Exposition is located close to Austin’s downtown, and residents have a higher than average household income that likely translates to lower transit



(a) Trip distance



(b) Trip duration



(c) Driver reach time

Fig. 6. Description of TNC and microtransit trips.

reliance. The clear delineation by the MoPac expressway to the east of this mobility zone also supports the continued lower trend in transit use in the buffered areas.

The difference in transit demand between the control and treatment zones is captured by the coefficient β_2 , and is largely negative across all but one zone, East ATX, which implies that the control group in this area showed a lower transit ridership than the treatment group. The magnitude of β_2 is higher for the buffer areas, as expected. In the buffer case, the treatment group included a higher number of TAZs, and therefore, it captured a higher transit ridership. However, it can be highlighted that the magnitude in East ATX increased significantly when the buffer area was included. This result is significant because it captures the transit demand in one of the main terminals of CapMetro, a place that includes several transit routes.

The primary objective of this paper was to test the differential impact of bus transit use with microtransit availability in these mobility zones. Prior studies have been divided on whether microtransit or TNC availability for FMLM transit access helps improve transit demand. The DID estimate is captured by the coefficient β_3 or the ATT (refer to Eq. (3)), which will directly assess the microtransit treatment effect on transit trips. The DID analysis found no significant difference in transit use based on the introduction of microtransit use in Exposition, East Austin, and Walnut Creek neighborhoods, but found a statistically significant decrease in transit use in Northeast Austin.

The three mobility zones not showing a difference in transit use are quite different in household and socio-economic characteristics. The key difference between these three zones and Northeast Austin was the

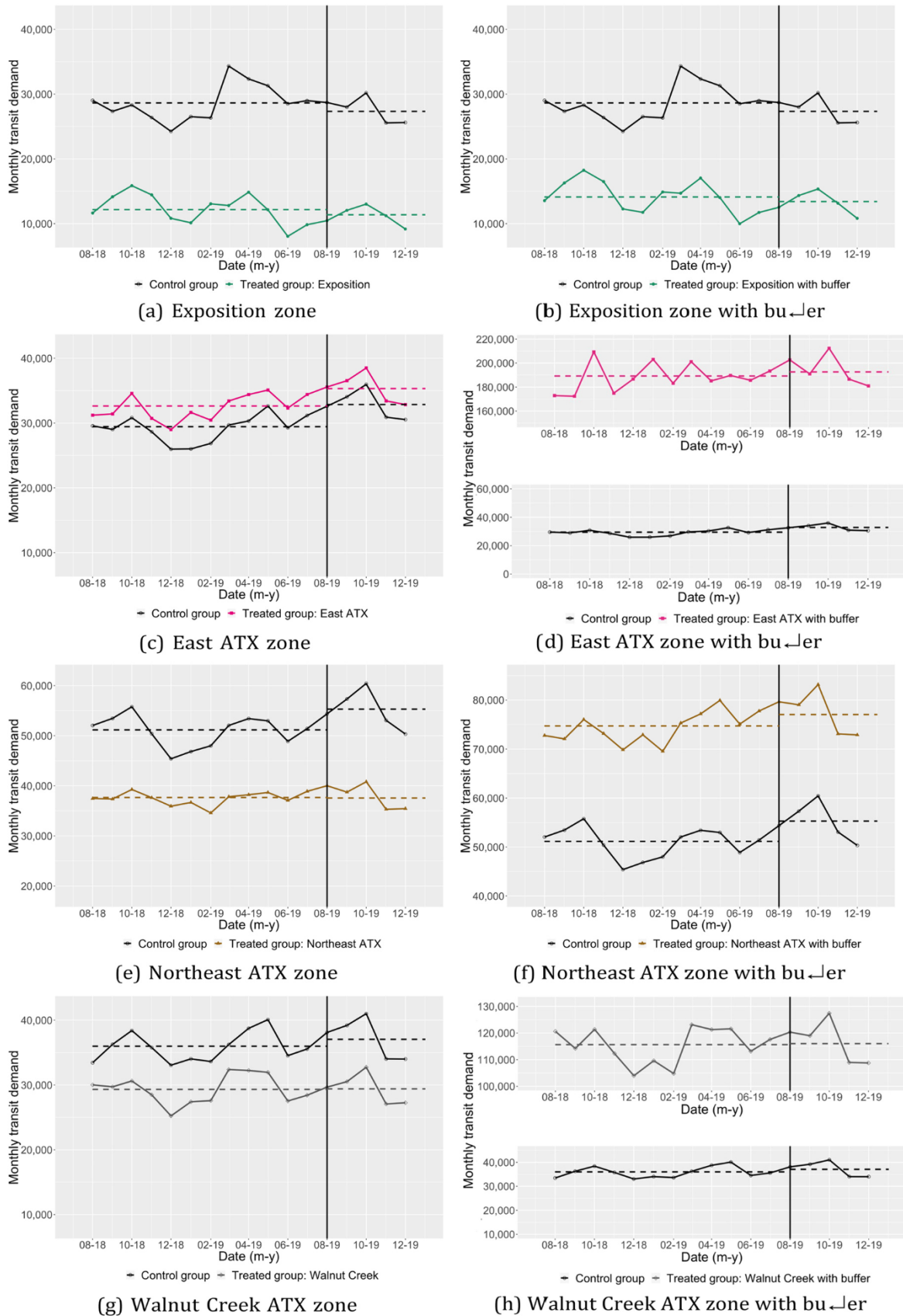


Fig. 7. Average transit demand trends of the mobility innovation zones and the control groups before and after the microtransit service.

Table 4
DID Results.

Coefficient	Estimate	p-value	Estimate	p-value
Zone:	Exposition		Exposition with buffer	
β_0	28,641	0.00*	28,641	0.00*
β_1	-1302	0.35	-1302	0.37
β_2	-16,467	0.00*	-14,527	0.00*
β_3	495	0.80	604	0.77
R^2	0.93		0.90	
Adj. R^2	0.92		0.89	
Zone:	East ATX		East ATX with buffer	
β_0	29,428	0.00*	29,428	0.00*
β_1	3435	0.01*	3435	0.51
β_2	3200	0.00*	159,805	0.00*
β_3	-738	0.69	50	1.00
R^2	0.48		0.99	
Adj. R^2	0.42		0.99	
Zone:	Northeast ATX		Northeast ATX with buffer	
β_0	51,150	0.00*	51,150	0.00*
β_1	4139	0.01*	4139	0.05*
β_2	-13,490	0.00*	23,566	0.00*
β_3	-4227	0.05*	-1805	0.54
R^2	0.89		0.92	
Adj. R^2	0.88		0.92	
Zone:	Walnut Creek		Walnut Creek with buffer	
β_0	35,984	0.00*	35,984	0.00*
β_1	1071	0.45	1071	0.73
β_2	-6661	0.00*	79,701	0.00*
β_3	-1000	0.62	-718	0.87
R^2	0.70		0.98	
Adj. R^2	0.67		0.98	

* Significant at 95% confidence level

ratios of population to employment density, which means that many short trips may have been possible within these mobility zones. Contrary to that, Northeast Austin had an imbalance in trip-generations and trip-attractions. This may intuitively mean that this neighborhood sees a larger share leaving the zone for work, which would also explain that this zone had the highest number of TNC trips. The high average household size may mean that a microtransit FMLM trip to a transit route may not have been more attractive than a personal vehicle available at the origin location.

These results can be inferred from two lenses. From the transit operator’s perspective, the deployment of microtransit in transit deserts helps provide mobility options for travel within the demarcated zone. Travelers cannot be expected to choose to transfer from a microtransit ride to a fixed-route transit line to reach their destinations outside these zones. Suppose the transit operator’s primary objective is to provide mobility options while saving costs associated with unused fixed-route transit lines. In that case, mobility innovation zones in locations that may not be transit-dependent but have sufficient zonal trip generations and attractions can be expected to find the microtransit service useful. However, the microtransit service does not help increase fixed-route transit ridership. From a system perspective, microtransit geofenced in transit deserts may not help improve travelers’ mobility and access at the system level. Personal auto ownership may continue to be essential to access destinations outside of these zones.

The results presented in this analysis are related to the service provided in the Austin area. Other on-demand PPP programs such as the Dallas service showed successful improvements to transit access in the area (Parks et al., 2020). One of the main differences between the services provided is the software. Dallas service includes a comprehensive application that connects the user among all the modes provided, including bus services. This allowed the user to be informed about the options. The Austin service includes independent applications for each service, increasing the friction for the usage (although it also includes a phone service for ordering a trip by call). Furthermore, the Dallas marketing campaign was more aggressive and initiated at an earlier project stage. Experience from other PPP shows that the

marketing plan is one of the main keys to the success of the projects (Blodgett et al., 2017). Although Austin provided a focus marketing plan, developing two different projects in a short period (TNC and microtransit) might have caused users confusion since both services were offered in different ways and serviced different goals.

6. Summary and conclusions

This study analyzed the integration of two shared mobility services into the public transit service using data from pilot programs offering TNC and microtransit services in the same area during different periods. Ridership data was used to compare the demand for transit, TNC, and microtransit and describe the trips’ principal characteristics, including trip distance, duration, and driver reaching times. Furthermore, a DID quasi-experimental method was developed using monthly transit ridership data to analyze the causal relationships between the microtransit service and bus demand. The main results suggest that TNC services, focusing only on FMLM, were not as popular as microtransit services offering FMLM and intrazonal trips. Even though the microtransit trips were longer and, in some cases, the driver response times were higher than for TNC trips.

This research suggests that TNCs and microtransit are not attractive FMLM solutions in areas where the ratio of population to employment density is low because trips in the area are mainly zonal. However, the in-zone transit access for short trips can be beneficial for the area. Successful programs from other cities (like the city of Dallas) suggest that the most important factors are the integration of the service in a functional software and an intensive marketing plan to attract and inform users. Therefore, it is possible that a unique (and integrated) software application for the services and a broader marketing campaign could increase the demand for FMLM services in Austin. One of the main drawbacks of the pilot programs provided in the area is that two different services were offered in the same location in a short period, which could have confused riders and challenged the effectiveness of the informative campaigns.

In terms of policy implications, the development of on-demand services in areas with low transit demand should include a careful selection of the service type based on the area characteristics. Offering only FMLM service (either by TNC or microtransit) showed to be not attractive in high-income zones and areas with a low ratio of population to employment density, as users tend to do low intra-zonal trips and personal vehicles are highly used. A focus on door-to-door service for these locations can result in high ridership while keeping options to access the transit network as well to warrant equity access. Agencies aiming to implement the services should also put emphasis on the information given, with a strong marketing campaign, and the accessibility provided to the services since multiple applications can challenge user interest.

This case study reflects the challenges that public transit agencies face in areas with low demand, where fixed-route services are not cost-effective. Although the results indicate no integration between these shared mobility options and the transit system, the microtransit service was successful at providing zonal trips, and the program’s benefits go beyond measurable demand and costs. There is a need for performance metrics that can capture the benefits of these options for both users and providers, capable of measuring the improved mobility, increased safety, and enhanced customer experience that these users experienced. For example, a transit accessibility metric that describes the type of services provided (like alternative mobility on demand) can be used to warrant equity in areas where fixed-route transit is removed due to low demand.

The results and methods proposed in this study can serve multiple purposes. First, from the transit agency point of view, this study provides a methodological framework for analyzing mobility services’ integration into the transit system that can be used in other areas with similar PPP services. Second, it evaluates how these partnerships can

potentially be used to help under-served areas and improve transit accessibility from the users' point of view. Finally, from a transportation research perspective, this study contributes to the scarce literature in this area by providing empirical evaluations of the effects of incorporating these services into the transit system.

Limitations of this study include the short period of the analysis. Both PPP programs were offered initially for a six-month period. Ideally, a longer analysis period can provide stronger conclusions. However, most pilot programs, used by transit agencies to test service viability, have 6-month duration. Therefore, short-period analysis can be helpful to provide insights into the services, and the methodology used here proved applicable for such analyses.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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